Calibration of measurement microphones

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1. OVERVIEW

For the metrological investigation of an acoustic system, a measurement microphone with a known transmission function is required. To calibrate the measurement results correctly, the frequency response and sensitivity of the measurement microphone must be known. However, the transmission function is often unknown or insufficiently specified, especially in the case of inexpensive measurement microphones. Therefore, a measurement procedure has been developed to determine the frequency response and sensitivity of measurement microphones. The determined transmission function is saved in an ASCII file that can be used with most common measurement systems to calibrate the measurement data recorded with the respective measurement microphone. The precision of the measured amplitude-frequency response is approximately 0.1 to 0.2 dB over the frequency range from 10 Hz to 20 kHz.

2. MEASUREMENT METHOD

The unknown transmission behavior of a microphone ("device under test", DUT) is determined by a comparison with a reference microphone (REF) with known transmission behavior. The frequency response and the sound level of a broadband loudspeaker is measured with both microphones, and from the difference between the DUT and REF measured values, the unknown DUT transfer function is determined from the difference between the DUT and REF measurements. The DUT and REF microphones are alternately positioned at a distance of 1 m in front of the loudspeaker. The microphones can be positioned either axially or perpendicular to the sound incidence from the loudspeaker to allow for deviations in the omnidirectional characteristic of the microphones.

However, in the frequency range below approximately 100 Hz, the signal-to-noise ratio of the free-field measurement described becomes large, resulting in significant uncertainty of the measurement results in the low-frequency range. Therefore the transfer function is supplemented by a measurement in a pressure chamber, which enables a precise measurement in the frequency range below approximately 400 Hz.

2.1 Material

- REF Microphone: Beyerdynamic MM1 (S/N 14308) with external calibration by an independent measurement laboratory (see section 3.2).
- Loudspeaker for free-field measurements: "Cheap Trick 154", developed by Bernd Timmermanns
- Pressure chamber for low-frequency measurements (see section 2.3)
- Digital measurement system: Mat's Audio Analyzer (MATAA http://audioroot.net/mataa)

2.2 Free-field measurement

The measurement procedure is as follows:

1. The REF microphone is positioned in front of the speaker.

2. The frequency response of the loudspeaker is measured with the REF microphone and calibrated with the transmission of the REF microphone.

3. The REF microphone is removed and the DUT microphone is positioned in front of the loudspeaker.

4. The frequency response of the loudspeaker is measured with the DUT microphone (without calibration).

5. The difference between the uncalibrated DUT frequency response and the calibrated REF frequency response is calculated. The result corresponds to the frequency response of the DUT microphone.

6. From the ratio of the uncalibrated DUT sound level and the calibrated REF the sensitivity of the DUT microphone at 1 kHz is determined.

7. The measurement results are displayed graphically and saved in an ASCII file as a table.

The sequence of steps 1-4 can be repeated several times to improve the data quality (see section 3.1). The transmission behavior of measurement microphones usually shows only a slight dependence on the direction of sound incidence (omnidirectional characteristic). Especially at high frequencies, systematic deviations of the omnidirectional characteristic can occur. To minimize the dependence of the direction of sound incidence, the frequency response of the loudspeaker is determined with a digital measuring system from the impulse response, which is freed from room echoes by applying a time window (steps 2 and 4). This ensures that only the direct sound from the direction of the loudspeaker is taken into consideration, and that sound coming from the side (room echoes, room modes) have no influence on the result (see also section 2.2.1).

