Application Note
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Testing of Acoustical Isolation of Hearing protectors and Ear Phones using G.R.A.S. 45CB Acoustic Test Fixture

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Introduction

The G.R.A.S. 45CB Acoustic Test Fixtures (ATF) is primarily designed for objective testing of hearing protectors. The 45CB is designed in accordance with the ANSI S12.42 standard.

While normal Acoustical Test fixtures like the G.R.A.S. KEMAR, which is optimized for testing devices like hearing aids, headphones and telephones, only have a self-insertion loss in the range of 40-60 dB, the 45CB has self insertion loss of more than 70 dB.

This document describes how to use the 45CB to measure the acoustic attenuation of hearing protectors as well as of active noise cancelling headphones. Both circum-aural and in-ear type products have been tested using broad band noise.

Figure 1 G.R.A.S. 45CB Acoustical Test Fixture

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Theory

The acoustic test fixture can be seen as a number of different sub-systems each with a different function for the correct measurement of insert loss of hearing protectors.

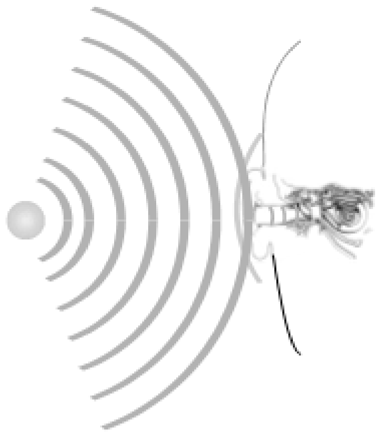


Figure 2

Sub-system 1

The first part is the general outer shape of a human head with shoulders. When a human head is introduced in a sound field, the sound field will be changed due to diffraction around the head and torso. In the mid frequency range the presence of the head will result in an increase of the sound pressure close to the head. This pressure increase depends on the orientation of the head in the sound field, and for a plane wave arriving to the front of the head, the pressure increase at the ear reference point (ERP) is as shown in Figure 3.

