Objective

This example demonstrates how to use a PSoC® 3 or PSoC 5LP device to measure temperature using a thermocouple. This example does not explain thermocouple calibration; for that, see CE219929.

Overview

Thermocouples are sensors commonly used to measure temperature in applications that measure very high temperatures, or require a sensor that is rugged. A thermocouple produces a small change in voltage per change in temperature (40 µV/°C). This requires a precise and accurate measurement system. The Delta Sigma ADC on PSoC 3 and PSoC 5LP devices has the required precision and accuracy to measure temperature using a thermocouple with no need for external amplifiers or ADCs. For full details on the theory of thermocouple measurement, see AN75511.

This code example demonstrates how to configure a PSoC 3 or PSoC 5LP device to accurately measure temperature using a thermocouple. The measured temperature is displayed on an LCD on either CY8CKIT-030 or CY8CKIT-050. This code example allows the use of either an IC temperature sensor or thermistor for cold junction compensation. CY8CKIT-025 is required to run this example.

Requirements

Tool: PSoC Creator™ 4.2 or newer

Programming Language: C (Arm® GCC 5.4.1, Arm MDK 5.22, DP8051 Keil 9.51)

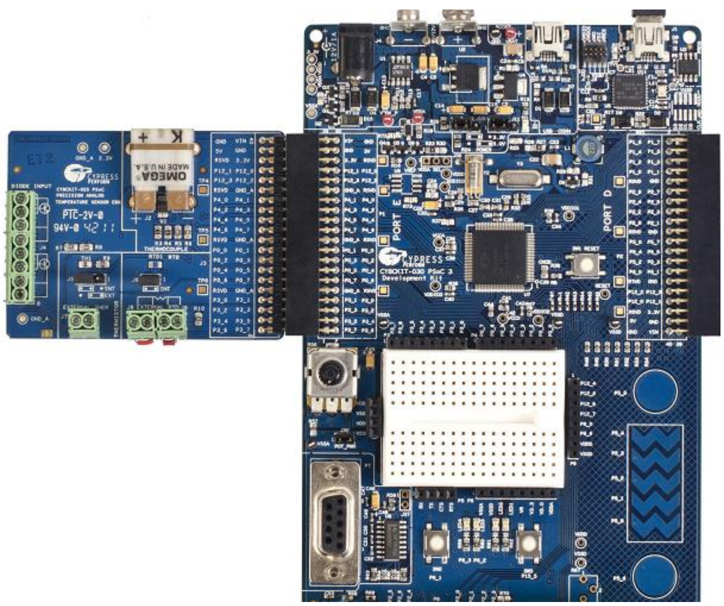
Associated Parts: All PSoC 3 and PSoC 5LP parts

Related Hardware: CY8CKIT-050, CY8CKIT-030, CY8CKIT-025

Hardware Setup

1. Plug CY8CKIT-025 into PORT E of either CY8CKIT-030 or CY8CKIT-050, as Figure 1 shows.

Figure 1. CY8CKIT-025 Plugged into CY8CKIT-030



2. Plug the thermocouple provided in CY8CKIT-025 into the thermocouple connector as Figure 2 shows.

Figure 2. Thermocouple Section of the EBK

3. Connect an LCD to the LCD port on CY8CKIT-030 or CY8CKIT-050.
4. Plug a USB cable into a PC and then into the programming USB connector on the kit.

Software Setup

To modify the filter characteristics of the IIR filter go to *main.h* and adjust:

```
/* Filter coefficient for sensors */
#define MAX_FILTER_COEFF_SHIFT     8
#define TC_FILTER_COEFF_SHIFT      6

/* Filter Feed Forward Term. It is set equal to 640 ADC counts or 2°C.
 * 256 (2^MAX_FILTER_COEFF_SHIFT) is to make the comparison fair */
#define FILTER_FEEDFORWARD     ((int32)640 * 256)
```

Important: If you create this project from an empty project, go to the System tab and change the heap size from 0x80 to 2048. This is needed for the sprintf function.

