Designing with temperature sensors, part three: RTDs

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The temperature coefficient of an RTD (resistance-temperature-detector) element is positive. Most stable, linear, and repeatable RTDs are of platinum-metal construction. You can use the constant 0.00385Ω/Ω/°C to approximate the resistance change over temperature for the platinum RTD element. In contrast, the NTC (negative-temperature-coefficient) thermistor has a negative change with increasing temperature. See a comparison of resistance and temperature performance for RTD sensors and NTC thermistors in the figure below.

The RTD element’s resistance is much lower than that of an NTC thermistor element, which ranges to 1 MΩ at 25°C. Typical specified 0°C values for RTDs are 25Ω to 1 kΩ. Of these options, the 100Ω platinum RTD is the most stable over time and linear over temperature.

An RTD element must be excited with a stable current reference at a level that does not create an error due to self-heating. A current source that is 1 mA or less is usually adequate. Under this circumstance, the accuracy of an RTD can be ±4.3°C over its temperature range of −200 to +800°C. If higher accuracy is required, you can use the Callendar-Van Dusen equation to generate a look-up table:

\[ R_{RTD(TA)} = R_{RTD(T0)} \left[ 1 + aT_A + bT_A^2 + cT_A^3 (100-T_A) \right], \]

where \( R_{RTD(TA)} \) is the resistance of the RTD at ambient RTD temperature; \( R_{RTD(T0)} \) is the value of the RTD at 0°C; and \( a \), \( b \), and \( c \) are constants, supplied by the RTD vendor.

You can implement an RTD signal-conditioning circuit in a number of ways. Figure 1 shows an example that uses four OPA335 amplifiers, an REF5025 voltage reference, an ADS8634 ADC, and an MSP430C1101 microcontroller, all from Texas Instruments, as well as a PT100 RTD (Reference 1). In this figure, a 2.5V reference, \( A_1 \), \( A_2 \), and five resistors generate a 1-mA current source.
The signal-conditioning portion of the circuit includes $A_3$ and $A_4$. $A_3$ senses the voltage drop across the RTD element and cancels the RTD wire resistance errors: $R_{W1}$, $R_{W2}$, and $R_{W3}$. $A_4$ provides gain, and a lowpass filter, such as TI’s FilterPro, provides the RTD’s output voltage (Reference 2). In this circuit, the RTD element has a value of 100Ω at 0°C. If this RTD senses temperature over its entire range of −200 to +600°C, the RTD would provide a nominal 23 to 331Ω range of resistance. You can use TINA-TI to simulate the analog portion of this circuit (Reference 3). Within TINA-TI’s examples, under the Files tab, a PT100 RTD element accurately simulates the correction of the nonlinearity of the RTD.

The circuit in Figure 1 generates a current source that is ratiometric to the voltage reference. The ADC uses the same voltage reference to provide a ratiometric digital output. Over temperature, the ADC digitizes the changes in the RTD resistance. Although an RTD requires more circuitry in the signal-conditioning path than a thermistor or a silicon temperature sensor requires, it ultimately provides a high-precision, relatively linear result over a wider temperature range. If you use the Callendar-Van Dusen equation, this RTD circuit can achieve ±0.01°C accuracy.

References
2. FilterPro Active Filter Design Application, Texas Instruments.
3. TINA-TI SPICE-Based Analog Simulation Program, Texas Instruments.

Read the whole series:
- Designing with temperature sensors, part one: sensor types
- Designing with temperature sensors, part two: thermistors
- Designing with temperature sensors, part four: thermocouples
- Designing with temperature sensors, part five: IC temperature sensors
Editor's note: Figure 1 and the amplifier part number in the text were updated on Jan 5, 2012.