DOI 10.5162/SMSI2025/A5.1

Low-Cost Acoustic Measurments by Calibration of Consumer Grade Hardware

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Summary: Multiple sensors with excellent linearity and high precision are often necessary to investigate acoustic problems (e.g., beamforming, impedance tube, spacial decomposition). This paper explores a flexible acoustic measurement system consisting of low-cost consumer-grade hardware. A MEMS capsule is paired to a P48-compatible pre-amplifier to form the microphone, which can then be used with off-the-shelf microphone amplifiers and converters available from the consumer or pro audio industry. Because the converters use widely available protocols like ASIO, CoreAudio, and others, an open-source Python module can be used to conduct the measurements. The acoustic measurement system is first calibrated and then evaluated at each stage to examine its performance and find its weaknesses to be explored by future research.

Keywords: Acoustics, Microphone, Low-Cost, Calibration, Measurement

Motivation

Acoustic measurements demand a precise and frequency-independent measurement chain, starting from the electro-acoustic transducer over several signal conditioning and amplification stages, to finally reach AD conversion. Due to the trend towards integration, the MEMS microphone was established as a low-cost and better performance alternative to the standard integrated FET capsules [1]. There were previous attempts to use MEMS capsules in high-precision measurement [2]. They still lag behind in frequency response and noise, but the gap is narrowing [3]. The steady consumerization trend has made high-quality converters and amplifiers widely available and affordable, especially in the consumer and pro audio industry. Of course, the low price has disadvantages like missing specifications, no user support for measurement purposes, and no specialized software.

The low-cost alternative

With the motivation of a decentralized hardware and software approach and the inclination toward open-source projects, this paper assesses a complete audio measurement chain using only cheap and widely available resources. The proposed framework consists of a MEMS microphone capsule, the Infineon IM73A135. The centerpiece of the proposed measurement chain is an in-house developed pre-amplifier, signal- and power-conditioner circuit [4], enabling the connection between the capsule output and the interface input with P48 power supply [5]. The RME Fireface UFX+ is used as a microphone amplifier, power supply, and converter, offering up to 24bit depth and 192kHz sample rate. Due to the use of widely available audio protocols like ASIO on Windows or CoreAudio on MacOS, the list of compatible software is extensive and includes many open-source options. The measurement software used in this paper is the ASMU Python package [6]. It is an audio framework for sound measurement and manipulation purely written in Python and offers great flexibility for simple measurement tasks. Due to the pure Python implementation, integration in post-processing code is nearly effortless. All measurements for this paper are conducted with the described setup.

Measurement and Results

Before the measurements, the audio interface inputs are calibrated. We use a sine generator ($1\,\mathrm{kHz}$, $1\,\mathrm{Vp}$) and connect it to the audio interface input. A high-precision multimeter (Keithley 2000) is used to measure the input voltage, and due to the grounding of the generator, a $50\,\Omega$ resistor provides pseudo balancing (Fig. 1a). This calibrated input is now used to calibrate the outputs of the interface (Fig. 1b) by again using a $1\,\mathrm{kHz}$ sinusoidal signal. A microphone calibrator (B&K Type 4231) is used to calibrate the acoustics by prescribing a known sound pressure to the capsule for the microphone connected, as shown in Fig. 1f. This is done for the low-cost microphone and a reference microphone (B&K Type 4190).

We first evaluate the linearity of the interface's outputs and inputs. Therefore, we create a loopback connection (Fig. 1c) called LOOP. The interface is used to excite a pink noise signal while simultaneously recording it. Fig. 2 shows the latency-adjusted voltage transfer function of the

