Experimental determination of the difference between free-field and pressure sensitivity levels of half inch laboratory standard microphones

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ABSTRACT

According to the definitions of free-field and pressure sensitivities of a microphone, the two sensitivities will differ from each other because the effects of diffraction and reflection. According to the free-field receiving characteristics of a microphone the difference between of the pressure and the free-field sensitivity is determined not only by the scattering, but also by the relation between the acoustic impedance of the microphone and the radiation impedance. This paper will present a study of the technical specification IEC TS 61094-7 which gives a polynomial function for the difference between free-field and pressure sensitivity levels of laboratory standard microphones, it will present the results of experimental determination for half inch laboratory standards microphones and it will compare the experimental result with the result obtained according to IEC TS 61094-7.

Keywords: Microphone, Sensitivity, Free-field I-INCE Classification of Subjects Number(s): 71.1.1, 71.9, 81.2.2.

1. INTRODUCTION

According to the definitions of free-field and pressure sensitivities of a microphone, the two sensitivities will differ from each other because the effects of diffraction and reflection. The introduction of a microphone into a free-field disturbs the sound field, giving rise to the effects of reflection and diffraction, and the sound pressure at the microphone diaphragm is not the same as that when it is introduced into a pressure field, when it does not disturbs the sound field. Moreover, because the diffraction and reflection, the sound pressure over the diaphragm of the microphone is not uniform (1).

According to the free-field receiving characteristics of a microphone, the difference between of the free-field and pressure sensitivity levels is determined not only by the scattering, but also by the relation between acoustic impedance of the microphone and the radiation impedance. However, a minor part of the difference is determined by the interaction between the impedances and for half inch laboratory standards microphones this part is insignificant (1, 2).

The technical specification IEC TS 61094-7 gives a free-field correction to obtain the free-field sensitivity levels of laboratory standard microphones from the pressure ones. It would be natural to imagine that this free-field correction was obtained from the results of key comparisons on sensitivity calibration of microphones by the reciprocity technique in pressure field and in free-field, however this technical specification was published in 2006, before the end of the first key comparison on free-field sensitivity calibration of microphones by reciprocity technique whose final report was published in 2010. Thus, the objective of this paper is to discuss the IEC TS 61094-7 and to contribute to the determination of a new free-field correction.

2. IEC TS 61094-7 MEASUREMENT MICROPHONES – PART 7: VALUES FOR

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THE DIFFERENCE BETWEEN FREE-FIELD AND PRESSURE SENSITIVITY LEVELS OF LABORATORY STANDARD MICROPHONES

The IEC TS 61094-7 was published in 2006 and it gives a polynomial function derived from a least square fit to data from several laboratories (DPLA-DTU from Denmark, JQA from Japan, LNE from France, NPL from United Kingdom and PTB from Germany) for the difference between free-field and pressure sensitivity levels of laboratory standard microphone, the one inch (LS1) and the half inch (LS2) ones, as specified in the international standard IEC 61094-1. The data provided for the construction of the polynomial function were derived from theoretical considerations combined with sensitivity measurement by the reciprocity technique in pressure field and in free-field in according to the international standards IEC 61094-2 and IEC 61094-3 of Brüel & Kjaer’s microphones types 4160 and 4180. Annex A of IEC TS 61094-7 reports the mean values of the data and the quoted expanded uncertainty, however, it is important note that this uncertainty refer to the experimental standard deviation of the mean values using a coverage factor 2. Equation 1 shows the polynomial function:

$$\Delta_{ff} = c_1 R^1(f,t) + c_2 R^2(f,t) + c_3 R^3(f,t) + \ldots + c_n R^n(f,t), \text{ dB} \quad (1)$$

where Δ_{ff} is the difference value between the free-field (for zero-degrees incidence) and the pressure sensitivity levels in dB; c_n, where n varies from 1 to 9, are the polynomial coefficients in dB/kHz and $R(f,t)$ is a function of frequency, f, and of temperature, t (1).

