Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp114-115

Multichannel Capacitance to Voltage Converter for Pressure Sensor Front-end

Ryudo Kuguminato[1], Toshihiro Matsuda[1], Koji Izumi[1], Hideyuki Iwata[1], Masanori Mizushima[2], and Tsutomu Obata[3]

[1] Toyama Prefectural University
Kurokawa, Imizu, Toyama 939-0398, Japan
Phone: +81-766-56-7500 E-mail: matsuda@pu-toyama.ac.jp
[2] Oga Inc.,Takaoka, 933-0871, Japan
[3] Toyama Industrial Technology Center, Takaoka, 933-0981, Japan

Abstract

A multichannel CV converter circuit for a capacitive pressure sensor is proposed. Sampling technique, which eliminates amplifier blocks and reduces time constant of the output low pass filter, improves operation power and speed. Two channel CV converter has been fabricated with 0.18 μm CMOS, and confirmed its performance and power of 0.63 mW/channel.

1. Introduction

Pressure sensors are widely used in various applications and key issues for further market expansion are low cost and miniaturization, particularly in the consumer fields. Flexible sheet-like structure is another requirement for the application with human contacts such as medical area [1].

We have developed a flexible capacitive pressure sensor with conductive silicone rubber and polyethylene terephthalate (PET) sheet [2]. The sensor has the following advantages: simple structure, low cost, thin and small outline, and multichannel capability. A low power and high speed capacitance to voltage (CV) converter circuit is necessary to take the advantages of the sensor.

In this study, a low power multichannel channel CV converter circuit, which utilizes sampling techniques, is proposed. 2 channel CV converter has been fabricated with a standard 0.18 μm CMOS and confirmed the performance.

2. Sensor Structure and Conventional CV Converter

Fig. 1 shows a schematic cross section and a photograph of a flexible capacitive pressure sensor. A movable conductive rubber electrode and a facing silver electrode printed on a PET sheet form a capacitance, which changes with the displacement of the movable electrode.

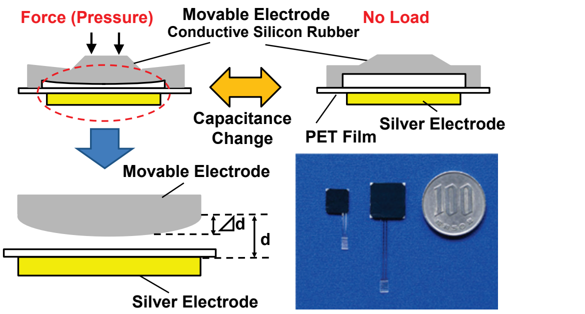

Fig. 1 A schematic cross section and a photograph of a flexible capacitive pressure sensor [2].

Fig. 2 shows a conventional CV converter circuit, which consists of three blocks of CV conversion, amplifier, and output [3]. V_{IN} and its inverted input pulses are supplied to the sensors C_1 and C_2, respectively. The difference charge stored in C_1 and C_2 are transferred to C_f, and the output V_{AMP1} is expressed as $V_{AMP1} = V_r + (C_1 - C_2)V_{IN} / C_f$. The pulsed output of V_{AMP1} is amplified and supplied to the output block of RC low pass filter, and is smoothed as the CV converter output V_{OUT}, which is proportional to the difference between C_1 and C_2. Relatively large output current of the amplifier and time constant of the low pass filter for the sufficiently stable output increase the power consumption and response time, which should be improved for multichannel applications.

