Comparison of New and Fast-Aged MEMS Microphones

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***Abstract* - MEMS microphones are increasingly used in systems exposed to open atmospheres. Therefore, it is important to test the durability of these microphones. Two groups of microphones were used, one with a fast-aging process in a controlled environment chamber and by leaving microphones exposed to the outside environment of a busy street. Their basic acoustic characteristics, especially sensitivity, were compared to new microphones. It was found that treated microphones show negligible loss of sensitivity relative to new microphones, proving their suitability for use in open, non-controlled atmospheres.**

Index terms - MEMS microphones, durability, controlled environment, acoustic properties

I. INTRODUCTION

MEMS (Micro Electro-Mechanical Systems) microphones are increasingly used in applications different from modern portable electronics. Those other applications include more challenging conditions for an electronic acoustic device, like acoustic cameras in open atmospheres, outside monitoring systems, and so on [1, 2]. On the other hand, these microphones are used for monitoring urban environmental noise using networked devices, like smartphones [3, 4]. Therefore, their applications are also transferred to cases where they are for short or longer time exposed to open air or harsher environments.

These types of microphones are relatively small acoustic sensors, which are produced using similar processes used for the production of semiconductor integrated circuits [5, 6, 7]. Integrated circuits, as such, are tested for operation and storage in broad temperature ranges, but usually, they are enclosed in some type of enclosure; that is, they are rarely directly exposed to open atmospheres. Along with electronic parts, MEMS microphones have tiny and gentle mechanical parts, which for a microphone to operate, must be exposed to open atmospheres.

In our previous papers [8, 9], we measured MEMS microphones with analog and digital outputs and found they are suitable to be used for most applications, but one question was left unanswered. Since MEMS microphones are increasingly used in applications where they are exposed to open atmospheres, the question has arisen of how well they perform after been exposed to harsh environments for a longer time. This is a very important question if these devices are to be used in systems that are permanently installed for monitoring purposes. For example, they can be used for monitoring urban noise, surveillance [10], and similar applications. For good measurement precision, it is essential to know how their most important parameters change with time. This could enable proper calibration after a certain period and correction of measurement results.

In this paper, we measured and evaluated 12 digital MEMS microphones from the same producer and the same batch. The four microphones were left untouched, and we referred to them as original, not treated microphones. Another group of four microphones was exposed to an urban atmosphere for a certain time. The last group of four microphones was placed in a controlled environment chamber and exposed to certain cycles of changing climate conditions. Primarily we tested their sensitivity and transfer characteristics, and we found out that there was a slight decrease in sensitivity compared to original, not treated microphones.

II. OPERATIONAL PRINCIPLE OF MEMS MICROPHONES

MEMS microphones are very fine mechanical transducers produced with the similar principle as in the case of integrated circuits. Mainly, MEMS microphones are produced using so-called silicon micromachining [5, 6, 7]. This enables integrating the acoustical and electronic parts of the microphones.

One way of producing MEMS microphones with bulk silicon micromachining is by manufacturing a stopping layer on the front side of a silicon chip and etching down the necessary parts [5]. Then, this layer becomes a flexible membrane that moves with a corresponding change of the incoming sound pressure. In one case, the movement of the membrane can be detected by strain sensors. On the other hand, a moving membrane can be considered as one plate of a condenser, and movement is sensed by detecting the changes of capacitance, like in a conventional condenser microphone. Complete mechanical parts and electronics are placed in a small enclosure with an acoustic port, as shown in Figure 1. The enclosure is basically an SMD device, which can be soldered on a PCB, which must include a small hole to enable sound waves to come to the micromachined membrane. A complete system is an acoustic device with its frequency response, sensitivity, and resonant frequency. The physical dimensions of the system determine the resonant frequency and usually it is above the frequencies heard by the human ear.

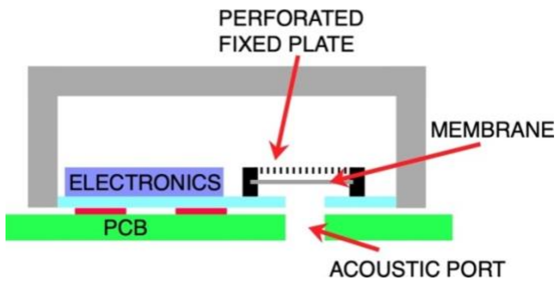

Figure 1. Schematics of a MEMS microphone

Figure 2 shows a used MEMS microphone soldered on a PCB. There is an acoustic port on the back side, which enables the passing of sound waves to the microphone's membrane. Cross-section and length of the acoustic port, together with the enclosure volume, determine the resonant frequency of the acoustic system, which is usually above 15 kHz.

