AN2030

Auto-Calibration of Internal Oscillator Using Signal Measurement Timer (SMT)

Author: *Elvin Hayes Gentiles*
Microchip Technology Inc.

INTRODUCTION

This application note describes a technique used to auto-calibrate, within ±1%, the internal oscillator of 8-bit PIC® microcontrollers using the Signal Measurement Timer (SMT) peripheral. Typically, the internal oscillator is factory calibrated at ambient temperatures. However, temperature variations and different operating environments can affect the accuracy of the internal oscillator. Thus, a calibration is useful to compensate the effect of temperature variations and to gain higher accuracy in timing-related applications such as serial communication.

The code used in this application note was developed using PIC12F1612. However, with minor changes, this code can be ported over to any device with the SMT peripheral.

Note: Visit www.microchip.com for products with SMT peripheral.

Devices without the SMT could also be calibrated using other methods, such as the use of Timer0 or Timer1. For more details about these calibration methods, refer to AN244, *Internal RC Oscillator Calibration* (DS00244) or AN250, *Auto-calibration of the PIC12F6XX Internal RC Oscillator to ±1%* (DS00250).

THEORY OF OPERATION

The application uses an external clock as the reference for calibration. This reference clock serves as the input signal for the SMT. The SMT is a 24-bit counter/timer which can be configured for measuring a variety of digital signal parameters such as pulse width, frequency, duty cycle, and time difference between the edges of two signals. For more information about the SMT, see TB3129, *Signal Measurement Timer on PIC® Microcontrollers* (DS90003129).

The SMT uses the internal oscillator as the clock source and operates in Period and Duty Cycle Acquisition mode. In this mode, either the duty cycle or the period of the input signal can be measured relative to the SMT clock. This means that the calibration method counts the number of SMT clock periods within a single reference clock period. For example, if the reference clock is running at 200 Hz and the SMT clock uses a 1 MHz internal oscillator, then the number of periods is equal to 500, (using Equation 1).

EQUATION 1: NUMBER OF PERIODS

$$No.\ of\ Periods = \frac{Clock_{SMT}}{Clock_{reference}}$$

To calibrate the internal oscillator within ±1% tolerance, a known range of calculated periods must be established. Table 1 shows the range of calculated periods using different reference and SMT clocks. The minimum and maximum calculated number of periods was derived using Equation 2.

TABLE 1: RANGE OF CALCULATED PERIODS

Reference Clock (Hz)	Calculated Number of Periods								
	CLKSMT = 500 kHz			CLKSMT = 1 MHz			CLKSMT = 4 MHz		
	Min.	Exact	Max.	Min.	Exact	Max.	Min.	Exact	Max.
1	495000	500000	505000	990000	1000000	1010000	3960000	4000000	4040000
5	99000	100000	101000	198000	200000	202000	792000	800000	808000
20	24750	25000	25250	49500	50000	50500	198000	200000	202000
50	9900	10000	10100	19800	20000	20200	79200	80000	80800
100	4950	5000	5050	9900	10000	10100	39600	40000	40400
250	1980	2000	2020	3960	4000	4040	15840	16000	16160
500	990	1000	1010	1980	2000	2020	7920	8000	8080
1000	495	500	505	990	1000	1010	3960	4000	4040

EQUATION 2: MINIMUM AND MAXIMUM NUMBER OF PERIODS

$$No.\ of\ Periods_{max} = \frac{1.01 \bullet Clock_{SMT}}{Clock_{reference}}$$

$$No.\ of\ Periods_{min} = \frac{0.99 \bullet Clock_{SMT}}{Clock_{reference}}$$

Note: The value of the SMT clock must be several times larger than the value of the reference clock.

CALIBRATION METHOD

Figure 1 shows the test circuit used in this application. An external reference clock, which serves as the input signal of the SMT, is connected on the SMTSIG2 pin of the device. The calibration starts by capturing the number of SMT clock periods within a single period of the reference clock. If the program determines that the captured number of periods is within the range, then no calibration is needed. If not, then the program will check if the captured number of periods is greater than the maximum calculated number of periods, or less than the minimum calculated number of periods. If the internal oscillator is running faster than the specified tolerance, the program will decrement the value of OSCTUNE by one. Otherwise, if the internal oscillator is running slower than the specified tolerance, the program will increment the value of OSCTUNE by one. The Oscillator Tuning Range (OSCTUNE) register contains a 6-bit value that can adjust the internal oscillator within a range of ±12% of the selected frequency. For more details about the OSCTUNE register, refer to the device data sheet. The changes in the internal oscillator can be monitored via the CLKOUT pin of the device. The flowchart in Figure 2 shows the calibration process used in this application note.

