Measurements of analog MEMS microphones

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***Abstract*—This paper presents acoustical and electrical measurements of analog output MEMS microphones. Microphones were measured using the simultaneous comparison method with a class 1 reference microphone. Measured parameters included sensitivity, frequency response, dynamic range, linearity and directivity. The results showed that measured MEMS microphones are suitable for use in microphone arrays and general use as acoustic sensors, but certain limitations should be taken into account.**

***Index Terms*—MEMS microphone, measurements, sensitivity, dynamic range, frequency response, linearity.**

I. Introduction

In recent years MEMS (micro electro-mechanical systems) microphones have become an important part of modern electronics. This type of microphones are small acoustic sensors, which are produced on silicon wafers using similar processes used for production of semiconductor integrated circuits. They are installed in all devices where small size, relatively good sound quality, reliability and small prices are key requirements, like smartphones, tablets and cameras. Due to their small size and relatively low costs, they are increasingly used for design of acoustic cameras, smartphones and microphone arrays [1]. These arrays usually involve relatively large number of microphones, which have to fulfil certain acoustic and electrical requirements, like higher sensitivity, dynamic range and low noise floor. Also, these microphones are increasingly used for measurement purposes, for example for urban environmental noise using networked devices, like smartphones [2]. Some research showed that in combination with smartphones, they in some cases can replace professional acoustic measuring devices [3].

Recently, new MEMS microphone models became available, with specifications which could be compared to not so affordable class of measuring microphones. Their specifications claim dynamic range larger than 100 dB, and noise floor below 10 µV [4]. We decided to test one MEMS microphone with analog output, in order to determine its suitability for installation in microphone arrays, and if their acoustical and electrical characteristics are consistent with manufacturers' specifications.

A. Operational principle of MEMS microphones

In general, microphones transform an acoustic signal in an electrical signal. In case of MEMS microphones, an acoustic signal is fed to a movable membrane through an acoustic port and fixed perforated membrane. The fixed and movable membranes make a condenser with changeable capacity. These changes are transformed in an electrical signal using integrated electronics. This integrated electronic circuit is also used for adapting the output signal to different loads. Basic schematics of a MEMS microphone is given in Figure 1.

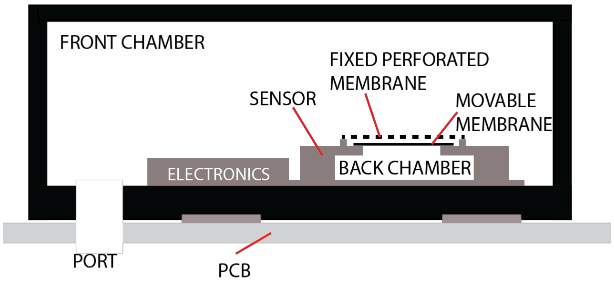

Figure 1. Schematics of a MEMS microphone

Depending on the electrical signal's nature, there are two basic types of MEMS microphones, with analog and digital output signals. The type of output signal also influences on the microphone's dimensions. Due to smaller electronics part, the analog output MEMS microphones tend to be smaller. Their output can be directly connected to an audio preamplifier, while output of digital output MEMS microphones requires additional circuitry.

Both types of MEMS microphones require external power supply, which could influence their electrical characteristics. Power supply should be stable and noise free, which could be easily achieved with a battery supply. Power consumption of MEMS microphones is very small, which also favors use of a battery.

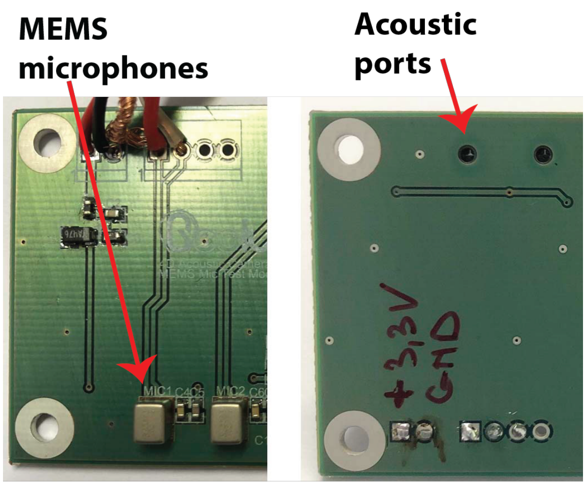

Figure 2. PCB with analog and digital output MEMS microphones

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In this paper we measured an analog output MEMS microphone. The microphone is selected according to its relatively good acoustic and electrical specifications, namely dynamic range. Figure 2 shows PCB with soldered two analog output MEMS microphones, which were used for measurements.

