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A simple resistance-to-time converter for resistive bridge sensors

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Abstract: A simple resistance-to-time converter is presented for interfacing resistive bridge sensors. It consists of two voltage comparators, a ramp voltage generator, and two logic gates. A prototype circuit built using discrete components exhibit a conversion sensitivity amounting to 2832.4 μs/Ω over the resistance deviation range of 0-2 Ω and a linearity error less than 0.005%. Power dissipation of the converter is 15.57 mW.

Keywords: circuit theory and design, resistance-to-time converters, resistive bridge sensors
Classification: Integrated circuits

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1 Introduction

The expanding use of microprocessors in measurement systems requires transducers with digital outputs. This is true of a low cost and high accuracy pressure and acceleration measuring system using resistive bridge sensors. A simplest approach of converting the bridge resistance deviation into a digital form is to convert the unknown resistance to frequency or time interval.

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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 conversion is based on pulse-width modulators [3] or current-tunable Schmitt triggers [4]. The former consists of a resistive bridge followed by pulse-width modulators and a digital time differentiator, while the latter by voltage-to-current converters, current-tunable Schmitt triggers, and a digital time differentiator. This paper describes a new resistance-to-time converter which is believed to be most simple in its configuration and operation. It requires two voltage comparators, a ramp voltage generator, and a digital time differentiator. The simplicity of the converter makes it suit for implementing a 'smart sensor', which gives a digital output directly connectable to a microprocessor.

2 Circuit Description and Operation

Fig. 1 (a) shows the circuit diagram of the resistance-to-time (R-to-T) converter for interfacing resistive bridge sensors. It consists of a ramp voltage generator, a resistive sensor bridge with four sensors, two voltage comparators, and two logic gates. The comparator 1 and the upper half bridge form a Schmitt trigger whose threshold voltage is given by

$$V_{TH1} = \left(1 - \frac{\Delta R}{R}\right)\frac{L_{1+}}{2} \tag{1}$$

where ΔR represents the change in resistance of the sensors and L_{1+} is the output saturation voltage of the comparator 1. Similarly, the comparator 2 and the lower half bridge form a Schmitt trigger whose threshold voltage is given by

$$V_{TH2} = \left(1 + \frac{\Delta R}{R}\right)\frac{L_{2+}}{2} \tag{2}$$

where L_{2+} is the output saturation voltage of the comparator 2. Note that V_{TH1} and V_{TH2} are proportional to the resistance change $1 - \Delta R/R$ and $1 + \Delta R/R$, respectively.

To see how the R-to-T converter operates, refer to Fig. 1 (b) which shows the signal waveforms at the various nodes of the converter, and assume that both of the Schmitt triggers are at their positive saturation levels (L_{1+}, L_{2+}) and the bridge is unbalanced. Prior to the start of the conversion cycle, the switch S connected in the ramp integrator is closed, thus discharging the timing capacitor C of the ramp integrator and setting the input voltages of the Schmitt triggers v_{INT} to 0 V. The conversion cycle begins with opening the switch S. Since the reference current I_R flows through the capacitor, v_{INT} rises linearly with a slope of I_R/C. When v_{INT} reaches the high threshold voltage of the upper Schmitt trigger V_{TH1}, the output of the upper Schmitt trigger v_{SMT1} falls to zero and the output of the XOR gate v_{OUT} becomes high. Denoting t_1 the time duration for which v_{SMT1} keeps L_{1+}, we can write

$$t_1 = \frac{C}{I_R}V_{TH1} = \frac{C}{2I_R}\left(1 - \frac{\Delta R}{R}\right)L_{1+} \tag{3}$$

