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A Low-cost Resistance-to-time Converter for Resistive Bridge Sensors

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Abstract: A low-cost resistance-to-time converter is presented for interfacing resistive bridge sensors. It consists of a resistive half bridge, two current-mode Schmitt triggers, a ramp voltage generator, a one-shot multivibrator, and two logic gates. SPICE simulations using discrete components exhibit a conversion sensitivity amounting to 6186.7 μs/Ω over the resistance deviation range of 0-2 Ω, and its linearity error is less than 0.0006 %. Power dissipation of the converter is 15.57 mW.

1. Introduction

The expanding use of microprocessors in measurement systems requires transducers with digital outputs. This is true of a low cost and high resolution pressure and acceleration measuring system using resistive bridge sensors. One of the simple approaches of converting the bridge resistance deviation into a digital form is to convert the unknown resistance to time interval or pulse width. Resistance-to-time conversion is based on pulse-width modulators [1] or current-tunable Schmitt triggers [2]. The former consists of a resistive full bridge followed by pulse-width modulators 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. This paper describes a low-cost resistance-to-time converter. It requires a resistive half bridge, two current-mode Schmitt triggers, a ramp voltage generator, and a digital time differentiator. Besides its simple configuration, the converter features two times higher conversion sensitivity than the previous works. These advantages make the converter especially suit for implementing a ‘smart sensor’, which gives a digital output directly connectable to a microprocessor.

2. Circuit Description and Operation

Figure 1 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 half bridge with two sensors, a one-shot multivibrator, two resistance(or current)-tunable Schmitt trigger, and two logic gates. The upper Schmitt trigger is composed of an operational transconductance amplifier(OTA)$_1$ and a resistor $R-\Delta R$. The high threshold voltage of the Schmitt trigger is expressed as

$$V_{TH1} = \left(R - \Delta R\right) I_{B1} \tag{1}$$

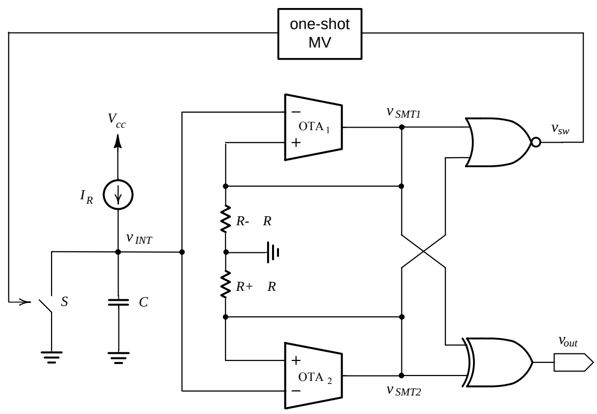

Figure 1. Circuit diagram of the resistance-to-time converter.

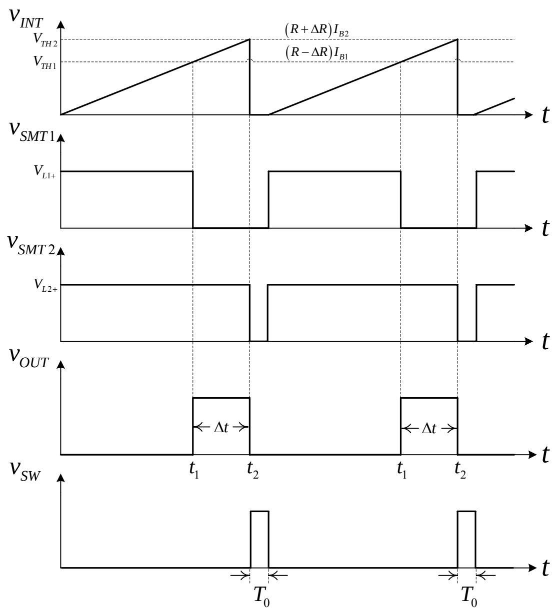

Figure 2. Voltage waveforms at the various nodes of the converter.

where ΔR represents a resistive sensor whose resistance change is to be detected and I_{B1} is the bias current of ota1.

Similarly, the lower Schmitt trigger is composed of an operational transconductance amplifier(OTA)$_2$ and a resistor $R+\Delta R$. The high threshold voltage of the Schmitt trigger is expressed as

$$V_{TH2} = \left(R + \Delta R\right) I_{B2} \tag{2}$$

where I_{B2} is the bias current of ota2. Note that V_{TH1} and V_{TH2} are proportional to the resistance of $R-\Delta R$ and $R+\Delta R$, respectively.

