TESTING & RATING OF ANR HEADSETS

Dan Gauger
Bose Corporation
tel 508-766-4206 dan_gauger@bose.com fax 508-879-3049
M/S 271, 145 Pennsylvania Avenue, Framingham MA 01701-9168

Abstract

This paper examines the issue of potential changes to the rules that define the noise reduction rating (NRR) from the perspective of Bose Corporation, one of the leaders in the active noise reduction (ANR) headset industry. Topics discussed include the impact on the ANR industry of the NRR as currently defined, Bose Corporation's perspective on the debate regarding ANSI S12.6 method A versus method B, issues pertaining to ANR device testing for attenuation and other characteristics, and implications of single number rating methods when applied to test data on ANR devices. Proposals are offered regarding how the EPA might approach the rating of ANR devices as part of changes to primary and secondary labeling requirements; these proposals extend the work the author has been doing with Elliott Berger as a member of ANSI S12/WG11. This paper is largely based on a presentation contributed to the U.S. EPA Workshop on Hearing Protection Devices (HPDs) held in Washington D.C. on March 27-28, 2003; it contains all of the information in that presentation plus additional text to better explain the ideas offered than was possible in the time allotted at the Workshop[1].

Introduction

Active noise reduction (ANR) in headsets or headphones in prototype form dates back to the 1950s [Meeker, 1958]. The underlying principle is that, by building a microphone into the earcup of a headset, one can sense and control the sound pressure heard by the wearer. In most cases this has been done by means of a feedback system comprised of the loop from microphone to electronic circuit to speaker, then through the earcup acoustics back to the microphone. This feedback loop regulates the sound pressure in the earcup to a desired signal, either zero (silence) or an audio signal the user wants to hear. From a physical perspective, the circuit "tells" the speaker diaphragm how to move to alternately raise or lower the pressure in the earcup to achieve the desired sound pressure. The constraints of earcup acoustics and feedback loop design dictate that ANR is effective against low frequency noise ranging from 20 Hz or lower to typically 500 to 1k Hz at the upper end; these values have changed little over the last several decades.

Advances in components in the 1970s began to make ANR headsets practical. Through the late 1970s and 1980s work continued at a few locations with the encouragement of the Bio-Acoustics Lab at Wright-Patterson AFB and the British MoD labs at Farnborough. ANR headsets began to see commercial use with the introduction by Bose of its first generation aviation headset in 1989. Since then various manufacturers have begun to offer ANR communication headsets for general aviation and military applications. ANR headphones for consumer use, particularly frequent airline travelers, have also been on the market for several years and one manufacturer has offered a product for use as an industrial hearing protector.

---

[1] A paper for publication is being prepared by Elliott Berger and the author which will comprehensively present the rating methods proposed in his Workshop presentation as well as in this paper, along with an analysis of rating accuracy.

Has The Time Come To Rate ANR?

Purchasers of ANR headsets today are not provided with an NRR rating describing the performance of the device. This is because the test method mandated for obtaining the attenuation data, the Real-Ear Attenuation at Threshold method [REAT, ANSI S3.19 now superseded by ANSI S12.6-1997], cannot be applied with reasonable accuracy to ANR devices, as is explained in the next section. The lack of an NRR has not proven to be a real barrier so far to the success of ANR in applications where it offers benefits. The military has been satisfied with evaluating ANR using the Microphone in Real-Ear method [MIRE, ANSI S12.42-1995, originally standardized as MIL-STD-912]. General aviation pilots and frequent-flying consumers have largely trusted their own ears, evaluating products by the residual noise they hear when using headsets on their travels. Bose (and presumably other purveyors of ANR headsets) offer customers various ways to "test fly" ANR headsets before paying for the product.

ANR has not succeeded in the market for industrial HPDs but we at Bose Corporation believe this is largely not for lack of an NRR. As will be shown later, ANR offers limited or no hearing protection benefit at present in the majority of industrial noise environments. However, at Bose we believe the real promise of ANR is not simply greater noise reduction (though it can offer that in the right environments) but more comfortable to wear and more natural sounding (*i.e.,* more uniform across frequencies) attenuation than conventional (passive) HPDs can provide. These benefits are desirable in industrial applications as well as general aviation, so it is conceivable that improvements to ANR will make it competitive with conventional HPDs at some point in the future. At that time, the lack of an NRR will be a severe impediment.

