Measurements of Silicon Microphone Arrays in Hearing Aids

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Introduction

Miniature electret microphones are the state-of-the-art hearing aid transducers. In modern hearing aids several omnidirectional microphones are combined to directional microphones in order to get a higher speech intellegibility in noisy environments. For this purpose it is essential to have a high directivity which can only be achieved if the microphones are matched accurately. Silicon microphones a priori have low interindividual tolerances since they are manufactured using silicon-micromachining processes. In principle they are very well suited for directional microphones. If the microphones are placed in one housing, the hearing aid manufacturing process can be simplified (e.g. easier electrical connection).

Specification of the microphone array

Packaging

In a first attempt we have realized a first order directional microphone consisting of two silicon microphones within one module. The package of this module has to accommodate at least four chips (two silicon microphone chips and two impedance converter chips. The dimensions of the package have been adapted from the dimensions of two single standard hearing aid microphones taking into account the space provided by the hearing aid (Siemens Triano SP). Fig. 1 shows a drawing of the proposed module.

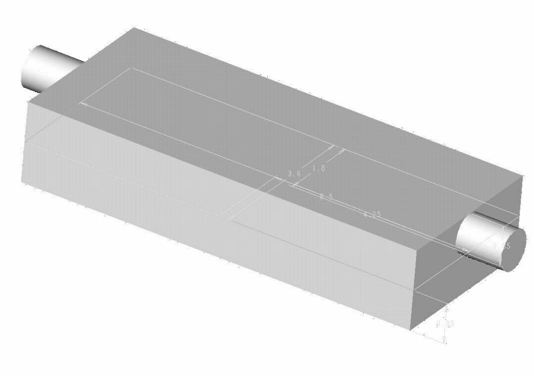

Fig.1: 1st order microphone module. The dimensions are 3.6 mm * 8.5 mm * 1,7 mm. The length of the spouts is 1.0 mm. The outer and inner diameter of the spouts is 1.0 mm and 0.8 mm respectively.

Electro-acoustic design

Modern hearing aids provide a very well stabilized 0.9V DC supply voltage. This is not yet sufficient for our silicon microphones. Therefore for the experiments an external voltage supply is necessary. In future designs a charge pump has to be integrated on the impedance converter chip.

The equivalent input-related noise level of an hearing aid microphone determinates the hearing level of the aided patient. Therefore the noise level has to be kept as low as possible. The acceptable value is at least 25 dB(A).

The sensitivity of a typical hearing aid microphone is 25 mV/Pa @ 1 kHz. In order not to overload the input stages of the hearing aid, the bandwidth should be limited to 200 Hz - 12 kHz. The resonance peak must not be higher than 6 dB.

Results and discussion

Experimental setup

Within the scope of the joint research project InFON microphone modules as proposed in Fig.1 have been manufactured. During the implementation process the dimensions of the modules had to be slighty adapted. The actual dimensions are 4.0 mm * 9.5 mm * 2.3 mm. In order to achieve an inner spout diameter of 0.8 mm, the outer spout diameter had to be increased up to 1.4 mm. Due to these geometrical changes the hearing aid shells had also to be slightly modified (Fig. 2).

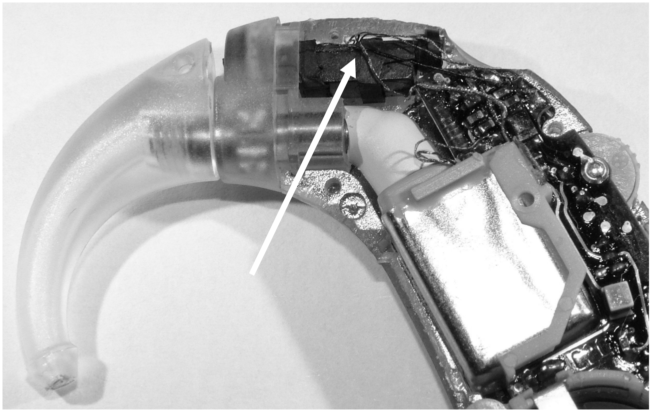

Fig. 2: Hearing aid (Siemens Triano SP) with built-in silicon microphone array module (arrow).