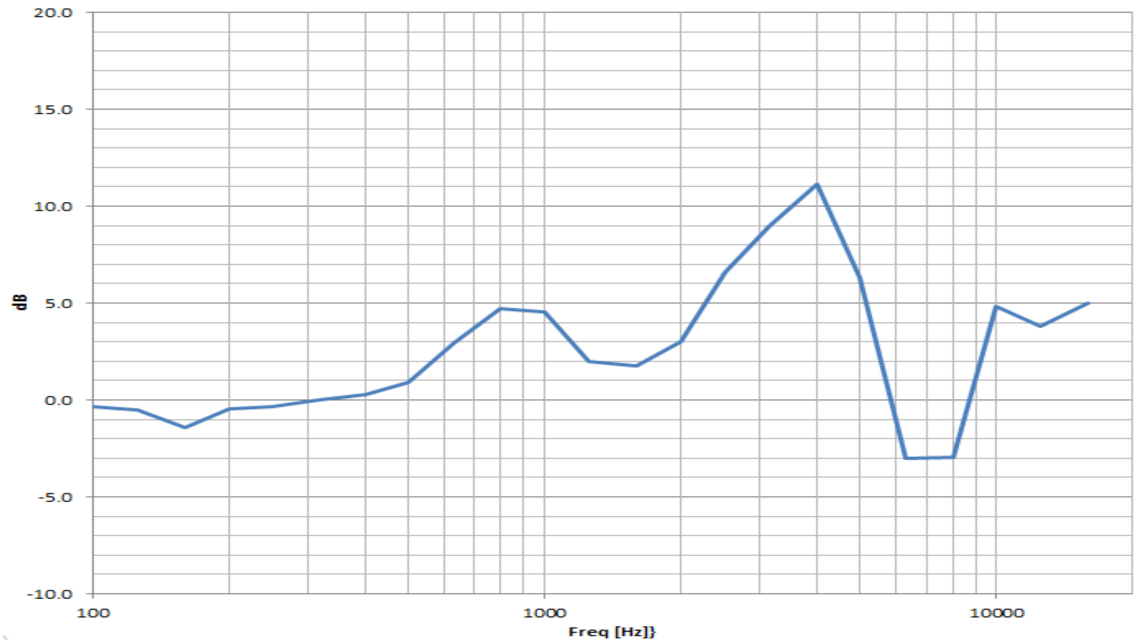


Figure 3 45CB Free Field to ERP transfer function

It can be seen that there is an increase of the sound pressure level of approximately 5 dB around 900 Hz and 10 dB around 4 kHz. In order to realistically test the performance of hearing protectors as they will perform on a human head, it is important that both size and structure of the test fixture resembles the human head.

Sub-system 2

The outer ear canal is followed by the Ear Simulator, which replicates the human ear impedance and also includes a microphone to simulate the function of the eardrum and inner ear. When a circum aural or in ear type hearing protector or headphone is mounted on the 45CB, this will be loaded with the input impedance of the ear and this will affect the sound transmission through the hearing protector.

While the rubber pinnae simulates the outer ear structure, the middle and inner ear is simulated by a standardized G.R.A.S. RA0045 Ear Simulator (IEC 60318-4, formerly known as the "711-coupler"). This has the same input- and transfer impedance as a typical human ear. The ear simulator is also equipped with a microphone in a position where the human eardrum would normally be. This means that the microphone will record the sound pressure as it would be at a typical ear drum of a typical human being. Figure 4 shows the real human ear and the corresponding rubber pinna with Ear Simulator.

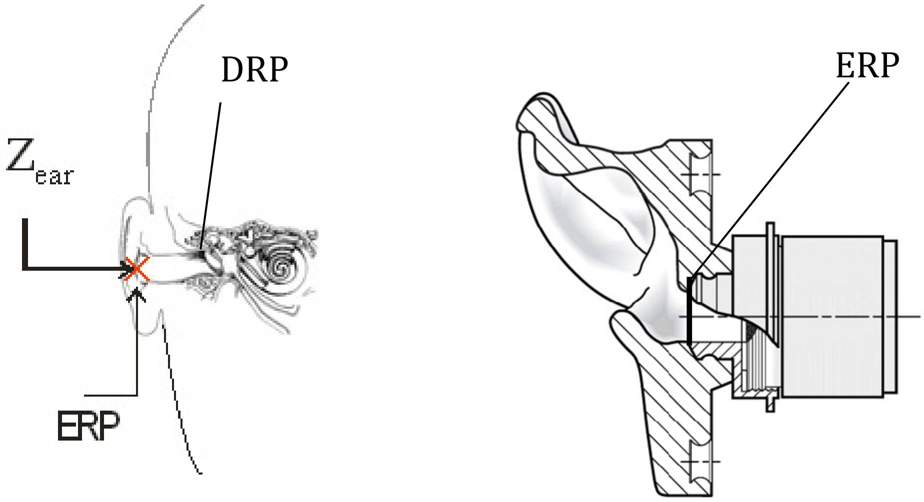


Figure 4 Human ear & corresponding Ear Simulator, showing Ear Reference Point (ERP) and Drum Reference Point (DRP)

Figure 5 shows the transfer function from the ear reference point (ERP) to the drum reference point (DRP) and it can be seen that the signal is attenuated by up to 10 dB in the mid frequency range.

