Oscillator Compensation Guide

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ABSTRACT

The Piccolo series of TMS320C28x™ microcontrollers can be run from either an external clock source or from one of two internal oscillators. Running from internal redundant clock sources is beneficial to system cost and complexity. However, care must be taken to ensure that the uncertainty in oscillator frequency is tolerable for the end system design.

This application report describes a factory supplied method for compensating the Piccolo internal oscillators for frequency drift caused by temperature. This is achieved by sampling the temperature sensor and then using factory supplied data in the one-time programmable (OTP) memory to determine appropriate oscillator trim vales for the current temperature.

Software examples implementing the calibration techniques discussed in this application report can be downloaded from the following URLs: http://www-s.ti.com/sc/techlit/sprc832.zip and http://www-s.ti.com/sc/techlit/sprc892.zip.

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1 Overview

To compensate the internal oscillator, the factory takes measurements of the internal oscillator and temperature sensor. It then calculates a reference point for temperature sensor and oscillator trim and calculates an oscillator trim slope. The trim slope can be used to adjust the oscillator fine trim as the temperature sensor reading moves away from that of the reference point.

The reference point for the internal oscillator consists of two pieces of data. The first is the temperature sensor reading at that point. The second is the oscillator trim values to get 10.0 MHz at that temperature. This trim itself is composed of two parts: the fine trim and the coarse trim. Only the fine trim will be adjusted by the compensation procedure. The coarse trim remains the same no matter what temperature the device is at.

The oscillator compensation slope contains the information needed to adjust the oscillator fine trim from the reference fine trim as the temperature moves away from the reference temperature. This slope contains the units of oscillator fine trim steps/analog-to-digital converter (ADC) codes (temperature sensor output).

If X is considered to be the temperature sensor reading and Y is considered to be the oscillator fine trim, then the basic oscillator compensation equation is:

$$Y_1 = m(X_1 - X_0) + Y_0$$

Where:

Y_1 is the oscillator fine trim at the current temperature.

Y_0 is the oscillator fine trim at the reference temperature.

X_1 is the temperature sensor reading at the current temperature.

X_0 is the temperature sensor reading at the reference temperature.

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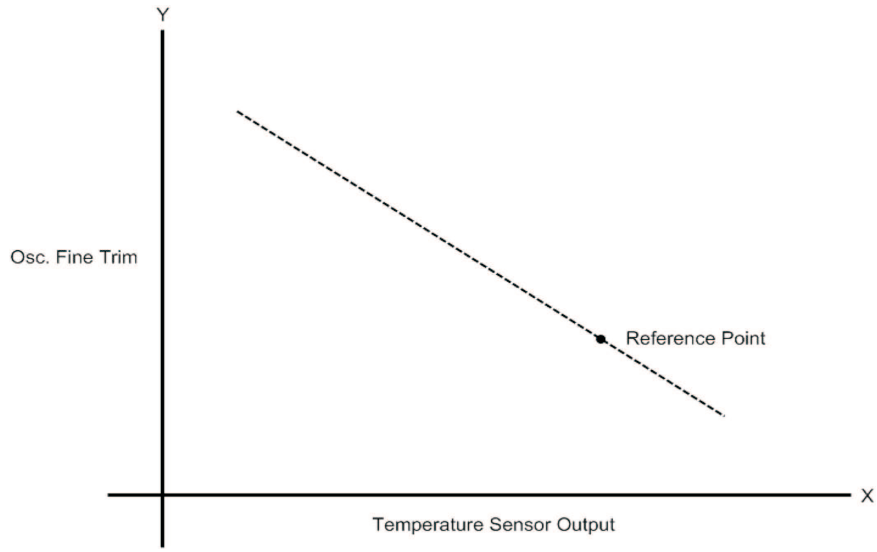
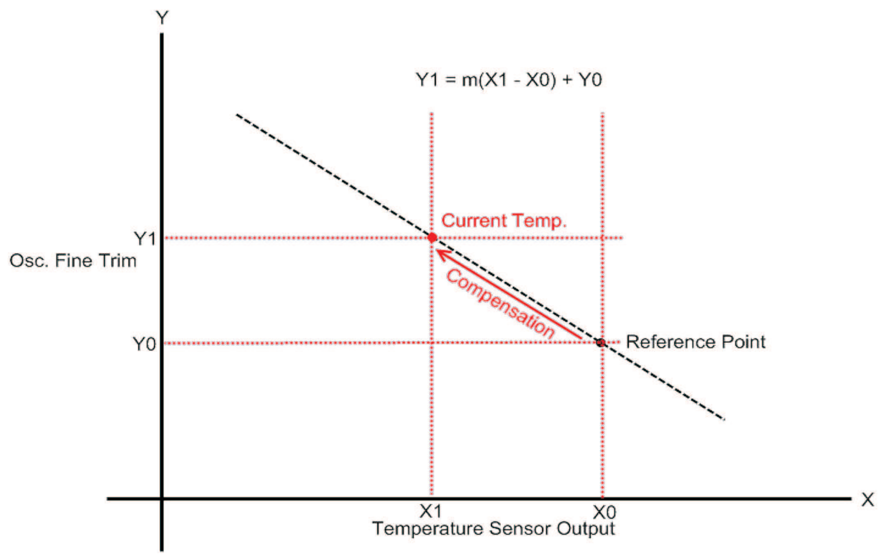
m is the oscillator compensation slope, which is $\frac{\text{change in oscillator fine trim}}{\text{change in temperature sensor reading}}$.

