AN66477

PSoC® 3, PSoC 4, and PSoC 5LP - Temperature Measurement with a Thermistor

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Associated Part Family: PSoC 3, PSoC 5LP, PSoC 4100, PSoC 4200

Associated Code Examples: click here.

Related Application Notes: click here.

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AN66477 describes how to measure temperature with a thermistor using PSoC® 3, PSoC 4, or PSoC 5LP. This application note describes the PSoC Creator™ Thermistor Calculator Component, which simplifies the math-intensive resistance-to-temperature conversion.

Contents

1 Introduction

Temperature is one of the most frequently measured environmental variables. Temperature measurement is typically done using one of four sensors: thermocouple, thermistor, diode, or resistance temperature detector (RTD). Table 1 compares the different types of temperature sensors and why you may want to use one versus another.

Table 1. Comparison of RTDs, Thermocouples, Thermistors, and Diodes

Parameter	RTD	Thermocouple	Thermistor	Diode
Temperature range	–200 to +850	–250 to +2350	–100 to +300	–50 to +150
Sensitivity at 25 °C	0.387 Ω/°C	40 µV/°C (K-type)	416 Ω/°C	250 µV /°C
Accuracy	High	Medium to High	Medium	Low
Linearity	Good	Fair	Poor	Good
Typical cost (US $)	$3–$80	$3–$15	$0.2–$10	<$0.2
Typical distance of sensing	Surface mount for onboard temperature Three- and four-wire up to a few hundred meters	<100 meters	Surface mount for onboard temperature Leaded for <1 meter	Onboard temperature
Resource requirement	Excitation current, amplifier, ADC, and reference resistor	Amplifier, ADC, voltage reference, and another temperature sensor for cold junction	Excitation current, ADC, and reference resistor	Excitation current, amplifier, and ADC
Response time	Slow	Fast	Fast	Slow
Computational complexity (best possible accuracy)	High	Very high	Very high	Medium

Use Table 1 to make an informed choice about the type of temperature sensor appropriate for your application. To learn more about temperature measurement using RTDs, thermocouples, or diodes, see one of the following application notes:

- AN70698 - PSoC® 3 and PSoC 5LP- Temperature Measurement with an RTD
- AN75511 - PSoC® 3 and PSoC 5LP- Temperature Measurement with a Thermocouple.
- AN60590 - PSoC® 3 and PSoC 5LP- Temperature Measurement with a Diode.

This application note focuses on thermistors. A thermistor is a temperature-sensitive resistor whose resistance varies with temperature. This application note focuses on Negative Temperature Coefficient (NTC) thermistors and the configuration of PSoC 3, PSoC 4, or PSoC 5LP to measure the resistance of a thermistor, and convert that resistance to temperature.

This application note assumes that you are familiar with developing applications using PSoC Creator for PSoC 3, PSoC 4, or PSoC 5LP. If you are new to PSoC 3, PSoC 4, or PSoC 5LP, see the introductions in the following application notes:

- AN54181 - Getting Started with PSoC 3
- AN79953 - Getting Started with PSoC 4
- AN77759 - Getting Started with PSoC 5LP

If you are new to PSoC Creator, see the PSoC Creator home page.

1.1.1.1 Using this Document

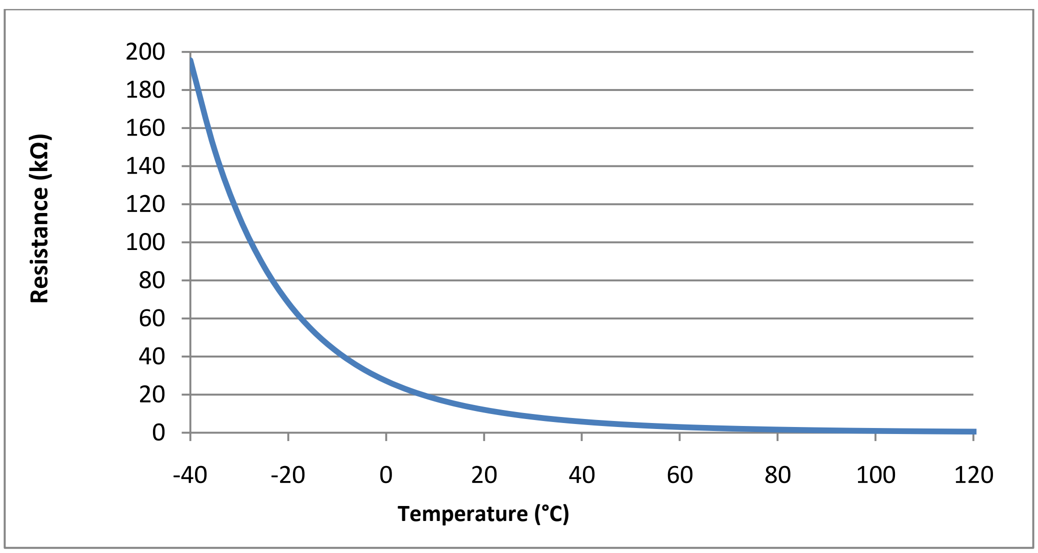
This document describes the theory behind thermistor temperature measurement. If you are looking for code examples for thermistor temperature measurement, see CE210514, and CE210528.

2 Thermistor – Theory of Operation

This application note focuses on NTC thermistors, which are used for precision temperature measurement applications. Positive temperature coefficient (PTC) thermistors are not discussed because they are not as commonly used.

For NTC thermistors the resistance of the thermistor decreases as the temperature rises. The variation of resistance with temperature is nonlinear. Figure 1 shows a typical resistance versus temperature curve for an NTC thermistor.

Figure 1. Resistance Versus Temperature for an NTC Thermistor



Because of this nonlinear response, a complex polynomial equation is required to calculate the temperature from the resistance. Equation 1 shows the Steinhart-Hart equation. This is the standard equation used for converting thermistor resistance to temperature.

Equation 1
$$\frac{1}{T_K} = A + B * ln(R_T) + C * (ln(R_T))^3$$

Where:

T_K = Temperature in Kelvin

A, B, and C = Steinhart-Hart coefficients, which vary for each thermistor.

R_T = Thermistor resistance in ohms

Equation 1 shows that the main unknown is the resistance of the thermistor. Thermistor temperature measurement requires two steps:

1. Thermistor Resistance Measurement
2. Resistance-to-Temperature Calculation

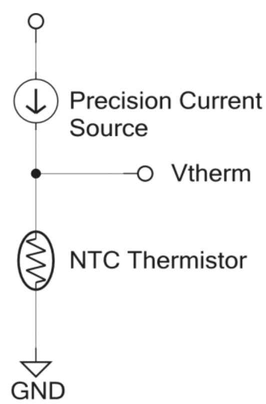
The following sections describe these two tasks in detail.

3 Thermistor Resistance Measurement

3.1 Current Source Measurement Method

Ohm's Law says $V = I * R$. To find resistance, we need to know V and I. From the equation $R = V/I$, it seems logical that one way to measure a thermistor's resistance is to force a known current through a thermistor and measure the output voltage, as Figure 2 shows.