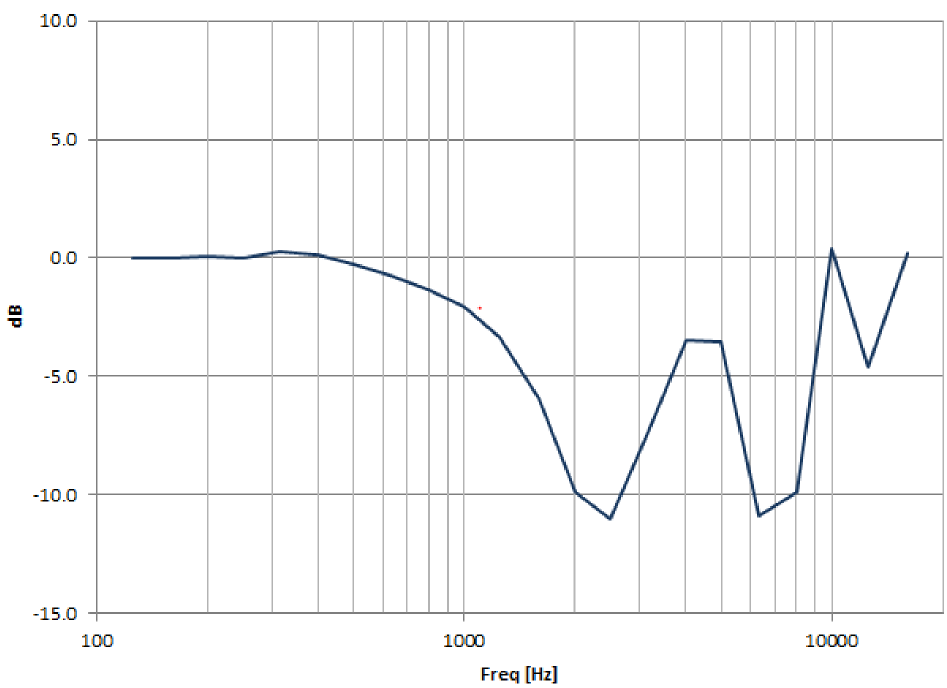


Figure 5 Transfer function from the ear reference point (ERP)

Sub-system 3

The final important subsystem is the mechanical link between the device under test and the test fixture. Pinna and outer ear-canal form the direct mechanical interface to the hearing protectors and are important in simulating transmission through the skin and flesh of a typical human head structure. Therefore the stiffness of the rubber used for the in the Acoustic Test Fixture is carefully controlled to a stiffness of 55 Shore AA.

The 45CB is equipped with heated ear canals so that the temperature can be kept as found in the human ear canal. This may be of importance when studying in–ear type headphones with rubber fittings, as the rubber may change properties with temperatures. It is then important that the measurements are performed with the in-ear type headphone at the same temperature as when mounted on a human ear.

When measuring the insertion loss, or damping, of hearing protectors, it is important that the test fixture is sufficiently dampened. This ensures that the microphones only pick up sound coming from the ear-canals and not the transmission through the test-fixture.

The self-insertion loss of the 45CB has been determined using sensitive microphones in a sound field with high sound pressure level. This can be seen in Figure 6 where it is also compared to the requirements given in ANSI S12.42. Throughout the frequency range, the 45CB exceeds the requirements in the standard.

The self insertion loss is measured while fully blocking the ear canal entrance with a solid steel plug with at least 10 mm length. Also the loss is measured without the rubber pinna mounted on the head as transmission through the rubber, simulating the human flesh, is an important path for sound transmission for normal circum-aural head protectors.

