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Variable Input Range Continuous-time Switched Current ΔΣ Analog Digital Converter for RFID CMOS Biosensor Applications

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Abstract**—** Continuous-time delta-sigma (ΔΣ) analog digital converter (ADC) for radio frequency identification (RFID) complementary metal oxide semiconductor (CMOS) biosensor has been reported. This ΔΣ ADC is suitable for digital conversion of biosensor signal because of small process variation, and variable input range. As the input range of continuous-time switched current ΔΣ ADC (Dynamic range : 50 dB [1], [2]) can be limited by using current reference, amplification of biosensor signal is unnecessary. The input range is switched to wide input range mode or narrow input range mode by command of current reference. When the narrow input range mode, the input range becomes ± 0.8 V. The measured power consumption is 5 mW and chip area is 0.31 mm^2 using 1.2 μm standard CMOS process. Additionally, automatic input range detecting system is proposed because of RFID biosensor applications.

Keywords**—** continuous time, delta sigma, A/D converter, RFID, biosensor, CMOS.

I. Introduction

RFID technology is a generic term that is used to describe a system that transmits the information of a tag wirelessly, using electromagnetic wave or inductive coupling. Depending on integrated circuit and antenna technology development, RFID has been used in various applications; smart card, factory automation system, toll gates for motor vehicles and container control system. Recently, other application examples have reported that RFID biosensor chips integrate the RFID and biosensor [3]-[5]. The advantage of RFID biosensor (Fig. 1) over wiring interface biosensor system include the following; inexpensive and low noise, subaqueous measuring system, the I/O buffer circuit is unnecessary, and application of implantable sensor. As the low power consumption and high accuracy, ADC that converts the biosensor analog signal is very important element of inner circuitry. However, existing ΔΣ ADC has some drawbacks.

In this paper, continuous-time ΔΣ ADC for RFID CMOS biosensor chip is discussed and optimized. In section 2 we decide the suitable ADC for RFID biosensor. Section 3 explains the principle of variable input range by using current reference. In section 4, the automatic input range detect system is proposed.

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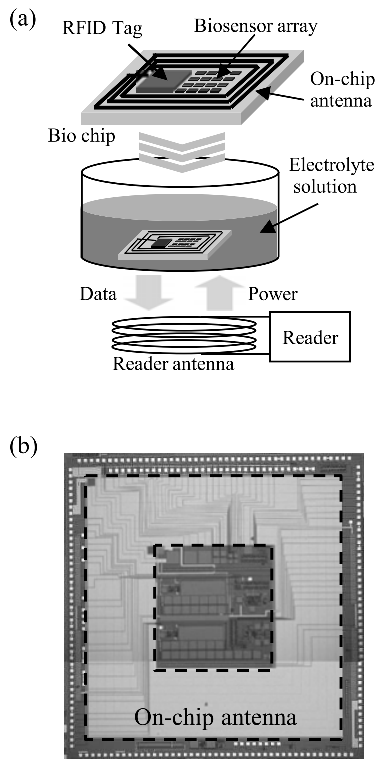

Fig. 1 (a) RFID biosensor measuring system.
(b) Micrograph of the chip.

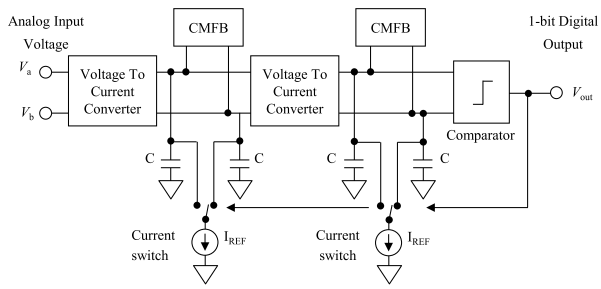

Fig. 2 The architecture of the continuous-time switched-current ΔΣ modulator.

The operation of this system is explained and confirmed by result of HSPICE simulation. Finally, Section 5 gives some conclusions.