Important: If you create this project from an empty project, right-click on the project and select build setting. Go to **Linker** > **command line** and add "`-u_printf_float`" without quotes.

Math Library

The Thermistor Calculator component used in this design requires the math library to be linked into the design. That step is already done for you in the attached example.

If you are creating a new PSoC Creator project and using the Thermistor Calculator Component, right-click on your project, and then select **Build Settings….** Expand the complier group by pressing the **+** button. The name of the compiler will depend on the compiler used in the design; for PSoC Creator 4.2, it is **ARM GCC 5.4-2016-q2-update.** Click on **Linker**, in **Additional Libraries** add m, and then click **Apply**.

When using third-party IDEs, the math library will need to be added as well. The steps to do this are specific to each IDE and not described in this document. See your IDE's Help.

Operation

1. Complete the steps in the previous sections.
2. Build either the mid-end or low-end project, and program it into the kit.

   The LCD displays thermocouple temperature and cold junction temperature.
3. Press SW2 on the DVK to toggle the cold junction temperature source between the thermistor and the IC.
4. Change the temperature of the thermocouple and observe the measurement change on the LCD.

Design

This code example includes two projects: *CE219005_PSoC3_5_Thermocouple_Mid_End* and *CE219005_PSoC3_5_Thermocouple_Low_End*. These two projects correspond to the mid-end and low-end segments described in AN75511. The mid-end provides a resolution of 0.1 °C. The low-end has a resolution of 1 °C. The projects are nearly identical except for the configuration of the ADC and software filtering applied.

Figure 3 shows the thermocouple measurement circuit (PSoC Creator schematic). The circuit has a five-channel ADC, the Thermistor Component, and a character LCD. The five ADC channels and their purposes are listed in Table 1.

Table 1. Five ADC Channels

Channel	Connection	Measurement
0	Thermocouple	Thermocouple Voltage (Thermo-emf)
1	IC voltage output	Cold junction temperature
2	Thermistor voltage	Cold junction temperature
3	Thermistor ref	Cold junction temperature
4	Short	Offset

As shown in Table 1, a thermistor or an IC can be used for measuring cold junction temperature. A switch is used in the project to select between the two cold junction sensors.

According to the National Institute of Standards and Technology (NIST) thermocouple tables, at –270 °C, the thermocouple gives an output voltage of –6.458 mV. Because PSoC devices are single-supply, the voltage on the input pins must be kept above 0 V. To accomplish this, external resistors are added to the negative input of the thermocouple to add a small 15-mV bias. These resistors have been populated on CY8CKIT-025.