3. Design of Low Power Multichannel CV Converter

Fig. 3 shows a proposed 2 channel CV converter circuit. The circuit from V_{IN} to V_{AMP1} is same as the conventional circuit. Since V_{AMP1} gives the proper output voltage periodically with V_{IN}, a sampling technique at the appropriate timing can extract the desired output only, and thus the amplifier block can be eliminated. In addition, it is

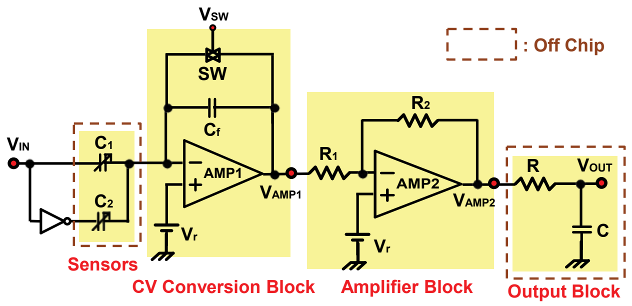

Fig. 2 Conventional single channel CV converter circuit [3].

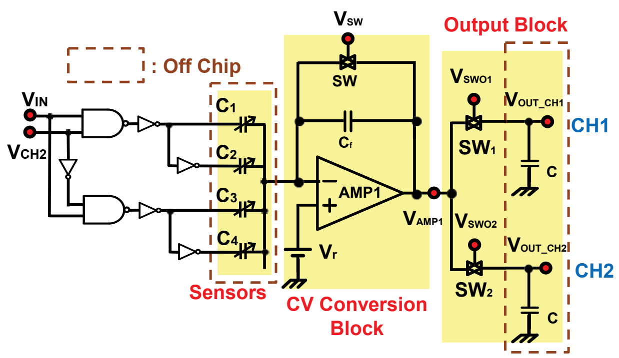

Fig. 3 Proposed 2 channel CV converter circuit.

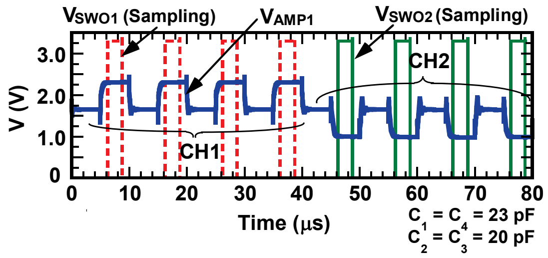

Fig. 4 HSPICE simulation result of V_{AMP1} and sampling signals V_{SWO1}/V_{SWO2}, which capture the proper voltage of V_{AMP1}.

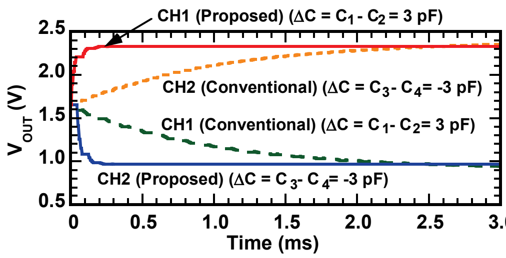

Fig. 5 Simulated waveforms of V_{OUT} for the conventional and proposed circuits.

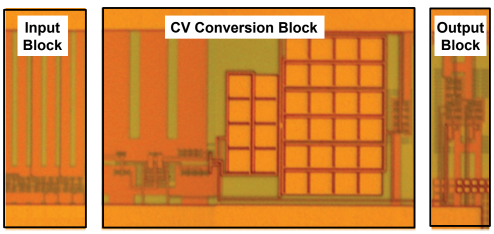

Fig. 6 Photographs of circuit blocks of 2 channel CV converter.

possible to reduce the time constant of the RC low pass filter significantly, and to use an on-resistance of the switching transmission gates as the resistor of the RC filter.

Fig. 4 shows a HSPICE simulation result of V_{AMP1} and sampling signals V_{SWO1}/V_{SWO2}, which capture the proper voltage of V_{AMP1}. Two different sampling periods of V_{SWO1}/V_{SWO2} can separate the 2 channel outputs. Fig. 5 shows simulated waveforms of V_{OUT} for our conventional and proposed circuits. The power and the response time become about 1/5 and 1/8, respectively. The proposed circuit is scalable and can easily expands channel counts. We also have designed an 8 channel CV converter, which can share a CV conversion block among the 8 channels.

