
Hearing Protectors: Paper ICA2016-808

Measurement of insertion loss of earmuff type protectors using the impulse response technique

**Gabriel A. Cravero^(a), Lucas G. Gilberto^(a), Sebastián P. Ferreyra^(a),
Marina G. Cortellini^(a), Fernando M. González^(a), Mario R. Serra^{(a)(b)}**

^(a) Centro de Investigación y Transferencia en Acústica - Universidad Tecnológica Nacional, Facultad Regional Córdoba - Unidad Asociada del Consejo Nacional de Investigaciones Científicas y Técnicas (CINTRA - UTN FRC - UA CONICET), Argentina, acustica@frc.utn.edu.ar

^(b) Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Buenos Aires, Argentina

Abstract

The essential requirements that hearing protectors need to fulfil as personal protective equipment are evaluated in Argentina through a series of IRAM (Instituto Argentino de Normalización y Certificación) standards. In particular, IRAM 4060-3 (equivalent to ISO 4869-3:2007) standard specifies a simplified method for the measurement of insertion loss (IL) of earmuff type protectors. This method can be used to test occasional performance differences on manufacturing, as part of type approval or certification procedures, and to investigate performance variations due to product aging. The IL of a hearing protector is commonly obtained using systems based on broadband pink noise (BPN) signals. This paper analyzes and compares the IL of eight different hearing protectors obtained with this technique and with an impulse response measurement based system. The results show that both techniques present similar IL values, within the dispersion range expected for this test. Also, the impulse response system reduces the test execution time, and proved to be robust, reliable and economical.

Keywords: hearing protectors; ear-muff; insertion loss; impulse response; broadband pink noise.

Measurement of insertion loss of ear-muff type protectors using the impulse response technique

1 Introduction

Hearing protectors' quality control requires the application of standardized acoustic and physical testing methods. This methodology allows comparing performance data and functional behaviour obtained from different laboratories under similar conditions. In addition, this information can be used to classify and select different brands and models, as well as to assess design and constructive features that influence hearing protectors' performance. In particular, Argentine IRAM 4060-3 standard (equivalent to ISO 4869-3:2007) specifies a simplified method for the measurement of insertion loss (IL) of ear-muff type protectors [1] [2]. This method can be used to test occasional performance differences on manufacturing, as part of type approval or certification procedures, and to investigate performance variations due to product aging.

This paper firstly explains the conditions and test procedures applied to obtain the IL according to IRAM 4060-3. Then, it examines the IL values obtained using the impulse response technique and compares them with those obtained using the traditional broadband pink noise technique (BPN). The analysis are based on measurements of eight different hearing protectors, including headband ear-muffs, neckband ear-muffs and ear-muffs attached to an industrial safety helmet.

2 Insertion loss

IRAM 4060-3 standard defines the IL as the algebraic difference, expressed in decibels, between the one-third-octave-band sound pressure level (SPL) measured by the microphone of an acoustic test fixture (ATF) with the hearing protector mounted and without it. Equation number (1) shows this:

$$IL [dB] = SPL_{without\ ear-muff} - SPL_{with\ ear-muff} \quad (1)$$

Therefore, the IL of a hearing protector could be considered as a measure of its sound attenuation, but the performance data obtained by this method are not intended to be quoted as representing the real-ear sound attenuation of an ear-muff. The major objective of this test is to ensure that ear-muff samples submitted for the subjective testing of attenuation according to IRAM 4060-1 have performances typical of the type [3]. IRAM 4126 standard specifies the requirements that the IL results must fulfil in order to certify the product quality [4]. These requirements define the IL standard deviations that may be observed in the one-third-octave bands, when measuring 10 samples (20 ear-cups) of a particular ear-muff. Paragraph number 5

of IRAM 4060-3 describes the ATF, the test site and the measuring system that shall be used for this test. Their main features are briefly described below.

2.1 Acoustic Test Fixture

The ATF is a cylindrical device made of non-magnetic material, with similar dimensions to an average size adult human head. It includes a pressure-operated microphone placed in one end face of the ATF, with its centre coinciding with the centre axis of the cylinder. The ATF allows an ear-muff to be placed properly by positioning one ear-cup of the hearing protector over the measuring microphone and its headband or head-strap over a headband support. When measuring ear-muffs attached to an industrial safety helmet the headband support is replaced with a helmet support. Figures 1-a and 1-b shows the ATF with and without a hearing protector.



