

# Replacing Resistance Temperature Detectors with the TMP116 Temp Sensor

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## ABSTRACT

The TMP116 is a low-power, high accuracy local digital temperature sensor. In this application note we compare the usage of the TMP116 with that of a platinum RTD (resistance temperature detector). RTDs are commonly used for their high accuracy, but here we show that over the temperature range supported by the TMP116, the TMP116 provides greater and more consistent accuracy at lower power, cost and complexity.

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## 1 Resistance Temperature Detector (RTD) Introduction

A resistance temperature detector (RTD) is a passive circuit element whose resistance increases as temperature increases. They are generally constructed using platinum, copper, or nickel, and one major advantage of RTDs is that they support a wide span of temperature, ranging from -200°C to +850°C. The accuracy limits of an RTD are defined by the class, or grade, of the RTD. The industry standard for platinum RTDs include Class B, Class A, 1/3 DIN, and 1/10 DIN with Class B being the least accurate, and 1/10 DIN being the most accurate. However, for each class, the accuracy varies as the temperature changes.

The characteristics of platinum, copper, or nickel determine the linear approximation of resistance vs temperature within the 0°C to 100°C temperature range. The platinum RTD is known for its strong linearity and repeatability characteristic. Given that the TMP116 carries similar characteristics, it is a suitable replacement for the platinum RTD. Platinum, which is generally the most commonly used metal in RTDs, has an alpha value of  $\alpha=0.003925 \Omega/\Omega/^\circ\text{C}$ . Each metal carries its own alpha value.

The following equation is used to find  $\alpha$ :

$$\alpha = \frac{R_{100^\circ\text{C}} - R_{0^\circ\text{C}}}{R_{0^\circ\text{C}}} \div 100^\circ\text{C}$$

where

- $R_{0^{\circ}\text{C}}$  is element resistance at  $0^{\circ}\text{C}$
  - $R_{100^{\circ}\text{C}}$  is element resistance at  $100^{\circ}\text{C}$
- (1)

Using the alpha value, the resistance change ( $\Delta R$ ) with response to the temperature change ( $\Delta T$ ) can be determined.

The following equation is used to determine the resistance change:

$$\Delta R = \alpha R_0 \Delta T$$

where

- $\alpha$  is Temperature Coefficient of Resistance (TCR) in  $\Omega/\Omega/^{\circ}\text{C}$
  - $R_0$  is the nominal sensor resistance at  $0^{\circ}\text{C}$
  - $\Delta T$  is the temperature change from  $0^{\circ}\text{C}$  in  $^{\circ}\text{C}$
- (2)

Because  $\alpha$  is small, the change in resistance for small temperature changes is also small which is why the RTD solutions require additional gain and high resolution analog to digital converters. As [Equation 2](#) shows, the output is linear to the resistance, and therefore RTDs are offered with different resistance values such as the PT100 and PT1000 platinum RTDs with a resistance of  $100\Omega$  and  $1000\Omega$  respectively.

## 2 TMP116 Local Temperature Sensor Introduction

The TMP116 temperature sensor operates from  $-55^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$  with high accuracy across the entire temperature range. It contains I2C and SMBus-interface communication, as well as an integrated EEPROM memory. There is no calibration required for the TMP116, and minimal current is consumed which minimizes self-heating. The TMP116 is typically found in applications with a heavy focus on high accuracy.

A BJT transistor is used to measure the temperature of the TMP116. The base and the collector of the BJT are connected which allows it to act as a diode, and therefore utilizes the diode equation, shown in [Equation 3](#), to internally determine the temperature of the device.

$$\Delta V_{\text{BE}} = \left( \frac{nkT}{q} \right) \ln(r)$$

where

- $\eta$  is the ideality factor
  - $k$  is the Boltzmann's constant
  - $T$  is the temperature in Kelvin
  - $q$  is the charge of the electron
  - $r = I_{c1}/I_{c2}$  is the ratio of the excitation currents
  - $\Delta V_{\text{be}}$  is the change in the voltage across the base to the emitter
- (3)

