A Current-Mode Wheatstone Bridge Employing Only Single DO-CDTA

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Abstract— **This article proposes a topology of current-mode improved Wheatstone bridge based on dual-output current differencing transconductance amplifier (DO-CDTA). The features of the proposed configuration are that: magnitude of output signal can be controlled via the input bias currents; the proposed circuit is low temperature sensitive, the circuit description is very simple. The circuit performances are depicted through PSPICE simulations, they show good agreement to theoretical anticipation and provide ability to measure small resistance changes at a wide range of frequency (more than 60MHz). The power consumption is approximately 4.55mW at ±1.5V supply voltages.**

I. INTRODUCTION

For many years, Wheatstone bridge is used for checking small resistance changes. Consequently, it is useful for instrumentation, sensing temperature, strain, pressure and dew point humidity [1-2]. The conventional voltage-mode Wheatstone bridge consisting of 4 resistors is shown in Fig. 1(a). Subsequently, a method based on the circuit duality concept has been modified to develop a current-mode Wheatstone bridge (CMWB) by Azhari and Kaabi [3], they have claimed that it can overcome several drawbacks of the Wheatstone bridge. These are reducing circuit elements, superposition principle and common mode cancellation. This is called AZKA cell [3], shown in Fig 1(b). However, by inspective survey, two different topologies to implement a CMWB have been proposed. The first one uses two second-generation current conveyors (CCIIs), therefore the accuracy is limited by the tolerance of intrinsic resistances of the CCIIs, which is low, the linearization is unavoidably needed. The second approach to implement a CMWB using operational floating current conveyors (OFCCs), has a higher accuracy, as the output current does not depend on the intrinsic resistance. However, there is no reduction of the sensing resistors, as the second approach uses two excess resistors.

Recently, a new CMWB topology using OFCCs has been introduced [4]. It has a smaller area for fabrication because it reduces the sensing passive elements, and uses only two resistors without degradation in the performance. Also, it uses the principle of superposition without adding any signal conditioning circuitry. Unfortunately, it confronts several drawbacks such as circuit complexity, temperature dependence, lack of electronic controllability to adapt in an automatic control system. Although, an appropriately controllable amplifier can be added to achieve adjustable gain, the offsets might be a much increased. By using the principle of AZKA cell, Jaikla and Siripruchyanun have proposed the voltage and current-mode Wheatstone bridge [5]. The features of these circuits are electronic controllability and low temperature sensitivity. Unfortunately, the circuits consist of many different active elements (2 CCCIIs and 1 CDBA for voltage-mode, 1 CDTA and 1 CCCII for current-mode) which is not appropriate for realizing in a monolithic chip.

The aim of this paper is to introduce a configuration of current-mode Wheatstone bridge. The proposed topology enjoys several features as follows: the proposed circuit is temperature-insensitive, electronic controllable, uncomplicated of circuit detail. In addition, the proposed topology has a much-improved common-mode cancellation and can work with a wide range of frequencies which is an important property to suppress any unwanted common-mode signal or noise at a high range of frequencies. So, the proposed circuit has a high accuracy and employs only single DO-CDTA. The mentioned properties are confirmed by PSPICE simulation. The proposed topology is very suitable for the measurement of small resistance changes.

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II. PRINCIPLE OF CONVENTIONAL TOPOLOGIES

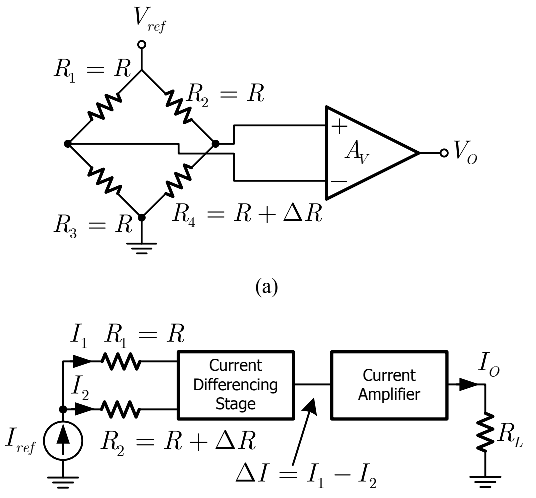
A. Conventional Wheatstone bridge

The basic system may be referred to as a voltage-mode resistance bridge and is well known and understood. It comprises a bridge arrange of resistors R_1, R_2, R_3 and R_4 as shown in Fig. 1(a), which are adjusted such that the difference voltage is zero. This can be achieved by setting all resistors to be equal, then the bridge is then said to be balanced. A resistance change in say R_4 creates a nonzero voltage $\Delta V = V_1 - V_2$, which is then amplified by an instrumentation amplifier. This provides an output