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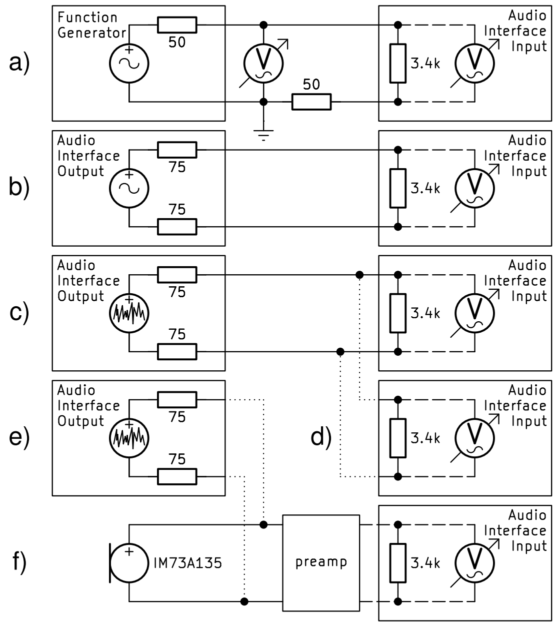

Fig. 1: Connection for input (a) and output (b) calibration. Measurement setups for loopback (c), channel mismatch (d), pre-amplifier (e), and acoustic measurements (f).

ideal and recorded signal. Additionally, we compute the input mismatch by comparing two inputs connected in parallel (Fig 1d). The $0.6\,\mathrm{dB}$ offset is explained by the active balancing circuit inside the interface, which exhibits different gains for balanced and unbalanced connections and by the changed generator impedance. Besides that the results show a frequency response from $6.3\,\mathrm{Hz}$ to $63\,\mathrm{kHz}$ within $0.5\,\mathrm{dB}$ deviation.

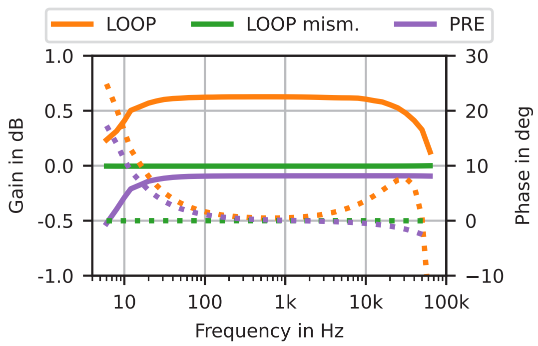

Fig. 2: Voltage frequency responses for the loopback (LOOP), channel mismatch (LOOP mism.), and pre-amplifier (PRE) measurements.

The pre-amplifier (PRE) is tested by inserting it into the discussed loopback connection (Fig. 1e) and again computing the voltage transfer function. The results in Fig. 2 show excellent linearity over the entire frequency range, with an expected highpass behavior due to internal coupling capacitors. The two microphones (low-cost and reference B&K) are placed membrane to membrane in an anechoic chamber, with a broadband speaker at $1\,\mathrm{m}$ distance. The speaker is calibrated (through the reference microphone) to excite a pink noise signal at $94\,\mathrm{dB}$. We finally compute the pressure transfer function between the two microphones and plot them over the frequency in Fig. 3. The results are characterized by a low-frequency drop and a significant rise in gain above $10\,\mathrm{kHz}$. The MEMS capsule frequency characteristics cause this behavior, which closely corresponds with the datasheet.

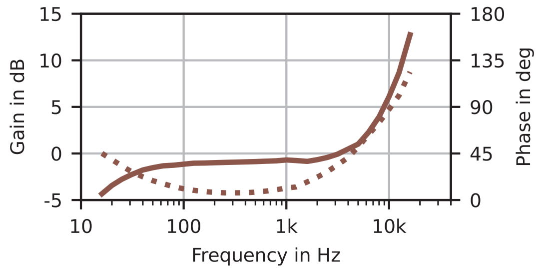

Fig. 3: Acoustic pressure frequency response between the low-cost MEMS microphone and the reference B&K Type 4190 microphone.

Summary and Outlook

The tested system shows outstanding electrical performance over a wide frequency range. Deploying the developed microphone for measurements below $10\,\mathrm{kHz}$ seems feasible. To overcome this limitation, the setup can be readily modified to accommodate newer, more linear MEMS capsules.

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