



## Resistive Temperature Detectors: An Alternative to Thermocouples for Precise, Repeatable Temperature Measurements

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### Temperature

Temperature is one of the most frequently measured quantities in science and industry, with several sensor technologies available. The Resistive Temperature Detector (RTD) offers several advantages over the well-known thermocouple for all but very high temperature applications.

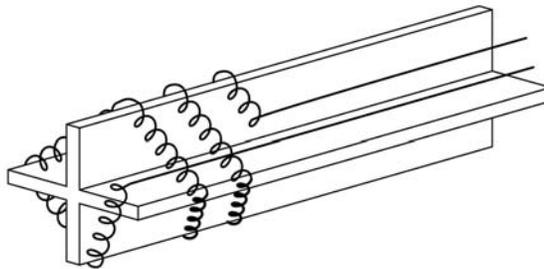
**Table 1. Common Temperature Sensor Types**

Characteristic	Thermocouples	Resistive Temperature Detectors	Thermistors	Solid State Monolithic Temperature Sensors
<b>General</b>	Broad range; moderate accuracy	High accuracy and repeatability	High resolution	Easy to use
<b>Range</b>	-200°C to +1500°C	-200°C to +800°C	-80°C to +150°C	-50°C to +150°C
<b>Accuracy</b>	±1°C – 2°C	± 0.1°C – 0.2°C	±0.1°C – 0.2°C	±1°C – 2°C
<b>Output Signal</b>	Very low V	Slight R change	Wide R change	Low V or low I
<b>Typical Applications</b>	<ul style="list-style-type: none"> <li>• Industrial</li> <li>• Food processing</li> </ul>	<ul style="list-style-type: none"> <li>• monitoring</li> <li>• processing</li> </ul>	<ul style="list-style-type: none"> <li>• Biological applications</li> <li>• Control systems</li> <li>• Measurement of environmental temps</li> <li>• Consumer devices</li> </ul>	<ul style="list-style-type: none"> <li>• See thermistor applications</li> </ul>
<b>Notes</b>	<ul style="list-style-type: none"> <li>• Several types, each with specific useful temperature range</li> </ul>	<ul style="list-style-type: none"> <li>• vs. <math>\Delta t</math></li> <li>• resistive bridge</li> </ul>	<ul style="list-style-type: none"> <li>• Relatively fragile</li> <li>• Non-linear <math>\Delta R</math> vs. <math>\Delta t</math></li> <li>• Require high-</li> </ul>	<ul style="list-style-type: none"> <li>• Low level V or I output</li> <li>• Linear <math>\Delta V</math> or <math>\Delta I</math> vs. <math>\Delta t</math></li> <li>• Require</li> </ul>

	<ul style="list-style-type: none"> <li>• Non-linear output</li> <li>• Require cold junction compensation</li> </ul>	circuit or 4-wire low-ohms	resolution ohms measurement	excitation
* Cost of sensor, probe assembly, cable, and connectors can affect total sensor pricing considerably.				

### Resistive Temperature Detectors

Resistive Temperature Detectors (RTDs) are among the most stable, accurate temperature sensors, covering approximately  $-200^{\circ}\text{C}$  to  $+800^{\circ}\text{C}$ , and are used where high accuracy and repeatability are required. Accuracy is often expressed as a percentage of resistance at a specified temperature. For instance, a Class B RTD is specified as  $100\Omega \pm 0.12\%$  at  $0^{\circ}\text{C}$ . IEC Class A accuracy provides  $\pm 0.15^{\circ}\text{C}$  at  $0^{\circ}\text{C}$ , with calibration performed at multiple temperatures. An interchangeability tolerance helps predict overall accuracy if RTDs are interchanged (a typical value is  $\pm 0.1^{\circ}\text{C}$ ).



*Figure 1. The most basic RTD design wraps a length of platinum wire around an insulating bobbin.*

### Construction

Basic RTD construction can impose tradeoffs between cost, durability, ease-of-use, and performance. The classic RTD design is a length of platinum wire wound and encapsulated on a glass or ceramic bobbin (**Figure 1**). A second consists of a conductive film deposited and encapsulated on an insulating substrate. Assemblies often include connectors, sheaths, and handles.

