SoC Temperature Sensor

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Keywords

- *Temperature Sensor*
- *ADC*
- *CC1110*
- *CC1111*
- *CC2430*
- *CC2431*
- *CC2510*
- *CC2511*

1 Introduction

The above mentioned SoCs contain a temperature sensor which is connected to the ADC. By setting the ADC to sample the voltage delivered from the temperature sensor, the temperature can easily be calculated.

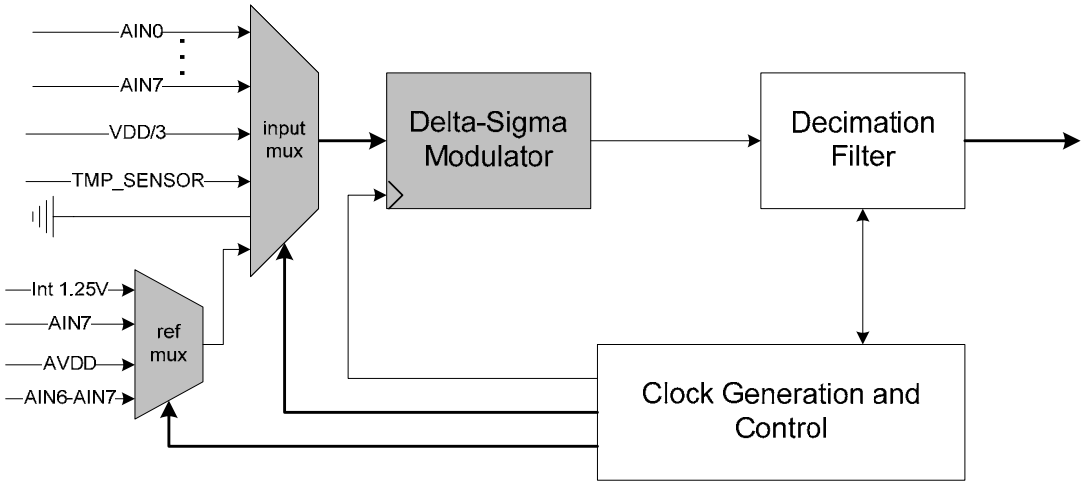

Figure 1. ADC Block Diagram

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2 Abbreviations

ADC	Analog to Digital Converter
SoC	System on Chip

3 Analog Temperature Sensor Parameters

The analog temperature sensor parameters will be different for the different SoCs as seen in Table 1. Please refer to the datasheets ([1], [2], and [3]) for more details on these parameters.

	Typical Output Voltage [mV] @ 0°C	Typical Temperature Coefficient [mV/°C]	Datasheet Revisions (from where the numbers are taken)
CC1110/CC1111	755	2.54	SWRS033D [1]
CC2510/CC2511	750	2.43	SWRS055D [2]
CC2430/CC2431	743	2.45	SWRS036F [3]

Table 1. Analog Temperature Sensor Parameters

This design note use numbers found in the CC2510/CC2511 datasheet [2] for all the calculations.

