Simulation of Acoustical and Electrical Performance of Silicon Microphones

M. Brauer, A. Dehé[1], M. Füldner[1], R. Laur

ITEM – University of Bremen, D-28334 Bremen, Germany, Email: brauer@item.uni-bremen.de

[1] *Infineon Technologies AG, D-81730 Munich, Germany, Email: alfons.dehe@infineon.com*

Abstract

This paper presents a microphone model, which allows the simulation of acoustical and electrical behaviour. The model is based on a SPICE network comprehending the possibility to use it with different simulation tools like PSpice or Spectre. So the benefit is a surrounding area where the most circuit designs are made and the acoustical behaviour can smoothly integrated into the simulation.

Introduction

The research of silicon microphones at Infineon Technologies starts in the year 1998 with first publicised results in the year 1999 [1]. Right from the start there was an activity in generating models to describe the acoustical system [2]. A SPICE based model is frequently used therefore [3], [4]. Unfortunately, the simulations are not often confirmed with measurements especially in the signal-to-noise ratio.

This paper presents a microphone model which considers the acoustical, mechanical and electrical behaviour. This allows the simulation of the whole microphone system including signal processing circuits and is necessary because of their interaction.

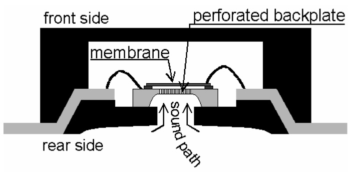

Figure 1: Cross-section of the microphone chip mounted in the housing.

The silicon microphone is based on a capacitive transducer with a perforated backplate and a thin polysilicon membrane. The sound reaches the membrane from the rear side of the housing through the perforation holes in the backplate (Figure 1).

Lumped Elements Network Model

The model is based on a Spice network including equivalent circuit diagrams (Figure 2, top). It is necessary to integrate the acoustical mechanical behaviour of the system into an electrical circuit diagram. This is based on the electromechanical analogy between mechanical, acoustical and electrical systems. Here a network is generated consisting of resistors (representing the damping elements), capacitors (compliance of cavities) and inductors (acoustical compound) (Figure 2, bottom).

The values of these parts are calculated by a parameter table. These parameters result from geometrical data, material properties or they are generated by means of finite element simulations [5]. The output value of this acoustical mechanical simulation is a voltage describing the relative movement of the membrane.

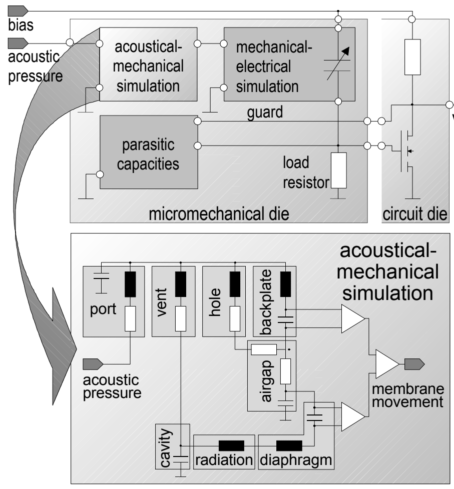

Figure 2: Equivalent circuit diagram for sensitivity and noise simulation (top) and equivalent acoustical mechanical model (bottom).

The mechanical-electrical transducer is a voltage controlled capacitor. The used simulation tool offers a four terminal network where the input voltage controls the outgoing capacitance. The transfer function is described by an equation. Alternatively the use of the Verilog Hardware Description Language - Analog Mixed Signals (VHDL-AMS) can replace the four terminal network.

Another relevant part of the network is the parasitic capacitance. Due to several depositions like the backplate or the membrane on the microphone chip parasitic capacitances arise. Because of their effect on sensitivity and noise they are considered. The parasitic capacitances are calculated by the same geometrical parameter table which is used to calculate the acoustics.

Finally, a source-follower or more complex circuits are included into the network. Thus a parametric model of the entire microphone system is generated.

Benefit of the Coupled Microphone Model

This model allows a precise circuit design for signal processing. Acoustical filters can simultaneously be simulated with electrical filters. Thus, a design of the full signal and noise path of the microphone is possible and already demonstrated [6]. Figure 3 shows the simulation results of an integrated microphone system for hands-free sets in automotive application. The signal processing circuit includes filters, amplifiers and a current controlled interface for the output signal. The complete system has been designed to meet a given automotive specification.

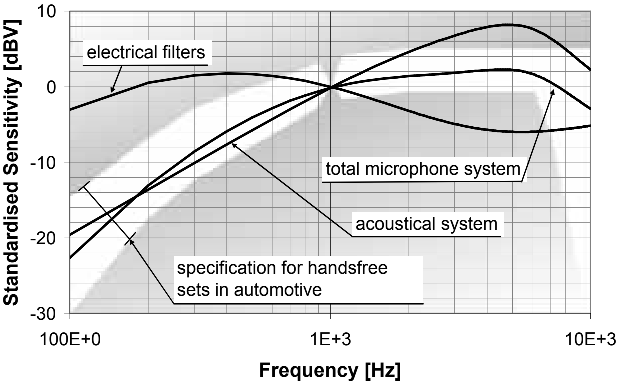

Figure 3: Complete system simulation allows a perfect matching of acoustical and electrical filters to observe the specification.

