ICIC Express Letters ICIC International ©2018 ISSN 1881-803X
Volume **12**, Number **5**, May **2018** pp. **473–478**

SIMPLE DC-EXCITED RESISTANCE-TO-PERIOD CONVERTER USING CFOAS

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Received November 2017; accepted February 2018

Abstract. *This paper presents a new method to implement a resistance-to-period converter for DC-excited resistive sensor. The proposed technique makes use of the characteristic of a controllable unity-gain inverting/non-inverting amplifier formed by current feedback operational amplifiers (CFOAs). Experimental results that verify the performance of the proposed circuit are also included.*

Keywords: Resistance-to-period converter, Readout circuit, CFOA, CCII

1. **Introduction.** A resistance-to-period converter is a circuit that generates a square-wave output signal. Its period is proportional to the resistance value of a sensing element. It is found that this circuit is one of useful circuits in the fields of electronics, measurement and instrumentation systems. It can be used as a readout circuit for various resistive sensors. Most reported resistance-to-period converters are usually implemented for the AC-excited resistive sensors [1-3]. However, some resistive gas sensors do not bear an alternating excitation signal since they give bad response and lower lifetimes [4]. To solve this problem, the resistance-to-period converter suitable for read-out circuit of DC-excitation resistive sensors based on operational amplifiers (Op-amps) has been introduced in [5]. Due to the bandwidth limit of the op-amp, six current conveyors (CCIIs) and two analog-switches are used to implement the resistance-to-period converter readout circuit for DC-excited resistive gas sensor [6]. However, this method has the complex structure. The commercial available current feedback operation amplifier (CFOA) consists of a CCII and a voltage buffer. Furthermore, the complementary metal-oxide semiconductor (CMOS) technology is an alternative technique used in the integrated circuit design of the resistance-to-period converter [7]. The CFOA has received much attention in the design and implementation of current mode function circuits. It can be found in many applications such as amplifiers, analog filters, sinusoidal oscillators, and read-out circuit for AC-excited capacitive and resistive sensors [8-13]. For ease of hardware implementation and low cost in design, a simple resistance-to-period converter for DC-excited resistive sensor using four commercial available CFOAs and an analog-switch is introduced in this paper. The electronic tuning is a technique used in the resistance-to-period converter design. The proposed circuit provides the period of the output signal which is directly proportional to the resistance of the resistive sensor. Finally, experimental results show the capableness and the correctness of the proposed circuit design. Furthermore, the circuit can also be used as the voltage-to-frequency converter.

The rest of the paper is organized as follows. In Section 2, we present a new method for designing the CFOA-based resistance-to-period converter with DC voltage excitation. The proposed circuit has a built-in controllable unity-gain inverting/non-inverting amplifier. Non-idealities of the CFOA device in practice affect the deviation from the ideal circuit performance as discussed in Section 3. Commercial available electronic devices used in building of the proposed circuit and experimental results are described in Section 4. Finally, we conclude in Section 5 that the proposed circuit can convert the resistance into the period for the DC-excited resistive sensor. Moreover, results also show the feature of the electronically tunable resistance-to-period converter.

2. **Circuit Description.** Figure 1 shows the basic circuit diagram of the designed controllable unity-gain inverting/non-inverting amplifier based on use of a CFOA. The voltage V_1 denotes the input voltage signal. The voltage V_4 is control signal which has two states: the positive saturation voltage $V_{sat(+)}$ and negative saturation voltage $V_{sat(-)}$. The resistance $R_3 = 2R_2$ and voltage $V_1 < 0$ V are assigned. If the control voltage $V_4 = V_{sat(-)}$, the analog switch (sw) will go to off-state. That is, no current flows through the resistors and the voltage V_2 is forced to equal the voltage V_1. Conversely, when the control voltage $V_4 = V_{sat(+)}$, the analog switch will go to on-state. The current flows through the resistors R_2-R_3. Then, the voltage V_2 is forced to equal the voltage $-V_1$. It can be rewritten as

$$V_2 = \begin{cases} V_{2(-)} = V_1 & \text{for } V_4 = V_{sat(-)} \\ V_{2(+)} = -V_1 & \text{for } V_4 = V_{sat(+)} \end{cases} \tag{1}$$

It is seen that the phase (inverting or non-inverting) of the voltage V_2 can be controlled by the voltage V_4.