Figure 1: Acoustic test fixture: a) side view, b) front view, with the hearing protector mounted.

2.2 Test site

The test sound field shall be either a random incidence field or a plane progressive wave field. In the first one, the sound arrives at microphone from any direction with equal probability, distributing its sound pressure uniformly around the ATF [5]. In the second one the acoustic waves arrive with grazing incidence on the end faces of the ATF. In both cases the background noise level at the test site, measured in one-third-octave-band with the microphone placed at the reference point, shall be at least 10 dB lower than the SPL of the test signal.

2.3 Measuring system

Diverse measuring systems may be used for this test. Such systems may be based on broadband pink noise signals, maximum length sequences, impulse response measurements, etc. Regardless of the measuring system used, the analysis shall give the IL in one-third-octave bands according to IEC 61620. The frequency range for this analysis may differ depending on IL measurement main objective. IRAM 4060-3 suggests it shall be at least from 63 Hz to 8000

Hz, although, for quality certification purposes, IRAM 4126 sets a range of evaluation from 250 Hz to 8000 Hz.

3 Insertion loss with impulse response method

The impulse response characterizes a linear time-invariant (LTI) system in the time domain, while the frequency response characterizes an LTI system in the frequency domain [6]. There are two methods for measuring a system impulse response: direct or indirect. Direct method uses an excitation signal with impulsive characteristics (e.g. gunshots, balloon explosions) and the impulse response is obtained directly, recording the output signal. The main problems with this method are its poor repeatability and its low signal to noise ratio, both inherent to an impulsive stimulus source [7]. Indirect method uses continuous-time signals at the system input, obtaining the impulse response by post-processing the input and output signal [8].

This work seeks to obtain the impulse response of the whole IL measuring system through the indirect method, with the hearing protector placed on the ATF and without it. Thus, the frequency response could be calculated using the Fourier Transform in both cases and the IL is obtained as the difference between them. Figure 2 shows the block diagram of the measuring system used for this purpose.

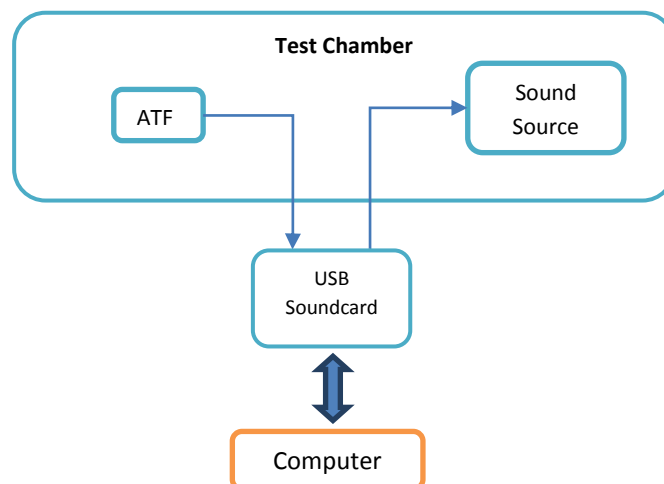


Figure 2: Impulse response measuring system.

Three types of excitation signals were used to examine the IL measurements: lineal and exponential sine sweeps (LSW and ESW, respectively) and maximum length sequences (MLS). The first ones are time-growing frequency sweeps which allow obtaining the impulse response by the convolution between the output signal and the inverse filter of the excitation signal. MLS is a pseudo-random signal having almost the same stochastic properties as a pure white noise. In this case, the impulse response is calculated as the cross-correlation between the output and input signals [9].

The IL measurements obtained with the impulse response technique were compared with those obtained with the BPN technique. This last technique is commonly used, primarily because it was a specific requirement concerning the measuring system in past versions of IRAM 4060-3

standard. Diverse measuring system possibilities are allowed since a few years, as stated in section 2.3. In order to observe the behaviour of the impulse response technique on different hearing protectors, eight ear-muffs from different type and manufacturers were analyzed. Table 1 shows the hearing protectors examined.

