Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp118-119

A Multi-sensor Readout Circuit Using Multiple Differential-input Operation Amplifier with Pulse Output

Ruey-Lue Wang[1], Chien-Cheng Fu[1], Chi Yu[1], Yan-Tse Chuang[2], Chen-Fu Lin[2], Hsin-Hao Liao[2], Hann-Huei Tsai[2] and Ying-Zong Juang[2]

[1] Department of Electronic Engineering, National Kaohsiung Normal University
No.62, Shenjhong Rd., Yanchao District, Kaohsiung City 824, Taiwan(R.O.C.)
Phone: +886-7-7172930ext7916 E-mail: rlwang@nknu.edu.tw
[2] National Chip Implementation Center, National Applied Research Laboratories
7F, Chimei Builiding, Tzu-Chiang Campus, No.1, Ta-Hsuch Rd., Tainan City 701, Taiwan(R.O.C.)

Abstract

In this paper, a CMOS multi-sensor readout circuit is presented. A multiple differential-input operational amplifier (MDI-OPA) with three distinct positive inputs and one common negative input is designed to take some one of three inputs to act as a general differential-input OPA by a built-in multiplexed architecture. A voltage-to-current converter and a current-controlled oscillator are integrated with the MDI-OPA in order that the analog voltages from sensors can be selectively multiplexed to generate pulse outputs which frequencies are linearly proportional to the related input voltage. A current-offset structure is added into the oscillator to shift the transfer characteristic line of the output frequency versus input voltage, which usually varies due to process variation. The measured output transfer characteristics of three input channels show nearly the same sensitivity of 90 Hz/mV or so with linearity of 99.99% at least by the assistance of the current-offset mechanism.

1. Introduction

For several decades, much attention has been paid to silicon-based biosensors in the biomedical applications. The ion-sensitive field-effect transistor (ISFET) is one of the most popular electric biosensors [1-3]. The ISFET is a modified MOSFET which gate oxide is open and is used as a sensing membrane. The variation in the ion concentration of the analyte is measured as a change in the threshold voltage [3] or a change in the effective gate voltage [2]. To make the implementation of sensing membrane flexible, an extended metal electrode, on which a sensing film is coated, can be interconnected to the polysilicon gate of a standard MOSFET. With the topology [4], the sensing area can be not constrained by gate size and the ISFET is easily integrated with its readout circuit.

The variation of performance with temperature is also an important issue for many biosensors. Thus, a temperature sensor, which generally has an analog output voltage [5], is usually necessary in an integrated CMOS multi-sensor chip. Sometimes, several biosensors must simultaneously be used to diagnose a disease or a biological molecular concentration. As mentioned above, the voltage is a common output type for biosensors. In this work, a CMOS multi-sensor readout circuit with three analog-voltage inputs is presented.

2. Circuit Design, Measurements, and Discussions

Fig.1 shows the circuit schematic of the multi-sensor readout circuit with pulse output which mainly consists of a voltage-to-current (V-I) converter and a current-controlled oscillator. Fig.2 shows a multiple differential-input operational amplifier (MDI-OPA) with three distinct positive inputs and one common negative input. In the MDI-OPA, a multiplex architecture is used to selectively supply one related differential input pair among the three positive inputs a biasing current and makes the MDI-OPA act as a general differential-input OPA with the selected input as its positive input. With the topology, all components of the whole readout circuit are common except the three differential pairs and the multiplex [2]. Thus, performance difference between three channels due to process variation or uneven layout parasitics in three readout signal paths can be decreased. The input MOSFET of the MDI-OPA can be replaced by the ISFET for biomedical applications. For the three input cases, circuit performance of the MDI-OPA is nearly the same. The MDI-OPA has gain of 88.6±0.02dB, 3-dB bandwidth of 624 ±1Hz, phase margin of 59±0.01°. The frequency response of biosensors is usually slower, so the design is focused on higher gain and good stability.

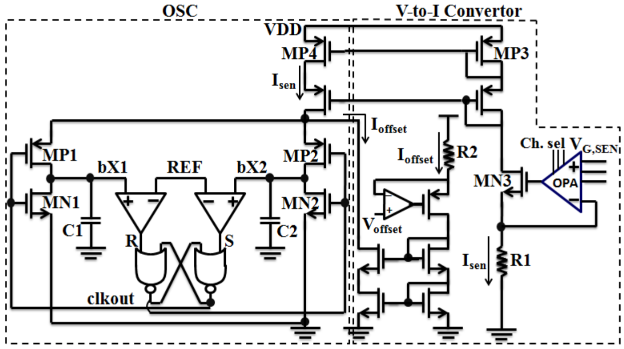

Fig. 1 The circuit schematic of the proposed multi-sensor readout circuit with pulse output.

