Balanced Constant Current™ Excitation for RTD Sensor Measurements

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Overview

Balanced Constant Current™ (BCC™) excitation uses a pair of matched constant current sources to excite an RTD sensor. The technique provides enhanced immunity from electrostatic noise pickup and may be employed for RTD measurement applications that require two or four wires to the transducer.

In this paper, the properties of balanced constant current excitation will be examined and compared against traditional techniques using the Wheatstone bridge or single-ended constant current excitation. A method to verify transducer health and cabling will also be presented.

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Introduction

There are various cabling and hookup schemes used for Resistance Temperature Detector (RTD) measurements ranging from a simple two-wire connection, to a four wire Kelvin connection depending on the desired accuracy. Constant voltage or constant current excitation in combination with a variety of circuits can be utilized to measure the RTD.

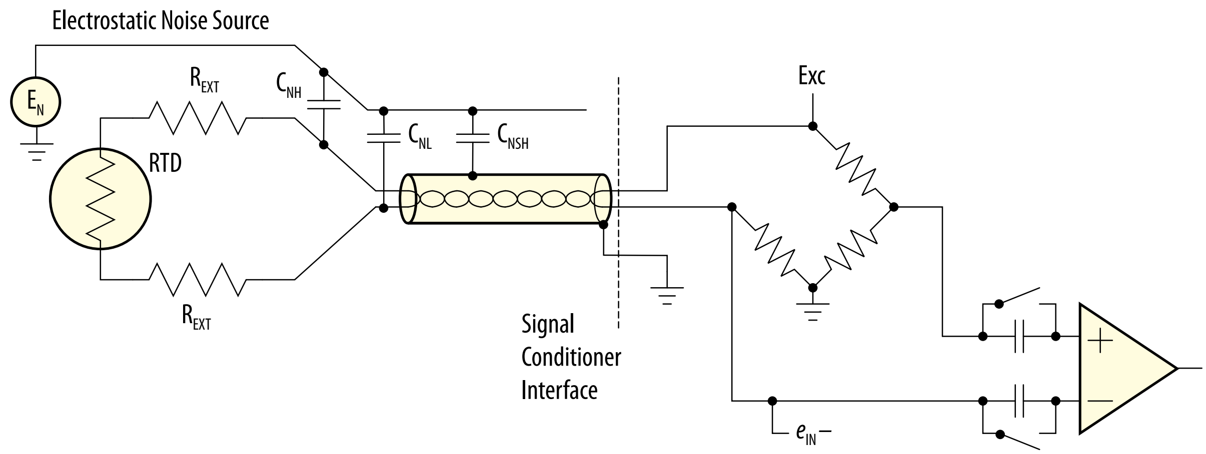

Figure 1: Two-Wire Wheatstone Bridge Connection

Wheatstone Bridge

The Wheatstone bridge is the most commonly used methodology for RTD measurements. A well documented problem with the Wheatstone bridge for RTD measurements is the inherent non-linearity of the bridge, particularly with the RTD is used to measure a wide range of temperatures. **Figure 1** shows a two-wire Wheatstone bridge connection. Zero errors are caused by drift of the extension wire lead resistance, R_{EXT}, and will cause errors and uncertainty in the measurement. The drift in zero of the circuit can be compensated for through the use of a three-wire connection however lead-wire resistance measurement desensitization from lead-wire resistance remains.

Measurement sensitivity is defined as the change in circuit output voltage to changes in RTD resistance. Measurement sensitivity errors caused by R_{EXT} can represent a much more troublesome characteristic of the Wheatstone bridge connection. Lead resistance for commonly used hookup and extension wire can range from 0.006 Ω per foot for standard 18 gauge RTD wire, to as high as high as 10 Ω per foot for high temperature wire commonly used in harsh environments. Let ΔE be the bridge output, per unit of excitation, for sensor resistance change, ΔR. Normalized measurement sensitivity is defined as:

$$\text{Normalized Measurement Sensitivity} = (\partial\Delta E/\partial\Delta R \mid R_{EXT}\neq 0)/(\partial\Delta E/\partial\Delta R \mid R_{EXT}=0) \quad (1)$$

Figure 2 shows variations in normalized measurement sensitivity versus R_{EXT} for a 100 Ω RTD Wheatstone bridge connection. Measurement sensitivity decreases as lead resistance increases. If the lead resistance is known, the decrease in measurement sensitivity may be compensated for with more amplification or via post processing. If the lead resistance is unknown or exhibits drift with temperature, it can represent significant measurement uncertainty.