Table 1. Examined hearing protectors

Id.	Type
Sample 1	Ear-muff attached to an industrial safety helmet
Sample 2	Ear-muff attached to an industrial safety helmet
Sample 3	Neckband ear-muff
Sample 4	Headband ear-muff
Sample 5	Headband ear-muff
Sample 6	Headband ear-muff
Sample 7	Headband ear-muff
Sample 8	Headband ear-muff

4 Results

This section presents a comparative analysis between the results obtained. Figures 3 to 10 show the differences expressed in dB for the IL measured through impulse response technique, with the three excitation signals (MLS, LSW and ESW) and for the eight hearing protectors under test, compared with the IL values obtained through the traditional BPN technique. The frequency range analyzed is the one suggested by IRAM 4126 for certification purposes (250 Hz ~ 8000 Hz). Every IL value shown is the result of averaging three different measurements. This is necessary because the IL depends not only on the hearing protector but also on its fitting over the ATF [1].

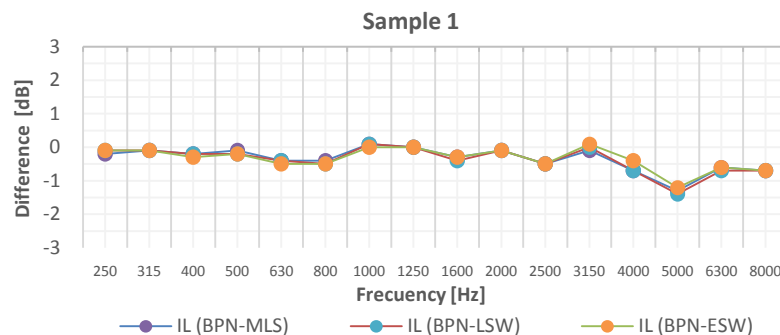


Figure 3. IL difference between broadband pink noise technique and impulse response technique for different excitation signals in sample 1.

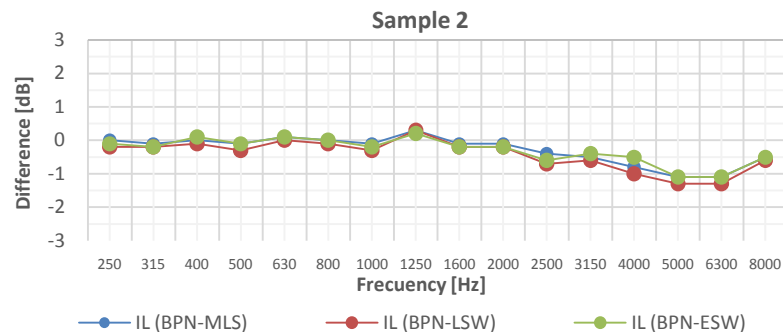


Figure 4. IL difference between broadband pink noise technique and impulse response technique for different excitation signals in sample 2.

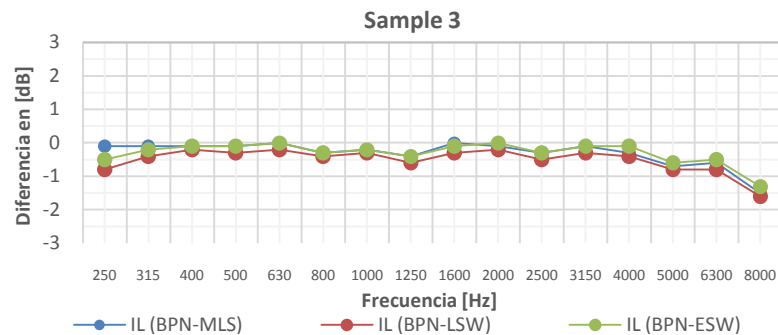


Figure 5. IL difference between broadband pink noise technique and impulse response technique for different excitation signals in sample 3.