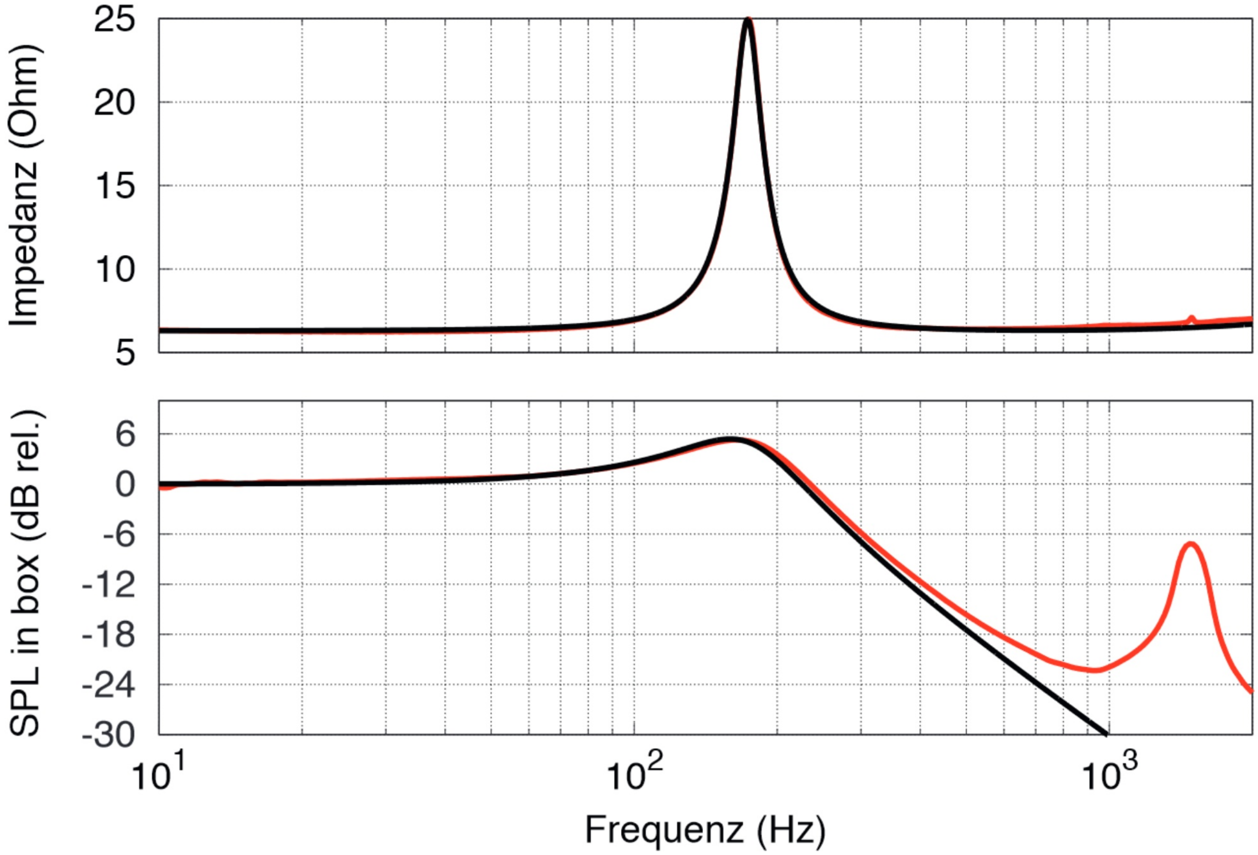


Figure 1: Impedance and sound pressure frequency response in the pressure chamber used (replica of the "ARTA pressure chamber", see text; Resonance frequency f0 = 173 Hz, resonance quality Qt = 1.79). Black: theoretically calculated curves, red: measured curves (the sound pressure level was measured with the calibrated REF microphone).

However, the time window method does not provide any data on the frequency response at low frequencies. The length of the reflection-free impulse response is limited by the time delay between the arrival of direct sound and the first room echo. Therefore, the application of the time window filters out all low-frequency signal components whose periods are longer than the time delay between the direct sound and the first room echo.

The lower cut-off frequency of the reflection-free frequency response is approximately 300 Hz. Sound waves with frequencies below 300 Hz have wavelengths of more than 1 m, which far exceeds the dimensions of the microphone capsule. The transfer function of measuring microphone at low frequencies is therefore independent of the angle of incidence of the sound at low frequencies. It is therefore not necessary to filter out the room echoes from the side. Therefore, in steps 2 and 4, the reflection-free frequency response uses the complete impulse response together with the room echoes at low frequencies.

