The accuracy of any circuit or system that uses a thermocouple to determine the temperature of a process is limited by the accuracy of the method used to perform cold-junction compensation. In a thermocouple measurement, two wires of dissimilar metal join together at the "hot," or measurement, junction. The isothermal termination of the thermocouple wires provides a second "cold," or reference, junction. The potential across the thermocouple is proportional to the temperature difference between the two junctions. Thus, to determine the absolute temperature of the hot junction, you must also know the absolute temperature of the cold junction. Tables of thermocouple voltage versus temperature use the assumption that the cold junction is maintained at 0°C. A somewhat impractical way to use these tables is to place the cold junction into an ice bath. A more practical way is to measure the temperature of the cold junction and then add an equivalent voltage to the one developed by the hot junction. You then find the temperature of the hot junction in the thermocouple tables.

A key issue to address is how to thermally bond the RTDs (resistance-temperature detectors) to the terminal block, which is the cold junction. If the temperature along the terminal block is constant, you could use a single sensor, thermally bonded to the block. If a linear temperature gradient exists along the terminal block, you could use a sensor at both ends of the block. This method allows for interpolation of the temperature at various points along the block. If the temperature gradient is nonlinear, you can add an electrically isolated copper strip along the length of the block to minimize the nonlinearity. In the extreme case, you could use a temperature sensor per thermocouple pair with each sensor, thermally bonded to its respective junction.

The design in Figure 1 uses a multichannel, high-resolution ADC to measure the thermocouple voltage and the resistance of two RTDs at the cold junction. Using the data from the ADC, a microprocessor determines the temperature of the cold junction, the amount of cold-junction compensation to apply, and, then, the temperature of the hot junction. Performing the cold-junction compensation in software allows users to use mixed thermocouple types and is both flexible and universal. The AD7708 digitizes the signals from the thermocouple and from two three-wire RTD sensors, which measure the cold-junction temperature at both ends of the terminal block. The terminal block is local, so you can ignore the wiring resistance between the ADC and the RTDs. It is easier to obtain precision resistors and voltage references than precision current sources, so the RTDs and the 470Ω precision resistor, R\textsubscript{PREC}, connect in series, and all obtain excitation from the same current source, I\textsubscript{EXC}. The voltage generated across R\textsubscript{PREC} determines the exact value of the excitation current. Hence, the current source need not be particularly stable over temperature. R\textsubscript{OFF} offsets input pair AIN7/-AIN8 by more than 100 mV from ground. R\textsubscript{OFF} is also a 470Ω resistor but need not be a precision resistor. The ADR421's 2.5V precision voltage reference directly drives the REFIN1(+)/REF-1N1(−) inputs.
With $I_{\text{exc}}$ set to 300 µA and the internal programmable-gain amplifier set to the 40-mV full-scale range, the ADC produces usable resolution of 2.4 µV. With 100Ω RTDs, it accurately resolves a 0.02°C temperature differential between the two ends of the terminal block and has an absolute accuracy of ±0.01°C for either measurement. The differential analog input pair, AIN1/AIN2, of the AD7708 reads an input voltage equal to $I_{\text{exc}}$ (RTD 1), where RTD 1 represents the resistance of the first RTD element. A second differential input pair, AIN5/AIN6, reads an input voltage equal to $I_{\text{exc}}$ (RTD 2), where RTD 2 represents the resistance of the second RTD element. One source of error pertains to the RTDs themselves. The most common type is the 100Ω platinum RTD with a resistance-temperature coefficient of 0.00385Ω/Ω/°C. It is available in accuracy-tolerance classes A and B (or DIN A and DIN B), which specify both the initial accuracy at 0°C and the interchangeability over the operating range. The Class A specification is ±(0.15±0.002|t|), where $t$ is the specified interchangeability temperature; the Class B specification is ±(0.3±0.005|t|).

It is possible to buy two Class A, 100Ω platinum RTDs from the same manufacturer and find that one is reading 0.2°C high at 25°C and the other is reading 0.2°C low at 25°C. Thus, you have an apparent 0.4°C difference before you even commission $t$. One way to combat this initial error is to request a matched pair of RTDs from the manufacturer. Leading RTD manufacturer Heraeus Sensor (www.4hcd.com) makes available PRTDs (platinum RTDs) that Heraeus sorts into tolerance groups with maximum $\Delta t$=±0.05°C over 0 to 100°C. A lower cost solution and one that uses off-the-shelf RTDs is to use the offset and gain registers on the AD7708 ADC to calibrate each of the RTD errors.

Noise pickup may be an issue if the hot junction of the thermocouple is a long distance from the measurement electronics. The very-high-input-impedance buffer inside the AD7708 allows the addition of lowpass filters $R_1-C_1$ and $R_2-C_2$ to the AIN3/AIN4 inputs to attenuate high-frequency-noise pickup in the wiring.

A single-ended analog-input channel, AIN9, and three burnout resistors, $R_{b1}$ through $R_{b3}$, provide both thermocouple open-circuit, or burnout, and short-circuit-detection functions by forcing the dc bias levels of AIN3/AIN4 away from their normal operating levels of approximately 2.5V. A thermocouple short-circuit fault condition from either Metal A or Metal B to ground pulls the voltage across $R_{b3}$ to 0V. A thermocouple open-circuit fault condition on either Metal A or Metal B causes the voltage across $R_{b3}$ to move to 1.66V. You can program either of these voltage levels (converted by AIN9) to raise an alarm signal.

A more difficult fault condition to detect is the condition in which the two thermocouple wires short only to each other. In this case, a new thermocouple junction forms at the location of the short circuit, and the junction behaves like a normal thermocouple. The only way to detect this fault condition is to implement a rate-of-change alarm in software. If the two wires short together at the exit of the thermo-well, the new thermocouple junction may well experience much the same temperature that the original thermocouple junction experienced. This fault condition is difficult to spot. However, if the short circuit occurs a long distance from the original thermocouple junction, then this new junction may be at a different temperature from that of the original junction and produces a rate of change that channel does not normally see. You can use this abnormal change to flag an alarm condition.