Development of Directional Silicon Microphones

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Introduction

In hands-free applications and hearing aids, microphones with directional characteristic are used for improved signal-to-noise-ratio. Basically there are two different approaches to separate a localised speech source from a noisy environment. Microphone arrays employ two or more omni-directional microphones with electronic processing of the directivity-dependent time delay between the signals. Microphone arrays offer high directivities but on the other hand fabrication is relatively complex and costly. In a single-microphone approach, the time delay between two sound ports in combination with an acoustical phase-shifting element provides a directivity-dependent differential sound pressure. Such pressure-gradient microphones can be fabricated in small size at comparably low costs.

This paper presents pressure-gradient microphones fabricated in silicon technology as surface mountable device, electro-acoustical modelling and measurements. Based on a microphone model, the design of the rear port is optimised regarding its acoustical impedance, resulting in measured directivities up to 19 dB at 1 kHz.

Modelling of Directional Silicon Microphones

According to the formal analogy between mechanical, acoustical and electrical systems, an equivalent circuit representation of the directional microphone was composed. In this technique, mass, stiffness and damping are represented by electrical inductors, capacitors and resistors. The model consists of a sound source, a front port, an inner microphone model and a rear port describing an acoustical phase-shifting RC-filter. The time delay between the signals entering the front and rear port is included by a directivity-dependent transmission line element (Figure 1).

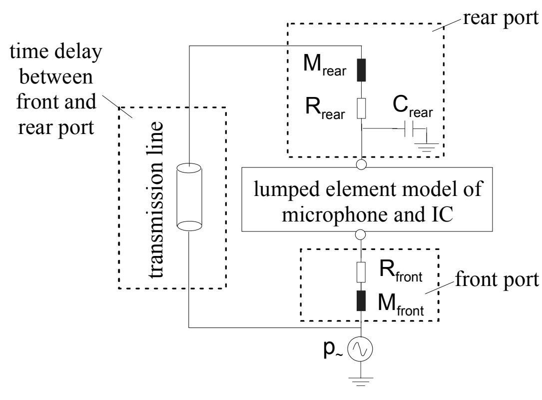

Figure 1: Network model for directivity simulations.

For more details on lumped element modelling of the silicon microphones refer [1].

Figure 2 shows an exemplary simulation of the directivity for 0°/180° sound incidence at 1 kHz versus the acoustical resistance of the rear port.

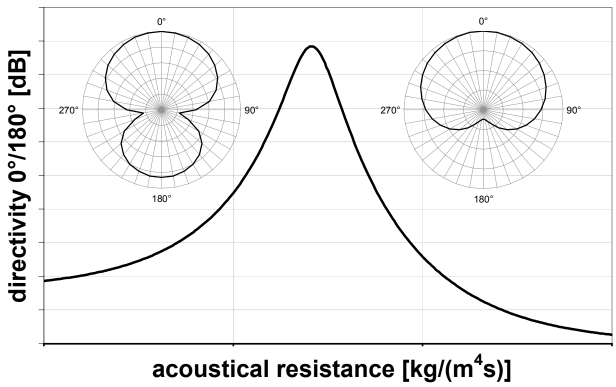

Figure 2: Adjustment of the directivity magnitude and characteristic by rear port's acoustical resistance.

With increasing acoustical resistance, at first the directivity for 0°/180° sound incidence increases since the polar pattern changes from hyper-cardioid to cardioid. A maximum is reached if the phase-shift due to different acoustical path lengths is equal to the phase-shift of the rear port RC-filter. For very high acoustical resistances the microphone behaviour reaches the omni-directional case without directivity.

The simulation demonstrates the adjustment of the directivity magnitude and characteristic by an acoustical resistance. The next section deals with different packaging concepts to realize a rear port with acoustical resistance.

Packaging Concepts

Microphones in a premolded package with metallic cap as well as microphones on a printed circuit board with premolded cap have been tested and optimised (Figure 3). The front sound port is a 1 mm hole in the bottom of the package below the microphone chip. The acoustical resistance of the rear sound port is realised by different damping materials back-mounted on a cap with hole (diameter 0.8-1.5 mm) or by small perforation holes (diameter below 150 µm) in the cap made by chemical etching and laser cutting, respectively.

