Primary calibration in acoustics metrology

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Abstract. SI unit in acoustics is realized by the reciprocity calibrations of laboratory standard microphones in pressure field, free field and diffuse field. Calibrations in pressure field and in free field are already consolidated and the Inmetro already done them. Calibration in diffuse field is not yet consolidated, however, some national metrology institutes, including Inmetro, are conducting researches on this subject. This paper presents the reciprocity calibration, the results of Inmetro in recent key comparisons and the research that is being developed for the implementation of reciprocity calibration in diffuse field.

1. Introduction
Confidence of sound pressure level measurements is guaranteed when its traceability is evidenced. Traceability which passes through the accredited calibration laboratories, the national metrology institutes (NMI) and the International Bureau of Weights and Measures (BIPM, abbreviation in French) [1].

BIPM, the highest body in the traceability hierarchy, determines that SI unit in acoustics, pascal, is realized by the reciprocity calibration of one inch and half inch laboratory standard microphones (LS1 and LS2) [1]. Figure 1 shows pictures of LS1 and LS2 microphones.

![Picture of LS1 and LS2 microphones](Image)

**Figure 1.** Pictures of LS1 (left) and LS2 microphones.

Calibration of a measurement microphone consists in determine its sensitivity and its frequency response. Sensitivity is the ratio between the output signal and the input signal. In the case of a microphone, input signal is the variation of dynamic pressure and output signal is the voltage. Thus, the sensitivity of a microphone is measured in volts per pascal and the sensitivity level in decibels referenced to 1 V/Pa.

A microphone calibration can be made in three distinct idealized sound fields: the free field, the diffuse field and the pressure field. The free field is a field with only one sound wave (there is no reflections). The diffuse field is a field such any position receives sound waves from all directions with equal probability and equal intensity. The pressure field is a field such in any section the sound wave is uniformly distributed.
The objective of this paper is to present the reciprocity calibration of microphones, the Inmetro’s participation in recent key comparisons of microphones in pressure field and in free field, and the Inmetro’s research for implementation of reciprocity calibration in diffuse field.

2. Reciprocity calibration

Calibration by reciprocity is traditionally obtained using three microphones. In the first step two microphones, microphones 1 and 2, are acoustically coupled. Using the microphone 1 as a transmitter and the microphone 2 as a receiver the product of sensitivities is determined (1):

\[ M_1 M_2 = \frac{Z_{e,12}}{Z_{a,12}} \]  

Where \( M_1 \), \( M_2 \), \( Z_{e,12} \), and \( Z_{a,12} \) are the sensitivities of the microphones 1 and 2, the electrical transfer impedance between the microphones 1 and 2 and the acoustic transfer impedance between microphones 1 and 2. The electrical transfer impedance is the quotient of the open circuit voltage of the microphone used as a receiver by the input current through the electrical terminals of the microphone used as a transmitter. The acoustical transfer impedance is function of the acoustic coupling between the microphones [1].

In the second step the microphone 2 is replaced by the third microphone, the microphone 3, and the procedure is repeated. In the third step the microphone 1 is replaced by the microphone 2 and again the procedure is repeated. In the end, there is a system of three equations and three unknowns and each sensitivity can be calculated. [1] Thus, the sensitivity of the microphone 1 is obtained by:

\[ M_1 = \left( \frac{Z_{e,13} Z_{e,12}}{Z_{e,23}} \frac{Z_{a,23}}{Z_{a,12} Z_{a,13}} \right)^{1/2} \]  

3. Reciprocity calibration in pressure field

Reciprocity calibration in pressure field provides traceability for calibration of sound calibrators, artificial ears, 6cc couplers and torso simulators. It is performed according to IEC 61094-2 [2], it is realized by many NMIs and its methods have been checked in several key comparisons [3]. In the last one, the CCAUV.A-K3, realized in 2003 and conducted by Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUUV) with the participation of fifteen NMIs, Inmetro showed that already consolidated this method as result presented in the final report [4]. In this key comparison were calibrated LS2 microphones. They were calibrated in magnitude for the frequency range from 31.5 Hz to 31.5 kHz [4]. Figure 2 shows graphs of degree of equivalence per country for 250 Hz and 1000 Hz.