II. Measurements and results

A. *Measured parameters and setup*

For measurements of MEMS microphones, we used the simultaneous comparison method [5]. This method includes a calibrated microphone, which is used as a reference microphone. This microphone is placed next to the tested microphone and their outputs are than compared. All measurements are performed in a free field conditions of an anechoic chamber. Microphones were placed in front of a loudspeaker at distance of 1 m, along the central axis of the loudspeaker. At first, we measured frequency response of the loudspeaker using the reference microphone. The measured frequency response was inverted using the response at 1 kHz as reference point. The corrected EQ curve was used for the signal source in order to obtain equal loudspeaker's response at all frequencies.

Balanced output of the MEMS microphone and analog output of the B&K Type 2250 Analyzer were connected to an analog input of the Audio Precision AP2700 audio analyzer. The type 2250 analyzer included a class 1 ½" microphone capsule. Schematics of the measurement setup is given in Figure 3.

Five parameters were measured and compared to a reference microphone; sensitivity, frequency response, dynamic range, linearity and directivity.

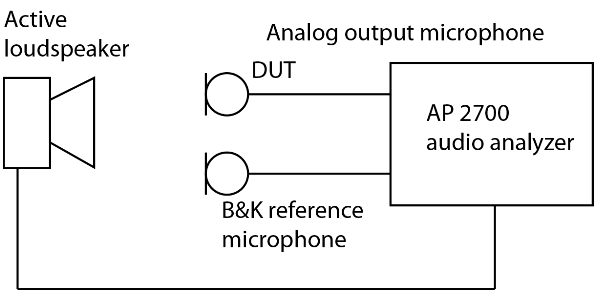

Figure 3. Schematics of the measurement setup for the analog output microphone

B. *Sensitivity and frequency response measurements*

The microphone sensitivity is a parameter which shows a ratio between output signal's level and sound pressure change in front of the microphone. In case of an analog microphone sensitivity it is measured in mV/Pa.

The frequency response of a microphone shows how its sensitivity depends on frequency. The high and low limit frequencies correspond to frequencies where frequency response falls 3 dB below the response at reference frequency of 1 kHz. The frequency response of a MEMS microphone can be roughly divided in three frequency bands. At low frequencies, the response is determined by the acoustic resistance of the acoustic port through the microphone element and capacitance of the back chamber. This translates in a high pass filter whose limit frequency depends on dimensions of the MEMS microphone. In the medium frequency band, the frequency response is flat, and sensitivity of a microphone is specified at 1 kHz. Resonance of the microphone's enclosure occurs at higher frequencies, where the resonance frequency is determined by the volume of the front chamber and length of the acoustics path through the port. The thickness of the PCB and distance of the acoustic port to the PCB could influence the resonance frequency. If this thickness and distance are kept relatively small, the resonance frequency will be at higher frequencies, above 15 kHz. Equation (1) represents the Helmholz resonator formula

$$f_{res} = \frac{c}{2\pi}\sqrt{\frac{A}{V \cdot L_{eq}}} \tag{1}$$

where c is speed of sound, A cross-section of the acoustic port, V volume of the enclosure and L_{eq} equivalent length of the acoustic port. In our case, thickness of the PCB board was 1 mm, which corresponds to the equivalent length. Effective volume of the MEMS microphone enclosure was around 40 mm^3 and cross-section of the port was around 3.14 mm^2. From this data and using the Helmolz resonator equation (1), we can calculate theoretical resonance frequency of the used MEMS microphone which is around 15 kHz.

At first, we set up the sound pressure level at 1 m in front of the loudspeaker at 94 dB at frequency of 1 kHz. The sound pressure level was detected with B&K analyzer. The level of 94 dB corresponds to the acoustic sound pressure level of 1 Pa. The frequency response of the sound source was corrected in order to obtain constant level at all considered frequencies and the signal level of the reference microphone at 1 kHz was taken as the reference level. The level at all other frequencies was compared to the reference level, and as such was plotted in Figure 4. Normalized response of 0 dB corresponds to sound pressure level of 94 dB, which was equal in the entire considered frequency range. As can be seen from Figure 4, frequency response of the analog output MEMS microphone has relatively flat response to about 2 kHz. After that its sensitivity starts to increase. This could be attributed to the resonance frequency of the microphone, which depends on enclosure dimensions and type of installation on the PCB. The frequency response corresponds to manufacturer's specifications and the measured sensitivity of the analog output MEMS microphone at 1 kHz was 30 mV/Pa, which is around 5 dB below the reference microphone in the frequency range up to 2 kHz.