FIGURE 1: TEST CIRCUIT

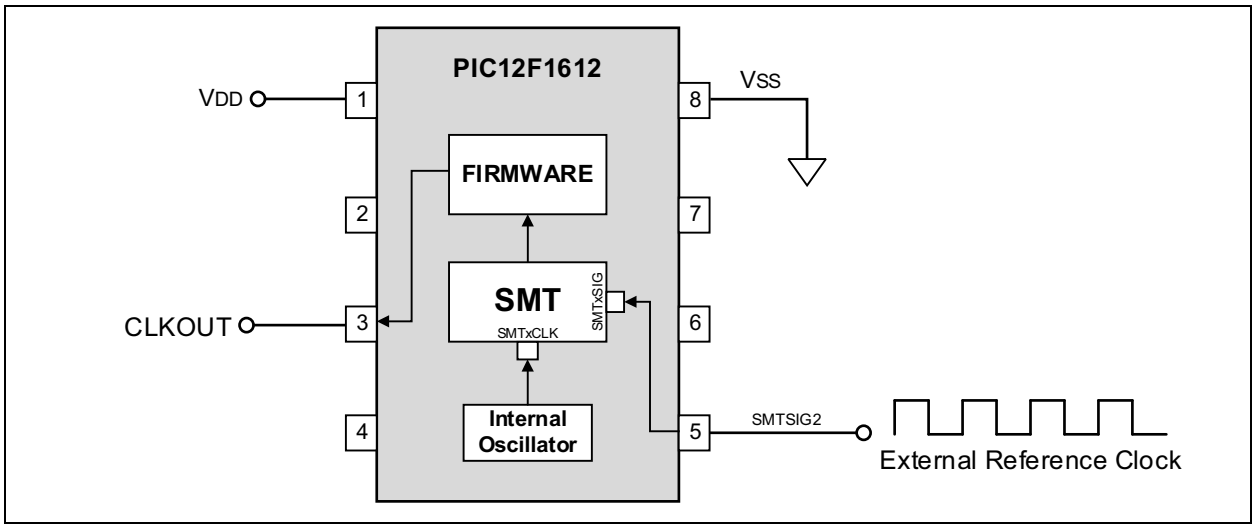
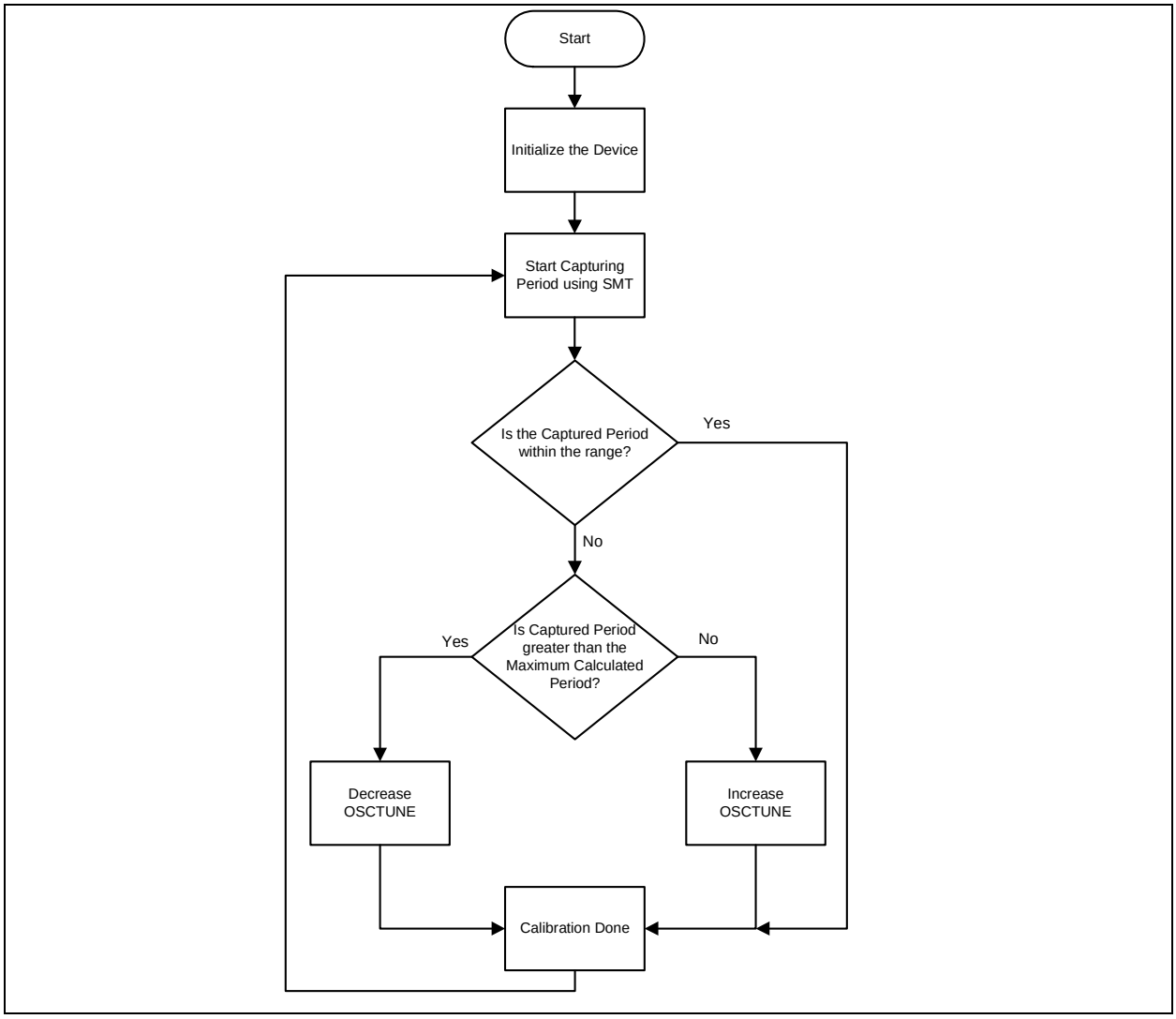