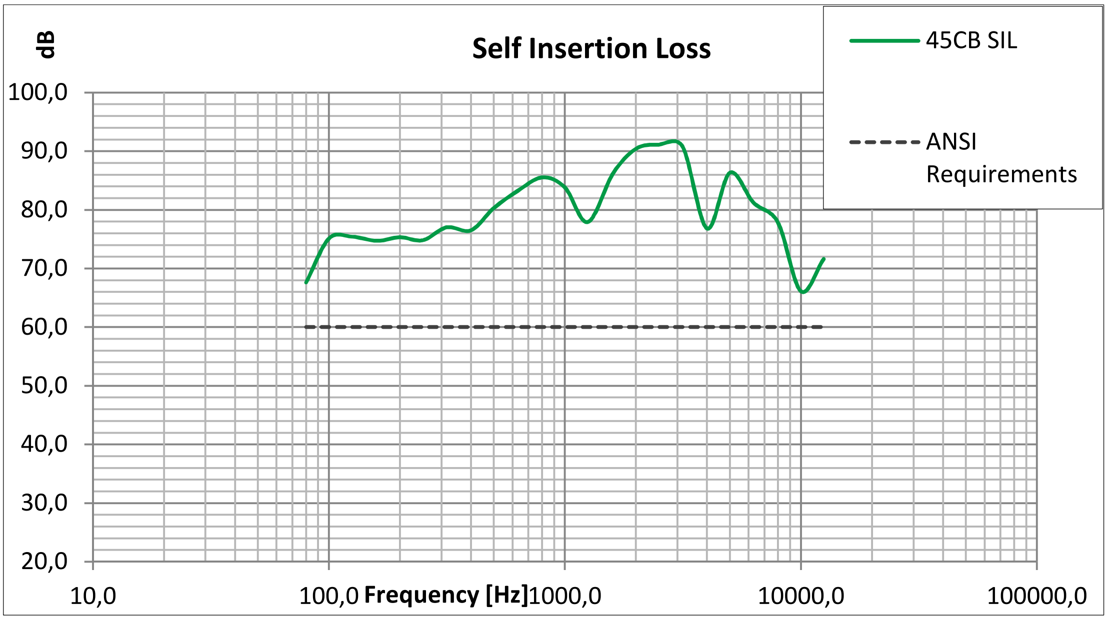


Figure 6 Self insertion loss of 45CB meets ANSI requirements with large margin

Test setup

The test fixtures may be used for testing with both continuous and impulsive excitation of hearing protectors, but here we will focus on continuous excitation testing using broad band noise.

The test should be performed in a diffuse sound field, for example in a reverberation room. In order to test hearing protectors with high attenuation, it is necessary to establish a high sound pressure level in the diffuse field. This may require the use of several high power loudspeakers distributed in the test room so that a diffuse field is obtained where the test fixture is positioned.

In this example the diffuse sound field was established in a large room (16 x 12 x 6m) with reflecting walls (Reverberation room) by four loudspeakers pointing away from the test object. The loudspeakers were driven by four power amplifiers and produced a sound pressure level of about 90 dB (in 1/3 octave bands) from 50 Hz to 20 kHz as seen in Figure 7, upper blue graph. This level was measured with a reference microphone in the position where the test fixture would be, but without the test fixture in the sound field. This level should be compared to the noise floor the test fixture.

In the standard configuration, the 45CB is equipped with ear couplers with 1/4" pressure microphones with a sensitivity of 1.6 mV/Pa. With these microphones, the test fixture has a noise floor as indicated in lower red graph. The difference between the sound pressure level in the diffuse field and the noise floor determines the range of insertion loss which can be measured with this setup and is in the range of 60 dB. For higher ranges either the sound pressure level in sound field should be increased or the microphones should be replaced with more sensitive units with lower noise floor.