![Figure 2. Graphs of degree of equivalence per country for 250 Hz and 1000 Hz [4].](image-url)
Today Inmetro is participating in the key comparison CCAUV.A-K5 which began in 2011 also conducted by CCAUV with the participation of twelve NMIs [5]. In this key comparison are being calibrated LS1 microphones according to the new edition of IEC 61094-2 [6]. They are being calibrated in magnitude and phase for the frequency range from 2 Hz to 10 kHz [5].

4. Reciprocity calibration in free field
Reciprocity calibration in free field provides traceability for the calibration of sound level meters and work standard microphones, for the measurement of the frequency response of loudspeakers and any measurements of sound pressure level in free field. It is performed according to IEC 61094-3 [7], it is realized by few NMIs and its methods were checked only once in key comparisons [3], the CCAUV.A-K4, realized in 2007 also conducted by CCAUV with the participation of seven NMIs. In this key comparison Inmetro also showed that already consolidated this method as result presented in the final report [8]. In this key comparison were calibrated LS2 microphones. They were calibrated in magnitude for the frequency range from 1 kHz to 40 kHz. Figure 3 shows graphs of degree of equivalence per country for 2.5 kHz and 8 kHz.

5. Reciprocity calibration in diffuse field
Reciprocity calibration in diffuse field provides traceability for the calibrations of sound level meters and work standard microphones and any measurements of sound pressure level in diffuse field. There isn’t yet any international standard on this subject, any NMI declares this calibration to BIPM and any key comparison was realized to check this method [3]. Some NMIs, however, begun to develop research about this as DPLA [9], Denmark’s NMI, and NPL [10], United Kingdom’s NMI.

Follow these same lines Inmetro also begun to develop research about this. It was built a reverberation chamber of approximately 2 m³ with of polished granite slabs mounted on a set of four steel springs [11]. In a first step was measured the acoustic transfer impedance. The procedures adopted proved adequate and the results pointed where the investigations should be concentrated. The procedures adopted and the results obtained will be presented at the international congress Internoise 2013 [12]. In a second step will be measured the electrical transfer impedance and will be calculated the sensitivity of LS1 microphones. Figure 4 shows the photo of the reverberant chamber before the measurements for determining the acoustic transfer impedance.
Figure 4. Photo of the reverberant chamber before the measurements for determining the acoustic transfer impedance.

References
[1] Milhomem T A B 2008 Technique for free field calibration of half inch microphone by reciprocity Dissertation for the degree of Master of Science PEM / UFRJ / COPPE. (In Portuguese)
[2] IEC 61094-2:1992 Measurement microphones – Part 2: Primary method for pressure calibrations of laboratory standard microphones by the reciprocity technique 1 ed.
[3] http://www.bipm.org. Access: jun. / 2013
[4] Henriques V and Rasmussen K 2006 Final report on the key comparison CCAUV.A-K3
[5] Barham R 2010 Technical protocol for the key comparison CCAUV.A-K5
[6] IEC 61094-2:2009 Measurement microphones – Part 2: Primary method for pressure calibrations of laboratory standard microphones by the reciprocity technique 2 ed.
[7] IEC 61094-3:1995 Measurement microphones – Part 2: Primary method for free-field calibrations of laboratory standard microphones by the reciprocity technique 1 ed.
[8] Barrera-Figueroa S, Nielsen L, Rasmussen K, Matzumoto A E P and Razo J N R 2010 Final report on the key comparison CCAUV.A-K4
[9] Barrera-Figueroa S and Rasmussen K 2008 A note on determination of the diffuse-field sensitivity of microphones using the reciprocity technique Jasa 124 3 1505-12
[10] Jackett R 2012 Implementations of diffuse-field microphone calibration system Internoise 2012
[11] Müller S 2011 Final Report. (In Portuguese)
[12] http://www.internoise2013.com. Access: jun. / 2013