FIGURE 2: CALIBRATION PROCESS FLOW DIAGRAM



SMT CONFIGURATION USING MPLAB® CODE CONFIGURATOR (MCC)

This section shows how to configure the device and the SMT using MPLAB® Code Configurator (MCC). MCC is a free and user-friendly plug-in for MPLAB® X IDE that generates drivers and libraries for controlling and driving peripherals of PIC® microcontrollers, based on the settings and selections made in its Graphical User Interface (GUI). For more information on how to install and setup MCC, refer to *"MPLAB® Code Configurator User's Guide"* (DS40001725). The following steps show how to configure the device and the SMT on PIC12F1612 using MCC:

1. Go to *Tools > Embedded > MPLAB Code Configurator* to launch the MCC.
2. Click the **System** under the Project Resources panel. Set the System Clock Select to **INTOSC**, choose the Internal Clock that you want to calibrate, and enable the CLKOUT function under CONFIG1 (See Figure 3). The CLKOUT function is used to monitor the changes in the internal oscillator while calibrating.
3. In the Device Resources panel, expand the *SMT>SMT2* tree view and double click on **Synchronous** to load the peripheral in the Project Resources panel.
4. Click **SMT2::Synchronous** to configure the SMT2 peripheral. Set the Operation mode to **Period and Duty-Cycle Acquisition** and choose **Repeat** for the Data Acquisition. In the Pin Manager Area, click the **Lock** icon under column **PORTA2**, row **SMT2SIG**, to set RA2 as the input pin for the SMT signal. Input pins vary depending on the device used, so it is recommended to consult the device data sheet. Be sure that the Enable SMT is checked, the Clock Select is set to **FOSC**, and the Signal Select is set to **SMTxSIG** (See Figure 4).
5. Click the **Generate Code** button. This will automatically generate a `main.c` file with an empty `while(1)` loop for custom code entry. It will also initialize the device and the peripheral used in the project. Example 1 shows the generated code for the SMT peripheral.