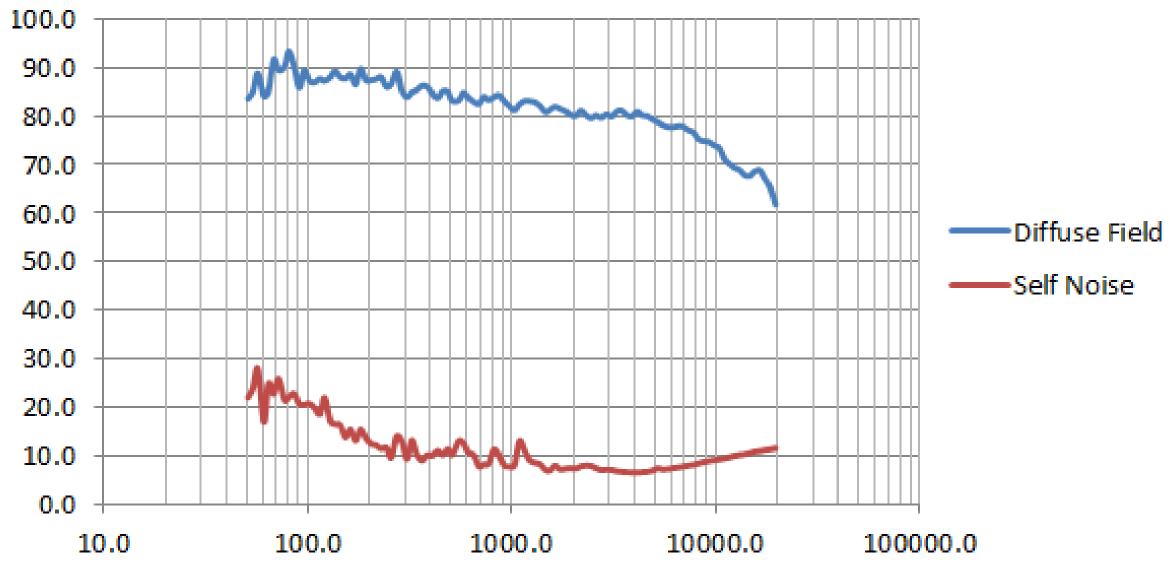


Figure 7 Self Noise (Noise Floor) and diffuse field SPL pf the setup example

The measurements were performed with a setup as shown in Figure 8 with data acquisition and output signal generation software implemented in LabView connected to a NI 4163 USB Dynamic Signal Analyzer. The output signal was broadband pink noise going to a four channel power amplifier driving four full range loudspeakers. The microphone signals from the two Ear Simulators in the 45CB were connected to a G.R.A.S. 12AA two channel power supply and from there to the NI 4163.

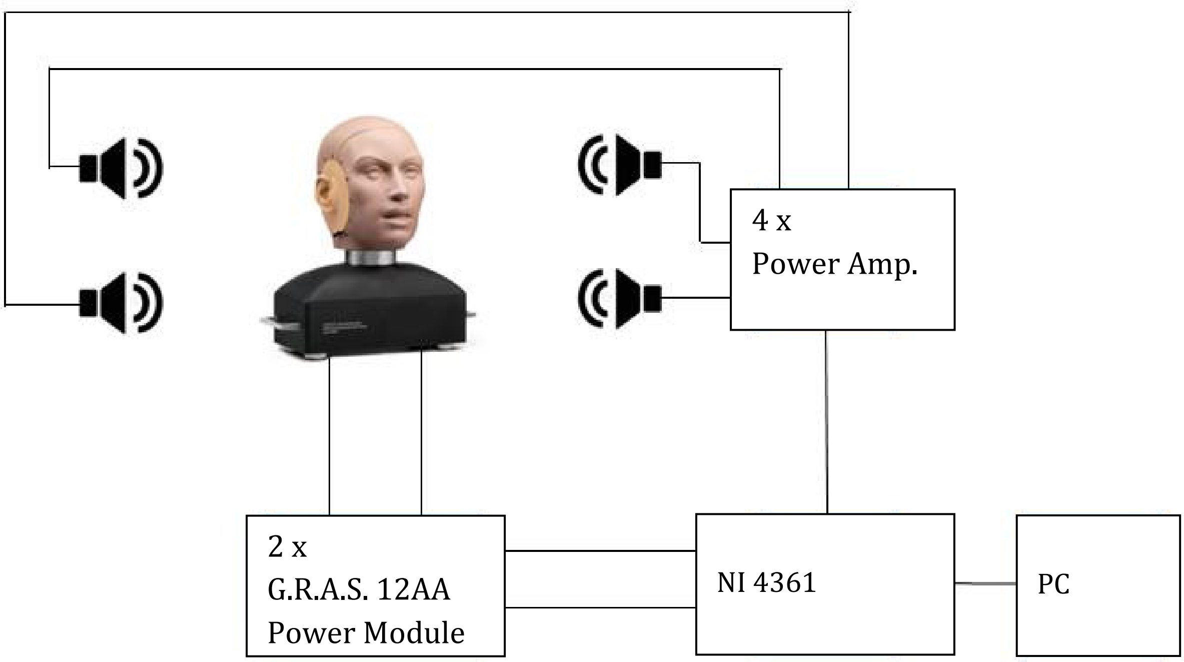


Figure 8 Test setup

Results

A series of tests were performed on both passive ear-protectors and on active noise cancelling headphones.