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II. Suitable ADC for RFID Biosensor

As for our RFID biosensor circuit, ADC of high accuracy, small size and low power consumption is required because a signal change is small, and chip area and RFID power is limited. The delta-sigma (ΔΣ) ADC is suitable because of small size, low power consumption, and high resolution. There are two kinds of ΔΣ ADC; discrete-time (DT) ΔΣ ADC and continuous-time (CT) ΔΣ ADC. DT ΔΣ ADC has disadvantages because it requires large area for low pass filter (LPF) for anti-aliasing and high power consumption in switched capacitor input circuit. Above all, switch of ADC input range disturbs biosensor circuit output signal, which is a significant problem. Conventional CT ΔΣ ADC uses resistance and a large capacitor, resulting in the large area. Moreover, it is not accurately controllable due to the process variation. To solve these problems, continuous-time switched current (CTSC) ΔΣ ADC [1], [2] is used (Fig. 2). LPF is not needed for this type, and there is an advantage that it does not use resistance because it uses the current source for feedback. The input stage of CTSC ΔΣ ADC has not switched capacitor circuit but differential pair of MOSFETs, so that biosensor output signal is not influenced by sampling clock. Hence, this type is suitable for our RFID system.

III. Variable Input Range by Current Reference

A. Principle

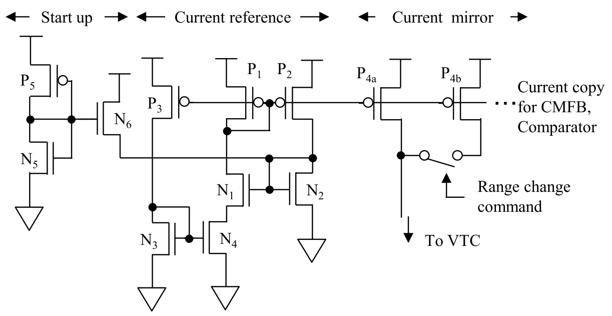

Fig. 3 Current reference with CMOS technology only.

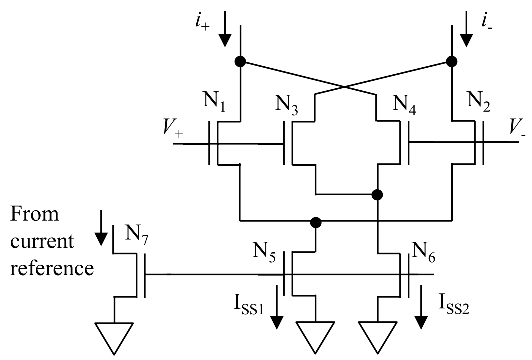

Fig. 4 The circuit diagram of voltage to current converter.

Because of a small signal change of biosensor, sensed signal should be amplified before digital converting [3], [4]. However, the same function can be achieved by limiting the input range of CTSC ΔΣ ADC. This is possible since the transconductance of voltage to current converter (VTC) [6] is determined by the tail currents. Figure 3 shows the circuit diagram of current reference [7]. This current reference is built by CMOS FETs only. The generated current can be copied by the current mirror and supplied to common-mode feedback (CMFB) circuit, comparator and VTC. For optimal linearity, the ratio of transistors ($N_1 = N_2 : N_3 = N_4$) is set to 5:3, and the ratio of the tail current level $I_{SS1}:I_{SS2}$ is set to 4:1 [6]. The circuit diagram of VTC is shown in Fig. 4. The difference of two output current is given by

$$i_+ - i_- = 2.58\sqrt{2 I_{SS2} K2}\left(V_+ - V_-\right), \qquad (1)$$

where $K2$ is proportional to W/L ratio of N_3 and N_4. Equation (1) shows that gain of VTC depends on the tail current I_{SS2}. Since the tail current of VTC is increased when the range change command is ON, the input range becomes narrower at higher gain of VTC.

B. Measurement

The measured result of variable input range CTSC ΔΣ ADC is shown in Fig. 5 and 6.The sampling frequency is set to 330 kHz. When input range is set to wide (Fig. 5), input range is almost 0 - 5 V. Contrastively, the input range become $V_b \pm 0.8$ V, when input range is set to narrow range mode (Fig. 6). In narrow input range mode, the input range is variable according to V_b. Figure 7 shows micrograph of the CTSC ΔΣ ADC fabricated by 1.2 μm standard CMOS process. The measured power consumption is 5 mW and chip area is 0.31 mm^2 (Current reference : 0.09 mm^2, CTSC ΔΣ ADC : 0.22 mm^2).

