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Novel Sensor Circuits Design Using Multi-physics Simulation for CMOS-MEMS Technology

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Abstract

This paper presents a novel sensor circuits design and measurement results with a single-axis integrated MEMS accelerometer fabricated on a 0.35-μm CMOS technology, using our in-house multi-physics simulation tool.

1. Introduction

Microelectromechanical systems (MEMS) sensors have been used in various fields such as accelerometers and gyroscopes [1]. Complementary metal-oxide semiconductor (CMOS)-MEMS technology is an attractive method to improve their performance [2, 3]. Comprehension of behavior of large-scale integrated circuits (LSI) and MEMS is beneficial to design CMOS-MEMS sensor circuits.

In this paper, we propose a novel sensor circuit design using a multi-physics simulation tool for CMOS-MEMS technology. A single-axis MEMS accelerometer has been developed on the proposed sensor circuit chip. Simulation and experimental results are discussed.

2. Concept of proposed sensor circuits

Figure 1 illustrates the cross section of a single axis MEMS accelerometer. A proof mass supported by four suspensions is moved vertically by the acceleration until hitting the stoppers placed to avoid mechanical failure due to overshoot. Upon an impinging mechanical shock such as an acceleration change, the capacitance changes between the proof mass and the fixed electrode, which is detected by the integrated sensor circuits.

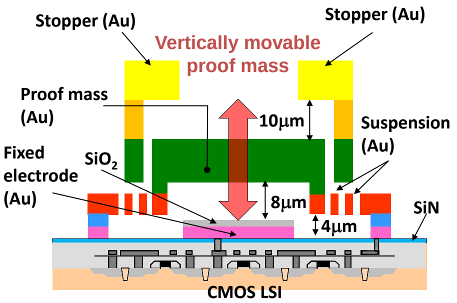


Fig. 1 Cross section of a single axis MEMS accelerometer.

Figure 2 shows a concept of the proposed sensor circuits. In most conventional sensor circuits, differential capacitance change is read as input from a comb-drive accelerometer. In our proposed sensor circuits, however, we read a capacitance signal from a MEMS and compare it with a reference capacitor built-in the sensor LSI. This concept has three features: (1) reference capacitor in MEMS is spared to save the total device footprint. (2) Measurement scheme is universally applicable to various types of MEMS devices. (3) Calibration procedure is simple because the reference capacitor values are already known.

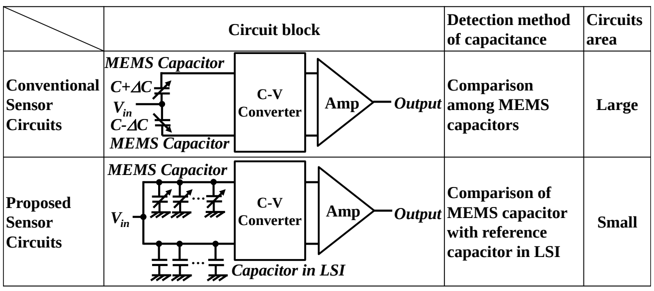
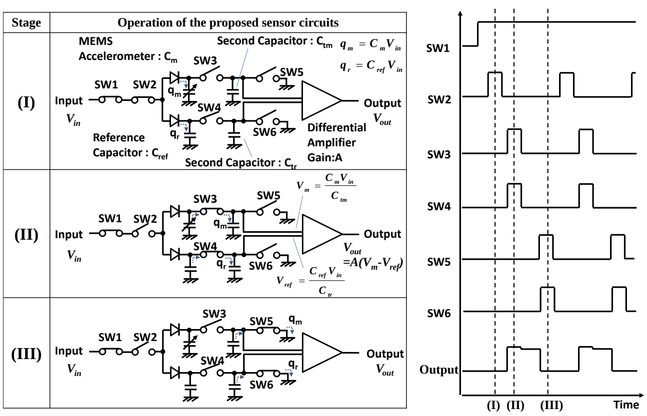


Fig. 2 Concept of proposed sensor circuits in comparison with conventional scheme.



(a) (b)

Fig. 3 (a) Operational principle of the proposed sensor circuits with three stages and (b) timing chart.

