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Spec Title: AN80248 - PSOC(R) 3 / PSOC 5LP IMPROVING THE ACCURACY OF INTERNAL OSCILLATORS

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AN80248

PSoC® 3 / PSoC 5LP Improving the Accuracy of Internal Oscillators

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Software Version: PSoC Creator™ 2.2 or higher
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AN80248 shows how to improve the accuracy of the PSoC® 3 or PSoC 5LP internal low-speed oscillator (ILO) and internal main oscillator (IMO) through run-time trim. Two Components developed for this purpose greatly simplify the process of calibrating the ILO and IMO with respect to a reference time base.

Contents

1 Introduction 1
2 ILO Basics 2
2.1 Applications of a Trimmed ILO 2
3 IMO Basics 3
3.1 Applications of a Trimmed IMO 3
4 Trimming Theory 3
5 Component Usage 5
5.1 kHz_ILO_Trim 5
5.2 IMO_Trim 6
6 Test Project Description 8
7 Component Internal Implementation 9
7.1 ILO Trim Design Considerations 9
7.2 IMO Trim Design Considerations 11
8 Component Performance 12
9 Summary 13
10 Appendix A – IMO and ILO Frequency Variation Graphs 14
11 Appendix B – Identifying Nominal Clock Frequencies 15
12 Appendix C – main.c code for the Test Project 16
Document History 18
Worldwide Sales and Design Support 19

1 Introduction

PSoC® 3 and PSoC 5LP (hereafter referred to as PSoC) have a very powerful clocking system. This system offers the flexibility and performance to suit the needs of most embedded applications. It is comprised of clock sources and a clock distribution network. The clock sources available to you are: the internal main oscillator (IMO), external crystal oscillators (ECO) and internal low-speed oscillator (ILO). This application note describes the IMO and ILO as well a method to improve their accuracy through run-time calibration.

For more information on the clocking resources in PSoC, see AN60631 - PSoC 3 and PSoC 5LP Clocking Resources.

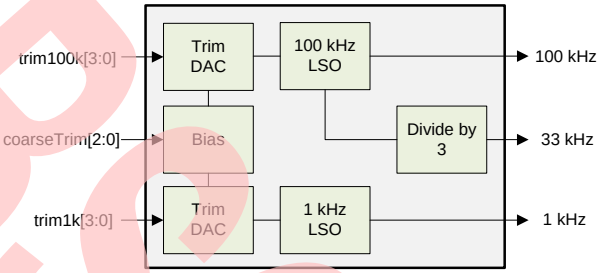
This application note assumes that you are familiar with the PSoC 3 or PSoC 5LP architecture and the PSoC Creator design environment. If you are new to PSoC 3 or PSoC 5LP, a good introduction is AN54181 - Getting Started with PSoC 3 or AN77759 - Getting Started with PSoC 5LP.

2 ILO Basics

The ILO is a low-speed, low-power and low-accuracy oscillator used as a kHz clock source, watchdog timer, and sleep timer. As shown in *Figure 1*, the ILO consists of two low speed oscillators (LSOs) and generates three frequencies – 1 kHz, 33 kHz, and 100 kHz. You can have any two of these frequencies output simultaneously.

After factory trim, the 1 kHz LSO has an accuracy range of -50%/+100%, while the 100 kHz LSO has a range of -55%/+100% over the entire operating range of voltage and temperature. Refer to *Appendix A* for graphs of ILO and IMO frequency variation versus temperature and voltage.

Figure 1. Simplified ILO Block Diagram



Run-time trimming can greatly improve the ILO's performance. This is done by adjusting the trim DACs and bias block shown in *Figure 1* via dedicated trim registers. *Figure 2* describes the trim registers in more detail.

Though you can use the methods presented here to trim both the 1 kHz and 100 kHz LSOs, this application note focuses on trimming the 1 kHz output. Henceforth, you can assume that all mentions of the ILO refer to the 1 kHz output of the ILO.