This equation enables the determination of the free-field sensitivity level of laboratory standard microphones by adding the result to the pressure sensitivity level. It is valid from 200 Hz to 12.5 kHz for LS1 microphones and from 400 Hz to 25 kHz for LS2 microphones. Below these frequency ranges, the difference values are less than 0.01 dB and can be neglected. The maximum deviation between the values obtained with Equation 1 and the average values of the data provided by the laboratories is within 0.05 dB. It should be noted that this equation is applicable when a suitable free-field calibration is not available (1).

When Equation 1 is used to obtain the free-field sensitivity level of LS1 and LS2 microphones the combined standard uncertainty is derived from the standards uncertainties of: the pressure sensitivity level, the average value of the data provided by different laboratories and presented in Annex A of IEC TS 61094-7 and the Equation 1 assumed to be 0.05 dB (1). Table 1 shows the difference between the free-field and pressure sensitivity levels for a temperature of 23 ^{o}C and for LS2 microphones obtained according to Equation 1.

Table 1 - Differences between free-field (for zero-degrees incidence) and pressure sensitivity levels for temperature of 23 ^{o}C and for LS2 microphones, obtained according to IEC TS 61094-7.

Frequency, kHz	Magnitude, dB	Expanded uncertainty (k=2), dB
1.000	0.056	0.117
1.250	0.096	0.109
1.600	0.166	0.123
2.000	0.267	0.139
2.500	0.422	0.150
3.150	0.667	0.159
4.000	1.058	0.156
5.000	1.612	0.147
6.300	2.462	0.158
8.000	3.734	0.197
10.00	5.309	0.290
12.50	7.086	0.348
16.00	8.683	0.250
20.00	9.141	0.349

3. EXPERIMENTAL DETERMINATION OF THE DIFFERENCE BETWEEN FREE-FIELD AND PRESSURE SENSITIVITY LEVELS FOR HALF INCH LABORATORY STANDARD MICROPHONES

For the experimental determination of the difference between free-field and pressure sensitivity levels for LS2 microphones, were measured the free-field and the pressure sensitivity levels by the reciprocity technique according to IEC 61094-3 and IEC 61094-2 of six Brüel & Kjaer's microphones type 4180. The measurements were corrected for the reference environmental conditions, were calculated the difference between the levels for each microphone and were calculated the average values. Table 2 shows the average difference between free-field and pressure sensitivity levels.

Table 2 - Average differences between the free-field (for zero-degrees incidence) and pressure sensitivity levels for LS2 microphones, obtained in this work.

Frequency, kHz	Average, dB	Standard deviation, dB
1.000	0.07	0.06
1.259	0.18	0.05
1.585	0.13	0.03
1.995	0.27	0.02
2.512	0.48	0.04
3.162	0.70	0.03
3.981	0.99	0.01
5.012	1.60	0.01
6.310	2.41	0.02
7.943	3.52	0.02
10.00	5.14	0.02
12.59	7.01	0.05
15.85	8.42	0.07
19.95	9.04	0.04

To quote the expanded uncertainty we must first define the objective of determining the difference between the free-field and the pressure sensitivity levels: to determine an average value or to determine a free-field correction. If the objective is to determine an average value, the expanded uncertainty should be calculated from the equation of average (assume the equation of average as a model function and proceed the calculations). In this case, the expanded uncertainty of the average will be smaller than the expanded uncertainty of each difference, assuming that they are equal. Figure 1 shows this situation for the frequency of 10 kHz.