## Principle of Operation

The resistance of most metals increases with temperature. An ideal metal for temperature detection would exhibit a high, linear change in resistance over temperature, and high durability. Platinum wire is fragile, but highly resistant to contamination, and only slightly non-linear in its  $\Delta R$  vs.  $\Delta T$ . Most general-purpose RTDs are made of platinum wire, and are standardized to a value of  $100\Omega$  at  $0^\circ\text{C}$ . Depending on purity of the platinum, the temperature coefficient ( $\alpha$ ) is  $0.00385\Omega/\Omega/^\circ\text{C}$  (the European curve) to  $0.00392\Omega/\Omega/^\circ\text{C}$  (American curve).

## Application

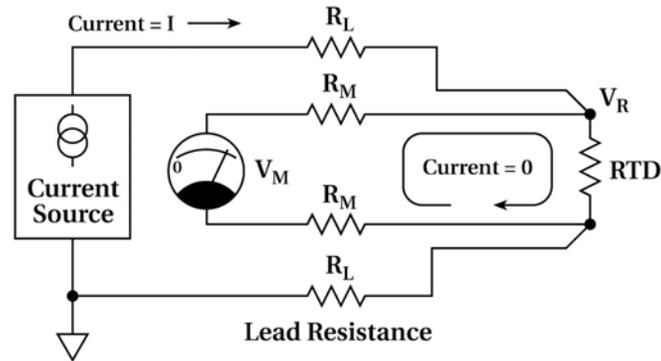
Unlike thermocouples, RTDs need no reference junction, but they do require sensitive instrumentation optimized for low resistance measurements. For example, a  $100\Omega$  RTD with  $\alpha = 0.00385\Omega/\Omega/^\circ\text{C}$  changes resistance only  $0.385\Omega/^\circ\text{C}$ . However, the wire leads connecting the RTD to the instrumentation might have a value of a few ohms, equivalent to an error of several degrees.

RTDs are available in two-, three-, or four-wire models to accommodate different measurement configurations. The two-wire RTD is suitable where lead lengths are very short, and some error can be tolerated. The three-wire RTD bridge offers more refinement, with a separate voltage sensing lead that helps minimize the effects of lead resistance. The four-wire RTD configuration shown in **Figure 2** is recommended for best performance, and is discussed here.

Three measurement methods are possible with this configuration: an ohmmeter reads resistance directly, or a voltmeter reads the voltage drop ( $V_M$ ) across the RTD, which is used to calculate resistance:

$$RTD = \frac{V_M}{I_{RTD}}$$

The third method, and the easiest, is to use a data acquisition product that offers a regulated excitation source, four-wire RTD configuration, and built-in algorithms to convert readings to temperature (*Figure 3*).



*Figure 2. The four-wire RTD provides the simplest circuit and best performance.*



*Figure 3. A DMM/data acquisition system such as this Model 2701 offers four-wire measurement, multiple channels, built-in engineering units conversion, and plant-wide range via Ethernet connectivity .*

### **Four-Wire RTD Configuration**

Four-wire RTDs have two leads at each end of the RTD element. Excitation flows through one pair of leads, while the resistance or voltage drop is measured with the other pair. Lead resistance ( $R_L$  and  $R_M$ ) has no effect on accuracy, as insignificant current flows in the measurement side of the circuit as long as a high impedance voltmeter is used.

To minimize self-heating errors, excitation current should be limited to 1mA or less, meaning that  $V_M$  will be a maximum of 0.1V for a 100Ω RTD. Therefore, a high gain, low noise analog input channel will provide best results. Filtering or other forms of signal conditioning may be helpful.

### Converting RTD Resistance to Temperature

There are two options for converting resistance to temperature. Consulting a look-up table is workable in software programs where an event must be triggered at a specific temperature (the corresponding resistance or voltage can be used as a trigger level).