$$V_o = A_V V_{ref} \frac{\Delta R}{4R + 2\Delta R}, \tag{1}$$

where A_V is the gain of the associated instrumentation amplifier. Since $\Delta R \ll R$ for strain gauges, Eq. (1) can be reduced to

$$V_o = A_V V_{ref} \frac{\Delta R}{4R}. \tag{2}$$



(a)

(b)

Figure 1. (a) the conventional voltage-mode Wheatstone bridge (b) AKZA current-mode Wheatstone bridge

B. Current-mode Wheatstone bridge

Recently, in an interesting attempt to improve the current-mode resistance bridge was described [3] as shown in Fig. 1(b). Instead of a voltage involving a voltage difference as in the voltage-mode resistance bridge, this circuit comprises a current source and a current subtraction process through resistors R_1 and R_2 involving I_1 and I_2. The current difference stage produces an output $\Delta I = I_1 - I_2$ and this is amplified by the current amplifier A_I. If $R_1 = R_2$, a change ΔR of R_2 say gives

$$I_o = A_I I_{ref} \frac{\Delta R}{2R + \Delta R}. \tag{3}$$

where A_I is the gain of the associated current amplifier. Since $\Delta R \ll R$ for strain gauges, Eq. (3) can be reduced to

$$I_o = A_I I_{ref} \frac{\Delta R}{2R}. \tag{4}$$

This approach enjoys a number of advantages over the voltage-mode resistance bridge. Firstly, it utilizes half of the resistors of the conventional bridge. Secondly, it permits the addition of other sensors while utilizing the same current differencing stage and current amplifier; no additional signal conditioning circuiting is required. Finally, the basic current subtraction process produces twice the output of the basic voltage subtraction process of the voltage-mode resistance bridge.

III. PRINCIPLE OF CONVENTIONAL TOPOLOGIES

From our investigation, the above mentioned current-mode circuit suffers from additionally several drawbacks. 1) It has a large common input signal and overcoming this complicates the system. 2) In practical, active elements employed in this circuit are typically temperature-sensitive. A compensation technique must be used, especially in temperature measurement, this make the circuit more complicated. 3) Electronic adjustability can not be achieved, which is hard to implement in an automatic control system.

This paper proposes improved current-mode Wheatstone bridge, as followed.

A. Basic Concept of DO-CDTA

Since the proposed circuit is based on DO-CDTA, a brief review of DO-CDTA is given in this section. Basically, DO-CDTA properties are similar to the conventional CDTA [6], except that the DO-CDTA has two x terminals. The relationship of voltages and current of DO-CDTA can be shown in the following equation

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_{x1} \\ I_{x2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & g_{m1} \\ 0 & 0 & 0 & 0 & g_{m2} \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_{x1} \\ V_{x2} \\ V_z \end{bmatrix}, \tag{5}$$

where $$g_{m1} = \frac{I_{B1}}{2V_T}, g_{m2} = \frac{I_{B2}}{2V_T}. \tag{6}$$

I_B and V_T are the input bias current and thermal voltage, respectively. The symbol and equivalent circuit of DO-CDTA can be respectively shown in Fig. 2(a) and (b).

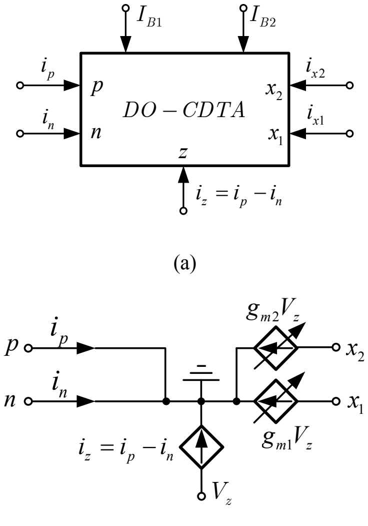
B. Proposed Current-mode Wheatstone bridge