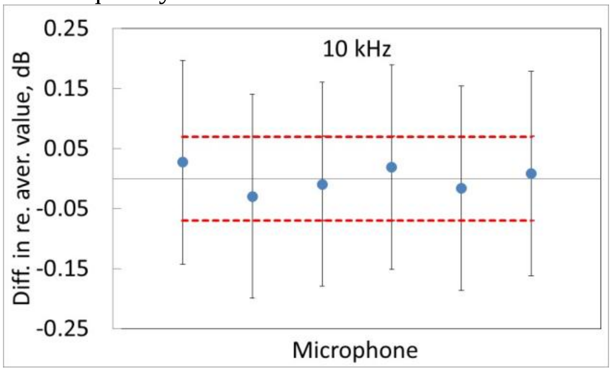

Figure 1 - Differences between the free-field and pressure sensitivity levels in relation to the average value,

for each microphone and for the frequency of 10 kHz, obtained in this work. The dashed line is the expanded uncertainty of the average value.

On the other hand, if the objective is to determine a free-field correction covering the largest possible number of differences between the sensitivity levels and their expanded uncertainties, the procedure should be another. The expanded uncertainty should be the sum of the greatest deviation from the average value with its expanded uncertainty. In this case, the expanded uncertainty of the free-field correction will be greater than the expanded uncertainty of each difference. Figure 2 shows this situation for the frequency of 10 kHz.

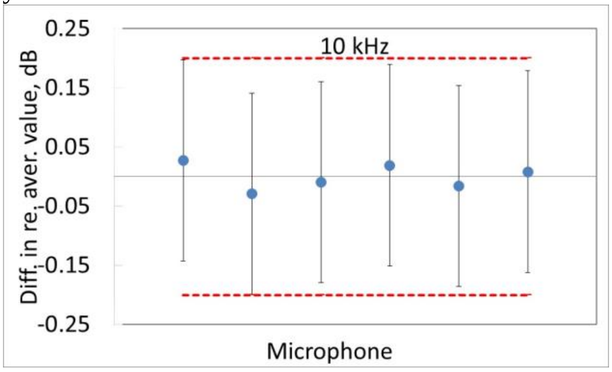

Figure 2 - Differences between the free-field and pressure sensitivity levels in relation to the average value, for each microphone and for the frequency of 10 kHz, obtained in this work. The dashed line is the expanded uncertainty of the free-field correction.

The objective of IEC TS 61094-7 is to determine a free-field correction applicable when a free-field calibration in according to IEC 61094-3 is not available. For this reason, for later comparison with the IEC TS 61094-7, the expanded uncertainty should be quoted as a free-field correction. Table 3 shows the quoted expanded uncertainty.

Table 3 - Expanded uncertainties quoted for the free-field correction for LS2 microphones, obtained in this work.

Frequency, kHz	Expanded uncertainty (k=2), dB
1.000	0.24
1.259	0.22
1.585	0.18
1.995	0.16
2.512	0.20
3.162	0.18
3.981	0.15
5.012	0.16
6.310	0.16
7.943	0.19
10.00	0.20
12.59	0.27
15.85	0.32
19.95	0.29

4. COMPARISON

Table 4 shows the difference between the free-field correction obtained in this work and the free-field correction obtained according to IEC TS 61094-7. Figure 3 shows the corresponding graph.

Table 4 - Differences between the free-field correction obtained in this work and the free-field correction obtained according to IEC TS 61094-7.

Frequency, kHz	Difference, dB
1.000	0.02
1.259	0.08
1.585	-0.04
1.995	0.00
2.512	0.06
3.162	0.03
3.981	-0.07
5.012	-0.01
6.310	-0.05
7.943	-0.21
10.00	-0.17
12.59	-0.08
15.85	-0.26
19.95	-0.10

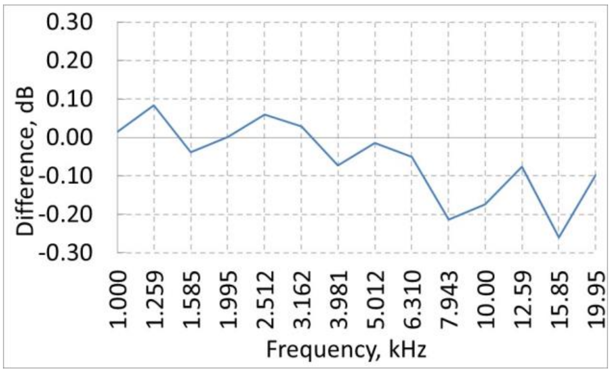

Figure 3 - Differences between the free-field correction obtained in this work and the free-field correction obtained according to IEC TS 61094-7.