Figure 2. ILO Trim Registers and Their Description

ILO_TR0								
Bits	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
SW Access: Reset	R/W: 1000				R/W:1000			
HW Access	R				R			
Name	tr_100k				tr_1k			

ILO_TR1								
Bits	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
SW Access: Reset	NA: 00000					R/W:0	R/W:10	
HW Access	NA					R	R	
Name						ct_range	ctrim	

Bits	Name	Description	Maximum frequency	Minimum frequency
ILO_TR0[7:4]	tr_100k	Trim for 100 kHz output	4'b1111	4'b0000
ILO_TR0[3:0]	tr_1k	Trim for 1 kHz output	4'b1111	4'b0000
ILO_TR1[1:0]	ctrim	Coarse trim for ILO	2'b11	2'b00
ILO_TR1[2]	ct_range	Coarse trim range select	1'b0	1'b1

2.1 Applications of a Trimmed ILO

One of the major uses of the ILO is as a clock in sleep mode instead of the 32 kHz external crystal. A more accurate ILO allows for more precise event timing.

3 IMO Basics

The IMO is the main clock source of the PSoC. It provides clock outputs at 3, 6, 12, 24, 48 and 62.6 MHz. A factory trim value for each frequency range is stored in the device's flash memory. During the PSoC's boot-phase, the trim value corresponding to the speed setting of the IMO is loaded into the trim registers shown in *Figure 3*. The process of run-time trim modifies these registers, and does not affect the trim values stored in flash.

With factory trim, IMO accuracy in precision PSoC devices: CY8C38xx, CY8C36xx, CY8C58xx, CY8C56xx (across the range of operating temperature and voltage) varies from ±1% at 3 MHz to ±7% at 62.6 MHz. Please see the respective PSoC family datasheets for more information.

The IMO is generally used with the phase-locked loop (PLL) to generate a wide range of frequencies. Cypress recommends that you run the IMO at 3 MHz and use the PLL to generate the desired operating frequency. This is because the PLL introduces no additional error, and consumes less power than the IMO for frequencies greater than 24 MHz.

Similar to the ILO, the IMO contains an 11-bit trim DAC which is used to achieve a considerable accuracy improvement through run-time calibration.

Figure 3. IMO Trim Registers and Their Description

IMO_TR0								
Bits	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
SW Access: Reset	R/W: 000			NA:00000				
HW Access	R			NA				
Name	imo_lsb							

IMO_TR1								
Bits	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
SW Access: Reset	R/W:00000000							
HW Access	R							
Name	imo_trim							

Bits	**Name**	**Description**	**Maximum frequency**	**Minimum frequency**
IMO_TR0[7:5]	imo_lsb	3 LSB of IMO trim	3'b111	3'b000
IMO_TR1[7:0]	imo_trim	8 MSBits of IMO trim	8'b11111111	8'b00000000

3.1 Applications of a Trimmed IMO

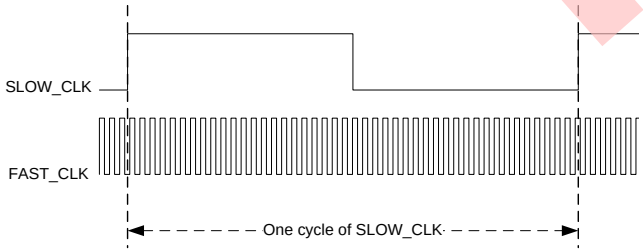
An accurate IMO has a wide range of applications, particularly for high-reliability communication. MHz crystals are generally more expensive than kHz crystals. Thus, calibrating the IMO with respect to a kHz crystal can reduce bill-of-material costs.

4 Trimming Theory

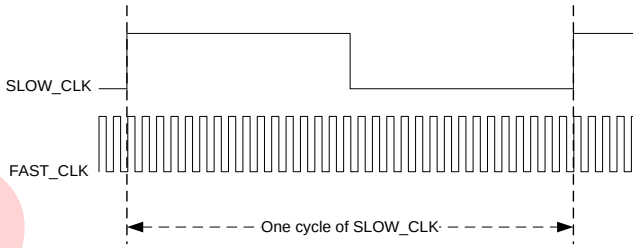
Trimming involves measuring the frequency of the clock of interest against an accurate time base. This reference time base may be slower or faster than your clock of interest.

