Application Note

How to Achieve Higher Accuracy Timer with Internal Oscillator on MSP430™

TEXAS INSTRUMENTS

ABSTRACT

Many applications require accurate low frequency signal generation and timing, but also need to save cost and simplify part sourcing by eliminating the need for any external 32-kHz crystal. This application note discusses a method to achieve higher accuracy timer output using only the internal REFO oscillator on the MSP430™ MCUs, to save system cost compared to using external crystal.

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1 Overview

MSP430FR4xx and MSP430FR2xx (FR4xx/FR2xx) family microcontrollers (MCUs) provide various clock sources. Users can select the best balance of performance, power consumption, and system cost. REFO is an internal trimmed low-frequency oscillator with 32768-Hz typical frequency included in FR4xx/FR2xx family MCUs, which can be used as a clock reference into the FLL (frequency-locked loop). REFO is widely used in cost-sensitive applications in which a crystal is not required or desired. REFO, combined with the FLL, provides for a flexible range of system clock settings without the need for a crystal.

Related software can be downloaded here.

1.1 Clock System Introduction

Before discussing the estimated REFO frequency, it is important to understand the clock system of the FR4xx/FR2xx family. For more information, see the clock system (CS) chapter in the MSP430FR4xx and MSP430FR2xx Family User's Guide (SLAU445). The FR4xx/FR2xx clock system supports four internal and two external clock sources:

- VLOCLK: Internal very-low-power oscillator with 10-kHz typical frequency
- REFOCLK: Internal trimmed low-frequency oscillator with 32768-Hz typical frequency
- DCOCLK: Internal digitally controlled oscillator (DCO) that can be stabilized by the FLL
- MODCLK: Internal high-frequency oscillator with 5-MHz typical frequency

The REFOCLK frequency tolerance is ±3.5% over the full operating temperature and supply voltage range. This is why applications, which do not use external crystals for lower cost and require accuracy at the same time, may need to calibrate the REFOCLK. The DCOCLK can use REFOCLK as reference with the FLL enabled to get high frequency. The VLOCLK is the lowest-power clock which is commonly used in applications requiring low power consumption. VLOCLK has wider frequency variation than REFO. See the device-specific data sheet for more information about clock accuracy specifications of the internal clocks.

2 REFO Frequency Estimation Mechanism

The REFO clock frequency may change across different devices even with the same supply voltage and temperature, due to normal device-to-device variation. Additionally, the frequency can also drift with the temperature. Therefore, improved REFO accuracy can be achieved by estimating the frequency at different temperature ranges. The change and drift of REFO frequency across different devices and temperature have the same trend. Knowing that, we can leverage the on-chip temperature sensor and a fitting curve to estimate the accurate REFO frequency, compensated for temperature drift. We will do a one-point calibration for the fitting curve to minimize the frequency error at the most critical temperature point.

We assume the curve between REFO frequency and temperature is as follows.

$$f(\mathrm{t}) = At^2 + Bt + C \quad (1)$$

As we will involve one point at typical temperature (using 25°C as an example) for calibration, the gap between t°C and 25°C is:

$$k(\mathrm{t}) = A\left(t^2 - 25^2\right) + B(t - 25) \quad (2)$$

Then the equation to calculate the REFO frequency at different temperature t based on the tested REFO frequency at 25°C is:

$$F(\mathrm{t}) = Freq_{25} + k(t) \quad (3)$$

See Figure 2-1, compared with using f(t) to estimate the real REFO frequency, using F(t) can help to get the smallest error at the typical temperature.

