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An investigation on diffuse-field calibration of measurement microphones by the reciprocity technique

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Abstract

In the calibration of measurement microphones by the reciprocity technique, microphone sensitivity is usually determined from the electrical transfer impedance and the acoustical transfer impedance between three microphones acoustically coupled in pair-wise combinations. This calibration is well known in pressure-field and in free-field conditions but it is under research for diffuse-field. In this paper is presented a proposal to perform this calibration in diffuse-field. The microphones are placed in a small reverberation chamber with boundary (volume) diffusers. The electrical transfer impedance is obtained from the average of measurements at different positions in the chamber. In each measurement, the reverberation is separated from the direct sound using a suitable window function. The acoustical transfer impedance is obtained from the chamber reverberation time, which is determined using the same measurements employed to obtain the electrical transfer impedance. The results support the viability of the proposal.

Keywords: calibration, microphone, reciprocity, diffuse-field

An investigation about diffuse-field calibration of measurement microphones by the reciprocity technique

1 Introduction

Primary calibration of measurement microphones is usually performed by the reciprocity technique [1,2,3,4]. It could be carried out by means of three microphones or by means of an auxiliary sound source and two microphones, the former being the most common. In the reciprocity technique using three microphones, the microphones are combined in pairs, one microphone being used as a sound source and the other as a sound receiver. When the microphones are acoustically coupled, the electrical and the acoustical transfer impedances between them are measured. From these measurements, the product of the sensitivities of the two coupled microphones can be determined. Using pair-wise combinations of the three microphones, three such mutually independent products are available, from which an expression for the sensitivity of each of the three microphones can be derived.

The calibration of measurement microphones by reciprocity in pressure field and in free-field conditions are well known [5], but it is under research for diffuse-field [6,7,8,9]. In this paper, a proposal to perform that calibration in diffuse-field is presented.

For each pair of microphones, the electrical transfer impedance between them, $Z_{e,sr}$, is measured from:

$$Z_{e,sr} = U_r / i_s, \tag{1}$$

where U_r is the signal voltage at the electrical terminal of the receiver microphone and i_s is the current through the electrical terminal of the source microphone. The acoustical transfer impedance between the microphones in diffuse-field, $Z_{a,sr}$, is determined from [7,8]:

$$Z_{a,sr} = {\frac{\pi \log e}{6}}^{1/2} \rho_0 f \, {\frac{c T_R}{V}}^{1/2}, \tag{2}$$

where ρ_0 is the density of the gas, f is the frequency, c is the speed of sound in the gas, T_R is the chamber reverberation time and V is the chamber volume.

2 Procedure

2.1 Electrical transfer impedance

The source microphone was driven by frequency sweeps of 6.9 V_{rms} in the frequency range from 500 Hz to 47000 Hz with a substantial emphasis at lower frequencies made by sweeping through them slower [10]. Signal voltage at the electrical terminal of the receiver microphone was measured using a 20 dB amplifier. Current through the electrical terminal of the source microphone was measured by placing a capacitor in series with the source microphone. Both were transformed to the frequency domain by a fast Fourier transforms and the corresponding transfer-function were obtained.

To improve the signal-to-noise ratio, sixteen synchronous averages were performed. Also, to improve the diffuse-field conditions, two suitable window functions were applied to the impulse responses: a shorter one for the frequency range where the source microphone is more efficient as a sound source and a larger for the frequency range where it is less efficient and more energy it is needed. As the sound field is not perfectly homogeneous, the measurements were performed at thirty-two random pairs of positions in the reverberation chamber and the spatial average and, after that, the frequency average of the measurements were calculated.

The gain of the pre-amplifiers and amplifier were eliminated using the insert voltage technique [1].

2.2 Acoustical transfer impedance

The reverberation time of the chamber was measured by the integrated impulse response method [11] using the impulse responses obtained during the measurement of the electrical transfer impedance. It was measured also at thirty-two random pairs of positions in the reverberation chamber for each pair-wise combination of microphones and the final value was taken as the average of the measurements.

The volume of the reverberation chamber was calculated from the measurements of its dimensions and was discounted the volume of the used diffusers. The gas density and the speed of sound in the gas were calculated from the measurements of the static pressure, temperature and humidity [1].

2.3 Sensitivity

The sensitivity was measured three times and the final value was taken as the average of the measurements.