Assume that the clock of interest is FAST_CLK and the reference is SLOW_CLK. If you count the number of FAST_CLK positive edges per cycle (or for a fixed number of cycles) of SLOW_CLK, there exist three cases:

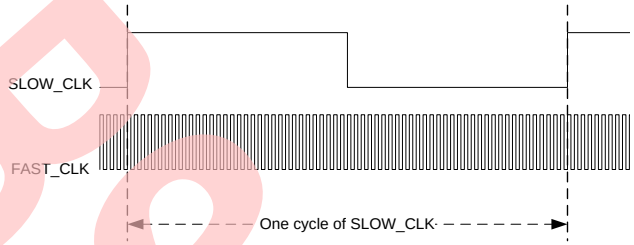
1. Edges Counted = Ideal number of edges FAST_CLK error = 0



2. Edges Counted < Ideal number of edges FAST_CLK error < 0

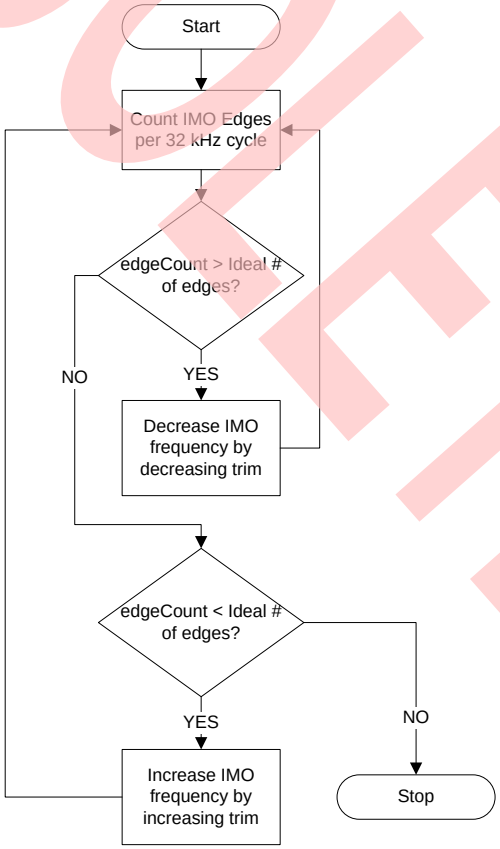


3. Edges Counted > Ideal number of edges FAST_CLK error > 0



This concept applies to trimming the IMO and the ILO. For example, say the SLOW_CLK is the 32 kHz crystal oscillator and the FAST_CLK is the IMO itself. The flowchart in *Figure 4* shows the procedure to trim the IMO.

Figure 4. Theoretical Flowchart for IMO Trim



This method works for an accurate FAST_CLK and inaccurate SLOW_CLK as well. This is the case when you trim the ILO using a reference such as the IMO.

5 Component Usage

This section discusses the trimming Components: kHz_ILO_Trim and IMO_Trim, their inputs, parameters, and APIs.

Note: As of PSoC Creator 3.0 and later, the ILO Trim Component is now included as part of the standard Creator Component Catalog. For additional details on this Component, refer to the ILO Trim Component datasheet within PSoC Creator.

5.1 kHz_ILO_Trim

5.1.1 Symbol

As shown in *Figure 5*, the kHz_ILO_Trim Component has only one input – the Reference clock from which the ILO derives the higher accuracy. The ILO frequency is supplied to the Component internally.

Note: The clock Component in PSoC Creator can supply the ILO, 32 kHz XTAL or BUS_CLK frequencies without consuming digital clock dividers.

Figure 5. kHz_ILO_Trim Symbol

5.1.2 Parameters

You must define two parameters in the Component customizer (*Figure 6*):

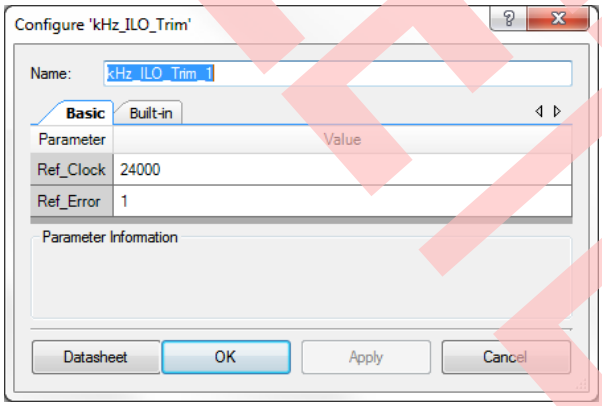
- Ref_Clock (kHz) – Frequency of the reference

The upper bound for this frequency is limited to 32 MHz due to timing constraints, while the lower bound is determined by the acceptable level of error (see the section in this application note on *Accuracy Attainable*). It is recommended that this clock be the 3 MHz IMO directly or a clock derived from it.