The purpose of the NRR and other EPA-mandated HPD labeling should be to inform consumers, either at home, in the industrial workplace, or when flying in aircraft. To do so, the data provided to the consumer should be simple to understand, contain information allowing meaningful comparison of different products, and provide a reasonably accurate portrayal of the performance the consumer can expect to achieve in his or her application of the device. If the NRR rule is to be explicitly extended to encompass ANR devices, it should allow such meaningful comparisons between ANR and conventional devices as well as between ANR devices. If this is achieved then a redefined NRR can foster innovation, leading over time to HPDs and headsets — both conventional and ANR — that better meet the needs of consumers. If these goals are not achieved (*e.g.,* if a new NRR does not fairly portray the relative performance of ANR to conventional devices in markets where ANR is beneficial) then a redefined NRR can have the opposite effect, with likely severe adverse impact on the ANR industry.

Method A or Method B

Many presentations at the EPA Workshop on HPDs addressed improvements to the REAT testing standard embodied in the ANSI S12.6-1997. The debate centers on the choice between method A (experimenter supervised fit) and method B (subject fit) in that standard. It is Bose's opinion that any change to the NRR should be built around a subject fit approach to testing. After all, HPD users fit themselves in actual day-to-day use without careful supervision by highly trained fitting experts. Some criticize method B as not testing the attenuation a device is able to provide but, instead, testing the ergonomics of the device. It is true that device ergonomics is an important factor influencing method B attenuation and this is appropriate; the performance users will achieve in the real world depends both on the attenuation capabilities of the device as well as the ergonomics — how easy it is to fit the device to oneself. Some criticize method B for testing the instructions the HPD manufacturer provides, not the training the user receives in the field. But, as data presented at the Workshop by both Elliott Berger and John Franks showed, method B data correlates well with real-world tests, both as a measure of the level of noise reduction provided as well as the relative performance (rank ordering) among different devices. We also suggest that testing the manufacturer's instructions is appropriate because this will provide an incentive to HPD manufacturers to improve instructions and, as was reported by John Casali at the Workshop, improved instructions have been shown to improve the noise reduction wearers achieve when wearing earplugs. If the NRR is to provide the majority of consumers with meaningful data indicative of their use of the product, then the subject selection and level of experimenter oversight specified by method B is the best means to achieve that goal based on available data[2].

---

[2] ANSI S12.6-1997 method B requires the use of subjects "naïve with respect to the use of hearing protection". It may be appropriate, in the case of a select population working in very high noise levels who receive particularly diligent training in the use of HPDs, to allow an employer to arrange testing of the HPDs offered to that population with a sample of subjects who have

Ratings for Method B Data

At the Workshop, Elliott Berger presented the rating proposed by ANSI S12/WG11; this rating is identified by the name NRP_A (for "noise reduction percentile, A-weighted") in the working group's analysis of rating accuracy. Because the approach to rating ANR devices presented later in this paper builds on the NRP_A approach it is worth reviewing here. NRP_A is motivated by four goals:

