A Simple and Compact Transimpedance Mode dc Bridge Readout

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Abstract—**This paper presents a new circuit configuration of a transimpedance mode dc bridge based on an operational trans-resistance amplifier (OTRA) as an analog building block. The proposed circuit suits for small changing resistance detector. By taking the benefit of grounding property at the internal input port of the OTRA, a simple and compact dc bridge is obtained. The proposed circuit is composed of two sensing components together with a feedback resistor and only one operational trans-resistance amplifier. The circuit performances are verified by the PSPICE simulation using 0.35 µm CMOS technology model parameters. The simulation results from circuit level agree well with the theoretical values.**

***Keywords.** —Bridge, Mixed mode, Operational trans-resistance amplifier, Analog circuit.*

I. INTRODUCTION

It is well known that a classical dc Wheatstone bridge has a valuable role for a measurement and control systems. The circuit can measure and detect a small value changing of resistor with accuracy and gives a wide linearity range for those output. Also, it can eliminate a common mode signal and noise disturbing in the circuit. With such advantages, various passive transducers such as strain gauge, resistant temperature detector (RTD), light-dependent resistor (LDR), and potentiometer need the Wheatstone bridge to convert the signal into proportion output.

The original Wheatstone bridge is composed of four resistors incorporating with a voltage reference. It works in voltage-mode by mean of comparing the voltage between the two arm-bridges. Later the current mode Wheatstone bridge had been developed [2]. It supplied the arm-bridge with a constant current source instead of a voltage source. The above bridge circuit shows its advantage that two resistor-arm bridge were reduced by operating in current mode. However, the concept also needs a current different stage and a current amplifier. There is an attempt to increase the output current of a bridge circuit by using various analog building blocks such as current conveyor, op-amp, operational floating current conveyors (OFCC). Unfortunately, those circuits reported in the literature [2] consisted of many op-amps, some of them were implemented with different types of current conveyors (positive and negative). Although, a new topology current mode bridge is presented in [3], the number of the active building remains large and the circuit requires several passive resistors. Recently, a current mode bridge has been presented in [5]. It used a dual-output current differencing transconductance amplifier (DO-CDTA). The circuit can control gain via adjusting the dc bias current. However, the DO-CDTA is unavailable in commercial IC and hence inconvenient from the practical point of view.

This paper presents a transimpedance mode dc bridge with a simple structure consisting of an operational trans-resistance amplifier (OTRA) and a few resistive sensing elements. The configuration of the proposed circuit is simple and can easily adapt to be inverting bridge and non-inverting bridge circuit. Besides, the proposed bridge circuit gives the output voltage signal similar to the traditional bridge circuit but requires a small number of sensing elements. Moreover, the proposed bridge circuit gives output voltage at the low impedance terminal therefore it allows cascading itself with other circuits without adding a buffer circuit.

II. PROPOSED CIRCUIT

An OTRA perform an important role in the proposed circuit, its characteristics are briefly given. An OTRA is an analog building block with three terminals. The symbol of an OTRA depicts in fig.1. The two input terminals represent the symbol V_+ and V_- while V_0 is the output terminal.

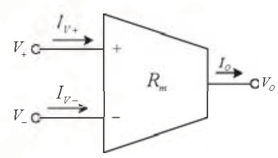

Fig. 1. The schematic symbol of an OTRA

A relationship between current and voltage at each port describes as the following equation:

$$\begin{bmatrix} V_+ \\ V_- \\ V_0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ R_m & -R_m & 0 \end{bmatrix} \begin{bmatrix} I_{V+} \\ I_{V-} \\ I_0 \end{bmatrix} \quad (1)$$

Whereas R_m is the trans-resistance gain. Ideally, R_m approaches to infinity. An input impedance and an output impedance at the input-output ports are low. By applying negative feedback, the amount currents sending to the terminal input are the same values. The voltage difference between the two input ports is zero and still stays at a grounded level. The represented circuit of the OTRA based on CMOS transistor consists of PMOS and NMOS showing in fig.2

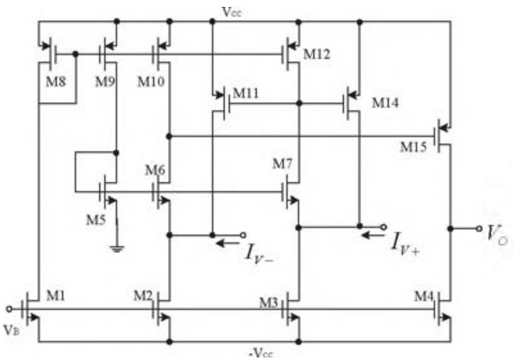

Fig. 2. The CMOS circuit represents an OTRA [6]