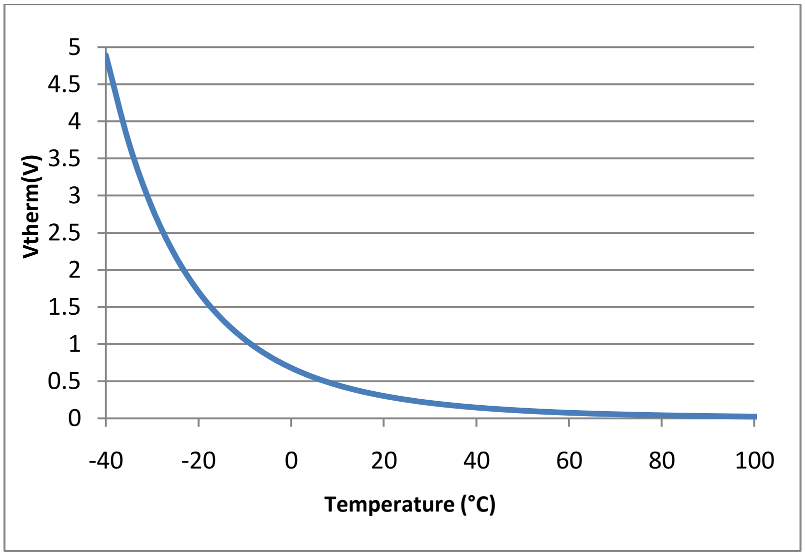
Figure 2. Common-Sense Approach to Measure Thermistor Resistance



This method does work, but there are four problems with the circuit shown in Figure 2.

1. The current source needs to be very accurate; any current error causes an error in the temperature reading.
2. If too much current is passed through the thermistor it can heat itself and cause temperature error; this problem is described in the Performance Analysis section.
3. The offset, gain, and integral nonlinearity (INL) error of the ADC can lead to inaccuracies in the measured resistance.
4. The voltage output directly follows the nonlinearity of the thermistor, as Figure 3 shows.

Figure 3. Voltage to Temperature Relationship of Circuit in Figure 2 with a 25-µA Current Source



With this method the voltage difference between temperatures is small at high temperatures, requiring a high-resolution ADC.

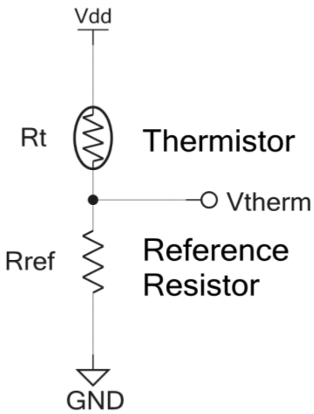
According to the datasheet for the NCP18XH103F03RB thermistor, the resistance at 125 °C is 531.0003 Ω. At 124.9 °C, the resistance is 532.214675 Ω. Passing 25 µA through these resistances produces 13.275 mV and 13.305 mV, respectively. This is a difference of 30 µV.

The LSB of the ADC must be half of this value, or 15 µV. To calculate the required resolution, divide the full-scale input range by the smallest measurement quantity. The graph in Figure 3 shows that the full-scale input is ~5 V. Therefore, 5 V/15 µV is approximately 333k steps or 18 bits.

3.2 Resistor Divider Method

Figure 4 shows a method to reduce some of the errors associated with Figure 3.

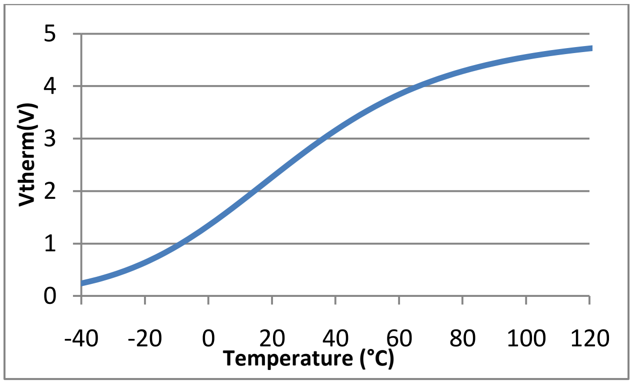
Figure 4. Resistor Divider Method



Note: The location of the reference resistor and thermistor do not matter. The reference resistor could be on the top.

The reference resistor is used to create a voltage divider with the thermistor. This method reduces the nonlinearity of the output voltage. Typically, the reference resistor is the same value as the thermistor at 25 °C. Figure 5 shows the temperature-to-voltage curve for the NCP18XH103F03RB in series with a 10-kΩ resistor and V_{DD} set to 5 V.

Figure 5. Voltage-to-Temperature Relationship of Circuit in Figure 4



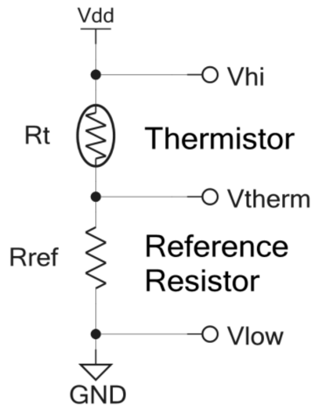
For 125.0 °C and 124.9 °C, the Vtherm is 4.74788 V and 4.74734 V, respectively. This is a difference of 540 µV. The required resolution of an ADC to resolve 0.1 °C at high temperatures is 14 bits—much lower than the method discussed in the previous sections.

There are problems with the circuit shown in Figure 4. If there is any error in the value of the reference resistor, V_{DD}, or GND there will be an error in the temperature conversion. In addition, the ADC gain and offset errors remain issues that must be handled. The next section shows a third method that overcomes some of these problems.

3.3 Ratiometric Resistor Divider Method

Figure 6 offers another method that overcomes some of the problems mentioned previously.

Figure 6. Ratiometric Resistor Divider Method



The best way to remove any dependence on V_{DD} is to measure it at V_{HI}. The best way to remove any dependence on GND (if it is not exactly 0 V) is to measure it at Vlow.

If a differential ADC is used only two ADC readings are required: the differential voltages across Rref and Rt. Using these voltage measurements, the resistance of the thermistor is calculated using Equation 2.

Equation 2 $$Rt = Rref * \frac{Vhi - Vtherm}{Vtherm - Vlow}$$

As mentioned previously, the circuit in Figure 6 provides a more linear voltage-to-temperature response, thus requiring a lower-resolution ADC. Performing ratiometric measurements eliminates ADC gain errors from the calculations (see Offset Error Cancellation). This method still results in errors from self-heating and inaccurate reference resistor value. However, due to the advantages of this method and its widespread use, this method is discussed in detail in this application note. For more information on calculating errors in measuring thermistors, see Performance Analysis.

3.3.1 Reference Resistor Selection

To achieve the maximum resolution at either extreme of temperature, the reference resistance should be close to the resistance of the thermistor at the middle of the temperature range. If you are more interested in measuring the temperature at one extreme, then the reference resistance should match the resistance of the thermistor at the temperature extreme being measured.