FIGURE 3: MCC: SYSTEM SETTING

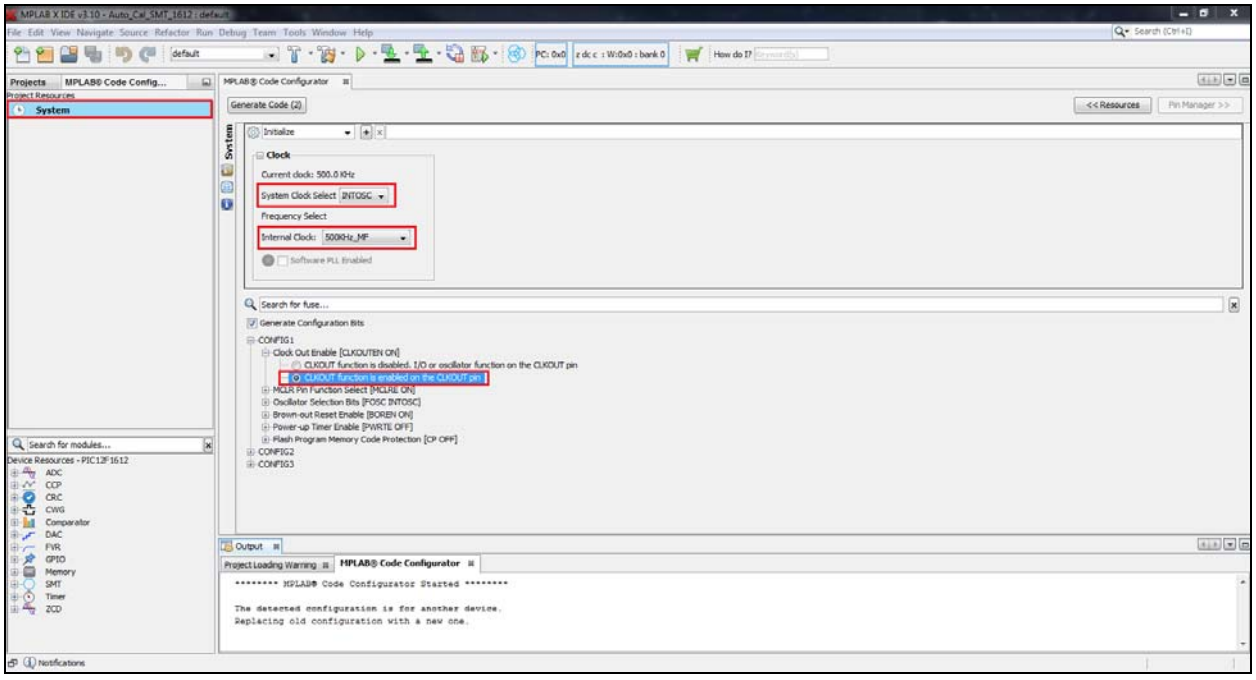
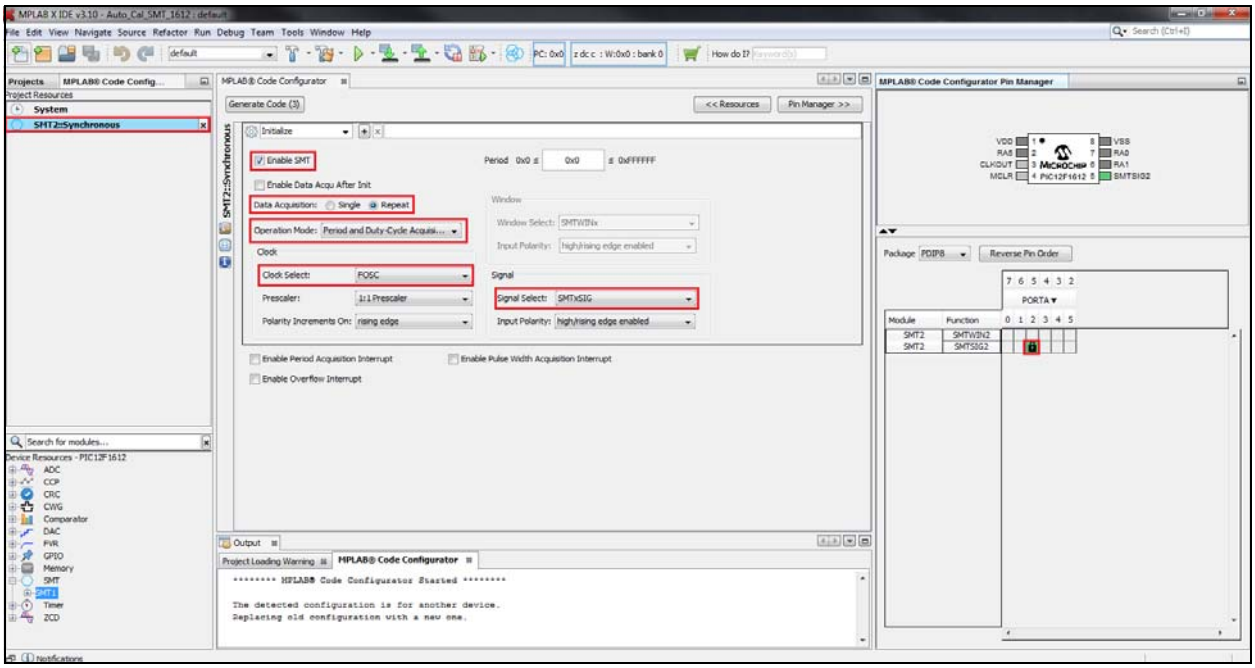