1) A single number rating should be of the constant protection type; *i.e.*, intended for subtraction from the A-weighted noise exposure in the workplace (A–A' or noise level dBA minus protected dBA). By contrast, the current NRR is a Botsford-type rating meant to be subtracted from C-weighted levels when properly used (C–A'). A-weighted levels or time-weighted averages are the type of data collected in assessing the need for hearing protection so a constant protection type rating is straightforward to apply. By comparison, a Botsford-type rating, though more accurate with traditional muff-type passive HPDs because of their sloped attenuation response, is burdensome (since it requires both C- and A-weighted data to be collected) or confusing (if adjustments are applied in the absence of C-weighted data, potentially leading to errors in its application)[3].
2) It is desirable to have a rating convey the range of performance a device may be expected to provide. This can be done by providing two numbers, a lower one that the majority of users will exceed and an upper one that highly experienced and motivated users can achieve. A single number creates a false impression of precision and, in the absence of advice to the contrary, encourages an unwarranted focus in device selection on slight differences in rating values. Upper and lower estimates of HPD performance are also supportive of evolving standards to consider both over-protection as well as under-protection; the lower of the two values would be subtracted from the workplace noise level to make sure that workers are under the level deemed safe (85 or 90 dBA) while the higher of the two values could be used against an over-protection threshold such as 70 dBA. Finally, note that while a device that has a narrow range between the two values is more precise and repeatable in the protection it provides the novice user, a device with a wide range could be considered adaptable to a wide variety of noise levels when used with regular training of workers as to how to achieve the performance they need, preferably including feedback from a system that allows measurement of HPD performance as part of the training.
3) Two sources of uncertainty constrain the accuracy of a rating method for HPDs: the variation in attenuation of the HPD from person to person and the variation in protection provided in different noise spectra caused by the deviation of the HPD from a flat attenuation response[4]. A rating that provides two numbers to convey the range of performance a device offers should be designed so that range is a function of both of these sources of uncertainty. This will motivate innovation by encouraging the development of HPDs that offer predictable, natural sounding (flat attenuation) and perhaps adjustable levels of performance.
4) All existing rating systems to date make recourse to normal (Gaussian) statistics to establish a conservative estimate of protection that the majority of users can be expected to exceed. While the assumption of attenuation normality is reasonable when working with experimenter-fit data, attenuation data measured with less experimenter intervention (such as method B) is often quite bi-modal because of the way ease of fitting enters the picture. When working with non-normal data, it is better to establish a conservative estimate by means of percentiles calculated directly from the data rather than assuming that the mean less one standard deviation corresponds to the 84th percentile.

---

been through the training provided. This would test the HPD in conjunction with the training that population receives rather than with the manufacturer's instructions. However, testing with naïve subjects based on the manufacturer's instructions should remain the basis for device labeling for the general population.

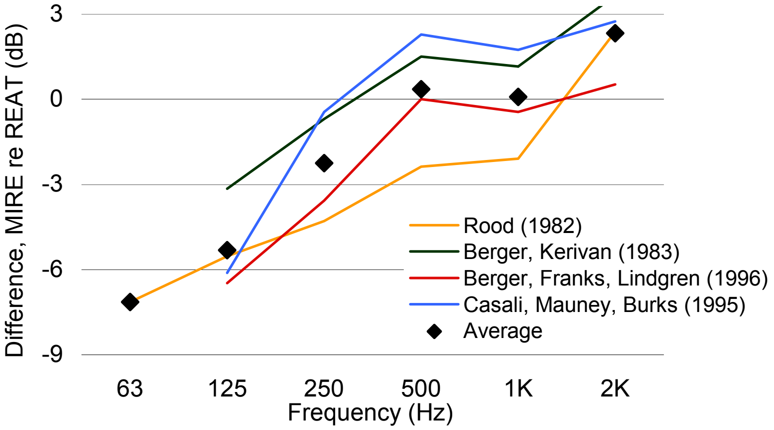
[3] In recent years there has been growing interest in "flat attenuation" devices because of the more natural perception of the users acoustic environment (including speech and warning sounds) they can offer. For a truly flat attenuation device, the situation reverses and constant protection ratings are more accurate than Botsford-type ratings. A constant protection rating does not build in a bias toward a particular attenuation response; it simply gives a figure for the protection the device provides.

[4] One can characterize the subject-to-subject protection uncertainty by calculating the protection in pink noise (close to the median spectrum for industrial noise) for each subject then computing the standard deviation over the subjects tested. One can then characterize the spectrum-to-spectrum protection uncertainty by calculating the protection in a variety of noise spectra (say, the NIOSH 100 [Johnson and Nixon, 1974]) using the mean attenuation. If one does this with method B data, the subject/fit standard deviation for plugs is always much larger than the spectral standard deviation (typically 8 versus 2 to 3 dB), whereas for muffs the spectral and subject/fit standard deviation are usually close (typically 4 dB for each).

The proposed NRP_A rating addresses all of these considerations in a straightforward way. It provides two values that are computed by taking the attenuation measured on each test subject using method B and the 100 NIOSH noise spectra and computes the protection using the octave band method in each combination of subject and spectra. This will yield 2000 protection values in the case of a plug (20 subjects) and 1000 in the case of a muff (10 subjects). Upper and lower percentiles are then found on this set of protection values. The 84th and 16th percentiles can be used for comparison with mean less one standard deviation based ratings; this is done in all cases presented in this paper. Preferably, the 80th and 20th percentiles would be used since these are more readily explained and understood (*e.g.,* the 80th percentile is the value exceeded by four out of five individuals).