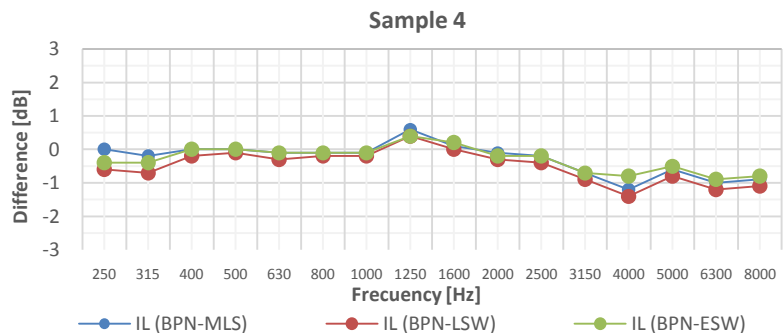


Figure 6. IL difference between broadband pink noise technique and impulse response technique for different excitation signals in sample 4.

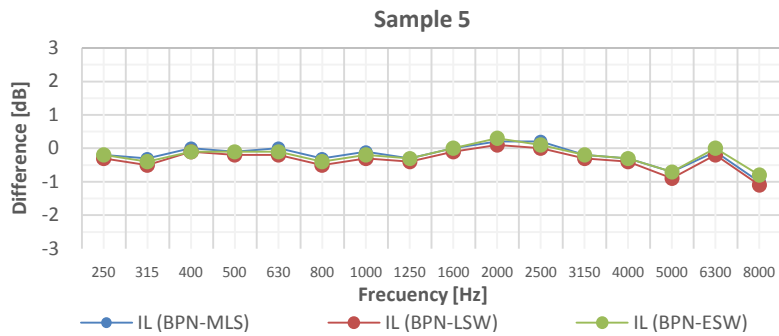


Figure 7. IL difference between broadband pink noise technique and impulse response technique for different excitation signals in sample 5.

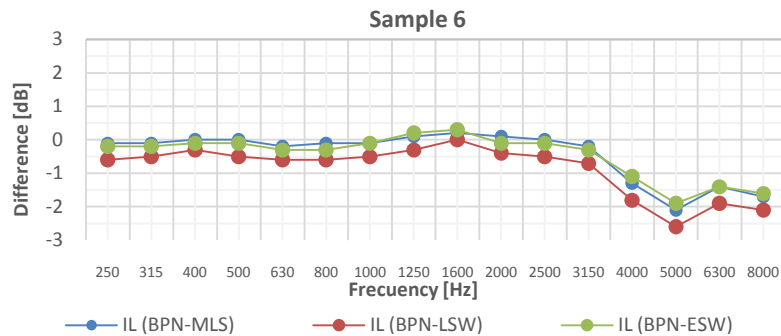


Figure 8. IL difference between broadband pink noise technique and impulse response technique for different excitation signals in sample 6.

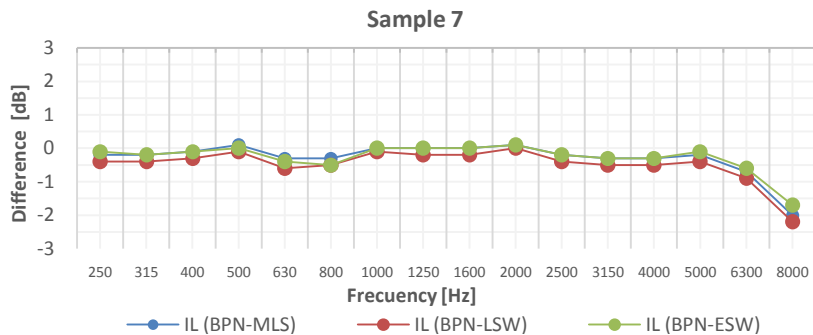


Figure 9. IL difference between broadband pink noise technique and impulse response technique for different excitation signals in sample 7.

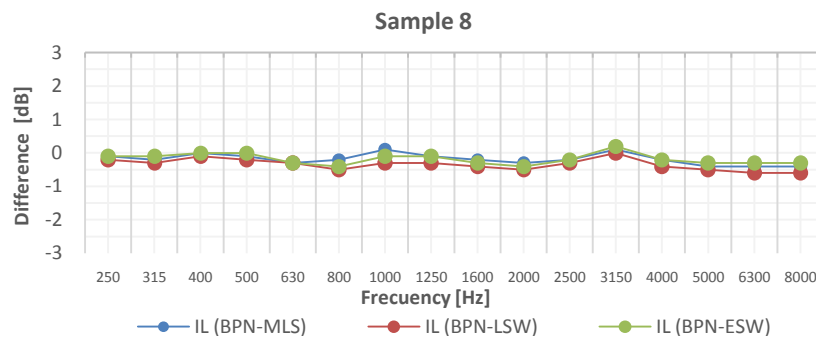


Figure 10. IL difference between broadband pink noise technique and impulse response technique for different excitation signals in sample 8.