FIGURE 4: MCC: SMT2 SYNCHRONOUS SETTING



EXAMPLE 1: MCC GENERATED CODE FOR SMT

```
void SMT2_Initialize(void) {
    // CPOL rising edge; EN enabled; SPOL high/rising edge enabled; SMT2PS 1:1 Prescaler; STP
rolls over to 24'h000000; WPOL high/rising edge enabled;
    SMT2CON0 = 0x80;

    // SMT2GO disabled; SMT2MODE Period and Duty-Cycle Acquisition; SMT2REPEAT Repeat Data
Acquisition;
    SMT2CON1 = 0x42;

    // SMT2TS not incrementing; RST SMT2TMR2 update complete; SMT2WS closed; SMT2CPWUP SMT2CPW2
update complete; SMT2CPRUP SMT2PR2 update complete; SMT2AS acquisition not in progress;
    SMT2STAT = 0x00;

    // SMT2CSEL FOSC;
    SMT2CLK = 0x00;

    // SMT2WSEL SMTWINx;
    SMT2WIN = 0x00;

    // SMT2SSEL SMTxSIG;
    SMT2SIG = 0x00;

    // SMT2PR16 0x0;
    SMT2PRU = 0x00;

    // SMT2PR8 0x0;
    SMT2PRH = 0x00;

    // SMT2PR0 0x0;
    SMT2PRL = 0x00;

}

void SMT2_DataAcquisitionEnable(void) {
    // Start the SMT module by writing to SMTxGO bit
    SMT2CON1bits.SMT2GO = 1;
}

void SMT2_DataAcquisitionDisable(void) {
    // Start the SMT module by writing to SMTxGO bit
    SMT2CON1bits.SMT2GO = 0;
}

void SMT2_HaltCounter(void) {
    SMT2CON0bits.STP = 1;
}
```

EXAMPLE 1: MCC GENERATED CODE FOR SMT (CONTINUED)

```
void SMT2_SetPeriod(uint32_t periodVal) {
    // Write to the SMT2 Period registers
    SMT2PRU = (periodVal >> 16);
    SMT2PRH = (periodVal >> 8);
    SMT2PRL = periodVal;
}

uint32_t SMT2_GetPeriod() {
    return (SMT2PR);

}
void SMT2_SingleDataAcquisition(void) {
    SMT2CON1bits.SMT2REPEAT = 0;

void SMT2_RepeatDataAcquisition(void) {
    SMT2CON1bits.SMT2REPEAT = 1;
}

void SMT2_ManualPeriodBufferUpdate(void) {
    SMT2STATbits.SMT2CPRUP = 1;
}

void SMT2_ManualPulseWidthBufferUpdate(void) {
    SMT2STATbits.SMT2CPWUP = 1;
}

void SMT2_ManualTimerReset(void) {
    SMT2STATbits.RST = 1;
}

bool SMT2_IsWindowOpen(void) {
    return (SMT2STATbits.SMT2WS);
}

bool SMT2_IsSignalAcquisitionInProgress(void) {
    return (SMT2STATbits.SMT2AS);
}
bool SMT2_IsTimerIncrementing(void)  {
    return (SMT2STATbits.SMT2TS);
}

uint32_t SMT2_GetCapturedPulseWidth() {
    return (SMT2CPW);
}

uint32_t SMT2_GetCapturedPeriod() {
    return (SMT2CPR);
}

uint32_t SMT2_GetTimerValue() {
    return (SMT2TMR);
}
```

CONCLUSIONS

This application note shows a method to auto-calibrate the internal oscillator of the 8-bit PIC microcontrollers. It also provides the calculations of relevant values such as the number of periods. The Signal Measurement Timer (SMT) provides an easy way to calibrate the internal oscillator within ±1% tolerance. The configuration of SMT is demonstrated using the MPLAB® Code Configurator (MCC).

APPENDIX A: SOURCE CODE LISTING

The latest version can be downloaded from the Microchip website (http://www.microchip.com/). The user will find the source code appended to the electronic version of this application note.

APPENDIX B: REVISION HISTORY

Revision A (12/2015)

Initial Release of Document.

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