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## Sensitivity recalibration of MEMS microphones to compensate drift and environmental influences

S. Walser<sup>a\*</sup>, M. Loibl<sup>a</sup>, M. Winter<sup>b</sup>, C. Siegel<sup>b</sup>, G. Feiertag<sup>a</sup>

<sup>a</sup> Munich University of Applied Sciences, Munich, Germany

<sup>b</sup> EPCOS AG a TDK group company, Munich, Germany

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### Abstract

In this paper a new method for sensitivity recalibration of capacitive MEMS microphones is presented. Recalibration can be applied to compensate ageing or environmental influences. Recalibration can be done by measuring the sensitivity for only one bias voltage after a stress test. A microphone with a variable bias voltage can measure its pull-in voltage. Unfortunately, the drift of the pull-in voltage does not correlate with the sensitivity drift. So a true self-calibration without a defined acoustical test signal was impossible.

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### 1. Introduction

Today microelectromechanical system (MEMS) condenser microphones are commonly used as acoustic sensors in the segment of consumer electronics [1]. Reasons for this trend are their small size, their good acoustic performance and their resistance to soldering heat [2]. In the segment of mobile phones MEMS microphones have replaced all other solutions. Sensitivities of -38 dBV/Pa, signal to noise ratios (SNR) of up to 66 dB(A) and component sizes of approximately 3.5 x 2.5 x 1.0 mm<sup>3</sup> are state of the art [3]. During the last few years, research has focused on the sensor design, e.g. single-ended [4] and double backplate [5] as well as on the microphone package, e.g. wire bonding [6] and flip-chip [3]. For the following research a flip-chip bottom-port capacitive silicon microphone, which is presented in [3], was used as shown in Figure 1.

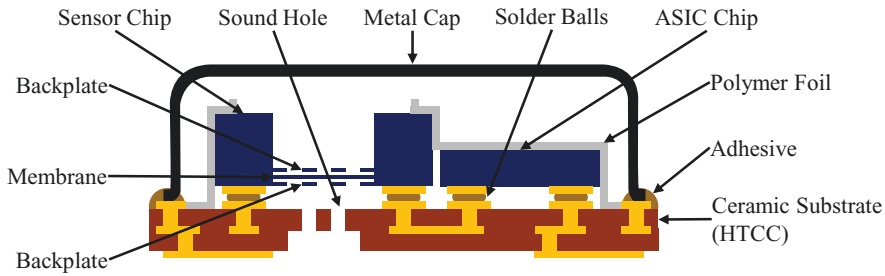


Fig. 1. Schematic cross section of a flip-chip bottom-port MEMS microphone with large back-volume [3]: HTCC substrate with sound hole; double backplate sensor chip; separation of front and back volumes by a polymer foil; back volume closed by a metal cap.

Most MEMS microphones consist of two chips. A capacitive sensor chip and a programmable application-specific integrated circuit (ASIC) chip. In our case both chips are integrated by a flip-chip process into a surface-mount device (SMD) package. After the flip-chip bonding of the two chips, the acoustic front and back volumes are separated by a polymer foil. The back volume is then closed by a metal lid. The fabrication process is explained in detail in [3].

Sensitivity variations are caused by fabrication tolerances and packaging stress. To reduce the variations, a programmable ASIC chip was integrated [7]. This chip allows modifying the microphone’s sensitivity after the fabrication process by programming the gain and the bias voltage. A detailed theoretical and practical investigation of the influence of programming on the electroacoustic microphone performance was published in [8].

Figure 2 shows the schematic diagram of the programmable MEMS microphone (left) and the benefit of programming (right). The standard deviation of the sensitivities was reduced by programming from 0.97 dB to 0.11 dB. [7]