3.3.2 V_{DD} or V_{HI} Selection

The thermistor and reference resistor circuit is driven with a voltage. There are four main factors in determining this voltage:

1. What voltage is available in the system? For most systems this is the V_{DD} rail. However, PSoC 3 and PSoC 5LP have a VDAC which can be used to drive the circuit at something other than V_{DD}.
2. To reduce the resolution requirements for the ADC V_{DD} or V_{HI} should be as high as possible. This way, the voltage difference between 1 °C can be as large as possible thus reducing the required resolution of the ADC.
3. V_{DD} or V_{HI} should also be set such that the voltage across the reference resistor and thermistor are within the ADC input range. For example, the Delta Sigma ADC in PSoC 3 and PSoC 5LP has a differential input range of ±1.024V, so V_{HI} should be chosen such that the voltage across either the reference resistor or thermistor doesn't exceed 1.024V.
4. If the voltage is too high more current is passed through the thermistor leading to self-heating. For details, see the Self Heating section. Designers of thermistor systems must make tradeoffs between resolution and self-heating error.

   One common approach to avoid self-heating is to duty-cycle the VDAC. When not measuring, turn the VDAC off, or disconnect ground. When measuring, turn it back on. In PSoC devices the VDAC can quickly be turned off. Another method is to connect the bottom of the reference resistor to a GPIO pin; set that pin to High-Z when not measuring, and set it to 'Strong Drive Low' when measuring.

3.3.3 Offset Error Cancellation

In PSoC devices the ADC offset and signal chain offset can easily be removed through correlated double sampling (CDS). In CDS, the offset is measured and then in firmware it is subtracted from the other voltage measurements. See AN66444 – PSoC® 3 and PSoC 5LP Correlated Double Sampling for details.

For thermistor temperature measurement, the best way to measure the system offset is to short two inputs of the ADC together.

3.3.4 Gain Error Cancellation

Assume that the ADC has a gain error of k. This error is reflected as multiplicative factor in the voltage measurements, V_{Therm} and $V_{ref.}$ Because Equation 3 includes a ratio, the multiplicative error cancels k out.

Equation 3 $$R_{Therm} = \frac{k*(V_{Hi} - V_{Therm})}{k*(V_{Therm} - V_{Low})} * R_{ref}$$

Now the error depends primarily on the accuracy of the reference resistor, R_{ref}.

This method also removes any errors associated with gain drift, because the ratiometric measurement is being taken every time.

4 Thermistor Resistance-to-Temperature Calculation

Now that we have a method to measure the resistance, we need to convert that resistance to temperature. As Figure 1 shows, the relationship between resistance and temperature is highly nonlinear. The most common conversion method is the Steinhart-Hart (Equation 1), reproduced below.

$$\frac{1}{T_K} = A + B*ln(R_T) + C*(ln(R_T))^3$$

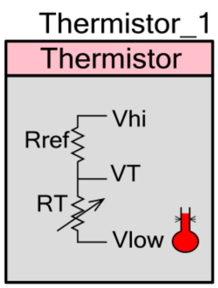
Some thermistor datasheets provide the three Steinhart-Hart coefficients (A, B, and C). Other datasheets provide "Temperature coefficient" (Alpha) values, "Sensitivity index" (Beta) values, or a table of resistance to temperature. Although the Alpha or Beta coefficients can determine temperature, they are limited to the temperature range for which they are specified. The Steinhart-Hart equation does not have this limitation.

Because the parameters provided for thermistors can vary, their usage and interchangeability in an application can be complicated. To simplify the process of converting thermistor resistance to temperature, Cypress provides a Thermistor Calculator Component that calculates the required A, B, and C coefficients, based on the resistance versus temperature table or curve available in datasheets.

4.1 Thermistor Calculator Component

"Thermistor_Calc", shown in Figure 7, is a PSoC Creator Component that is software only—it has no hardware input or output. You can find it in the Cypress Component Catalog under the Thermal Management Folder.

Figure 7. Thermistor Calculator Component



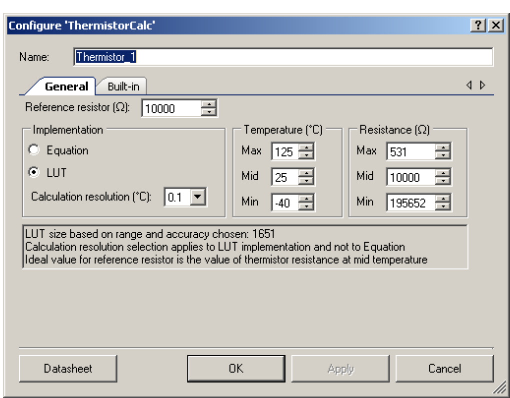
The Component uses the temperature and resistance of the thermistor, calculates the Steinhart-Hart coefficients, and generates the API code required for resistance-to-temperature conversion.

The Component Configuration Tool and API provide the interface to the Component.

To configure the Component for your thermistor, double-click the symbol to open the Component Configuration Tool. Figure 8 shows the Component Configuration Tool.

First, enter the reference resistor value, along with the three temperature points; the Component determines the proper coefficients for the Steinhart-Hart equation.

Figure 8. Thermistor Calculator Component Configuration Tool



The values entered in Figure 8 are from the datasheet for the NCP18XH103F03RB thermistor. The datasheet includes a table of resistance-to-temperature values, similar to that shown in Figure 9.

Figure 9. NCP18XH103F03RB Temperature to Resistance Table

Part Number	NCP☐☐XH103
Resistance	10kΩ
B-Constant	3380K
Temp. (°C)	Resistance (kΩ)
−40	195.652
−35	148.171
−30	113.347
−25	87.559
−20	68.237
−15	53.650
−10	42.506
−5	33.892
0	27.219
5	22.021
10	17.926
15	14.674
20	12.081
25	10.000
30	8.315
35	6.948
40	5.834
45	4.917
50	4.161
55	3.535
60	3.014
65	2.586
70	2.228
75	1.925
80	1.669
85	1.452
90	1.268
95	1.110
100	0.974
105	0.858
110	0.758
115	0.672
120	0.596
125	0.531

The Component Configuration Tool also provides an **Implementation** option to use either an equation or a lookup table (LUT). Table 2 shows the tradeoff between the two methods.

Table 2. Comparison of Equation and LUT

	Implementation		Comments
	Equation	LUT	
Calculation Resolution (±) °C	0.01°C	≤ 0.01°C	Resolution shown is the resolution of calculation alone and does not consider the resolution of the ADC. Even though the resolution of the equation can be greater than ±0.01 °C, the output is limited to a resolution of ± 0.01 °C because the output is scaled by 100 and stored as an integer. The higher the resolution on the LUT, the more the memory it consumes.
Calculation Speed	Slow (~1 msec)*	Faster (~300 usec)*	Using the LUT, zero mathematical calculations need to be performed, so it is much faster at converting resistance to temperature.
Memory Usage	Higher	Lower	The memory usage of the equation method is fixed because of the use of the floating-point library. If other code already uses the floating-point library, the equation method is more efficient. The memory usage of the LUT depends on the range and accuracy chosen.
Range	Wider than specified	Limited to specified	In the equation method, the temperature can be measured outside of the range specified, at the cost of lower accuracy. With the LUT, temperature values outside the range specified are not measured.