Passive In-ear ear protector Model A	Passive In-ear ear protector Model B	Passive In-ear ear protector Model C

Figure 9 The tested ear protectors

For each test, the signal from the ATF (G.R.A.S. 45CB) was first recorded without the headphone mounted, then with the ear protector mounted. For all types it is critical to ensure a proper sealing as leaks may seriously affect the measurement results especially at low frequencies.

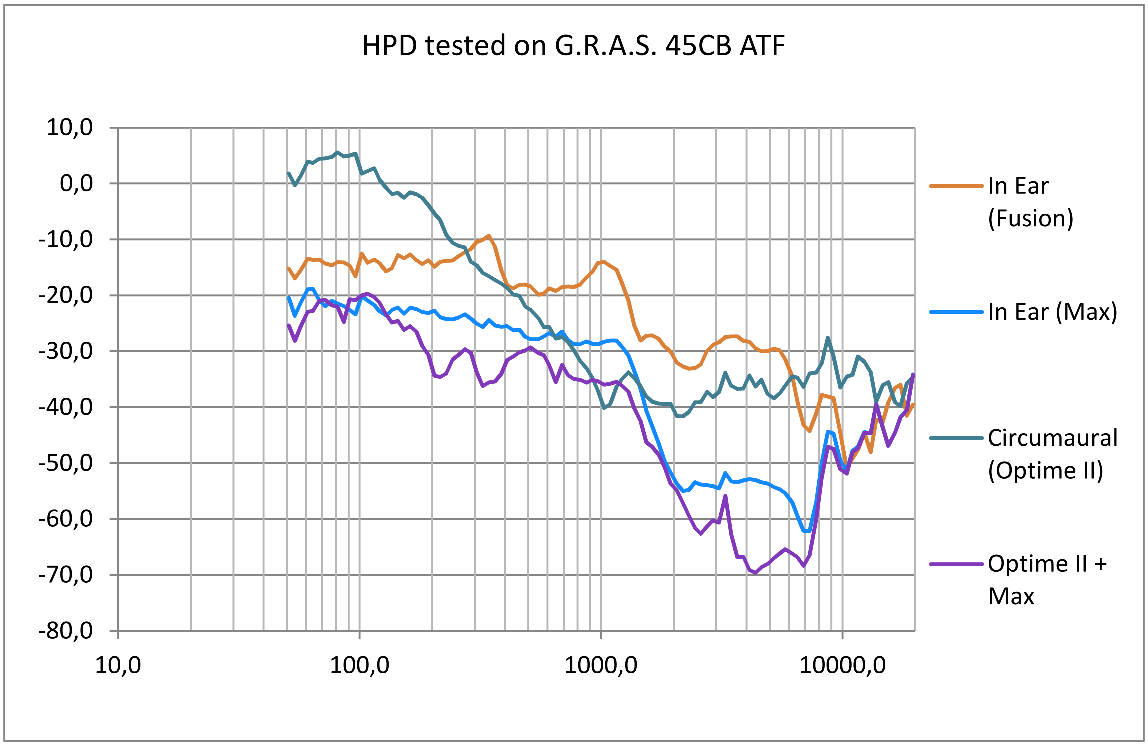
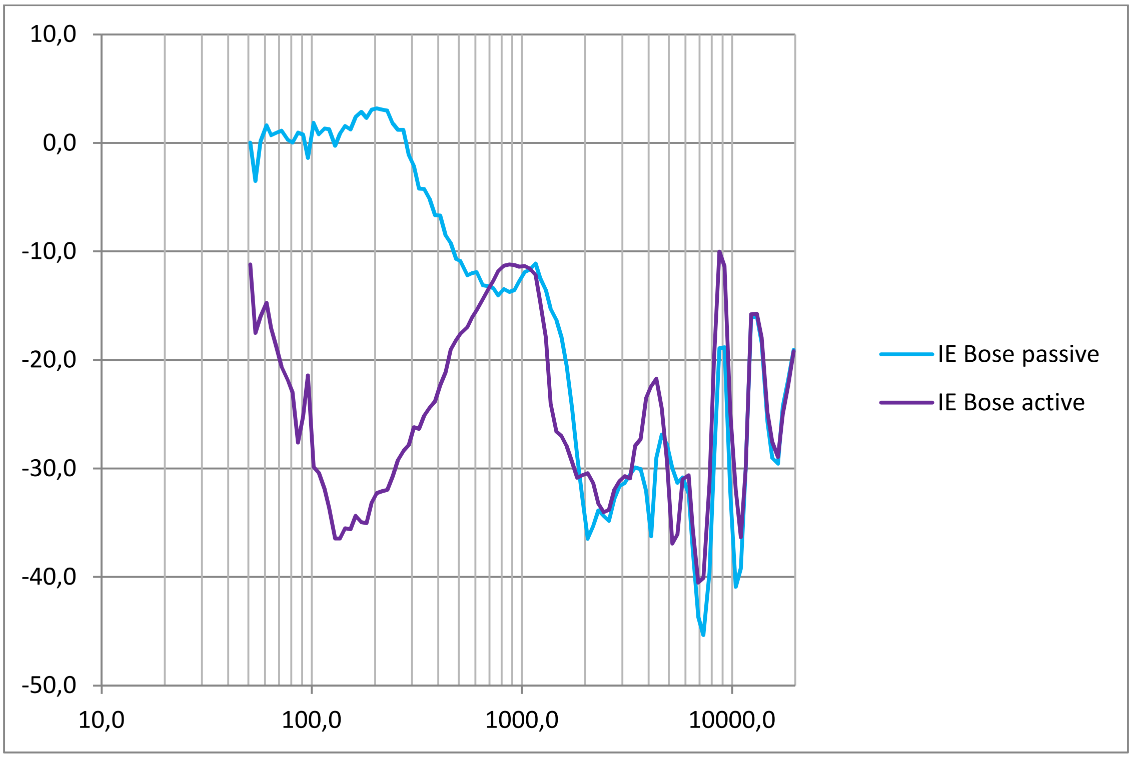