Figure 3(a). Thermocouple Measurement Circuit

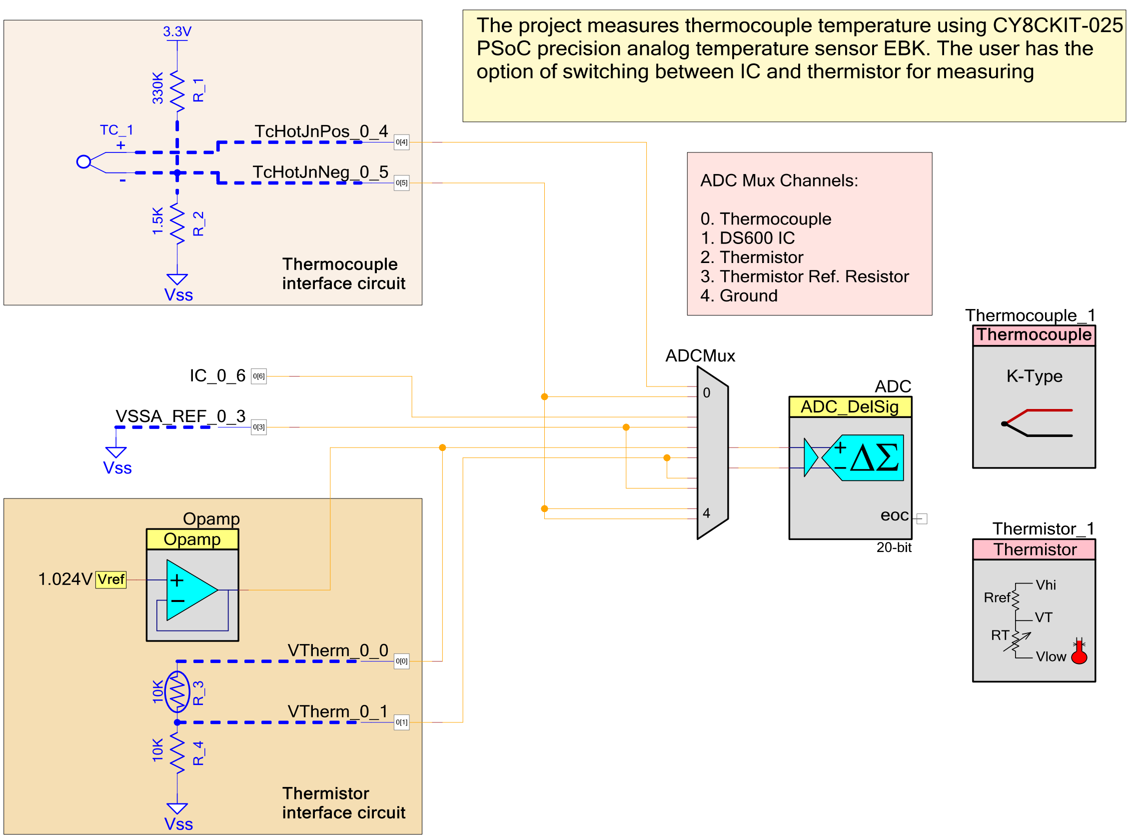
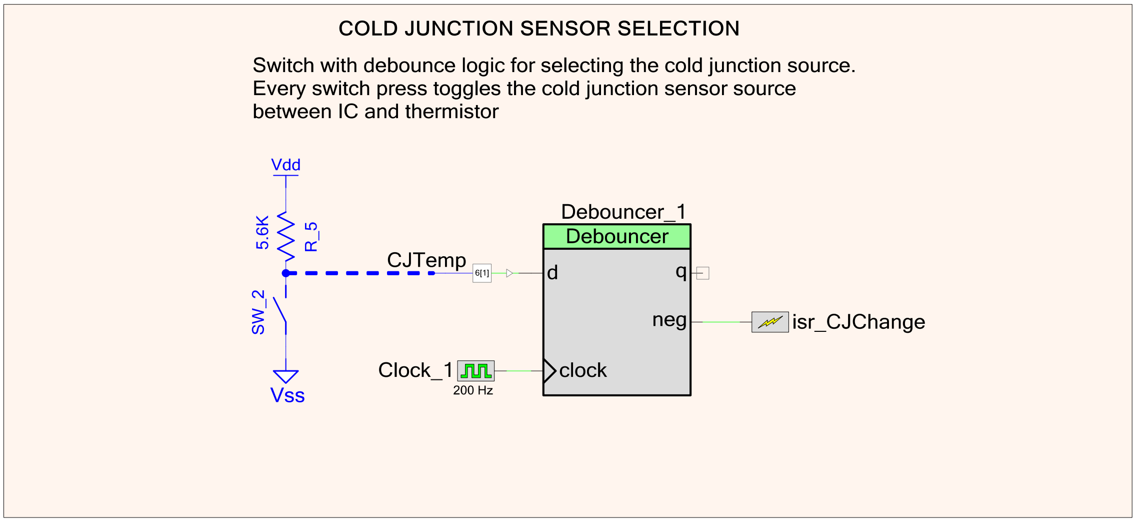
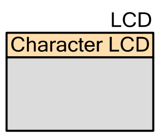