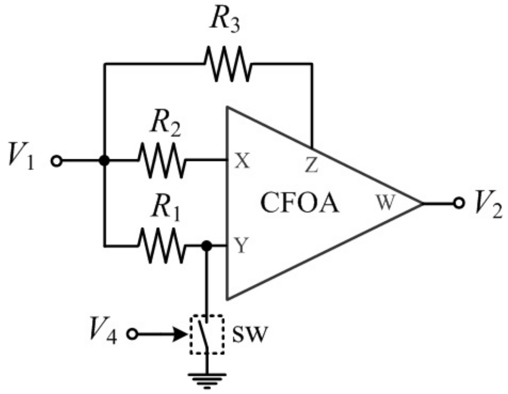

FIGURE 1. Controllable unity-gain inverting/non-inverting amplifier

Figure 2 shows the proposed resistance-to-period converter. This circuit is built around the controllable unity-gain inverting/non-inverting amplifier shown in Figure 1. The signal V_B denotes the DC-bias voltage. The resistance R_{sens} represents the resistance of the sensing resistive element. CFOA$_1$ acts as an electronically tunable resistance-to-voltage converter with DC-voltage excitation. Hence, the voltage V_1 can be expressed as

$$V_1 = \frac{-R_4}{R_{sens}} V_B \tag{2}$$

CFOA$_3$ forms an integrator circuit to generate a triangular-wave signal V_3 of amplitude $|V_{utp} - V_{ltp}|$ which denotes respectively the upper and lower threshold voltages of the circuit. The relation between voltage V_3 and V_2 can be stated as

$$V_3 = \frac{1}{R_5 C_1} \int V_2 dt \tag{3}$$

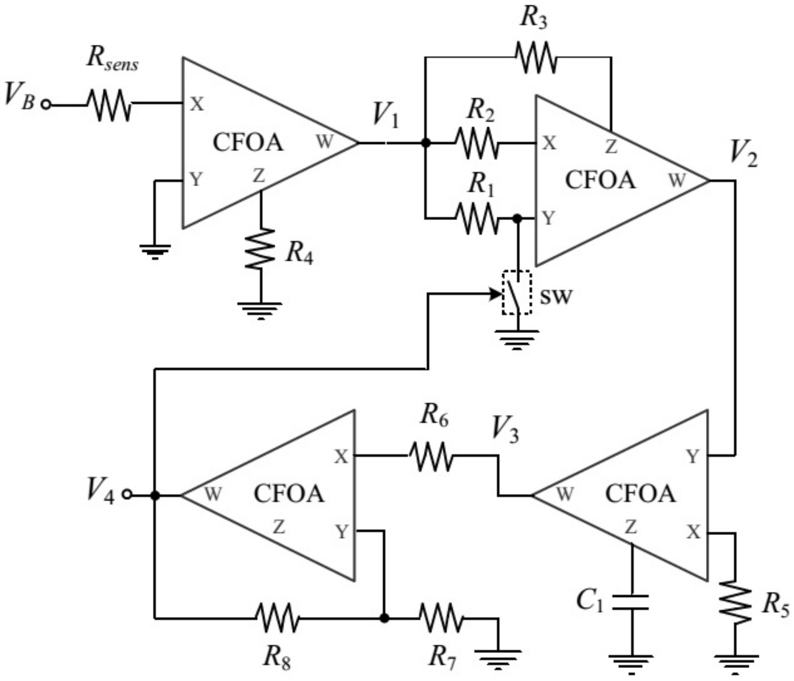

Figure 2. Proposed resistance-to-period converter V

CFOA$_4$ forms a Schmitt-trigger to generate a square-wave signal V_4 of magnitude $V_{sat(+)}$ and $V_{sat(-)}$. Thus, the upper threshold voltage V_{utp} and the lower threshold V_{ltp} can be given by

$$V_{utp} = \frac{R_7}{R_7 + R_8} V_{sat(+)} \tag{4}$$

$$V_{ltp} = \frac{R_7}{R_7 + R_8} V_{sat(-)} \tag{5}$$

From the characteristic of CFOA$_1$, CFOA$_3$, and CFOA$_4$, a voltage-to-period converter (or a voltage controlled relaxation oscillator) can be obtained. Hence, the oscillation period T_{out} can be expressed as

$$T_{out} = \frac{2\left|V_{utp} - V_{ltp}\right| R_5 C_1}{V_1} \tag{6}$$

By substituting (2), (4), and (5) into (6), the period T_{out} can be rewritten as

$$T_{out} = \frac{2\left|V_{sat(+)} - V_{sat(-)}\right| R_7 R_5 C_1}{V_B R_4 (R_7 + R_8)} R_{sens} \tag{7}$$

Thus the circuit in Figure 2 also realizes the resistance-to-period converter with the DC-voltage excitation. In addition, it can be electronically adjusted by biasing the voltage V_B.