Using principle of current-mode Wheatstone bridge or AZKA cell in Fig 1(b), an improved circuit is developed, which is readily available in practice. Fig. 3 shows proposed improved current-mode Wheatstone bridge, where the DO-CDTA functions as differencing current and current amplifier, simultaneously. In the circuit, the resistors R_1 and R_2 symbolize the resistances of any sensors (one or both of them can represent a sensor). I_{B1} and I_{B2} are input bias currents of DO-CDTA. Based on the characteristics of DO-CDTA in section III.A, the currents at n and p terminals can be expressed to be

$$I_n = \frac{R_2}{R_1 + R_2} I_{ref}, \tag{7}$$

and

$$I_p = \frac{R_1}{R_1 + R_2} I_{ref}. \tag{8}$$



(a)

(b)

Figure 2. DO-CDTA (a) symbol (b) equivalent circuit

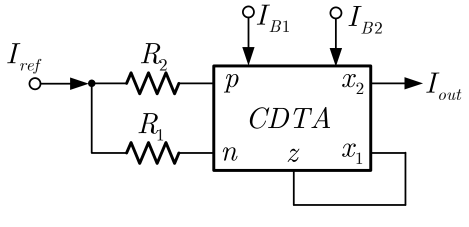


Figure 3. Proposed current-mode Wheatstone bridge

The current at z terminal can be found to be

$$I_z = I_p - I_n = \frac{R_1 - R_2}{R_1 + R_2} I_{ref}. \tag{9}$$

The current at x_1 terminal can be written as $I_{x1} = -I_z$. Due to $I_{x1} = -g_{m1}V_z$, it yields voltage at z terminal to be

$$V_z = \frac{I_{x1}}{g_{m1}} = \frac{I_{ref}}{g_{m1}} \left(\frac{R_1 - R_2}{R_1 + R_2} \right). \tag{10}$$

The output current can be found to be

$$I_o = -g_{m2}V_z = -\frac{g_{m2}}{g_{m1}} \left(\frac{R_1 - R_2}{R_1 + R_2} \right) I_{ref}. \tag{11}$$

Thus, if we have $g_{m1} = I_{B1}/2V_T$ and $g_{m2} = I_{B2}/2V_T$, $R_1 = R \mp \Delta R$ and $R_2 = R \pm \Delta R$, then

$$I_O = -\frac{I_{B2}}{I_{B1}} \left(\frac{\Delta R}{R} \right) I_{ref}. \tag{12}$$

Consequently, from Eq. (12), we can observe that the output current can be linearly controlled through input bias currents of the DO-CDTA and is theoretically temperature-insensitive. Furthermore, the output current shows a twice value relative to the current-mode Wheatstone bridge in Eq. (4).

C. Non-Ideal Case

For non-ideal case, the I_z, I_{x1} and I_{x2} of DO-CDTA can be respectively characterized by

$$I_z = \alpha_p I_p - \alpha_n I_n + \varepsilon_z, \tag{13}$$

$$I_{x1} = \beta_1 g_{m1} V_Z + \varepsilon_{x1}, \tag{14}$$

and

$$I_{x2} = \beta_2 g_{m2} V_Z + \varepsilon_{x2}. \tag{15}$$

where α and β are transferred error values deviated from one. ε_z and ε_x are the offset currents at z and x terminals, respectively. In the case of non-ideal and brief considerations, the I_O is subsequently changed to

$$I_o = -\left\{ \begin{array}{l} \dfrac{\beta_2 g_{m2}}{\beta_1 g_{m1}} \left[\dfrac{R(\alpha_p - \alpha_n) \pm \Delta R(\alpha_p + \alpha_n)}{2R} \right] I_{ref} \\ -\dfrac{\varepsilon_z \beta_2 g_{m2}}{\beta_1 g_{m1}} - \dfrac{\varepsilon_{x1} \beta_2 g_{m2}}{\beta_1 g_{m1}} + \varepsilon_{x2} \end{array} \right\}. \tag{16}$$

From Eq. (16), we can see that the last three terms are offset currents. Consequently, to reduce the offset currents, the DO-CDTA should be carefully designed to achieve these errors as low as possible. In addition, for the first term, these errors affect the magnitude of the output current. As a result, the magnitude output slightly depends on temperature due to temperature dependence of these errors. Thus, good design of the DO-CDTA should be strictly considered to alleviate the effects.

