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SELF-TESTING OF SIGMA-DELTA MEMS SENSORS USING BIMBO

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Sigma-delta MEMS (mostly micro-accelerometers) have been a large field of interest over the past few years [1][2]. Such sensors are feedback-controlled systems where the feedback is a high-frequency binary signal which represents, in an averaged sense, the system's input (e.g. the acceleration). There are many advantages to this approach such as linearization of the (electrostatic) feedback forces, enhancement of the sensor's dynamic range, digital measurement and easy VLSI implementation [3]. A typical sigma-delta sensor architecture is shown in Fig. 1.

It can be shown [4-5] that the resolution obtained with advanced architectures such as those of Fig. 1 is directly linked to the choice of the corrector $G(z)$ which appears in the feedback loop. However, even choices based on robust control considerations [4] do not guarantee the optimal performance of the system, nor can they always cope with the large dispersions, mostly due to variations in the fabrication process or environmental fluctuations, which affect MEMS devices. As a consequence, a self-testing routine is a desirable feature of such architectures: if the parameters of the physical sensing cell and of the associated analog electronics are correctly estimated, the coefficients of $G(z)$ can be automatically adjusted, in order to ensure a better performance.

One of the major difficulties in implementing a self-testing routine in a microelectronic device is to keep the cost of the design and of the integration of the method as small as possible. Therefore, classical system identification methods [6], which rely on high-resolution ADCs and are, thus, uneconomical in terms of design and integration costs, are usually ruled out. Although it may be possible, in some cases, to develop low-cost *ad hoc* self-test methods, a more systematic approach should be preferred, if only to reduce the design time of a given device. The BIMBO (Basic Identification Method using Binary Observations) method has recently been developed in order to address these issues [7-8].

The principle of BIMBO is the following (see Fig. 2 for notations):

- generate a spectrally rich signal u_k , such as a white noise. This signal can be a one-bit signal so that the DAC can be implemented with ease.
- measure the system's output y_k using a comparator, i.e. measure $s_k = S(y_k)$
- using a discrete parametric model of the system, compute the estimated time response \hat{y}_k and $\hat{s}_k = S(\hat{y}_k)$
- adjust the parametric model of the discrete system so that a correct estimation \hat{y}_k is produced.

An optimization algorithm is necessary for this last step. Letting θ be the unknown system parameters, the criterion that must be minimized is of the form:

$$J(\theta) = \sum_{k=1 \dots N} (s_k - S(\hat{y}_k))^2 \hat{y}_k^2, \quad (1)$$

where N is the number of samples and $S(\cdot)$ is the sign function. An outstanding feature of BIMBO is that the only analog component it requires is a one-bit ADC, which makes for a very low integration cost. More details can be found in [8].

The present paper deals in detail with the use of BIMBO in the context of sigma-delta MEMS. Mostly, we show how the BIMBO method can be used for estimating the parameters of sigma-delta sensor architectures, such as those of Fig. 1. In such designs, the binary signal s_k is taken at the sigma-delta ADC's output. As for the input signal u_k , it may be generated with different approaches, depending on whether the feedback loop can be opened or not. Regardless of which approach is used, BIMBO yields an estimation of the input acceleration along with an estimation of the parameters of the sensing cell and of the associated electronics. The coefficients of $G(z)$ can then be modified accordingly for optimal sensor performance. Simulated and experimental results are commented in the case of a sigma-delta micro-gyroscope (Fig. 3).