3. **Circuit Performance.** Deviations from the ideal performance of the proposed circuit are due to device non-idealities such as the parasitic resistances r_x at the port x of CFOAs and the voltage drop across the analog switch in on/off-state. Reanalysis of the proposed circuit yields the output voltages V_1, V_2, and the output period T_{out} characteristics as follows:

$$V_1 = \frac{R_4}{R_{sens}} V_B (1 - E_1) \tag{8}$$

$$V_2 = \begin{cases} V_{2(-)} = V_1(1 - E_{2a}) & \text{for } V_4 = V_{sat(-)} \\ V_{2(+)} = -V_1(1 - E_{2b}) + V_{off} & \text{for } V_4 = V_{sat(+)} \end{cases} \tag{9}$$

$$T_{out} = \frac{2\left|V_{sat(+)} - V_{sat(-)}\right| R_7 R_5 C_1}{V_B R_4 (R_7 + R_8)} R_{sens}(1 - E_3) \tag{10}$$

The parameters E_1, E_{2a}, E_{2b} and E_3 are error factors which result from the parasitic resistance r_x of CFOAs. The error values of these parameters can be calculated by the equations:

$$E_1 = \frac{r_{x1}}{(R_{sens} + r_{x1})} \tag{11}$$

$$E_{2a} = \frac{R_3}{(R_2 + r_{x2})} \frac{R_1}{\left(R_{w(off)} + R_1\right)} \tag{12}$$

$$E_{2b} = \frac{2r_{x2}}{(R_2 + r_{x2})} \tag{13}$$

$$E_3 = \frac{R_5\left(V_{2(-)} - V_{2(+)}\right) - r_{x3}\left(V_{2(-)} + V_{2(+)}\right)}{2R_5 V_{5(-)}} \tag{14}$$

where r_{x1}, r_{x2} and r_{x3} are respectively the parasitic resistances at the port x of CFOA$_1$, CFOA$_2$, and CFOA$_3$. The $R_{w(off)}$ is the resistance of the analog switch in off-state. When we consider the analysis of the controllable unity-gain inverting/non-inverting amplifier with parasitic resistance, the output voltage V_2 in the case of the analog switch in on-state has the offset voltage V_{off}, indicated in Equation (9). Note that the V_{off} can be estimated by Equation (15) where the $V_{w(on)}$ represents the voltage drop across the analog switch in on-state.

$$V_{off} = \frac{R_3}{(R_2 + r_{x2})} V_{w(on)} \tag{15}$$

4. **Experimental Results.** The proposed circuit in Figure 2 was constructed using commercially available AD844 CFOAs and 1% tolerance resistors. The resistors used in the circuit were chosen as follows: $R_1 = R_7 = R_8 = 1$ kΩ, $R_2 = R_5 = 10$ kΩ, $R_3 = 20$ kΩ, $R_5 = 5$ kΩ, and $R_6 = 200$ Ω. The power supply voltages used were set to ±5 V. The positive saturation value $V_{sat(+)}$ and the negative saturation value $V_{sat(-)}$ were measured

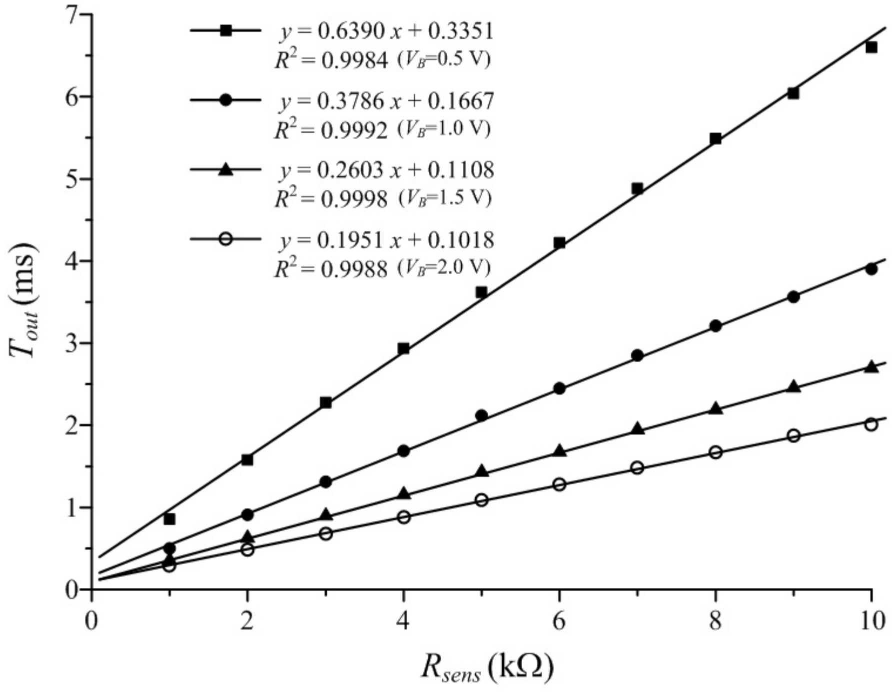

FIGURE 3. Plots of T_{out} against R_{sens} and V_B for $R_{sens} = 1$ kΩ to 10 kΩ