- Ref_Error (%) – Error of the reference clock

In the case of the 3 MHz IMO, the Ref_Error is 1 in PSoC 3. *Appendix B* shows where you can find the frequency and accuracy of system clocks.

Figure 6. kHz_ILO_Trim Component Customizer



5.1.3 APIs

The Component comes with pre-defined APIs to simplify its use. For simplicity, assume that the Component is named kHz_ILO_Trim.

- kHz_ILO_Trim_Start()
- kHz_ILO_Trim_Stop()
- kHz_ILO_Trim_BeginTrimming()
- kHz_ILO_Trim_StopTrimming()
- kHz_ILO_Trim_ClearFIFO ()

- kHz_ILO_Trim_CheckStatus()
- kHz_ILO_Trim_CheckError()
- kHz_ILO_Trim_RestoreTrim()
- kHz_ILO_Trim_GetTrim()
- kHz_ILO_Trim_SetTrim()
- kHz_ILO_Trim_Sleep()
- kHz_ILO_Trim_Wakeup()

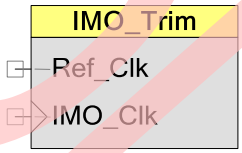
The `kHz_ILO_Trim_Start()` function initializes the Component but does not start trim iterations. The `kHz_ILO_Trim_BeginTrimming()` function is called to initiate trimming. Once the calibration is complete, the correction iterations automatically stop. At any point, you can use the `kHz_ILO_Trim_CheckStatus()` function to check whether the ILO is within the desired accuracy range. The `kHz_ILO_Trim_CheckError()` function calculates the ILO error. If you want to revert to the original factory trim values, use the `kHz_ILO_Trim_RestoreTrim()` function. Sleep, Wakeup and Stop APIs are also available. Refer to the Component datasheet for more information.

5.2 IMO_Trim

5.2.1 Symbol

As shown in *Figure 7*, the IMO_Trim Component has two inputs: Ref_Clk and IMO_Clk. The 32 kHz crystal clock is typically used as Ref_Clk. IMO_Clk can be either the direct IMO output or a clock derived from the IMO via the PLL or clock dividers. The IMO_Clk terminal is external to the Component so that you can reuse the associated clock.

Figure 7. IMO_Trim Symbol



5.2.2 Parameters

You must define three parameters in the Component customizer (*Figure 8*):

- Averaging_Duration (cycles) – Number of Ref_Clk cycles for which IMO edges are counted.

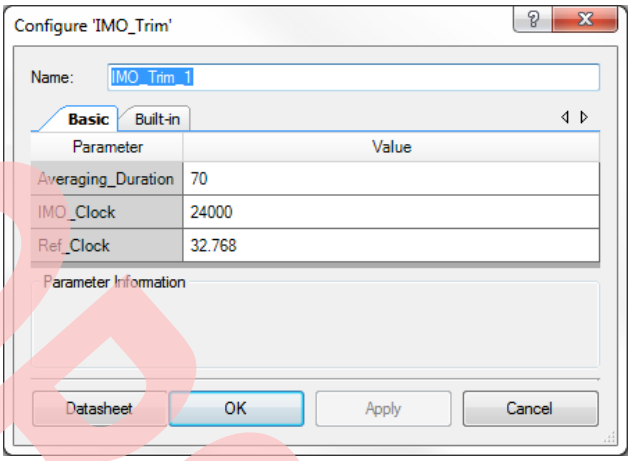
  Due to the Component implementation, this parameter must be specified within the range of [2,127]. However, the actual limits depend on the values of IMO_Clock and Ref_Clock. A larger value for Averaging_Duration increases the clock stability but increases the time taken to settle to the final accuracy.

- IMO_Clock (kHz) – Frequency of IMO_Clk input.

  The lower limit for this input is the lowest IMO frequency – 3 MHz. The upper limit is 32 MHz due to timing considerations. *Appendix B* shows where you can find the exact frequency and accuracy of system clocks.

- Ref_Clock (kHz) – Frequency of the reference clock.

