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# A Novel Method for Reducing the Sensitivity Deviation of MEMS Microphones by Programming

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## Abstract

This paper describes a novel method for trimming a low noise, differential micro-electromechanical system (MEMS) microphone with a state of the art signal to noise ratio (SNR) of 66 dB(A) and a sensitivity of -38 dBV/Pa @ 1kHz after completing the fabrication process. The method allows compensating the electroacoustic variations caused by process tolerances and reducing specification limits of the microphone sensitivity from  $\pm 3$  dB to  $\pm 0.5$  dB. Trimming is done by programming the bias supply voltage of the capacitive membrane-backplate-system and the gain factor of the output pre-amplifier. Microphone sensitivity can be modified within a range of 11.2 dB. Thus the standard deviation of the sensitivity of a production batch could be reduced from 0.97 dB to 0.11 dB. Furthermore the SNR could be increased to 66.5 dB(A).

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## 1. Introduction

Today microelectromechanical systems (MEMS) microphones are used for mobile phones as acoustic sensors because of their small size, good acoustic performance and their resistance to soldering heat [1,2]. In most smartphones more than one MEMS microphone is used for digital audio signal processing e.g. noise canceling. Therefore it is necessary to have microphones with similar electroacoustic characteristics assembled within one

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mobile phone device [3]. In particular the deviations of the sensitivities must be small. The challenge is therefore to minimize the sensitivity variation caused by the microphone fabrication process. Variations of the electroacoustic microphone parameters are caused by tolerances of the front-end processes of MEMS and application-specific integrated circuit (ASIC) chips and their assembly in a package. In addition to the tight sensitivity specifications the requirements for MEMS microphones have increased during the last few years to a signal to noise ratio (SNR) of 66 dB(A) and a sensitivity of -38 dBV/Pa [4]. Today mobile phone manufacturers define sensitivity tolerances down to  $\pm 1$  dB for analogue microphones. The specification can be reached by sorting MEMS and ASIC chips during the packaging process or by trimming MEMS microphones after completing the fabrication process.

## 2. Programmable microphone

To compensate the sensitivity variations arising from MEMS and ASIC chip fabrication as well as packaging, a novel capacitive MEMS microphone with adjustable acoustic characteristics was developed. To achieve the goal of a high SNR microphone a new MEMS microphone package ( $3.35 \times 2.5 \times 1.0 \text{ mm}^3$ ) was developed [5]. A sectional view is shown in figure 1.

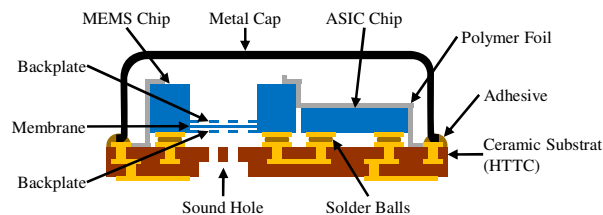


Fig. 1. MEMS microphone flip-chip package with small front-volume and large back-volume [5]: HTCC substrate with sound hole, flip-chip bonding of MEMS and ASIC chip, MEMS chip with a double-backplate structure, separation of front- and back-volume by a polymer foil, back cavity closed by metal lid.

The microphone consists of two chips, a double-backplate MEMS sensor [7] and an ASIC. Both chips are integrated in a package by flip-chip mounting [6]. A high temperature cofired ceramic (HTCC) substrate with sound hole is used for the microphone bottom side. A polymer foil separates front-volume and back-volume. A metal lid closes the back-volume and shields the microphone from electromagnetic interferences. The package combines the advantages of a double backplate MEMS structure [8] and a large back-volume to reach high sensitivity and SNR. A small front-volume entails a flat frequency response [9]. The detailed MEMS microphone fabrication process and the advantages of such a package are explained in [5].

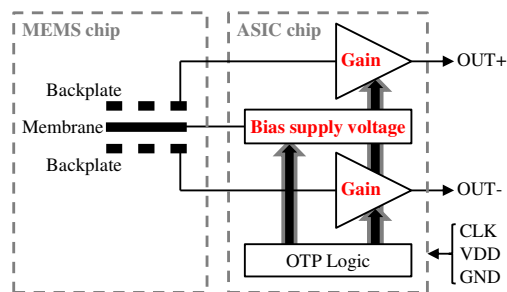


Fig. 2. Basic setup of the new programmable MEMS microphone: The electroacoustic microphone parameters are modified by varying the bias supply voltage and the gain factor of the output pre-amplifier. An OTP logic block is integrated in the ASIC chip to program bias and gain.

To achieve the goals of reducing the sensitivity variation caused by the microphone fabrication process tolerances and increasing the SNR a new programmable ASIC chip was developed. Together with the differential silicon MEMS chips it is assembled in the microphone package. Figure 2 shows the working principle of the new programmable MEMS microphone. By tuning the supplied bias voltage and the gain factor of the output pre-amplifier the microphone sensitivity can be adjusted. For the adjustment of the parameter a one-time programmable (OTP) logic block is integrated in the ASIC chip. The microphones are tuned by a programming sequence after completion of the production test. Figure 3 exemplarily shows the measured frequency response of one new microphone for various bias supply voltages and the gain factors. All measurements were carried out in an acoustic pressure chamber, calibrated to 1 Pa by using a reference microphone and limited to frequencies to 10 kHz.

