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On The Sensitivity Characteristics In Novel Automatic Wheatstone Bridge-Based Interfaces

Paolo Mantenuto, Andrea De Marcellis*, Giuseppe Ferri

University of L'Aquila, Department of Industrial and Information Engineering and Economics
Via Gronchi 18, 67100, L'Aquila, Italy

Abstract

The sensitivity characteristics of two novel fully-analog uncalibrated read-out circuits, based on a suitable modification of the classic Wheatstone bridge topology, employed for resistive sensor measurements, are here described and discussed. The proposed circuits maintain the bridge characteristics of a simple architecture and an easy estimation technique. The proved advantages of these two solutions are related to the evaluation of about 5 resistive decades variations [100Ω ÷10MΩ] and to the reduced error confined within ±2%. Moreover, it is here demonstrated that, in the proposed interfaces, sensitivity values are higher than those of the classic Wheatstone bridge, supply-voltage independent and can be set through a proper choice of the passive element values.

Keywords: Fully-analog interface; Fully-analog four quadrant multiplier; Read-out electronic interface; Resistive sensors; Resistive gas sensor; Resistance-to-voltage conversion; Uncalibrated circuit; Voltage controlled resistance; VCR; Wheatstone bridge; Wide dynamic range.

1. Introduction

Recently, the authors have presented two new self-balancing bridge-based resistive sensor interfaces (one for a "grounded" and one for a "floating" sensor configuration), performing the Resistance-to-Voltage (*R*-*V*) conversion [1-2], able to reveal and quantify a wide-range resistive variation with reduced error, when compared to Resistance-to-Period (*R*-*T*) interfaces, typically used in these cases. In the literature, a number of solutions (e.g., [3-5]) capable to perform the resistance estimation have been proposed but the most of them employ complex topologies, control digital blocks or only integrated solutions with switched capacitors and MOS/BJT transistors as Voltage Controlled Resistances (*VCR*s). In this work we want to examine, in particular, the sensitivity characteristics of two new efficient auto-balancing circuit topologies which employ only two active low-cost commercial devices, that is the fully-

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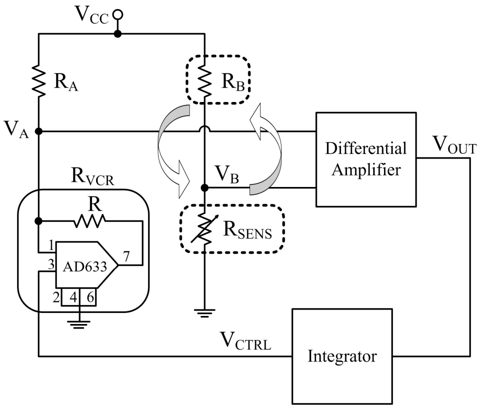

Fig. 1. Proposed bridge-based resistive interfaces schematic.

analog four quadrant multiplier AD633 and the low-offset operational amplifier LF411.

Experimental results on PCB have demonstrated that, for both these configurations, sensitivity characteristics are much better than those obtained with the traditional Wheatstone bridge topology.

2. The proposed interfaces working principle

In Fig.1 the "grounded" and "floating" sensor resistance interfaces are reported, according to the position, in the right branch, of R_{SENS} and R_B, respectively. They maintain the simple architecture based on Wheatstone bridge and, through a suitable feedback loop which is able to properly tune an active resistance (*VCR*) based on the analog four quadrant multiplier AD633, the equilibrium condition is automatically provided (uncalibrated system) over a range much wider than that of typical resistive bridge configurations.

The advantages of these architectures, with respect to the traditional bridge [3], are the following: 1) wider and settable operative range (automatic tuning range: 1.6 decades, complete estimation range: 5 decades), 2) uncalibrated characteristic (then, the adopted sensor features are not fundamental), 3) higher and settable sensitivity, thanks to a suitable choice of the element values adopted in the architecture.

When a sensor variation occurs, the balancing condition (ΔV=0) is continuously performed through a suitable control voltage level (V_{CTRL}), generated through an appropriate feedback loop, which tunes the equivalent *VCR* value $R_{VCR}=10R/(10\text{-}V_{CTRL})$, being R its internal load (see Figure 1). Thus, while the circuit response for classic Wheatstone bridge is only a function of its differential output ΔV, for the here proposed configurations it is a function of also V_{CTRL}, outside the auto-tuning range [1-2].

3. The proposed interfaces sensitivity

According to Figure 1, the "grounded" configuration provides the equilibrium condition ($\Delta V=0$) when $R_A R_{SENS}=R_B R_{VCR}$, so, being $K=R_B/R_A$, from eq.2, related to a generic resistive variation, and eq.4, concerning a reduced one ($R_{SENS}=R_{S0}(1+\delta)$), it can be seen that the here proposed solution shows a sensitivity value, defined with respect to V_{CTRL} in Table 1, which is voltage supply, V_{CC}, independent.

In the same way it is possible to examine the "floating" configuration considering the schematic in Figure 1, where R_B and R_{SENS} resistors have switched their position. In this manner, the equilibrium condition is now performed by $R_A R_B=R_{SENS} R_{VCR}$, so, being $R_{K1}=R_B R_A/R$, eq.s 6 and 8 show that sensitivity does not depend both on V_{CC} and on the sensor variations but assumes a constant value that depends on the components employed in the bridge (see Table 2).