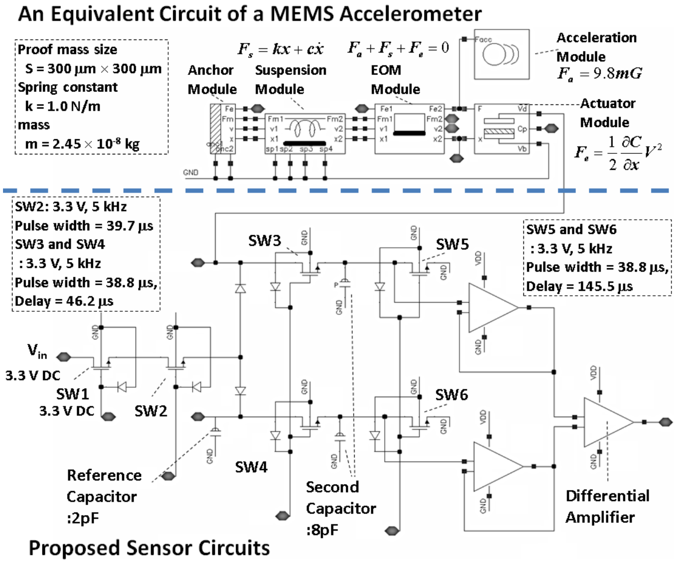


Fig. 4 Schematic of a proposed sensor circuits connected with an equivalent circuit of a MEMS accelerometer.

Operational principle and time chart of the proposed sensor circuits are shown in Figure 3 (a) and (b), respectively. The capacitor of the MEMS accelerometer and the reference capacitor are charged by the input voltage V_{in} (stage (I)). The charged electrons are then transferred to the second capacitors, C_{tm} and C_{tr}, where the difference of the charged-up voltages is read out by the differential amplifier (stage (II)), followed by discharging the capacitors (stage (III)). Switches from SW1 to SW6 are operated according to the time chart.

Figure 4 shows the schematic of the proposed sensor circuits connected with an equivalent circuit of the MEMS accelerometer. The equivalent circuit consists of five modules: an actuator module to read out the electrostatic force F_e, a suspension module for viscoelastic restoring force F_s, an acceleration module to calculate acceleration force F_a, an equation-of-motion (EOM) module to calculate the velocity and displacement as a result of impinging force, and an anchor module to fix the mechanical ends. These modules are described by a Verilog-a compatible hardware description language, and designed to handle with the multi-physics simulations in a single LSI design platform such as Cadence Virtuoso [4]. The behaviors of LSI and MEMS are simultaneously simulated to design the sensor circuits.

3. Measurement results

Figure 5 shows the optical microscope image of the developed MEMS accelerometer stacked on a 0.35-μm-CMOS circuit. Figure 6 shows the output voltages of the sensor circuits at the input acceleration as 3G. Operational frequency of SW1 to SW6 and input voltages are used as shown in Fig.4. We found a good agreement of the waveforms and voltages between the measurement results and the multi-physics simulation results, thereby confirming the feasibility of our sensor circuits.

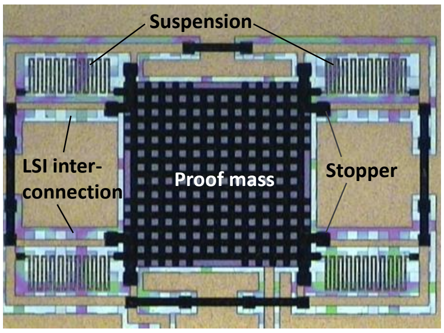
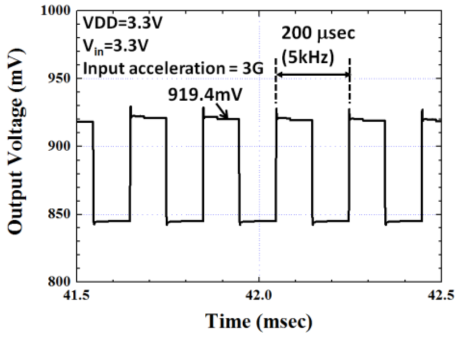
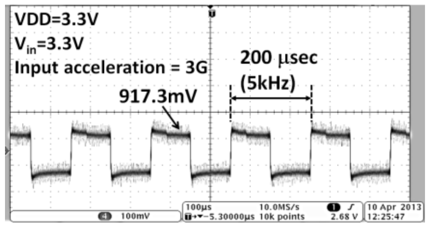


Fig. 5 Optical microscope image of the fabricated MEMS accelerometer stacked on 0.35-μm proposed sensor circuits.



(a)



(b)

Fig. 6 . Output voltages of proposed sensor circuits; (a) multi-physics simulation results, and (b) measurement results with Tektronix MSO3014 oscilloscope.

4. Summary

We have developed a novel sensor circuit design using a multi-physics simulation. A single axis MEMS accelerometer stacked on a 0.35μm-CMOS sensor circuit has been developed, and its electromechanical performance has been experimentally confirmed to agree with the simulation results. We confirmed that proposed circuits design will shed light on realizing CMOS-MEMS sensors.

Acknowledgements

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