New Low Temperature-sensitive and Electronically Controllable Configurations for the Measurement of Small Resistance Changes

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ABSTRACT

This article proposes two topologies of voltage-mode and current-mode improved Wheatstone bridges. The features of the proposed configurations are that: they can control magnitude of output signals via the input bias current; the proposed circuits are low temperature sensitive, the circuit descriptions are 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 frequencies (more than 30MHz). The power consumption is approximately 2.38mW and 1.13mW for voltage-mode and current-mode, respectively, at ±1.5V supply voltages.

Keywords: Current-mode, Voltage-mode, Wheatstone bridge.

1. INTRODUCTION

For many years, Wheatstone bridge is used for checking small resistance changes. So, it is usefulness for instrumentation, sensing temperature, strain, pressure and dew point humidity [1-2]. The conventional voltage-mode Wheatstone bridge consist 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 as AZKA cell, 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 (CCIs), therefore the accuracy is limited by the tolerance of intrinsic resistance 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 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 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.

The aim of this paper is to introduce new two configurations of Wheatstone bridge, they comprise voltage-mode and current-mode improved Wheatstone bridges. The proposed topologies enjoy several features as follows: the proposed circuits are temperature-insensitive, electronic controllable, uncomplicated of circuit details. In addition, the proposed topologies have a much-improved common-mode cancellation and can work with a wide range of frequencies which is an importance property to suppress any unwanted common-mode signal or noise at a high range of frequencies [5]. So, the proposed circuits have a high accuracy. The mentioned properties are confirmed by PSPICE simulation. The proposed topologies are very suitable for the measurement of small resistance changes.

![Fig. 1 (a) the conventional voltage-mode Wheatstone bridge (b) AKZA current-mode wheatstone bridge](image-url)
voltage $\Delta V = V_1 - V_2$, which is then amplified by an instrumentation amplifier. This provides an output

$$V_o = A_I V_{ref} \frac{\Delta R}{AR + 2\Delta R} \quad (1)$$

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

$$V_o = A_I V_{ref} \frac{\Delta R}{AR}. \quad (2)$$

### 2.2 Current-mode Wheatstone bridge

Recently, in an interesting attempt to improve the voltage-mode resistance bridge, a 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 $\Delta R$ of $R_2$ says gives

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

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

$$I_o = A_I I_{ref} \frac{\Delta R}{2R}. \quad (4)$$

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 circuit is required. Finally, the basic current subtraction process produces twice the output of the basic voltage subtraction process of the voltage-mode resistance bridge.

### 3. PRINCIPLE OF PROPOSED CIRCUITS

From our investigation, the above mentioned current-mode circuit suffers from additionally some 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 makes the circuit more complicated. 3) Electronic adjustability can not be achieved, which is hard to implement in an automatic control system.

This paper proposes new two improved Wheatstone bridges, which comprise voltage-mode and current-mode circuits, as followed.

### 3.1 Proposed voltage-mode improved Wheatstone bridge

Using principle of current-mode Wheatstone bridge or AZKA cell in Fig 1(b), an improved circuit in voltage-mode is developed, which is readily available in practice. Fig. 2(a) shows proposed improved voltage-mode Wheatstone bridge, where the first second generation current controlled current conveyor (CCCIH1) is used as a voltage to current converter. A Current Differencing Buffered Amplifier (CDBA) and CCCI2 function as differencing current to voltage converter. In the circuits, the resistance $R_1$ and $R_2$ symbolize the resistance of any sensors (one or both of them can represent a sensor). $I_{BI}$ and $I_{B2}$ are input bias currents of CCCI1 and CCCI2, respectively. Based on the characteristics of CCCI [6] and CDBA [7-8], for a bipolar technology, the output current of CCCI1 is obtained by

$$I_{out} = I_{ref} \frac{R_1}{R_2}. \quad (5)$$

Where $R_{11}$ is an intrinsic resistance of the CCCI1, $R_{11} = I_{BI} / 2V_R$, $V_T$ is the thermal voltage equal to 26mV at room temperature. The output current at Z terminal of the CDBA can be shown as

$$I_{out} = I_{ref} \frac{R_2}{R_1} \quad (6)$$

Then, the voltage $V_{out}$ is obtained by

$$V_{out} = V_s = R_{IP} i_x = V_{ref} \frac{R_{12}}{R_{11}} \left( \frac{R_2 - R_1}{R_1 + R_2} \right). \quad (7)$$

Finally, substituting $R_{11}$ and $R_{12}$, Eqn. (7) is modified to

$$V_{out} = I_{B2} \frac{R_{11}}{I_{BI}} \left( \frac{R_2 - R_1}{R_1 + R_2} \right) V_{ref} \quad (8)$$

Thus, if we have $R_1 = R \pm \Delta R$ and $R_2 = R \pm \Delta R$, then

$$V_{out} = I_{B2} \frac{\Delta R}{I_{BI}} \left( \frac{\Delta R}{R} \right) V_{ref} \quad (9)$$