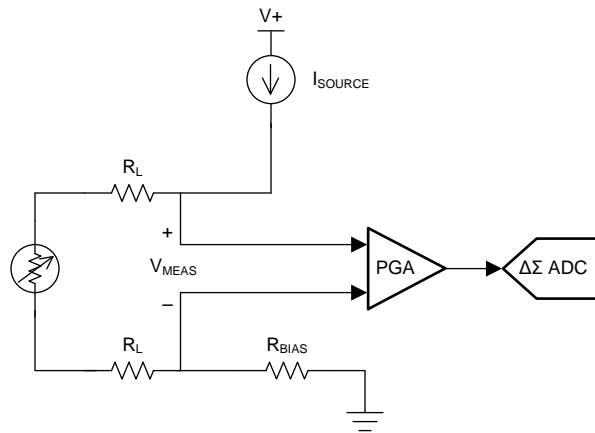
To find the change in the voltage across the base and the emitter, two excitation currents are applied to the BJT. One current produces one voltage value, and the other current produces the second voltage value. The difference between both voltages is then measured by the internal analog-to-digital converter, and converted to the temperature of the device.

## 3 RTD and TMP116 Comparison

### 3.1 Resistance Temperature Detector (RTD)

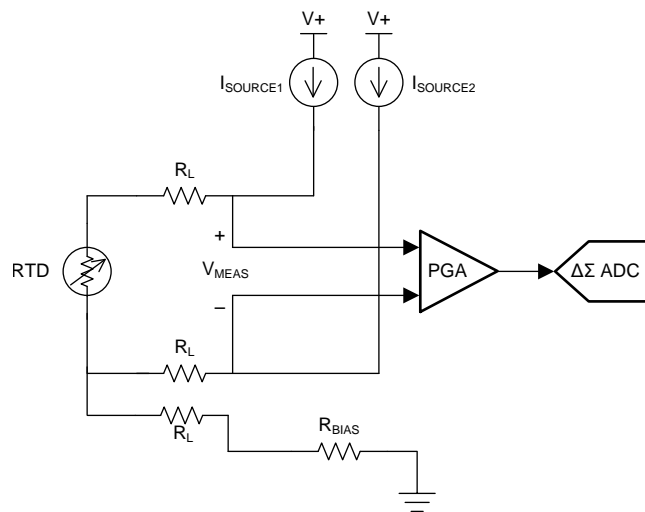
The RTD device contains a 2-wire, 3-wire, or 4-wire connection. The more wires that exist within the RTD, the lower the resistance errors the RTD signal-chain will have. The RTD errors are explained more in details below.

A 2-wire connection RTD experiences a voltage drop across the wires due to the resistance of the wires as the excitation currents are applied. The voltage drop is included in the total voltage calculated within the ADC, and therefore, it produces an error in the calculation of the temperature proportional to the voltage drop. The 2-wire connection RTD is shown below in [Figure 1](#).



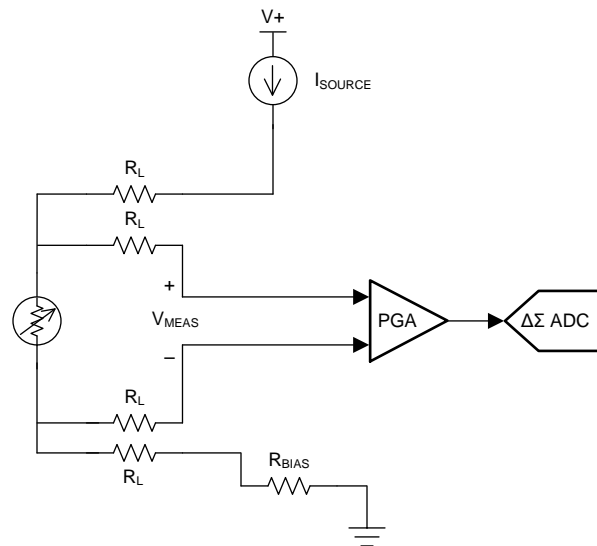
**Figure 1. A 2-wire RTD Connection Block Diagram**

A 3-wire RTD, shown in [Figure 2](#), also experiences a voltage drop across the wire. However, the third wire connected to the RTD cancels out the voltage drop from the calculation as long as the excitation currents are equal, and the wires are the same length.