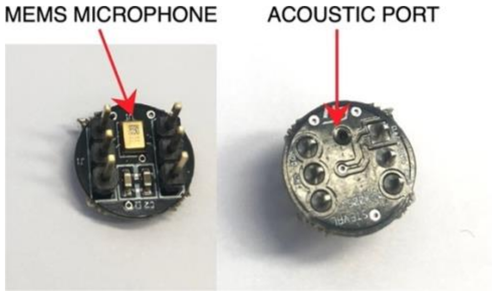

Figure 2. PCB with used MEMS microphone (upper side) and acoustic port (bottom side)

The principle of operation is based on a typical condenser microphone. Very thin, usually polysilicon membrane, is spanned over the back cavity with controlled tensile stress. The perforated fixed backplate is constructed from a composite highly tensile silicon with enough rigidity to act as a reference electrode.

The diameter and density of holes in the perforated fixed plate are essential for determining the noise level of the microphone. The system's sensitivity is determined by membrane compliance and encapsulated air volume. Reduction of the back enclosure volume can reduce the microphone's sensitivity.

The open-circuit sensitivity of a condenser microphone consists of two components, mechanical sensitivity S_m and electrical sensitivity S_e. [7] The mechanical sensitivity is defined as a ratio between the membrane's displacement *x* and sound pressure *p*, as

$$S_m = \frac{dx}{dp} . \quad (1)$$

If the microphone includes a circular membrane with large tensile stress, for a large vibration amplitude span, we can assume it moves as a rigid piston, and mechanical sensitivity is equal to

$$S_m = \frac{r^2}{8\sigma d} , \quad (2)$$

where r is membrane's radius, σ membrane's tensile stress, and d membrane's thickness. Equation (2) does not include compression coming from the air in the enclosure, which must be included for larger vibration amplitudes of the membrane. For the moment, it is important to point out that the sensitivity depends on the membrane's thickness and its dimensions.

The electrical sensitivity can be defined as a ratio between the bias voltage across and thickness of the air gap between fixed and moving membrane [5,7], as in

$$S_e = \frac{V_g}{d_g} . \quad (3)$$

Taking into account equations (2) and (3), the open circuit microphone's output signal can be defined as

$$u_{out} = S_m S_e p . \quad (4)$$

Materials used for manufacturing of membranes are various [11], but mainly are based on silicon (average tensile strength is 100 MPa). Average surface of the membrane is around 1 mm2, membrane thickness is around 1 µm and air gap thickness is around 4 µm. In our case applied bias voltage was 3 V. Putting this data in equation (4) for sound pressure level of 1 Pa (SPL of 84 dB) gives output voltage around 1 mV. The selection of the membrane material is very important and small changes in mechanical parameters would give different output voltage.

There are two basic types of MEMS microphones considering the electrical signal's nature, i.e., with analog and digital output signals, Due to the smaller electronics part, the analog output MEMS microphones tend to be smaller, and their output can be directly connected to an audio preamplifier. In contrast, the digital output of MEMS microphones requires additional circuitry. In our research, we used MEMS microphones with the digital output, but since the mechanical parts are very similar, all conclusions in this paper can also be applied to the analog output MEMS microphones.

III. CONDITIONING OF THE MICROPHONES

For comparison, we divided microphones into three groups. The first group consisted of four microphones, which were not placed in a controlled environment chamber nor left outside for a certain period of time. This group was titled as original, not treated microphones, and the other two groups of microphones were compared to these microphones. The second group consisted of four microphones exposed to an open atmosphere of a busy city street. These four microphones were left outside for two months on a balcony approximately 15 meters above a street with very dense traffic, which means these microphones were mainly exposed to traffic pollution and general city pollutants. Average daily temperature changes were from 10°C to 25°C, with an average relative humidity of 50%. After two months, these microphones were measured and compared to the original microphones.

The third group consisted of four microphones placed in a controlled environment ACS Compact Climatic chamber. The microphones were exposed to cycles of defined controlled environment. For this purpose, we used processes described in standard EN 61672-1:2013 [12] to test the most precise electro-acoustical devices. Table 1 shows one set of programmed cycles of the controlled environment chamber. This set of cycles is then repeated five more times. After all cycles, these microphones were also measured and compared to the original not treated microphones.