The Wheatstone bridge topology has another significant disadvantage for RTD measurements. As shown in **Figure 1** the signal conditioner differential amplifier connection consists of one input from the external sensor and the second from an internal reference point. It is clear that electrostatic and electromagnetic noise pickup on the external extension wire will not be equivalent to that picked up on the internal reference point and thus will not be eliminated by common mode rejection (CMR) of the differential amplifier. This topology is inherently unbalanced and effectively presents a single-ended input to the external bridge corner connection, converting all noise pickup to a normal mode interference signal. In noisy environments, this pickup can dominate signal conditioner input noise and severely degrade input signal to noise ratio (SNR).

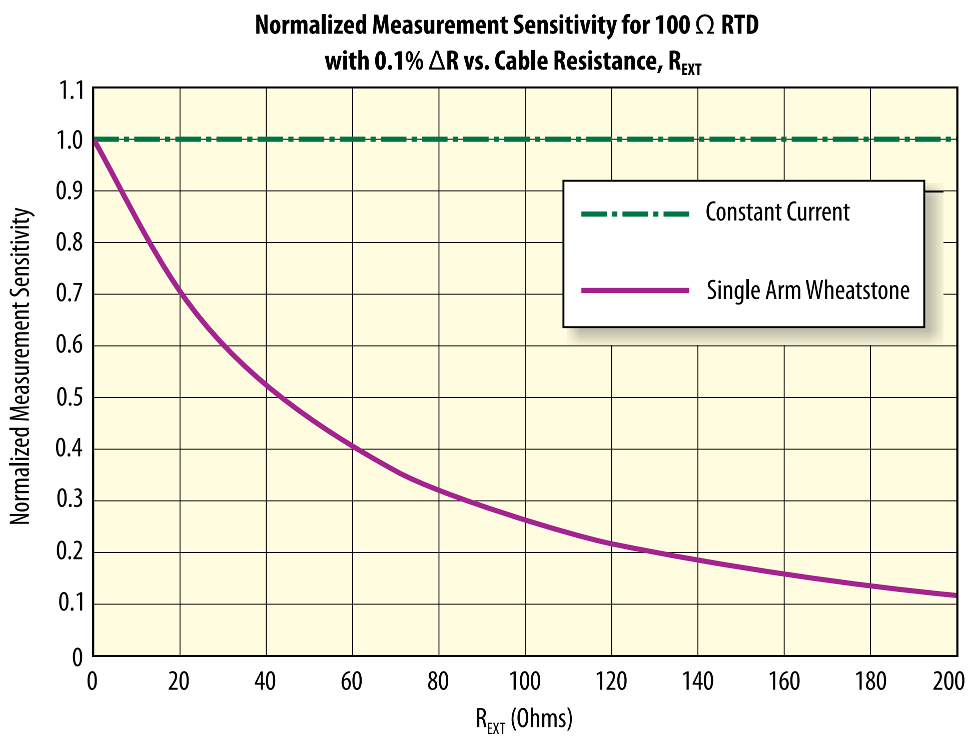

Figure 2: Normalized Measurement Sensitivity vs. R_{EXT}

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Single-Ended Constant Current Excitation

A second test methodology often preferred for RTD measurements is the single-ended constant current excitation technique shown in **Figure 3**. Here a single-ended constant current source is used to excite the sensor. Since the current through the RTD is held constant, sensor resistance fluctuations are converted directly to voltage fluctuations with no need for ballast or completion resistors. Optional sense lines (not shown in Figure 3) are required for accurate DC measurements since lead wire resistance, even if known, can change with changes in ambient temperature. Changes in lead wire resistance is indistinguishable from changes in RTD resistance.