4 Temperature Calculation

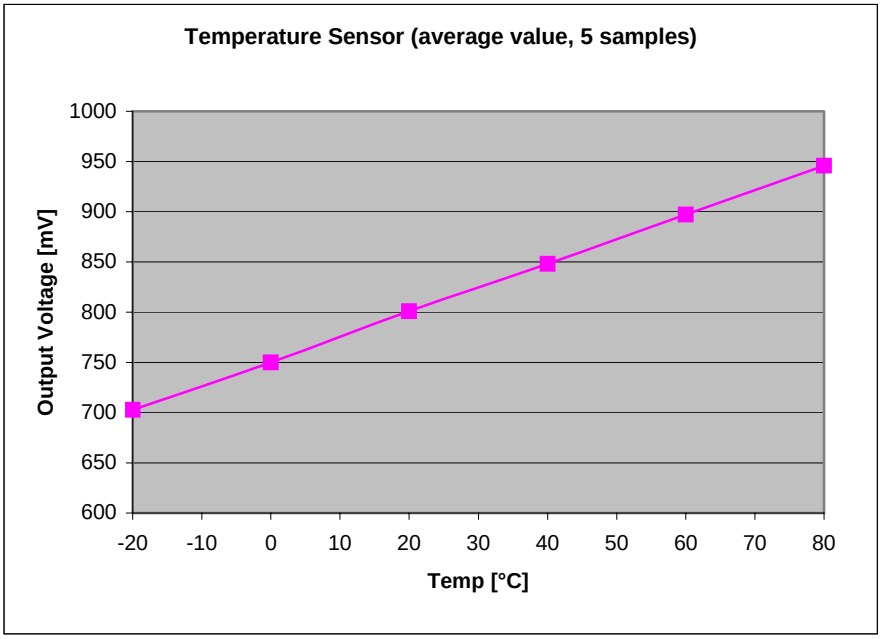

Figure 2. Output Voltage vs. Temperature

From Figure 2 and Table 1 we see that the output voltage from the temperature sensor and the temperature is related as shown in Equation 1:

$$Output\ Voltage\left[mV\right] = Temp.Coeff.\left[mV/°C\right] \cdot Temp\left[°C\right] + Output\ Voltage\ at\ 0\ °C\left[mV\right]$$

Equation 1.

The output voltage is 750 mV @ 0°C for CC2510 and CC2511 and the temperature coefficient is 2.43 mV/°C (see Table 1).

This means that the temperature, T, is given as shown in Equation 2:

$$T = \frac{(Output\ Voltage\,[mV] - 750\,[mV])}{2.43\,[mV/°C]}$$

Equation 2.

5 1-Point Calibration

To make sure that the error in calculated temperature is within ±2°C it is necessary to perform a 1-point calibration, as the output voltage from the ADC might have an offset compared to what is shown in Figure 2. The easiest is to perform a 1-point calibration at room temperature by simply measuring the output voltage from the temperature sensor at 25°C.

5.1 Measuring the Output Voltage

To measure the output voltage from the temperature sensor, the temperature sensor must be selected as input to the ADC. This is done by setting `ADCCON2.SCH[3:0]` = 1110. Assume that the internal 1.25 V reference is used (`ADCCON2.SREF[1:0]` = 00) and that the ADC is configured for 12 bits resolution (`ADCCON2.SDIV[1:0]` = 11). With 12 bits resolution, the maximum ADC value is 2047 (2^{11}) since the ADC value is given in 2's complement form.

The output voltage from the temperature sensor is given by Equation 3 (given the assumptions above):

$$Output\ Voltage\,[mV] = ADC\ Value \cdot \frac{1250\,[mV]}{2047}$$

Equation 3.

The ADC value always resides in MSB section of `ADCH:ADCL`.

When measuring the output voltage at room temperature for Chip x, there might be offset compared to the output voltage calculated using Equation 1.

