Signal Conditioning Wheatstone Resistive Bridge Sensors

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ABSTRACT

Resistive elements configured as Wheatstone bridge circuits are used to construct force and pressure sensors. The resistive elements used to make the bridge change resistance in response to mechanical strain.

This report discusses the basic concepts of resistive bridge sensors and three circuits commonly used for signal conditioning their output.

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1 Introduction

There are two main technologies used to create resistive bridge sensors: strain gauge (or gage) and integrated circuits.

Strain gages are widely used and have been available for many years. Typically, the strain gauge is bonded to a rigid structure, and when a force acts upon the structure, the strain gauge changes resistance. Strain gauge sensors are commonly used for both force and pressure measurement. For more details refer to *The Pressure Strain and Force Handbook*, Omega Engineering, Inc. http://www.omega.com.

More recently, monolithic resistive bridge sensors have become commercially available as integrated circuits. The bridge circuit is constructed on a silicon die. When a force is exerted on the die, the resistance changes. Normally this type of sensor is used to measure pressure. For more information refer to *Solid–State Pressure Sensors Handbook*, Sensym, http://www.sensym.com.

Figure 1 shows a resistive Wheatstone bridge circuit and its Thevenin equivalent. When an excitation voltage is applied between Vexc and GND and all resistances are equal, the voltage at SIG+ and SIG– is 1/2 Vexc.

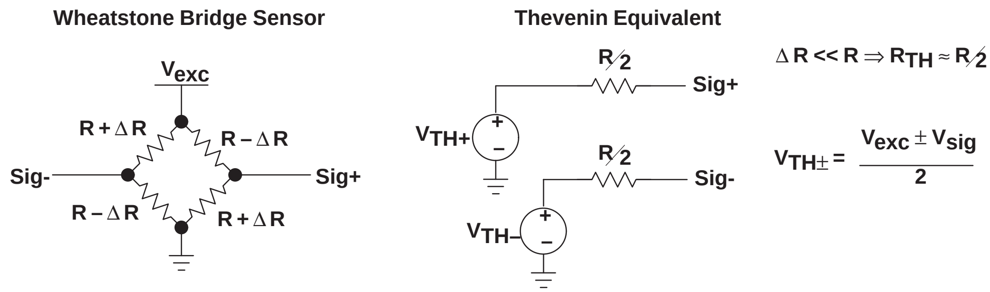

Figure 1. Wheatstone Bridge Sensor and Thevenin Equivalent

Sensors are designed so that when acted upon, opposite resistors in the bridge change resistance as shown by ±ΔR. The voltage at SIG+ and SIG– is then offset from 1/2 Vexc.

In a measurement system, the differential voltage, Vsig = (SIG+) – (SIG–), is the electrical signal indicating the amount of force or pressure acting upon the sensor. With four active elements, the output voltage is: $Vsig = Vexc \times \frac{\Delta R}{R}$. Since ΔR is proportional to the force or pressure, this can be rewritten as Vsig = Vexc × F × S, where F is the force or pressure and S is the sensitivity, or output voltage, of the sensor in mV per volt of excitation with full scale input, as specified by the sensor manufacturer.

Wheatstone resistive bridge sensors can be analyzed using Thevenin's Theorem, where the circuit is reduced to voltage sources with series resistance. Figure 1 shows the Thevenin equivalent circuit. ΔR is normally very small in comparison to R so the Thevenin equivalent series resistance, commonly known as the source resistance, can be taken as equal to R. The Thevenin voltage sources have a common mode component equal to 1/2 Vexc and a differential component equal to 1/2 Vsig.

2 Signal Conditioning

Normally full scale output voltages are in the 10 mV to 100 mV range, and need to be amplified in a data acquisition system. Three circuits commonly used for amplification are the one op amp differential amplifier, the three op amp instrumentation amplifier, or the two op amp instrumentation amplifier. These amplifiers amplify the differential input voltage, and reject the common mode input voltage. They are well-suited for use with Wheatstone bridge sensors. Depending on design requirements one may be better suited than the other.

All three circuits require resistor matching to achieve good CMRR. Variations of these amplifiers, which add gain and offset adjustment, can be found in various application literature.

2.1 Single Op Amp Differential Amplifier

The single op amp, differential amplifier is shown in Figure 2. Its input impedance is relatively low and requires the source impedance of the sensor be considered in the gain calculation.

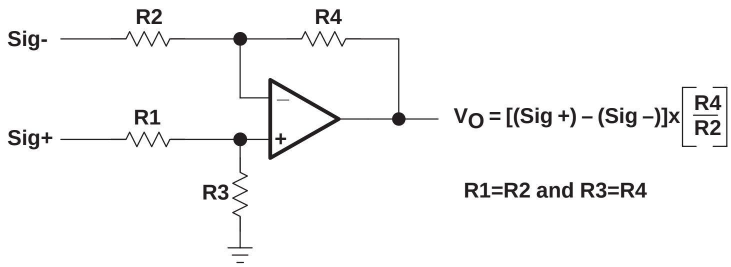

Figure 2. Single Op Amp Differential Amplifier

The Thevenin equivalent of the sensor is useful in calculating gain. For example:

> Given a sensor having 1 kΩ elements and a sensitivity of 10 mV/V is being used with 5 V of excitation. At full-scale, the resistors will have ΔR=10 Ω and 50 mV will be seen from SIG– to SIG+ if measured with a high impedance voltmeter. Refer to Figure 3.