This implies also that, for integrated solutions, where the low-voltage design is mandatory, higher sensitivity values can be now obtained, when compared (inside the operating range) to sensitivity values of traditional Wheatstone bridge (Table 3).

In Figure 2a the sensitivity trend with respect to high sensor variations is depicted; the equilibrium condition is performed and sensitivity must be calculated in the auto-tuning range with respect to V_{CTRL} (eq.s 2 and 6) because ΔV=0; outside this region, V_{CTRL} is saturated and sensitivity has to be determined considering ΔV as in the traditional Wheatstone bridge topology (eq.10). Moreover, in Figure 2b, sensitivity trend with respect to small sensor variations (δ) inside the automatic range is depicted; here, results from eq.s 4, 8 and 12 are compared.

From these figures, it comes that sensitivity values are higher in the proposed interfaces with respect to those determined with the traditional bridge. This feature, together with the capability of evaluating high resistive variations, allows the proposed circuits to be suitable as general purpose resistive interfaces.

Table 1. Voltages and sensitivity equations for the grounded resistive sensor configuration

Grounded resistive sensor sensitivity		
$V_{CTRL} = 10\left(1 - \frac{RR_B}{R_A R_{SENS}}\right)$	[V]	(1)
$S_{GR_{VCTRL}} = \frac{\partial V_{CTRL}}{\partial R_{SENS}} = 10\frac{RR_B}{R_A R_{SENS}^2}$	$\left[\frac{\text{V}}{\Omega}\right]$	(2)
$V_{CTRL\delta} = 10\left(1 - \frac{RR_B}{R_A R_{S0}(1+\delta)}\right)$	[V]	(3)
$S_{G_\delta} = \left.\frac{\partial V_{CTRL\delta}}{\partial \delta}\right\|_{(R_A = R_B = R_{S0})} = \frac{10R}{R_{S0}(1+\delta)^2}$	[V]	(4)

Table 2. Voltages and sensitivity equations for the floating resistive sensor configuration

Floating resistive sensor sensitivity		
$V_{CTRL} = 10\left(1 - \frac{RR_{SENS}}{R_A R_B}\right)$	[V]	(5)
$S_{FR_{VCTRL}} = \frac{\partial V_{CTRL}}{\partial R_{SENS}} = 10\frac{R}{R_A R_B}$	$\left[\frac{\text{V}}{\Omega}\right]$	(6)
$V_{CTRL\delta} = 10\left(1 - \frac{RR_{S0}}{R_A R_B}(1+\delta)\right)$	[V]	(7)
$S_{F_\delta} = \left.\frac{\partial V_{CTRL\delta}}{\partial \delta}\right\|_{R_A = R_B = R_{S0}} = 10\frac{R}{R_{S0}}$	[V]	(8)

Table 3. Voltages and sensitivity equations for traditional Wheatstone bridge topology (where R_C replaces R_{VCR} in Figure 1)

Traditional Wheatstone bridge sensitivity		
$\Delta V = V_{CC}\left[\frac{R_{SENS}R_C - R_A R_B}{(R_A + R_C)(R_{SENS} + R_B)}\right]$	[V]	(9)
$S_{WR_{\Delta V}} = \frac{\partial \Delta V}{\partial R_{SENS}} = V_{CC}\frac{R_B}{(R_B + R_{SENS})^2}$	$\left[\frac{V}{\Omega}\right]$	(10)
$\Delta V_\delta = V_{CC}\left[\frac{R_{S0}(1+\delta)R_C - R_A R_B}{(R_A + R_C)(R_{S0}(1+\delta) + R_B)}\right]$	[V]	(11)
$S_{W_\delta} = \left.\frac{\partial \Delta V_\delta}{\partial \delta}\right\|_{(R_A = R_B = R_{S0})} = \frac{V_{CC}}{4 + 4\delta + \delta^2}$	[V]	(12)

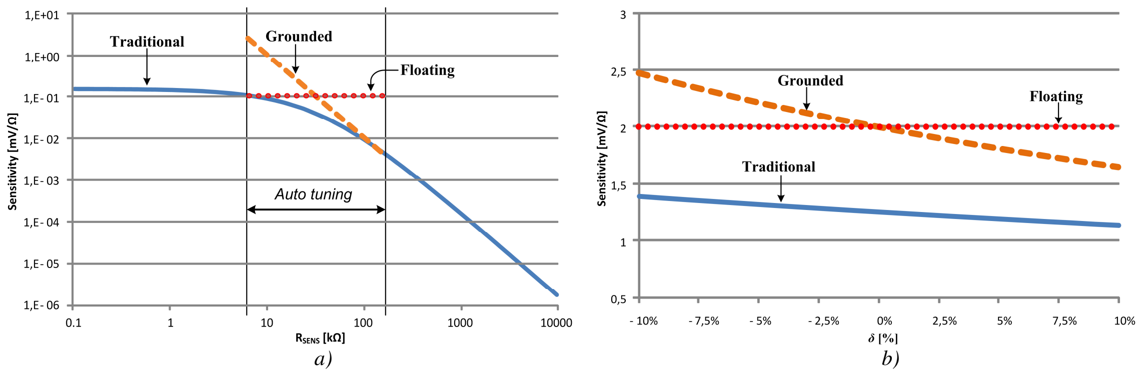

Fig. 2. Sensitivity trend of the proposed interfaces, compared to traditional Wheatstone bridge for both wide-range (a) and reduced (b) sensor resistive variations.

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