3 Setup, measurements and results

3.1 Setup

Three half-inch working standard microphones designed for diffuse-field [12] were calibrated. Signal generation and measurements were made using the CMF22 platform, a transmitter unit, a pre-amplifier and a 20 dB amplifier. Signal processing was made using the software Monkey Forest.

The microphones were acoustically coupled by a small rectangular reverberation chamber of 2 m^3 in which were placed some boundary (volume) diffusers [13]. Eleven caps made in glass being five of 1400 cm^3 and six of 3900 cm^3 were used. Figure 1 shows a photo of the reverberation chamber with boundary diffusers.

Figure 1: The reverberation chamber with boundary diffusers.

3.2 Measurements and results

3.2.1 Electrical transfer impedance

Figures 2 and 3 show the transfer-function and the correspondent impulse response relative to the current through the electrical terminal of the source microphone and the signal voltage at the electrical terminal of the receiver microphone.

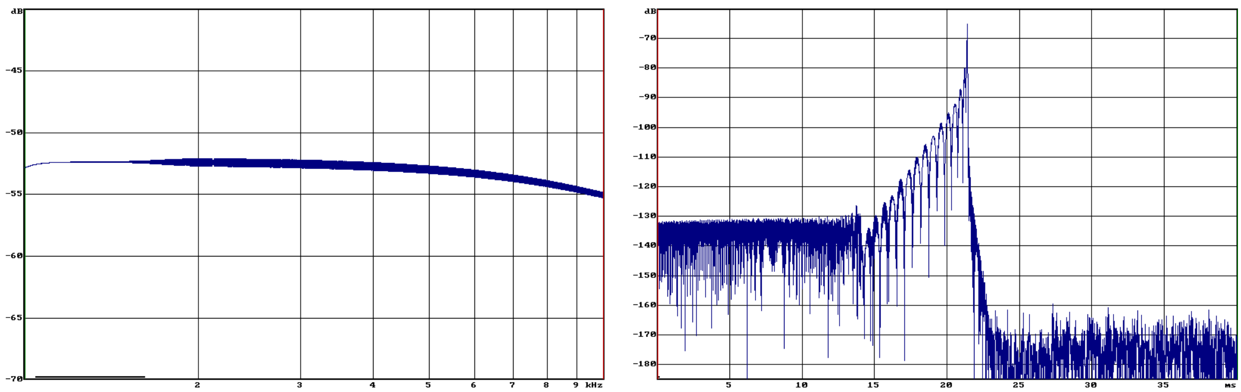

Figure 2: Transfer-function (left) and the correspondent impulse response (right) relative to the current through the electrical terminal of the source microphone.

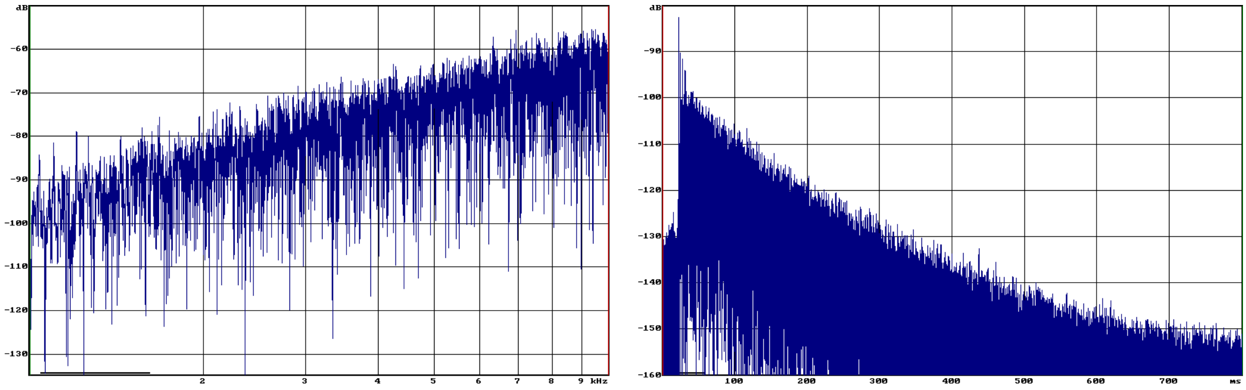

Figure 3: Transfer-function (left) and the correspondent impulse response (right) relative to the signal voltage at the electrical terminal of the receiver microphone.

