Minimizing Errors in Multiplexed 3-Wire RTD Data-Acquisition Systems

By Henry He

Resistance temperature detectors (RTDs) monitor temperature in many industrial applications. In a distributed control system (DCS) or programmable logic controller (PLC), one data-acquisition module may monitor the temperature of many remotely located RTDs. In high-performance applications, the best accuracy will be obtained when each RTD has its own excitation circuit and ADC, but the data-acquisition module will be large, expensive, and power hungry. Multiplexing leads to a smaller, lower cost, lower power module, but some accuracy can be lost. This article discusses how to minimize errors in a multiplexed system.

Circuit Structure

RTDs are available in 2-wire, 3-wire, and 4-wire configurations, where 2-wire devices are the least expensive and 4-wire devices are the most accurate. Commonly used in industrial applications, 3-wire RTDs can be excited by two identical current sources to cancel out lead resistance. When used with a precision reference resistor, current source errors do not affect the measurement accuracy. High-performance ADCs, such as the AD7792 and AD7793, integrate the excitation current sources, making them ideal for high-accuracy RTD measurements.

Figure 1 shows two 3-wire RTDs excited by the on-chip current sources. The RTD channel is selected by a multiplexer, such as the ADG5433 high-voltage, latch-up proof, triple SPDT switch. Only one RTD can be measured at one time. S1A, S1B, and S1C are closed to measure RTD #1; S2A, S2B, and S2C are closed to measure RTD #2. A single ADG5433 can switch two 3-wire RTDs; additional multiplexers can be added to handle more than two sensors. RL_{XX} represents the resistance introduced by long wires between the RTD and the measurement system, plus the *on* resistance of the switches.

Calculating the RTD Resistance

With S1A, S1B, and S1C closed to measure RTD #1, the resistance of the RTD can be calculated as follows:

$$\text{Define } \Delta V_{IN} = V_{IN+} - V_{IN-}$$

$$\text{Assume } I_{OUT1} = I_{OUT2} = I_{OUT} \text{ and } RL_{1A} = RL_{1B} = RL_{1C}$$

$$I_{OUT1} + I_{OUT2} \text{ flows through } R_{REF}, \text{ so } I_{OUT1} = \frac{V_{REF}}{2R_{REF}}$$

$$RTD = \Delta V_{IN} / I_{OUT} = \frac{\Delta V_{IN} \times 2R_{REF}}{V_{REF}}$$

Thus, the measurement depends only on the value (and accuracy) of R_{REF}. Remember, however, that we assumed $I_{OUT1} = I_{OUT2}$ and $RL_{1A} = RL_{1B} = RL_{1C}$. In fact, mismatches in these currents and resistances are the main source of measurement error.

Impact of Mismatched Current Sources and Wire Resistors

Next, assume that the two current sources are mismatched, such that $I_{OUT2} = (1 + x)\, I_{OUT1}$. Now, consider the following:

$$RTD = \frac{\Delta V_{IN}}{V_{REF}} (2 + x) R_{REF} + (1 + x) RL_{1C} - RL_{1A}$$

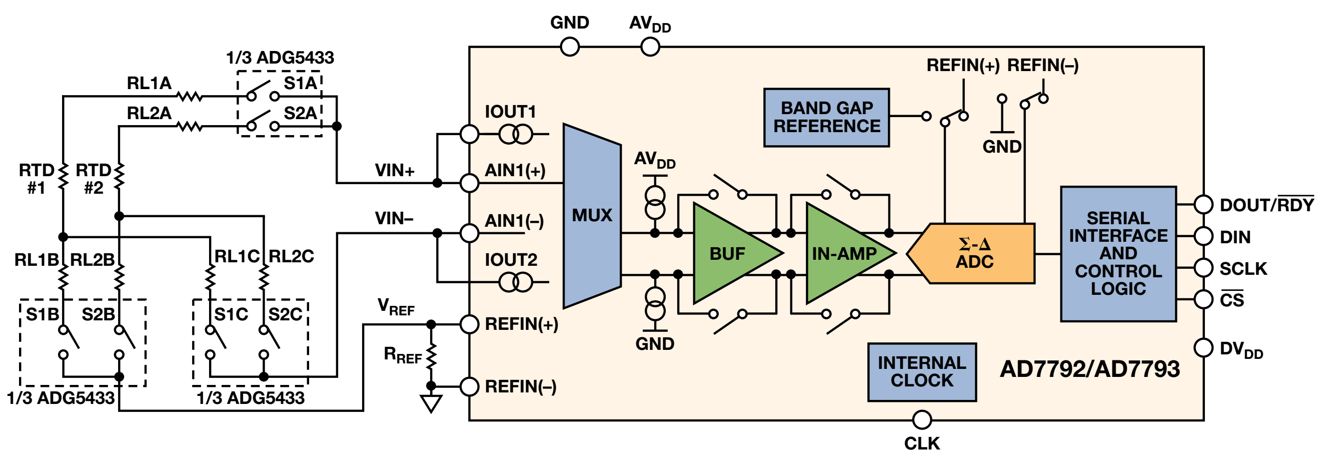

Figure 1. Two 3-wire RTDs multiplexed into one AD7792/AD7793 ADC.

