An investigation about the effect of diffusivity of sound field for reciprocity calibration of measurement microphones in diffuse-field

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ABSTRACT

The primary calibration of measurement microphones is usually performed by the reciprocity technique. In this technique the microphone sensitivity is commonly calculated from the electrical transfer impedance and the acoustic transfer impedance between three microphones connected acoustically in pair-wise combinations. In diffuse-field, the acoustic transfer impedance is determined from the measurement of chamber reverberation time. This paper presents an investigation about the effect of diffusivity of the sound field in the measurement of the chamber reverberation time for reciprocity calibration. The microphones were connected acoustically by a small reverberation chamber and to improve the diffusivity two types of diffusers were tested: hanging panels diffusers and boundary diffusers. The reverberation time was measured using the integrated impulse response method in thirty two source-receiver configurations. The microphone sensitivities were calculated and the results point differences up to 0.2 dB in higher frequencies.

Keywords: Calibration, Microphone, Diffuse-field I-INCE Classification of Subjects Number(s): 71.1.1

1. INTRODUCTION

The primary calibration of measurement microphones is usually performed by the reciprocity technique (1, 2, 3, 4). In this technique, the microphone sensitivity is commonly calculated from the electrical transfer impedance and the acoustic transfer impedance between three microphones connected acoustically in pair-wise combinations. Let two of the three microphones be connected acoustically by a reverberation chamber. Using one of them as a sound source (source microphone) and the other as a sound receiver (receiver microphone), the electrical transfer impedance between microphones 1 and 2 ($Z_{e,12}$) is measured from:

$$Z_{e,12} = U_2 / i_1, \tag{1}$$

where U_2 is the signal voltage at the electrical terminals of the receiver microphone and i_1 is the current through the electrical terminals of the source microphone. As the acoustic transfer impedance between microphones 1 and 2 ($Z_{a,12}$) is (5, 6):

$$Z_{a,12} = \left(\frac{\pi \log e}{6}\right)^{1/2} \rho_0 f \left(\frac{c T_{60}}{V}\right)^{1/2}, \tag{2}$$

where ρ_0 is the density of the gas, f is frequency, c is the speed of sound in the gas, T_{60} is the chamber reverberation time and V is the chamber volume; the product of the diffuse-filed sensitivities of the two coupled microphones can be determined. Using pair-wise combinations of three microphones, three such mutually independent products are available, from which an expression for the diffuse-field sensitivity of each the three microphones can be derived as:

$$M_{d,1} = \left(\frac{Z_{e,12} Z_{e,13}}{Z_{e,23}} \frac{Z_{a,23}}{Z_{a,12} Z_{a,13}}\right)^{1/2}, \tag{3}$$

where $M_{d,1}$ is the diffuse-field sensitivity.

This paper presents an investigation about the effect of diffusivity of the sound field in the measurement of the chamber reverberation time for reciprocity calibration. Towards this aim, two types of reverberation chamber configuration will be tested: 1) reverberation chamber with hanging panels diffusers and 2) reverberation chamber with boundary diffusers (7, 8, 9). After that, the chamber reverberation time and the microphone diffuse-field sensitivity will be discussed.

2. PROCEDURE

2.1 Electrical Transfer Impedance

Source microphone was driven with a swept sine and the transfer function of each one of the two connected microphones was measured. An inverse Fourier transform was calculated and a time-selective window was applied to the resulting impulse response in order to separate the direct response (direct sound and early reflections) and the reverberant response (5). Then a Fourier transform was calculated to the reverberant part of the impulse response and the electrical transfer impedance was calculated. That procedure was repeated for thirty-two source-receiver configurations in the reverberation chamber, being four source positions combined with eigth receiver positions, and the final value was taken as the average of the measurements. Gain of the preamplifier and the transmitter unit were eliminated using the insert voltage technique.

2.2 Acoustic Transfer Impedance – Reverberation Time

The reverberation time (T_{20}) of the chamber was measured by the integrated impulse response method (10) and, for this, the impulse response obtained during the measurement of the electrical transfer impedance were used what ensures that the environmental conditions were the same for both measurements. Note that the air absorption and thus the reverberation time might change with changes in environmental conditions. This procedure was also repeated for thirty-two source-receiver configurations in the reverberation chamber and the final value was taken as the average of the measurements. Then, the acoustic transfer impedance was calculated.

The chamber volume was calculated from measurements of its dimensions. The speed of sound and the density of air were calculated from the measurements of the environmental conditions (1).

3. SETUP, MEASUREMENTS AND RESULTS

3.1 Setup

Three half-inch working standard microphones designed for diffuse field measurement (WS2D microphones) were calibrated in a small rectangular reverberation chamber of 2 m^3. Generation and acquisition of signals were made using the platform CMF22 and the software Monkey Forest. Figure 1 shows a photo of part of the measurement system.

