

저항형 바이오 센서를 위한 브릿지 저항 편차-주기 변환기

정원섭*

Bridge Resistance Deviation-to-Period Converter for Resistive Biosensors

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요약 저항형 바이오 센서를 인터페이싱하기 위해 브릿지 저항 편차-주기 변환기를 제안한다. 이 변환기는 선형 OTA(linear operational transconductance amplifier)와 전류-제어 발진기(current-controlled oscillator)로 구성된다. 브릿지 오프셋저항이 1 k Ω 일 때, 프리러닝 주기는 1.824 ms이다. 변환기의 변환 감도는 0-1.2 Ω 의 저항편 범위에서 3.814 ms/ Ω 이다. 변환 특성의 선형 에러는 ± 0.004 % 이내이다.

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 k Ω . 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

1. 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 simple

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

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Received : January 07, 2014

Revised : January 21, 2014

Accepted : January 27, 2014

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.

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

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

where V_{CC} is the source exciting the bridge and ΔR represents the change in resistance of the biosensors and R_F is fixed resistance for free running oscillation when ΔR is zero. The bio-sensor bridge output voltage V_{OB} is converted into its corresponding dc current I_{B1} by the linear OTA marked LOTA

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

where G_m is the transconductance gain of the LOTA. This dc current I_{B1} 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 R_1 and the other OTA1 and R_2) connected in a positive-feedback manner form a Schmitt trigger whose

threshold voltage is directly proportional to the dc current I_{B1} . OTA2 and the timing capacitor C form an integrator whose integration time constant is proportional to I_{B2} . 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

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

Substituting (2) into (3), we have

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

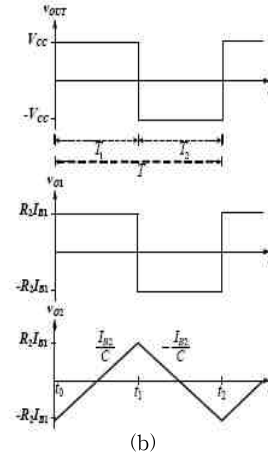
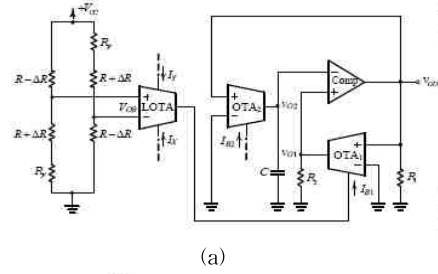


Figure 1. (a) Circuit diagram of the proposed bridge BRD-to-P converter. (b) Output waveforms of the BRD-to-P converter.

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

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

It is noticeable that the conversion sensitivity can be controlled by the dc bias current I_{B2} .

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 R_E , a translinear current gain cell Q9~Q12, and three Wilson current mirrors Q13~Q21. The LOTA converts the differential input voltage V_{in} into the single-ended output current I_{out} expressed as follows:

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

The transconductance gain G_m is given by $(I_Y/I_X)(1/R_E)$. Equation (6) indicates that the transconductance gain of the LOTA can be adjusted by varying the ratio of the dc bias currents I_Y and I_X . The input linear range of the LOTA is

$$|V_{in}| \leq R_E I_X$$

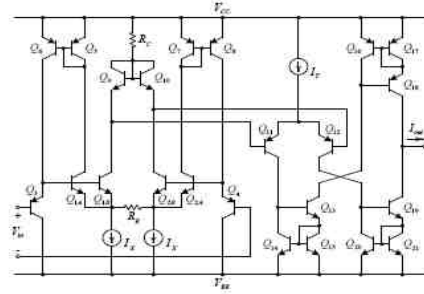


Figure 2. Circuit diagram of a LOTA designed for the BRD-to-P converter.

IV. Experiment Results

The LOTA circuit shown in Fig. 2 was breadboarded using the commercially available transistor arrays. The transistor arrays used were 2N2222 (nnp) and 2N2907 (pnp). The resistors were $R_C = 150 \text{ k}\Omega$ and $R_E = 1 \text{ k}\Omega$. The current sources were implemented with a Wilson current-mirror circuit. The bias currents I_X and I_Y was set to $50 \mu\text{A}$ and 10 mA , respectively. The supply voltage V_{CC} was 5 V and V_{EE} was -5 V . The measured linearity error in its dc transfer characteristic of the LOTA was less than $\pm 0.2 \%$ in the differential input voltage range of $\pm 20 \text{ mV}$.

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: $C = 5 \text{ nF}$, $R_1 = 10 \text{ k}\Omega$, $R_2 = 2 \text{ k}\Omega$, and $R_F = 1 \Omega$. The bias current I_{B2} was set to $10.4 \mu\text{A}$. All measurements were performed at the supply voltages of $V_{CC} = 5 \text{ V}$ and $V_{EE} = -5 \text{ V}$.

One arm of the bridge was constructed with a resistor of $1 \text{ k}\Omega$ in series with a potentiometer of 10Ω . 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 k Ω . Fig. 3 shows the measured period changes when ΔR was changed in 0.1 Ω steps from its fixed offset value of 1 k Ω . Resistance was measured using the Agilent digital multimeter type 3458A, and the HP frequency counter 53131A with a resolution of 0.01 μ s 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 .

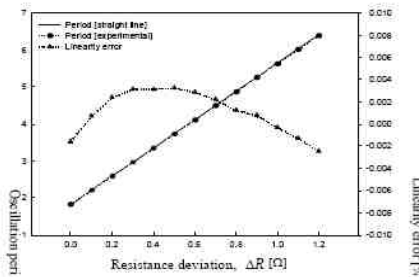


Figure 3. Measured period versus resistance deviation and its linearity error.

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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