To see how the R-to-T converter operates, refer to Figure 2 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 resistive half 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 vol tages 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

$$t_1 = \frac{C}{I_R} V_{TH1} = \frac{C}{I_R}\left(R - \Delta R\right) I_{B1} \tag{3}$$

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 write

$$t_2 = \frac{C}{I_R} V_{TH2} = \frac{C}{I_R}\left(R + \Delta R\right) I_{B2} \tag{4}$$

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

$$\Delta t = t_2 - t_1 = \frac{C}{I_R}\left[\left(R + \Delta R\right) I_{B2} - \left(R - \Delta R\right) I_{B1}\right] \tag{5}$$

If the OTAs are identical, then I_{B1} = I_{B2} = I_B and Δt is simplified to

$$\Delta t = 2\frac{C}{I_R} I_B \Delta R \tag{6}$$

Equation (6) indicates that the converter offers an equivalent output pulse whose time interval is proportional to the resistance change.

3. Simulation results

Figure 3 shows the circuit diagram of the OTA. All cascade current mirrors M_3-M_{14} have 350 μm / 0.35 μm (W/L) for the PMOS(M_3-M_{10}) and 420 μm / 0.35 μm (W/L) for the NMOS(M_{11}-M_{14}), while two differential stages M_1-M_2 have W = 420 μm and L = 0.35 μm. The bias current I_B was set to 10 mA for convenience.

A prototype converter shown in Figure 1 was simulated using SPICE with the following integrated circuits: 74LS02 for the NOR gate, and 74LS86 for the XOR gate. The one-shot multivibrator shown in Figure 4 was constructed by using two NOR gates, a capacitor C_0 of 47 nF, and a resistor R_0 of 50 kΩ .

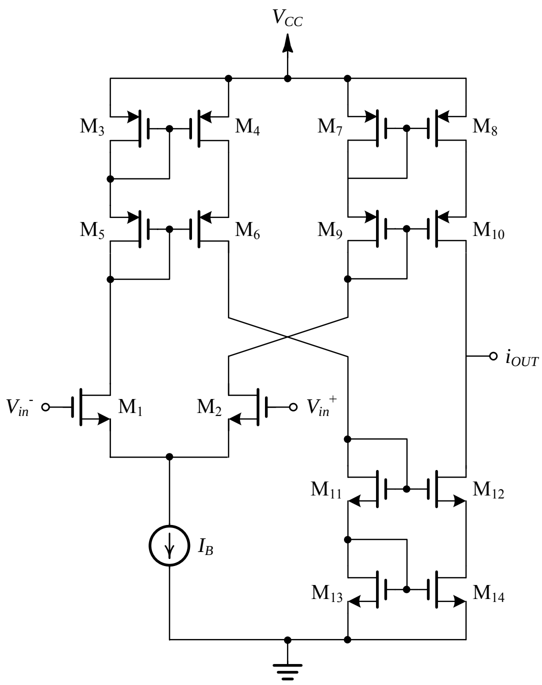

Figure 3. Circuit diagram of an operational transconductance amplifier(OTA).

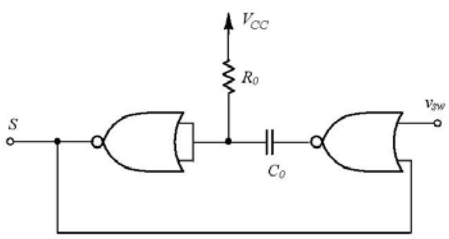

Figure 4. Circuit diagram of the one-shot multivibraotr

The following component values were adopted for the ramp voltage generator shown in Figure 5: C = 2 μF and I_R = 5.8 μA. 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.

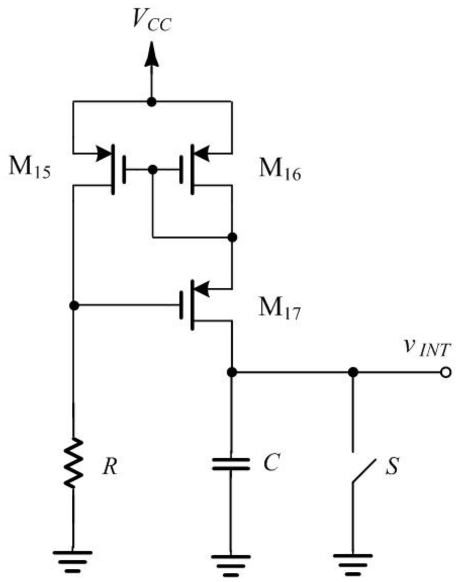

Figure 5. Circuit diagram of ramp voltage generator.

