1 Introduction

This application note provides an overview of how to use RT600 SDK software with EVK hardware to validate the RT600 built-in temperature sensor using the ADC controller. The SDK ipadc sample application is used as an example setup. Channel 7 is used to provide a sample voltage signal input to the ADC. While running the project, typing any key in the debug console triggers the conversion. ADC watermark interrupt is asserted when the number of data words stored in the ADC results FIFO is greater than the watermark value. In ADC ISR, the watermark flag is cleared when the conversion result value is read. Also, the result is printed when the execution returns to the main function.

2 Temperature sensor overview

The temperature sensor transducer uses an intrinsic pn-junction diode reference and outputs a Complement To Absolute Temperature (CTAT) voltage. The temperature sensor is linear with a slight curvature. The output voltage is measured over different ranges of temperatures and fit with linear-least-square lines. After power-up, the temperature sensor output must be allowed to settle to its stable value before it is used as an accurate ADC input.

2.1 Characteristics

![Figure 1. Temperature sensor static and dynamic characteristics](image)

**Table 1.** Temperature sensor static and dynamic characteristics

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>DT&lt;sub&gt;on&lt;/sub&gt;</td>
<td>sensor temperature accuracy</td>
<td>T&lt;sub&gt;amb&lt;/sub&gt; = -20°C to +70°C</td>
<td>11</td>
<td>-</td>
<td>2.77</td>
<td>°C</td>
</tr>
<tr>
<td>E&lt;sub&gt;L&lt;/sub&gt;</td>
<td>linearity error</td>
<td>T&lt;sub&gt;amb&lt;/sub&gt; = -20°C to +70°C</td>
<td>11</td>
<td>-</td>
<td>2.70</td>
<td>°C</td>
</tr>
</tbody>
</table>

2.2 Connection between ADC channel input and analog output

![Diagram showing connection between ADC channel input and analog output]

Figure 2. ADC channel input and analog output

2.3 Registers needed for ADC temperature sensor

2.3.1 Temperature sensor control (SYSCTL0_TEMPSENSORCTL)

This register enables the on-chip temperature sensor to be measured by the ADC.

<table>
<thead>
<tr>
<th>Bit</th>
<th>Symbol</th>
<th>Value</th>
<th>Description</th>
<th>Reset value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>TSSRC</td>
<td>0</td>
<td>Temperature Sensor Source:</td>
<td>0x0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>Reserved.</td>
<td></td>
</tr>
<tr>
<td>31:1</td>
<td></td>
<td></td>
<td>Reserved</td>
<td></td>
</tr>
</tbody>
</table>

**NOTE**
This register is not available as of now in RT600 SDK and will be available from SDK 2.9.0 onwards. By default, the on-chip temperature sensor is selected, therefore no changes are required for SDK 2.7.0 or lower versions.

2.3.2 Run configuration register 1 clear (SYSCTL0_PDRUNCFG1_CLR)

Writing a 1 to a bit position in this register clears the corresponding position in PDRUNCFG1. This is a write-only register.
3 Demo application

3.1 Environment

3.1.1 Hardware environment

- Board
  - MIMXRT685EVK
- Debugger
  - Integrated CMSIS-DAP debugger on the board
- Miscellaneous
  - 1 Micro USB cable
  - PC
- Board Setup
  - Set VREF_L to GND, VREF_H to 1.8 V by connecting jumpers JP9, JP10, and J25 as shown in the following figure.
3.1.2 Software environment

- Tool chain
  - IAR embedded workbench 8.50.1 or MCUXpresso IDE v11.1.1 or Keil 5.29
- Software package
  - SDK_2.7.0_EVK-MIMXRT685

3.2 Steps and result

1. Follow the Getting Started with MCUXpresso SDK for MIMXRT600 (available inside SDK\docs) to go through the steps for opening lpadc_interrupt project (SDK\boards\evkmimxrt685\driver_examples\lpadc\interrupt).

