

Linearization of the Output of a Wheatstone Bridge for Single Active Sensor

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Abstract: The output of a Wheatstone bridge with only a single active resistive sensor is inherently nonlinear. A generalized feedback compensation scheme is presented in this paper that provides a linear output for a Wheatstone bridge with only a single active resistive sensor, even for large variations in the resistance of the sensor. Simulation studies and experimental verifications establish the efficacy of the proposed linearization technique. The proposed method is best suited for single active resistive sensors involving Resistive Temperature Devices (RTD) and piezo-resistive type sensors possessing large range of variation.

I. Introduction

The Wheatstone bridge is a simple and popular signal conditioning circuit for resistive sensors such as Strain gages, RTD, and piezo-resistive sensors [1]. The typical form of a Wheatstone bridge circuit with a single active sensor is given in Fig. 1. The resistance R_S of the sensor can be expressed as $R_S = R_0(1 \pm kx)$, where x is the parameter being measured, R_0 is the nominal value of the resistance of the sensor (when x is zero) and k is the sensitivity of the sensor and can be either positive (for RTD) or negative (for sensors with negative temperature coefficient of resistance, such as

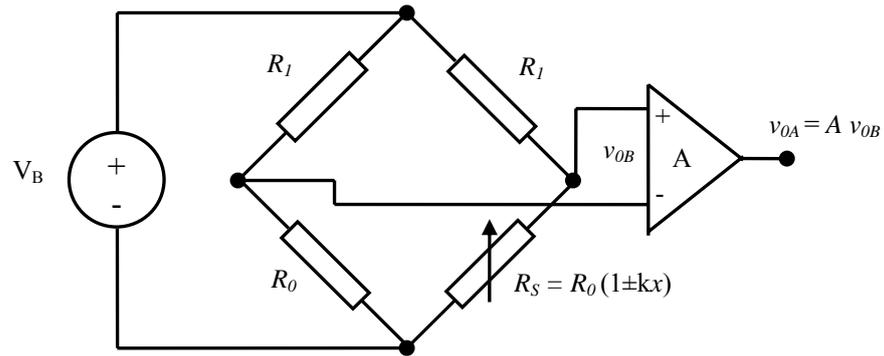


Figure 1 Wheatstone Bridge for a single active Resistive Sensor

thermistors). Since the output of the bridge will be small, the same is amplified with the help of an instrumentation amplifier of gain A . The output v_{OB} of the bridge shown in Fig. 1 in terms of the bridge excitation voltage V_B is given by

$$v_{OB} = V_B \left[\frac{\gamma}{(1 + \gamma)^2} \right] \left(\frac{kx}{1 + \frac{kx}{(1 + \gamma)}} \right), \quad (1)$$

where $\gamma = R_1 / R_0$. It is easily seen that the output of the bridge is a nonlinear function of the measurand x [2], [3]. The nonlinearity can be reduced to a large extent by the choice of γ and the maximum value of kx [4]. Resistive sensors such as metallic strain gages have low maximum permissible values for kx (~ 0.1), thus minimizing the nonlinearity. Nonlinearity can also be made insignificant, by choosing a large value for γ . The output of the bridge shown in Fig. 1, for various values of γ , is given in Fig. 2. It can be observed from Fig. 2 that large values of γ improve linearity but the sensitivity of the bridge is reduced, resulting in low bridge output and hence low resolution. For resistive sensors like the