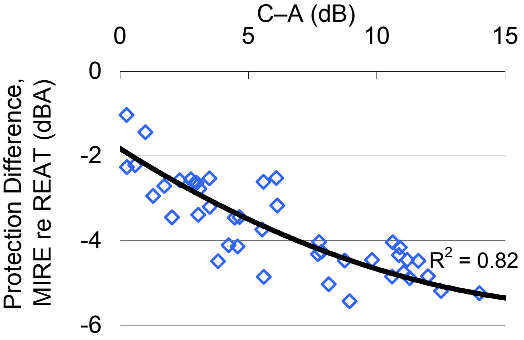
Measuring ANR Attenuation

Figure 1: REAT error due to physiological masking noise



In a comprehensive paper written for the EPA Workshop, John Casali and Gary Robinson describe various issues associated with measuring the attenuation of ANR headsets; the reader is encouraged to review that paper. Several of these issues pose challenges in trying to find a way to encompass ANR devices in a re-defined NRR in way that allows fair comparison between ANR and conventional devices. Two methods of measuring the insertion loss of an HPD are standardized: the REAT and MIRE methods. REAT, though the accepted method for conventional devices, cannot be applied to ANR devices because the self-noise (hiss) from the electronics is loud enough to mask the quiet test signals used and thus raise the occluded thresholds, causing the resulting attenuation values to be inaccurately high. The MIRE test method solves this by using microphones placed in the subject's ear canals to make physical measures of the noise under the earcup, allowing testing at louder noise levels. The problem is that MIRE and REAT for the same circumaural device disagree at low frequencies. The REAT method overstates low frequency performance because sounds of physiological origin (*e.g.*, the subject's heart beat) are loud enough in the occluded ear to mask the low frequency bands. Figure 1 shows the difference between REAT and MIRE data for circumaural devices from four different published studies, the average across the studies is shown by the black diamonds: 5 dB at 125 Hz and 2 dB at 250 Hz[5].

Figure 2: REAT protection estimate error



To illustrate that this REAT error at low frequencies is important from a protection perspective, examine Figure 2. This figure [from Gauger, 2002] shows the change in protection that results when octave band protection calculations (A–A') are done using REAT data for a good quality conventional (passive) muff before and after correction by the averages from Figure 1. Each diamond in the figure represents one spectrum from the set of 50 AF noises [Johnson and Nixon, 1974]. The protection values are plotted against the C–A (dBC–dBA) values for the noise spectrum, a measure of the low frequency content of the noise. The 50 AF noises were used because they are uniformly distributed in C–A value. Figure 2 shows that the REAT error at low frequencies causes a 3 - 4 dB overestimate

---

[5] At higher frequencies (2kHz and above) MIRE data is typically slightly higher (2-3dB) than REAT because it does not include the effects of bone conduction. This is of less consequence than the low frequency REAT error in most situations, however, because the level of attenuation is generally so high at these frequencies that the level of the A-weighted spectrum under the HPD is determined primarily by the octaves at 1kHz and below.

of protection (*i.e.,* larger than the typical subject-to-subject standard deviation) for C–A values of 4 - 6 dB. While this constitutes only 20% or so of industrial noises it comprises almost all environments encountered in general aviation, a key market for ANR devices [Gauger, 2002, Figure 1]. Thus, not accounting for this error in defining test methods for rating ANR devices would unfairly disadvantage them compared to conventional devices.

To eliminate this bias in favor of devices tested with REAT and to provide the most accurate data on which to base a rating it would be best to test all devices, conventional and ANR, using the MIRE method. However, testing earplugs using MIRE is impractical because of the need to place a microphone in the ear canal underneath the plug. The practical way to eliminate the low frequency error is to correct REAT data by the observed REAT–MIRE difference at low frequencies. While this correction is not standardized in ANSI S12.6, the averages presented in Figure 1 could form the basis for this in the case of muffs. There is limited published data upon which to base a correction for plugs, though the existing data indicates the correction should be less [Berger and Kerivan, 1983].