2.2.1 Positioning the microphones.

The sound level in the vicinity of the microphone can vary spatially due to the directional effect of the loudspeaker and room modes, depending on the frequency of the signal. If the diaphragms of the DUT and REF microphones are not positioned at exactly the same location, the two microphones are exposed to slightly different sound fields. The resulting measurement uncertainties are, however, small (time window method, large wavelengths below 300 Hz). Nevertheless, care is taken to position the diaphragms of the DUT and REF microphones as closely as possible.

2.2.2 Signal-to-noise ratio.

Background noise can distort the measurements, which can affect the measurement precision particularly at low frequencies. The corresponding measurement uncertainties are minimized by the following measures:

- Background noise is minimized by eliminating or avoiding noise sources. Loud machines or devices are switched off whenever possible. In addition, the measurements are preferably conducted during the evening or at night to avoid background noise from traffic, sining birds and similar noise sources.

- A special sliding sine wave is used as the measurement signal which spends most of it’s time in the low-frequency range (longer than the widely used logarithmic sliding sine signals).

- The signal-to-noise ratio is optimized by averaging repeated measurements (see section 2.2.1).
and a sufficiently long duration of the test signal.

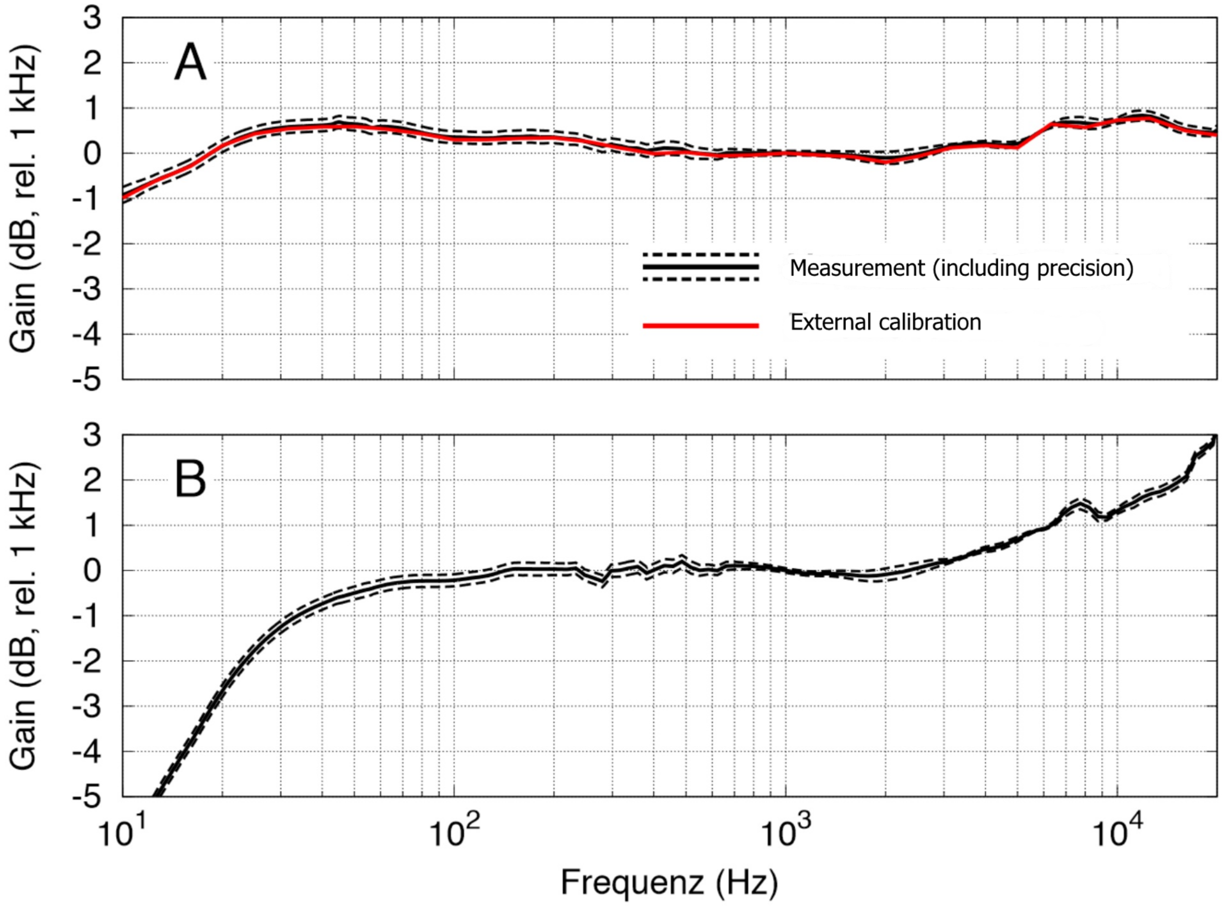
2.3 Pressure Chamber Measurement

The pressure chamber measurement used here follows the procedure described in "ARTA Application Note No 5" (http://www.artalabs.hr/support.htm). Figure 1 shows the electroacoustic behavior of the pressure chamber used. The measurements show that a standing wave with a frequency of approx. 1.4 kHz is formed in the pressure chamber. At lower frequencies, however, the measurements of impedance and sound pressure frequency response agree very well with the theoretically calculated behavior. The pressure chamber measurement therefore provides reliable results, which can be used to supplement the free-field measurement of the DUT transmission function below approx. 400 Hz.

3. MEASUREMENT UNCERTAINTY

In order to validate the measurement method presented, the transfer function of the REF microphone was measured using the described method and the result was compared with the calibration data of the REF microphone (Fig. 2-A). The good agreement of the measurement with the external calibration confirms that the measurement procedure delivers the correct result.