Figure 8. IMO_Trim Component Customizer



In a typical use-case, Ref_Clk is the 32.768 kHz crystal clock. *Table 1* shows some valid combinations of IMO_Clk and Averaging_Duration values when Ref_Clk is the 32 kHz crystal. In the test project attached with this application note, Cypress uses an Averaging_Duration of 70 with a 24 MHz IMO_Clk.

Table 1. Table of Valid Averaging_Duration Values

Actual IMO (MHz)	IMO_Clk (MHz)	Averaging_Duration (Max cycles)
3 ± 1%	3	127
6 ± 2%	6	127
12 ± 3%	12	127
24 ± 4%	24	85
3 ± 1%	24*	88
3 ± 1%	32*	65
62.6 ± 7%	31.3**	64

* Via the PLL

** Via the clock divider

5.2.3 APIs

The APIs for IMO_Trim are exactly the same as those for kHz_ILO_Trim. For more information, see the IMO_Trim Component datasheet.

- IMO_Trim_Start()
- IMO_Trim_Stop()
- IMO_Trim_BeginTrimming()
- IMO_Trim_StopTrimming()
- IMO_Trim_ClearFIFO()
- IMO_Trim_CheckStatus()
- IMO_Trim_CheckError()
- IMO_Trim_RestoreTrim ()
- IMO_Trim_GetTrim()
- IMO_Trim_SetTrim()
- IMO_Trim_Sleep()
- IMO_Trim_Wakeup()

6 Test Project Description

Open the example project available on the application note landing page by first unzipping the AN80248.zip file. The AN80248.cywrk workspace file contains two types of projects: a library project – '*Trim_Components.cyprj*' with the Components and a test project – '*AN80248.cyprj*' to implement them. The test project works with PSoC 3 by default.

The trim Components reside in the **Components** tab of the **Workspace Explorer**. You can add the Trim_Component library to any project. In PSoC Creator, select **Project** > **Dependencies** and specify the directory in which *Trim_Component.cyprj* is located. This can be done by clicking the folder icon under 'User Dependencies'. For more information on how to create and use library projects, see PSoC Creator help articles "Library Component Project" and "Basic Hierarchical Design Tutorial".

6.1.1 TopDesign Schematic

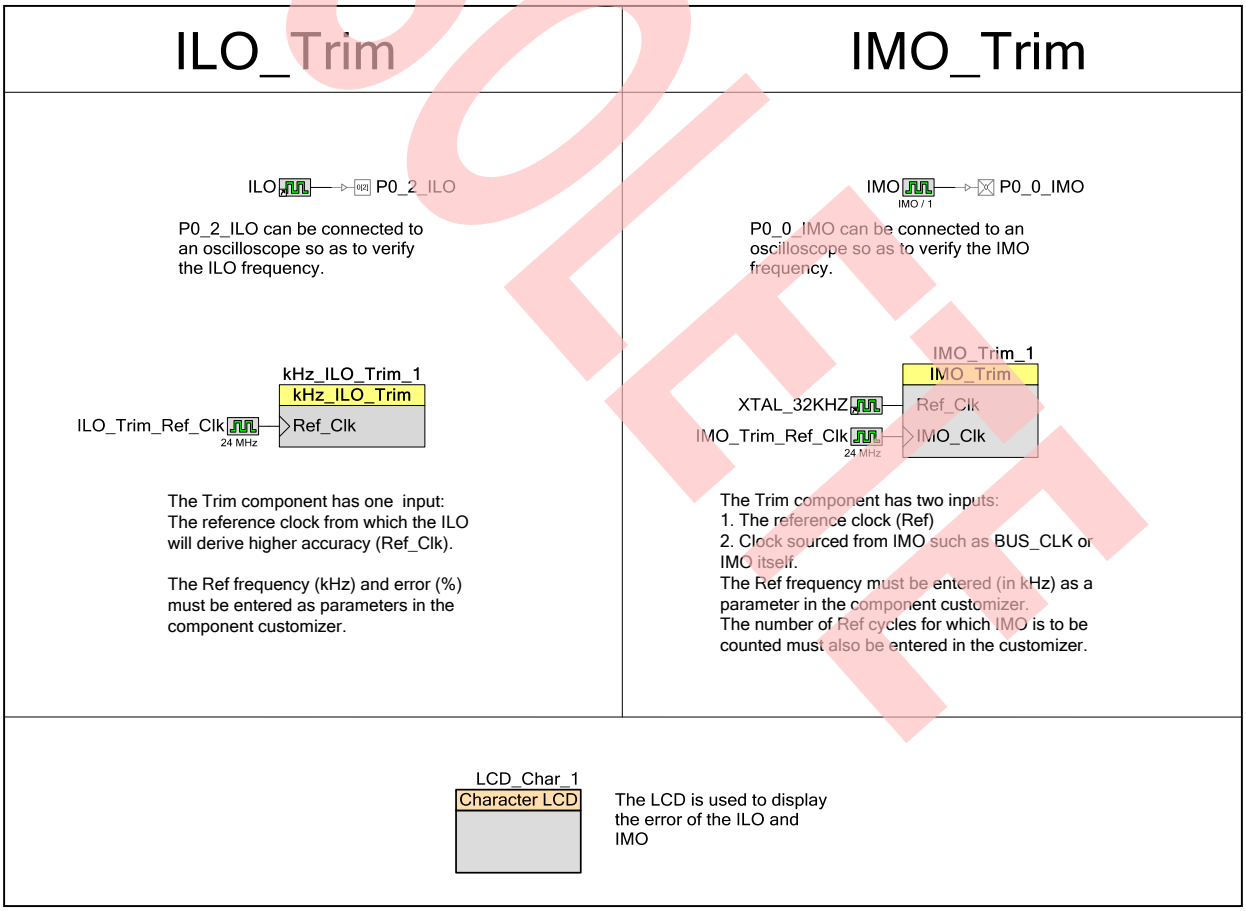
Figure 9 shows the TopDesign schematic of *AN80248.cyprj*. In this project, MASTER_CLK is set at 24 MHz and is derived from the 3 MHz IMO using the PLL.

