Experimental determination of the difference between diffuse and pressure field sensitivities of half-inch laboratory standard microphones

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ABSTRACT

Frequently, is important to assure high accuracy to a measurement result then, a practical way to do that is calibrating the measurement instrument. Traditionally, a calibration can be performed by a comparison or an absolute method and the choice depend on the desired measurement uncertainty. In acoustics, absolute calibration of measurement microphone's sensitivity is usually performed by the reciprocity technique in three standardized sound fields: free, diffuse and pressure. Depend on the sound field, microphone's sensitivity will be different at high frequencies because the interaction between microphone and sound wave. While reciprocity in pressure field is performed by many institutes, in free-field, it is performed by a small number, and in diffuse-field, only by a very few. Institutes that do not perform free-field or diffuse-field calibration, commonly use a correction applied to the pressure field sensitivity to obtain the free-field or diffuse-field sensitivity. In this paper, diffuse and pressure field reciprocity calibrations are summarized and a correction to the pressure field sensitivity to obtain the diffuse-field sensitivity is presented. That correction, which is determined from reciprocity calibrations in the range from 1.25 to 16 kHz for half-inch laboratory standard microphones, is compared with standardized values.

Keywords: Microphone, Diffuse-field, Pressure field
I-INCE Classification of Subject Number: 71, 81

1. INTRODUCTION

Frequently, is important to assure high accuracy to a measurement result then, a practical way to do that is calibrating the measurement instrument. That calibration gives a feedback about the instrument performance, make the data taken with it more credible and minimize risk of error.

Traditionally, a calibration can be performed by a comparison or an absolute method and the choice depend on the desired measurement uncertainty. That uncertainty

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is a quantification of the doubt in a measurement result and understand it helps to take more confidence in a quality measurement.

In acoustics, absolute calibration of measurement microphone's sensitivity is usually performed by the reciprocity technique in three standardized sound fields: free, diffuse and pressure. According to that technique, three microphones are acoustically coupled in pair-wise combinations and using one microphone as a sound source and the other as a sound receiver, the electrical and the acoustic transfer impedances between them are measured. From those measurements, the sensitivity of each microphone is calculated [1, 2]. Depend on the sound field, microphone's sensitivity will be different at high frequencies because the interaction between microphone and sound waves [3]. Figure 1 illustrates the different sensitivities of a measurement microphone developed for pressure field measurements.

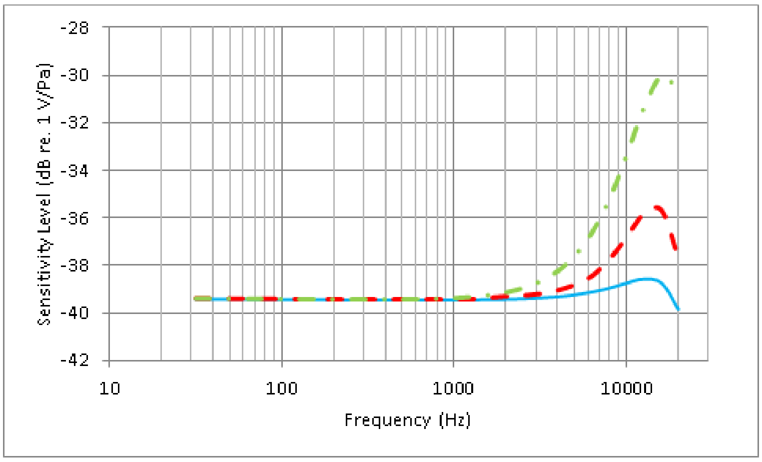

Figure 1. Sensitivities in pressure field (solid line), in diffuse-field (dashed line) and in free-field (dot-dash line) of a microphone developed for pressure field measurements.

While reciprocity in pressure field is performed by many institutes [4], in free-field, it is performed by a small number [5], and in diffuse-field, only by a very few [6-8]. Institutes that do not perform free-field or diffuse-field calibration, commonly use a correction applied to the pressure field sensitivity to obtain the free-field [3, 9] or diffuse-field sensitivity [10, 11].