Figure 2: Result of the combination of free-field and pressure chamber



measurement. A: Comparison of the measured transfer function of the REF-microphone with the external calibration (to validate the measurement method). B: Example of a measurement of the unknown transfer function of a Behringer ECM-8000 microphone. The precision of the measurements is 0.14 dB (RMS value over the frequency range from 10 Hz to 20 kHz).

3.1 Precision of the Measurement Results

Precision describes how well repeated measurements of the of the DUT transfer function agree with each other. With the measurement procedure described, the precision is determined using the standard deviation of the individual REF and DUT measurements carried out several times for both the free-field and pressure chamber measurements. In addition, the data quality is improved by averaging of the multiple measurements.

The examples in Fig. 2 (A and B) show that the standard deviation of the individual measurements is approximately 0.1 to 0.2 dB. With N = 5 individual measurements, this corresponds to an uncertainty of the mean value of approximately 0.05 to 0.1 dB (factor $1/\sqrt{N-1}$).

3.2 Accuracy of the Measurement Results

The accuracy describes how close the measured transmission measured transfer function is to the actual ("correct") transfer function. With the measurement method described here, the accuracy is ultimately determined by how well the external calibration of the REF microphone matches the actual REF transfer function.

Calibration data for the REF microphone used here was provided by the manufacturer. Additionally, calibration data for the REF microphone used here was obtained by an independent measurement laboratory through a comparative measurement with a high-quality, calibrated measurement microphone (ACO Pacific 7052E). Furthermore, a comparative measurement of the REF microphone was conducted with another high-quality measurement microphone (calibrated Brüel+Kjær 1/2"-capsule type 4189 with Norsonic impedance converter type 1201). During this, the REF and Brüel+Kjær microphones were positioned side by side. Then, a test signal (pink noise) was recorded simultaneously with both microphones for about 10 seconds. The frequency response of the REF microphone was determined from the difference between the two recordings. However, at high frequencies, the two microphones influenced each other, and the speaker used did not exhibit homogeneous omnidirectional behavior at high frequencies. Both factors led to strong ripple in the REF frequency response above 2.5 kHz. Therefore, the comparative measurement is only considered in the range below this frequency.