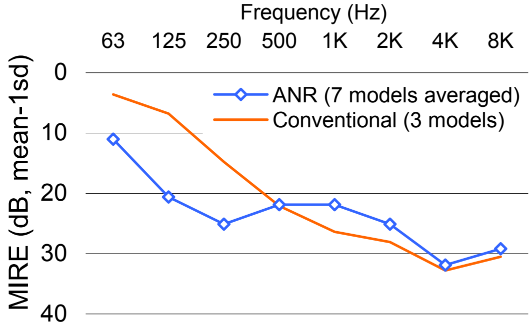
An alternative way to "level the playing field" between conventional and ANR devices would be to require ANR devices to be tested using REAT for their passive performance and MIRE for their active part. The passive performance is measured with ANR turned off, just as if the device were a conventional HPD. The active part is measured, after placing the MIRE microphones in the subject's ears and donning the headset, by taking the difference in the spectra at the microphones with ANR off and with ANR on. The REAT and MIRE tests should be done with the same subject pool; the averages of the passive and active data across trials for each subject can then be added to obtain the total attenuation for each subject to use in rating computation. While this REAT+MIRE approach levels the playing field, it has two disadvantages: (1) it does not eliminate the over-estimate of protection in high C–A noise environments illustrated in Figure 2 and (2) it imposes extra cost on ANR manufacturers, requiring two tests on a device, not just one. Finally, two issues should be addressed in the MIRE standard (ANSI S12.42) to support the adoption of REAT+MIRE testing for ANR devices. First, the MIRE standard includes no method B (subject fit) protocol, though adapting the approach from ANSI S12.6 is straightforward. Second, some further guidance as to how to mount the test microphones on plugs and seat them in the ear is desirable so as to ensure both accurate and repeatable ANR measurements while ensuring that experimenter coaching of subjects on proper plug+mic fitting for MIRE tests does not disqualify the subjects for method B REAT testing of plugs where the subjects are required to be inexperienced in plug use.

Finally, it is worth mentioning two other ANR testing issues that lack any standardization that supports inclusion in EPA changes to the NRR. First is the issue of "overload". ANR devices must produce a out-of-phase sound of the same level as the noise to be canceled; every ANR device has some maximum noise limit determined by the acoustical and electronic characteristics of the device. When operated in noise above this limit ANR performance rapidly decreases. This limit is both frequency and subject fit dependent; it should be measured with the headset worn on human subjects by some MIRE-like protocol. No standard exists for how to measure this limit and very few labs that measure hearing protector performance have the capability to generate the necessary sound pressure levels at low frequencies. The second issue is the fact that ANR devices that adapt dynamically to the noise environment are starting to appear on the market. For such devices, the ANR performance measured with pink noise (typically used in MIRE tests) can differ substantially from that measured with recordings of the noise for which the device is designed (*e.g.,* general aviation noise which often has a few strong periodic tones an adaptive ANR headset can attack). The lack of standards to address either of these issues make it hard for the EPA to address them in any near-term rule-making in anything but a qualitative, advisory way.

ANR from the Single Number Rating Perspective

What might typical ratings look like if the EPA were to change the NRR to require MIRE testing for ANR devices and REAT testing for conventional devices, corrected for the REAT low frequency error as discussed above? What impact would it have on the ANR industry? To examine this assume that the EPA changes the NRR to the NRP$_A$ rating proposed by ANSI S12/WG11 and described earlier. For attenuation use an average of MIRE data for conventional and ANR communication headsets sold for general aviation, as shown in Figure 3 [from Gauger, 2002].

