New Configuration for the Measurement of Small Resistance Changes Employing only CCCCTAs

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Abstract

This article proposes a novel topology of current-mode improved Wheatstone bridge based on current controlled current conveyor transconductance amplifiers (CCCCTAs). The features of the proposed configuration are that: it can control magnitude of output signals via the input bias current; the proposed circuit is low temperature sensitive, the circuit description is very simple. The circuit performances are depicted trough 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 10MHz). The power consumption is approximately 3.93mW at ±1.5V supply voltages.

Keywords : Current-mode, CCCCTA, 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 voltagemode 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 currentmode 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, 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 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. 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 that: electronic controllable, low temperature sensitive. Unfortunately, the circuits consist of many different active elements (2 CCCIIs and 1 CDBA for voltagemode, 1 CDTA and 1 CCCII for current-mode) which is not appropriate for realize in a monolithic chip.

The aim of this paper is to introduce 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 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. So, the proposed circuit has a high accuracy and employs only one type building block, called current controlled current conveyor transconductance amplifier (CCCCTA) which has recently been reported [6]. It seems to be an useful active building block to synthesize and design electronic circuits and systems because it consumes a fewer number of active elements that employing any other active elements. The mentioned properties are confirmed by PSPICE simulation. The proposed topology is very suitable for the measurement of small resistance changes.

2. Principle of Conventional Topologies

2.1 Conventional Wheatstone bridge

The basic system may be referred to as a voltagemode resistance bridge and is well known and understood. It comprised a bridge arrange of resistors R_1,R_2,R_3 and $_4R$ as shown in Fig. 1(a), which are adjusted such that the difference voltage is zero. This can be achieved by setting all resistors equal, then the bridge is then said to be balanced. A resistance change in say ${}_4R$ creates a nonzero voltage $\Delta V = V_1 - V_2$, which is then amplified by an instrumentation amplifier. This provides an output

$$V_o = A_V V_{ref} \frac{\Delta R}{4R + 2\Delta R} \qquad (1)$$

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

$$V_o = A_V V_{ref} \frac{\Delta R}{4R} \qquad (2)$$

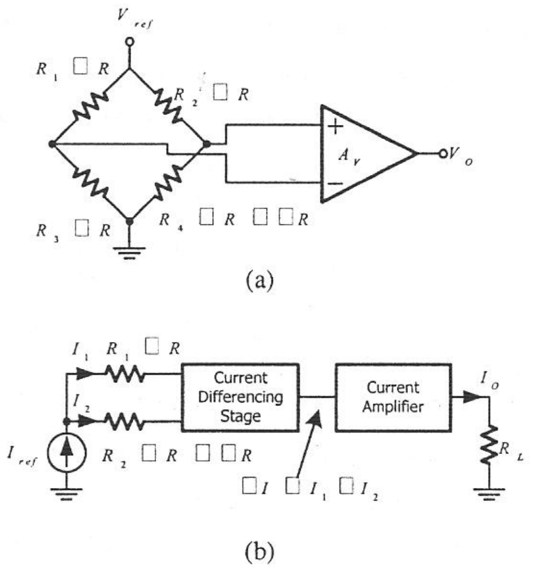

Figure 1. (a) the conventional voltage-mode Wheatstone bridge (b) AKZA current-mode Wheatstone bridge

2.2 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

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

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

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

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.

3. Principle of Operation

From our investigation, the above mentioned currentmode 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.

3.1 Basic Concept of CCCCTA

Since the proposed circuit are based on CCCCTAs [6], a brief review of CCCCTA is given in this section. Basically, CCCCTA properties are similar to the conventional CCTA, except that the CCCCTA has finite input resistance R_x at the x input terminal. This parasitic resistance can be controlled by the bias current I_{B1} as shown in the following equation

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ \pm 1 & 0 & 0 & 0 \\ 0 & 0 & g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix} \tag{5}$$

where R_x and g_m are the parasitic resistance and transconductance of CCCCTA respectively. For the bipolar CCCCTA, the R_x and g_m can be expressed to be

$$R_X = \frac{V_T}{2I_{B1}} \tag{6}$$

and

$$g_m = \frac{I_{B2}}{2V_T} \tag{7}$$

where I_B and V_T are the input bias current and thermal voltage respectively. The schematic symbol and equivalent circuit of CCCCTA can be respectively shown in Fig. 2 (a) and (b).