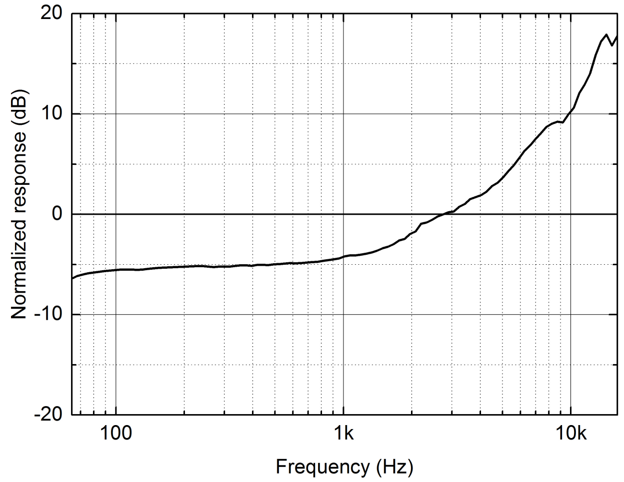

Figure 4. Output signal of the analog output MEMS microphone plotted versus frequency at sound source level of 94 dB in the entire frequency range (0 dB reference).

C. Dynamic range

An important parameter for microphones installed in microphone arrays is the dynamic range. Dynamic range is difference between the maximum and minimum output signal, which respectively correspond to maximum and minimum detectable sound pressure level. Connected to the dynamic range is the noise floor value, which is in some applications more important than dynamic range. The noise floor determines the lowest possible detectable sound pressure level, which directly influences on the range and sensitivity of a microphone array. Figure 5 shows FFT measurements of the broadband noise of the analog output MEMS microphone. The relatively larger value at low frequencies below 1 kHz can be attributed to increased noise and vibrations at low frequencies in the anechoic chamber. This value could not be decreased even when we covered and insulated the microphone. At higher frequencies noise level is around -120 dBV, which represents very low value. If we consider maximum output signal level of around -3 dBV, at higher frequencies this enables signal dynamics over 100 dB, which corresponds to manufacturer's specifications.

In order to get more detailed information about dynamic range, we measured the microphones' transfer characteristics, which shows how the microphone's output signal depends on sound pressure level in front of its membrane. Because sensitivity of the microphone largely depends on frequency, especially at higher frequencies, we measured the transfer characteristics at few frequencies. Figure 6 shows transfer characteristics of the analog output MEMS microphone at four frequencies. As can be seen, maximum measured value of the sound pressure level is around 120 dB, when output signal's level was, depending on frequency, between -3 and –10 dBV. These characteristics also show large dynamic range of over 100 dB, depending on frequency.

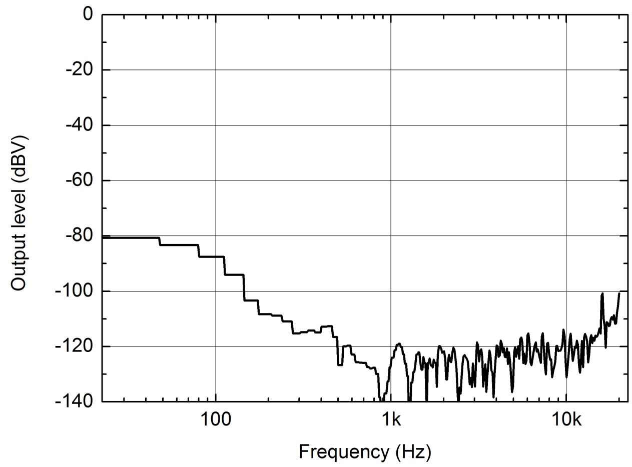

Figure 5. FFT of the broadband noise of the analog output MEMS microphone

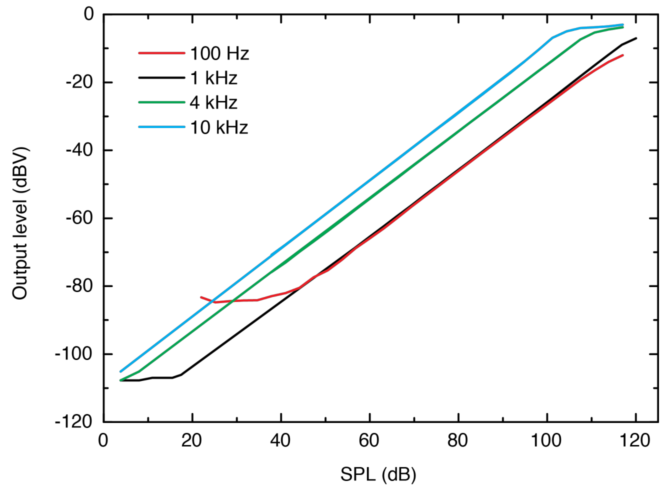

Figure 6. Transfer characteristics of the analog output MEMS microphone measured with 1 kHz signal.