* These numbers were taken on a PSoC 3 device with master clock and bus clock at 24 MHz.

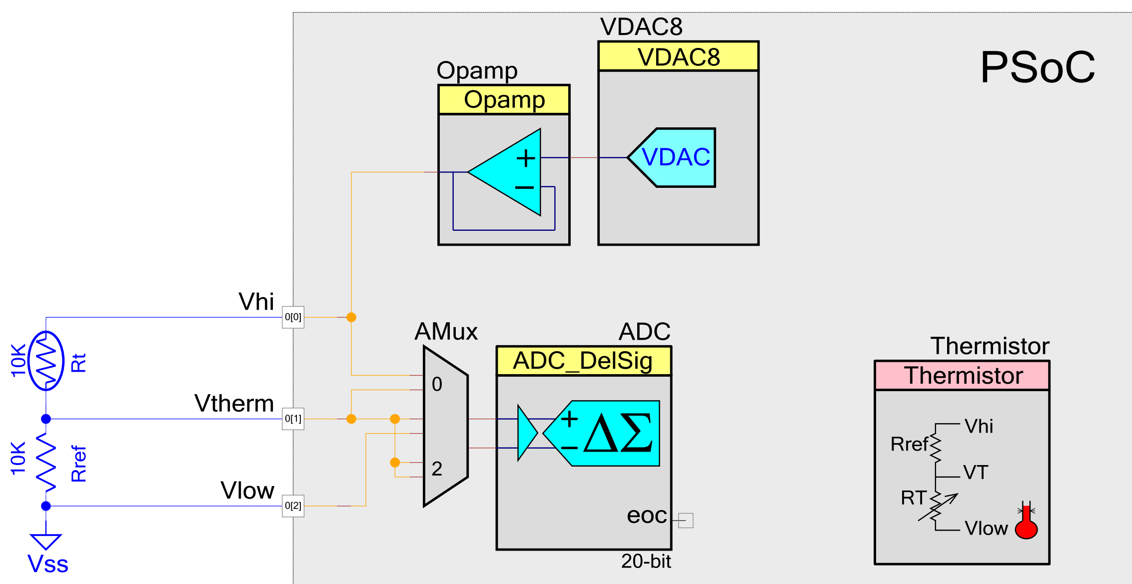
For information about other Component Configuration Tool options, see the Component datasheet.

5 Thermistor Temperature Measurement with PSoC

CE210514 demonstrates how to measure temperature with thermistors, using PSoC 3, PSoC 4, and PSoC 5LP. See CE210514 for details on how the example works. This section briefly describes how to configure a PSoC device to measure temperature with a thermistor.

Figure 10 shows a typical PSoC Creator schematic for a PSoC 3 or PSoC 5LP thermistor temperature measurement project.

Figure 10. Thermistor Temperature Measurement Circuit for PSoC 3 and PSoC 5LP

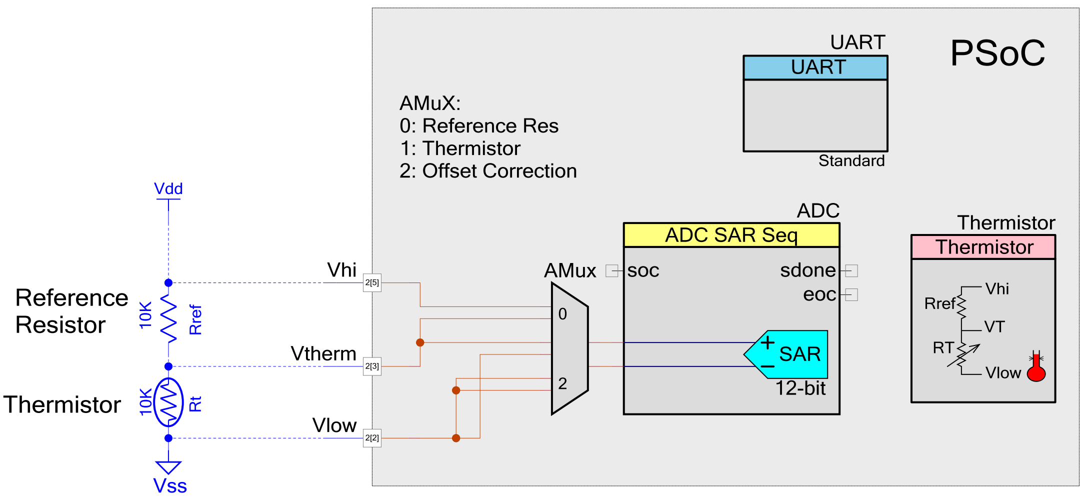


Notice how similar this schematic is to Figure 6. The ADC measures the differential voltage across the reference resistor and the thermistor. The VDAC and Opamp are used to set the voltage at the top of the thermistor. This is useful as the voltage can be changed to best fit inside the ADC input range. Also, the VDAC or Opamp can be turned on and off, reducing self-heating.

Amux channel 2 is used to measure the offset of the ADC. The two inputs are tied to the same voltage and then read. This reading returns the offset of the ADC, and this offset can then be removed from subsequent readings. This method, called correlated double sampling, is discussed in AN66444 - PSoC 3 and PSoC 5LP Correlated Double Sampling.

Figure 11 shows the schematic for PSoC 4 Thermistor Temperature measurement.

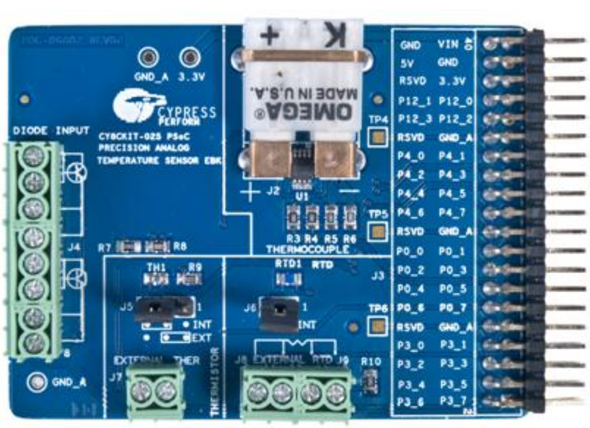
Figure 11. Thermistor Measurement Circuit for PSoC 4



The main difference between this project and the PSoC 3/PSoC 5LP project is that there is no DAC. The top of the divider must be connected to an external voltage. It can either be tied directly to the power supply, or it can be connected to a GPIO pin that is configured for a strong drive output. The advantage of using a GPIO pin is that the GPIO pin can be turned on and off, thus saving power and reducing self-heating. Also, PSoC 4 uses a successive approximation register (SAR) ADC instead of a delta-sigma ADC.

Cypress has created a special kit for temperature sensing: the PSoC Precision Analog Temperature Sensor EBK (CY8CKIT-025). The kit provides four sensors—thermocouple, thermistor, RTD, and diode—for measuring temperature. In addition, connectors are provided to let you plug in your own thermocouple, thermistor, RTD, or diode. You can connect the EBK to the CY8CKIT-030 PSoC 3 Development Kit (DVK), or to the CY8CKIT-050 PSoC 5LP DVK. Figure 12 shows the kit. For more details on the kit, go to www.cypress.com/go/Cy8CKIT-025.

