

Proc. EuroSensors XXV, September 4-7, 2011, Athens, Greece

Determining the acoustic resistance of small sound holes for MEMS microphones

Gregor Feiertag^{a*}, Matthias Winter^b, Petko Bakardjiev^c, Elmar Schröder^c,
Christian Siegel^b, Mustafa Yusufi^a, Peter Iskra^d, Anton Leidl^b

^aMunich University of Applied Sciences, Lothstr. 64, 80335 Munich, Germany

^bEPCOS AG a group member of TDK-EPC, Anzinger Str. 13, 81671 Munich, Germany

^cMüller-BBM, Robert-Koch Str. 11, 82152 Planegg, Germany

^dFraunhofer EMFT, Hansastraße 27d, 80686 Munich, Germany

Abstract

Capacitive MEMS microphones are now widely used for mobile phones and headsets. The frequency response of MEMS microphones is influenced by the package geometry. This can be applied to tune the performance of the microphone in the system. Packages with small sound inlet holes are acoustic low-pass filters. The cut-off frequency is determined by the diameter of the holes. In previous work we did not find sufficient agreement between a lumped element simulation and the measured frequency response of the microphones. Now we measured the acoustic resistance of small sound inlet holes directly. The measured resistances agree well with calculated values. The frequency response of MEMS microphones was measured for different sound hole diameters and lengths. The results are in good agreement with calculated transfer functions of the package.

© 2011 Published by Elsevier Ltd. Open access under [CC BY-NC-ND license](https://creativecommons.org/licenses/by-nc-nd/4.0/).

Keywords: MEMS microphone; MEMS package; sound hole; acoustic resistance

1. Introduction

Most MEMS microphones are packaged with die and wire bonding on a PCB substrate (see Fig. 1a). Earlier we presented a package technology where the microphone and the ASIC chips are placed on a High Temperature Co-fired Ceramic (HTCC) substrate using a flip-chip process (see Fig. 1b) [1, 2]. The

* Corresponding author. Tel.: +49-89-1265-3463; fax: +49-89-1265-3403.
E-mail address: feiertag@ee.hm.edu.

sound inlet hole of the system is realized by punched holes in the HTCC substrate. Compared to wire-bonding type packages a significant reduction of the package size can be achieved. The small acoustic front volume of the flip-chip package improves the linearity of the frequency response. Furthermore, small sound inlet holes can be used as an acoustic low-pass filter to compensate the non-linear response of the microphone on the system level.

The frequency response was simulated using an analogous electro-acoustic-mechanical circuit diagram [3]. Lumped elements describe the different parts of the system. To achieve agreement between simulation and measurement a value for the resistance of the sound inlet holes was used for the simulation which was significantly higher than the value calculated by the law of Hagen-Poiseuille. The occurrence of turbulences in the air flow through the sound inlet hole was assumed to cause the difference.

To understand the reason for the disagreement we now calculated and measured the air flow resistance of small sound holes at air velocities in the range of the particle velocity of speech. This was done for sound holes in ceramic and silicon substrates with several diameters and lengths.

We also calculated and measured the frequency response of MEMS microphones with sound holes in the diameter range from 50µm to 300µm.

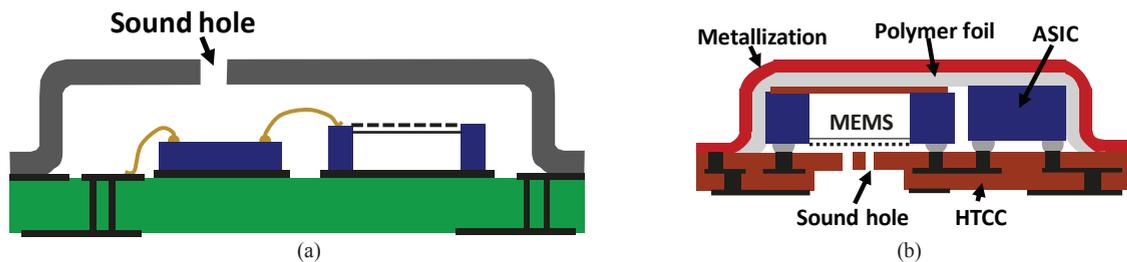


Fig. 1. (a) Wire-bonding type MEMS microphone package; (b) Flip-chip MEMS microphone package

