Summary

This application note describes the implementation of a simple temperature controller in a CoolRunner™-II CPLD device. This thermometer uses a minimum of design resources and on board components (resistors, capacitor, and NTC) to measure, observe, monitor or control temperatures.

CoolRunner-II devices, the latest CPLD family from Xilinx, offer low power and high performance and come in a variety of sizes. A thermometer or temperature controller can be implemented beside additional designs and provides a low cost method of measuring temperatures.

Introduction

Xilinx CoolRunner-II devices provide features, such as Schmidt Trigger inputs, which allow users to implement an easy and simple ADC. This can be used to monitor an analog input value (in this case the temperature) and compute the result in a digital manner for further arrangements. This application consists of four different blocks:

- Analog
- Analog to Digital Converter
- Digital
- Monitoring, computing, displaying, or controlling, depending on the application

The analog portion of the design consists of a sensor, which changes its resistance depending on the temperature. This characteristic changes in the analog to digital converter to a time based variable, which can be handled by a CPLD. How to implement the last part is up to the application, the elicit temperature can be used for a temperature controller, for an overload and overheat protector or it just can be used to display or observe temperatures. All these features are implemented in the same design. The only limitation is the size of the design.
Description of Parts

Analog Circuit

Temperature Range and Reliability

The limitation of the temperature range is primarily given by the sensor. Any sensor that changes its resistance depending on temperature can be used for this application. It is up to the user to choose range, accuracy and type of sensor. In this application an NTC is used, as it is a cost efficient solution, and the range is ideal for observing the ambient temperature.

Let’s look at the following example:

**General Purpose Thermistors (NTC).** For example, from RS Components.

- 50 Ohms at 25° C
- Resistance tolerance ±10% at 25° C
- Maximum ambient temperature up to 125° C

For exact details and characteristics see the data sheet: [http://rswww.com](http://rswww.com)

NTC

An NTC is used as sensor in this application. The analog circuit is based on the following term:

\[
\text{Tau (time constant)} = R \text{ (NTC sensor)} \times C \text{ (capacitor)}
\]

![Resistance by Temperature](image.png)

*Figure 2: Resistance by Temperature*
As shown in the NTC characteristics of Figure 2, there is a coherence between the temperature and the resistance. See the Monitoring / Computing / Displaying for information on how to adjust the NTC curve.

Figure 3: Analog Circuitry

The analog part (Figure 3) consists of a sensor and a capacitor. The waveforms on the right show the stimulus (Charge) given from the CPLD and the resulting response (Feedback) resulting from the analog part.

Analog to Digital Convertor

The easiest way to ascertain $\tau$ (tau) is to set the threshold (Figure 3). CoolRunner-II provides a feature (Schmitt Trigger) to elicit the threshold.

Digital Circuitry

The digital part consists of a FSM. Figure 4 shows the Waveforms of the required signals.

- The CPLD charges (signal Charge) the capacitor through the NTC and counts the clock cycles until the feedback (signal D Feedback) coming from the analog-to-digital converter tells the CPLD that the threshold for $\tau$ is reached.
- The number of counted clock cycles correlates to the temperature (depending on accuracy and temperature range, this can be seen as a linear coherence).
- When the threshold is reached the signal Charge changes to ‘0’ and the signal Discharge changes from ‘Z’ to ‘0’. So the current will be discharged through the NTC and the signal Discharge into the CPLD (to protect the CPLD IOB, a resistor on the Feedback signal will limit the current).

Figure 4: Required Signals
• The FSM will stay in this state for a certain time (for a low power application this time can increase; for a fast response application this value can decrease, but the minimum should not be less then 5 times $t$ to make sure the capacitor is completely discharged).

• At this point the FSM begins charging the capacitor with the signal Charge. The signal Discharge changes back to ‘Z’ at the same time.

**Monitoring / Computing / Displaying**

This section of the design can be customized for your application. The design can be used for overload protection, or just for observing and/or monitoring the temperature. It is also possible to control the temperature (see “Reliability”).

