

AN FPGA-BASED SYSTEM FOR THE MEASUREMENT OF FREQUENCY NOISE AND RESOLUTION OF QCM SENSORS

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Abstract— The use of Quartz Crystal Oscillators (QCM) as high accuracy microbalance sensors is limited by the frequency noise present in the circuit. This work deals with the design and implementation of an FPGA-based system for the real-time measurement of the frequency noise and resolution of QCM sensors. This reconfigurable system integrates the frequency measurement and the mass resolution computation in a single FPGA chip. Parallel processing, pipeline stages and prediction techniques are combined in order to accelerate the computations maintaining a low hardware complexity. By this way, a reconfigurable and low cost QCM sensor system working as a standalone measurement platform with communication capabilities is obtained. The implemented system was validated with a Xilinx Virtex-4 FPGA and a QCM sensor operating in damping media for electrochemical applications.

Keywords—FPGA, QCM, SoC, DSP, Frequency Noise, Mass Resolution, Allan Deviation.

I. INTRODUCTION

A QCM sensor is an acoustic resonator used as high accuracy microbalance intended to measure mass changes in the nanogram range on the basis of frequency variations. The sensor consists of an oscillator circuit containing a thin disk of AT-cut quartz crystal with circular metallic electrodes on both sides (Fig. 1). By applying an alternating voltage to the electrodes the resonator is excited to mechanical oscillations due to the piezoelectric effect. The quartz crystal resonance frequency is sensitive to any mass change at its surface (Sauerbrey, 1959; Granstaff and Martin, 1994).

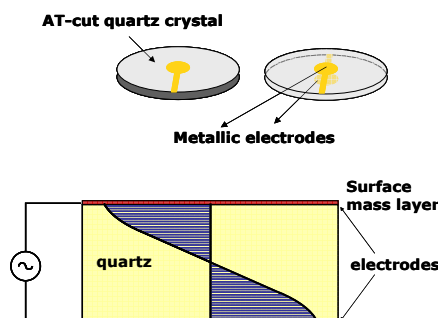


Figure 1. QCM device structure.

To characterize the behavior of QCM sensors, it is not enough to determine their experimental sensitivity, but rather it is essential to study the frequency fluctuations in order to establish the sensor resolution (Rodríguez-Pardo *et al.*, 2004). This is fundamental in the case of oscillators for damping media, because the noise level rises due to the strong decline of the quality factor of the resonator, resulting in a lesser ability to resolve small changes in the measurand (Vig and Walls, 2000). To normalize the frequency stability measurements in the time domain, the IEEE has proposed a two-sample variance without dead time, called Allan variance (IEEE Std. 1139, 1999), whose expression is the following:

$$\sigma_y^2(m, \tau) = \frac{1}{2f_o(m-1)} \sum_{n=1}^{m-1} (\bar{f}_{n+1}(\tau) - \bar{f}_n(\tau))^2 \quad (1)$$

The oscillator detection limit, i.e. the smallest frequency deviation that can be detected in presence of noise is equal to:

$$\Delta f(\tau) = \sigma_y(\tau) \cdot f_o \quad (2)$$

Finally, the mass resolution can be obtained by the relationship between the detection limit and sensitivity by:

$$Resolution = \frac{\Delta f(\tau)}{k} \quad (3)$$

In the above equations $f_n(\tau)$ (from now f_n) is the n -esim sample of the average frequency calculated over a time interval τ starting from an instant t_n , f_o is the nominal frequency of the sensor, m is the number of samples and $k=2,26 \cdot 10^{-6} \cdot f_o^2$ (Hz g⁻¹ cm²) is the mass sensitivity coefficient, known as the Sauerbrey coefficient (Sauerbrey, 1959).

In practice, the implementation of a real-time system to estimate the Allan deviation directly from Eq. 1 is not simple because of the amount and complexity of the required calculus when an elevate number of samples (m) is analized. There have been some proposals in the past for the implementation of the real-time Allan deviation measurement. Kuboki and Ohtsu (1990) used a system combining a personal computer and an ad-hoc high speed data acquisition card in order to estimate the Allan deviation. Mingfu *et al.* (2000) proposed a software algorithm for reducing the computation complexity on the basis of using a recursive formula. In this paper we propose the implementation of a SoC ("System On Chip") combining software and hardware parts to perform the complete Allan deviation calculation and