The international standard IEC 61183 [10], published in 1994, describes a free-field calibration method for determining random-incidence sensitivity levels of sound level meters and a diffuse-field calibration method for determining diffuse-field sensitivity levels. For that last calibration, it presents the difference between diffuse-field and pressure sensitivity levels (diffuse-field correction) for half-inch laboratory standard microphone (type LS2 microphone) for the frequency range from 25 Hz to 20 kHz (central frequencies of third-octave bands). That difference is null from 25–1250 Hz and the measurement uncertainty is estimated to be 0.03 dB.

More recently, in 2006, Barrera-Figueroa *et al.* [11] presented the difference between random-incidence and pressure sensitivity levels (random-incidence correction) for a type LS2 microphone and for the frequency range from 2 to 30 kHz (in steps of 0.5 kHz). The random-incidence sensitivity has been considered equivalent to the diffuse-field sensitivity and widely used in practical application. It is not presented the measurement uncertainty of the random-incidence correction.

This paper will present the diffuse and pressure field reciprocity calibrations of a type LS2 microphone and the difference between diffuse-field and pressure sensitivity levels determined from those calibrations. This diffuse-field correction will be compared with the diffuse-field correction presented in IEC standard [10] and the random-incidence correction determined by Barrera-Figueroa *at al.* [11].

2. DIFFUSE-FIELD RECIPROCITY CALIBRATION

2.1 Theory

In diffuse-field reciprocity calibration, the microphones are acoustically coupled placing them in a reverberation chamber that creates the diffuse field conditions [6-8, 12-16]. The electrical transfer impedance between the microphones, $Z_{e,sr}$, is determine from [12]

$$Z_{e,sr} = U_r / i_s , \qquad (1)$$

where U_r is the output voltage at the electrical terminals of the microphone used as a sound receiver and i_s is the current through the electrical terminals of the microphone used as a sound source. The acoustic transfer impedance between the microphones, $Z_{a,sr}$, is given by [12]

$$Z_{a,sr} = \left(\frac{\pi \log e}{6}\right)^{1/2} \rho_0 f \left(\frac{cT_R}{V}\right)^{1/2}, \qquad (2)$$

where ρ_0 is the density of the medium, f is the frequency, c is the speed of sound, T_R and V are, respectively, the reverberation time and the volume of the reverberation chamber employed.

In order to deal with the poor signal-to-noise ratio of that calibration, relatively small reverberation chambers have been preferred and time windowing have been employed. Furthermore, measurements are performed at different positions in the chamber with further use of the window function to deal with insufficient degrees of diffuseness and homogeneity of the sound field [8].

2.2 Procedure

For this study, three type LS2 microphones developed for pressure field measurements (Brüel and Kjaer 4180) and a rectangular reverberant chamber of 2 m^3 volume (1.3 m x 1.5 m x 1.0 m) were used. Signal generation and measurements were performed with a compact measurement system (Monkey Forest software together with Aurelio Audio CMF22 frontend). A transmitter unit (Brüel and Kjaer ZE0796), a preamplifier (Brüel and Kjaer 2673) and a homemade 20 dB amplifier were used. Figure 2 shows a picture of the microphones placed in the used reverberation chamber.

Figure 2. Reverberation chamber with microphones placed inside.

Procedure adopted is described in Ref. 8 and is summarized here. The microphones are placed in the 2 m^3 reverberation chamber. The microphone used as a sound source is driven using a sweep and the complex transfer-functions of the system microphone-chamber-microphone are measured [17]. An impulse response is obtained and a time-selective technique is applied in order to separate the reverberant response from the direct sound and the first reflections. After that, a frequency response is obtained from the reverberant part of the impulse response, the electrical transfer impedance is calculated, and it is smoothed in third-octave bands with a gliding window. That procedure is repeated at sixteen different source-receiver configurations in the reverberation chamber (four positions for the source combined with four positions for the receiver) and the spatial average is calculated. Preamplifier and the transmitter unit gains are measured separately, by the insert voltage technique [1], and subsequently used to correct the acquired transfer-functions.

Chamber reverberation time, used to calculate the acoustic transfer impedance, is measured by the integrated impulse response method [18] and, for that, the same impulse responses used on determination of the electrical transfer impedance are employed. For that procedure, forty-eight impulse responses (obtained from three pairs of microphones and sixteen source-receiver configurations for each pair) are employed. Those measurements are repeated five times.