2. Air flow resistance of sound holes

2.1. Calculation of air flow resistance

The resistance caused by laminar flow in a tube can be calculated by the Hagen–Poiseuille equation:

$$R_{HP} = \frac{\eta \cdot l}{\pi \cdot r^4}$$

where η is the viscosity of air, l is the length of the hole and r the diameter of the hole. Turbulence will not occur in sound holes. Even at a sound pressure level of 100 dB the particle velocity of air is only 49 mm/s. So the Reynolds numbers of sound holes are well below the critical Reynolds number. Turbulence could occur at sharp edges of the sound holes.

2.2. Measurement of air flow resistance

It is difficult to measure the air flow resistance of single sound holes. So we measured the air flow resistance of arrays of one hundred up to several hundred holes in ceramic and silicon. Sound holes with diameters in the range between 50 µm and 300 µm were etched in silicon wafers using the Bosch process.

The air flow resistance was measured for pressure drops (Δp) at the apertures in the range from 0.05 Pa up to 1000 Pa. In Table 1 the values measured at small Δp are compared with values calculated by the Hagen–Poiseuille equation. For higher pressure drops at the sound holes the resistance is higher because

of the energy necessary to accelerate air for the passage through an aperture. Measurement and calculation are in sufficient agreement.

Table 1. Comparison between measured and calculated resistances

Diameter of sound hole [μm]	Length of sound hole [μm]	Material	Measured Resistance [Pa s/m]	Calculated Resistance [Pa s/m]
102 (four holes)	150	HTCC	$3.58 \cdot 10^{-8}$	$2.26 \cdot 10^{-8}$
142 (two holes)	150	HTCC	$2.05 \cdot 10^{-8}$	$1.35 \cdot 10^{-8}$
306 (single hole)	500	Si	$5.33 \cdot 10^{-7}$	$4.07 \cdot 10^{-7}$
102 (single hole)	300	Si	$5.16 \cdot 10^{-8}$	$4.07 \cdot 10^{-8}$

3. Frequency response of MEMS Microphones

3.1. Calculation of frequency response

Sound hole and front volume form an acoustic second order low-pass. The frequency-dependent transfer function of the low-pass is given by:

$$H(\omega) = \sqrt{\frac{1}{\omega^4 \cdot M_{in}^2 \cdot C_{in}^2 + \omega^2 \cdot R_{in}^2 \cdot C_{in}^2 - 2 \cdot \omega^2 \cdot M_{in} \cdot C_{in} + 1}}$$

with the acoustic resistance of the sound hole R_{in} , the acoustic compliance of the front volume C_{in} and an inductance M_{in} caused by the mass of the air in the sound hole.

3.2. Measurement of frequency response

As reference the frequency response of a microphone was measured where the sound inlet was enlarged manually (see figure 2a). The effect of the low pass filter can be neglected for these microphones.

The frequency response of microphones with small sound holes etched in silicone was measured with the setup shown in Fig. 2b. First we glued silicon chips with sound holes on top of packaged MEMS microphones. Then wires were soldered to the input, output and ground pads of the microphones. The frequency response of the microphones was then measured in the free field in an anechoic chamber.