Figures 4 and 5 show the impulse responses and the transfer-functions after the window function were applied.

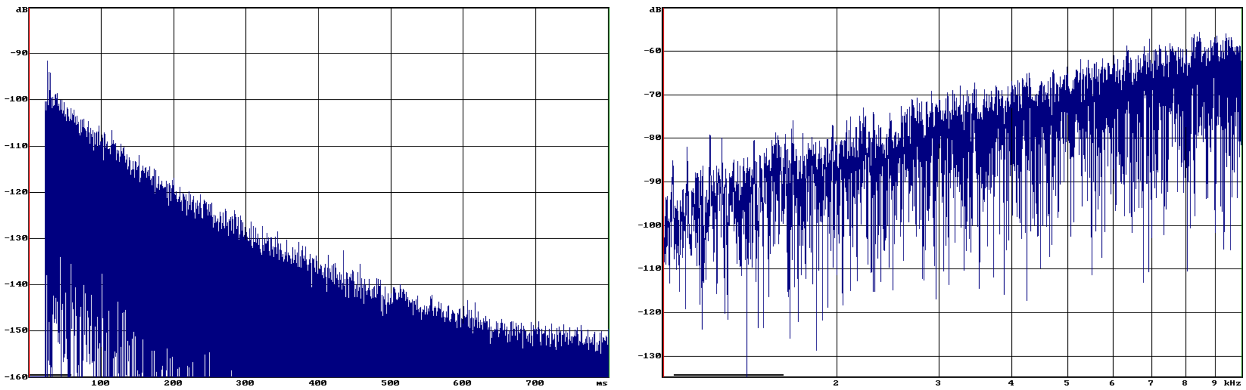

Figure 4: Impulse response (left) and the correspondent transfer-function (right) relative to the signal voltage at the electrical terminal of the receiver microphone after the shorter window function was applied.

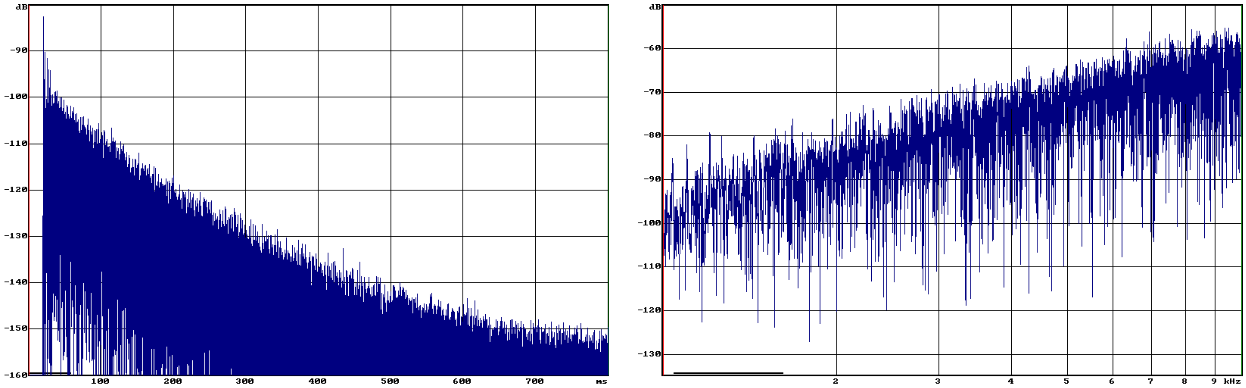

Figure 5: Impulse response (left) and the correspondent transfer-function (right) relative to the signal voltage at the electrical terminal of the receiver microphone after the larger window function was applied.

Figures 6 and 7 show the spatial and frequency averages of the electrical transfer impedance.