4. Measurement Results of the Fabricated LSI

Fig. 6 shows photographs of circuit blocks of 2 channel CV converter fabricated with a standard 0.18 μm CMOS. Fig. 7 shows measured results of V_{AMP1} for $C_{1(4)}$ = 20 – 23 pF keeping $C_{2(3)}$ =20 pF. Although it gives slight overshoots around the transient region, V_{AMP1} holds the proper voltage during the sampling periods. Fig. 8 shows CV converter output V_{OUT} for ΔC (= $C_{1(3)}$ – $C_{2(4)}$) = ± 3 pF. Although the transient change of V_{OUT} cannot be observed in our setup, measured results of V_{OUT} agree with the simulation. V_{OUT} is proportional to ΔC in the range of 0 through 7 pF as shown in Fig. 9. The two channel CV converter LSI is successfully demonstrated and Table I summarizes the performance.

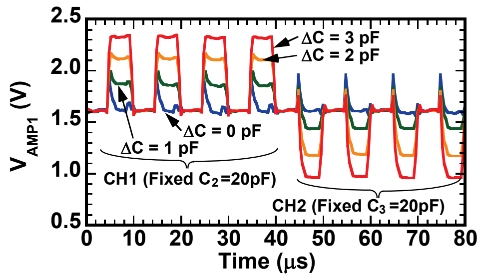

Fig. 7 Measured results of V_{AMP1} for various C_1 for fixed C_2.

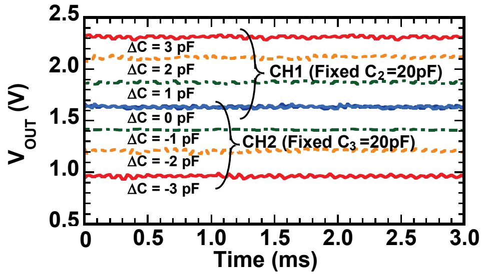

Fig. 8 CV converter output V_{OUT} for ΔC = ± 3 pF.

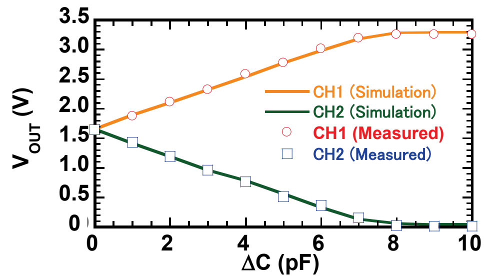

Fig. 9 Capacitance change ΔC dependence of V_{OUT}.

Table I Performance summary of the proposed circuit

	Proposed (2 CH)	Our Conv. (2 CH)	Ref. [4]
V_{DD} (V)	3.3 V	3.3 V	3.3 V
Process	0.18 μm CMOS	0.18 μm CMOS	0.6 μm CMOS
Circuit Area	0.13 mm²	0.27 mm²	0.71 mm²
Power consumption	0.63 mW	3.5 mW	2.7 mW
Response Time	0.3 ms	2.4 ms	1.0 ms

5. Conclusions

A two channel CV converter circuit for flexible pressure sensors has been proposed and fabricated with a standard 0.18 μm CMOS. The output is proportional to the difference of sensor capacitances up to 7 pF. Power consumption of the circuit is 0.63 mW, which is reduced by 80% from our conventional circuit. Response time of 0.3 ms is sufficiently fast for the further multichannel systems.

Acknowledgements

This work is supported by VLSI Design and Education Center (VDEC), the University of Tokyo in collaboration with Cadence Design Systems, Inc., Mentor Graphics, Inc., Rohm Corporation and Toppan Printing Corporation.

References

[1] H. Kim et al., Sensors and Actuators A: Physical, 165(2011) 2.
[2] T. Kasahara et al., Jpn. J. Appl. Phys., 50 (2011) 016502.
[3] K. Mochizuki et al., IEEE Trans. Instrum. Meas., 47 (1998) 823.
[4] X. Zhang et al., IEEE Trans. Instrum. Meas., 57 (2008) 1492.