Figure 1 – The reverberation chamber with the measurement rigs.

3.2 Measurements and Results

3.2.1 Configuration 1: Reverberation Chamber with Hanging Panels Diffusers

Figure 2 shows a photo of the reverberation chamber with hanging panels diffusers. Five rectangular panels of 1200 cm^2 made in hard plastic were used.

Figure 2 – The reverberation chamber with hanging panels diffusers.

Figure 3 shows the calculated electrical transfer impedance.

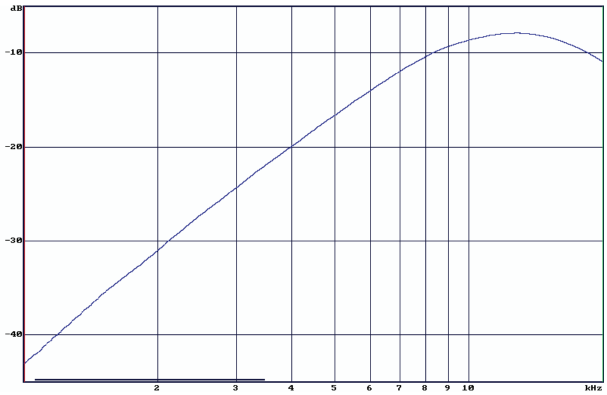

Figure 3 – Electrical transfer impedance between the microphones in the reverberation chamber with hanging panels diffusers.

Figure 4 and Table 1 show the measured reverberation time.

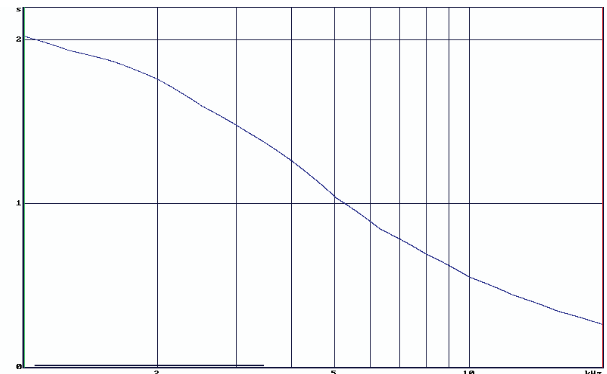

Figure 4 – Reverberation time for the reverberation chamber with hanging panels diffusers.

Table 1 – Reverberation time for the reverberation chamber with hanging panels diffusers.

Frequency, kHz	Reverberation time, s
1	2.02
1.25	1.94
1.6	1.87
2	1.74
2.5	1.60
3.15	1.43
4	1.25
5	1.03
6.3	0.84
8	0.69
10	0.54
12.5	0.44
16	0.34
20	0.26

Figure 5 and Table 2 show the microphone sensitivity.

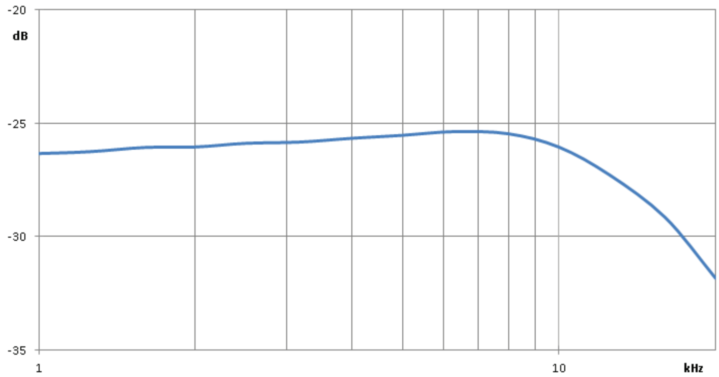

Figure 5 – Microphone sensitivity measured using the reverberation chamber with hanging panels diffusers.

Table 2 – Microphone sensitivity measured using the reverberation chamber with hanging panels diffusers.

Frequency, kHz	Sensitivity, dB re. 1 V/Pa	Standard deviation, dB re. 1 V/Pa
1	-26.33	0.01
1.25	-26.25	0.07
1.6	-26.06	0.01
2	-26.04	0.05
2.5	-25.88	0.04
3.15	-25.83	0.06
4	-25.66	0.04
5	-25.52	0.02
6.3	-25.36	0.02
8	-25.46	0.04
10	-26.04	0.03
12.5	-27.27	0.04
16	-29.15	0.03
20	-31.82	0.04

3.2.2 Configuration 2: Reverberation Chamber with Boundary Diffusers

Figure 6 shows a photo of the reverberation chamber with boundary diffusers. Eleven caps made in glass were used being five ones of 1400 cm^3 and six of 3900 cm^3.