Figure 3(b). Thermocouple Measurement Circuit





ADC Configurations

One useful feature of the Delta Sigma ADC is that it can be reconfigured during runtime to different configurations. For the mid-end project, three configurations are used:

1. IC_Config – Used to measure temperature using an IC temperature sensor
2. TC_Config – Used to measure temperature using a thermocouple
3. Therm_Config – Used to measure temperature using a thermistor

For the low-end project, two configurations are used:

1. IC_Therm_Config – Used to measure temperature using an IC temperature sensor and a thermistor
2. TC_Config – Used to measure temperature using a thermocouple

Offset Cancellation

A K-type thermocouple has a typical sensitivity of approximately 40 µV/°C. A 40-µV offset results in a 1 °C temperature error. Therefore, eliminating the offset is important. Offset cancellation is done by correlated double sampling (CDS). In this technique, the offset is measured and subtracted after every voltage reading.

CDS not only removes the offset drift and reduces the low-frequency noise, but also reduces the ADC sample rate by 50 percent. Offset can be measured in a number of ways. See *AN66444 - PSoC® 3 and PSoC 5LP Correlated Double Sampling* for details on different ways to measure offset. Offset in this case is measured using ADC channel four (see Figure 3).

Broken Thermocouple

If the thermocouple wire breaks, the small negative voltage applied to the negative terminal of the thermocouple connector (see Figure 3 (a)) takes the ADC reading to a large negative value. Checking the ADC for a large negative value (< –10 mV) detects a broken thermocouple connection. This code example detects a broken thermocouple connection and displays a broken alert on the LCD if the thermocouple is broken.

Filtering the Thermocouple Output

The thermocouple output is filtered using a software infinite impulse response (IIR) filter to reduce the noise and improve the noise-free temperature resolution. See AN2099 for details on the filter.

For the mid-end project, the firmware IIR filter used has an attenuation factor of 32. From Table 1 in AN2099, the temperature settling time (0.1%) would be 219 cycles. For the project, the cycle time is about 50 ms, resulting in a temperature settling time of 10 s.

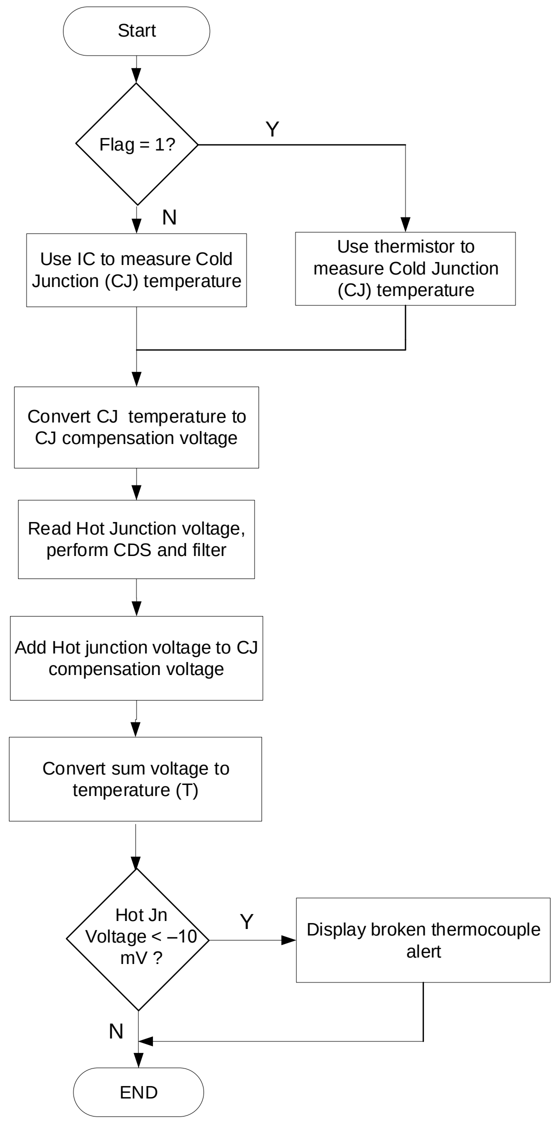
The IIR filter has a feed forward term that ensures that the temperature settles to within 2 °C in 50 ms. That is, if the source temperature changes from 50 °C to 150 °C, the temperature shown by PSoC will reach 148 °C in 50 ms and 149.9 °C in 10 s.

