Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp798-799

Novel Gain-Controlled Sensor Circuits Designed by Multi-physics Simulation for CMOS-MEMS Accelerometer

Toshifumi Konishi[1], Daisuke Yamane[2, 4], Motohiro Takayasu[2, 4], Hiroyuki Ito[2, 4], Shiro Dosho[2, 4], Noboru Ishihara[2, 4], Kazuya Masu[2, 4], Hiroshi Toshiyoshi[3, 4], and Katsuyuki Machida[1, 2, 4]

[1] NTT Advanced Technology Corporation
3-1 Wakamiya, Morinosato, Atsugi, Kanagawa 243-0124, Japan
Phone: +81-46-250-3682 E-mail: toshifumi.konishi@ntt-at.co.jp
[2] Tokyo Institute of Technology
4259-S2-14 Nagatsuta, Midori-ku, Yokohama, Kanagawa 226-8503, Japan
[3] Research Center for Advanced Science and Technology, The University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan
[4] CREST, JST
4-1-8 Honcho, Kawaguchi, Saitama, 332-0012, Japan

Abstract

This paper presents novel gain-controlled sensor circuits for CMOS-MEMS accelerometer. We have precisely designed the sensor LSI through analysis of both mechanical and electrical behaviors by multi-physics simulation. Measurement results of the developed MEMS accelerometer fabricated onto 0.18-μm CMOS LSI show that we could achieve the sensitivity ranging from 23 mV/G to 604 mV/G with the use of the gain-controlled amplifier.

1. Introduction

MEMS (microelectromechanical systems) accelerometers are used in various field, and required to obtain wider detection range, lower noise for sub-1 G (1 G = 9.8 m/s^2) detection, and smaller footprint [1]. To solve the above issues, we have proposed an integrated CMOS (complementary metal-oxide-semiconductor) –MEMS inertial sensor, where MEMS structures have been implemented onto LSI (large scale integrated circuits) [2-4].

In this paper, we propose novel gain-controlled sensor circuits for a CMOS-MEMS accelerometer. To comprehend the electromechanical behavior of both MEMS structure and sensor circuits simultaneously, circuit design using multi-physics simulation has been demonstrated. The accelerometer has been fabricated onto a 0.18-μm CMOS sensor LSI using post-CMOS gold electroplating process.

2. Design of Gain-Controlled Sensor Circuits

Figure 1 shows the conceptual image of the developed CMOS-MEMS accelerometer. The MEMS structures and sensor LSI are simultaneously designed by our multi-physics simulation environment with equivalent circuits of a MEMS accelerometer as shown in Fig. 2. Design parameters are listed in Table I. As an advanced concept from our previous work [3], we propose gain-controlled sensor circuits that a gain of the differential amplifier is controlled by a gain selector from x10 to x100. Moreover, the operation of analog circuits, such as switches and multiple built-in capacitors, are controlled by a digital frequency

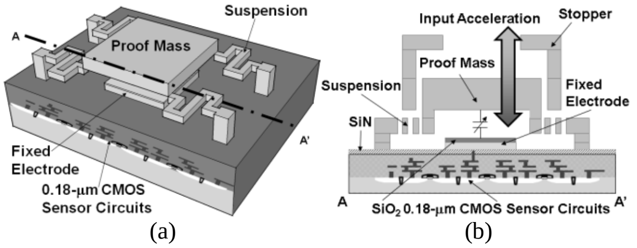

Fig. 1 Conceptual image of a CMOS-MEMS accelerometer; (a) bird view and (b) A-A' cross sectional image.

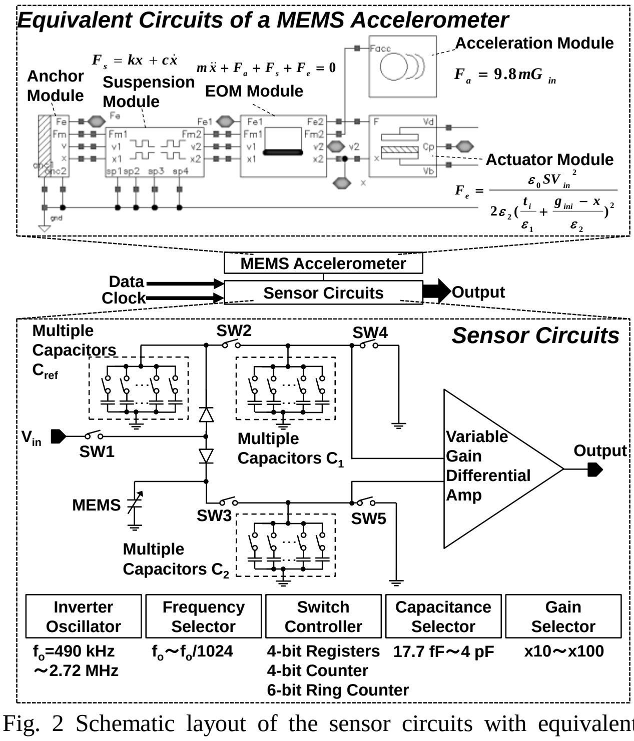

Fig. 2 Schematic layout of the sensor circuits with equivalent circuits of the MEMS accelerometer.