As shown by the dashed curve in **Figure 2**, measurement sensitivity is unaffected by lead wire resistance since all of the current excitation reaches the sensor. Unlike the Wheatstone bridge circuit, constant current excitation provides inherently linear response, even for large variations in RTD resistance.

As with the two-wire Wheatstone bridge topology, the single ended constant current circuit is unbalanced. All noise pickup on the input is converted directly to a normal mode interference signal, which again significantly degrades SNR of the measurement.

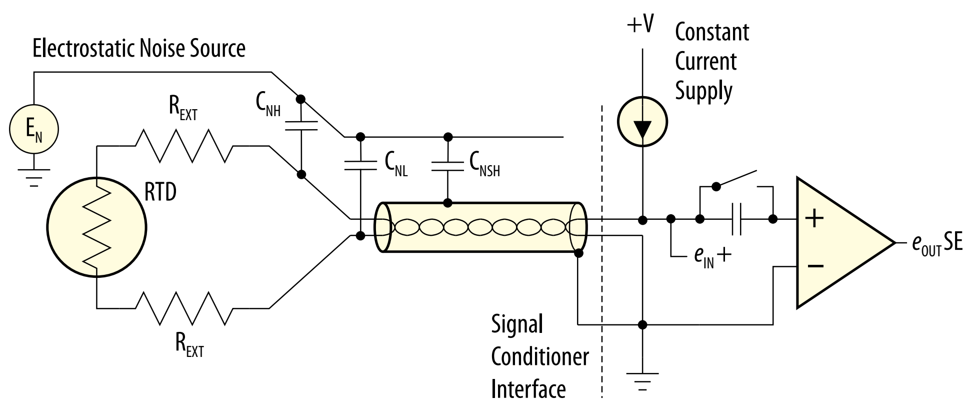

Figure 3: Single-Ended Constant Current Excitation Circuit

Balanced Constant Current Excitation

Balanced constant current excitation uses a pair of matched current sources to excite the RTD and a differential amplifier to measure RTD voltage as shown in **Figure 4**. In addition to the measurement sensitivity and linearity advantages described for single ended constant current excitation, the balanced topology provides other measurement advantages. We can see in **Figure 4** that the two differential amplifier connections are balanced both physically and electrically with respect to the interfering noise source acting upon the RTD and interconnecting cables. With proper attention to cabling and hookup techniques, noise pickup will be nearly equal on the two balanced inputs and therefore greatly reduced by the CMR of the differential amplifier.