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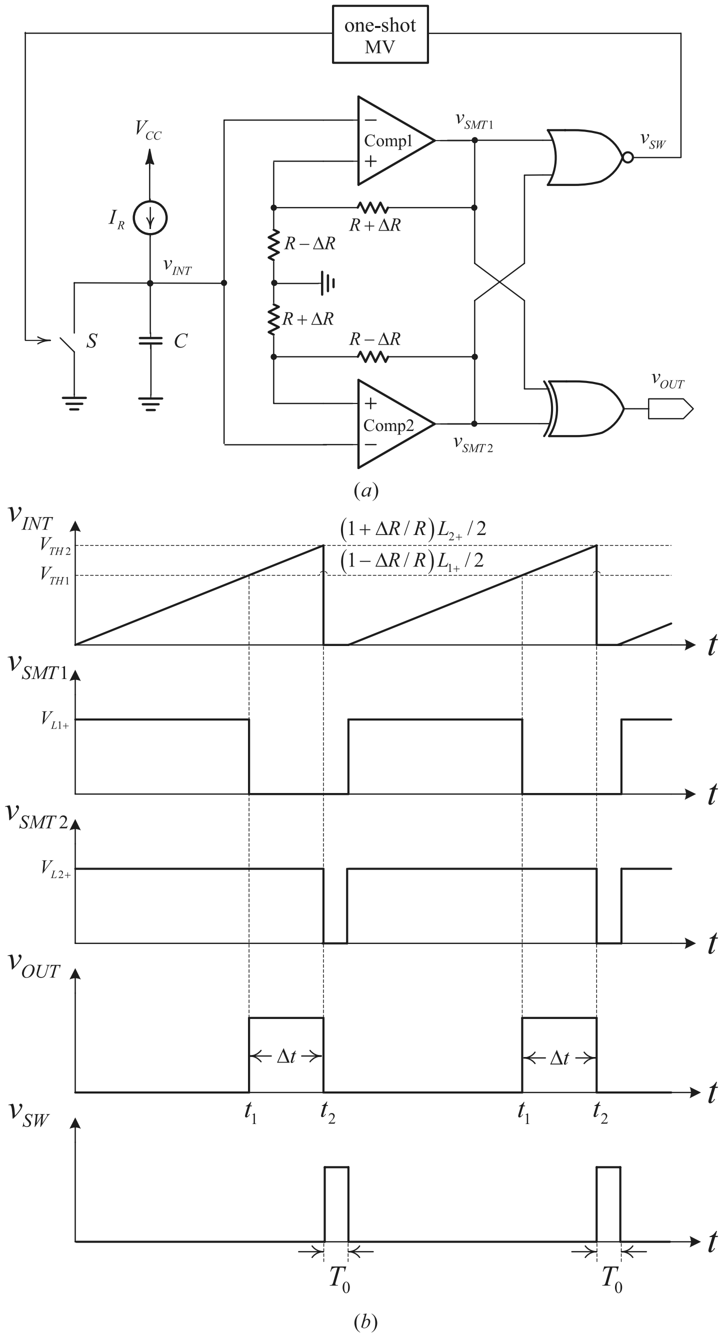

Fig. 1. (a) Circuit diagram of the resistance-to-time converter. (b) Voltage waveforms at the various nodes of the converter.

The conversion process continues until v_{INT} reaches the high threshold voltage of the lower Schmitt trigger V_{TH2}. At this instant the output of the lower Schmitt trigger v_{SMT2} falls to zero, thereby v_{OUT} becomes low and the output of the NOR gate v_{SW} becomes high. The switch S in the ramp integrator is now closed and thus clamping the voltage v_{INT} to ground. This in turn triggers the Schmitt triggers, causing their outputs rise to L_{1+} and L_{2+}, respectively, and v_{SW} go to low. The switch S is now opened after the fixed duration T_0 of the one-shot multivibrator and a new conversion process is started. Denoting t_2 the time duration for which v_{SMT2} keeps L_{2+}, we can

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write

$$t_2 = \frac{C}{I_R} V_{TH2} = \frac{C}{2I_R}\left(1 + \frac{\Delta R}{R}\right) L_{2+} \tag{4}$$

The time interval of v_{OUT} pulse is given by

$$\Delta t = t_2 - t_1 = \frac{C}{2I_R}\left\{\left(1 + \frac{\Delta R}{R}\right) L_{2+} - \left(1 - \frac{\Delta R}{R}\right) L_{1+}\right\} \tag{5}$$

If the comparators are identical, then $L_{1+} = L_{2+} = L_+$ and Δt is simplified to

$$\Delta t = \frac{C}{I_R}\frac{\Delta R}{R} L_+ \tag{6}$$

Equation (6) indicates that the converter offers an equivalent output pulse whose time interval is proportional to the resistance change. If L_{1+} is not equal to L_{2+}, the output can be expressed as follow:

$$\Delta t = t_2 - t_1 = \frac{C}{2I_R}(L_{2+} - L_{1+}) + \frac{C}{2I_R}\frac{\Delta R}{R}(L_{2+} + L_{1+}) \tag{7}$$

Examination of this result indicates that there is an offset error produced by differences of comparators.

3 Experimental Results

A prototype converter shown in Fig. 1 (a) was breadboarded using commercially available integrated circuits: LM311 for the comparators, 74HC02 for the NOR gate, and 74HC86 for the XOR gate. The one-shot multivibrator was constructed by using two NOR gates, a polystyrene capacitor of 47 nF, and a resistor of 50 kΩ. The following component values were adopted for the ramp voltage generator: an electrolyte capacitor $C = 2\,\mu$F and a constant current source $I_R = 5.8\,\mu$A. A Wilson current mirror and a resistor of 615 kΩ were used for producing the dc current source I_R. The transistors used for the current mirror were MPQ2907. The switch was 54HC4066. The supply voltage V_{CC} was +5 V.