Table I Design Parameters

Parameters	Value
Proof mass size	2.1×2.4 mm^2
Detection range	< 1 G
Mechanical resonant frequency	266.8 Hz
Drive voltage of LSI	1.8 V

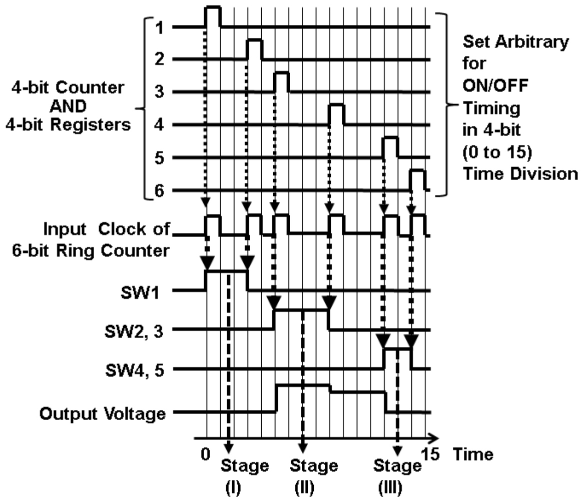

Fig. 3 Time chart of the designed sensor LSI.

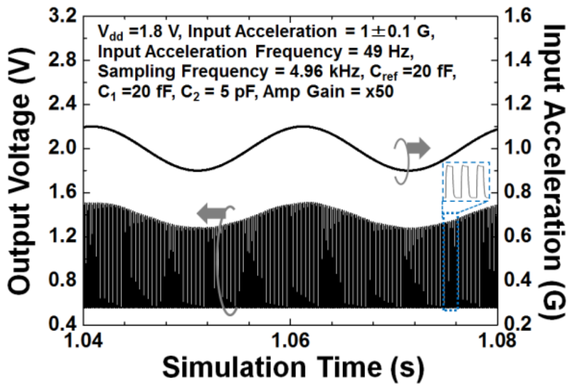

Fig. 4 Transient analysis results of the designed CMOS-MEMS accelerometer with the multi-physics simulation environment.

selector, a switch controller, and capacitance selectors.

The time chart of the sensor circuits consist of three stages as shown in Fig. 3. Signal flow is as follows: electron charge is supplied into the built-in capacitor C_{ref} and the MEMS capacitance between the proof mass and the fixed electrode (stage I). Charge transfer to C_1 and C_2, and the differences of the charged-up voltages between C_1 and C_2 are amplified (stage II), and discharge (stage III). By repeating the above stages, a transient change of the MEMS capacitance can be detected as an output voltage of the sensor circuits. Operational frequency of the sensor LSI is generated by the inverter ring oscillator, and divided by the frequency selector. Figure 4 shows the transient analysis results of the designed CMOS-MEMS accelerometer with circuit schematic as shown in Fig. 2. Simulation results indicate that the output voltages are changed by the input acceleration.

3. Results and Discussions

Designed sensor circuits have been fabricated with 0.18-μm CMOS process. Then, MEMS structures have been successfully implemented onto the LSI chip with the footprint of 4×4 mm^2 by gold electroplating as shown in Fig. 5. Figure 6 shows the output voltage as a function of input acceleration of the developed CMOS-MEMS accelerometer using a vibration exciter. These results showed that the developed CMOS-MEMS accelerometer achieved sensitivity of 23 mV/G, 211 mV/G, and 604 mV/G that were produced by the gain-controlled amplifier at x10, x20, and x100 using adequately selected capacitance values of C_{ref}, C_1, and C_2.

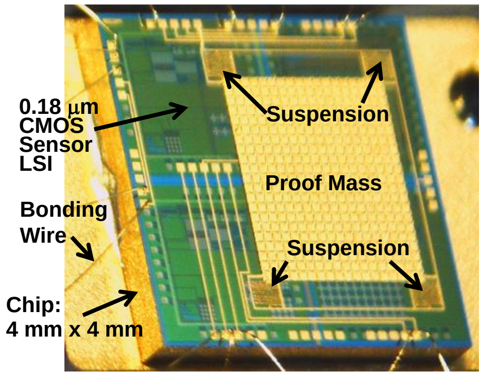

Fig. 5 Optical microscope image of the fabricated CMOS-MEMS accelerometer.

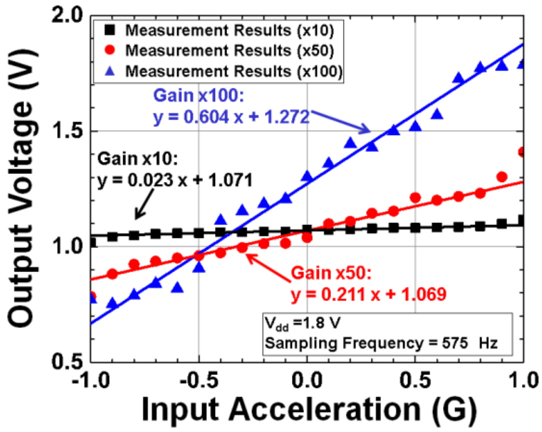

Fig. 6 Output voltage of the fabricated CMOS-MEMS accelerometer as a function of input acceleration at 49.9 Hz (sinusoidal wave) with Yokogawa DLM2022 oscilloscope.

4. Conclusions

We have proposed novel gain-controlled sensor circuits designed by multi-physics simulation for CMOS-MEMS accelerometer. We confirmed the validity of proposed circuit operation using the MEMS accelerometer fabricated onto a 0.18-μm CMOS sensor LSI. Our developed circuits shed light on a potential to detect below sub-1 G acceleration.

Acknowledgements

The authors would like to thank Dr. T. Maruno, Dr. Y. Akatsu, M. Yano, K. Kudo, T. Matsushima, and M. Fujinuma for technical discussion.

References

[1] S.-S. Tan, *et al.*, IEEE Trans. Circuits and Syst.-I, **58** (2011) 2661.
[2] D. Yamane, *et al.*, App. Phys. Lett., **104** (2014) 074102.
[3] T. Konishi *et al.*, *Ext. Abst. the SSDM 2013* (2013) 844.
[4] T. Konishi, *et al.*, Jpn. J. Appl. Phys. **52** (2013) 06GL04.