Figure 6. shows the measured time interval changes when ΔR was changed in 0.1 Ω steps from its fixed offset value of R = 350 Ω. It appears that the conversion sensitivity amounts to 6186.7 μs/Ω over the resistance deviation range of 0-2 Ω. The linearity error of the conversion characteristic is less than ±0.0006 %, which is a factor of two lower than that of the converter in [1].

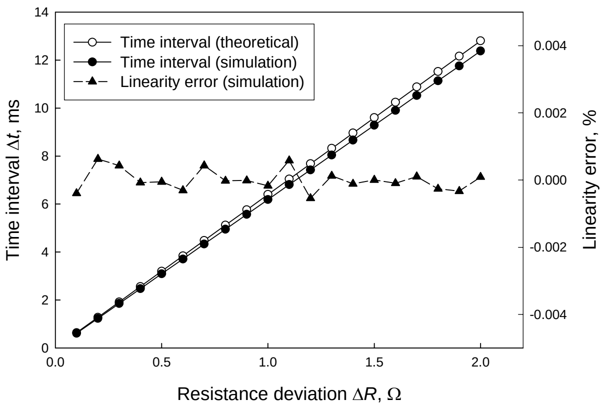

Figure 6. Measured time interval versus resistance deviation and its linearity error.

Figure 7 shows the simulated voltage waveforms at the various nodes of the converter when ΔR = 2 Ω. Figure 8 shows the layout arrangement of the proposed converter shown in Figure 1.

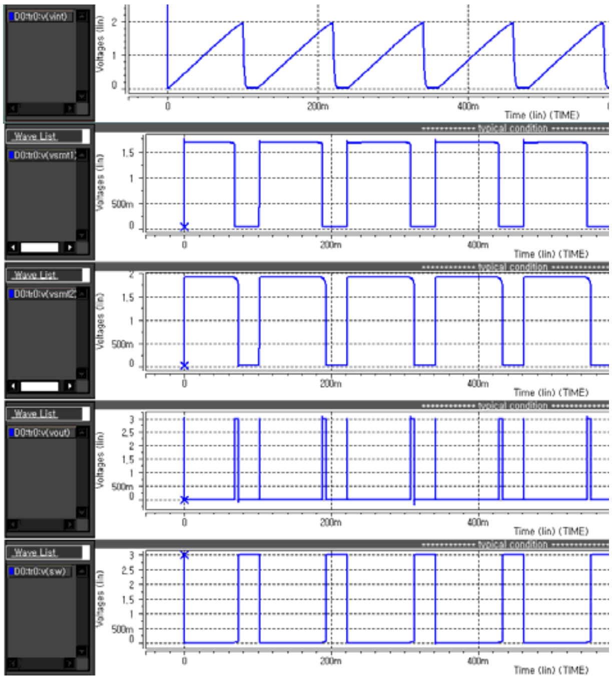

Figure 7. Simulated voltage waveforms at the various nodes of the converter.

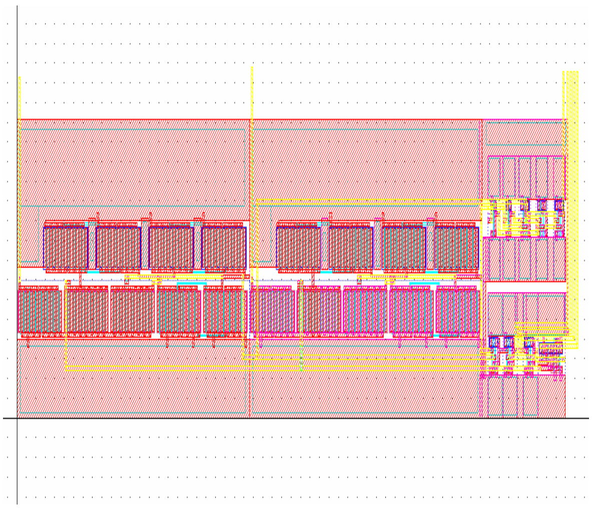

Figure 8. The layout arrangement of the converter

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.

Acknowledgments

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