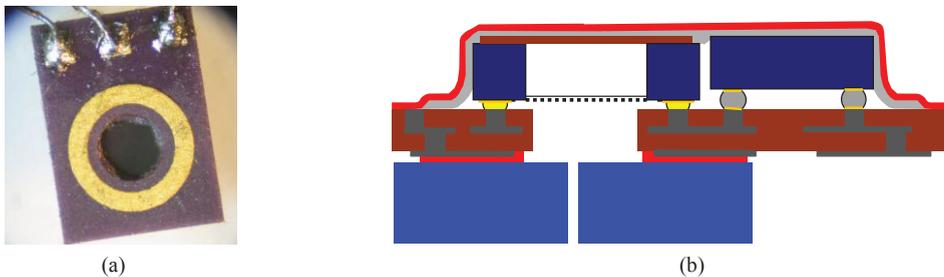


Fig. 2. (a) Microphone with large sound hole; (b) microphone with sound hole in silicone

In Fig. 3 examples of the calculated and the measured frequency response are shown for a sound inlet hole of 50 μm diameter and a sound inlet hole of 100 μm diameter. In order to fit the theoretical curves to the measurement data the acoustical compliance of the front volume was adapted. In case of the smaller hole the correction was less than 15%, in case of the larger hole the correction factor was 1.44. This deviation is not fully understood yet, but it is only slightly larger than the expected variation due to process variations.

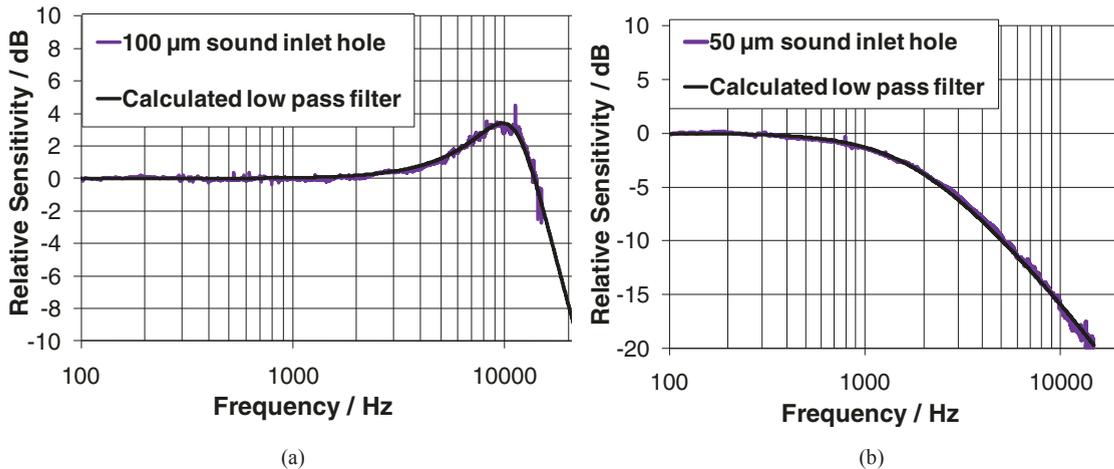


Fig. 3. (a) Microphone with sound inlet of 100 μm diameter; (b) microphone with sound inlet hole of 50 μm

4. Summary

The measured resistances of small holes in a substrate are in good agreement with values calculated by the Hagen–Poiseuille equation. Sound hole and front volume form an acoustic second order low-pass. The transfer function of this low-pass could be verified by measurements of the frequency response of MEMS microphones for different sound hole diameters.

Acknowledgements

This work was funded by the Bavarian Ministry of Economic Affairs within the project MEMSMikro.

References

- [1] Feiertag G, Winter M, Leidl A. Flip chip packaging for MEMS microphones. *Microsystem Technologies* 2010; **16/5**:817-23
- [2] Winter M, Feiertag G, Leidl A, Seidel H. Chip scale package of a MEMS microphone and ASIC stack. *Proc IEEE int Conference on Micro-Electro-Mechanical Systems*, Hong Kong; Jan 2010.
- [3] Winter M, Feiertag G, Leidl A, Seidel H. Influence of a chip scale package on the frequency response of a MEMS microphone. *Microsystem Technologies* 2010; **16/5**:809-15.