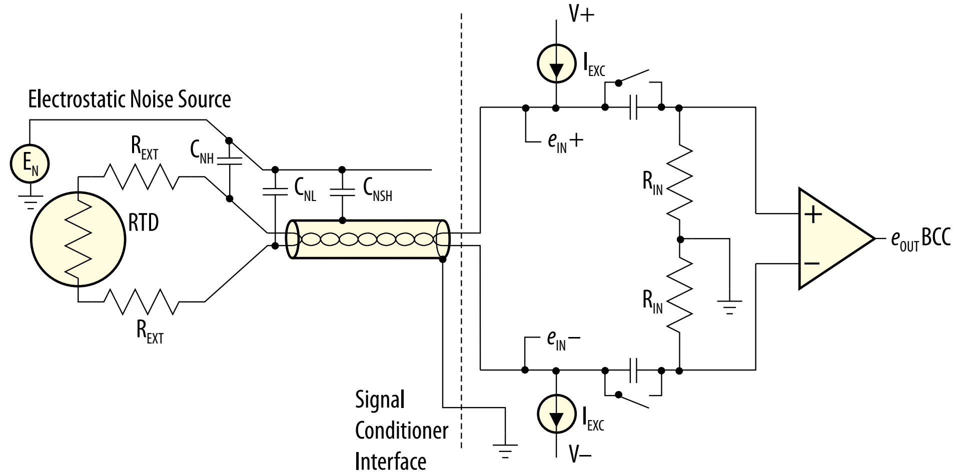

Figure 4: Balanced Constant Current Excitation Circuit

Balanced Constant Current Excitation

Figure 5 shows a circuit diagram of the balanced differential constant current technique developed by Precision Filters. Two matched current sources are used in a "push pull" configuration, one sourcing current to the RTD, the other pulling current from the RTD. Providing the two current supplies are well matched and the floating RTD is connected to the input through a twisted/shielded pair, the circuit is both physically and electrically balanced and provides excellent noise immunity.

In the four-wire mode, high impedance sense lines connect the differential amplifier directly to the RTD terminals so that voltage drops across the cable lead resistance do not affect the measurement. Since no current flows in these sense lines, the reading is uncorrupted by DC drops of the current carrying excitation lines. Since the input connection is a balanced differential input, the shield of the cable may be driven (guarded) with the common mode voltage as shown in **Figure 5** and the CMR of the differential amplifier will be further improved.

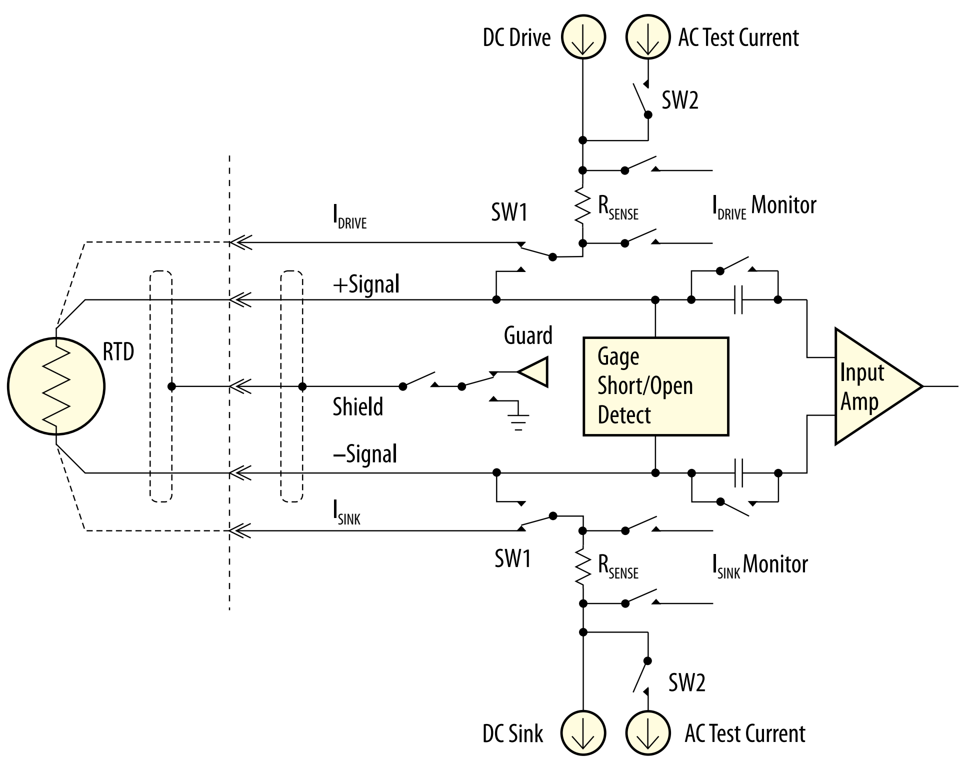

Figure 5: Balanced Constant Current Excitation Circuit Diagram

Balanced Constant Current Excitation Properties

The balanced topology offers two principal advantages when compared to single-ended constant current excitation: 1) Significantly less susceptibility to electrostatic and electromagnetic noise sources and 2) immunity to certain RTD fault conditions.