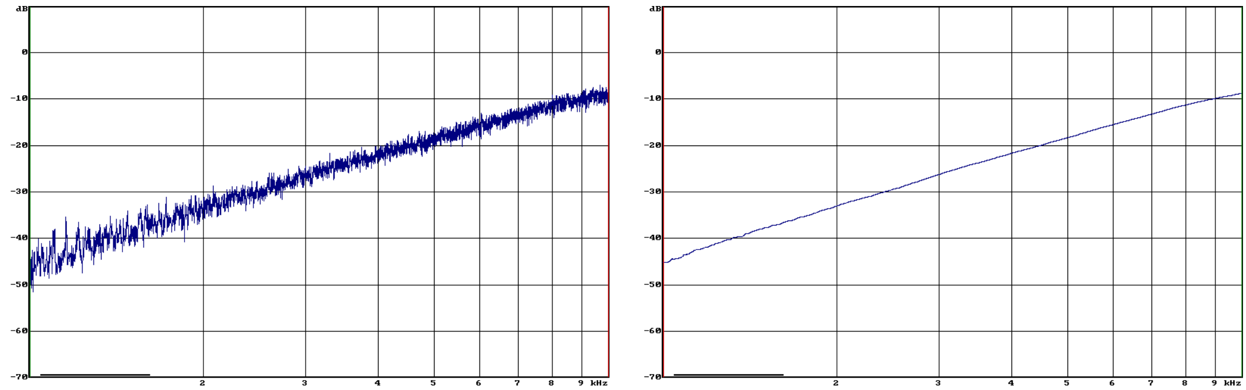

Figure 6: Spatial (left) and frequency (right) averages relative to the signal voltage at the electrical terminal of the receiver microphone after the shorter window function was applied.

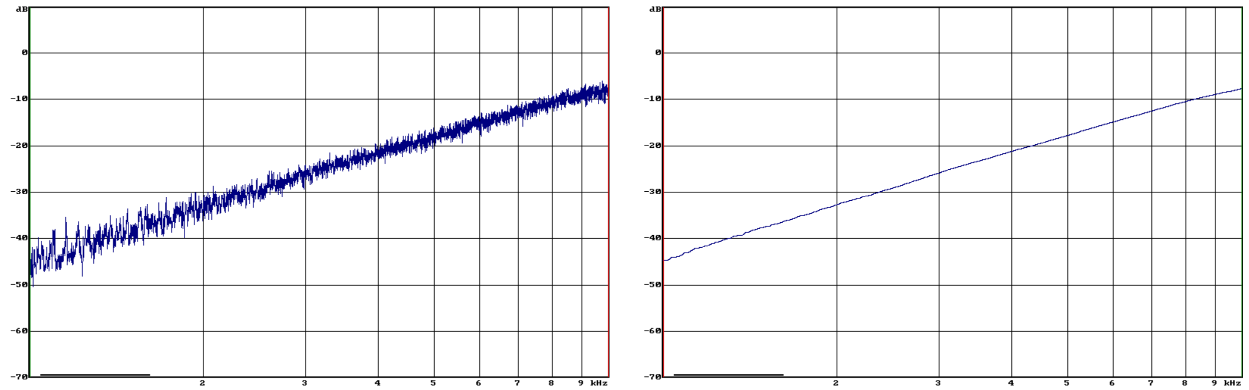

Figure 7: Spatial (left) and frequency (right) averages relative to the signal voltage at the electrical terminal of the receiver microphone after the larger window function was applied.

3.2.2 Acoustical transfer impedance

Figure 8 shows the chamber decay curves and reverberation time.

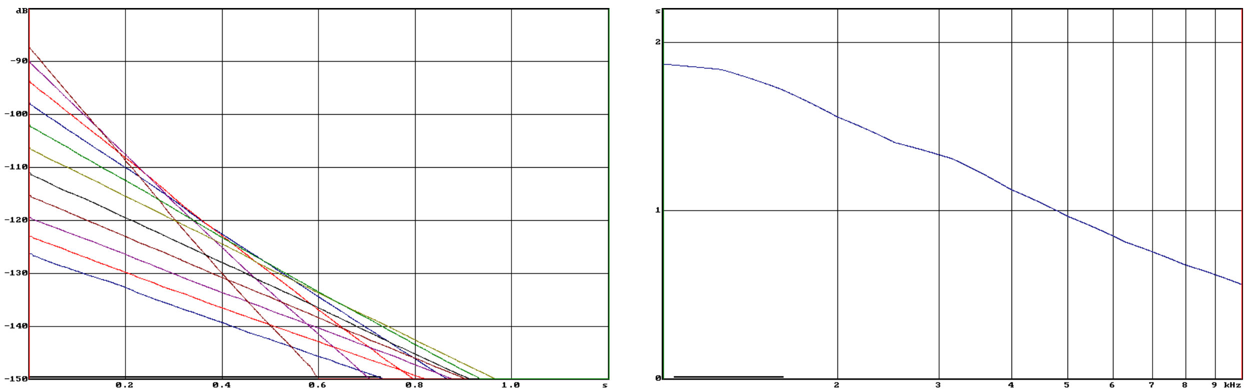

Figure 8: Decay curves (right) and the reverberation time (left) of the reverberation chamber.

