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AND FRAN GRANVILLE

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Platinum-RTD-based circuit provides high performance with few components

Jordan Dimitrov, Toronto, ON, Canada

The standard way of using an RTD (resistance-temperature-detector) sensor is to include it in a bridge followed by a differential amplifier. The problem is that two nonlinearities—one from the sensor and another from the bridge—affect the transfer function. Some approaches are available that attempt to avoid the problem, but they tend to be bulky and expensive (**references 1, 2,** and **3**). An alternative circuit proposes adding only one extra resistor to the differential amplifier but provides neither design guidelines nor results (**Reference 4**). This Design Idea fills the gap. Although circuit analysis is somewhat complex, performance is good, and the circuit uses few components.

Besides the platinum RTD, R_θ, the circuit features only six precision resistors, an op amp, and a voltage reference (**Figure 1**). R_4, the extra resistor for the differential amplifier, delivers additional current to the sensor that relates to the temperature you are measuring. With proper design, the circuit can provide good linearity and stability over a wide range of input temperatures. The output voltage, V_O, depends on circuit components in the following way:

$$V_O = V_{REF} \times \frac{Y_1}{Y_2} \times \frac{R_\Theta(Y_0 + Y_2 - Y_3 - Y_4) - 1}{R_\Theta[Y_1 + Y_3 - R_2 Y_4(Y_0 + Y_1)] + 1},$$

where $Y_I = 1/R_I$ and I=0 to 4.

For positive temperatures, a second-degree polynomial of the following form can approximate RTD characteristics:

$$R_\Theta = R_0(1 + \alpha \times \Theta + \beta \times \Theta^2),$$

where R_0 is sensor resistance at 0°C, α and β are coefficients, and Θ is the measured temperature.

After replacing the second equation in the first and doing some rearrangements, you get:

$$V_0 = \frac{\Theta - B}{\Theta^2 - B\Theta - C} \times K \times \Theta = f(\Theta)K\Theta,$$

where B, C, and K are constants and f(Θ) is a function of temperature. **Figure 2** shows the general shape of f(Θ). The output voltage depends linearly on temperature when f(Θ) is as close as possible to a constant. This situation is most true around the minimum point of f(Θ).

Some additional relations provide that the output voltage is 0V at temperature 0°C, the conversion coefficient is 10 mV/°C, the minimum of function f(Θ) is in the middle of the measurement span, and

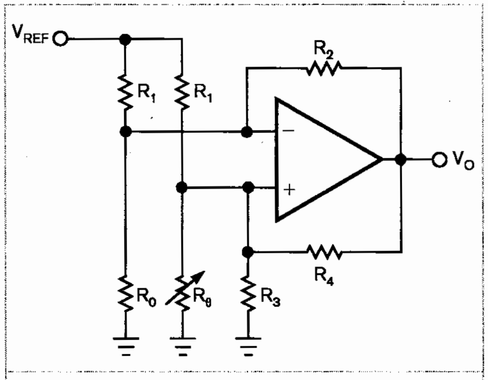

Figure 1 This generic RTD circuit needs few components.

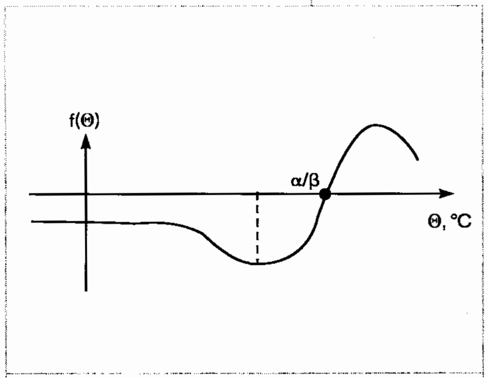

Figure 2 The general shape of function f(Θ) varies with temperature.

the current through R_θ causes negligible self-heating of the sensor.

Figure 3 shows the circuit that meets these requirements. The sensor is a DIN-IEC 751 platinum RTD. Microsoft (www.microsoft.com) Excel software fits 13 points of 0 to 600°C in steps of 50° from the RTD's calibration table. The spreadsheet software determined R_0 to have a value of 100Ω, α to have a value of $3.908\times10^{-3}\,^{\circ}\mathrm{C}^{-1}$, and β to have a value of $-5.801\times10^{-7}\,^{\circ}\mathrm{C}^{-2}$ with an R^2 factor of one.

All the circuit's resistors have tolerances of 0.02%, and the temperature coefficient is 50 ppm/°C. You can use two trimming potentiometers, V_{R1} and V_{R2}, to independently adjust zero and span readings. You should perform span adjustment at 550°C to match the magnitudes of the positive and the negative errors. You can also extend the temperature range to start from −100°C instead of 0°C without exceeding the basic nonlinearity. The three-lead connection to the sensor significantly reduces the influence of connection-cable resistance, R_C, on accuracy.

Table 1 shows the results of evaluating this circuit's performance with a calibrated, precision-decade resistance and a calibrated, 4.5-digit multimeter with readings at ambient temperatures of 24 and 68°C; power supplies of ±12, ±15, and ±18V; and cable resistances of 0 and 5Ω. EDN

TABLE 1 **EXPERIMENTAL RESULTS**

Measurement range	−100 to +600°C
Nominal sensitivity	10 mV/°C
Basic accuracy (nonlinearity)	Well below ±1°C
Ambient-temperature effect	0.05°C/10°C
Power-supply effect	0.1°C/V
Cable effect (three-lead connection)	0.7°C/Ω
Power-supply range	±12 to ±18V
Consumption (600°C input)	9 and −3 mA
Operating temperature	−40 to +85°C

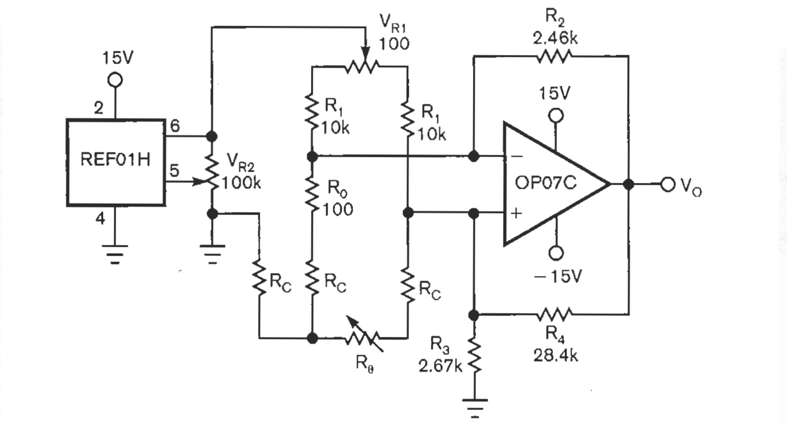

Figure 3 The full circuit needs trimming potentiometers V_{R1} and V_{R2} to adjust zero and span, respectively, and a three-lead cable for sensor connection. R_C is the cable's resistance.

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