IV. SIMULATION RESULTS

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examinations. The PNP and NPN transistors employed in the proposed circuit were simulated by respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [7] with ±1.5V supply voltages. Internal construction of slight the DO-CDTA in Fig. 4 was used in the simulations. I_A was set to be 200μA. Fig. 5 shows DC characteristics of the proposed circuit. We will see that the effect of slight offset currents will appear at the output as depicted in Eq. (16) since the DO-CDTA, which was employed in the simulation, is implemented by the simple topologies. Moreover, it shows a good linearity and wide input dynamic range. Electronic controllability of the proposed circuit also shows in Fig. 6, where $R_1 = 1k\Omega$ and $R_2 = 2k\Omega$, which is accordance to Eq. (12).

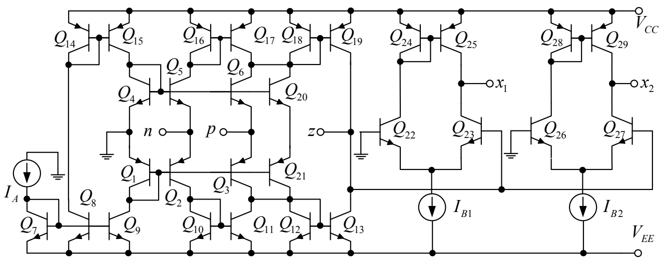


Figure 4. Internal construction of DO-CDTA

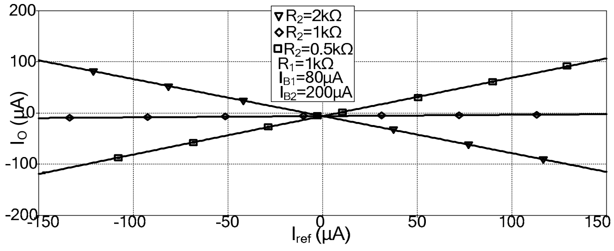


Figure 5. DC response of the proposed circuit

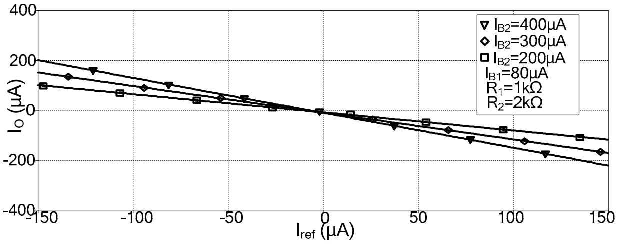


Figure 6. Simulated electronic controllability of the proposed circuit

The frequency responses of the circuit were also investigated shown in Fig. 7, where $R_1 = 1k\Omega$ and R_2 is varied. These results show that the improved Wheatstone bridge provide a wide range of frequencies, more than 64.26MHz. Additionally, circuit performance due to temperature variations for 27°C, 50°C and 100°C are illustrated in Fig. 8, where $R_1 = 1k\Omega$ and $R_2 = 0.5k\Omega, 1k\Omega$ and $2k\Omega$, they show a small deviation. The simulated maximum power consumption is about 4.55mW.

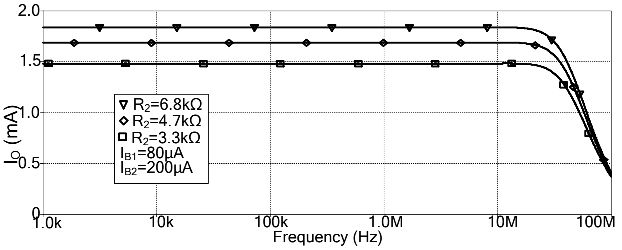


Figure 7. Frequency responses of the improved current-mode Wheatstone bridge

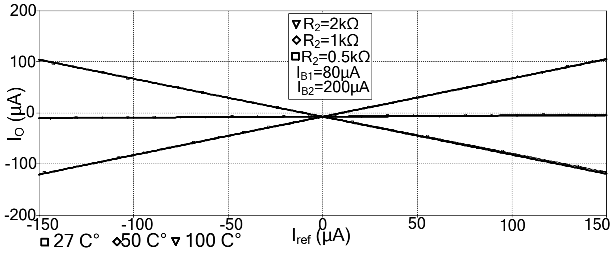


Figure 8. DC response for temperature variations of the proposed circuit

V. CONCLUSIONS

The improved current-mode Wheatstone bridge has been introduced via this article. The proposed circuit enjoys several features; electronic controllability, high gain availability, wide range of frequency responses, low temperature-sensitivity, circuit simplicity. As mentioned advantages, which are confirmed by the simulation results, the proposed circuit is appropriate for realize in a monolithic chip for use with a sensor in a measurement system.

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