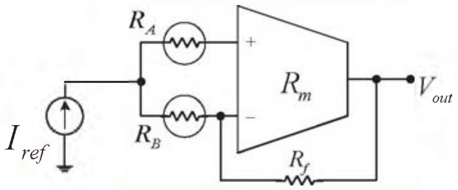

Fig. 3. The proposed trans-impedance mode bridge circuit

By using an OTRA and two sensing resistors together with a constant current source, the proposed bridge circuit in mixed mode illustrated in fig.3. The resistor R_f is a part of the feedback loop thus allows to control the trans-resistance gain of the bridge. Obviously, the proposed bridge circuit has a simple configuration. Routine analysis of the circuit gives the output voltage related to the reference current as of the following equation

$$V_{out} = \left(\frac{R_A - R_B}{R_A + R_B} \right) R_f I_{ref} \quad (2)$$

Determining, R_A and R_B are the arm-resistor of the dc bridge. The sensing resistances of the arm bridges are varied correspond as $R_A = R \pm \Delta R$, $R_B = R \mp \Delta R$. Therefore, the output voltage relates to the current reference is given as

$$V_{out} = \left(\frac{\pm \Delta R}{2R} \right) R_f I_{ref} \quad (3)$$

Clearly, the output voltage of the proposed bridge has a linear proportion to the changing resistances of the sensing resistors. Although the proposed circuit operates in mixed mode, the proposed bridge gives the output voltage similar to the Wheatstone bridge in voltage mode. Remarkably, the number of sensing elements reduced when compared to the classical Wheatstone bridge. Besides, the output impedance at the voltage node of the OTRA is low. The proposed bridge has the property to cascade without adding a buffer circuit. The proposed bridge can be modified to be a half-bridge configuration as the circuit in fig. 4. The bridge requires only one sensing resistor connecting to an input port of the OTRA. Assuming $R_A = R \pm \Delta R$ and $R_B = R$, the output voltage of non-inverting half-bridge expresses as

$$V_{out} = \left(\frac{\pm \Delta R}{2R \pm \Delta R} \right) R_f I_{ref} \quad (4)$$

If $2R \gg \Delta R$, the output voltage in above equation can be approximated as the followed equation

$$V_{out} \approx \left(\frac{\pm \Delta R}{2R} \right) R_f I_{ref} \quad (5)$$

By switching between the two input terminals of the OTRA showing in fig.5, the proposed circuit is an inverting half-bridge configuration.

Defining $R_A = R$ and $R_B = R \pm \Delta R$, the output voltage becomes

$$V_{out} = \left(\frac{\mp \Delta R}{2R \pm \Delta R} \right) R_f I_{ref} \quad (6)$$

Similarly, under the condition $2R \gg \Delta R$, the output voltage in equation (6) can be rewritten as followed equation

$$V_{out} \approx \left(\frac{\mp \Delta R}{2R} \right) R_f I_{ref} \quad (7)$$

From equation (5) and equation (7), it can be seen that the both inverting and non-inverting half-bridges have the output voltage relate to the changing of the resistance as linearly. Notably, the number of sensing element in the proposed half-bridge circuits less than the classical half-bridge circuit which operated in voltage mode. The proposed circuit have only one sensing element, while the traditional bridge requires two elements.

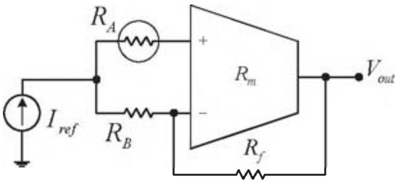

Fig. 4. The proposed non-inverting trans-impedance mode with only a resistive element

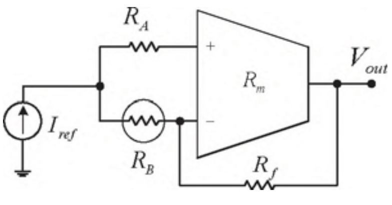

Fig. 5. The proposed inv erting trans-impedance mode with only a resistive element

III. Simulation results

To affirm the theoretical analysis, the proposed circuits were simulated through the SPICE simulation program. The OTRA based on the CMOS realization is presented in fig.2. The CMOS model parameters employed TSMC 0.35μm technology and the aspect ratios for each CMOS transistors are given in Table 1. The dual power supply voltages of the OTRA were ±1.5V while bias voltage V_B was -0.9V.

