The Current Status of Standards for Testing Electroacoustic Hearing Protectors.

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Electroacoustic hearing protectors encompass several classes of electronics: level –limiting, amplitude compression and active noise control (ANC) devices. Each class of protector seeks to enhance performance by overcoming insertion loss and/or improving low-frequency attenuation. Level-limiting devices turn off the amplification when the external sound level exceeds a preset threshold. Amplitude compression devices apply variable gain and limit amplification of signals above the threshold. ANC devices create an out-of-phase signal under the protector to improve the low-frequency attenuation of earmuffs. ANC devices typically perform best in continuous noise that has strong harmonic components that can be predicted and cancelled. The different methods of enhancing protector performance require separate standards to understand both the static and dynamic performance. Testing of ANC devices has further requirements which require knowledge of both passive and active electronic conditions and in noise with different crest factors. This talk will review a variety of tests of the different protector classes.

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Current Status of International Standards for Electroacoustic Hearing Protectors

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This afternoon, I will review the status of international standards for electroacoustic hearing protectors. Before I get too far, I will define what seem to be three classes of protectors. The first would be sound restoration devices. These devices have some form of amplification to overcome the insertion loss of the earmuff. The second class would be Active Noise Reduction protectors. ANR devices create an out-of-phase signal to cancel the external noise and work well below 500 Hz. The third class of devices would be personal communication systems. These devices can include communication headphones that can be connected to external radios, FM radio headsets, and complete full-duplex personal communication systems that incorporate the transmitter/receiver in the headset. Finally, hybrid systems must be considered.

What Standards Exist?

- ISO/TR 4869-4 Sound Restoration Earmuffs
- ISO/PWI 4869-5 HPD Attenuation in Impulsive Noise
- PREN352 Hearing Protectors - Safety Requirements and Testing
  - Part 4: Level-Dependent Ear-Muffs
  - Part 5: Active Noise Reduction Ear-Muffs
  - Part 6: Ear-Muffs with Audio Communications
  - Part 7: Level-Dependent Ear-Plugs
- ANSI S12 Working Group 39 on nonlinear hearing protection devices.

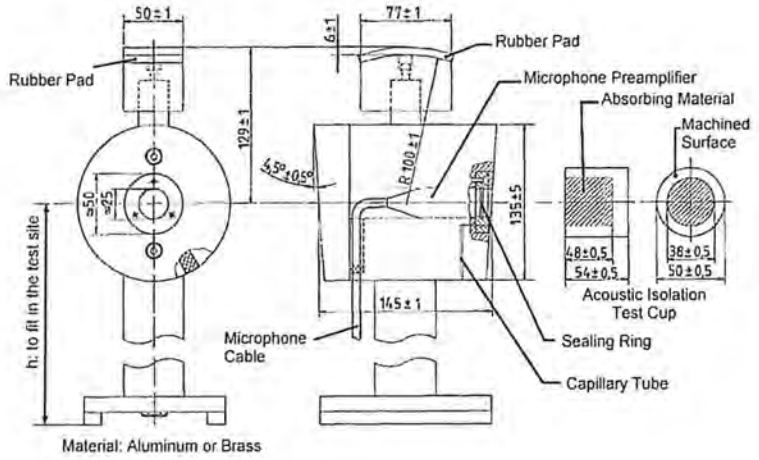
As I investigated the question of what standards currently exist, the conclusion I reached is that there are none in place. The ISO 4869-4 is a technical report and has not achieved standard status although it has been voted on two times. ISO PWI4869-5 Is not available through the ISO standards store. The PREN352 Parts 4-7 are proposed standards, but have not been circulated for evaluation. I believe that they exist in Swedish and unfortunately I was unable to obtain them for this talk. ANSI has a working group 39 which has yet to produce a proposed standard. I have been a co-chair for that group for the past year. Hopefully, it will have a product by this time next year. Since the ISO 4869-4 is what is available for critique, the majority of this talk will focus on this standard. Currently in the United States, only the passive performance is required to be assessed. The EPA regulation requires the protectors be tested with ANSI S3.19-1974 experimenter fit method and that the Real-Ear Attenuation at Threshold be reported.

