Bridge Resistance Deviation-to-Period Converter for Resistive Biosensors

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ABSTRACT A bridge resistance deviation-to-period (BRD-to-P) converter is presented for interfacing resistive biosensors. It consists of a linear operational transconductance amplifier (OTA) and a current-controlled oscillator (CCO) formed by a current-tunable Schmitt trigger and an integrator. The free running period of the converter is 1.824 ms when the bridge offset resistance is 1 kΩ. The conversion sensitivity of the converter amounts to 3.814 ms/Ω over the resistance deviation range of 0-1.2 Ω. The linearity error of the conversion characteristic is less than ±0.004 %.

Key Word : Resistive Biosensor, Resistive Bridge Circuit, Bridge Resistance Deviation-to-Period Converter, Interface

Ⅰ. Introduction

Due to their high sensitivity, resistive biosensor bridges with four sensors can be widely used in many areas, especially biomedical measurement such as blood pressure, pulse and pulse transit time (PTT), and body temperature. In order to interface these sensors with digital systems, an accurate interface circuit converting a small change of resistance into a digital readout is required. A simplest approach of converting the bridge resistance deviation into a digital form is to convert the unknown resistance to frequency or time interval. Resistance-to-frequency conversion is mainly based on a relaxation oscillator [1], [2], which consists of a resistive bridge followed by an analog voltage differentiator (i.e., differential amplifier or differential integrator). On the other hand, resistance-to -time interval conversion is based on pulse-width modulators (PWMs) [3] or current- tunable Schmitt triggers [4]. The former consists of a resistive bridge followed by PWMs and a digital time differentiator, while the latter by voltage-to-current converters, current-tunable Schmitt triggers, a ramp voltage generator, and a digital time differentiator. These converters allow linear conversion of resistance deviation over time with high sensitivity. The main disadvantages of the converters are their complex circuit configurations and relatively low conversion linearity.

In this paper a new simple bridge resistance deviation-to-period (BRD-to-P) converter with high linearity is presented. The converter consists of a linear operational transconductance amplifier (OTA) and a current-controlled oscillator (CCO) formed by a current-tunable Schmitt trigger and an integrator.

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Ⅱ. Circuit Description and Operation

Fig. 1(a) shows the circuit diagram of the proposed BRD-to-P converter. The resistive biosensor bridge provides the voltage outputs given by

$$V_{OB} = \frac{2\Delta R + R_F}{2R + R_F} V_{CC} \qquad (1)$$

where VCC is the source exciting the bridge and ΔR represents the change in resistance of the biosensors and RFis fixed resistance for free running oscillation when ΔR is zero. The bio- sensor bridge output voltage VOB is converted into its corresponding dc current IB1 by the linear OTA marked LOTA

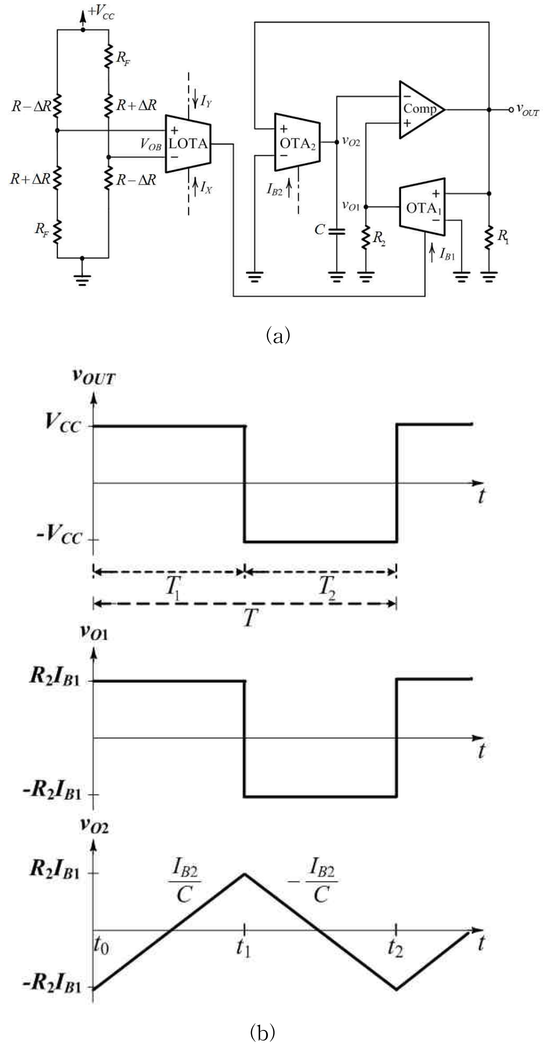
$$I_{B1} = G_m V_{OB} = G_m V_{CC} \frac{2\Delta R + R_F}{2R + R_F} \qquad (2)$$

where Gmis the transconductance gain of the LOTA. This dc current IB1 controls the oscillation period of the CCO so that the oscillation period is proportional to ΔR of the resistive biosensor. Two voltage amplifiers (one is composed of the comparator and R1 and the other OTA1 and R2) connected in a positive- feedback manner form a Schmitt trigger whose threshold voltage is directly proportional to the dc current IB1. OTA2 and the timing capacitor C form an integrator whose integration time constant is proportional to IB2. The waveforms associated with the oscillator are shown in Fig. 1(b). From these waveforms, one can find that the oscillation period T is given by

$$T = 4CR_2 \frac{I_{B1}}{I_{B2}} \qquad (3)$$

Substituting (2) into (3), we have

$$T = 4CR_2 \frac{G_m V_{CC}}{I_{B2}} \left(\frac{2\Delta R}{2R + R_F} + \frac{R_F}{2R + R_F} \right) \qquad (4)$$



(a)

(b)

Figure 1. (a) Circuit diagram of the proposed bridge BRD-to-P converter. (b) Output waveforms of the BRD-to-P converter.