Figure 12. PSoC Precision Analog Temperature Sensor EBK



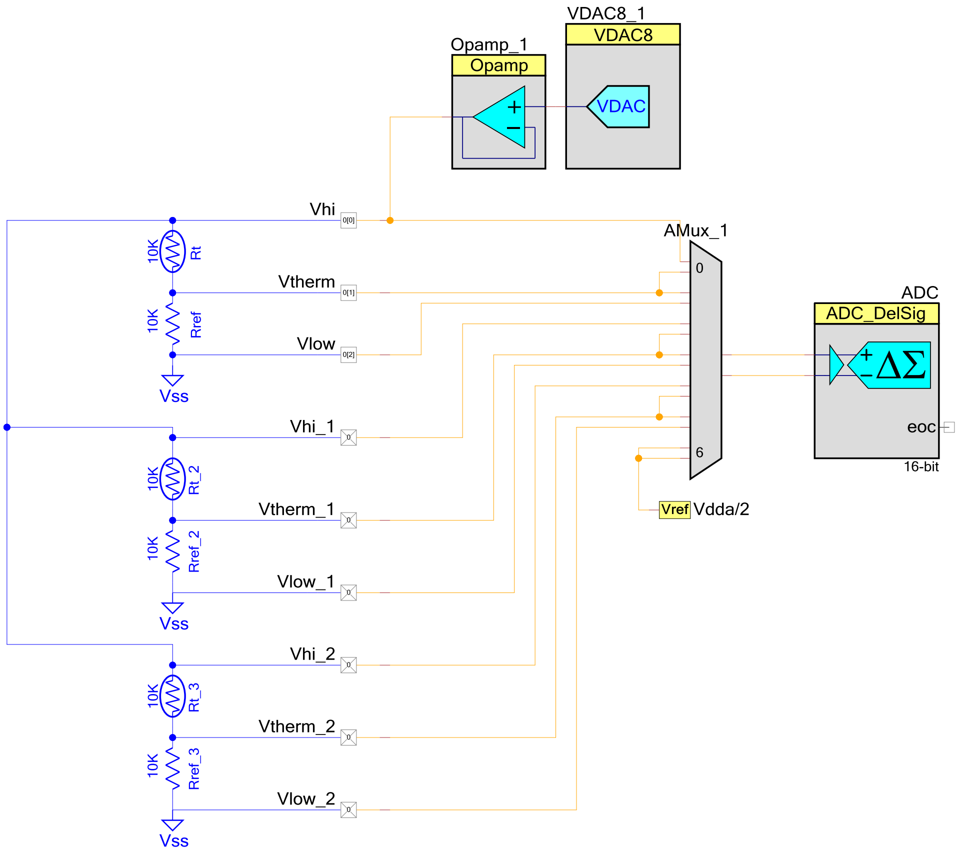
You are not required to use this kit to measure the temperature of a thermistor. The circuit required to measure temperature with a thermistor is a simple voltage divider, as Figure 6 shows. This can easily be prototyped on the CY8CKIT-001, CY8CKIT-030, CY8CKIT-050, or CY8CKIT-042 kits.

6 Measuring Multiple Thermistors

It is often desirable to measure more than one thermistor with one PSoC device. There are two ways to do this:

1. Measure the thermistors in parallel, as Figure 13 shows.

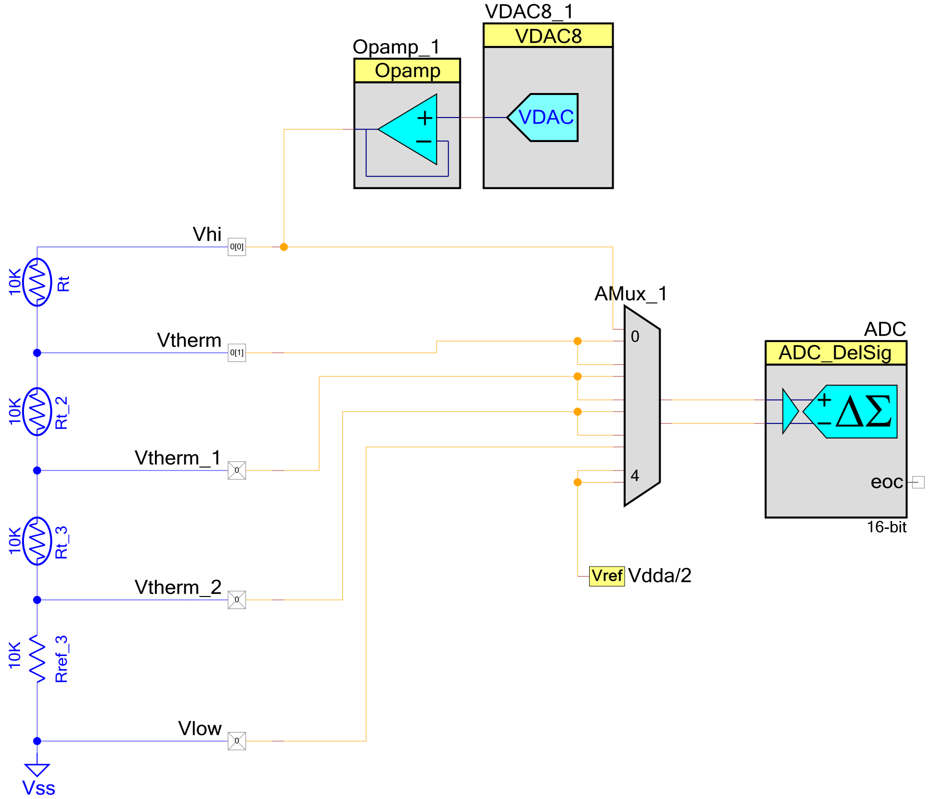
Figure 13. Multiple Thermistors Connected in Parallel



Only one VDAC and opamp are used to drive multiple thermistors. If you need to drive thermistors at different voltages, then separate VDACs and opamps are required. Remember that the maximum number of VDACs and opamps on a single PSoC 3 or PSoC 5 LP device is four.

2. Connect the thermistors in series, as Figure 14 shows.

Figure 14. Multiple Thermistors Connect in Series



The advantage of this method is that it uses fewer pins to measure the same number of thermistors as in the parallel method. However, a disadvantage of this method is that the voltages across the thermistors and the reference resistor are smaller, and may require a higher resolution ADC to obtain the required temperature resolution.

If all of the thermistors are identical (same part number), then only one Thermistor Calculator Component is needed. However, if different thermistors are used, then separate Thermistor Calculator Components need to be used.

7 Performance Analysis

7.1 Temperature Resolution

This section teaches you how to determine the ADC resolution required for measuring your particular thermistor.