2. Open the file lpadc_interrupt.c (lpadc_interrupt\source) and modify as follows:

   The ADC temperature sensor is internally connected to channel 7 as shown in Figure 2. Set the channel to 7 by modifying the macro DEMO_LPADC_USER_CHANNEL.

   ```
   #define DEMO_LPADC_USER_CHANNEL 7U /* temperature sensor */
   ```

3. Open clock_config.c (lpadc_interrupt\source) and in the function BOARD_BootClockRun():

   Program other system registers, group 0 (SYSTCTL0) to enable the ADC temperature sensor on the ADC analog switch. Then enable it by clearing SYSCTL0_PDRUNCFG0.

   ```
   //SYSTCTL0->TEMPSENSORCTL = 0; /* enable the ADC built-in temperature sensor on ADC analog switch */
   ```
The TEMPSENSORCTL register is not available as of now in RT600 SDK and will be available from SDK 2.9.0 onwards. By default, the on-chip temperature sensor is selected and no changes required for SDK 2.7.0 or lower versions. Therefore, the above code is commented out as of now.

```c
SYSCTL0->PDRUNCFG0_CLR = SYSCTL0_PDRUNCFG0_ADCTEMPSNS_PD_MASK; //enable ADCTEMPSNS_PD
```

4. Open fsl_lpadc.c (lpadc_interrupt\drivers), the STS bits of CMDH1 register are set to 7. So, the sample time is 131 (3 + 2STS) ADCK cycles since a sample time of over 35 is required. A long sample time allows higher impedance inputs to be accurately sampled. This is done by modifying the `sampleTimeMode` which is member of conversion commands configuration structure inside `LPADC_GetDefaultConvCommandConfig` function.

```c
config->sampleTimeMode = kLPADC_SampleTimeADCK131;
```

5. Follow the Getting Started with MCUXpresso SDK for MIMXRT600 (available inside SDK➜docs) to go through the steps for building and running lpadc_interrupt demo.

6. When running the demo, type any key in the debug console which triggers the conversion.

7. Results:

   During the test, the heat gun is used to heat the RT600 chip. The following interrupt count intervals show when the heater is OFF or ON:
   
   - ADC interrupt count 1 – 34 (heater is OFF)
   - ADC interrupt count 35 – 80 (heater is ON)
   - ADC interrupt count 81 – 100 (heater is OFF)

   Actual LPADC interrupt example output:

   **LPADC interrupt example**
   
   ADC Full Range: 4096
   
   Full channel scale (Factor of 1).
   
   Press any key to get user channels ADC value.