Sound sensitivity

Fig. 3 shows the good performance of the InFON microphones. Unfortunately, the impedance converter cannot be driven at 0.9 V. The shape of the frequency response curve is quite flat except for the low-pass behavior beyond 3 kHz. This is given by the acoustic design of the microphone housing. The microphone membrane is placed between a front and a back volume. In combination with the acoustical mass of the sound inlet the front volume forms an acoustical low-pass filter. Although the spout has a sufficient inner diameter, the acoustical canal between the spout and the front volume is still too narrow.

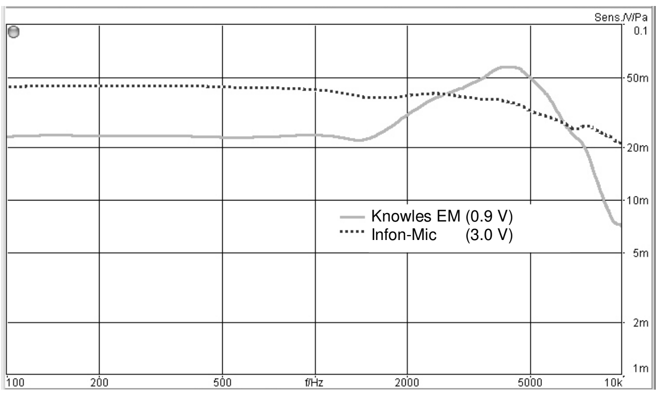

Fig. 3: Comparison of the sensitivity of a standard microphone (Type EM, Knowles Electronics) and the InFON silicon microphone. The supply voltage was 3.0 V for the InFON-Mic and 0.9 V for the Knowles EM.

The acoustic fluid in a narrow canal has a high acoustical mass that decreases the cut-off frequency of the acoustical low-pass filter. This can be seen in the experimental result of the frequency response. The acoustic damping is relatively strong in a narrow acoustic canal. No resonance peak appears in the frequency response in Fig. 3. To achieve a flat frequency response of the microphones within the audio range, the acoustical inlet has to be changed in the future.

Equivalent input-related noise

The equivalent input-related noise level shown in Fig. 4 results from the electrical noise output level divided by the sound sensitivity. Besides the sound sensitivity the equivalent input-related noise is an important parameter, since a high noise level of a microphone is not acceptable for an application in a hearing aid. In Fig.4 the silicon microphone shows a lower noise level in comparison to the standard microphone. At very low frequencies external influences are responsible for the noise level increase.

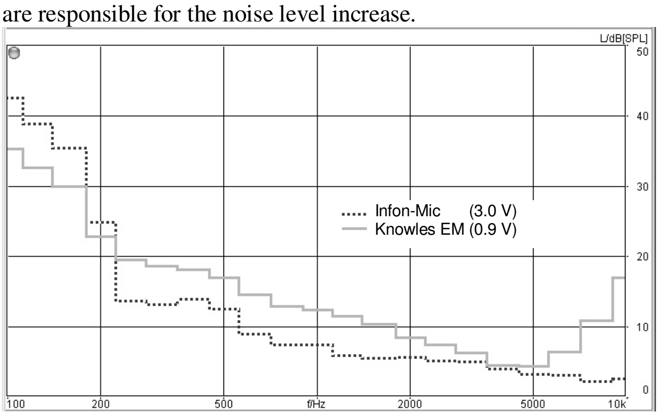

Fig. 4: Equivalent input-related noise level. Comparison between the InFON-Mic and a standard microphone (Type EM, Knowles Electronics). Noise levels (A-weighted): InFON: 24.15 dB, EM: 24.64 dB

Directivity measurements

The hearing aid shown in Fig. 2 has been investigated on the KEMAR dummy head (Knowles Electronics Manikin for Acoustical Research). All measurements were performed according to ANSI standard S 3.35. Fig. 5 shows the directivity index of the hearing aid with standard microphones and silicon microphones in comparison.