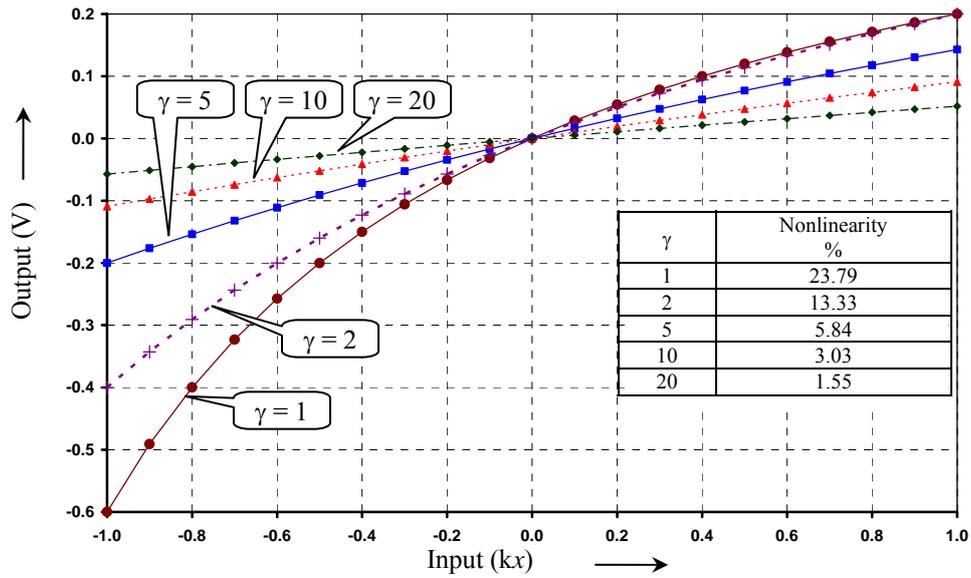


Figure 2 Output of the single active sensor Wheatstone Bridge

Pt100, the platinum resistance temperature device (RTD), the value of kx can be as large as 3 [5] and hence even with a γ of 10, the nonlinearity will be much more than depicted in Fig. 2, where the maximum value of kx is chosen to be 1. Thus the Wheatstone bridge, though simple, cannot provide a perfectly linear output for a single active sensor, especially if the sensor possesses large variation in kx . Attempts have been made to linearise the bridge using positive feedback compensation [6],[7] but they involve specific application designed chips and are expensive. Moreover, they are limited to a narrow dynamic range of the RTD. Even ICs which have been specifically designed for Strain Gage / RTD type of sensors require external components as well as iterative procedures for linearising the transducer output in addition to manual operation to determine the sense of the feedback [8].

We now present a novel, generalized feedback scheme that operates on the output of the Wheatstone bridge of Fig. 1 and provides a final output that is linearly proportional to the measurand x .

II. Feedback Compensation Scheme

The proposed scheme is shown in Fig. 3. The output of the bridge v_{oB} is amplified by an instrumentation amplifier of gain A to obtain the final output v_o . A part of the output, say βv_o ($\beta < 1$) is added to a reference voltage V_R , employing a unity gain adder and the output of the adder provides the bridge excitation V_B . Then,

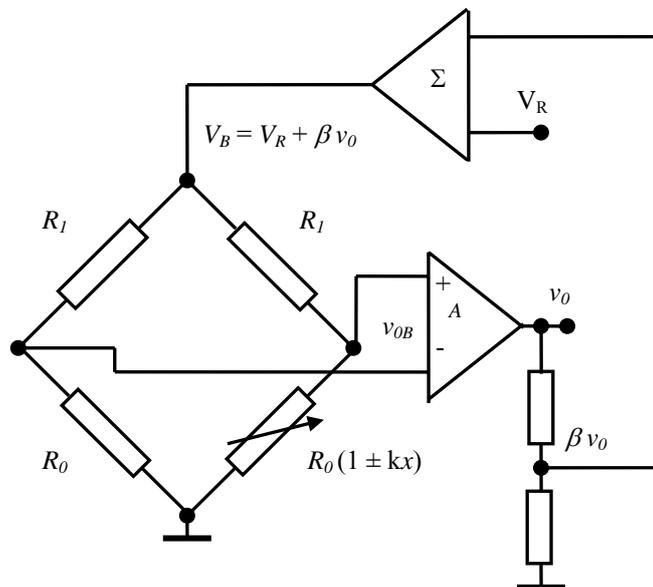


Figure 3 Feedback compensation for linearising the output of a Wheatstone bridge with a single active resistive sensor

$$v_o = Av_{ob} = AV_B \left[\frac{\gamma}{(1+\gamma)^2} \right] \frac{kx}{\left(1 + \frac{kx}{(1+\gamma)}\right)} \text{ and } V_B = V_R + \beta v_o, \quad (2)$$

resulting in

$$v_o = Av_{ob} = (V_R + \beta v_o)A \left[\frac{\gamma}{(1+\gamma)^2} \right] \frac{kx}{\left(1 + \frac{kx}{(1+\gamma)}\right)} \quad (3)$$

Rearranging equation (3) we get:

$$v_o - A\beta v_o \left[\frac{\gamma}{(1+\gamma)^2} \right] \frac{kx}{\left(1 + \frac{kx}{(1+\gamma)}\right)} = V_R \left[\frac{\gamma}{(1+\gamma)^2} \right] \frac{kx}{\left(1 + \frac{kx}{(1+\gamma)}\right)} A \quad (4)$$