Test Conditions

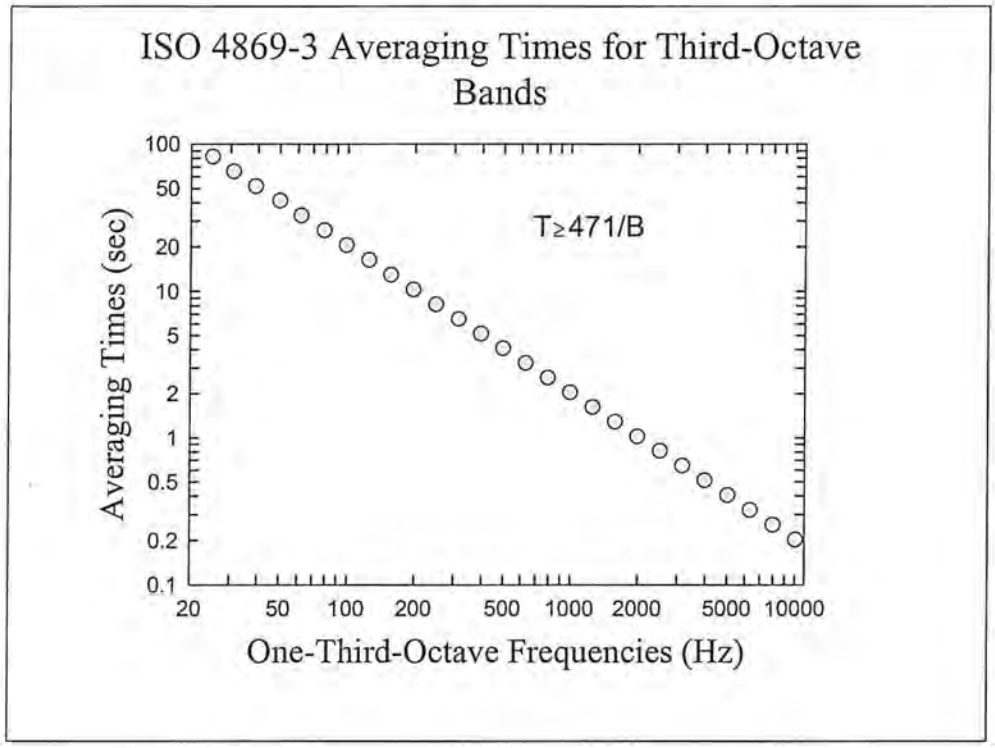
- Diffuse Sound Field, ISO 4869-1
- Pink Noise with uniform levels
  - ±2 dB 125-8000 Hz,
  - -3dB at 100 and 10000 Hz
  - Range of 50 to 110 dB
- ATF or HATS compliant with ISO/TR4869-3
- Signal-to-Noise Ratio > 10 dB
  - Test by turning off noise stimulus
- Three protectors, Six ear-cups

Since the only standard that has been proposed is the ISO 4869-4 Technical Report, we will discuss this through the remainder of the report. The diffuse sound-field is the same as that required for human testing under 4869 part 1: 15 cm radius front-back right-left, up-down no more than ±2.5 dB variation. The noise should have equal energy in each one-third octave band from 125 to 8000 Hz. Each band should vary no more than ±2 dB over that frequency range. At 100 and 10000 Hz the signal should be 3 dB lower and have a -12 dB/octave slope outside 125 and 8000 Hz. The signal should be reproducible from 50 to 110 dB. The Signal to Noise Ratio should be > 10 dB. This can be tested by turning off the Noise stimulus at 50 dB and the noise level at the microphone should drop by 10 dB or more. The minimum number of protectors to test is three, or six ear cups.

ISO 4869-3 Example Acoustic Test Fixture



This drawing was extracted from the ISO 4869-3 standard. It shows a fixture with sloped faces and the microphone centered in one of the faces and a support for the headband. It also shows the details of the microphone mounting with a capillary tube for pressure equalization and the suspension of the preamplifier of the microphone.