   ADC value: 1757
   ADC interrupt count: 1
   ADC value: 1756
   ADC interrupt count: 2
   ADC value: 1754
   ADC interrupt count: 3
   ADC value: 1756
   ADC interrupt count: 4
   ADC value: 1755
   ADC interrupt count: 5
   ADC value: 1757
   ADC interrupt count: 6
   ADC value: 1756
ADC interrupt count: 7
ADC value: 1759
ADC interrupt count: 8
ADC value: 1757
ADC interrupt count: 9
ADC value: 1758
ADC interrupt count: 10
ADC value: 1754
ADC interrupt count: 11
ADC value: 1757
ADC interrupt count: 12
ADC value: 1756
ADC interrupt count: 13
ADC value: 1755
ADC interrupt count: 14
ADC value: 1756
ADC interrupt count: 15
ADC value: 1758
ADC interrupt count: 16
ADC value: 1755
ADC interrupt count: 17
ADC value: 1757
ADC interrupt count: 18
ADC value: 1758
ADC interrupt count: 19
ADC value: 1755
ADC interrupt count: 20
ADC value: 1758
ADC interrupt count: 21
ADC value: 1754
ADC interrupt count: 22
ADC value: 1756
ADC interrupt count: 23
ADC value: 1755
ADC interrupt count: 24
ADC value: 1758
ADC interrupt count: 25
ADC value: 1758
<table>
<thead>
<tr>
<th>ADC interrupt count</th>
<th>ADC value</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>1754</td>
</tr>
<tr>
<td>27</td>
<td>1754</td>
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<tr>
<td>28</td>
<td>1759</td>
</tr>
<tr>
<td>29</td>
<td>1755</td>
</tr>
<tr>
<td>30</td>
<td>1756</td>
</tr>
<tr>
<td>31</td>
<td>1755</td>
</tr>
<tr>
<td>32</td>
<td>1755</td>
</tr>
<tr>
<td>33</td>
<td>1756</td>
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<tr>
<td>34</td>
<td>1737</td>
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<td>1736</td>
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<td>38</td>
<td>1731</td>
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<td>39</td>
<td>1731</td>
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<tr>
<td>40</td>
<td>1728</td>
</tr>
<tr>
<td>41</td>
<td>1726</td>
</tr>
<tr>
<td>42</td>
<td>1722</td>
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<tr>
<td>43</td>
<td>1725</td>
</tr>
<tr>
<td>44</td>
<td>1720</td>
</tr>
</tbody>
</table>
ADC interrupt count: 45
ADC value: 1722
ADC interrupt count: 46
ADC value: 1722
ADC interrupt count: 47
ADC value: 1721
ADC interrupt count: 48
ADC value: 1716
ADC interrupt count: 49
ADC value: 1717
ADC interrupt count: 50
ADC value: 1718
ADC interrupt count: 51
ADC value: 1721
ADC interrupt count: 52
ADC value: 1717
ADC interrupt count: 53
ADC value: 1719
ADC interrupt count: 54
ADC value: 1716
ADC interrupt count: 55
ADC value: 1717
ADC interrupt count: 56
ADC value: 1717
ADC interrupt count: 57
ADC value: 1716
ADC interrupt count: 58
ADC value: 1719
ADC interrupt count: 59
ADC value: 1717
ADC interrupt count: 60
ADC value: 1716
ADC interrupt count: 61
ADC value: 1712
ADC interrupt count: 62
ADC value: 1715
ADC interrupt count: 63
ADC value: 1713
ADC interrupt count: 64
ADC value: 1713
ADC interrupt count: 65
ADC value: 1711
ADC interrupt count: 66
ADC value: 1716
ADC interrupt count: 67
ADC value: 1714
ADC interrupt count: 68
ADC value: 1710
ADC interrupt count: 69
ADC value: 1714
ADC interrupt count: 70
ADC value: 1712
ADC interrupt count: 71
ADC value: 1711
ADC interrupt count: 72
ADC value: 1713
ADC interrupt count: 73
ADC value: 1711
ADC interrupt count: 74
ADC value: 1710
ADC interrupt count: 75
ADC value: 1712
ADC interrupt count: 76
ADC value: 1710
ADC interrupt count: 77
ADC value: 1712
ADC interrupt count: 78
ADC value: 1712
ADC interrupt count: 79
ADC value: 1711
ADC interrupt count: 80
ADC value: 1749
ADC interrupt count: 81
ADC value: 1749
ADC interrupt count: 82
ADC value: 1744
The ADC output decreases with rise in temperature, as it measures the VBE of the diode plotted over PVTs versus temperature, see the following figure.
4 Conclusion

The example shows how the SDK software with EVK hardware can be used to validate RT600 built-in temperature sensor using the ADC controller. It also shows, how the built-in temperature sensor can be used to indicate temperature value based on ADC output value.

5 References

1. RT600 User Manual
2. RT600 Data Sheet
3. MCUpresso SDK Release Notes for EVK-MIMXRT685 (available inside SDK)
4. Getting Started with MCUpresso SDK for EVK-MIMXRT685 (available inside SDK)

6 Revision history

Table 1. Revision history

<table>
<thead>
<tr>
<th>Revision number</th>
<th>Date</th>
<th>Substantive changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>08/2020</td>
<td>Initial release</td>
</tr>
</tbody>
</table>
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