Number of microphones in each group is low (4) and strictly speaking is not statistically significant. Our goal was not to compare the microphones with manufacturer's data, but to compare three different groups of microphones, which were manufactured from the same batch.

Table 1. Programming the conditions in the controlled environment chamber. One set of cycles.

Cycle	Temperature	Rel. humidity
1	-10°C to +40°C, 1 °C/minute	30%
2	+40°C to -10°C, 1 °C/minute	30%
3	-10°C to +10°C, 1 °C/minute	30%
4	Constant temperature +10°C, 1 hour	50%
5	-10°C to +40°C, 1 °C/minute	50%
6	+40°C to -10°C, 1 °C/minute	50%
7	Constant temperature +10°C, 1 hour	70%
8	-10°C to +40°C, 1 °C/minute	70%
9	+40°C to -10°C, 1 °C/minute	70%
10	Constant temperature +25°C, 1 hour	30%

IV. MEASUREMENT SETUP AND RESULTS

The simultaneous comparison method [13] was used for measurements of the MEMS microphone. This method prescribes using a calibrated microphone as the reference measuring device. The reference microphone is placed next to the tested microphones, and their outputs are then compared. All measurements were performed in a free field condition of an anechoic chamber at the Department of electroacoustics at the Faculty of EE and Computing in Zagreb. All microphones were placed in front of an active loudspeaker at distance of 1 m, along the central axis of the loudspeaker. The output signal from microphones were fed to the Audio Precision System Two measuring device. Schematic of the measurement setup is given in Figure 3.

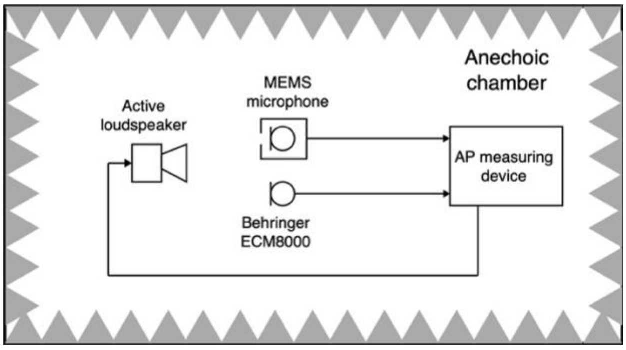

Figure 3. Schematics of the measurement setup

We measured how the microphone's sensitivity depends on frequency and sound pressure level (SPL). The microphone sensitivity is a parameter that shows how the output signal's level depends on the sound pressure level in front of a microphone.

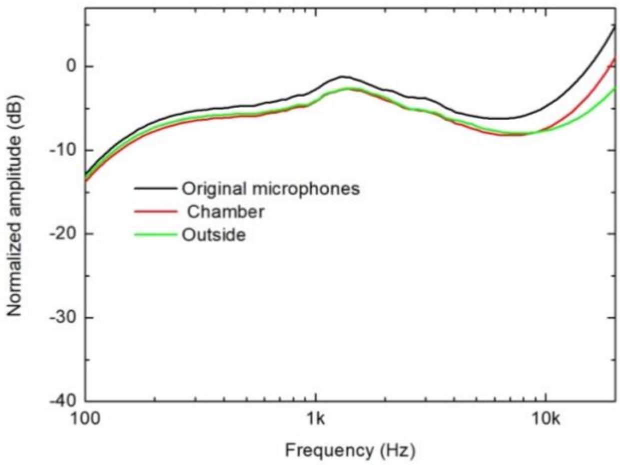

Figure 4. Normalized sensitivity versus frequency. Reference pressure level 94 dB (1 Pa).

First, we set up the sound pressure level at 1 m in front of the active 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 sound source's frequency response was corrected in relation to the signal level of the reference microphone at 1 kHz to obtain constant sound pressure level at other measuring frequencies from 100 Hz to 20 kHz. This means that signal level fed in the active loudspeaker was corrected to the frequency response of the active loudspeaker, measured with the reference microphone. The frequency response was simply inverted, and input signal level was corrected to this inverted frequency response with reference signal at frequency of 1 kHz.

Figure 4 shows the sensitivity measurements versus frequency for three groups of microphones. The shown curves represent average results of four microphones from each group. As can be seen, the frequency response for all three groups of microphones is similar. It is relatively flat for low frequencies and increases at higher frequencies. Compared to the not treated, original microphones, microphones left outside, and microphones treated in the controlled environment chamber, have slightly lower sensitivity, with a higher difference for frequencies above 10 kHz. Value of 0 dB corresponds to the output signal of the reference microphone Behringer ECM8000 at 94 dB sound pressure level.