Typical uncertainties of this kind of measurements shall be considered in order to properly weight the differences observed. Uncertainties in the measurement of the IL can arise from different sources, such as the uncertainty in the measurement of the SPL, the uncertainty in the test signal generator, fitting of the hearing protector on the ATF, etc [1]. For samples 1 to 7, the results of the complete IL test (20 ear-cups from 10 samples, measured with the BPN technique) and its associated expanded uncertainty ($U_{95\%}$) in accordance with IRAM 4126 were available. Table 2 shows the values and frequencies where the maximum $U_{95\%}$ was observed in each sample.

Table 2. Maximum expanded uncertainty (95%) in a 10 samples test measured with BPN technique.

Sample	1	2	3	4	5	6	7
Maximum $U_{95\%}$ [dB]	4,6	5,1	5,3	5,8	4,3	5,5	4,6
Frequency [Hz]	5000	800	1000	1250	6300	1600	3150

Also, it was examined whether the IL values obtained through the impulse response technique were located within the range of mean values $\pm U_{95\%}$ of the complete test. The results showed that 96,3% of all the measurements were within this range. The percentages for each excitation signal were: 94,0% for LSW, 98,0% for ESW and 97,0% for MLS.

5 Conclusions

The results show that the maximum difference observed between the impulse response technique and broadband pink noise technique, for all samples under test, does not exceed 2,5 dB. Such deviations are considerably below the typical uncertainty of this kind of measurement. Moreover, for each sample, a great proportion of the IL values measured with the impulse response technique were located within the range of mean values $\pm U_{95\%}$ of a 10 samples IL test measured with the BPN technique. In addition, the correspondence between methods remains independently from the hearing protectors' type (i.e. headband ear-muffs, neckband

ear-muffs and ear-muffs attached to an industrial safety helmet). Based on these results it is concluded that the impulse response technique could correctly replace the traditional BPN technique, also providing some extra advantages:

- Test execution time was reduced by more than 15%
- Versatility of the measurement chain was enhanced
- The measurement equipment has lower costs.

6 References

- [1] IRAM, Argentine Standard IRAM 4060-3: *Acústica. Protectores auditivos. Parte 3 - Método simplificado de control de calidad para medir la pérdida por inserción de protectores del tipo cobertor*. Argentina, 2012.
- [2] ISO, International Standard ISO 4869-3: *Part 3: Measurement of insertion loss of ear-muff type protectors using an acoustic test fixture*. Switzerland, 2007.
- [3] Miretti, G., Serra M.R., Henin C., Roggio I. Aplicación de métodos normalizados de ensayos acústicos y físicos a protectores auditivos en el CINTRA. *Proceedings of Primeras Jornadas Regionales de Acústica - AdAA 2009*, Rosario, Argentina. November 19-20, 2009, pp 88.
- [4] IRAM, Argentine Standard IRAM 4126-1: *Protectores auditivos. Requisitos de seguridad y ensayos. Parte 1: Cobertores*. Argentina, 1999.
- [5] Long, M. *Architectural Acoustics*, Elsevier Academic Press, Burlington (USA), 1^o edition, 2006.
- [6] Saposhkov, M. A. *Electroacústica*. Editorial Reverté, 1983.
- [7] Farina, A. *Simultaneous measurements of impulse response and distortion with a swept-sine technique. Proceedings of 108th Convention of Audio Engineering Society*, Paris, France, 2000.
- [8] Ferreyra S. P., Ramos O. A. Análisis físico-acústico-espacial de respuestas impulsivas de un recinto con alta dispersión sonora obtenidas por métodos indirectos. *Mecánica Computacional*, Vol. XXVI, 2007, pp 3-14.
- [9] Daigle J. N., Xiang, N. A specialized fast cross-correlation for acoustical measurements using code sequences. *Journal Acoustical Society of America*, Vol 119, 2006, pp 330-335.