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MICRO-G MEMS ACCELEROMETER BASED ON TIME MEASUREMENT

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KEYWORDS

MEMS accelerometer, pull-in time.

INTRODUCTION

A considerable amount of researched is dedicated to MEMS accelerometers and despite the efforts, there are still high resolution applications for which there are no suitable micromachined accelerometers available. Applications such as inertial navigation, seismic activity monitoring and space microgravity measurements (Beeby et al. 2004), require resolutions better than 5 µg and typically demand a dynamic range of at least ± 1 g (120 dB if 1 µg resolution is considered).

State-of-the-art capacitive parallel-plates accelerometers have already demonstrated sub-µg resolution, with the total noise floor threshold being currently set on 230 ng√Hz by the device described in (Abdolvand et al. 2007). This device is open-loop operated and has a 5 Hz bandwidth. Nevertheless, the modified and dedicated micromachining procedures required for its fabrication render the path towards commercialization longer and more difficult.

A promising approach for the realization of µg-resolution accelerometer, introduced in (Rocha et al. 2008), uses the pull-in time measurement of microfabricated closed-loop operated structures as the detection mechanism. The micromachined structures to implement this accelerometer concept can be fabricated using standard commercially available fabrication processes. The devices presented here have been fabricated in a commercial SOI process (Cowen et al. 2009). The main disadvantages are the increase in the system complexity as compared to open-loop operation and the low system bandwidth.

ACCELEROMETER CONCEPT

The underlying physical principle for the transduction approach is the high sensitivity of the pull-in time to external forces in electrostatically operated micromechanical devices (Rocha et al. 2008). The existence of a metastable region during a pull-in transition has been demonstrated in overdamped micromechanical devices (Rocha et al. 2004). A very important feature of the meta-stability and associated pull-in time is its high sensitivity to external forces, such as acceleration.

A block diagram of the proposed time-based accelerometer is shown in Fig. 1. The core of the microsystem is a parallel plate microstructure with separate sensing and actuation electrodes. The microdevice is actuated by a square wave with voltage Vstep = αVpi, α>1 (where Vpi is the pull-in voltage) and period larger than the nominal pull-in time. The capacitive changes of the microdevice are converted to a voltage by a front-end readout circuit. Since the changes in capacitance are quite large (considering nearly full gap displacements), the capacitive readout specifications are low in terms of resolution and noise which is a competitive advantage to the conventional direct transduction and signal processing in the electrical domain approach. Following the capacitive transduction, the signal is fed to a comparator, and as soon as a threshold is reached (nearly full gap), the time measurement is stopped and ground is applied to prevent the movable electrode to reach the counter-electrode.

Finally, a time counting mechanism is used to measure the pull-in time, counting the time elapsed from rising edge of square wave to rising edge of comparator output. The pull-in time changes with the external acceleration sensed by the accelerometer.

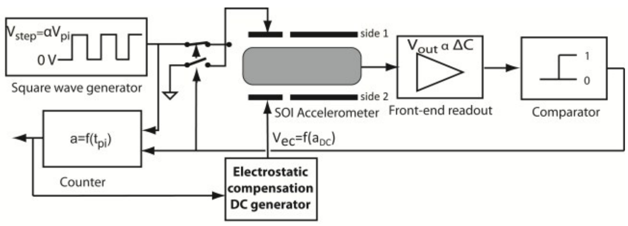

Figure 1: Microaccelerometer block diagram

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RESULTS

MEMS structures have been fabricated (Fig. 2), characterized and used to measure acceleration using a front-end capacitive readout circuit based on a charge amplifier (Fig. 3). The accelerations were applied by changing the horizontal angle of the supporting platform (Fig. 4).

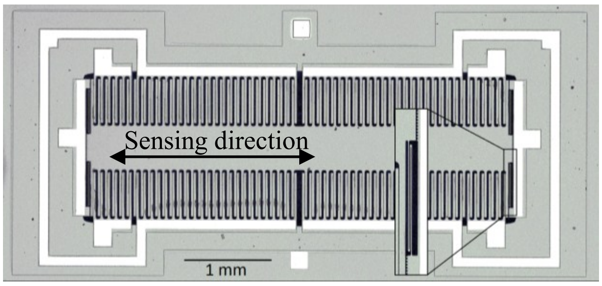

Figure 2: Microscope picture of the evaluated microstructure

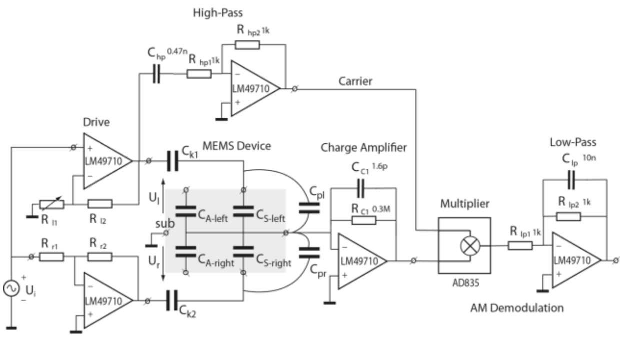

Figure 3: Displacement detection circuit with charge amplifier and AM demodulation stage

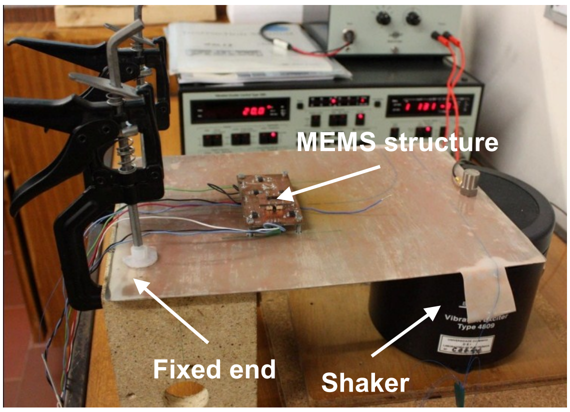

Figure 4: Experimental setup with the microstructure and the readout circuit mounted on a movable platform

The experimental results are in accordance with the simulations performed in Matlab/Simulink (Fig. 5).
Table 1 summarizes the accelerometer specifications.

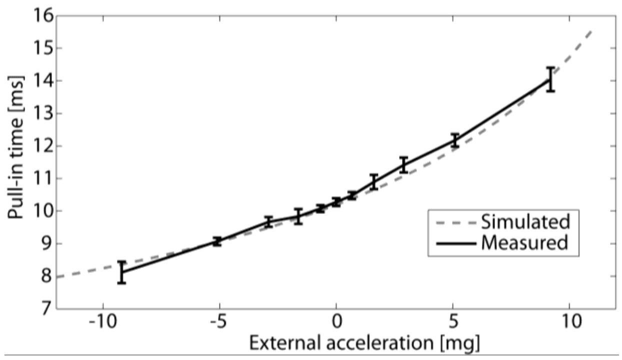

Figure 5: Accelerometer pull-in time response to small external accelerations.

Table 1: Main accelerometer parameters.

Device parameters	**Value**
Natural resonance frequency (f_0)	515 Hz
Sensor bandwidth (BW=1/2tpi)	50 Hz
Sensitivity	0.26 µs/µg
Operation range	± 0.4 g
Time measurement resolution	0.38 µg (clk 10MHz)
Dynamic range	120 dB
Mechanical-thermal noise	2.8µg/√Hz (200Hz,40µg)
Pull-in voltage (V_{pi})	3.005 V

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