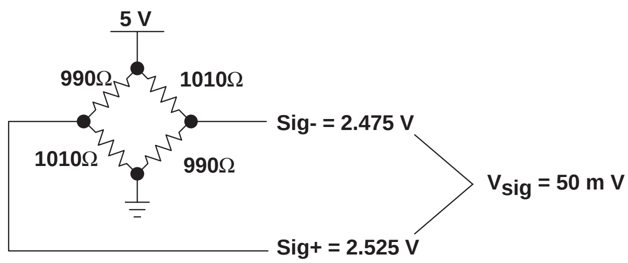

Figure 3. Sensor Output With No Load

Assuming full scale at the output of the amplifier is 5 V, a gain of 100 is needed. Choosing R1 = R2 = 1 kΩ and R3 = R4 = 100 kΩ seems to be correct, but when tested the output is 30% lower than expected. What is wrong?

The source impedance must be taken into account. As shown in Figure 4, using the Thevenin equivalent of the bridge, it is obvious that R3 and R4 need to be 150 kΩ to get the required gain of 100.

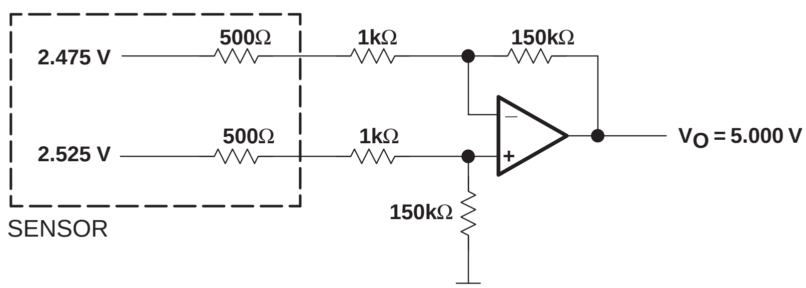

Figure 4. Thevenin Equivalent Shows Required Gain is 50% Higher

Note that the impedance seen at the negative input (SIG–) is not constant. It varies with the output voltage which causes slight non–linearity.

Due to its low cost and general simplicity the single op amp differential amplifier circuit is attractive, and is often used with success.

2.2 Three Op Amp Instrumentation Amplifier

The three op amp instrumentation amplifier, or in-amp, uses three op amps. The circuit, shown in Figure 5, has high input impedance, and source impedance does not play a role in calculation of gain.

To achieve better CMRR performance, use a resistor pack for resistors R1–R4 and RF. Set the gain using Rg.

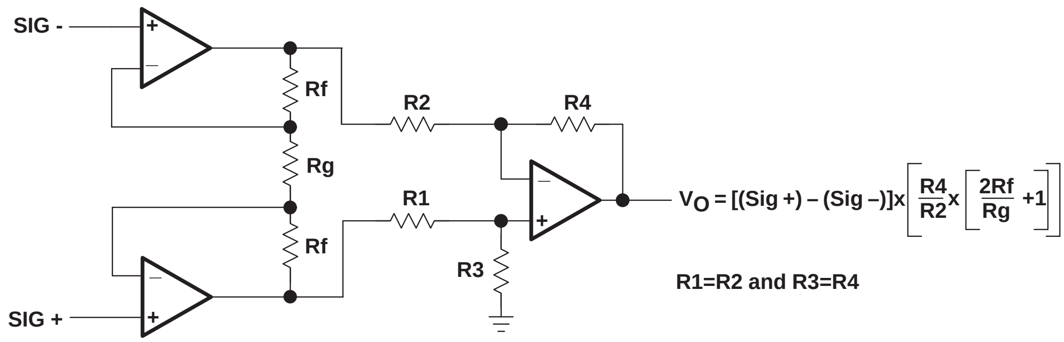

Figure 5. Three Op Amp Instrumentation Amplifier

2.3 Two Op Amp Instrumentation Amplifier

The two op amp instrumentation amplifier, shown in Figure 6, also has high input impedance like the three op amp in-amp, but requires one less op amp. Source impedance does not play a role in calculation of gain.

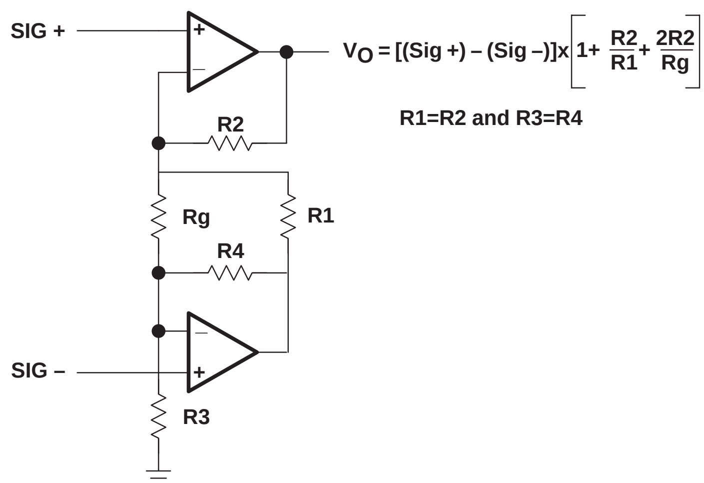

Figure 6. Two Op Amp Instrumentation Amplifier

Again, using a resistor pack for R1–R4 and setting the gain using Rg will help achieve better CMRR performance. This amplifier is not as balanced as the 3 op amp in-amp. A signal at SIG– passes through both op amps, whereas, only one op amp is seen from SIG+.

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