A fixed-frequency 24 MHz clock sourced from the MASTER_CLK is the reference input to the ILO Trim Component. You can verify the ILO frequency on P0[2].

The reference for IMO_Trim is the 32 kHz crystal. A fixed-frequency 24 MHz clock feeds IMO_Clk. You can verify the IMO frequency on P0[0].

The character LCD on P2[6:0] displays the IMO and ILO error in percentage.

Figure 9. PSoC Creator Schematic for Trim Component Test Project



6.1.2 *main.c*

At the beginning of the main block (see *Appendix C*), temporary variables are initialized to store and display IMO and ILO error, start the LCD, start the two Components, and enable global interrupts.

In the infinite 'for' loop, the IMO and ILO frequency errors are calculated by using the CheckError function. If the IMO frequency error is calculated successfully, it is displayed on the character LCD as a percentage. IMO trimming is restarted if the IMO accuracy is outside a ±0.05% range.

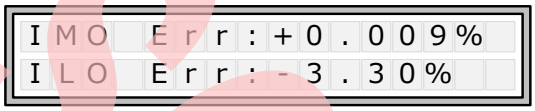
Similarly, the ILO frequency error is displayed on the LCD as a percentage. Typically, you would not use both CheckStatus and CheckError functions in the same design. However, for the purpose of illustration, both functions are used in the attached project. ILO trimming is restarted if the CheckStatus function returns `kHz_ILO_Trim_1_IS_INACCURATE`.

Note: The `kHz_ILO_Trim_1_CheckError()` function returns ILO error in parts per thousand, while the `IMO_Trim_1_CheckError()` function returns IMO error in parts per million.

6.1.3 Expected Output

- The frequency of the IMO output on P0[0] should be within ±0.05% accuracy.
- The frequency of the ILO output on P0[2] should be within ±7.5% accuracy.
- The LCD should show ILO, IMO accuracy in percent (*Figure 10*).