This is equivalent to a line with equation Y = mX + b:





2 Compensation Function

The following variables are stored in OTP and are accessible through functions programmed in the OTP. They are used for oscillator compensation.

- Reference Temperature Offset (0x3D7EA2):

  This is the temperature sensor reading of the reference point for oscillator compensation.
- Oscillator 1 Fine Trim Offset (0x3D7E93):

  This is the fine trim of the reference point for oscillator 1. This is the fine trim required to get 10.0 MHz when the temperature sensor reads the value of *High Temperature Offset*.
- Oscillator 2 Fine Trim Offset (0x3D7E9C):

  This is the fine trim of the reference point for oscillator 2. This is the fine trim required to get 10.0 MHz when the temperature sensor reads the value of *High Temperature Offset*.

- Oscillator 1 Fine Trim Slope (0x3D7E90):
  This is the slope of the oscillator temperature characteristic determined by the factory for internal oscillator 1. Units are oscillator fine trim steps/ADC codes (temperature sensor output). This variable is stored as a Q15 fixed point number, e.g., if the slope = -0.04, then this value is stored as $-0.04*(2^{15})$ = -1311. Note that the use of fixed-point math is required to compensate the oscillator.
- Oscillator 2 Fine Trim Slope (0x3D7E99):
  This is the slope of the oscillator temperature characteristic determined by the factory for internal oscillator 2. Units are oscillator fine trim steps/ADC codes (temperature sensor output). This variable is stored as a Q15 fixed point number, e.g., if the slope = -0.04, then this value is stored as $-0.04*(2^{15})$ = -1311. Note that the use of fixed-point math is required to compensate the oscillator.
- Oscillator 1 Coarse Trim (0x3D7E96):
  Always use this coarse trim for oscillator 1 when doing oscillator compensation.
- Oscillator 2 Coarse Trim (0x3D7E9F):
  Always use this coarse trim for oscillator 2 when doing oscillator compensation.

Call these variable as follows:

- X_0 = Reference Temperature Offset
- Y_0 = Oscillator Fine Trim Offset
- m = Oscillator Fine Trim Slope

Also call:

X_1 = The current reading of the temperature sensor (as sampled through the ADC)

Then, the oscillator can be compensated using the basic following formula:

Fine Trim = $m(X_1 - X_0) + Y_0$

However, m is stored as a fixed point Q15 number, meaning that m is stored as $m*2^{15}$, therefore, use the following equation to account for this:

$$\text{Fine Trim} = \frac{m\left(X_1 - X_0\right)}{2^{15}} + Y_0$$

Also, the value of $m(X_1 - X_0)$ should be rounded before it is truncated from Q15 to integer. To achieve this, add .5 and then truncate. (Note that adding 0.5 to Q15 means adding $0.5*2^{15}$). This form of rounding only works on positive numbers, so add 32 before truncation (here, $32*2^{15}$ has been added), and then subtract 32 after truncation. Adding 32 makes the value positive because the valid fine trim range is -31 to 31.

So, the final compensation formula is:

$$\text{ine Trim} = \frac{m\left(X_1 - X_0\right) + 32 * 2^{15} + 0.5 * 2^{15}}{2^{15}} - 32 + Y_0$$

Once the fine trim is calculated, it is packed along with the coarse trim into the format of SysCtrlRegs.INTOSCnTRIM.all and then placed in the register.

Note that m and Y_0 are different for oscillator 1 and 2. As an example, the following values have been programmed by the factory for oscillator 1.

- Reference Temperature Offset = 2000 = X_0
- Oscillator Fine Trim Offset = -25 = Y_0
- Oscillator Fine Trim Slope = -0.04 = Stored as $-0.04*2^{15}$ = -1311 = m
- Oscillator Coarse Trim = 8

If the sampled temperature sensor is:

X_1 = 1500

Then, the fine trim is calculated for compensation using the following operations:

1. Subtract 1500 – 2000 = -500 (16 bit value).
2. Cast -1311 to 32 bit.
3. Multiply 32-bit of -1311 and -500 = 655500 (32 bit value).
4. Add 655500 + 32*215 = 655500 + 1048576 = 1704076 (32 bit value).
5. Add 1704076 + 0.5*215 = 1704076 + 16384 = 1720460 (32 bit value).
6. Divide 1720460/215 = 52 (truncated) (32 bit value).
7. Cast 52 to 16 bit value.
8. Subtract 52 – 32 = 20 (16 bit value).
9. Add 20 + -25 = -5 (16 bit value).

-5 is the best fine trim for the current temperature.

Then, the fine trim of -5 and the coarse trim of 8 is packed into the oscillator trim register.

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