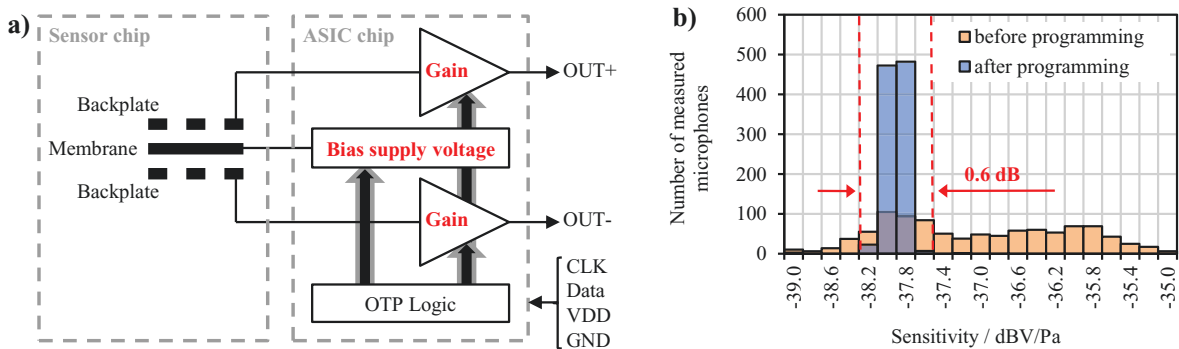


Fig. 2. (a) Schematic diagram of a programmable MEMS microphone with adjustable gain and bias; (b) Sensitivity distribution of two production lots “before programming” and “after programming”. [7]

With programmable microphones tight sensitivity specification limits of  $\pm 1$  dB can be fulfilled in mass production. Especially for high performance microphone applications, e.g. noise canceling or sound direction detection, the sensitivity deviations of the microphones assembled in one system must be small to achieve a good quality of audio signal processing [9].

One big challenge for all MEMS microphone applications is avoiding or compensating ageing or environmental influences after assembly of the microphone in a system. Mechanical stress, high temperatures or humidity can modify the sensitivity. This paper shows a new method for recalibrating microphone sensitivity by programming the

bias voltage of the capacitive membrane-backplate system, to compensate ageing or environmental impacts, e.g. by the soldering process.

## 2. A method for sensitivity recalibration

The main idea is to recalibrate the microphone by varying the bias supply voltage of the capacitive membrane-backplate system and measuring the microphone’s sensitivity close to the microphone pull-in point. The microphone pull-in point is the point where the membrane collapses onto the backplate [10]. This means that the deflection of the membrane has reached a value where the electrostatic attraction to a backplate is larger than the opposite forces [8]. A detailed theoretical description of this phenomenon was given in [10]. However, up to the pull-in the sensitivity can be raised by increasing the bias supply voltage, see Figure 3. Close to the pull-in point the system is non-linear. As a result the sensitivity close to the pull-in shows considerable variations. To eliminate these variations, for recalibration the sensitivity values at bias voltages 0.3 V below the pull-in are used.

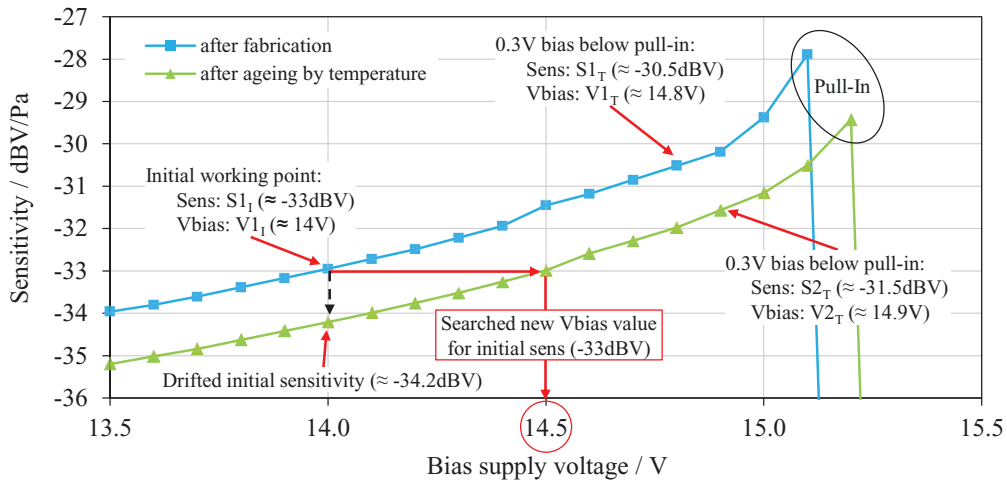


Fig. 3. Sensitivity as a function of the bias voltage for one MEMS microphone after fabrication and after ageing by temperature cycle.