Figure 6 – The reverberation chamber with boundary diffusers.

Figure 7 shows the calculated electrical transfer impedance.

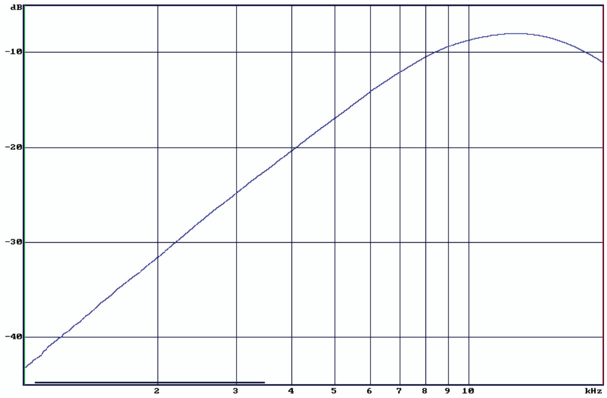

Figure 7 – Electrical transfer impedance between the microphones in the reverberation chamber with boundary diffusers.

Figure 8 and Table 3 show the measured reverberation time.

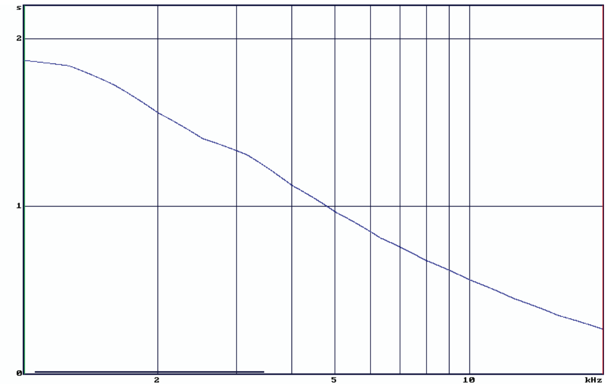

Figure 8 – Reverberation time for the reverberation chamber with boundary diffusers.

Table 3 – Reverberation time for the reverberation chamber with boundary diffusers.

Frequency, kHz	Reverberation time, s
1	1.85
1.25	1.82
1.6	1.70
2	1.56
2.5	1.41
3.15	1.30
4	1.12
5	0.95
6.3	0.81
8	0.67
10	0.55
12.5	0.44
16	0.34
20	0.26

Figure 9 and Table 4 show the microphone sensitivity.

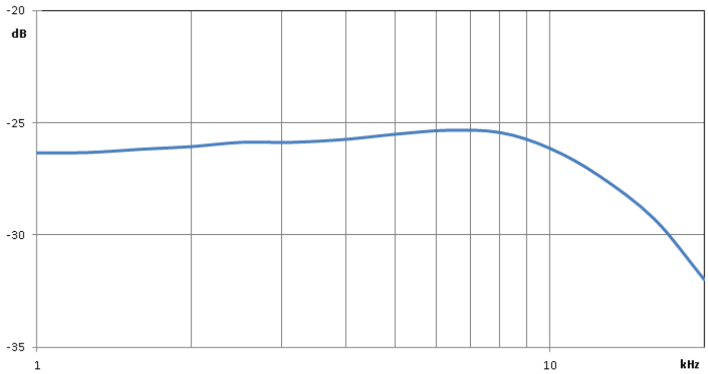

Figure 9 – Microphone sensitivity measured using the reverberation chamber with boundary diffusers.

Table 4 – Microphone sensitivity measured using the reverberation chamber with boundary diffusers.

Frequency, kHz	Sensitivity, dB re. 1 V/Pa	Standard deviation, dB re. 1 V/Pa
1	-26.33	0.06
1.25	-26.32	0.05
1.6	-26.18	0.03
2	-26.06	0.01
2.5	-25.87	0.04
3.15	-25.87	0.03
4	-25.74	0.05
5	-25.51	0.07
6.3	-25.34	0.04
8	-25.43	0.01
10	-26.13	0.02
12.5	-27.37	0.04
16	-29.29	0.04
20	-31.98	0.04

3.2.3 Expanded Uncertainty

The expanded uncertainty for the measurements were estimated in 0.20 dB. They were stated as the combined uncertainties multiplied by the coverage factor $k = 2$, which corresponds to a coverage probability of approximately 95%. The expanded uncertainties were estimated in accordance with ISO/IEC Guide 98-3 (11).

4. DISCUSSION

Figure 10 shows the difference between the electrical transfer impedance calculated for the reverberation chamber with hanging panels diffusers and the electrical transfer impedance calculated for the reverberation chamber with boundary diffusers. It is possible to note that the ETI for the reverberation chamber with hanging panels diffusers is greater than the ETI for the reverberation chamber with boundary diffusers.