Consequently, from Eqn. (9), we can observe that the output voltage can be linearly controlled through input bias currents of the CCCIIs and is theoretically temperature-insensitive. Furthermore, the output voltage shows a twice value relative to the current-mode Wheatstone bridge in Eqn. (4).
If a CMOS technology is used to realize with component matching of both CCCIIIs, the output voltage is easily modified to

\[ V_{\text{out}} = \frac{I_{B2}}{I_{B1}} \left( \frac{\Delta R}{R} \right) V_{\text{ref}}. \]  

From Eqn. (10), it clearly insists that the output voltage still is insensitive. Also, the output voltage shows a twice value relative currents of the CCCDTA and CCCII and ideally temperature-insensitive.

### 3.2 Proposed current-mode improved Wheatstone bridge

To achieve simpler circuitry and easy addition of sensors, current-mode improves circuit is proposed shown in Fig. 2(b). The proposed circuit employs a Current Controlled Current Differencing Transconductance Amplifier (CCCDTA) [9] as both current differencing and current amplifier, a CCCII is also used to make the circuit temperature-insensitive in ideal. From examining the circuit and use of property of CCCDTA [9], the output current \( I_{\text{out}} \) is obtained by

\[ I_{\text{out}} = \frac{I_{B1}}{I_{B2}} \left( \frac{R_2 - R_1}{R_2 + R_1} \right) I_{\text{ref}}. \]  

where \( I_{B1} \) and \( I_{B2} \) are the input bias current of the CCCDTA and CCCII, respectively. Then, if \( R_1 = R \mp \Delta R \) and \( R_2 = R = \pm \Delta R \), Eqn. (11) is modified to

\[ I_{\text{out}} = \frac{I_{B2}}{I_{B1}} \left( \frac{\Delta R}{R} \right) I_{\text{ref}}. \]  

Similar to the voltage-mode one, the output current of circuit-mode circuit can be linearly tuned by the input bias currents of the CCCDTA and CCCII and ideally temperature-insensitive. Also, the output voltage shows a twice value relative to the current-mode Wheatstone bridge in Eqn. (4).

If a CMOS technology is used to realize the current-mode circuit in Fig. 2(b), the output voltage is easily modified to

\[ V_{\text{out}} = \frac{I_{B2}}{I_{B1}} \beta \frac{R(\alpha_2 - \alpha_n) \pm \Delta R(\alpha_n + \alpha_1)}{2R} V_{\text{ref}}. \]  

In similar derivation, the output current of the current-mode circuit, with non-ideal consideration for bipolar and CMOS realization, can be respectively obtained as

\[ I_{\text{out}} = \frac{I_{B2}}{I_{B1}} \alpha \frac{R(\alpha_2 - \alpha_n) \pm \Delta R(\alpha_n + \alpha_1)}{2R} I_{\text{ref}}. \]  

Practically, from Eqns. (15-18), \( \alpha \) and \( \beta \) originate from intrinsic resistances and stray capacitances in the active elements. These errors affect the sensitivity to temperature and high frequency response of the proposed circuits, then a circuit should be designed to achieve these errors as low as possible.

### 4. SIMULATION RESULTS AND DISCUSSIONS

To prove the performances of the proposed circuits, the PSPICE simulation of a CMOS realization was used for the examinations. The PMOS and NMOS transistors employed in the proposed circuit were simulated by using the parameters of a 0.35μm TSMC CMOS technology [10]. The aspect transistor ratios (W/L) of PMOS and NMOS are 18/0.8μm and 5.6/0.8μm, respectively. The both circuits were biased with ±1.5V supply voltages. Fig. 3(a)-(b) show DC characteristics of the voltage-mode and current-mode, respectively, where \( R_1 = 2k\Omega \) and \( R_2 = 3k\Omega \). They show a good linearity and wide input dynamic range. Electronic controllability of the proposed circuits also shows in Fig. 4, where \( R_1 = 2k\Omega \) and \( R_2 = 3kh\Omega \), which is accordance to Eqns. (10) and (13). Both results show a very low offset level.
Additionally, circuit performances due to temperature variations provide a wide range of frequencies more than 30MHz.

The frequency responses of the circuits were also investigated shown in Fig. 5, where $R_1 = 2k\Omega$ and $R_2$ is varied. These results show that the improved Wheatstone bridge provide a wide range of frequencies more than 30MHz. Additionally, circuit performances due to temperature variations at 27°C, 50°C and 100°C are illustrated in Fig. 6, where $R_1 = 2k\Omega$ and $R_2 = 1k\Omega$, 2k$\Omega$ and 3.3k$\Omega$, they show a small deviation. The simulated maximum power consumptions for the voltage-mode and current-mode circuits are respectively 2.38mW and 1.13mW.

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