Figure 10 Hearing protectors tested on G.R.A.S. 45CB ATF

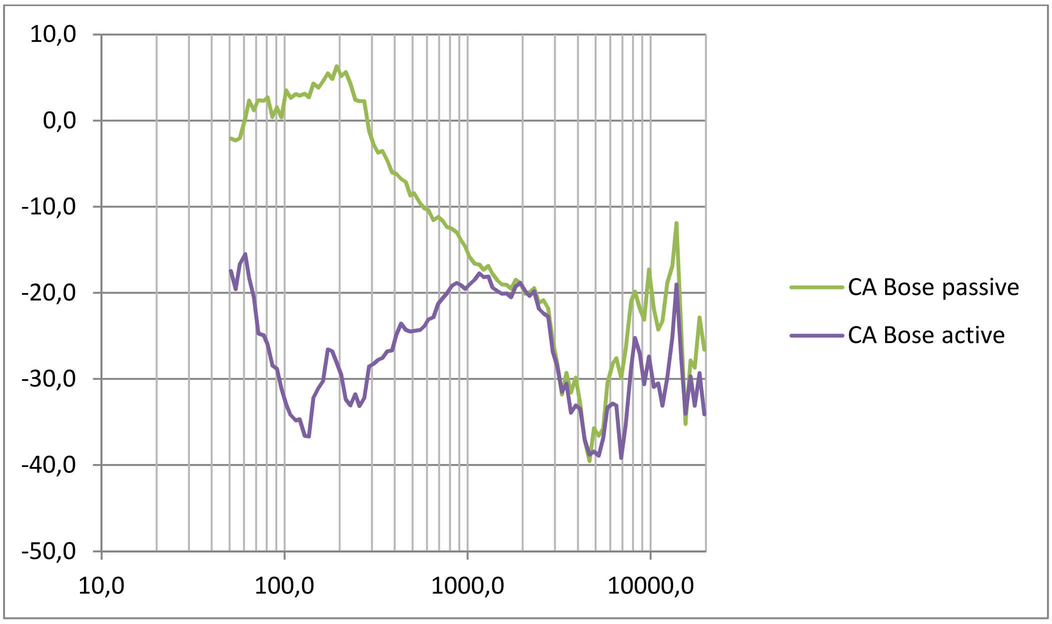
Similar measurements were performed on active noise control headphones of both in-ear type and circum-aural as shown in Figure 12. Both units were measured in both active and passive mode as seen in Figure 11.