as 2.33 V and −1.36 V. Hence, the amplitudes of voltage signals V_3 and V_4 calculated will be 3.69 $\mathrm{V_{p\text{-}p}}$ and 7.38 $\mathrm{V_{p\text{-}p}}$, respectively.

For testing the proposed circuit, we prepared four differential values of the DC-voltage V_B for exciting the sensing resistor R_{sens}. The variable resistor used as the R_{sens} was varied in the range of 1-10 kΩ. Increasing of the R_{sens} has effects on the T_{out} as seen from experimental results. Figure 3 shows plots of the T_{out} measured against the values of the R_{sens}. It is apparent that the relationship between the T_{out} and the R_{sens} is linearly increased. In the worse case, the R-Squared value R^2 achieved is equal to 0.9984.

To show that the proposed circuit also works as a voltage-to-frequency converter or a frequency modulator, the triangular wave of 100 Hz and 3 $\mathrm{V_p}$ has been used as the bias voltage V_B. The 1.5 V offset voltage is required while the $R_{sens} = 5$ kΩ and $C_1 = 10$ nF parameters are assigned. The performance of the circuit in this case is confirmed by the measured voltage waveforms which are shown in Figure 4.

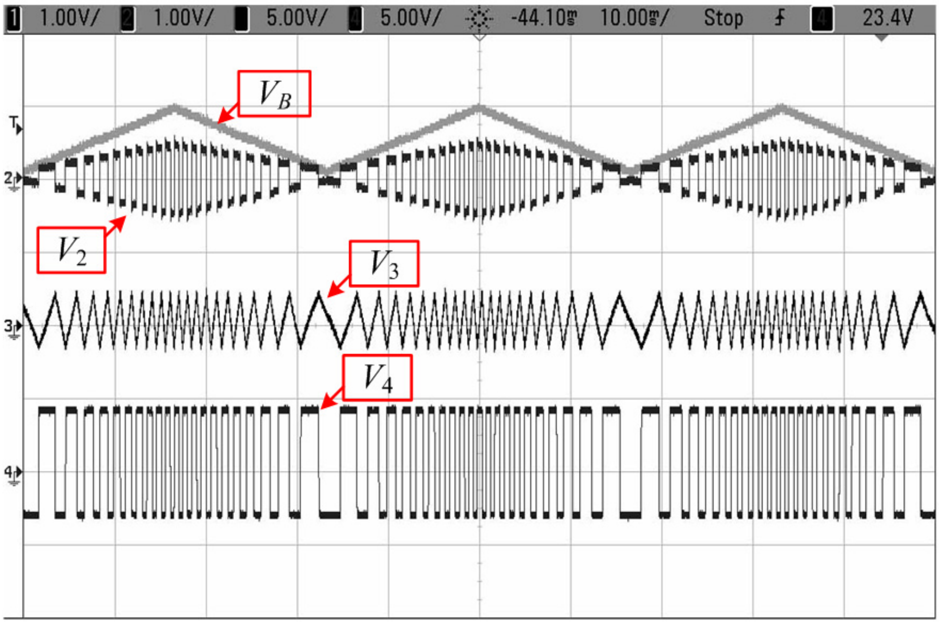

FIGURE 4. Measure results of the proposed circuit for triangular-wave bias voltage V_B

It is evident from the test results that the proposed circuit can be used to convert the resistance of the sensing resistor into the period with DC-voltage excitation and can be electronically adjusted by varying the DC-bias voltage V_B. In addition, the circuit can also act as the voltage-to-frequency converter.

5. **Conclusion.**

A simple DC-excited resistance-to-period converter has been described in this paper. The realization method is based on the proposed controllable unity-gain inverting/non-inverting amplifier formed by a CFOA. The proposed circuit provides simple construction, good performance and practical implementation. Expectation of the proposed circuit design is to adapt for DC-excited resistive sensors. Experimental results show that the proposed circuit exhibits basic feature of the electronically tunable resistance-to-period converter and also acts as the voltage-to-frequency converter.

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