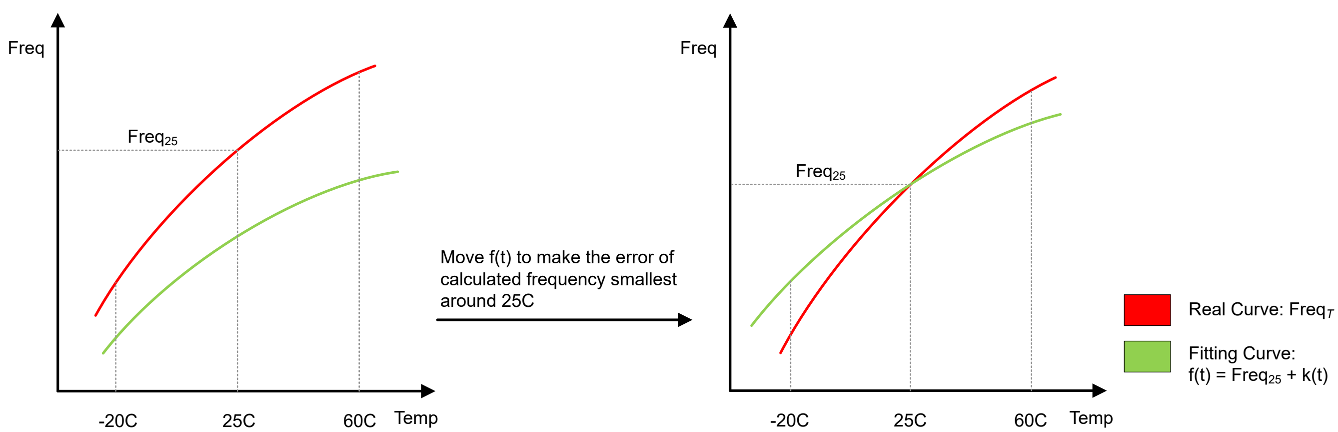

Figure 2-1. REFO Drift Correction Using Single Point Calibration

For coefficients A and B, calculate by performing least square or average method to a certain amount of data. When the device runs, we will use the internal temperature sensor to get temperature t and then combine it with the fitting curve to estimate the actual REFO frequency and calibrate the peripherals like timer and RTC.

2.1 Procedure to Estimate the REFO Frequency

Here is what users need to do to apply this method to estimate the REFO frequency. The hardware peripherals used are ADC and the internal temperature sensor to measure the current temperature.

As an example, TI provided all the software code for this procedure with MSP430FR4133IG56 device including the fitting curve. Users only need to download the example code and call the function CalculateRealOscillatorFrequency(). Then the estimated REFO frequency will be calculated and available for other clock or peripherals to use.

For other devices, users need to calculate the coefficients A and B to generate the fitting curve, and test the typical device's REFO frequency at 25°C.

3 Example: Improve Timer PWM and RTC Accuracy

After estimating the REFO frequency, users can calibrate the timer PWM output frequency. For example, we use the timer to generate 44-kHz PWM output with 16-MHz system clock to understand how to use the estimated REFO frequency to calibrate the timer. 32-kHz REFO can be used as a reference for DCOCLK to generate a 16-MHz system clock for the timer. Equation 4 calculates the value save in TAXCCR0 to generate 44-kHz PWM. TAXCCR0 means the value saved in the capture and compare register of timer. SMCLK means the 16-MHz system clock, which is used as the input clock source of timer.

$$TAXCCR0 \; = \frac{SMCLK}{44kHz} - 1 \tag{4}$$

SMCLK can be calculated by using the estimated REFO frequency so the user knows the SMCLK frequency at a given temperature. And the TAXCCR0 value can be calibrated to make sure the output PWM frequency is close to 44 kHz. As we multiply the REFO frequency (32768 Hz) by 448 times to get 16-MHz system clock, the equation of TAXCCR0 can be further simplified. Input the estimated REFO frequency to Equation 5, then users can get the estimated TAXCCR0 value.

$$TAXCCR0 \; = REFO \; Frequency * \frac{488}{44kHz} - 1 \tag{5}$$

Estimated REFO frequency can be used for other peripherals. TI provides example code with two applications based on this method.

- First, generate a high accurate 44-kHz PWM, based on 16-MHz SMCLK sourced from REFO.
- Second, generate a high accurate 500-ms RTC clock, using VLO as the clock source, which is calibrated by ACLK sourced from REFO. For the VLO calibrating method, please refer to VLO Calibration on the MSP430FR4xx and MSP430FR2xx Family (SLAA693).