Firstly, the dc response of the proposed bridge in fig. 3 was verified by assigning I_{ref} from 0-100 μA and setting R_f =10 kΩ. The resistor R_B was fixed at 1kΩ while R_A were different values as 0.8kΩ with 100Ω step up. The simulation results of the output voltage against input currents illustrates in fig.6. Obviously, the results show the zero-output at the balance point ($R_A = R_B$). The proposed circuit has ability to get rid of the common currents. If the resistance of resistor R_A was higher than resistor R_B , the output voltage gave positive outputs. On the other hand, If the resistance of resistor R_A was lower than resistor R_B , the output voltage became negative voltages.

In order to verify the linearity of the proposed circuit, the resistor R_A was set to be constant at 1kΩ while R_B was varied (R_B = 0.8kΩ -1.2kΩ). The feedback resistor R_f was 10 kΩ and I_{ref} was equal to 100uA. The graphs of the output voltages versus changing resistance in the theoretical value (eq.3) and simulation can be shown in fig.7. For the simulation results in fig.8, the feedback resistor and input current were the same with the previous simulation and setting R_B constant at 1kΩ and varying R_A from 0.8kΩ to 1.2kΩ. From the graphs depicted in fig.7 and fig.8, they can confirm that the output voltages have a wide linearity range and agree well with the theoretical values. However, some slight errors may occur when the deviation of resistor ratio shifts about 20% from the center value because of the dc offset effect of the OTRA.

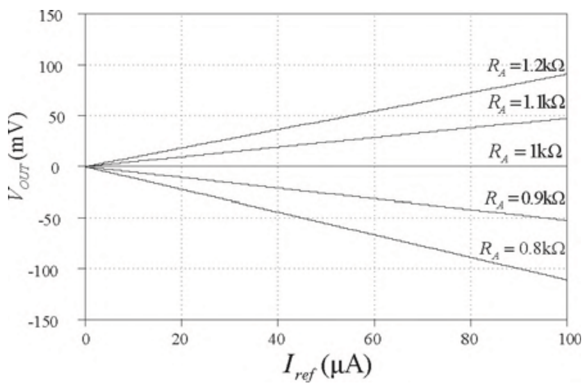

Fig. 6. The dc responses of the proposed circuit with R_B =1kΩ and R_A is varied

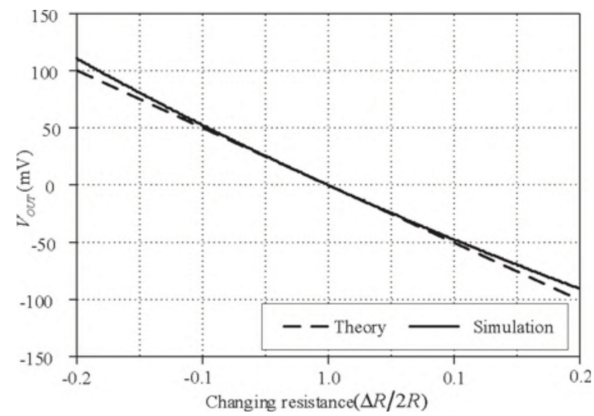

Fig. 7. The relationships of the output voltage and the changing resistance of R_B

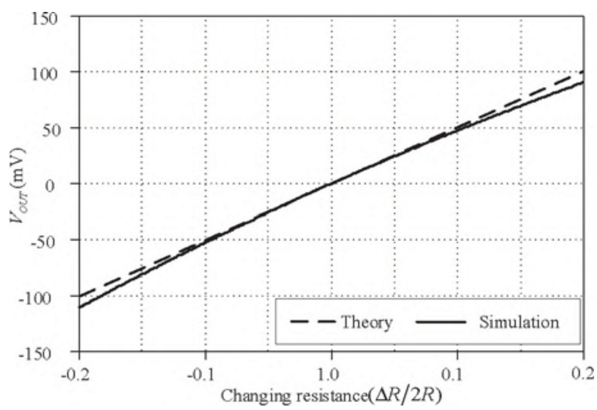

Fig. 8. The relationship between the output voltage and the changing of resistance R_A

Second, to demonstrate the characteristics of non-inverting bridge, the proposed circuit in fig.4 was examined by given resistor R_B constant at 1kΩ and R_A was varied (R_B=1.1kΩ, 1.2kΩ and 1.3 kΩ) while feedback resistor R_f was about 10 kΩ. The dc responses related to different current inputs can be depicted in fig.9.