TABLE I
Truth Table of Input Range Decide Command

Input range	A	B	a	b	c
~ 2.5 V	High	High	High	Low	Low
2.5 V ~ 3.5 V	Low	High	Low	High	Low
3.5 V ~	Low	Low	Low	Low	High

TABLE II
Karnaugh Map of Control Circuit Output a

B \ A	Low	High
Low	Low	Low
High	*	High

a = A

TABLE III
Karnaugh Map of Control Circuit Output b

B \ A	Low	High
Low	Low	High
High	*	Low

$b = \overline{A} \bullet B$

TABLE IV
Karnaugh Map of Control Circuit Output c

B \ A	Low	High
Low	High	Low
High	*	Low

$c = \overline{B}$

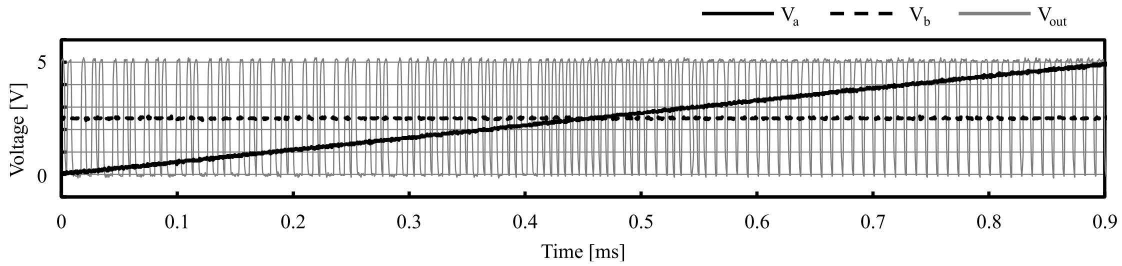

Fig. 5. The measured result of CTSC ΔΣ ADC. (Wide range mode)

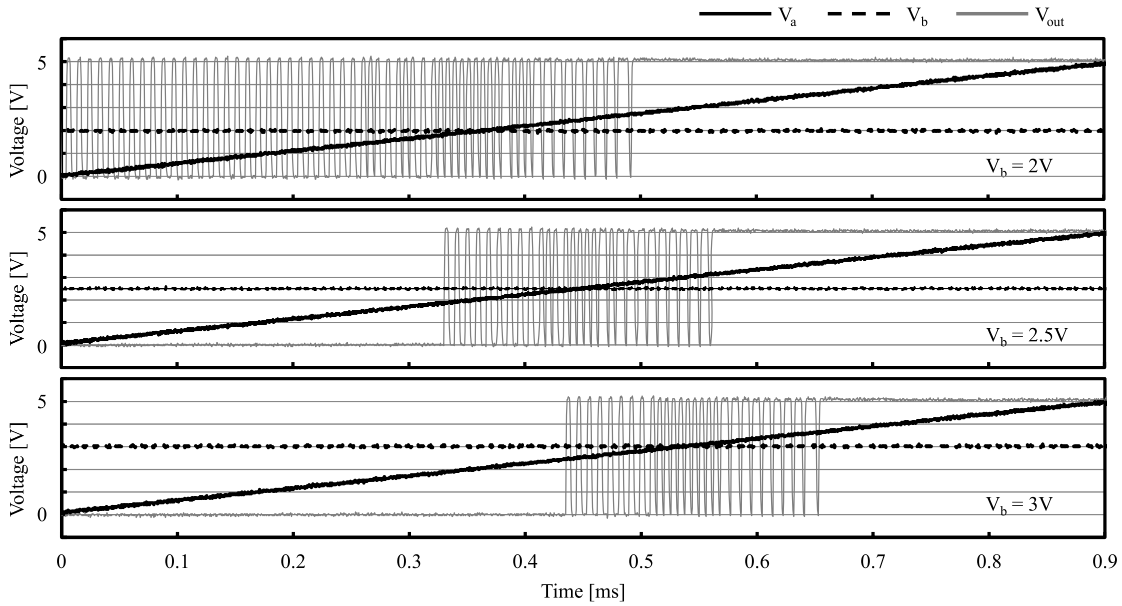

Fig. 6. The measured result of CTSC ΔΣ ADC. (Narrow range mode) The input range becomes $V_b \pm 0.8$ V.

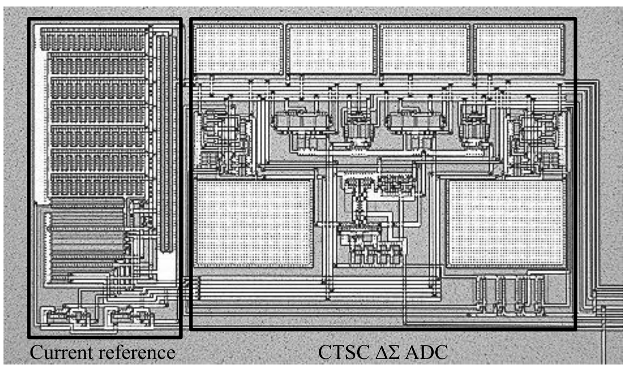

Fig. 7 Micrograph of CTSC ΔΣ ADC.