3. PRESSURE FIELD RECIPTOCITY CALIBRATION

3.1 Theory

On the other hand, in pressure field reciprocity calibration, the microphones are acoustically coupled mounting them in a coupler that creates the pressure field conditions. The electrical transfer impedance between the microphones, $Z_{e,sr}$, is also determine from [1]

$$Z_{e,sr} = U_r / i_s \quad . \tag{3}$$

The acoustic transfer impedance between the microphones, $Z_{a,sr}$, when the physical dimensions of the coupler are very small compared with the wavelength is given by [1]

$$\frac{1}{Z_{a,sr}} = \frac{1}{Z_{a,V}} + \frac{1}{Z_{a,s}} + \frac{1}{Z_{a,r}} = j\omega\left(\frac{V}{\kappa p_s} + \frac{V_{e,s}}{\kappa_r p_{s,r}} + \frac{V_{e,r}}{\kappa_r p_{s,r}}\right), \tag{4}$$

where $Z_{a,V}$ is the acoustic impedance of the gas enclosed in the coupler; $Z_{a,s}$ and $Z_{a,r}$ are the acoustic impedance of the microphones used as a sound source and as a sound receiver respectively; ω is the angular frequency; V is the total geometrical volume of the coupler; $V_{e,s}$ and $V_{e,r}$ are the equivalent volume of the microphone used as a sound source and as a sound receiver respectively; κ and κ_r are the ratio of the specific heat capacities at measurement and at reference conditions respectively; and p_s and $p_{s,r}$ are the static pressure at measurement and at reference conditions respectively.

At higher frequencies, when the dimensions of the coupler are not sufficiently small compared with the wavelength, the evaluation of $Z_{a,sr}$ becomes complicated and is suitable to use plane-wave couplers. A plane-wave coupler is a cylindrical coupler whose diameter is the same as that of microphone diaphragms. In that case, $Z_{a,sr}$ is given by [1]

$$\frac{1}{Z_{a,sr}} = \left[\left(\frac{Z_{a,0}}{Z_{a,s}} + \frac{Z_{a,0}}{Z_{a,r}}\right) cosh\gamma l_0 + \left(1 + \frac{Z_{a,0}}{Z_{a,s}}\frac{Z_{a,0}}{Z_{a,r}}\right) senh\gamma l_0\right], \tag{5}$$

where $Z_{a,0}$ is the acoustic impedance of plane waves in the coupler, γ is the complex propagation coefficient and l_0 is the length of the coupler including the microphones front cavity depth.

3.2 Procedure

The same three type LS2 microphones calibrated in diffuse-field and four plane-wave couplers of 0.21, 0.26, 0.32 and 0.64 cm^3 volume were used. Others equipment were the same used in diffuse-field calibration, without the use of the 20 dB amplifier that was not required. Figure 3 shows a picture of the microphones mounted in a plane-wave coupler. All that assembly were built inside a camera that isolates the background noise and on an antivibration table.

Figure 3. Microphones mounted in a plane-wave coupler.

The procedure adopted complies with the IEC 61094-2 [1] and is summarized below.

The microphones are mounted in the 0.21 cm^3 plane-wave coupler. The microphone used as a sound source is driven using a sweep and the complex transfer-functions of the system microphone-coupler-microphone are measured [17]. An impulse response is obtained and a window function is applied in order to select the direct sound (excluding noise and distortion). After that, a frequency response is obtained and the electrical transfer impedance is calculated. Those steps are repeated using the other three plane-wave couplers and the average sensitivity is calculated. Preamplifier and the transmitter unit gains are also measured separately by the insert voltage technique [1]. Those measurements are repeated five times.

4. EXPERIMENTAL DETERMINATION OF THE CORRECTION TO THE PRESSURE FIELD SENSITIVITY TO OBTAIN THE DIFFUSE-FIELD SENSITIVITY

4.1 Results

The difference between the diffuse and pressure field sensitivities for each of three microphone was calculated and the average between them was determined. Table 1 presents the average values, their standard deviation and expanded uncertainty. The highest contribution for the expanded uncertainty is the uncertainty of the diffuse-field reciprocity calibration which estimation varies from 0.50 to 1.4 dB as a function of frequency.

Table 1. Average difference between the diffuse and pressure field sensitivity levels for type LS2 microphones obtained in this investigation.