This example shows how to display the temperature on a 7-segment Liquid Crystal Display (LCD):

1. For the most accurate solution create a look-up table (LUT) that correlates clock cycles to temperature (Figure 2). For example:
   - If $t$ is between 5 and 7 clock cycles the temperature corresponds (for example) to 15°C or
   - If $t$ is between 7 and 9 clock cycles the temperature corresponds (for example) to 14°C…

2. Or, an arithmetic expression can be used to evaluate the temperature.

   **Note:** To display the temperature, a simple “BIN2BCD” decoder can be used in the design.

   **Note:** For an LCD display, a frequency is required to refresh the segments (typically 20 Hz - 50 Hz).

   **Note:** For an LED display, see the CoolRunner-II data sheet concerning information on maximum power consumption.

**Drive a LCD Display**

To drive an LCD, a clock at the common pin of the display is required. The following example shows how to enable the display:

![Figure 5: LCD Clocking](image)

**Calculation**

The following calculations are for example purposes. The values depend on the temperature range, the specific sensor, and the application.

- Choose a value for the NTC:

  $\text{NTC}_{\text{min}} = \frac{V_{\text{CC}}}{I_{\text{max}}}$

  where $I_{\text{max}}$ is from the data sheet ‘IOB’.

  Example: $\text{NTC}_{\text{min}} = 3.3 \text{ Volts}/200 \text{ mAmps.} = 15.5 \text{ Ohms}$ (Choose 50 Ohms at 25°C)

- Select a minimum value for the resistor that limits the discharge current at the Feedback and Tau signal:

  $\text{R}_{\text{discharge min}} = \frac{V_{\text{DD,33}}}{I_{\text{max}}}$

  where $I_{\text{max}}$ is from the data sheet ‘IOB’.

  Example: $\text{R}_{\text{discharge min}} = \text{approx. } 3V/200 \text{ mAmps.} = 15 \text{ Ohms}$ (Choose 100 Ohms)
• Define the range of $t$ which corresponds to the temperature range ($t_{\text{max}} - t_{\text{min}}$):
  \[
t_{\text{diff}} = (\text{NTC\_range\_min} \times \text{Capacitance}) - (\text{NTC\_range\_max} \times \text{Capacitance})
  \]
  Example: $t_{\text{diff}} = (66 \text{ Ohms} \times 470 \text{ uF}) - (44 \text{ Ohms} \times 470 \text{ uF}) = 100 \text{ ms}$.

• Define a sample frequency depending on the range of $t$ and accuracy ($x$ defines resolution):
  \[
  F_{\text{clock}} = \frac{1}{t_{\text{diff}}} \times x
  \]
  Example: $F_{\text{clock}} = \frac{1}{100 \text{ ms}} \times 100 = 1 \text{ kHz}$ (resolution of 100 in given range).

• Define the Time to discharge the capacitor ($5$ is the recommended minimum value):
  \[
  \text{Wait\_min} = 5 \times (\text{NTC\_range\_min} \times \text{Capacitance})
  \]
  Example: $\text{Wait\_min} = 5 \times (66 \text{ Ohms} \times 470 \text{ uF}) = 155 \text{ ms}$.

• Define $t_{25}$:
  \[
  t_{25} = \text{NTC\_25} \times \text{Capacitance}
  \]
  Example: $\tau_{25} = 50 \text{ Ohms} \times 470 \text{ uF} = 23.5 \text{ ms}$

**Why Low Power?**

• Current consumption at $25^\circ \text{C}$:
  \[
  I_{25} = \left(\frac{\text{V\_DD}}{\text{NTC\_25}}\right) \times \left(\frac{t_{25}}{\text{Wait\_min}}\right)
  \]
  Example: $I_{25} = \left(\frac{3.3 \text{ Volts}}{50 \text{ Ohms}}\right) \times \left(\frac{23.5 \text{ ms}}{155 \text{ ms}}\right) = 10 \text{ uA}$ maximum.

  *Note:* Double the time Wait will halve the current consumption!

  *Note:* Additionally, there is some current used by the voltage divider and the CoolRunner-II itself.

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**Reliability**

The first step to make the system reliable is to make sure the chosen sensor can handle the required temperature range. Further deterioration can be a problem. The influence of ambient temperature (junction temperature of the CoolRunner-II) can carefully be ignored.

**Test Design**

*Note:* This design is a functional example. It can be easily optimized by simple changes, such as using vectors instead of integers, or using the “clock divider” feature. This example is written for a better understanding and therefore not "size optimized."
Behavior Simulation

The following simulation shows the detailed function of this application.

![Behavior Simulation Diagram]

**Figure 6: Behavior Simulation**

VHDL Code and UCF File

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How to Connect Sensor and LCD Display to CoolRunner-II Design Kit

Figure 7 shows how to connect the Sensor and LCD Display according the .ucf File.

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Revision History

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<th>Date</th>
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<tr>
<td>11/29/04</td>
<td>1.0</td>
<td>Initial Xilinx release.</td>
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