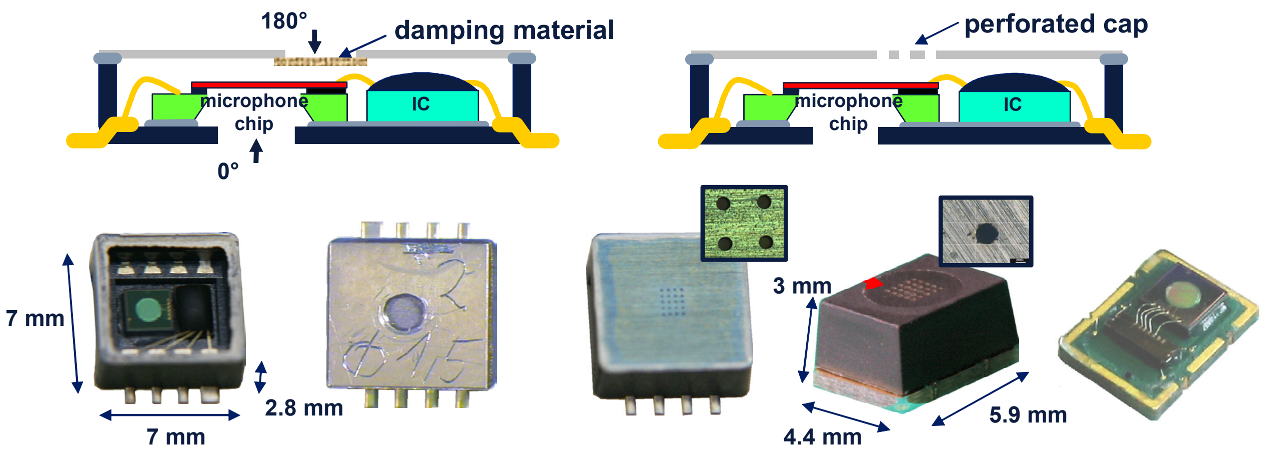

Figure 3: Demonstrators of directional silicon microphones with damping material mounted on cap or perforated cap.

Measurements

Measurements have been carried out under free-field conditions in an anechoic chamber. The measured directivity regarding 0° and 180° sound incidence at 1 kHz for a microphone with perforated cap depending on the number of holes is shown in Figure 4. In agreement with simulation results, the directivity passes a maximum for increasing acoustical resistance which is inversely proportional to the number of perforation holes. A similar behaviour is obtained for different damping materials with hole diameters from 0.8 to 1.5 mm (Figure 5).

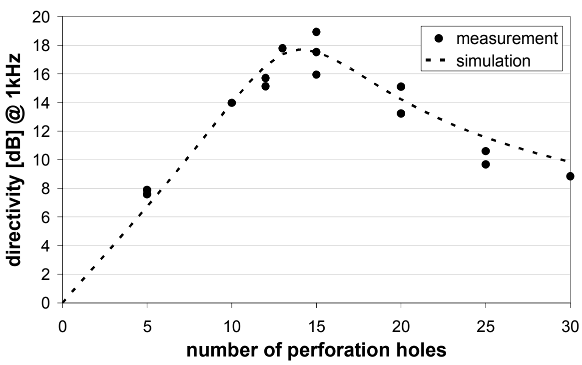

Figure 4: Directivity optimization by the number of perforation holes.

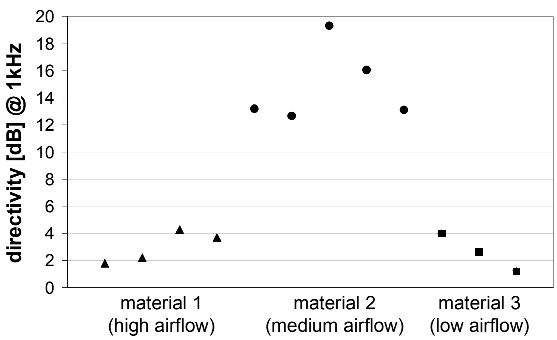

Figure 5: Directivity optimization by different damping materials.

The directivity for any angle of sound incidence is summarized in polar patterns. As predicted by the network model, the polar pattern is hyper-cardioid for relatively low acoustical resistances and cardioid for higher resistances (Figure 6).

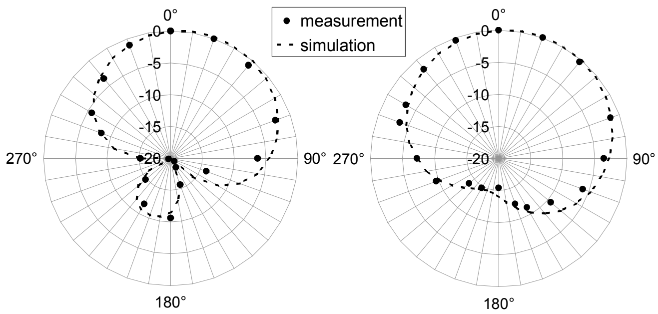

Figure 6: Typical polar pattern at 1 kHz for low and high acoustical resistance, respectively.

Summary

The achieved directivity up to 19 dB is above specification for both packaging concepts. In terms of the thermal instability of the damping materials and the sequential process of laser-cutting, a metallic cap with chemical etched perforation holes is most advantageous.

Acknowledgements

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References

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