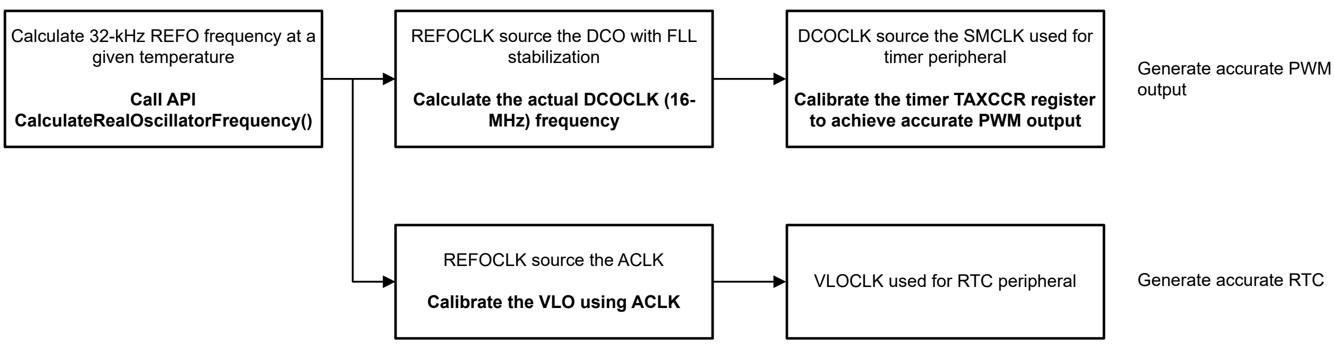

Figure 3-1. Software Flow for Achieving Improved PWM and RTC Accuracy

There are five error sources for this method provided in the following list.

- First is the fitting curve error, which is caused by the difference between the real REFO curve and the fitting curve.
- Second is the temperature evaluation error caused by the on-chip temperature sensor.
- Third is the step error which is caused by timer step only change in integer value.
- Forth is the DCO tap error (The max value of DCO register in CSCTL0 is 512. The max error is around 0.085%).
- Fifth is the math error affected by data significant bit. The math error can be overcame by changing the data type or doing calculation compensation.

Figure 3-2 shows the absolute value of a typical error percentage for a 44-kHz PWM signal sourced from 16-MHz SMCLK over the temperature range. The absolute value error percentages shown below can be interpreted as either positive or negative resulting in a slightly faster or slower PWM frequency.

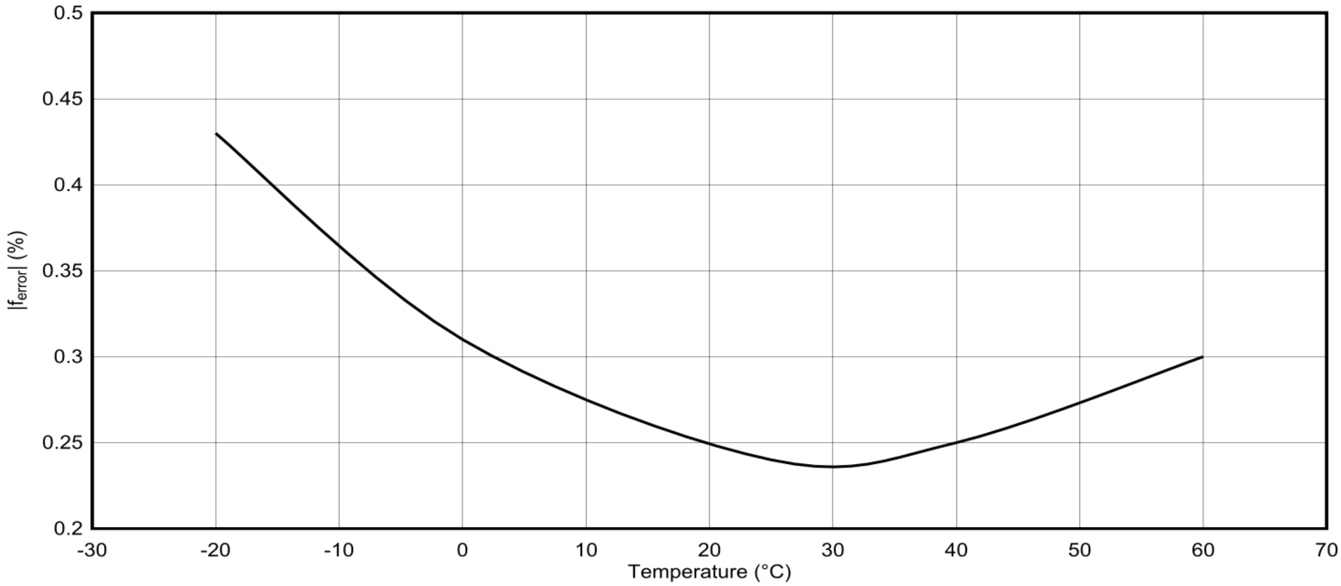

Figure 3-2. Calibrated 44-kHz Timer PWM Error Magnitude

4 Summary

This application note describes how to estimate REFO frequency in FR4xx/FR2xx family MCUs and help to increase the accuracy of typical peripherals. It can be used for applications that require all of the following: per-test of REFO frequency at typical temperature, typical applying temperature range, high-accuracy peripheral frequency output, ultra-low power, and without external crystal for low cost.

Software download link

MSP430FR4133 data sheet link

MSP430FR4xx and MSP430FR2xx family User's Guide