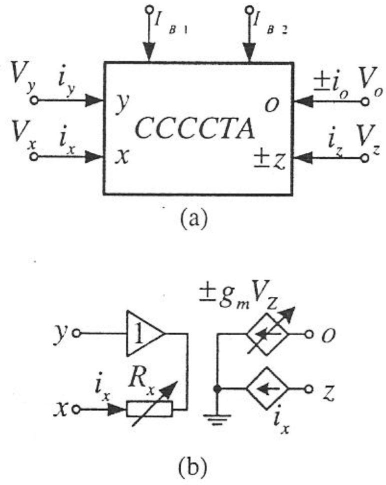

Figure 2. CCCCTA (a) symbol (b) equivalent circuit

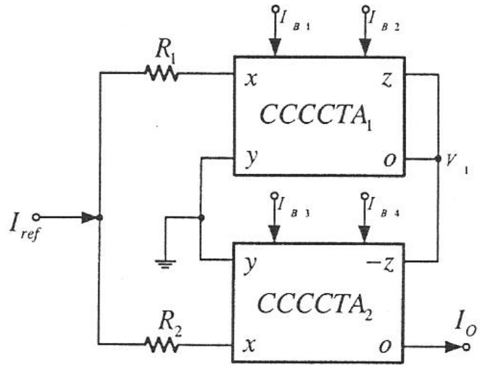

Figure 3. Proposed current-mode Wheatstone bridge

3.2 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. 2 shows proposed improved current-mode Wheatstone bridge, where the CCCCTA1 and CCCCTA2 function as differencing current and current amplifier. In the circuit, the resistances R_1 and R_2 symbolize the resistance of any sensors (one or both of them can represent a sensor). I_{B1}, I_{B2}, I_{B3} and I_{B4} are input bias currents of CCCCTA1 and CCCCTA2, respectively. Based on the characteristics of CCCCTA in section 3.1, the current at Z_1 and Z_2 terminal can be expressed to be

$$I_{z1} = -\frac{R_2 + R_{x2}}{R_1 + R_{x1} + R_2 + R_{x2}} I_{ref} \tag{8}$$

and

$$I_{z2} = \frac{R_1 + R_{x1}}{R_1 + R_{x1} + R_2 + R_{x2}} I_{ref} \tag{9}$$

The voltage at node V_1 can be found as

$$V_1 = -\frac{1}{g_{m1}}\left(I_{z1} + I_{z2}\right) \tag{10}$$

Substituting Eqs. (8) and (9) into (10), it yields

$$V_1 = -\frac{1}{g_{m1}}\left(\begin{array}{c} -\dfrac{R_2 + R_{x2}}{R_1 + R_{x1} + R_2 + R_{x2}} I_{ref} + \\ \dfrac{R_1 + R_{x1}}{R_1 + R_{x1} + R_2 + R_{x2}} I_{ref} \end{array}\right) \tag{11}$$

The output current can be found as

$$I_O = -g_{m2}V_1 = -\frac{g_{m2}}{g_{m1}}\left(\begin{array}{c} \dfrac{R_2 + R_{x2}}{R_1 + R_{x1} + R_2 + R_{x2}} I_{ref} - \\ \dfrac{R_1 + R_{x1}}{R_1 + R_{x1} + R_2 + R_{x2}} I_{ref} \end{array}\right) \tag{12}$$

From Eq. (12), if $R_{x1} \cong 0$ and $R_{x2} \cong 0$ which can be achieved by setting I_{B1} and I_{B3} more large. The output current will be changed to be

$$I_O = -\frac{g_{m2}}{g_{m1}}\left(\frac{R_2}{R_1 + R_2} - \frac{R_1}{R_1 + R_2}\right) I_{ref} \tag{13}$$

Thus, if we have $g_{m1} = I_{B2}/2V_T$ and $g_{m2} = I_{B4}/2V_T$, $R_1 = R \mp \Delta R$ and $R_2 = R \pm \Delta R$, then

$$I_O = -\frac{I_{B4}}{I_{B2}}\left(\frac{\Delta R}{R}\right) I_{ref} \tag{14}$$

Consequently, from Eq. (14), we can observe that the output current can be linearly controlled through input bias currents of the CCCCTAs and is theoretically temperature-insensitive. Furthermore, the output current shows a twice value relative to the current-mode Wheatstone bridge in Eq. (4).