**Figure 2. A 3-wire RTD Connection Block Diagram**

A 4-wire connection RTD does not have any resistance errors due to the current not passing through the wires in which the voltage is being measured. This diagram is shown in [Figure 3](#).



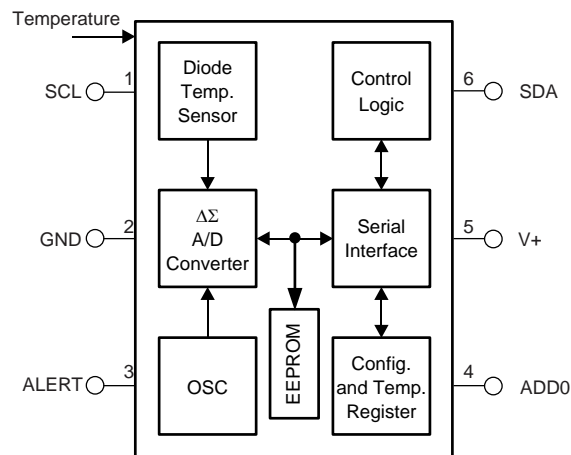
**Figure 3. A 4-wire RTD Connection Block Diagram**

A typical RTD signal-chain design uses the following components: a programmable gain amplifier (PGA), a high resolution analog-to-digital converter (ADC), and a reference bias resistor. The voltage drop across the RTD is extremely small, and therefore requires a PGA to increase the output signal prior to sampling the voltage with the ADC. The high resolution ADC is used to convert the voltage signal to a digital signal. The system utilizes an ADC of high resolution to maintain the required precision. The reference bias resistor is used as a voltage divider in the 2-wire and 4-wire RTD, and as a ratio for the ADC in a 3-wire RTD.

Once the resistance value is sampled, the temperature is determined in the microcontroller using a look-up table (LUT), or a best fit equation based on temperature coefficient parameters provided by the manufacture.

### 3.2 TMP116 Local Temp Sensor

The TMP116 device is fully integrated and requires no external integrated circuit components. In [Figure 4](#), a detailed view of the TMP116, shows the ADC integration as well as all other required blocks. The output of the TMP116 is the measured temperature and no additional functionality is required at the microcontroller.



**Figure 4. The TMP116 Block Diagram**

The temperature is also calculated internally, and then displayed on a Graphical User Interface (GUI) after it is received by the microcontroller.

### 3.3 TMP116 Accuracy vs RTD Accuracy

The RTD accuracy varies depending on the RTD class, as well as the temperature. However, over the operating range of the TMP116, the TMP116 has better accuracy.

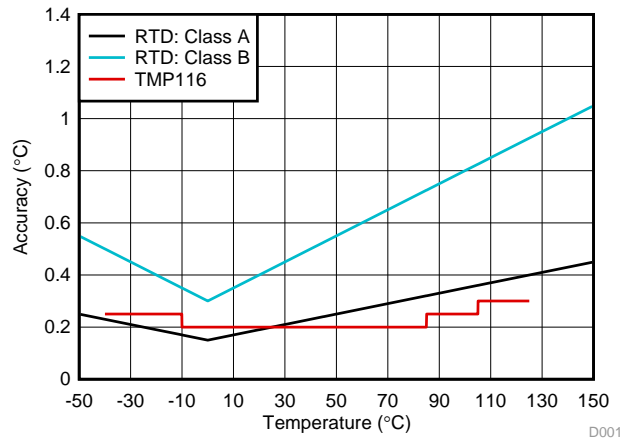


Figure 5. Comparing the Accuracy of an RTD to the TMP116

The graph in Figure 5, shows that the TMP116 device has significantly better accuracy than the Class B RTD. In addition, when compared to the Class A RTD, the TMP116 accuracy is also better over most of the TMP116 operating temperature range. From 30°C to 125°C, the TMP116 outperforms the Class A RTD by up to 10°C.

## 4 Conclusion

The TMP116 device is lower in cost, requires a much less complex design, and offers improved accuracy over most of the temperature range. These characteristics make it an interesting alternative to RTDs when accurate temperature measurements are needed in the -55°C to 125°C range.

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