Firmware Flow

An interrupt is triggered when the switch is pressed (see Figure 3 (b)). A flag is toggled in the interrupt service routine (ISR), changing the cold junction temperature source between the IC and the thermistor.

APIs generated by the thermocouple Component are used for converting thermocouple voltage to temperature and vice versa.

Figure 4. Firmware Flow



Design Considerations

CY8CKIT-025 provides a connector for a K-type thermocouple. The cold junction sensor, DS600 IC, is placed very near to the cold junction terminals. Silkscreen marked 'U1' shows the position of the IC on the board. Ideally, an isothermal connection should be provided between the cold junction sensor and the cold junction terminals as described in AN75511. This requires a material with very good thermal conductivity providing a thermal connection between the thermal pad of the IC and the cold junction terminals. In cases where this is not possible, place the cold junction sensor very near to the cold junction terminals as it has been done in CY8CKIT-025. The temperature difference between the cold junction terminals and the IC is expected to be approximately 0.5 °C in this case.

Note that the thermistor, RTD, or diode on CY8CKIT-025 can also be used for cold junction temperature measurement. The included project gives the option of using a thermistor for cold junction compensation. Similarly, the RTD or diode can be used for cold junction temperature measurement. Cypress application notes *AN66477 - Temperature Measurement with a Thermistor*, *AN70698 - Temperature Measurement with an RTD*, and *AN60590 - Diode Temperature Measurement* explain thermistor, RTD, and diode temperature measurements with PSoC devices in detail.

However, these temperature sensors (RTD, thermistor, and diode) are farther from the cold junction than the IC and the temperature difference between the cold junction and these sensors will be higher if there is air flow. With no significant air flow, the temperature difference between the cold junction terminals and the other sensors is expected to be less than 1 °C.

Components

Table 2 lists the PSoC Creator Components used in this example, as well as the hardware resources used by each.

Table 2. List of PSoC Creator Components

Component	Hardware Resources
Delta Sigma ADC	1 Delta Sigma ADC
Opamp	1 Opamp
Thermocouple	Firmware
Thermistor	Firmware
AMux	Analog Routing
Debouncer	1 UDB
Character LCD	7 Pins

Parameter Settings

The following tables list the Component parameters that have been changed from the default configuration.

Table 3. Mid End ADC IC Temp Config

Parameter	Change
Conversion rate (SPS)	10000 → 2000
Buffer Mode	“Rail to Rail” → “Level Shift”

Table 4. Mid End ADC Thermocouple Config

Parameter	Change
Resolution	16 → 20
Conversion rate (SPS)	10000 → 60
Input Range	±1.024 V → ± 0.064 V
Buffer Mode	“Rail to Rail” → “Level Shift”

Table 5. Mid-End ADC Thermistor Config

Parameter	Change
Buffer Mode	"Rail to Rail" → "Level Shift"

Table 6. Low-End ADC IC and Thermistor Config

Parameter	Change
Resolution	16 → 12
Buffer Mode	"Rail to Rail" → "Level Shift"

Table 7. Low End ADC Thermocouple Config

Parameter	Change
Resolution	16 → 12
Input Range	±1.024V → ± 0.064V
Buffer Mode	"Rail to Rail" → "Level Shift"