1. Determine your temperature resolution requirements. For example, is it 1°C, 0.1°C, or 0.01°C.?
2. Determine the maximum temperature you will measure. For example, is it 125°C or 60°C?
3. Calculate the resistance at your maximum temperature, and at the maximum temperature minus the resolution, using Equation 4 below.
4. Calculate the voltage across the thermistor at those two voltages, using Equation 5. Take the difference of those two voltages and divide the result by 2.
5. Determine the maximum voltage across the thermistor and reference resistor for your temperature range.
6. Determine the voltage range of your ADC that is capable of measuring the maximum voltage found in step 5.
7. Take the result from step 6 and divide it by the result from step 4. This will tell you how many ADC counts you need. Take the LOG of this value and divide it by the LOG of 2 to get the required ADC resolution.

Calculating the resistance from temperature requires calculating the inverse of the Steinhart-Hart equation. This is a daunting mathematical task. It has been solved below in Equation 4.

Equation 4 $$R = e^{\left[\left(Y - \left(\frac{X}{2}\right)\right)^{\frac{1}{3}} - \left(Y + \left(\frac{X}{2}\right)\right)^{\frac{1}{3}}\right]} \quad \text{Where} \quad X = \frac{A - \frac{1}{T}}{C} \quad and \quad Y = \sqrt{\left(\left(\frac{B}{3C}\right)^3 + \frac{X^2}{4}\right)}$$

A, B, and C are the Steinhart-Hart Coefficients. T is the temperature in degrees kelvin. The Steinhart-Hart coefficients generated for your thermistor can be found in the generated .h file for the Thermistor Calculator Component.

To find the voltage across the thermistor, use Equation 5, which is a standard resistor divider equation.

Equation 5 $$V_{Therm} = V_{Bias} * \left(\frac{R_{Therm}}{R_{Ref} + R_{Therm}}\right)$$

The following is an example:

1. My required resolution is 0.01 °C.
2. The maximum temperature I want to measure is 125 °C.
3. Using Equation 4, the resistance at 125 °C is 531.0003 Ω, and the resistance at 124.99 °C is 531.1214 Ω.
4. Using Equation 5, the voltages across those resistances are 80.676 mV and 80.694 mV. This assumes a Vbias of 1.6 V, which is what is used in CE210514. The difference between these two values is 18 µV. 18 µV / 2 = 9 µV.
5. The maximum voltage across the reference RTD occurs at -40 °C; using Equation 5 you can determine it is 1.52 V. The maximum voltage across the reference resistor occurs at 125 °C. Use Equation 5, but replace R_{Therm} in the numerator with R_{Ref}. This yields a voltage of 1.519 V. Thus, the maximum voltage is 1.52 V
6. The delta sigma ADC in PSoC 3 and PSoC 5LP has an input voltage range of ±2.048 V.
7. 4.096 V / 9 µV = 455112 steps, or log(455112) / log(2) = ~19 bits.

The delta sigma ADC in PSoC 3 and PSoC 5LP has a 20-bit resolution, so it is capable of measuring across a wide temperature range with a 0.01 °C resolution.

The method described above can be used with any thermistor and any measurement device.

7.1.1 Increasing the Resolution

There are several methods to increase the temperature resolution.

1. Increase the Vbias voltage. This increases the voltage delta between the resistances.
2. ADC resolution can be increased by oversampling. This is a common industry practice where multiple ADC samples are used to create a higher resolution result. To increase the resolution by 1 bit, 4 ADC samples are summed, and the result right-shifted by 1 (divided by 2). To get 2 extra bits, 4^2 ADC samples are summed and the result right-shifted by 2. To get 3 extra bits, 4^3 ADC samples are summed, and the result shifted right by 3. This can be extended to any number of extra bits. The tradeoff is conversion speed—the more extra bits required, the more samples required for each conversion, and the slower the conversion.
3. Reduce the maximum temperature measured. The higher the temperature, the smaller the difference is between resistances.

7.2 Temperature Accuracy

The accuracy of temperature measurement depends on the entire signal chain. In this section, we analyze the accuracy of different parts of the chain to determine total measurement accuracy.

Let us break down the signal chain analysis into different sections and consider each one in detail:

- Signal measurement: ADC
- Sensor bias circuit: reference resistor
- Actual Sensor: Thermistor
- Voltage-to-temperature conversion: Thermistor Component

7.2.1 Signal Measurement Chain

7.2.1.1 Error Due to Offset and Gain Error

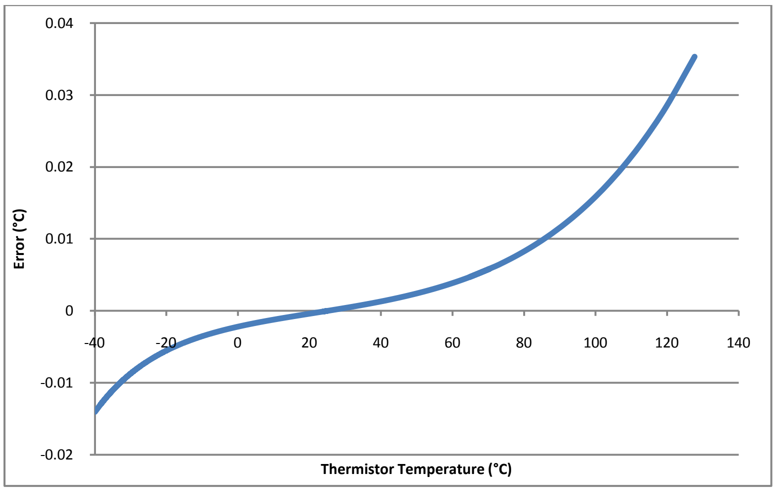
As discussed previously, the error due to offset is canceled through CDS, and the error due to gain is canceled due to ratiometric measurements.

7.2.1.2 Error Due to ADC Integral Nonlinearity for PSoC 3 and PSoC 5LP

The integral nonlinearity (INL) of the ADC appears in the measurement; you cannot eliminate it with measurement techniques or calibration. The INL for the delta sigma ADC in PSoC 3 is ±2 LSB; this equates to ±62.5 µV. This 62.5 µV can be added or subtracted from the numerator or denominator of Equation 2.

The worst-case error occurs when 62.5 µV is added to both the numerator and denominator of Equation 2. Figure 15 shows the temperature error across the range of the thermistor due to INL.

Figure 15: PSoC 3 and 5LP Temperature Error Due to INL

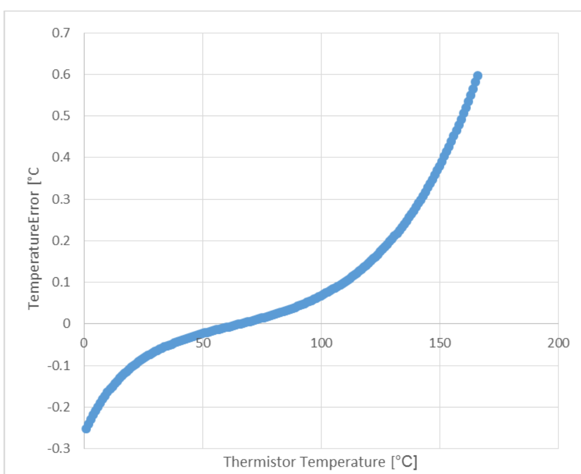


Note: This is the absolute worst-case error. In most cases, the INL is much less than 64 µV.