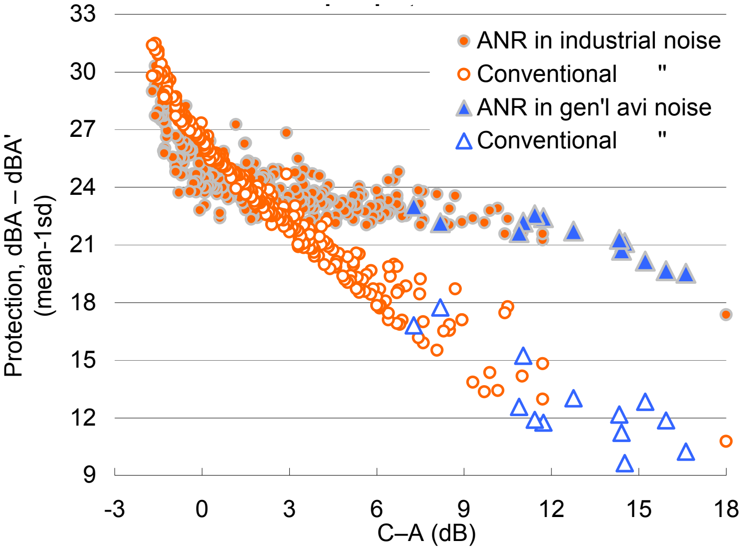
Figure 3: ANR & conventional headsets for rating comparison



Estimated NRP$_A$	Conventional	ANR
MIRE	22 – 30	24 – 29
REAT+MIRE	24 – 31	25 – 29

The table at right shows the NRP$_A$ values (84th and 16th percentiles) computed from the MIRE data used to create Figure 3. The table also shows estimates of the NRP$_A$ values that would be obtained if REAT+MIRE data were used, estimated by adding to the MIRE data the average REAT–MIRE difference from Figure 1. Note that the difference in performance between the conventional and ANR headsets is only 1 - 2 dB at the lower value; this is because the NRP$_A$ is computed using the 100 NIOSH noises which are dominated by spectra with low C–A values. It is only in noise with high C–A where ANR offers benefits, as shown in Figure 4. That figure shows that the average difference between the conventional and ANR performance in industrial noise (orange marks[6]) is minimal whereas the difference in general aviation noise (blue marks) is about 10 dB.

Figure 4: Protection versus C–A for communication



The assumption of industrial-type, low C–A noise in a single number rating is appropriate for a new NRR, given that the industrial workplace is where an improved NRR label is most needed. However, requiring a label with a rating as shown in the table on general aviation headset packaging would misinform consumers. The label would say a conventional headset offers virtually the same performance as an ANR one whereas, in its intended application in general aviation noise, the benefit is substantial as shown in Figure 4. Such a primary label on the box could have a severe financial impact on the ANR industry, impeding future innovation. The best thing to do is to not require simple, single-valued ratings on a primary label for an ANR headset. The numbers on the primary label should be replaced with the text “ANR device — see secondary label for data”.

Information on the Secondary Label

To properly convey to consumers the performance of ANR devices compared to conventional ones or to allow comparison of different ANR headsets, some easy-to-use way to communicate performance as a function of noise spectrum is needed. The current secondary label includes a table of octave band attenuation values, both mean and standard deviation. However, only a small percentage of people understand how to use this data and only a small percentage of users have means to obtain octave band noise data in their noise environment(s) of interest.

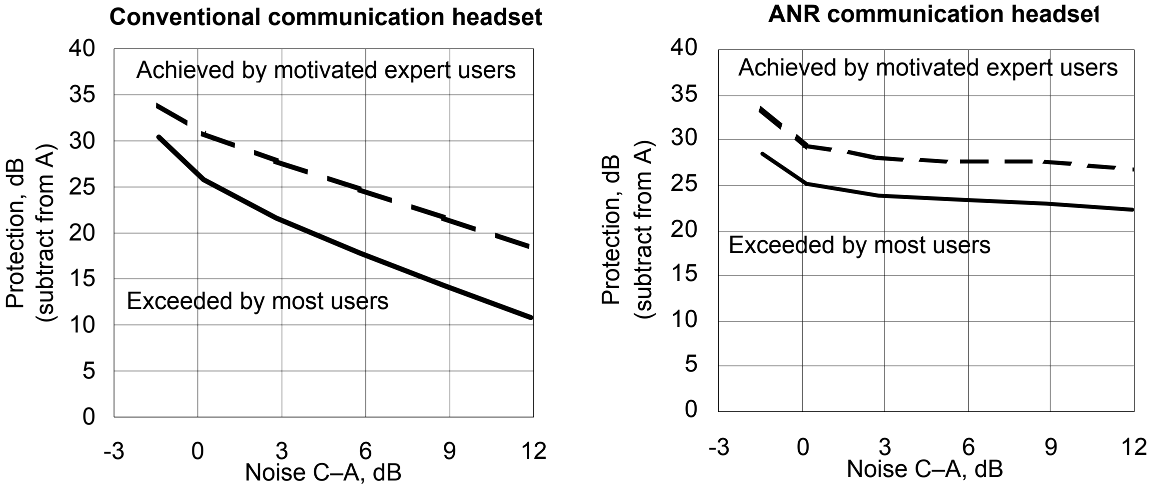
An alternative is to replace the octave band attenuation table with data that describes the protection the HPD provides as a function of the noise C–A value; the C–A value for a noise can easily be obtained with many sound level meters. Protection as a function of C–A is the basis of the ISO 4869-2 HML method as well as a multi-number method used by the USAF [R. M^{c}Kinley correspondence]. The approach proposed here is inspired by these methods while, at the same time, extending the proposed NRP$_A$ intended for primary label use. This proposed rating for the secondary label may be called NRP$_G$ where the “G” stands for “graph” since the data is presented graphically rather than in tabular form. The idea is simple: take sets of noise spectra centered on various C–A values and, with each set, compute high and low protection (A-A') percentiles using the subject-by-subject attenuation data in the same manner that the NRP$_A$ is computed using the 100 NIOSH noises. The values can then be plotted as high and