D. Total harmonic distortion

Linear response is important in terms of recording quality and proper processing of the output signal. The signal should be free from unwanted harmonics and noises. The parameter used to measure linearity of the response is total harmonic distortion factor (THD). This factor represents a ratio between level of harmonics and level of the complete signal. Specifications sometimes give the THD+N factor, which, together with harmonics also includes the level of broadband noise.

In order to ensure proper measurements of the distortion components it is necessary to ensure sound source with small distortions level. Full band loudspeakers are not suitable for this task, because THD factor in their case usually exceeds 0.5% even for small reproduction levels. Therefore, we used a calibrated sound source. The disadvantage of this sound source is that emits sound only on one frequency, namely 1 kHz. Measured THD+N ratio of the analog output microphone at SPL of 94 dB at frequency of 1 kHz was 0.4 %.

E. *Directivity pattern*

Directivity pattern shows how sensitivity of a microphone depends on angle of incidence of the incoming acoustic signal. MEMS microphones are designed as pressure microphones, which according to the acoustic theory should have an omnidirectional characteristic. However, this is valid only in certain frequency range. The directivity pattern is important for calculation of a microphone array gain.

Directivity pattern was measured in the entire frequency range and was represented as frequency response at five angles of incidence, 0°, 45°, 90°, 135° and 180°. Position of 0° angle of incidence is the position of the microphone where the acoustic port is directed to the sound source. The sound pressure level at all frequencies was kept at 94 dB. Figure 7 shows frequency responses of the analog output microphone for five angles of incidence. As can be seen, sensitivity at higher frequencies for higher angles starts to fall with maximum difference to 0° angle of incidence of about 5 dB. This was expected, since shape and dimensions of the PCB influence of the frequency response at higher frequencies.

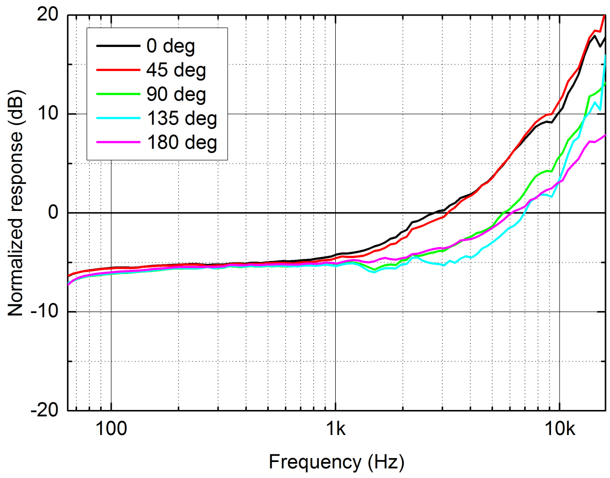

Figure 7. Measured frequency responses for five angles of incidence for the analog output MEMS microphone

III. CONCLUSION

Acoustic and electrical characteristics of analog output MEMS microphones were measured. These characteristics included sensitivity and frequency response, dynamic range, distortion and directivity pattern. Microphones were measured using the simultaneous comparison method with a calibrated reference microphone.

Measurements showed that these MEMS microphones in general correspond to manufacturers' specifications. They sensitivity is relatively high but significantly depends on frequency, especially in the higher frequency range. Therefore, in order to be used for measurements and in microphone arrays, this frequency response should be taken into account. Also, care must be taken when placing microphones on the PCB in order to avoid influence of the PCB's shape and dimensions on microphone's performance.

Relatively large dynamic range of over 90 dB in broad frequency range, makes them suitable for microphone arrays, when large array's gain is requested. The care should be taken to the design of the PCB in order to keep unwanted noises at minimum.

In order to additionally test their suitability for outdoor installed microphone arrays and acoustic sensors, further research and analyses shall include measurement of these MEMS microphones in various environmental conditions, and how they perform in more extreme environments.

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REFERENCES

[1] R. Barham, "New paradigm for environmental noise measurement," Proc. Inst. Acoust. 36(3), 266–268, 2014.

[2] S. Grubeša, A. Petošić, M. Suhanek, I. Đurek, "Mobile crowdsensing accuracy for noise mapping in smart cities", Automatika, 59, 3; pp. 287-294, December 2018.

[3] C. A. Kardous and P. B. Shaw, "Evaluation of smartphone sound measurement applications," J. Acoust. Soc. Am. 135(4), EL186–EL192, 2014.

[4] Ultra-Low Noise Microphone with Differential Output – ICS-40730, Document number: DS-000139, InvenSense, 2016, https://www.invensense.com/products/analog/ics-40730/

[5] Standard IEC 60268-4:2014, IEC 2014

[6] Application Note AN-1112, Microphone Specifications Explained, InvenSense, 2016, https://www.invensense.com/download-pdf/an-1112-microphone-specifications-explained/