One arm of the bridge was constructed with a resistor of 330 Ω in series with a potentiometer of 100 Ω. All resistors are 0.5% tolerance. Positive saturation levels of the comparators with a pull-up resistor of 300 Ω were measured. Their mismatch was about 0.3%. It is clear from Equation (7) that the offset error due to this mismatch is negligible. Fig. 2 shows the measured time interval changes when ΔR was changed in 0.1 Ω steps from its fixed offset value of $R = 350\,\Omega$. Resistance was measured using the Agilent digital multimeter type 34405A, and the HP frequency counter 53131A with a resolution of 0.01 μs in "period mode" was used to measure the time interval of the output pulses. Fig. 2 indicates that the conversion sensitivity amounts to 2832.4 μs/Ω with an offset error of 0.3 ms over the resistance deviation range of 0-2 Ω. The offset error is mainly due to the finite output resistances of the comparators. The linearity error of the conversion characteristic is less than 0.005%. The nonlinearity is caused by the nonlinear relation between the output current and voltage of the dc current source.

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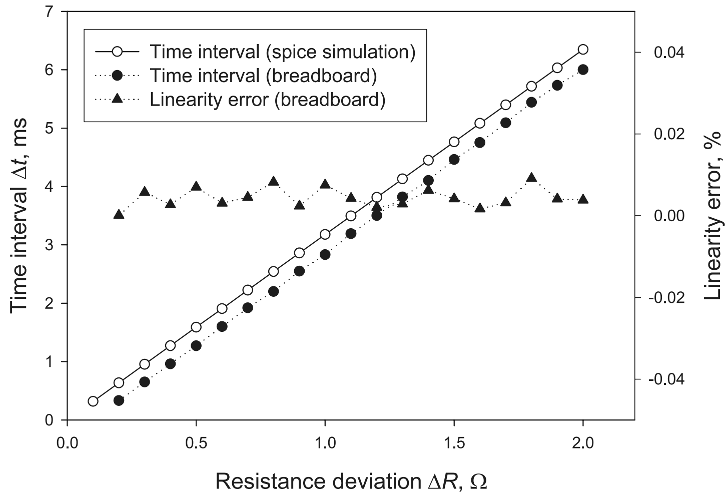

Fig. 2. Measured time interval versus resistance deviation and its linearity error.

This error can be reduced by adopting a precision current source using an operational amplifier [5].

Fig. 3 shows the time interval variation due to the power-supply voltage variation when $\Delta R = 0.5$ and $1.5\,\Omega$, respectively. For comparison, the converter in [4] was also examined and the results are plotted in Fig. 3, which indicates that the proposed converter is about six times more accurate than the conventional one at the power supply voltage of 3 V. This property together with its low power consumption of 15.57 mW makes the converter suit for the resistive sensor applications in which the low-voltage and low-power implementation is important.

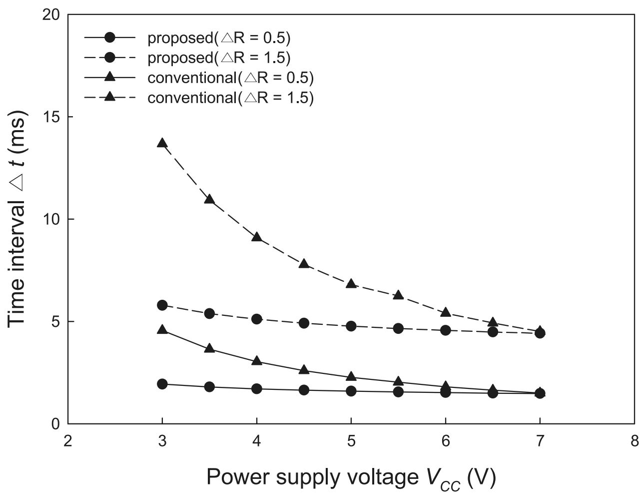

Fig. 3. Time interval variation due to the power-supply voltage variation when $\Delta R = 0.5$ and $1.5\,\Omega$, respectively.

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4 Conclusions

A new circuit has been described which converts a resistance change in the bridge into its equivalent time interval change. The design principle and the circuit configuration are simple. Besides these, the converter features good linearity in its conversion characteristics and high accuracy in the low-power supply voltages. These properties make the converter suit for implementing the smart sensors using the resistive bridge sensors.

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