---

[6] Compare the apparent mean of the orange open (conventional) or filled (ANR) marks in the figure to the lower values in the MIRE row of the NRP$_A$ table. Note also that the ANR protection varies less with C–A because the attenuation is flatter. This is why the range between the two values in the NRP$_A$ table is smaller for ANR than it is for the conventional headset.

low performance bounds on a graph of protection as a function of C–A. Graphical presentation is proposed instead of tabular form (like the HML) since most people can readily read a graph whereas an approach like the HML requires arithmetic computation to interpolate the table. Figure 5 shows examples of what this graph might look like based on the MIRE attenuation data shown in Figure 3.[7]

Figure 5: Protection versus C–A graph (NRP_G) for secondary label



From such a graph it is easy to see that an ANR device offers advantages in high C–A noise but not low C–A ones. The secondary label could include advice that if the noise is from moving vehicles, large air moving equipment or has a "humming", "rumbling" or "roaring" sound to it then the C-weighted level of the noise should be measured so that the C–A can be determined and the graph used. Additionally, publications could provide typical C–A values for different types of noise sources and industries. This graphical approach to increasing rating accuracy through the use of C–weighted noise data is preferable to the approach described in Elliott Berger's presentation at the Workshop (wherein a constant correction is added to an A–A' rating such as NRP_A and then this new constant value is subtracted from a C-weighted noise level) since that approach relies on the HPD having the sloped attenuation response characteristic of passive earmuffs. For flat attenuation devices such as circumaural ANR headsets that method can overestimate protection in high C–A environments such as general aviation by 10 dB or more.

In addition to the graph showing protection versus C–A in place of the octave band attenuation statistics table, the secondary label should address several other issues in our opinion at Bose.

1) Consumers should be advised that noise reduction is not the sole, nor in all cases the most important, consideration in choosing a hearing protector. Other factors such as comfort and the ability to communicate or hear important sounds in one's environment must be considered as well. We encourage the EPA to consider the advice of the NHCA Task Force on Hearing Protector Effectiveness in requiring wording to address these issues on a secondary label.
2) In the case of communication headsets or radio-equipped hearing protectors consumers should be advised to choose a headset that reduces their noise environment to at least 5 dB below the level considered safe (*i.e.*, 80 rather than 85 dBA). This is so that communications can be listened to at a level loud enough above the attenuated noise at the ear to allow good intelligibility without the communication signal posing risk of hearing damage.
3) Should the EPA require passive (ANR off) performance data for ANR headsets on the label? This could, for example, be done by adding one or two additional contours to the graph shown in Figure 5. In our opinion, this should not be required. ANR headsets are designed to be used with ANR operating; they are not used with

---

[7] A Microsoft® Excel spreadsheet and supporting documentation that computes the NRP_A and NRP_G ratings is being prepared to better explain them and allow interested parties to experiment with them using attenuation data of their choosing. They will be available very shortly. For further information contact the author at Bose Corporation or Elliott Berger at Aearo.