Figure 5. Opamp Settings

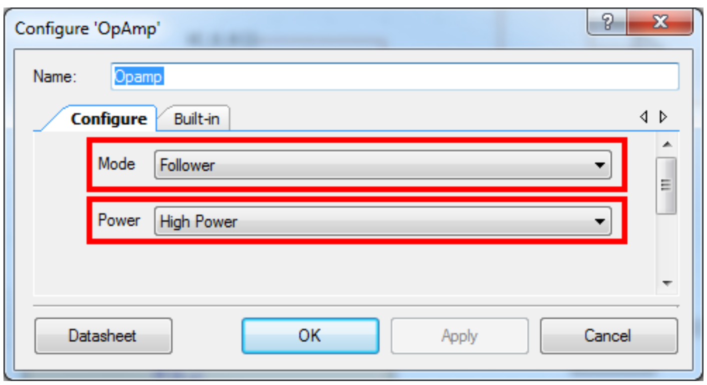
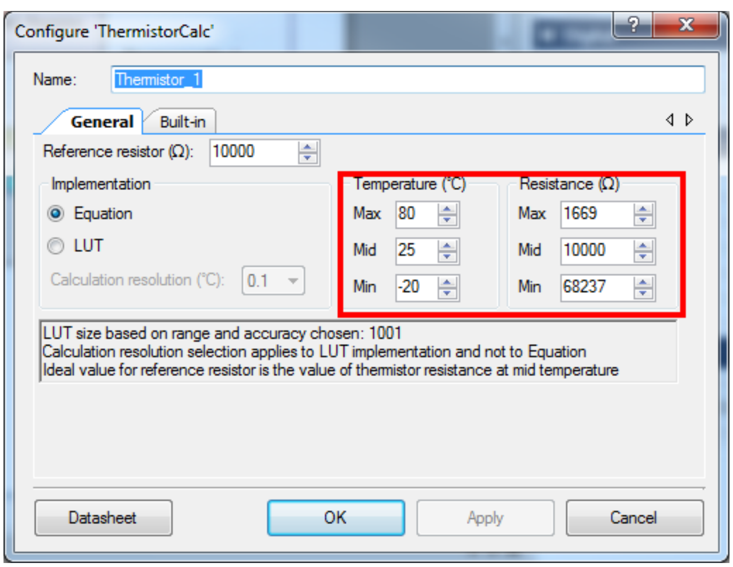


Figure 6. Thermistor Settings



Design-Wide Resources

Table 8. Pin locations for PSoC 3 and PSoC 5LP Devices

Pin Name	PSoC 3/ PSoC 5LP Device Pin Location
LCD	P2[6:0]
CJTemp	P6[1]
IC	P0[6]
TcHotJnNeg	P0[5]
TcHotJnPos	P0[4]
VSSA_REF	P0[3]
VThermPos	P0[0]
VThermNeg	P0[1]

Related Documents

Code Example		
CE219929	PSoC 3 and PSoC 5LP Thermocouple Calibration	Explains how to calibrate a thermocouple measurement system to achieve 0.1° C accuracy
Application Notes		
AN75511	Temperature Measurement with Thermocouples	Describes how PSoC 3 and PSoC 5LP devices can be used to measure a thermocouple.
AN66444	Correlated Double Sampling to Reduce Offset, Drift, and Low Frequency Noise	Describes how to implement correlated double sampling on a PSoC device.
AN2099	Single Pole Infinite Impulse Response (IIR) Filters	Describes how to implement a software IIR filter.
PSoC Creator Component Datasheets		
Thermocouple Component	Thermocouple Calculator	
Thermistor Component	Thermistor Calculator	
Delta Sigma ADC	Precision ADC component	
Device Documentation		
PSoC 3 Datasheets	PSoC 3 Technical Reference Manuals	
PSoC 5LP Datasheets	PSoC 5LP Technical Reference Manuals	
Development Kit (DVK) Documentation		
PSoC 3 and PSoC 5LP Kits		
CY8CKIT-025		

Document History

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Document Number: 002-19905

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**	5791140	TDU	07/10/2018	New spec

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