After fabrication two sensitivity and bias values are stored: the initial working point ( $S_{1_I}$  and  $V_{1_I}$ ) and sensitivity and bias 0.3 V below pull-in ( $S_{1_T}$  and  $V_{1_T}$ ). In the application the sensor performance can be changed e.g. by ageing. As a result sensitivity drifts e.g. in the example shown in Figure 3 from -33.0 dBV to -34.2 dBV for a constant bias supply voltage (black arrow). As a solution a new bias voltage compensating the sensitivity drift must be found.

For a self-calibration it would be necessary to find the new bias voltage without a defined acoustical test signal. A microphone with a variable bias voltage could do a self-measurement of the pull-in voltage. We investigated if the shift of the pull-in voltage can be used to compensate the drift. Unfortunately, the shifts of the pull-in voltage did not correlate with the sensitivity shifts.

A recalibration is possible by measuring the sensitivity for one bias voltage, for example 0.3 V below the pull-in voltage ( $V_{2_T}$  and  $S_{2_T}$ ). With these values the sensitivity shift can be compensated by a new bias supply voltage ( $V_{2_{new}}$ ), see formula 1.  $V_{1_I}$ ,  $V_{1_T}$  and  $V_{2_T}$  allow compensating the bias drift ( $\Delta V_{Bias}$ ). The sensitivity drift ( $\Delta Sens$ ) can be compensated by using a linear approximation ( $S_{1_T}$ ,  $S_{2_T}$ ,  $S_{1_I}$ ,  $V_{1_T}$  and  $V_{1_I}$ ).

$$V_{2_{new}} = \underbrace{V_{1_I}}_{V_{Bias_{original}}} - \underbrace{(V_{1_T} - V_{2_T})}_{\Delta V_{Bias}} + \underbrace{(S_{1_T} - S_{2_T})}_{\Delta Sens} * \underbrace{\frac{V_{1_T} - V_{1_I}}{S_{1_T} - S_{1_I}}}_{slopefactor} \quad (1)$$

### 3. Results and Conclusion

With the example values of Figure 3 and formula 1, a new bias voltage of 14.4 V can be calculated. With this voltage the sensitivity can be shifted close to the initial sensitivity of -33.3 dBV. To demonstrate the functionality of this new recalibration method 12 MEMS microphones were measured and recalibrated. Figure 4 shows the results after fabrication, after stress tests and after recalibration.

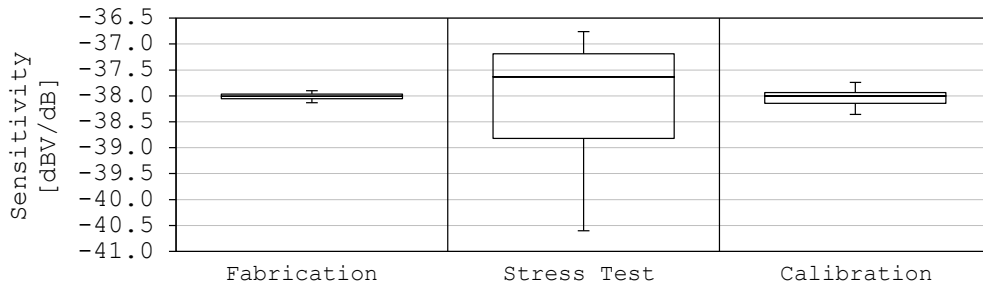


Fig. 4. Sensitivity deviation after fabrication, after stress tests and after recalibration.

After fabrication and the first calibration the microphones had sensitivities with a mean value of -38.01 dBV and a standard deviation of 0.09 dBV. After stress tests the mean value was -37.635 dBV and the standard deviation increased to 1.97 dBV. After recalibration with the new method the mean value of the sensitivity was again -38.00 dBV and the standard deviation was reduced to  $\pm 0.27$  dBV.

Unfortunately, the shift of the pull-in voltage does not correlate with the sensitivity shift. So a self-calibration without a defined acoustical test signal was not possible. However, a recalibration could be done by measuring the sensitivity for only one bias voltage.

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