Furthermore, the inverting characteristics of the circuit in fig.5 was verified by setting resistor R_A equal to 1kΩ and R_B was varied (R_B=1.1kΩ, 1.2kΩ and 1.3 kΩ) while feedback resistor was the same value. The output voltage against the current input can be shown in fig. 10. Clearly, the simulation results can confirm that the proposed circuits in fig.4 and fig.5 have the dc response as all expect.

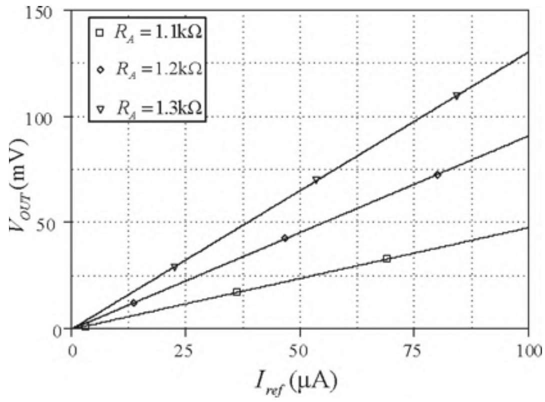

Fig. 9. The dc output responses of the proposed non-inverting half-bridge with v arying R_A

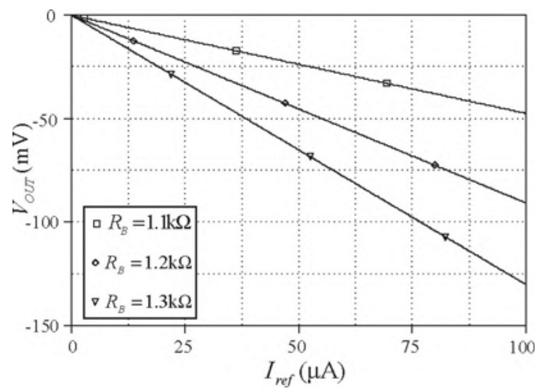

Fig. 10. The dc output responses of the proposed inverting half-bridge with varying R_B

TABLE I. Aspect ratio of the CMOS transistors

CMOS transistor	W(μm):L(μm)
M1	10:1.8
M2-M3	30:1.8
M4, M8-M10, M12	50:1.8
M5-M7, M11, M14-M15	100:1.8

In addition, for checking uncertainty of some resistors, the Monte-Carlo simulation was carried out by setting the resistor R_A = 1.1kΩ±1% and R_B = 0.9kΩ±1%, I_{ref} =50μA, R_f = 10kΩ. The histogram of the output voltage of the proposed circuit with running 100 samples shows in fig.11. The average output voltage was about 49.7 mV although there was some variation process. The results had a normal distribution curve satisfactorily.

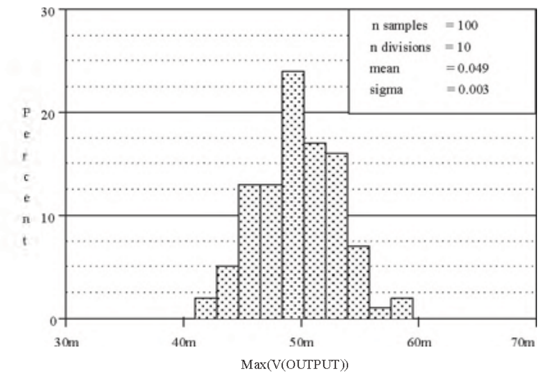

Fig. 11. The histogram result when the R_A and R_B with 1% error

CONCLUSION

A circuit configuration of a transimpedance mode dc bridge based on an operational trans-resistance amplifier (OTRA) is presented in this paper. The proposed circuit capable to detect small changing resistance with a simple structure and using a minimal component. The half-bridge configuration in the trans-impedance mode can reduce the necessary resistor when compare to the previous bridge in voltage mode. The simulation results from the PSPICE program are carried out and that can insist on the workability of the proposed circuits.

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