Table 5 shows the differences between the expanded uncertainties for the free-field correction obtained in this work and for the free-field correction obtained according to IEC TS 61094-7. Figure 4 shows the corresponding graph.

Table 5 - Differences between the expanded uncertainties for the free-field correction obtained in this work and for the free-field correction obtained according to IEC TS 61094-7.

Frequency, kHz	Difference, dB
1.000	0.12
1.259	0.11

1.585	0.06
1.995	0.02
2.512	0.05
3.162	0.02
3.981	0.00
5.012	0.01
6.310	0.00
7.943	-0.01
10.00	-0.09
12.59	-0.08
15.85	0.07
19.95	-0.06

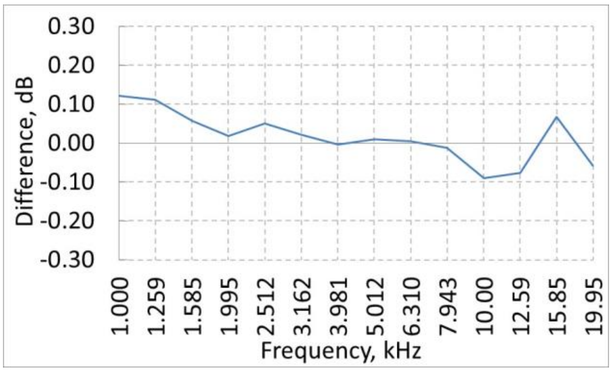

Figure 4 - Differences between the expanded uncertainties for the free-field correction obtained in this work and for the free-field correction obtained according to IEC TS 61094-7.

Figure 5 shows the graph of the free-field correction obtained in this work and the free-field correction obtained according to IEC TS 61094-7 with their expanded uncertainties for the frequency of 10 kHz.

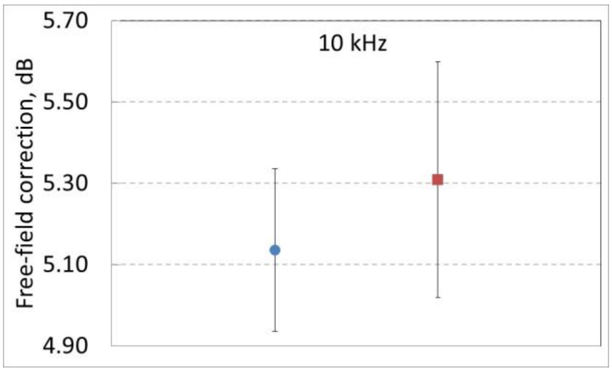

Figure 5 - Free-field corrections: ○ - obtained in this work and □ - obtained according to IEC TS 61094-7 with their expanded uncertainties for the frequency of 10 kHz.

5. OTHER ANALYZES

One important analysis is to compare the expanded uncertainty of free-field sensitivity obtained from the application of the free-field correction with the expanded uncertainty of free-field sensitivity obtained from measurement. For obvious reasons the uncertainty of sensitivity obtained from the application of the free-field correction must be bigger than the uncertainty of sensitivity obtained from measurement. To make this comparison we use the typical expanded uncertainties practiced by the national metrology institute of Brazil, Inmetro, showed in Table 6.

Table 6 - Typical expanded uncertainties (k=2) practiced by Inmetro (3, 4).

Frequency, kHz	Pressure field, dB	Free-field, dB
1.000	0.05	0.13
1.259	0.05	0.12
1.585	0.05	0.12
1.995	0.05	0.12
2.512	0.05	0.12
3.162	0.05	0.11
3.981	0.05	0.11
5.012	0.05	0.11
6.310	0.05	0.12
7.943	0.06	0.13
10.00	0.08	0.15
12.59	0.09	0.18
15.85	0.12	0.18
19.95	0.13	0.18

Table 7 shows the expanded uncertainties for free-field sensitivity derived from the application of the free-field correction determined in this work and derived from the application of the free-field correction calculated according to IEC TS 61094-7. Figure 6 compares the expanded uncertainties.