3.2.3 Sensitivity

Figure 9 shows the sensitivity at measurement conditions (21.3-21.8 ^{o}C, 58.0-59.9%, 101.248-101.538 kPa) of one of the three microphones. The other microphones presented similar performance.

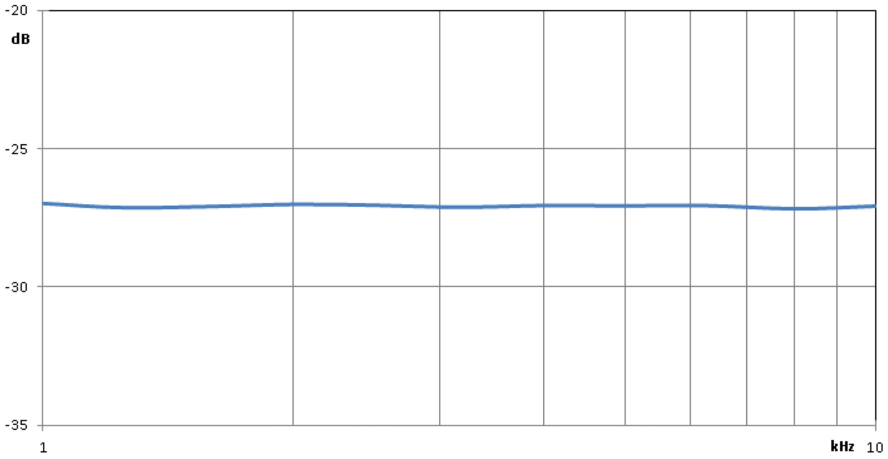

Figure 9: Microphone sensitivity at measurement conditions.

Figure 10 shows the difference between the sensitivity measured by reciprocity (using the proposed procedure) and the sensitivity measured by comparison with a reference microphone (calibrated in pressure field and corrected to diffuse-field by a correction factor according to IEC 61183 [14]).

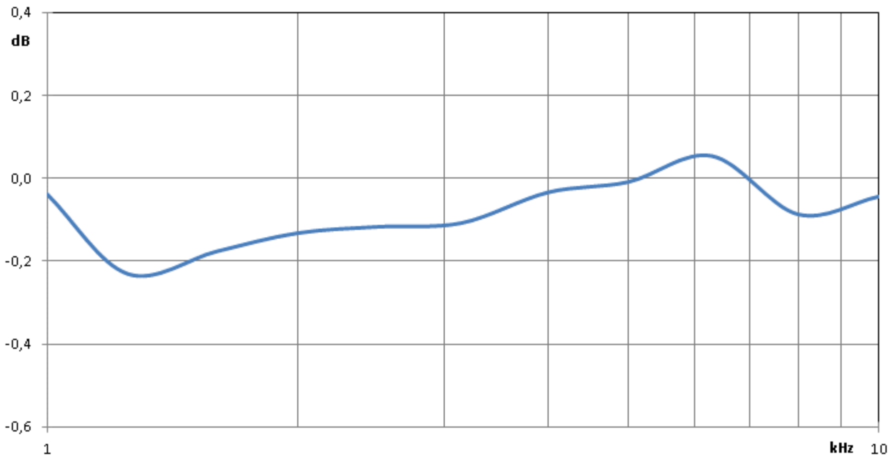

Figure 10: Difference between the sensitivity measured by reciprocity and the sensitivity measured by comparison with a reference microphone (calibrated in pressure field and corrected to diffuse-field according to IEC 61183).

The expanded uncertainties for the measurements were estimated as 0.20 dB for the calibration by reciprocity and as 0.3 dB for the calibration by comparison.

4 Conclusions

The difference between the sensitivity measured by reciprocity using the proposed procedure and the sensitivity measured by comparison with a reference microphone (calibrated in pressure field and corrected to diffuse-field according to IEC 61183) was found to be smaller than 0.25 dB. Since the expanded uncertainty for the reciprocity method is estimated as 0.20 dB and for the comparison method, as 0.3 dB one concludes that the results support the viability of the procedure because the difference and the uncertainties are of the same magnitude.

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