Besides, the model is helpful to analyse the system. E.g. the detection of noise sources is possible. This assists to identify and optimize the dominating noise sources [7].

Another possibility is the Monte Carlo simulation on the microphone system. This is an instrument to mirror the variations of the manufacturing process into the specifications of a product. The impact of the sensitivity of a directional microphone is shown in Figure 4. Thus, the expected sensitivity over the full technology uncertainty range can be compared with a given specification.

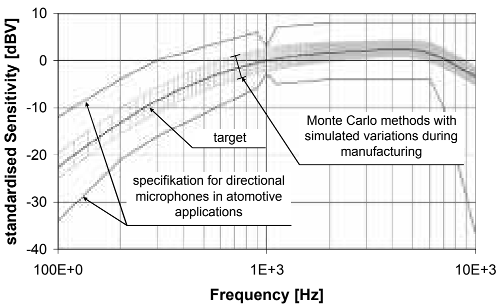

Figure 4: Monte Carlo methods show the influence on sensitivity as a result of variations during the manufacturing process.

Comparison between Simulation and Measurement

To allow for a “first time right” design it is necessary to have a good confidence level of the model.

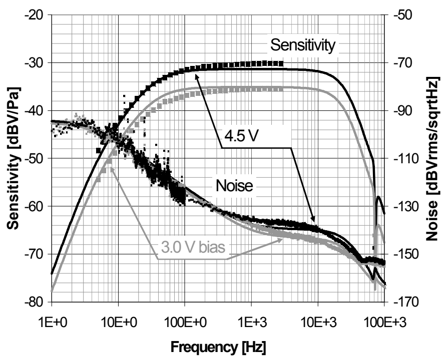

Figure 5: Sensitivity and noise of a packaged microphone under two bias conditions (measurement – dotted, simulation – lined).

In Figure 5 the results of this comparison are presented. The measured frequency responses of signal and noise fit very well to the simulation results.

In a second step the noise is integrated in the frequency range of interest (0.1 – 10 kHz). Because of the doninating influence of the load-resistor it was helpful to make a parameter sweep of this value. Figure 6 demonstrates this behaviour. The measurement with the optimised value of the load-resistor confirms the simulation: there is only a mismatch about 1 dB in signal-to-noise.

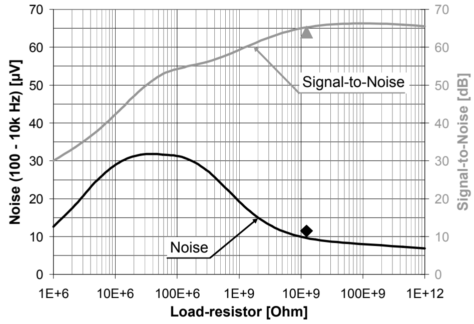

Figure 6: Influence of the load resistor on noise and signal-to-noise ratio (measurement - dots, simulation - lined).

Conclusions

In this paper a validated model of a silicon microphone has been demonstrated. The model considers all electrical and acoustical components like the source-follower, the parasitic capacitance, the sound path and the housing. It is possible to simulate sensitivity and noise. The concluding comparison between simulation and measurement shows a very good compliance (lower than 1 dB mismatch).

Acknowledgements

This work is funded by the German Federal Ministry for Education and Research (BMBF) under the contract 16SV1273.

References

[1] A. Dehé et al, “Silicon micromachined microphone chip at Siemens”, 137th Regular Meeting of the Acoustical Society of America, Forum Acusticum 1999 Acta Acustica 85 S71

[2] M. Füldner et al, “Empfindlichkeits- and Rauschanalyse eines kapazitiven Mikrofons in BICMOS-Technologie“, 4. Chemnitzer Fachtagung Mikromechanik & Mikroelektronik, 1999

[3] M. Lukeš, “Silicon condenser microphone: electroacoustic model and simulation”, Audio Technologies and Processing Conference – ATP2001, Prague, October 12th 2001.

[4] P. Rombach et al, “The first low voltage, low noise differential silicon microphone, technology development and measurement results”, in *Sensors and Actuators* A. 95 (2002) 196-201

[5] M. Füldner et al, “FEM-unterstützte Netzwerksimulation kapazitiver Silizium-Mikrofone”, 29. Deutsche Fachtagung für Akustik DAGA’03, Aachen, Germany, March 2003

[6] M. Brauer et al, “Funktionalitätserweiterung von Silizium-Mikrofone durch hybride Schaltungsintegration”, 9. GMM-Workshop, Methoden und Werkzeuge zum Entwurf von Mikrosystemen, Bielefeld, pp. 11-15, 2003-10-22

[7] M. Brauer et al, “Increasing the performance of silicon microphones by the benefit of a complete system simulation”, MEMS 2004, technical digest, p. 528 – 531, 2004