The V-I converter mainly consists of MDI-OPA, MN3 and R1, as shown in Fig.1. The transferred current, i.e. $V_{G,SEN}/R1$, is mirrored to the following current-controlled oscillator and controls the charging speed of the capacitors

C1 and C2. With the faster discharging speed, .i.e. larger width of MN1 and MN2, the pulse frequency is linearly proportional to the charging current and the $V_{G,SEN.}$ An added V-I converter is used to adjust the charging current of the oscillator, which is really I_{sen}-I_{offset}. That is to say that the transferred current is offset by the added current, which is controlled by the bias voltage V_{offset}, and hence the characteristic line of the output frequency against the selected input voltage can be shifted by the offset current. Usually, process variation and inaccurate estimation of layout parasitics make the real output pulse frequencies of the three inputs with the same voltage value to be significantly different. By the current-offset mechanism, these characteristic lines can be adjusted to be nearly the same. For a urea sensor, two pH-ISFETs are usually used to determine the urea concentration. One detects the pH value of the blood or urine itself, and the other detects the pH value of the blood or urine after urease catalyses urea hydrolysis, where H^+ ions are consumed. The urea concentration is related to the difference between the two pH values. Therefore, the current-offset mechanism is critical to this kind of sensing method.

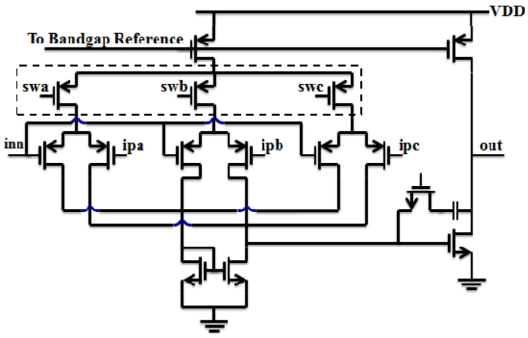

Fig. 2 The circuit schematic of the multiple differential-input operational amplifier.

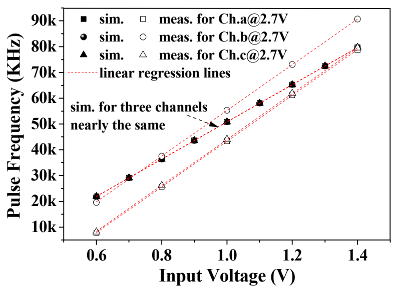

Fig. 3 Simulated and measured transfer characteristics of pulse frequencies versus three input voltages under the V_{offset} of 2.7V. Linear regression lines are also shown.

Fig.3 shows the simulated and measured transfer characteristics of pulse frequencies versus three input voltages under the V_{offset} of 2.7V, The simulated transfer characteristic lines are nearly the same for the three input cases under the same V_{offset}, but the three measured transfer characteristic lines are significantly different probably due to process-variation induced transistor mismatch in the multiplex or input differential pairs. By using different V_{offset} for the three input cases, the measured transfer characteristic lines are nearly the same, as shown in Fig.4, and the sensitivities are 90.68, 89.76, and 90.23 Hz/mV with linearity of 99.9996%, 99.9991%, and 99.9989%, respectively. The simulated sensitivities are smaller than the measured those probably due to process variation in R1 and inaccurate estimation of load parasictics. The chip is fabricated by TSMC 0.35um processes. The power consumption is 1.3mW under the supply voltage of 3V. The readout circuit itself occupies an area of 1.11×0.40 mm^2.

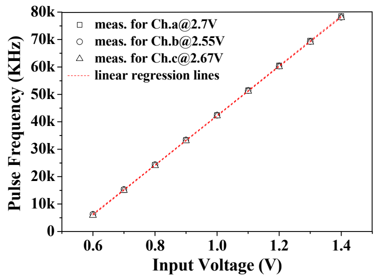

Fig. 4 Measured transfer characteristics of pulse frequencies versus three input voltages under different V_{offset} for the three input cases. Linear regression lines are also shown.

3. Conclusions

In this paper, a multi-sensor readout circuit using a multiple differential-input OPA is presented. The readout circuit selectively transfers one among three input voltages into a current by a multiplex architecture and a V-I converter, and then the current is used to control the charging current of a current-controlled oscillator. The output pulse frequency is linearly proportional to the input voltage with linearity of 99.99% at least. Transfer characteristic lines usually vary due to process variation in the attributes of transistor and resistor. An added V-I converter is used to adjust the charging current of the oscillator, and hence the transfer characteristic lines of the three input cases can be shifted to the wanted performance or identical performance. This architecture is suitable to be a readout circuit for urea sensors which need two identical pH-ISFET sensors. The readout circuit integrated with ISFETs is being prepared for measurement.

Acknowledgements

This work is supported by the National Science Council in Taiwan under the project contract NSC99-2221-E-017-004- MY3. The authors also want to thank the National Chip Implementation Center, Taiwan, for the support of TSMC CMOS processes.

References

[1] P. Bergveld, IEEE Trans. Biomed. Eng., **17**(1970) 70.

[2] R. L. Wang, C. C. Fu, C. M. Yeh, C. Yu, C. Y. Yu, C. F. Lin, H. H. Tsai, and Y. Z. Juang, *2012 International Conference on Solid State Devices and Materials* (2012) 142.

[3] D.R.S. Cumming, Electron. Lett., **47**(2011) S14.

[4] J.V.D Spiegel, I. Lauks, P. Chan and D. Babic, Sens. Actuators B, **4**(1983) 291.

[5] R. L. Wang, C. W. Yu, C. Yu, T. H. Liu, C. M. Yen, C. F. Lin, H. H. Tsai, and Y. Z. Juang, Electron. Lett. **48** (2012) 503.