Frequency (Hz)	Difference (dB)	Standard deviation (dB)	Expanded uncertainty (P = 95.45 %; *k* = 2) (dB)
1258.93	-0.5*	0.1	1.4
1584.89	-0.34*	0.03	0.91
1995.26	-0.27*	0.04	0.92
2511.89	-0.16*	0.05	0.67
3162.28	-0.03	0.06	0.53
3981.07	0.11	0.05	0.52
5011.87	0.31	0.04	0.58
6309.57	0.63	0.03	0.55
7943.28	1.12	0.05	0.59
10000.00	1.82	0.03	0.55
12589.30	2.57	0.04	0.55
15848.90	2.79	0.06	0.69

*See Sec. 5.

4.2 Comparison

The values of measurement uncertainty estimated in this investigation vary between 0.52 to 1.4 dB as a function of frequency, while in IEC standard is presented an unique value of 0.03 dB.

The difference between diffuse and pressure field sensitivities obtained in this investigation, the ones presented in IEC 61183 [10] and obtained by Barrera-Figueroa *et al*. [11] are shown in Fig. 4.

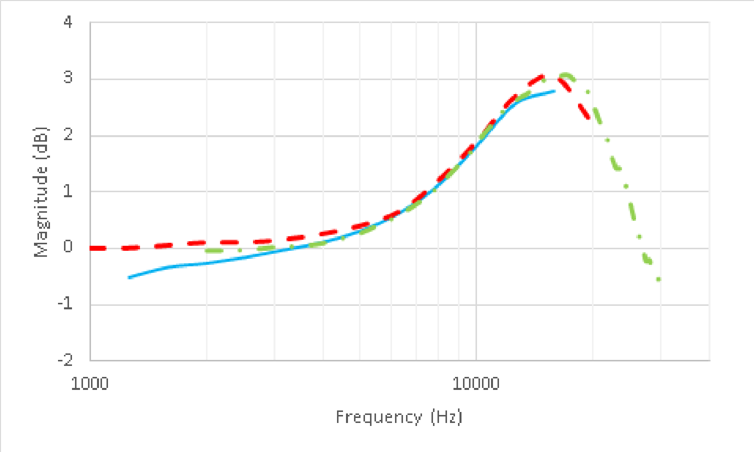

Figure 4. Difference between diffuse and pressure field sensitivity levels obtained in this investigation (solid line), presented in IEC 61183 (dashed line), and obtained by Barrera-Figueroa et al. (dot-dash line).

5. DISCUSSION

Comparing the results obtained in this study with the ones presented in standard and in literature, they presented good agreement in view of their measurement uncertainties: differences up to 0.5 dB in the range 1.25-2 kHz and smaller than 0.3 dB in the range 2.5-16 kHz. However, the negatives values in the range 1.25-2.5 kHz were not expected because it is believed that the interaction between microphone and sound waves increases the sensitivity and so, that values should be more investigated.

The difference between the uncertainties calculated in this investigation and that presented in IEC standard is significant. Considering the challenges of diffuse-field reciprocity calibration that affects the measurement uncertainty (i.e. poor signal-to-noise ratio and insufficient diffuseness and homogeneity of the sound field), it is possible to suppose that the value presented by IEC is quite optimistic. On the other hand, the uncertainties obtained in this investigation is little high and should be improved. As the main component of that uncertainty is the one associated with the diffuse-field reciprocity calibration, it should be developed. The uncertainties of absolute microphone calibration in diffuse-field are in order of 0.50-1.4 dB while in pressure and in free-field are in order of 0.05 dB and 0.13-0.20 dB respectively, however it is not expected lower uncertainties in diffuse-field much more.

Unfortunately, there are few investigations on diffuse-field reciprocity calibration, its measurement uncertainty estimation, and on diffuse-field or random-incidence correction.

6. CONCLUSIONS

Microphone calibration by reciprocity in diffuse and pressure fields were presented and the diffuse-field correction with its measurement uncertainty was determined for half-inch laboratory standard microphones developed for pressure field measurements. That obtained diffuse-field correction, the diffuse-field correction presented in standard and the random-incidence correction presented in literature show differences up to 0.5 dB in the frequency range 1.25-16 kHz showing good agreement (difference smaller than 0.3 dB) for the range 2.5-16 kHz. However, the obtained negatives values in the range 1.25-2.5 kHz should be investigated. On the other hand, the measurement uncertainty stated in the international standard IEC 61183 looks like quite optimist and should be reviewed.

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