7.2.1.3 Error Due to ADC Integral Nonlinearity for PSoC 4

The INL for the PSoC 4 SAR ADC in the 5V range is ±1.5LSB or ~3.6mV. Applying this to Equation 2 we can create the following graph of temperature error:

Figure 16. PSoC 4 Temperature Error due to INL



7.2.2 Sensor Bias Circuit

Reference resistance variation affects the resistance calculation of the thermistor, and therefore, the temperature measurement. Equation 2, reproduced below, shows how to calculate the thermistor resistance.

$$Rt = Rref\left(\frac{Vtherm - Vlow}{Vhi - Vtherm}\right)$$

Any deviation in the reference resistor value, shown as R_{ref_dev}, results in a deviation in thermistor resistance R_{T_dev}, as Equation 6 shows.

Equation 6
$$R_{T\_dev} = Rt\left(\frac{Rref}{R_{ref\_dev}}\right)$$

The reference resistor variation due to tolerance and drift is represented in Equation 7.

Equation 7
$$R_{ref\_dev} = Rref + Rref\left(R_{ref\_tolerance} + R_{ref\_drift} * abs(T - 25)\right)$$

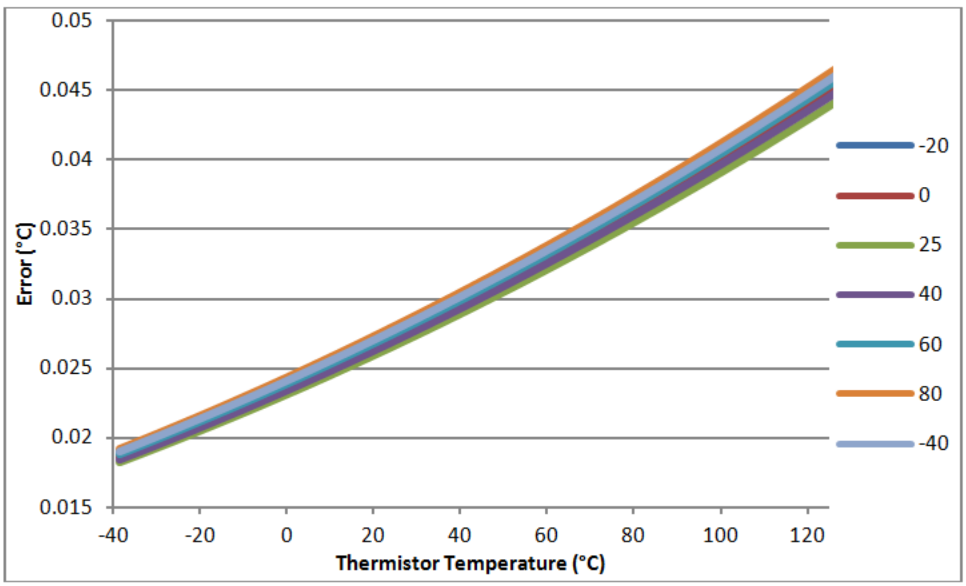
Where T is in °C and is the temperature of the reference resistor, not the thermistor.

Consider a 10-kΩ reference resistor with 0.1% tolerance and a temperature drift of 10 ppm/°C. Because the drift of the resistor is characterized at 25 °C, it must be included in the calculation as follows:

$$R_{ref\_dev@-40} = 10k + 10k\left(0.001 + 0.000001*(-40-25)\right) = 10009.35$$
$$R_{ref\_dev@125} = 10k + 10k\left(0.001 + 0.000001*(125-25)\right) = 10011$$

Using Equation 6 and Equation 7, we get the graph shown in Figure 17.

Figure 17: Reference Resistor Temperature Error

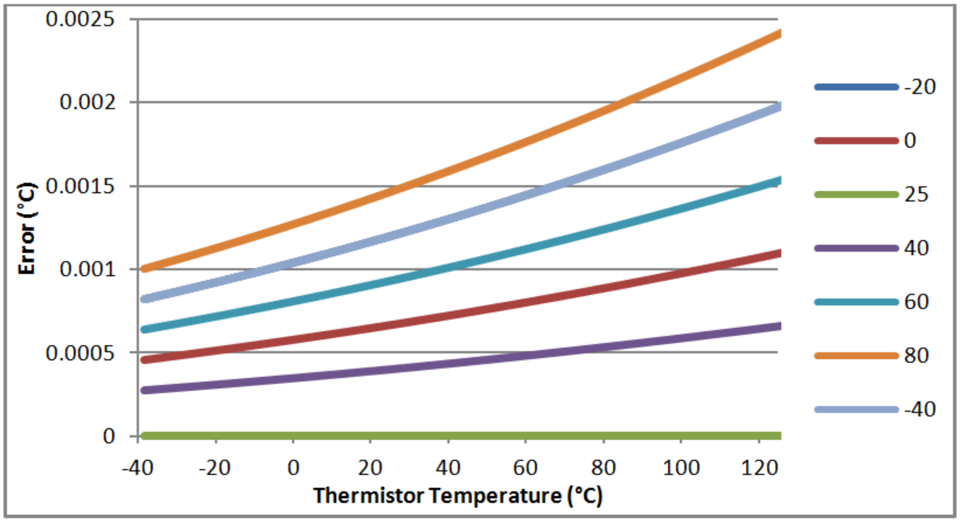


The X-axis is the temperature of the thermistor. The Y-axis is the temperature error; the different lines represent the error for the reference resistor at that temperature. The graph shows that the error introduced by the reference resistor is less than 0.05 °C

To cut cost, use a 1.0% resistor. With a 1.0% resistor using the same equations, the maximum temperature error would be ~0.45 °C.

Most of this error is caused by the initial tolerance of the reference resistor, not the temperature drift. For example, if a 1.0% reference resistor is used that has a temperature drift of 10 ppm and the initial tolerance error is calibrated out, the error due to the temperature drift will appear as Figure 18 shows.

Figure 18: Temperature Error Due to Reference Resistor Temperature Drift



The maximum temperature error due to the temperature drift of the reference resistor is ~.0025 °C. To achieve this, we must calibrate the initial tolerance of the reference resistor; this is demonstrated in CE210528.