Table 7 - Expanded uncertainties (k=2) for free-field sensitivity derived from the application of the free-field correction.

Frequency, kHz	Determined in this work, dB	Calculated according to IEC TS 61094-7, dB
1.000	0.24	0.13
1.259	0.23	0.12
1.585	0.19	0.13
1.995	0.16	0.15
2.512	0.21	0.16
3.162	0.19	0.17
3.981	0.16	0.16
5.012	0.16	0.16
6.310	0.17	0.17
7.943	0.20	0.21
10.00	0.21	0.30
12.59	0.29	0.36

15.85	0.34	0.28
19.95	0.32	0.23

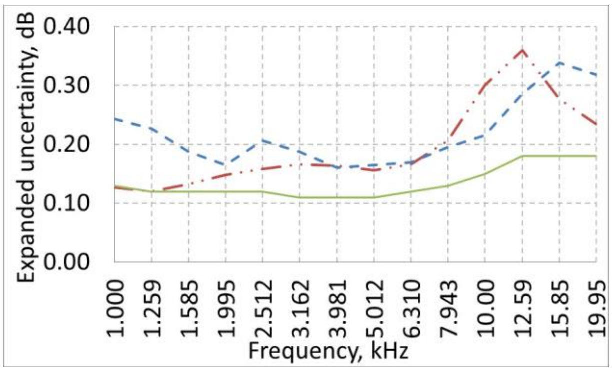

Figure 6 - Expanded uncertainties for the free-field sensitivity obtained from: — measurement, —··— the free-field correction calculated according to IEC TS 61094-7 and ---- the free-field correction determined in this work.

An interesting analysis is to compare it with similar work done by other institutes. Barrera-Figueroa et al (5) showed, in 2006, similar work. In that opportunity was determined the free-field correction at normal incidence of LS2 microphones from the calibration by the reciprocity technique of 24 microphones. The experimental standard deviation at frequencies below the resonance frequency was around 0.03 dB and around the resonance frequency it increases up to a maximum of 0.08 dB. According to Barrera-Figueroa et al the free-field correction were in good agreement with the data published in IEC TS 61094-7 however with a standard uncertainty smaller than the uncertainty of the standardized values because it has been assembled from a single source while the IEC TS 61094-7 has been assembled from very different sources. Table 8 shows the free-field correction determined by Barrera-Figueroa et al (5).

Table 8 - Free-field correction determined by Barrera-Figueroa et al.

Frequency, kHz	Free-field correction, dB	Expanded uncertainty (k=2), dB
3.000	0.63	0.06
4.000	1.08	0.06
5.000	1.63	0.05
6.000	2.28	0.05
7.000	2.98	0.05
8.000	3.74	0.05
9.000	4.51	0.05
10.00	5.30	0.05
11.00	6.05	0.06
12.00	6.75	0.06
13.00	7.39	0.06
14.00	7.93	0.06
15.00	8.37	0.07
16.00	8.70	0.07
17.00	8.92	0.09

18.00	9.06	0.09
19.00	9.12	0.09
20.00	9.13	0.09

Table 9 shows the difference between the free-field correction obtained in this work and the free-field correction determined by Barrera-Figueroa et al. Figure 7 shows the free-field corrections obtained in this work and determined by Barrera-Figueroa et al for the frequency of 16 kHz.

Table 9 - Difference between free-field correction obtained in this work and the free-field correction determined by Barrera-Figueroa et al.