IV. Automatic Input Range Detecting System

A. Principle

Figure 8 shows the block diagram of automatic input range detection system. The input range is switched to wide input range mode or narrow input range mode by range change command. When the wide input range mode is ON, center voltage of input range is set to 2.5 V and input range becomes almost 0 - 5V. Contrastively, when narrow input range mode is ON, input range is divided into 3 ranges (2.5V or less, 2.5 V to 3.5 V and 3.5 V or more). The range of input signal is detected by two comparators and center voltage of input range is decided by control circuit command a, b, and c. The truth table of command A, B, a, b, and c is shown in Table 1. The logic expression of control circuit output a, b, and c is simplified as Table 2, Table 3, and Table 4, respectively. As a result, control circuit can be composed as Fig. 9. Only 1 NAND and 1 inverter are needed. The input signal range can automatically detected by this system.

B. HSPICE simulation

The HSPICE simulation result of automatic input range detecting system is shown in Fig. 10. When narrow input range mode set to ON, V_b is changed by input signal V_a, automatically. The sampling frequency is set to 1 MHz. The simulated power consumption of entire system is 15 mW and estimated chip area is 0.45 mm^2 using 1.2 μm standard CMOS process. The circuitry operation is confirmed by HSPICE simulation result.

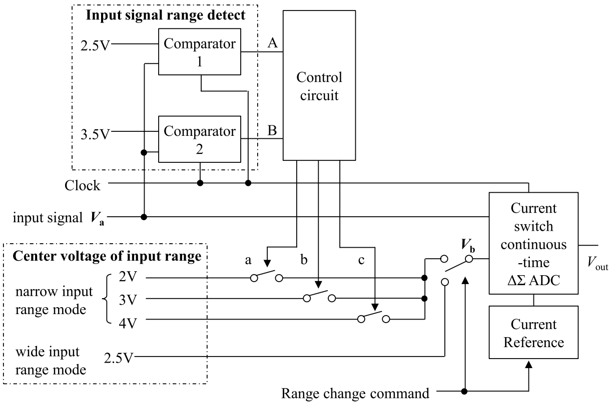

Fig. 8 Block diagram of automatic input range detecting system.

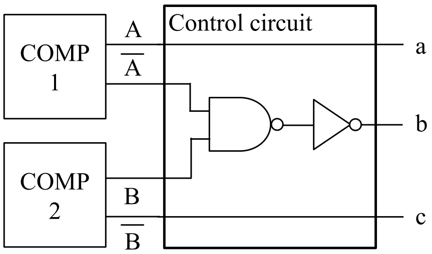

Fig. 9 Control circuit.

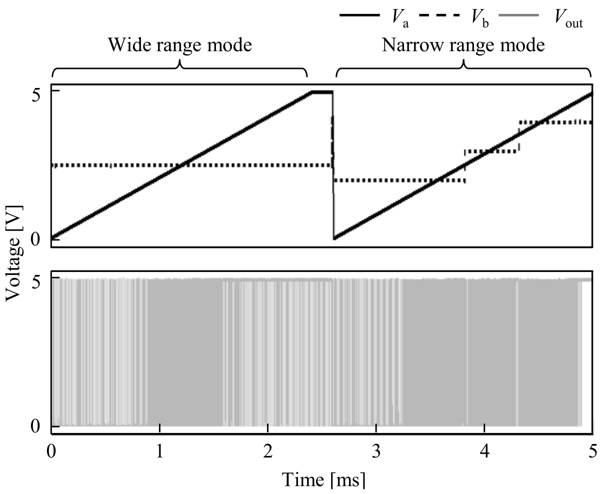

Fig. 10 The HSPICE simulation result of automatic input range detecting system.

V. CONCLUSIONS

The present work focuses on variable input range CTSC ΔΣ ADC. The input range is changed by the change of VTC gain, and the accuracy of ADC increases by narrowing the input range. The input range can be detected by proposed detecting system. Moreover, all operation can be controlled by only inside of the chip automatically and it is very advantageous to wireless system. Hence, this system is optimum for our RFID biosensor system.

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