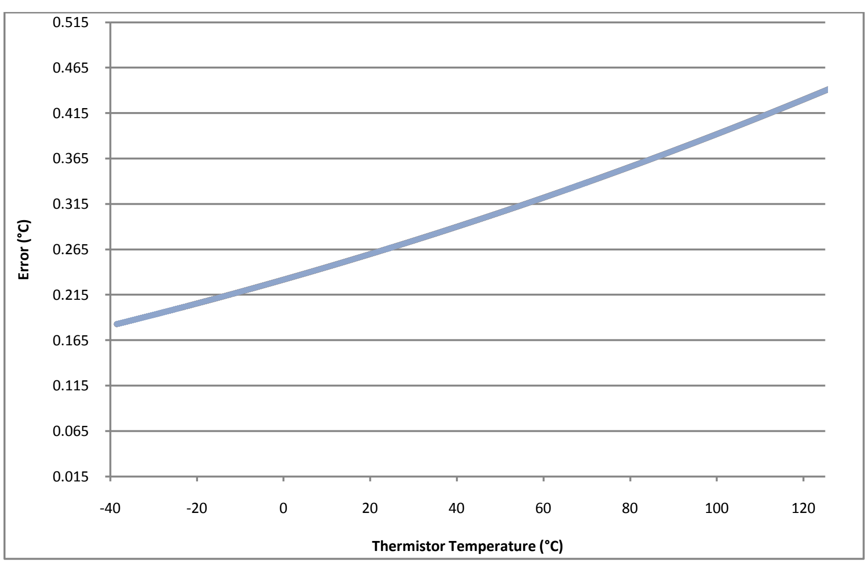
7.2.3 Actual Sensor

7.2.3.1 Tolerance

Every sensor has inaccuracies associated with it that are independent of the measurement system. For a thermistor, the significant parameters are accuracy, interchangeability, and self-heating. Some thermistor datasheets, such as the one for NCP18XH103F03RB, combine accuracy and interchangeability into one resistance tolerance parameter. The resistance tolerance of the thermistor under consideration is 1% across the temperature range.

Figure 19 shows the temperature error caused by the tolerance of the thermistor across the entire temperature range.

Figure 19: Thermistor Temperature Error



To calculate this error, we can use Equation 8:

Equation 8 $$R_{Therm\_Dev} = R_{Therm}\,(1 + 0.01)$$

Where 0.01 is the 1% tolerance of the thermistor. This new resistance must be entered back into Equation 1 to calculate the new temperature.

A simple way to remove this error is to do a single-point temperature calibration. For example, if the thermistor is used to measure human body temperature (37 °C), bring the thermistor to exactly 37 °C, record the temperature reported by the thermistor and note the difference between this temperature and 37 °C. Subtract this temperature from all subsequent readings.

This process is documented in CE210528.

7.2.3.2 Self Heating

The self-heating error in a thermistor is due to the power dissipated across the thermistor. To find the heating error, use the thermal dissipation constant C, which is the electric power required to raise the thermistor temperature by 1 °C.

Equation 9. $$C = \frac{P}{T - T_0}$$

C = 1 mW/°C for the NCP18XH103F03RB

When a reference voltage of 1.6 V is used for thermistor biasing, the power drop and therefore the temperature error is given as follows:

$$P_{@-40} = 11\mu W \rightarrow T_{error} = 0.011$$

$$P_{@125} = 12\mu W \rightarrow T_{error} = 0.012$$

Because self-heating depends on the bias voltage (or current in other techniques), keep the bias voltage low to maintain self-heating within an acceptable range.

7.2.4 Voltage-to-Temperature Conversion

The calculation used to convert the resistance to temperature also has associated error.

In the Thermistor Calculator Component, the error for the equation method across a temperature range of –40 °C to 125 °C is less than 0.01 °C. Because the resolution of the temperature measurement with the component is 0.01 °C, the error due to the equation is considered zero. With the LUT method, the error introduced is ±1/2 of the calculation resolution. This is added to the rest of the errors considered thus far.

7.3 Summary of Errors

Table 3 summarizes all the errors and typical measured results.

Table 3: Summary of Worst-Case Thermistor Errors from–40 °C to 125 °C

	Parameters	Max Error (°C)	Comments
Sensor Conditioning	VDAC inaccuracy	0*	It is measured
	Reference resistor	0.045	0.1% resistor with 10 ppm/°C
Thermistor	Tolerance	0.45	1% tolerance thermistor
	Self-heating	0.012	Thermal dissipation constant = 1 mW/°C
Measurement chain	Offset	0.00	Correlated double sampling
	Gain error	0*	Ratiometric measurement
	ADC INL	0.04	16-bit resolution with 2-LSB INL
Calculation error	Equation method	0*	Steinhart-Hart equation
	LUT method	1/2 calculation resolution	Resolution options: 0.01, 0.05, 0.1, 0.5, 1, 2

* Error values that are negligible for thermistor measurement are shown as ‘0’.

The table shows that the worst-case error is due to the thermistor itself. The maximum error is for a temperature range of –40 ºC to 125 ºC. Typically, thermistors are used for a smaller range, which results in higher accuracy.

8 Summary

When choosing a temperature sensor, a thermistor is one option that offers a high accuracy and low cost. In this application note, we looked specifically at negative temperature coefficient (NTC) thermistors, which are temperature-sensitive resistors.

This application note demonstrated how to measure the resistance of a thermistor, and showed how to configure PSoC 3, PSoC 4 or PSoC 5LP devices.

Converting from thermistor resistance to temperature is computationally complex. We showed how to use the PSoC Creator Thermistor Calculator Component to simplify the math-intensive resistance-to-temperature conversion.

9 Related Application Documents

9.1 Related Application Notes

- AN70698 - PSoC® 3 and PSoC 5LP- Temperature Measurement with an RTD
- AN75511 - PSoC® 3 and PSoC 5LP- Temperature Measurement with a Thermocouple.
- AN60590 - PSoC® 3 and PSoC 5LP- Temperature Measurement with a Diode.
- AN54181 - Getting Started with PSoC 3
- AN79953 - Getting Started with PSoC 4
- AN77759 - Getting Started with PSoC 5LP.
- AN66444 - PSoC® 3 and PSoC 5LP Correlated Double Sampling

9.2 Related Code Examples

- CE210514 - PSoC® 3, PSoC 4, PSoC 5LP Temperature Sensing with a Thermistor
- CE210528 - PSoC® 3, and PSoC 5LP Thermistor Calibration

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Document History

Document Title: AN66477 - PSoC® 3, PSoC 4, and PSoC 5LP - Temperature Measurement with a Thermistor

Document Number: 001-66477

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	3148830	YARA	01/20/2011	New application note.
*A	3216577	YARA	06/06/2011	1. In the library project associated with the AN, The Thermistor_v1_0 has been changed to Thermistor_Calc_v1_0. 2. Text in the AN has been modified to support the same. 3. The Library for the component has been changed from "CY_Ref" to "CYRef" as per the change in Spec: 001-58801.
*B	3453518	YARA	12/02/2011	Updated project to PSoC Creator 2.0. Minor text edits. Updated template.
*C	3682100	YARA	07/17/2012	Prototype status for component Provided two APIs instead of one for facilitating calibration in project and AN Added “Appendix A” Corrected “Accuracy” selection to “Calculation Resolution” Added “Performance Analysis” Updated the thermistor datasheet based on these changes Project code presentation changed based on best practices guidelines
*D	3836921	TDU	12/10/2012	Major Update Updated Flow of Document Updated content to reflect that the component is now part of Creator
*E	4155350	TDU	10/11/2013	Updated attached Associated Project Updated in new template Completing Sunset Review
*F	4224489	TDU	12/19/2013	Added PSoC 4 and difference performance level projects. Cleaned up accuracy calculations.
*G	4498523	TDU	09/10/2014	Corrected Table 3 title (from RTD to Thermistor) Updated the hyperlink and title for AN2099.
*H	5074214	TDU	01/14/2016	Updated to latest template Moved projects to Code Examples
*i	5705702	BENV	04/21/2017	Updated logo and copyright

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