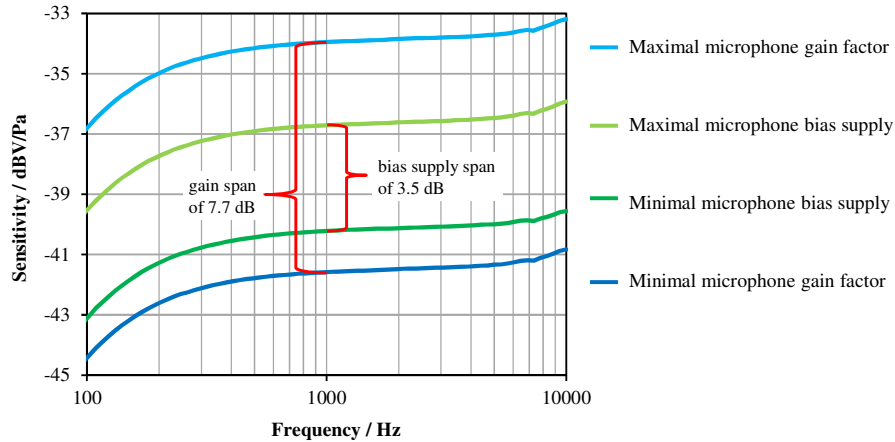


Fig. 3. Microphone sensitivity as a function of the frequency response for one microphone in relation to the programmed bias supply voltage and gain factor: By programming the minimal and maximal value for the bias supply voltage a span of 3.5 dB and for the gain factor a span of 7.7 dB could be reached.

Programming bias and gain result in a parallel shift of the acoustic frequency behavior. By adjusting the bias supply voltage a span of 3.5 dB could be reached. Programming of the gain factor provides a span of 7.7 dB. If both methods are combined the programmable sensitivity range reaches 11.2 dB.

### 3. Results

The tuneability of the microphones was used to balance the sensitivity variations within one production batch after the fabrication process. In figure 4 (a) the sensitivity distribution of one production lot after fabrication and after tuning is shown. In a first production batch the standard deviation of the sensitivity was reduced from 0.97 dB unprogrammed to 0.11 dB in programmed state. This method allows compensating the sensitivity variations caused by process tolerances and fabrication processes. The programmed microphones would fulfill a tight sensitivity specification of  $\pm 0.5$  dB. With the new OTP microphone tight specification limits to sensitivity e.g.  $\pm 1$  dB  $3\sigma$  can be maintained in mass production.

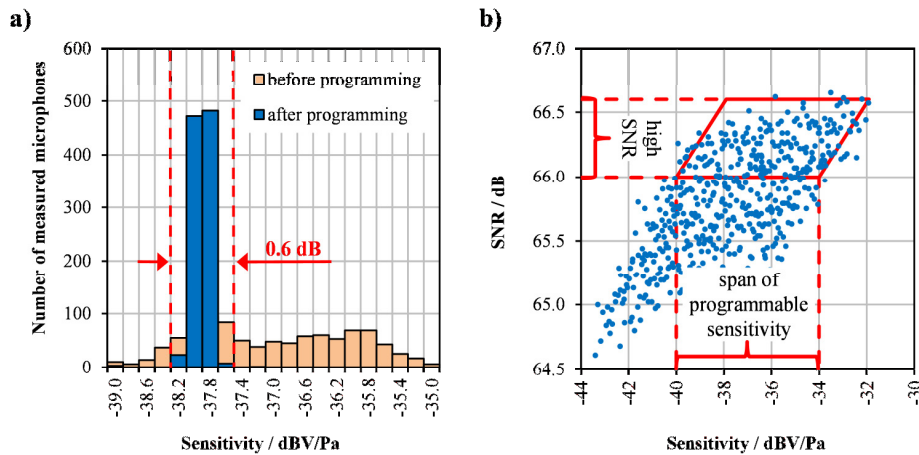


Fig. 4. (a) Sensitivity distribution of two production lots after fabrication (“before programming”) and after trimming (“after programming”): Sensitivity variation can be reduced to  $\pm 0.3$  dB, the standard deviation of sensitivity was reduced from unprogrammed 0.97 dB to programmed 0.11 dB; (b) Influence of programming algorithm to the microphone SNR as a function of the adjustable sensitivity carried out at one microphone device: Sweeping all programmable combinations of bias supply voltage and gain factor a high SNR range from 66.0 dB to 66.5 dB could be reached.

By choosing the right combination of bias supply voltage and gain the SNR of the microphones can be improved. The influence of the programming algorithm on the microphone SNR is shown in figure 4 (b) exemplarily for one microphone device. By sweeping all programmable combinations of bias supply voltage and gain factor a possible range for adjusting the SNR over sensitivity is shown. With the target of a high SNR microphone above 66.0 dB an adjustable sensitivity span of 6.0 dB was reached. With an optimized programming algorithm it is possible to trim a MEMS microphone towards a sensitivity of  $-38$  dBV/Pa @ 1 kHz and a high SNR of 66.5 dB(A).

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