ANR turned off but for short periods of time (*e.g.*, until a battery can be replaced). Thus the impact on hearing protection of very occasional, short-term use with ANR off is small.

Summary — Recommendation to the EPA

In conclusion, Bose Corporation offers the following recommendation to the EPA. This recommendation is motivated by our desire to see a revised HPD labeling standard provide consumers with reasonably accurate, meaningful and easy-to-use data by which to compare and choose devices appropriate to their needs.

1) The EPA should change the NRR so that it is based on subject fit data per ANSI S12.6 method B.
2) The rating should be designed for subtraction from A-weighted noise levels and convey to the consumer, by means of two numbers, the range of performance a protector can provide. This range should be computed by some method that factors in both the uncertainty in protection due to variation in subject fit as well as noise spectrum. The NRP_A rating described by Elliott Berger in his presentation and earlier in this paper accomplishes these goals. We recommend its adoption by the EPA as the basis for a redefined NRR.
3) Our preference at this time would be that the EPA not extend the NRR-defining rules to encompass ANR devices. This is because standards existing at this time do not define how to correct REAT data for the error caused by low frequency physiological noise masking. Correcting for this error is necessary to enable the computation of reasonably accurate noise reduction ratings in environments with significant low frequency noise energy (high C–A value). Standards also do not yet exist for the measurement of maximum safe noise level or overload performance of ANR devices.
4) Alternatively, if the EPA chooses to extend the NRR to encompass ANR at this time it should:
    a) Not require a NRR value on the primary label for ANR devices. Words to the effect "ANR device — see secondary label for data" should replace the NRR values.
    b) Require that the octave band table of attenuation statistics be replaced with a graph of high and low protection values versus noise C–A as illustrated in Figure 5 (the NRP_G graph).
    c) Require that the attenuation data used to define this graph be measured using MIRE for ANR devices and REAT for passive devices *and* that all REAT data for circumaural and supra-aural devices be adjusted downward by 5 dB at 125 Hz and 2 dB at 250 Hz to correct for physiological noise masking. If such a correction to REAT data is not mandated, then ANR should be tested by means of REAT for passive performance and MIRE for active performance.
    d) The secondary label should provide additional advice to consumers regarding the importance of choosing a protector that is comfortable to wear and which allows them to hear important sounds in their environment.
    e) Data on passive (ANR off) performance of protectors should not be required.

References

Berger, E. H., Franks J. R., and Lindgren F. (1996). "International Review of Field Studies of Hearing Protector Attenuation," Scientific Basis of Noise-Induced Hearing Loss, A Axelsson *et. al.* Editors, 361-377.

Berger, E.H. and Kerivan, J.E. (1983). Influence of physiological noise and the occlusion effect on the measurement of real-ear attenuation at threshold. *JASA* **74**(1), July 1983, 81-94.

Casali, J. G., Mauney, D. W., and Burks, J. A. (1995). "Physical vs. Psychophysical Measurement of Hearing Protector Attenuation — a.k.a. MIRE vs. REAT," *Sound and Vibration*, July 1995, 20-27.

Casali, J.G. and Robinson, G.S. (2003). "Augmented" HPDs: Active Noise Reduction, Level-Dependent, Sound Transmission, Uniform Attenuation, and Adjustable Devices -- Technology Overview and Performance Testing Issues. Invited paper, EPA Workshop on Hearing Protection Devices, 27-28 March 2003.

Gauger, D. (2002). Active Noise Reduction (ANR) and Hearing Protection: Where It's Appropriate and Why. NHCA 27th Annual Conference, *Spectrum* Supplement 1.

Johnson, D.L. and Nixon, C.W. (1974). Simplified Methods for Estimating Hearing Protector Performance. *Sound and Vibration*, June 1974, 22.

Meeker, W.F. (1958). Active ear defender systems: component considerations and theory. WADC Technical Report 57-368, Aeromedical Laboratory, Wright Air Development Center, Wright-Patterson AFB, OH.

Rood, G. (1982).). The In-Situ Measurement of the Attenuation of Hearing Protectors by The Use of Miniature Microphones. Personal Hearing Protection in Industry, editor P.W. Alberti, Raven Press, New York, 175-197.