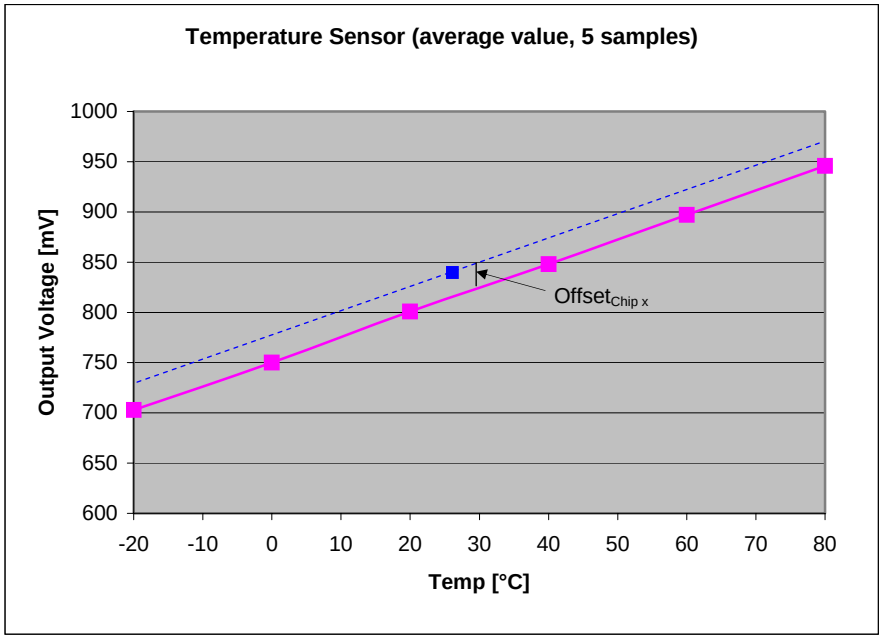

Figure 3. Voltage Measured @ Room Temperature

This offset can be calculated as shown in Equation 4.

$$Offset = Measured\ Voltage\ at\ 25°C\ [mV] - \left(Temp.Coeff.\left[mV/°C\right]\cdot Temp\ [°C] + Output\ Voltage\ at\ 0°C\ [mV]\right)$$

Equation 4.

Assume that for one specific chip, Chip x, the output voltage is measured to be 840 mV @ 25°C (see Figure 3).

$$Offset_{Chip\ x} = 840\ [mV] - \left(2.43\ [mV/°C]\cdot 25\ [°C] + 750\ [mV]\right) =$$
$$840\ \left[mV\right] - 810.75\ \left[mV\right] = \underline{\underline{29.75\ [mV]}}$$

The temperature, measured with Chip x, is given by Equation 5.

$$T_{Chip\,x} = \frac{Output\,Voltage\,[mV] - (750\,[mV] + Offset_{Chip\,x}\,[mV])}{2.43\,[mV/°C]} =$$
$$\frac{Output\,Voltage\,[mV] - (750\,[mV] + 29.75\,[mV])}{2.43\,[mV/°C]} =$$

$$T_{Chip\,x} = \frac{Output\,Voltage\,[mV] - 779.75\,[mV]}{2.43\,[mV/°C]} =$$

Equation 5.

6 Code Example

```
/* Reference voltage:   Internal 1.25 V,
   Resolution: 12 bits,
   ADC input: Temperature sensor

   In this example it is assumed that a 1-point calibration has been performed in
   production test and that the offset was found to be 29.75 mV */


#define SAMPLE_TEMP_SENSOR(v)                \
    do {                                     \
        ADCCON2 = 0x3E;                      \
        ADCCON1 = 0x73;                      \
        while(!(ADCCON1 & 0x80));            \
        v =  ADCL;                           \
        v |= (((unsigned int)ADCH) << 8); \
    } while(0)

#define CONST 0.61065 // (1250 / 2047)
#define OFFSET_DATASHEET 750
#define OFFSET_MEASURED_AT_25_DEGREES_CELCIUS 29.75
#define OFFSET (OFFSET_DATASHEET + OFFSET_MEASURED_AT_25_DEGREES_CELCIUS) // 779.75
#define TEMP_COEFF 2.43

float getTemp(void){
    unsigned int adcValue;
    float outputVoltage;

    SAMPLE_TEMP_SENSOR(adcValue);

    // Note that the conversion result always resides in MSB section of ADCH:ADCL
    adcValue >>= 4; // Shift 4 due to 12 bits resolution

    outputVoltage = adcValue * CONST;

    return ((outputVoltage - OFFSET) / TEMP_COEFF);
}
```

7 References

[1] CC1110Fx/CC1111Fx Low-Power Sub-1 GHz RF System-on-Chip (SoC) with MCU, Memory, Transceiver, and USB Controller (cc1110f32.pdf)

[2] CC2510Fx/CC2511Fx Low-Power SoC (System-on-Chip) with MCU, Memory, 2.4 GHz RF Transceiver, and USB Controller (cc2510f32.pdf)

[3] A True System-on-Chip solution for 2.4 GHz IEEE 802.15.4 / ZigBee® (cc2430.pdf)

8 General Information

8.1 Document History

Revision	Date	Description/Changes
SWRA101A	2007.10.05	The complete design note has been re-written to better explain how to use analog temperature sensor parameters from the datasheet when using the ADC to determine the temperature. Changes to Figure 1.
SWRA101	2006.07.06	Initial release.

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