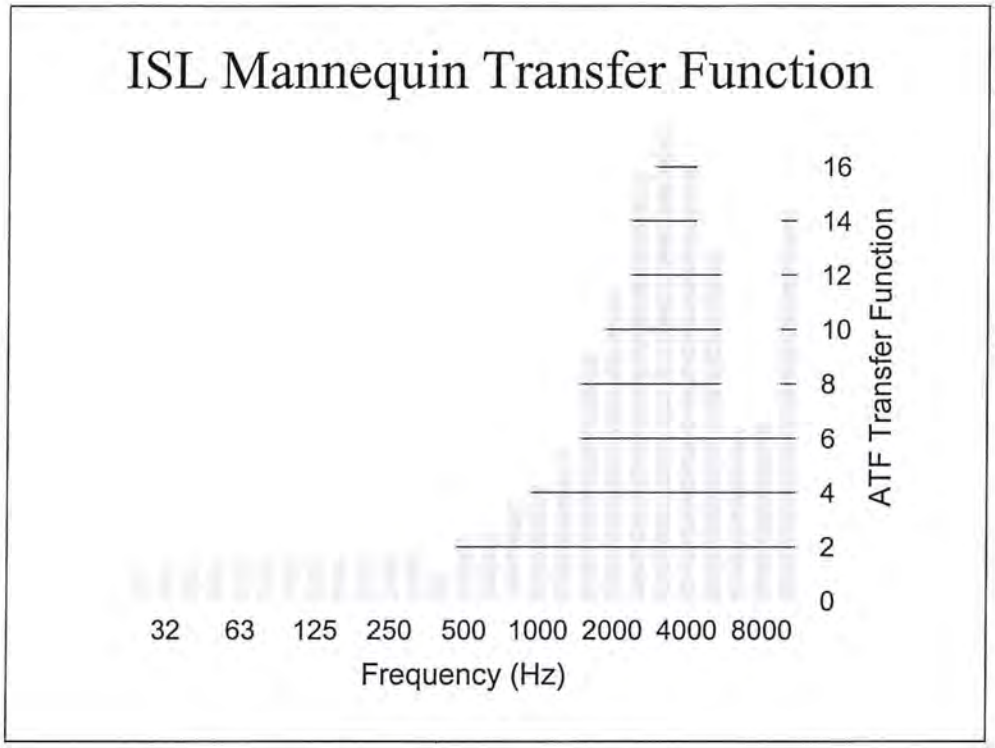
For each 1/3rd octave band, the time necessary to average each band is shown in this figure. Ideally, the standard deviation for each band should be less than 0.2 dB. For lower frequency bands, the averaging time is increased. At 25 Hz, the averaging time is ~80 seconds. At 10000 Hz, the time is ~0.2 seconds.

Measure the ATF/HATS Transfer Function

- Set A-Weighted sound pressure level at reference point
- Measure and Record the one-third octave band levels at reference point
- Position ATF/HATS at reference point
- Measure sound with microphone in the ATF/HATS

$$H_{ATF}(f) = L_{ATF}(f) - L_{REF}(f)$$

The transfer function between the reference point and the ATF of HATS is critical to the assessment of the attenuation. While the attenuation could be measured by measuring the sound levels for each stimulus with and without the protector, knowledge of the transfer function simplifies the calculations. The external sound levels can be determined once for the condition without the ATF or HATS present in the sound field. Then subsequent measurements with the ATF or HATS need only compensate for the frequency-dependent response of the fixture.



For our lab, I have performed this transfer function measurement with the ISL mannequin. The function exhibits significant resonance at 3150 and 10000 Hz. The resonance can be attributed to the 4157 Bruel & Kjaer ear simulator and the HEAD Acoustics ear canal and pinna.

Active Mode Performance

- Set the Gain to Maximum
- Measure 1/3rd Octave levels on the ATF/HATS
  - 50-90 dB in 10 dB steps
  - 90-110 dB in 5 dB steps
- Measure each of the sample ear-cups.
- Averaging times
  - 16 sec at 125 Hz
  - 0.3 sec at 8000 Hz

To assess the active mode performance of a protector, the gain of the amplifier should be set to maximum. The ATF/HATS level is measured at 10 dB intervals from 50 to 90 dB and 5 dB intervals from 90 to 110 dB. Each of the six ear cups should be individually tested. Note that the averaging times range from 16 seconds at 125 Hz to 0.3 seconds at 8000 Hz.

Passive Mode Performance

- Turn off Amplifier or disconnect Battery without removing from the protector
- Place muff on the ATF
- Sound level above 80 dB
- Measure 1/3rd Octave band levels for that level

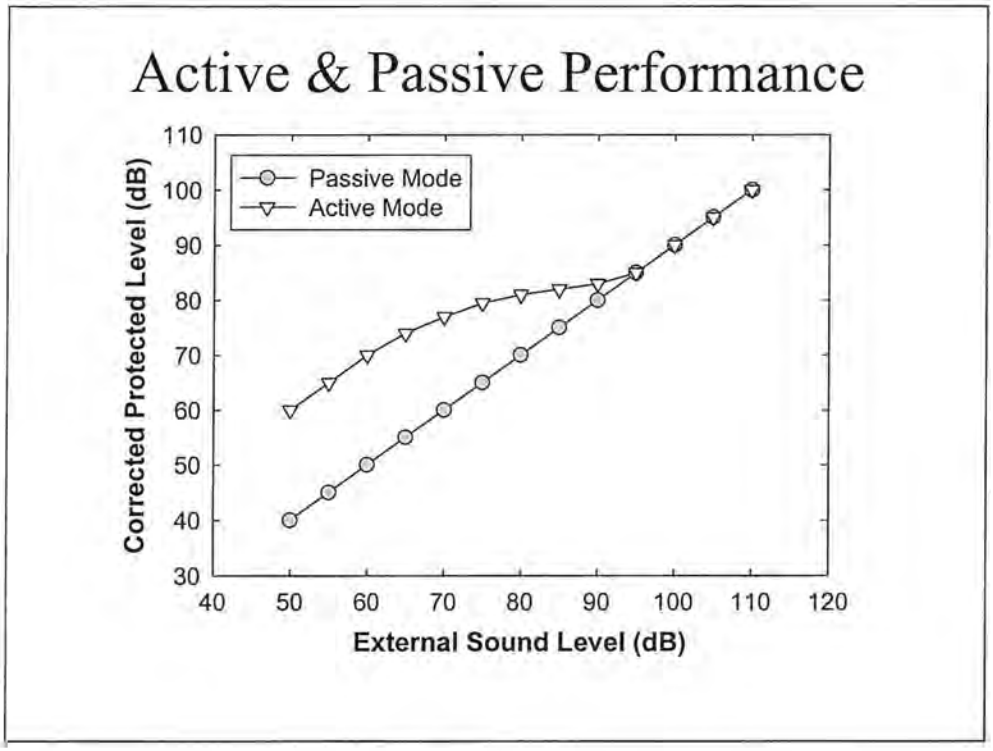
To measure the passive performance, the protector is turned off or the battery disconnected and not removed. The external sound filed should be at a level above 80 decibels. I believe the level was set at 80 to ensure that the attenuated signal was not below the noise floor of the ATF or HATS.