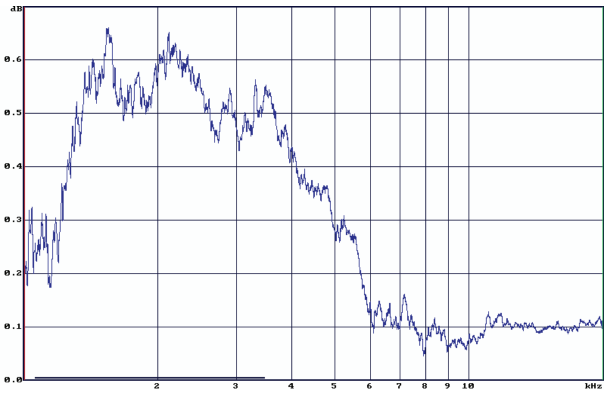

Figure 10 – Difference among the electrical transfer impedance between microphones in the reverberation chamber with hanging panels diffusers and the electrical transfer impedance between the microphones in the reverberation chamber with boundary diffusers.

Figure 11 shows the reverberation time measured for the reverberation chamber with hanging panels diffusers and the reverberation time measured for the reverberation chamber with boundary diffusers. Now it is possible to note that the RT for the reverberation chamber with hanging panels diffusers is also greater than the RT for the reverberation chamber with boundary diffusers.

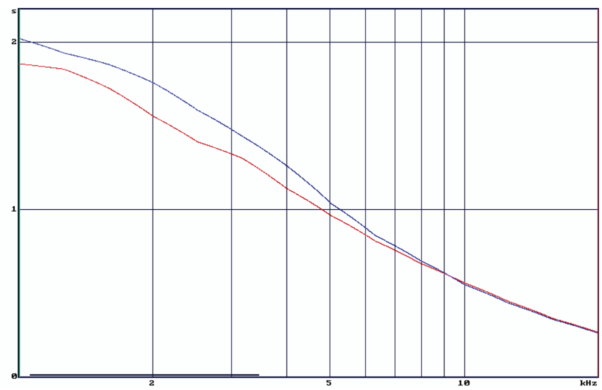

Figure 11 – Reverberation time measured for the reverberation chamber with hanging panels diffusers (blue line) and the reverberation time measured for the reverberation chamber with boundary diffusers (red line).

As the acoustic transfer impedance is directly proportional to the reverberation time it is possible to conclude that the acoustic transfer impedance is greater in the reverberation chamber with the hanging panels diffuser than in the reverberation chamber with boundary diffusers.

By way of the sensitivity is directly proportional to the ratio between the electrical and the acoustic transfer impedances, the same behavior of the transfer impedances lead to the same sensitivities regardless the configuration of the reverberation chamber. Figure 12 shows de difference between the sensitivity measured using the reverberation chamber with hanging panels diffusers and the sensitivity measured using the reverberation chamber with boundary diffusers. It points differences up to 0.2 dB.

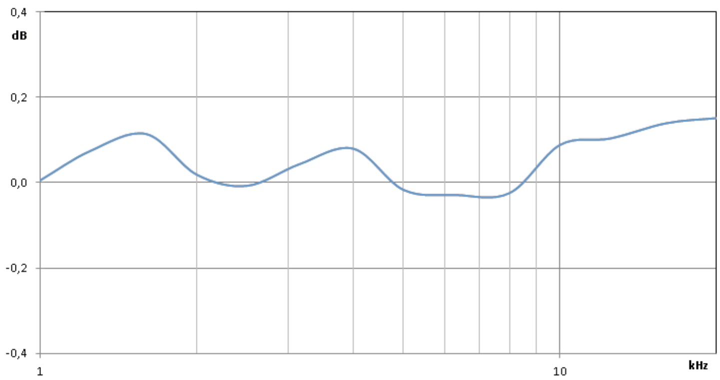

Figure 12 – Difference between the sensitivity measured using the reverberation chamber with hanging panels diffusers and the sensitivity measured using the reverberation chamber with boundary diffusers.

The difference between the sensitivity calculated for the reverberation chamber with hanging panels diffusers and the sensitivity calculated for the reverberation chamber with boundary are lower than the estimated expanded uncertainty.

5. CONCLUSIONS

The reverberation time (consequently the acoustic transfer impedance) for the reverberation chamber with hanging panels is greater than the reverberation time for the reverberation chamber with boundary diffusers. Despite this, as the electrical transfer impedance for the reverberation chamber with hanging panels is also greater than the electrical transfer impedance for the reverberation chamber with the boundary diffusers, the measured sensitivities lead to the same values.

Although the sensitivities calculated for both configuration present differences up to 0.2 dB as the estimated expanded uncertainty is about 0.2 dB it is possible to conclude that both configuration point to the same result.

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