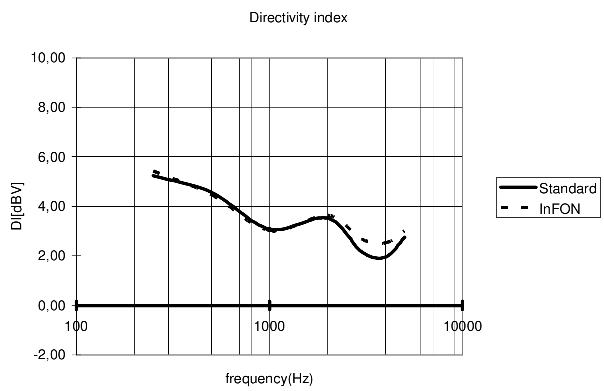

Fig 5: Directivity index measured on a Siemens TRIANO SP hearing aid on KEMAR: Comparison of the original microphones and the silicon microphones.

The AI-DI (articulation index – directivity index) is a single value for the description of the directivity of hearing aids (see ANSI standard 3.35). The AI-DI of the hearing aid with the original microphones was 3.39 dB in opposite to the AI-DI of the hearing aid with the silicon microphones of 3.52 dB. The silicon microphones show a higher directivity index at higher frequencies as well as a better AI-DI than the original arrangement. The reason for this is the better wide-band matching of the silicon microphones, although the conventional microphones already consist of a matched pair. The deeper notches in the measured directivity plots (Fig. 6) are an additional demonstration for the better silicon microphone matching.

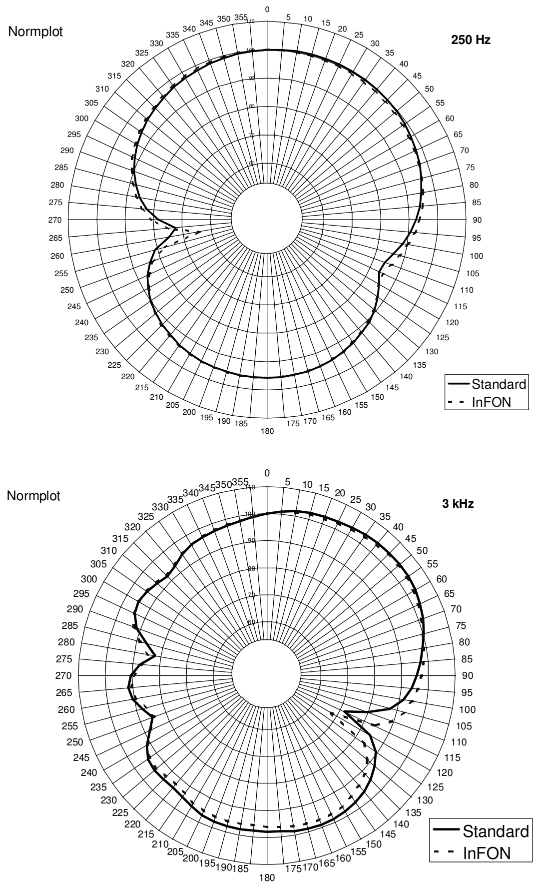

Fig. 6: Directivity plots at 250 and 3000 Hz: The notches of the silicon microphones are deeper than the notches of the original microphones. Since the hearing aid was positioned on the right ear of the KEMAR, the lobes are slightly distorted to the right hand side.

Summary

In principle silicon microphones are suitable for hearing aids. Concerning sensitivity and noise they show a good performance. The low power effieciency as well as the acoustic packaging need to be improved in the future. Due to the better matching the presented silicon microphone array shows a better directivity than the conventional microphones.

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