Active and Passive Level Calculation

$$L_{ACT\ Cor}(f,L) = L_{ACT}(f, L) - H(f)$$
$$L_{PAS\ Cor}(f,L) = L_{PAS}(f,L) - H(f)$$

$$L_{ACT\ Eff}(L) = 10\ Log[\Sigma\ 10^{0.1\ L_{ACT\ Cor}(f,L)}]$$
$$L_{PAS\ Eff}(L) = 10\ Log[\Sigma\ 10^{0.1\ L_{PAS\ Cor}(f,L)}]$$

Both the passive and active 1/3rd octave band functions must be corrected for the ATF/HATSD transfer function. The effective levels are determined from the log sum of the levels.



An example of the attenuation and input/output curves are shown in this graph. These data are not actual measurements. The active restoration circuit contribution is reduced as the external level increases. Eventually the output limit of the device is reached at an external level of 95 dB. The green line shows the passive attenuation is constant. In actuality, some interactions may take place as a function of level and frequency. Particularly with active noise reduction devices.

Performance Report

- Table of levels for each cup
- Means and Standard Deviations
- Maximum of Left/Right Levels
- Graph of Effective dBA levels and Insertion Loss
- Information about HATS or ATF
- Passive REAT data can be reported at discretion.

The ISO Report suggests the following information be included in the performance report for a protector. For each cup, the mean and standard deviations of the levels for the right and left ear cups should be reported. A graph like that from the preceding slide should be included. Information about the ATF/HATS should be included. Lastly, the passive performance of the device on human subjects should be included. The ISO technical report suggests a method for reconciling the ATF/HATS data with the subjective data. I am not going to discuss that appendix today. Without data from both the ISL mannequin and a panel of subjects, the discussion would be too hypothetical.

Criticisms

- HATS acoustic isolation is not well-defined
- The signals are ambiguous for A-weighted levels and Effective A-Weighted levels
- Only yields information about compression and passive attenuation.
  - What about attack and release time?
- No spectral variation considered.

The ISO 4869-4 document is a good start for developing an international standard. Several portions require clarification and expansion. Specifically, the acoustic isolation of the fixture described in ISO 4869-3 shall be 50 dB for 63-250 Hz, 65 dB for 315-4000 Hz and 55 dB for frequencies above 4000 Hz. No specification is given for the HATS. As one reads the part 4 report, the use of A-Weighted levels and Effective A-weighted levels is somewhat ambiguous. Effective A-weighted appears to refer to the overall level determined from the logarithmic sum of the individual bands. In addition, no consideration is given to the performance of the level-limiting circuitry. In one device that I have tested, the recovery of the circuitry overshot the target level after an impulsive event. Some measurement of the attack and release time is necessary. Finally, the only signal discussed in the ISO proposed standard was a broad-band pink noise.

Suggestions

- Measure Attack and Release Time
  - 1/3rd OBN amplitude-average level change between 50 and 90 dB.
- Spectral Content
  - Use H, M and L-weighted noises to check the effect of different spectra on sound restoration.
- Specify the acoustic isolation of ATF/HATS at below bone-conduction limits 125-8000 Hz.

The measurement of the attack and release times could be achieved by switching the amplitude of the external sound between 50 and 90 dB and performing an amplitude average. The spectral content could be varied between the H, M and L-weighted noises to determine whether that affects the performance of the sound restoration circuits. Finally, the acoustic isolation of the HATS should be required to be equivalent to that for the ISO fixture and should definitely be better than the bone-conduction limits as presented by Elliott Berger this morning.