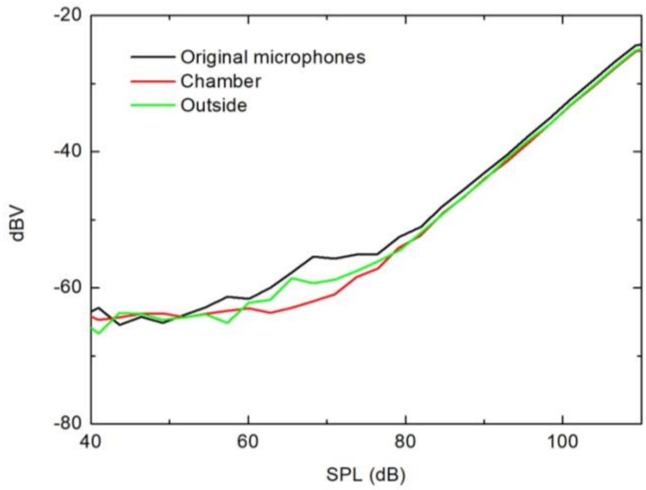

Figure 5. Transfer function at 1 kHz.

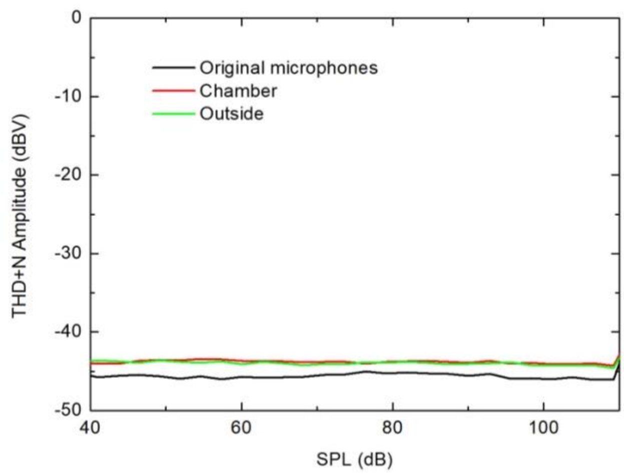

Figure 6. Amplitude of harmonic components versus sound pressure level at 1 kHz.

The second setup refers to the measurement of output signal versus sound pressure level with the signal frequency of 1 kHz. The results are shown in Figure 5. As with the previous measurement, microphones from the second and third groups show slightly lower sensitivity, but the linearity of the transfer function is not significantly changed. Noise level remains the same, around -65 dBV, which ensures a usable dynamic range of 40 dB. It is important to note that the reference value of 0 dBV corresponds to the maximum microphones' dynamic range, which is determined by the supply votage. In any case, since we were interested in comparing the three groups of microphones, the absolute values were not considered.

The third step was to measure harmonic components amplitude versus sound pressure level with signal frequency of 1 kHz. Instead of measuring the Total Harmonic Distortion (THD) factor, we measured only amplitudes of harmonic components and noise. This measurement better shows how distortions behave, especially at lower signal amplitudes. As shown in Figure 6, the level of distortions components and noise is constant in the full range of the input sound pressure level, but microphones from the second and third groups show slightly higher distortion levels than original, not treated microphones.

V. CONCLUSION

Two groups of four MEMS microphones were subjected to different operating atmospheres and then measured and compared to original, not treated microphones. One group was for two months subjected to an open-air atmosphere of a busy street. The other group was placed in a controlled environment chamber and subjected to various temperature and humidity cycles to simulate a fast-aging process.

Measurements of microphone's sensitivity versus signal frequency and sound pressure level showed a slight sensitivity decrease of a few dB compared to the original, not treated MEMS microphones. The shape of the frequency response and transfer characteristics was not significantly changed.

The measurement of the distortion components' level showed a slight increase in distortion level in case of treated microphones.

These results could be attributed to changes in mechanical parts of the MEMS microphone system. The temperature and humidity changes influenced the membrane's material, and tiny particles in open atmospheres could be deposited on the membrane. This led to an increase in the membrane's thickness and mass, which led to a decrease of sensitivity.

In general, MEMS microphones showed very good resistivity to environmental changes, which is very important when considering them for installation in open-air applications for a longer time.

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