**Table 1. Callendar-Van Dusen coefficients for common RTD alphas**

Standard	RTD Temperature Coefficient ( $\alpha$ )	A	B	C*
DIN 43760	0.003850	$3.9080 \times 10^{-3}$	$-5.8019 \times 10^{-7}$	$-4.2735 \times 10^{-12}$
American	0.003911	$3.9692 \times 10^{-3}$	$-5.8495 \times 10^{-7}$	$-4.2325 \times 10^{-12}$
ITS-90/IEC751	0.0038505	$3.9083 \times 10^{-3}$	$5.775 \times 10^{-7}$	$-4.183 \times 10^{-12}$

\* Used for temperatures less than 0°C only. For temperatures higher than 0°C, C=0.

Conversion of resistance to temperature via an equation offers more flexibility. The most common method is with the Callendar-Van Dusen equation and coefficients:

$$RTD = R_0 \left[ 1 + At + Bt^2 + C(t - 100)^3 \right]$$

where:

RTD = RTD resistance at temperature t

$R_0$  = RTD resistance at 0°C

A, B, and C are Callendar-Van Dusen coefficients (Table 1).

A typical linearity fit is shown in Figure 4.

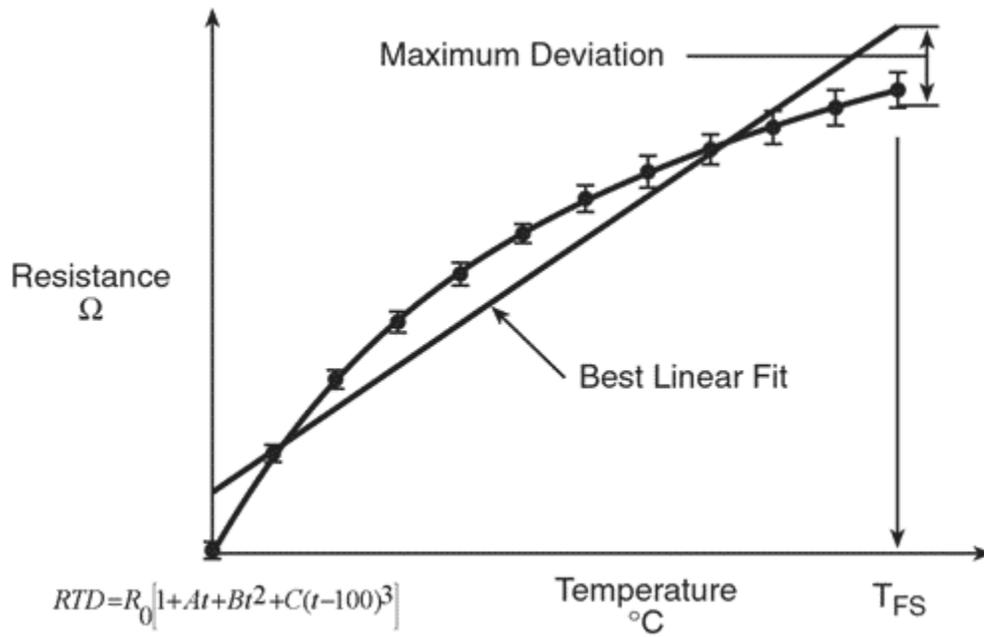


Figure 4. Typical linearity of the temperature/RTD resistance transfer function.

For temperatures greater than 0°C, “C” is 0, and the equation becomes:

$$RTD = R_0 [1 + At + Bt^2]$$

If a current  $I_{RTD}$  is passed through the RTD, and the voltage  $V_{RTD}$  measured, this equation can be solved for  $t$  as follows:

$$t = \frac{2(V_{RTD} - I_{RTD}R_0)}{I_{RTD}R_0 \left[ A^2 + \sqrt{A^2 + 4B(V_{RTD} - I_{RTD}R_0)/I_{RTD}R_0} \right]}$$

### In Conclusion

Resistive temperature detectors provide accuracy and repeatability that are among the best of all temperature sensors, over a wider temperature range than most (except for some thermocouples). RTDs can be read by quality DMMs or data acquisition systems capable of low ohms measurement, with four-wire techniques providing the highest accuracy.

Measurement hardware designed specifically for RTDs can eliminate the need for complex bridges and calculations to convert voltage or resistance to temperature.

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#### **About the Author**

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