A comparison of the various calibration data of the REF microphone (Fig. 3) shows that the manufacturer's specification does not match the calibration data of the independent measurement laboratory below 400 Hz and above 5 kHz. However, the comparative measurement with the Brüel+Kjær microphone agrees very well with the data of the independent measurement laboratory across the available frequency range (0.1 dB RMS deviation between 50 Hz and 2.5 kHz). Furthermore, the pressure chamber measurement, calibrated with the calibration data of the independent measurement laboratory, agrees very well with the theoretically expected frequency response below 500 Hz (Fig. 1). Therefore, the calibration of the independent measurement laboratory is used to calibrate the DUT measurements.

It cannot be ruled out that the REF transfer function may change over time due to microphone aging. To detect such changes, the transfer function of a second microphone, serving as a standard, is regularly measured. If changes in the measurement results of this standard microphone are noticeable, the REF microphone must be checked.

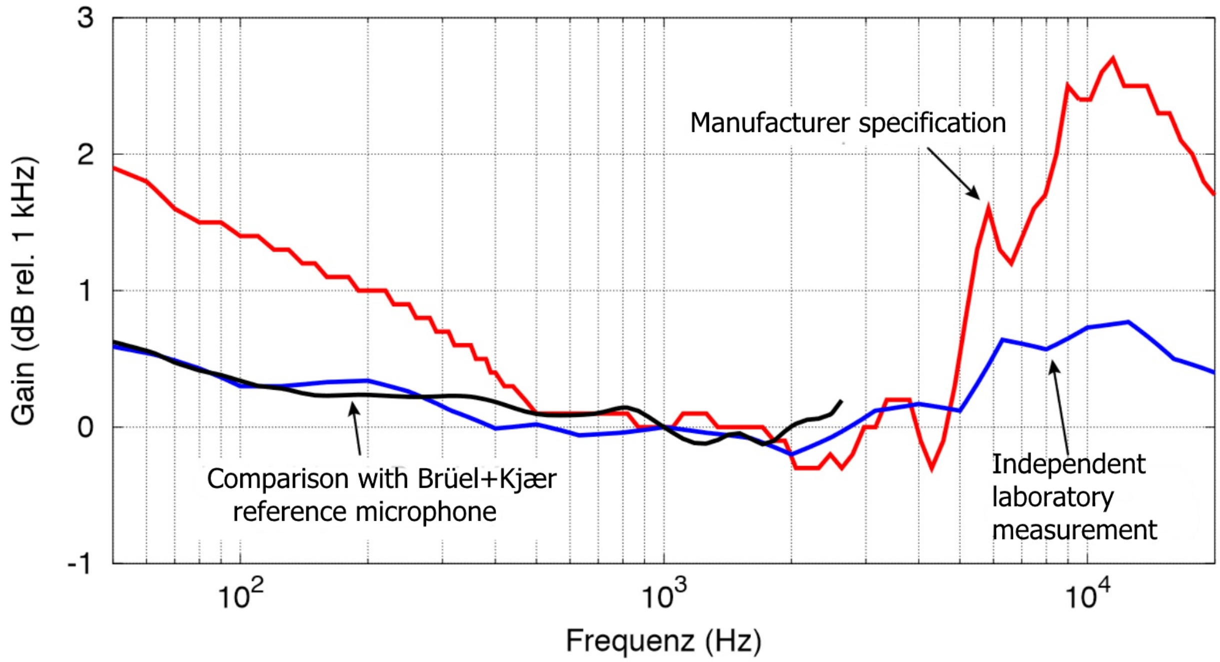


Figure 3: Comparison of different calibration data of the used REF microphone used (red: manufacturer's specifications; blue: measurement from independent laboratory; black: comparison measurement with Brüel+Kjær microphone, see text).

1I would like to thank Kurt Heutschi (Acoustics Department, Swiss Federal

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for his uncomplicated support with this measurement.

DOCUMENT VERSIONS

- September 2015: first version