Noise susceptibility is significantly reduced since the input cabling is balanced with respect to electrostatic pickup. Noise pickup in the extension wires appears as common mode signal and thus will be rejected by the CMR of the differential amplifier.

A typical failure mode for RTD measurements involves shorting one end of a fatigued or damaged RTD to the test model. When this occurs, data for the channel is typically lost and data for other channels may be corrupted by the newly created ground loop. The differential constant current topology assures a return current from the RTD exactly equal to the current sourced to the RTD, eliminating any possibility of current flow to the test model even if one end of the RTD is shorted directly to the model. The bias point of the RTD will shift to that of a single ended connection and the input lines will no longer be balanced but the RTD will continue to operate with proper excitation and proper measurement sensitivity.

Verification of Transducer Health and Cabling

As time in test cells becomes more expensive and test results more critical, modern day test protocols often include significant pretest setup and equipment verification steps. An effective pretest validation would consist of: RTD resistance check, RTD substitution calibration, excitation level check, cable and connector integrity check and measurement system gain and frequency response check. These tests can be automated by proper design of the signal conditioning front end. As shown in **Figure 5**, an AC test current can be summed with the DC excitation current (SW2) allowing for in situ validation of the cable resistance, RTD resistance and connector integrity, even with the input AC coupled. If the AC test current is programmable in level and frequency, then system gain and frequency response may be verified. Also, the AC current may be generated from an arbitrary waveform generator reference so that system response to complex waveforms similar to those encountered during an actual test may be evaluated.

From the point of view of the measurement system, it is not possible to distinguish whether the signal is generated from a stimulated transducer or the injected AC test current. Accurate low drift sense resistors in series with excitation current lines provide a means for measuring actual excitation current delivered to the RTD. Excitation current is sensed independently on source and sink lines to reveal leakage conditions produced by excitation current flow to the test model. RTD fault detectors provide continuous monitoring of open or short conditions and alert the user or controlling software.

RTD Resistor Substitution Calibration

The pretest calibration of the RTD can be performed using a technique known as resistor substitution. A range of precision 0.01% resistor values that span the range of the RTD may be substituted for the actual sensor under computer control. The precise calibration resistors allow the user to calibrate the measurement system for gain, linearity and offset. Once the calibration coefficients have been determined, the subsequent RTD measurement data can be corrected via post processing.

Summary

Balanced constant current excitation provides an accurate means of measuring RTDs using a two or four-wire connection. Electrostatic pickup will be reduced when compared to single-ended constant current excitation or a quarter bridge configuration with remote completion resistors. The balanced current excitation circuit proposed operates properly even under the certain common RTD fault conditions such as a direct short of the RTD to the test model. A technique for verification of the transducer, cabling and system frequency response by injection of an AC test current into the current loop was described. This AC excitation could represent simulation of expected signal energy to evaluate system response to complex waveforms. RTD resistor substitution allows for precise 0.01% calibration resistors to be substituted under program control to determine measurement system calibration coefficients.

Figure 6 shows an implementation of a signal conditioner having balanced constant current excitation. Developed by Precision Filters, Inc., the conditioner provides four channels of programmable excitation, amplification and anti-aliasing filters. The design embodies all of the balanced constant current excitation features and concepts discussed in this paper.

Figure 6: Precision Filters, Inc. Signal Conditioner with Balanced Constant Current Excitation

References

Dally, James W. and Riley, William F., 1978, *Experimental Stress Analysis*, New York: McGraw-Hill

Morrison, Ralph, 1967, *Grounding and Shielding Techniques in Instrumentation*, New York: John Wiley & Sons

Ott, Henry W., 1988, *Noise Reduction Techniques in Electronic Systems*, New York: John Wiley & Sons

Rich, Alan, "Shielding and Guarding", Analog Devices Inc., *Analog Dialogue* 17-1, 1983

Rich, Alan, "Understanding Interference Type Noise", Analog Devices Inc., *Analog Dialogue* 16-3, 1982

Wright, Charles, 1995, *Applied Measurement Engineering*, New Jersey: Prentice Hall

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