Note that the mismatch creates both an offset error and a gain error. The offset error is related to the mismatch between the two lead resistances, while the gain error is related to the mismatch between the two current sources. If these mismatches are not taken into consideration, the calculated value of the RTD resistance, based on the data read from the ADC, will be incorrect.

Using a 200-Ω RTD as an example, Table 1 shows the acquired values when the mismatches are not considered, given R_{REF} = 1000 Ω, I_{OUT1} = 1 mA, $I_{OUT2} > I_{OUT1}$ by the percentage shown, RL_{1A} = 10 Ω, and $RL_{1C} > RL_{1A}$ by the resistance shown.

Table 1. Measured RTD Values When Mismatches Are Not Considered

$RL_{1C} - RL_{1A}$ / $(I_{OUT2} - I_{OUT1})/I_{OUT1}$	0.01 Ω	0.1 Ω	1 Ω
0.1%	199.88	199.79	198.89
0.5%	199.44	199.35	198.45
1.0%	198.90	198.81	197.90

Minimizing the Errors

The data shows that small mismatches will degrade the accuracy severely, and that well matched current sources and switches should be used to improve performance.

The transfer function is linear, so initial errors due to current source and resistance mismatches can be calibrated out easily. Unfortunately, the mismatch varies with temperature, making it difficult to compensate. Hence, it's important to use devices that have low drift over temperature.

With $I_{OUT1} \neq I_{OUT2}$, and the current sources connected as shown:

$$\Delta V_{IN1} = I_{OUT1}\,(RL_{1A} + RTD) - I_{OUT2} \times RL_{1C}$$

Assume we swap I_{OUT1} and I_{OUT2}, so that I_{OUT1} now connects to V_{IN-} and I_{OUT2} now connects to V_{IN+}:

$$\Delta V_{IN2} = I_{OUT2}\,(RL_{1A} + RTD) - I_{OUT1} \times RL_{1C}$$

Now, if we sum the results from a conversion with the current sources connected in the original orientation and a second conversion with the current sources swapped, the result is

$$\Delta V_{IN1} + \Delta V_{IN2} = (I_{OUT1} + I_{OUT2}) \times (RTD + RL_{1A} - RL_{1C}) = \frac{V_{REF}}{R_{REF}}\,(RTD + RL_{1A} - RL_{1C})$$

Consequently, $RTD = \dfrac{\Delta V_{IN1} + \Delta V_{IN2}}{V_{REF}} \times R_{REF} + RL_{1C} - RL_{1A}$

Note that the measurement is now independent of current source mismatch. The only downside is the loss of speed, because two conversions are needed for each RTD calculation.

The AD7792 and AD7793 are designed for this application. As shown in Figure 2, integrated switches make it easy to swap the current sources to the output pins by writing to an I/O register.

Conclusion

Swapping the excitation current sources within the AD7792/AD7793 can improve accuracy in a multiplexed RTD measurement circuit. Calculations show the importance of mismatches between current sources and wire resistances.

References

Kester, Walt, James Bryant, and Walt Jung. "Temperature Sensors." *Sensor Signal Conditioning*, Section 7. Analog Devices, Inc., 1999.

Author

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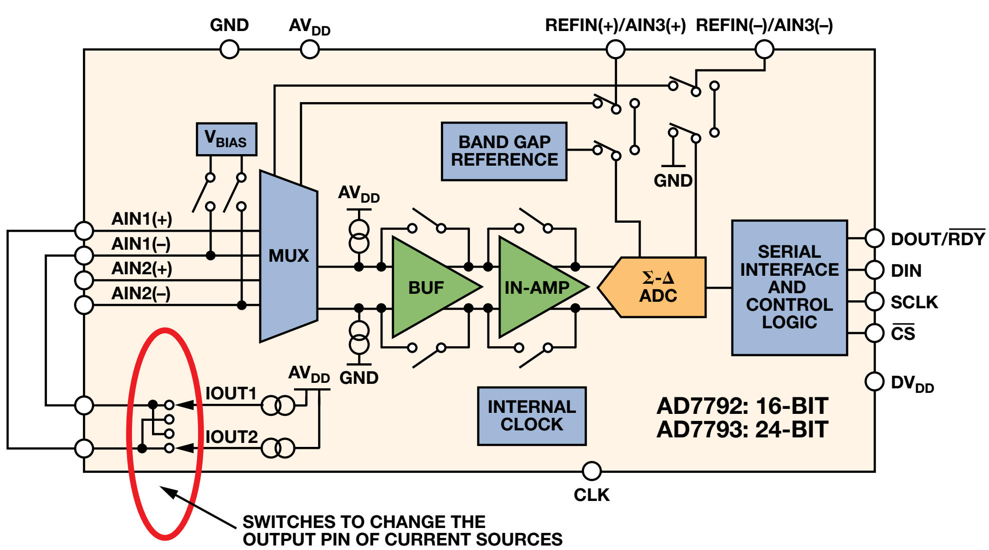

Figure 2. Functional block of AD7792/AD7793.