Figure 12 The tested head phones with active noise cancelling



Note: Passive means that the active noise cancelling is turned off.

Figure 13 BOSE In ear headphones with noise cancelling tested on G.R.A.S. 45CB ATF

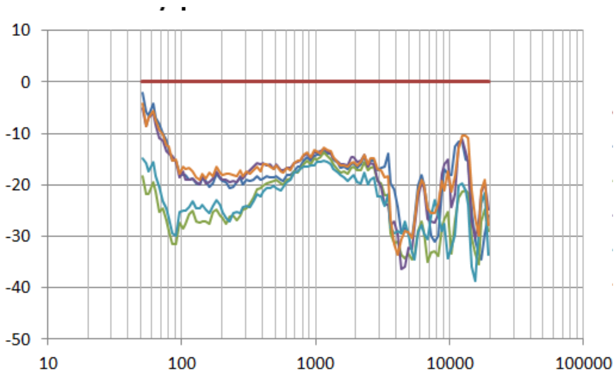


Note: Passive means that the active noise cancelling is turned off.

Figure 14 BOSE circum aural headphones with noise cancelling tested on G.R.A.S. 45CB ATF

Figure 15 shows repeatability of measurements in active mode for in-ear (left graphs) and circum aural headphones (right graphs). It can be seen that for the circum-aural type the repeatability is good in the mid-frequency range, while in the low frequency range the results fall in two groups, probably caused by leakage. This may occur if the headphone is not properly fitted to the ATF.

For the In-ear type it is critical how the headphone is fitted to the ear and this affects both the high frequency and the low frequency performance considerable.



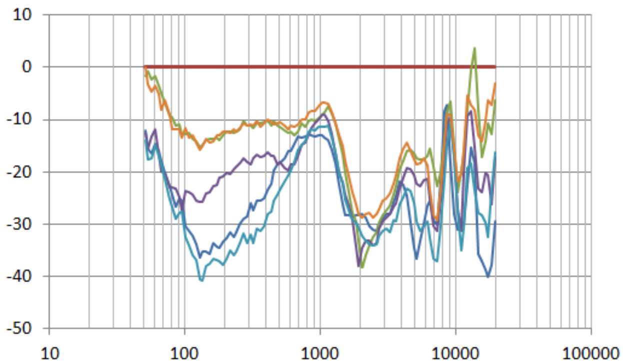


Figure 15   Variations when repeating the same measurement

Final comments

Examples have been shown of measurements of the effectiveness of hearing protectors using the G.R.A.S. 45CB Acoustic Test Fixture.

The ATF is equally well suited for measuring and evaluation of insertion loss of Active Noise Cancelling headphones.

The individual test is sensitive to the exact mounting of the headphone on the test fixture. This variation (repeatability) is larger than the differences found for type of fixture.

There are other methods like the REAT (Real Ear Attenuation at Threshold).

For a comparison of measurements using acoustical test fixture versus REAT test see for example E. Berger et al:
Performance of New Acoustical Test Fixtures Complying with ANSI S12.42-2010, With Particular Attention to the Specification of Self Insertion Loss , Internoise 2014.