Equation (4) simplifies to

$$v_o = V_R \left[\frac{\gamma}{(1+\gamma)^2} \right] \left[\frac{1}{\left(1 + \frac{kx}{(1+\gamma)} (1 + \gamma - A\beta\gamma)\right)} \right] A kx \quad (5)$$

If the attenuation factor β is chosen such that $A\beta$ is made equal to $\frac{(1+\gamma)}{\gamma}$ then

$$v_o = V_R \left[\frac{\gamma}{(1+\gamma)^2} \right] A kx \quad (6)$$

Equation (6) implies that the feedback scheme of Fig. 3 provides an amplified output, linearly proportional to the parameter x that is being sensed by the resistive sensor, provided the feedback is adjusted such that $A\beta = \frac{(1+\gamma)}{\gamma}$. To determine the efficacy of the proposed method, simulation and experimental studies were carried out as detailed next.

III. Simulation Studies

The entire circuit shown in Fig. 3 was simulated using the circuit layout and simulation software, OrCAD (v9.0). A resistor having a nominal value R_o of 100 Ω and kx varying from -1 to +1 was chosen to simulate the performance of the resistive sensor. The INA101 served as the instrumentation amplifier while the OP07 was used for realizing the summer and the voltage followers. The reference voltage of 1.2 V was obtained with the help of a precision Voltage Reference

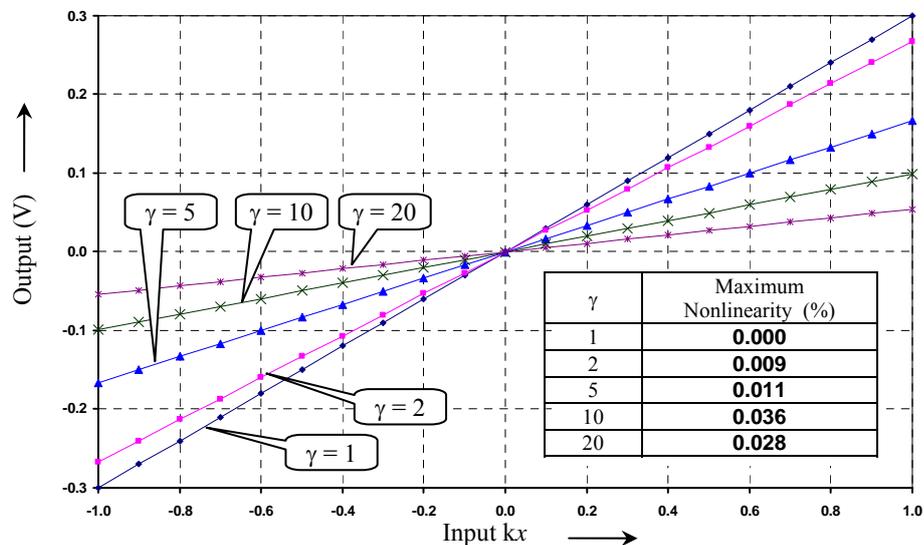


Figure 4 Simulated Output of the single active sensor Wheatstone bridge – with the proposed feedback compensation

Diode LM385-1.2. The results of the simulation are portrayed in Fig. 4. Figs. 2 and 4 clearly illustrate that the proposed scheme provides a linear output and considerably reduces the nonlinearity, that would otherwise be present in the output of the Wheatstone Bridge.

IV. Experimental Setup

The circuit shown in Fig. 3 was set up using off-the-shelf components and breadboarded. The INA101 from Burr-Brown (now Texas Instruments) was used for the instrumentation amplifier and the OP07 was the opamp of choice for the summer and voltage followers, mainly due to its low input offset voltage ($\sim 25\mu\text{V}$), easy availability and affordability. The LM385-1.2 Reference Voltage Diode from National Semiconductor Corp. was employed for generating the reference voltage. The sensor resistance was simulated using a precision resistance box ranging from $0.1\text{-}1221\ \Omega$ (Model V441 from Otto Wolff Berlin, Germany), having an accuracy of $\pm 0.001\%$. The bridge was set up to simulate the conditions of $\gamma = 1$ and 20 . The output across the bridge was carefully measured using a $6\frac{1}{2}$ -digit multimeter (HP34401A). The ambient temperature was maintained at 25°C , to nullify any change in the resistances due to temperature variations. The results obtained are plotted in Fig. 5 and the non-linearity in both the cases indicated.

