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AX8052F1xx Temperature Sensor Calibration

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APPLICATION NOTE

INTRODUCTION

The AX8052F1xx family of RF microcontroller and RF system−on−chip products include a built−in temperature sensor. Each of the corresponding datasheets specify that the measurement error is less than ±2°C after a factory calibration is applied. The purpose of this application note is to describe the procedure that customers must follow in order to achieve this level of temperature measurement accuracy.

Temperature Sensor Overview

The AX8052F1xx implements the built−in temperature sensor using two bipolar PNP transistors. The base−emitter voltage ΔV_{BE} is proportional to temperature, and ranges between about 55 to 100 mV for the operating temperatures of the device. The following function maps this voltage range to the signed 10−bit output of the ADC:

$$ADCVAL_{raw}[9:0] = \left[\frac{\alpha \times \Delta V_{BE} + \beta \times p \times VREF_T}{VREF_{ADC}}\right] \times 2^9$$

The coefficients and nominal values are listed in Table 1:

Table 1. ADC TEMPERATURE CONVERSION COEFFICIENTS AND NOMINAL VALUES

Coefficient	Nominal Value	Description
ΔV_{BE}	55 to 100 mV	Voltage output of the temperature sensor
α	48	Gain factor
β	−4	Gain factor
p	0.92	Resistor divider factor
$VREF_T$	1.0V	Temperature sensor reference voltage
$VREF_{ADC}$	1.0V	ADC reference voltage

While the ADC output is 10 bits, the value returned to the ADCCHxVAL register is a signed 16−bit Q8.8 representation of the temperature in degrees Celsius. In this format, the upper and lower 8 bytes represent the integer and fractional parts of the temperature, respectively. A decimal representation of the temperature is obtained by treating the 16−bit value as a signed integer, and dividing by 256.

The 10−bit ADC output is mapped into the 16−bit ADCCHxVAL register with the following function:

$$ADCCHxVAL[15:0] = 2 \times ADCCALTEMPGAIN \times \frac{ADCVAL_{raw}}{2^9} + ADCCALTEMPOFFS$$

Both ADCCALTEMPGAIN and ADCCALTEMPOFFS are trim values that are calculated during calibration and will be discussed in the following section.

ON Semiconductor Calibration Procedure

The factory calibration performed by ON Semicondcutor on AX8052F1xx parts includes the computation of ADCCALTEMPGAIN and ADCCALTEMPOFFS. These values are stored in flash as part of the calibration sector (address 0xFC00−0xFFFF), and are loaded into control register of the ADC as part of the flash_apply_calibration() function of the libMF library during runtime. This library is included and documented in the the AX−IDE software package that can be found at www.onsemi.com.

ADCCALTEMPGAIN has a nominal value of $2^7 \times 82$, and the calibrated value is dependent on the factory−measured reference voltage VREF of the ADC.

$$ADCCALTEMPGAIN = 2^7 \times 82 \times \frac{VREF_{meas}}{1.0\ V}$$

Because this voltage is accurately measured, it is assumed that ADCCALTEMPGAIN does not need further calibration by the customer.

ADCCALTEMPOFFS has a nominal value of $2^{8\times}$ 25, and the calibrated value is dependent on the error between the actual environmental temperature and the temperature measured by the AX8052F1xx temperature sensor.

$$ADCCALTEMPOFFS = 2^8 \times (25 + T_{env} - T_{8052})$$

While each part is kept at a uniform temperature immediately prior to testing, the test script is run in an uncontrolled temperature environment. Furthermore, the above equation uses an assumed environmental temperature value, and any difference between the assumed and the actual temperature values will introduce an error in the calibrated ADCCALTEMPOFFS value.

Figure 1 includes a plot of AX8052 measured temperature vs. actual temperature. In this test, an AX8052F143−3 development kit was placed under test with a Thermostream automated tester. The temperature was ramped and at each temperature step, the ADC temperature was recorded. It can be seen that the AX8052 temperature sensor reported values with a positive offset from the actual temperature.

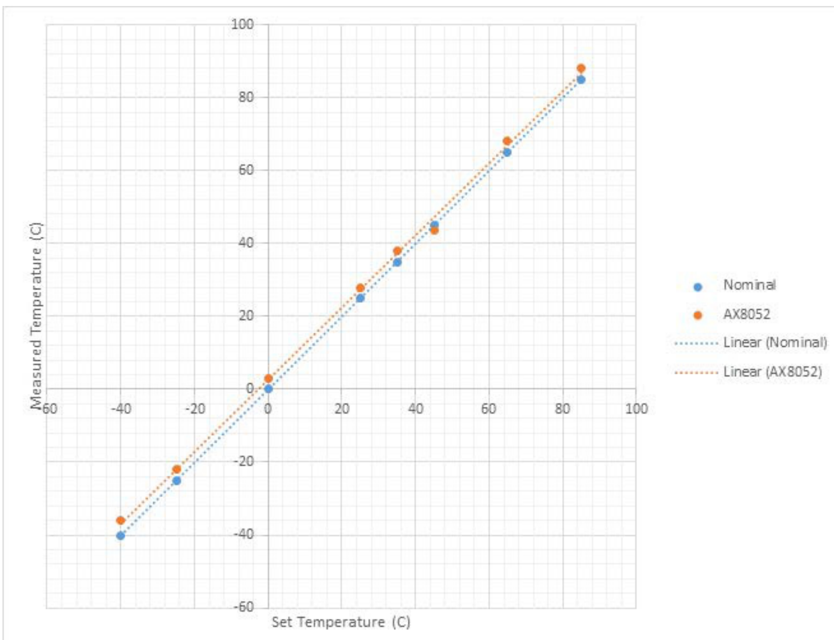

Figure 1. AX8052 Measured Temperature Vs. Actual Temperature

To compensate for this offset, additional calibration of the AX8052F1xx temperature sensor should be performed. The following sections will provide high−level descriptions of two methods to accomplish this. For additional guidance, please contact the ON Semiconductor support team via www.onsemi.com.