3.3 Non-Ideal Analysis

In non-ideal case, the CCCCTA can be characterized by

$$I_z = \alpha I_x + \varepsilon_z \tag{15}$$

and

$$I_o = \gamma g_m V_z + \varepsilon_o \tag{16}$$

where α and γ are transferred error values deviated from one. ε_z and ε_o 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

$$Io = \left\{\begin{array}{l} -\dfrac{\gamma_2 I_{B4}}{\gamma_1 I_{B2}}\left[\dfrac{R(\alpha_1 - \alpha_2) \pm \Delta R(\alpha_1 + \alpha_2)}{2R}\right] I_{ref} - \\ \dfrac{\gamma_2 I_{B4}}{\gamma_1 I_{B2}}\left(\varepsilon_{z1} - \varepsilon_{z2}\right) - \varepsilon_{O1}\dfrac{\gamma_2 I_{B4}}{\gamma_1 I_{B2}} + \varepsilon_{O2} \end{array}\right\} \tag{17}$$

From Eq. (17), we can see that the last three terms are offset currents. Consequently, to reduce the offset currents, the CCCCTA 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 CCCCTA should be strictly considered to alleviate the effects.

4. Simulation Results and Discussions

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 the CCCCTA in Fig. 4 was used in the simulations. I_{B1} and I_{B3} were set to be 200μA Fig. 5 shows DC characteristics of the proposed circuit, where $R_2 = 1k\Omega$. They show a good linearity and wide input dynamic range. Electronic controllability of the proposed circuit also shows in Fig. 6, where $R_1 = 0.5k\Omega$ and $R_2 = 1k\Omega$, which is accordance to Eq. (14). The result shows a quite low offset level.

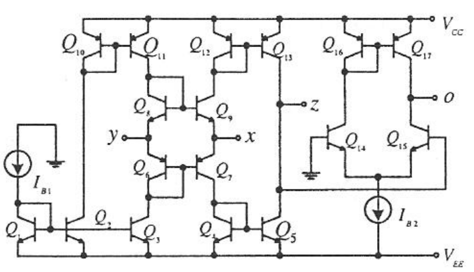

Figure 4. Internal construction of CCCCTA

The frequency responses of the circuit were also investigated shown in Fig. 7, where $R_2 = 1k\Omega$ and R_1 is varied. These results show that the improved Wheatstone bridge provide a wide range of frequencies more that 15.21MHz. Additionally, circuit performance due to temperature variations at 27°C, 50°C and 100°C are illustrated in Fig. 8, where $R_2 = 1k\Omega$ and $R_1 = 0.5k\Omega, 1k\Omega$ and $2k\Omega$, they show a small deviation. The simulated maximum power consumption is about 3.93mW.

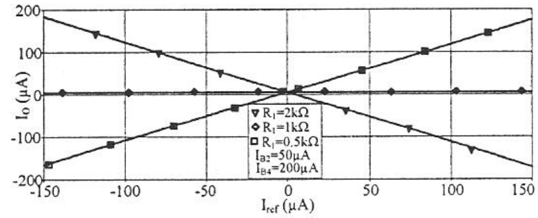

Figure 5. DC response of the improved current-mode Wheatstone bridge

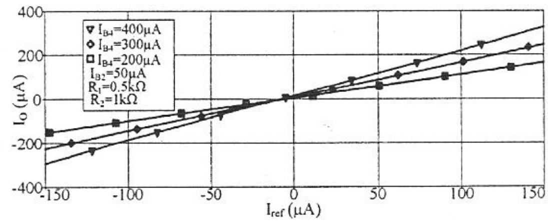

Figure 6. DC response with electronic controllability of the proposed circuit

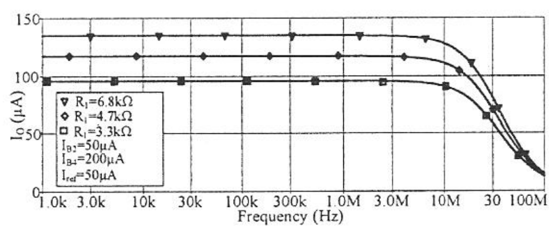

Figure 7. Frequency responses of the improved current-mode Wheatstone bridge

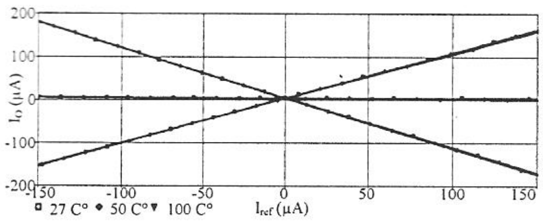

Figure 8. DC response with temperature variations of the proposed circuit

5. Conclusion

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 and low offset level. 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.

6. References

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