Equation (4) indicates that the oscillation period is linearly proportional to ΔR of the resistive biosensor. The digital information can be obtained by counting the period T with an external clock. The conversion sensitivity of the converter is given by

$$\frac{\partial T}{\partial \Delta R} = \frac{8CR_2}{I_{B2}} \frac{G_m V_{CC}}{2R + R_F} \qquad (5)$$

It is noticeable that the conversion sensitivity can be controlled by the dc bias current IB2.

III. Linear OTA

A circuit diagram of a LOTA designed for the BRD-to-P converter is shown in Fig. 2 [5], [6]. It consists of a linear transconductor formed by transistors Q1~Q8 and an emitter-degeneration resistor RE, a translinear current gain cell Q9~Q12, and three Wilson current mirrors Q13~Q21. The LOTA converts the differential input voltage Vin into the single-ended output current Iout expressed as follows:

$$I_{out} = \frac{I_Y}{I_X} \frac{V_{\in}}{R_E} = G_m V_{in} \qquad (6)$$

The transconductance gain Gm is given by (IY/IX)(1/RE). Equation (6) indicates that the transconductance gain of the LOTA can be adjusted by varying the ratio of the dc bias currents IY and IX. The input linear range of the LOTA is $|V_{in}| \leq R_E I_X$.

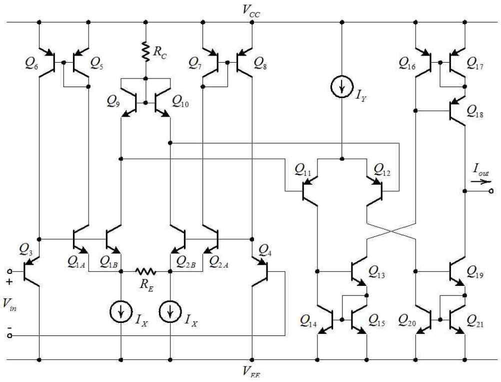


Figure 2. Circuit diagram of a LOTA designed for the BRD-to-P converter.

IV. Experiment Results

The LOTA circuit shown in Fig. 2 was breadboarded using the commercially available transistor arrays. The transistor arrays used were 2N2222 (npn) and 2N2907 (pnp). The resistors were RC = 150 kΩ and RE = 1 kΩ. The current sources were implemented with a Wilson current-mirror circuit. The bias currents IX and IY was set to 50 μA and 10 mA, respectively. The supply voltage VCC was 5 V and VEE was －5 V. The measured linearity error in its dc transfer characteristic of the LOTA was less than ±0.2 % in the differential input voltage range of ±20 mV.

The BRD-to-P converter circuit shown in Fig. 1(a) was built using the following discrete components: LM13600 for the OTA1 and the OTA2, LM318 for the comparator. The passive component values were adopted as follow: C = 5 nF, R1 = 10 kΩ, R2 = 2 kΩ, and RF = 1 ΩThe bias current IB2 was set to 10.4 μA. All measurements were performed at the supply voltages of VCC = 5 V and VEE = －5 V.

One arm of the bridge was constructed with a resistor of 1 kΩin series with a potentiometer of 10 Ω. All resistors are 0.5 % tolerance. The free running period of the converter is 1.824 ms when the bridge offset resistance R is 1 kΩ. Fig. 3 shows the measured period changes when ΔR was changed in 0.1 Ω steps from its fixed offset value of 1 kΩ. Resistance was measured using the Agilent digital multimeter type 3458A, and the HP frequency counter 53131A with a resolution of 0.01 μs in "period mode" was used to measure the period of the output rectangular waveform. Fig. 3 indicates that the conversion sensitivity of the converter amounts to 3.814 ms/Ω over the resistance deviation range of 0-1.2 Ω.

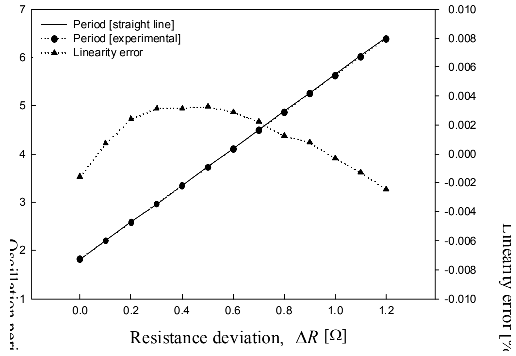


Figure 3. Measured period versus resistance deviation and its linearity error.

This sensitivity is comparable to that of the previous work [4]. The linearity error of the conversion characteristic is less than ±0.004 %, which is about three times lower than that of the previous work.

V. Conclusions

A new circuit has been described which converts a resistance change in the bridge into its equivalent period change. The design principle and circuit configuration of the converter is simple. Besides these, the converter features high sensitivity and linearity for small change of the resistive biosensors. Because of these advantages, the converter is expected to find wide applications in the signal processing of resistive bridge sensors.

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<Research Interests> Biomedical signal processing,
Image processing,
Signal processing system,
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