Frequency, kHz	Difference, dB
3.981	-0.09
5.012	-0.03
7.943	-0.22
10.00	-0.16
15.85	-0.27
19.95	-0.08

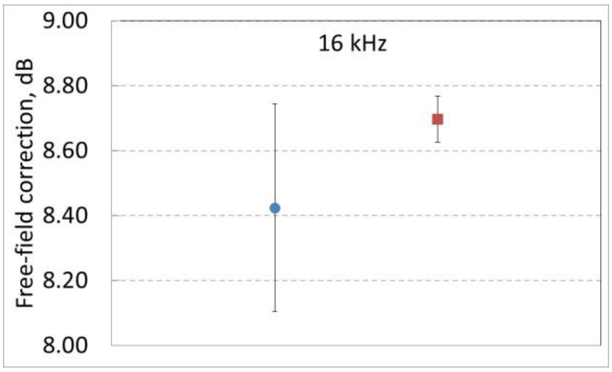

Figure 7 - Free-field corrections: ○ - obtained in this work and □ - determined by Barrera-Figueroa et al with their expanded uncertainties for the frequency of 16 kHz.

6. COMMENTS AND CONCLUSIONS

The IEC TS 61094-7 was published in 2006, before the end of the first key comparison on free-field sensitivity calibration of microphones by reciprocity technique, the CCAUV.A-K4, whose final report was published in 2010. The most appropriate would be its publication after this comparison using its results together with the results of the key comparison on pressure field sensitivity calibration of microphones by reciprocity technique, the CCAUV.A-K3, for the construction of the polynomial function for the difference between free-field and pressure sensitivity levels of LS2 microphones.

The data provided for the construction of the polynomial function in IEC TS 61094-7 were derived from measurements but also from theoretical considerations however, theoretical considerations are based on initial conditions that by themselves are a source of uncertainty difficult to quote. Thus, for the construction of the polynomial function is preferably the use of measurements and the theoretical considerations should be used only for the frequency range where measurements are not possible.

Although is said in IEC TS 61094-7 that the maximum deviation between the values obtained with Equation 1 and the average values of data provided by the laboratories is within 0.05 dB, comparing the values obtained for the temperature of 23 ^{o}C with the average values of data provided by the laboratories is found differences up to 0.18 dB at 10 kHz. This raises the question if the standard uncertainty of 0.05 dB quoted to the Equation 1 is adequate.

Analyzing the Figure 5, it shows that the expanded uncertainty of the free-field correction obtained according to IEC TS 61094-7 does not cover the free-field correction obtained in this work with its expanded uncertainty. One guess would be that the uncertainty quoted by IEC TS 61094-7 is underquoted. Analyzing the Figure 6 it shows that the expanded uncertainty of the free-field sensitivity obtained from the application of the free-field correction calculated according to IEC TS 61094-7 approaches the expanded uncertainty of the free-field sensitivity obtained from measurements at lower frequencies which supports the assumption presented above at least for those frequencies. Note that this fact is a nonsense that discourages research and development since, theoretically, it is possible to obtain close values of expanded uncertainty if the free-field sensitivity is derived from the application of the free-field correction or if the free-field sensitivity is measured.

Returning to the Figure 5, it shows that the expanded uncertainty of the free-field correction obtained in this work also does not cover the free-field correction obtained according to IEC TS 61094-7 with its expanded uncertainty. One explanation would be that the results of this study are assembled from a single source, in this case, from Inmetro. Analyzing the Figure 7, it shows that the free-field correction obtained in this work differs from the free-field correction determined by Barrera-Figueroa et al affiliated to DPLA-DTU, which supports the explanation provided above.

Thus, it is necessary to revise the IEC TS 61094-7. A short-term solution would be to use the results of key comparisons CCAUV.A-K3 and CCAUV.A-K4. A medium-term solution would be different national metrologies institutes that dominate both calibrations determine their free-field correction and after that determine the average free-field correction from all these institutes. A long-term solution would be the realizations of new key comparisons on sensitivity calibration of microphones by the reciprocity technique in pressure field and in free-field using the same microphones (the same serial numbers). In all solutions is important to quote the expanded uncertainty as a free-field correction and not as an average value.

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