TEMPERATURE CONTROLLED CALIBRATION PROCEDURE

The first, and most accurate, method to correct the temperature sensor offset is to perform a temperature−controlled calibration for ADCCALTEMPOFFS during the assembly and test of the system−level product. The steps required for the calibration are listed below:

1. Insert a calibrated temperature sensor into the production test flow such that it measures the expected temperature of the device under test
2. For each device under test:
   a. Query temperature from both calibrated temperature sensor and the AX8052F1xx device under test
   b. Calculate a new value for ADCCALTEMPOFFS = $2^8 \times (25 + T_{env} - T_{8052})$, where T_{env} and T_{8052} are the respective temperatures obtained from the sensor and the AX8052F1xx device, in degrees Celsius
   c. Store the new value in the calibration sector, outside of the existing calibration data. (0xFC60−0xFFFF should be available) This can be performed by using the FLASH functions of the libMF library
3. During runtime, after flash_apply_calibration() and prior to reading a value from the AX8052F1xx temperature sensor,
   a. Read the updated value from the calibration sector and write it to the ADCCALTEMPOFFS1 and ADCCALTEMPOFFS0 ADC control registers, located at addresses 0x703B and 0x703A, respectively
   b. Perform the temperature conversion and record the correct converted temperature. It is recommended to perform multiple conversions and average the results to further improve the accuracy of the measurement

STATISTICAL DATA−BASED ERROR COMPENSATION

An alternative approach is to perform a statistical data−based error correction. In this method, rather than measuring the temperature offset of each device, a periodic characterization is performed over a number of devices. This average offset is then maintained as a constant in the application firmware and used to correct the ADC temperature values. This method does not guarantee that every part will be corrected to within the specification, but it improves the average yield while not requiring additional test time for each unit.

This method relies on a key observation made by ON Semiconductor – that the temperature error across devices of different lots, but of the same package, fall into a very tight distribution. A test of 200 AX−SIP−SFEU modules from different lots demonstrates this. Figure 2 shows the distribution of reported AX8052 temperature sensor values that were obtained via the test handler. It can be seen that while the average offset is about +6°C from the correct 25°C temperature, all reported temperatures are within ±2°C from the collective mean. By simply subtracting 6C from each of the reported ADC temperatures, it could be reasonably guaranteed that each part would have a corrected temperature within ±2°C of the actual temperature.

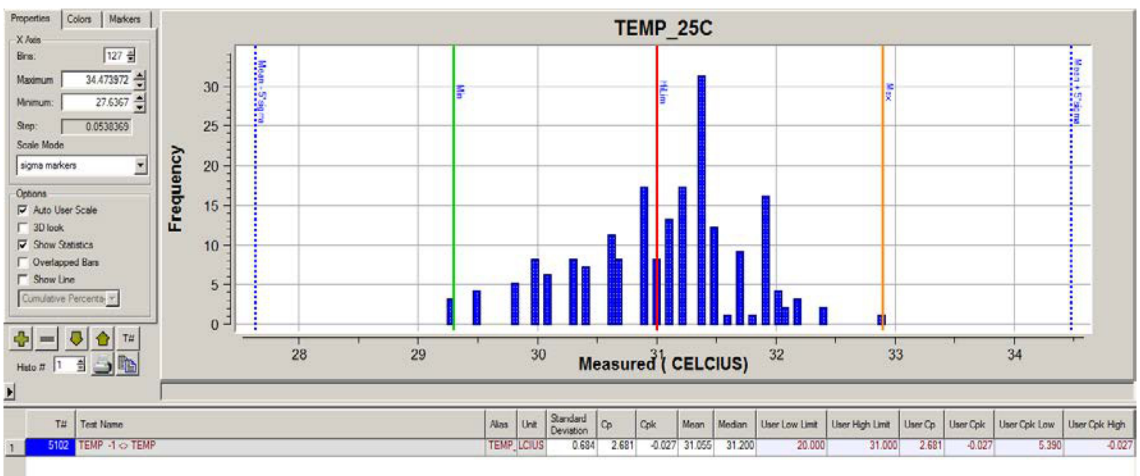

Figure 2. Test Handler Distribution of AX−SIP−SFEU ADC Temperature Measurements Temperature Measurements

It was also observed that the average absolute offset over temperature varied slightly depending on the test tool used (test handler vs. Thermostream) and the device package (SoC vs. SiP). For this reason, ON Semiconductor cannot provide a universal error characterization for all devices.

To implement the method described above, the following steps should be followed:

1. For a statistically significant number of products that utilize the AX8052F1xx temperature sensor, use a calibrated temperature sensor to obtain the average offset of the selected devices
   a. If possible, obtain this average at several different temperature points
2. Verify that the error distribution is tight and uniform over temperature
3. Modify the device firmware to subtract the average offset from each ADC temperature measurement

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