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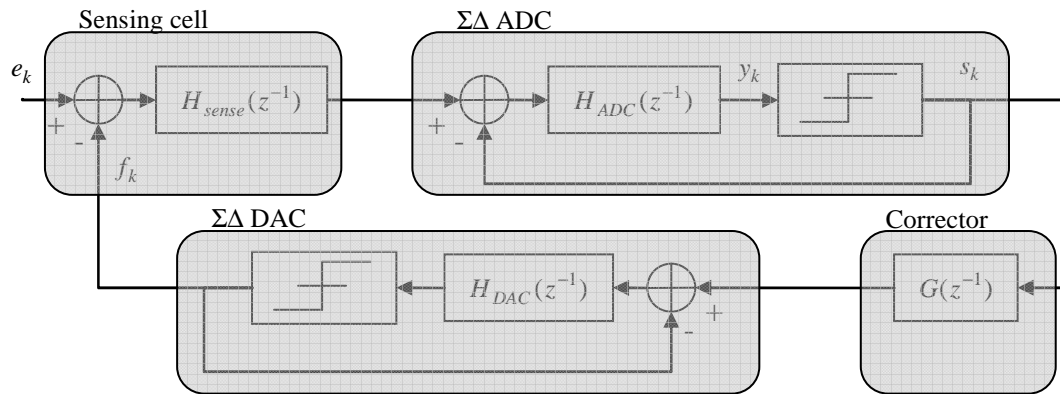


Fig. 1 - Generic architecture of a sigma-delta MEMS sensor, as appear in [4-5]. When the sensor works properly, it is possible to model the sensing cell as a linear system. Environmental variations and fabrication dispersions affect the coefficients of H_{sense} as well as those of H_{ADC} .

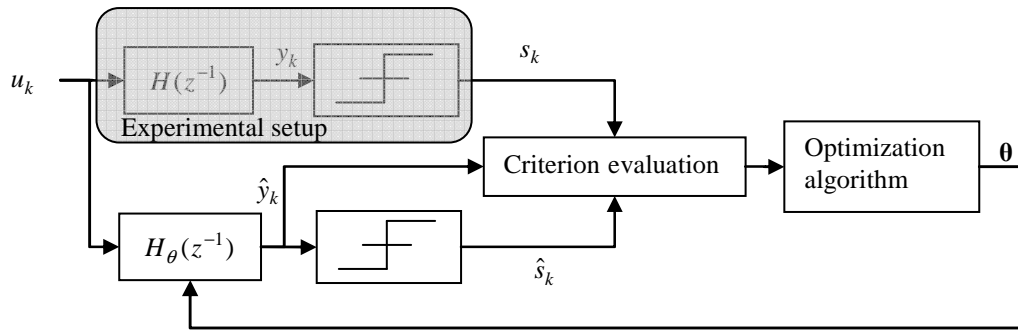


Fig. 2 - Block diagram of the BIMBO method. A parametric model of the real system is built so as to maximize the similarity between s_k and \hat{s}_k . A smooth criterion is given by (1)

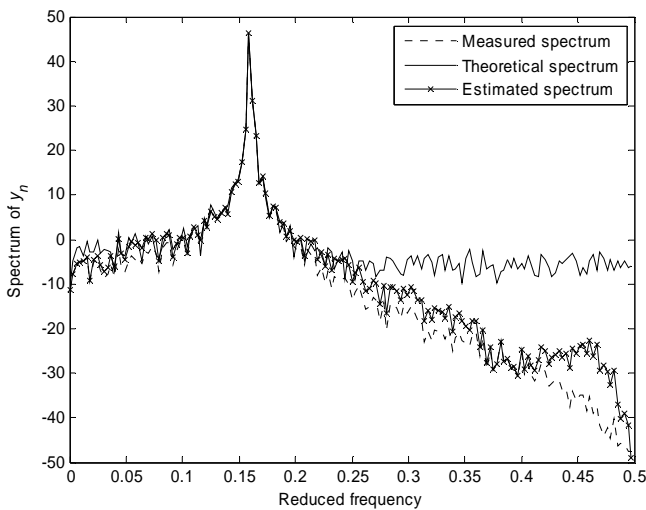


Fig. 3 - Estimation of the parameters of an ARX model of the sensing cell of a micro-gyroscope ($Q \approx 1000$). The spectrum obtained with BIMBO (using only the sign of the system's output) fits to the theoretical one, in spite of the presence of measurement noise at the comparator input.

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