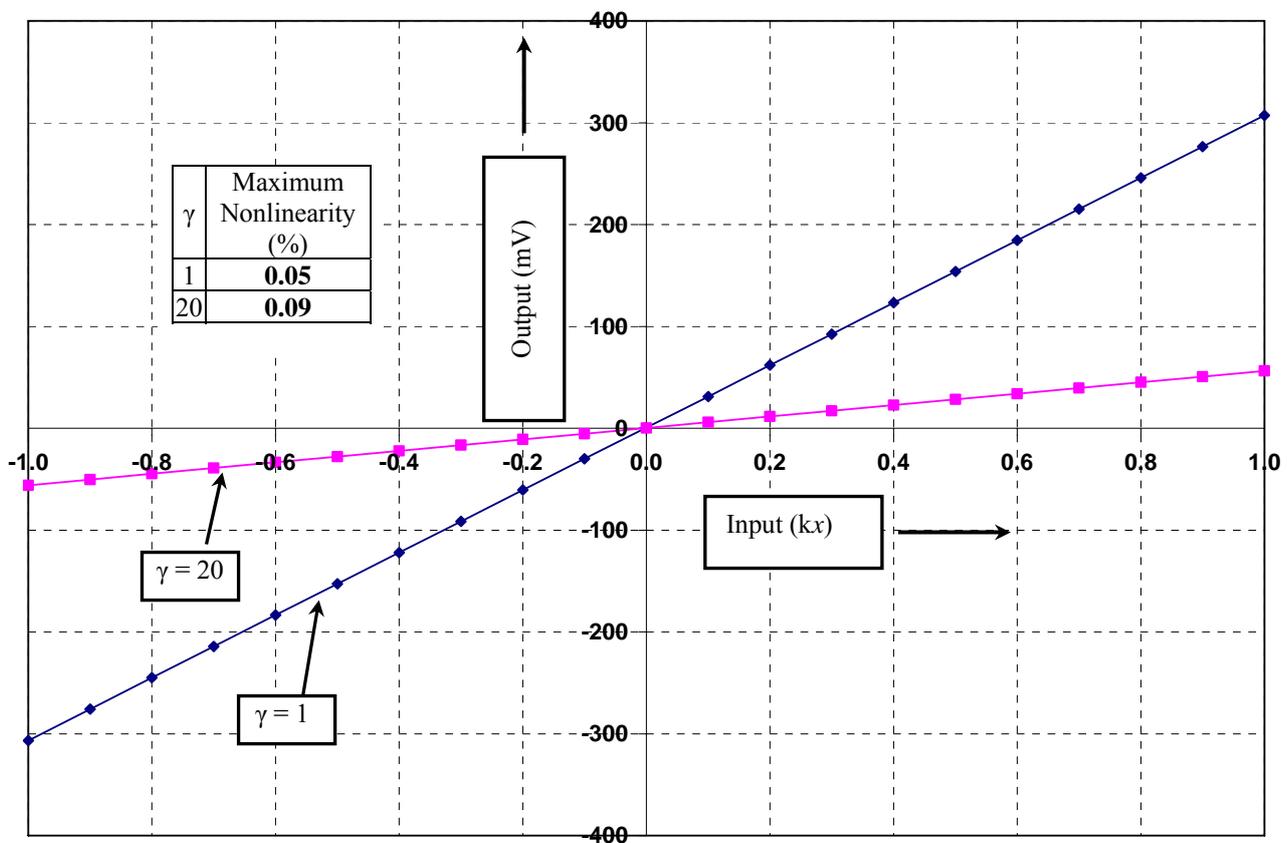


Figure 5 Output of the prototype for two different values of γ

V. Conclusions

A feedback compensation scheme for linearising the output of a Wheatstone Bridge has been presented in this paper. Results indicate that the circuit outlined in the paper significantly reduces the nonlinearity in the output of the bridge, using easily available, off-the-shelf, inexpensive components. It is to be emphasised that the reduction in non-linearity is due to the nature of the compensation employed and that further improvement in performance can be achieved if components with better specifications and tolerances are used. Further work needs to be carried out to determine the limits of operation of the circuit as well as to determine and quantify potential sources of errors in the circuit.

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