Figure 10. Example of Expected Output on LCD



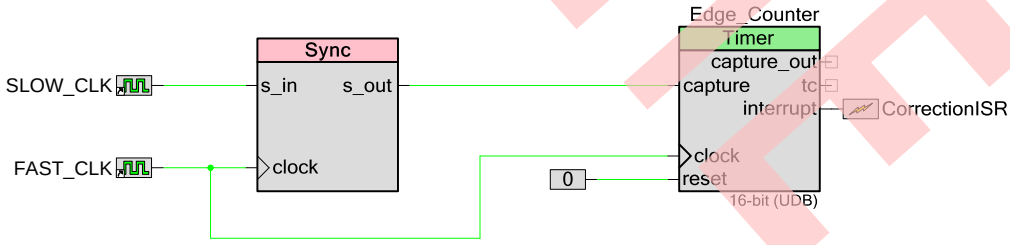
7 Component Internal Implementation

This section describes the internal working of the ILO and IMO Trim Components. *Figure 11* shows the generic PSoC Creator schematic used to trim either the ILO or IMO. The timer Component is perfectly suited for edge counting and is configured in continuous 16-bit UDB mode. The timer starts at its period value and counts down to zero for every positive edge of FAST_CLK. Once at zero, the timer reloads and then continues this cycle.

The timer captures the 'count' value every 'Capture Count' cycles of SLOW_CLK and stores this in a 4-capture deep FIFO. Note that 'Capture Count' is a user-defined parameter in the Timer configuration window; its default value is 1. The number of edges of FAST_CLK per 'Capture Count' SLOW_CLK cycles is then calculated in firmware by subtracting consecutive captures. The Sync block ensures timing constraints are met within the timer.

Note: In the projects attached to this application note when you trim the ILO, the ILO is SLOW_CLK and the IMO is FAST_CLK. When you trim the IMO, the clock from the 32 kHz crystal is SLOW_CLK, and the IMO is FAST_CLK.

Figure 11. Generic Schematic for Trimming



7.1 ILO Trim Design Considerations

When trimming the ILO, the ILO is the SLOW_CLK. The sources for FAST_CLK can be the 32 kHz crystal oscillator, the MHz oscillator or the IMO. This application note discusses the third case – trimming the ILO with the IMO (FAST_CLK) as reference.

7.1.1 Accuracy Attainable

The accuracy attainable by trimming the ILO depends on 3 factors:

- Ratio of FAST_CLK to SLOW_CLK
- Accuracy of the Reference
- Resolution of trim registers

7.1.2 Ratio of FAST_CLK to SLOW_CLK

The first step to trim the ILO is to count the edges of the FAST_CLK per cycle of the ILO. In other words,

$$edgeCount = \frac{\text{FAST\_CLK}}{\text{ILO}}$$

Let the ILO error be z%, where z is small and can be either negative or positive. Then:

$$edgeCount = \frac{\text{FAST\_CLK}}{\text{ILO} \times (1 + \text{z})}$$

If you denote the ratio of FAST_CLK to ILO by k, and apply a math result,

$$edgeCount \approx \text{k} \times (1 - \text{z})$$

Or

$$edgeCount \approx \text{k} - \text{k} \times \text{z}$$

Notice that k is the ideal number of edges that would be counted if the ILO were perfectly accurate. The term k×z arises due to the ILO error. For the timer to be able to resolve the change in edgeCount due to the k×z term, k×z must be greater than 1. So if an ILO error of z=0.1% must be resolved, then k should be greater than 1000 so that k×z is greater than 1. When trimming the 1 kHz ILO with the IMO as reference, this ratio is high enough so as not to introduce appreciable error.

7.1.3 Accuracy of the Reference

In the previous derivation, you can assume that FAST_CLK is perfectly accurate. However, the error of the reference clock directly adds to the minimum error output from the trim procedure. The 3 MHz output is the most accurate range of the IMO and hence is chosen to source FAST_CLK.

It is interesting to note that the IMO can directly source FAST_CLK or be sent through the PLL or clock dividers, which introduce no additional error. As discussed earlier, the upper bound for this frequency is limited to 32 MHz.

Note: Even in the worst case, the 16-bit timer does not dictate the limit on FAST_CLK frequency. When ILO is at lower limit of accuracy (500 Hz), the maximum FAST_CLK frequency that the 16-bit timer can handle without overflow is 65536 × 500 ≈ 32.7 MHz > 32 MHz.

7.1.4 Resolution of Trim Registers

How closely the ILO frequency can approach 1 kHz depends on the resolution (that is, the Hz/bit) of the trim registers. As shown in *Figure 2*, there are two trim ranges: fine trim and coarse trim. The coarse trim bit ct_range is not necessary when trimming the 1 kHz ILO. Thus, 6 bits are left (4 bits of tr_1k and 2 bits of ctrim) to trim the ILO.

From simulated ILO data over process, voltage and temperature, the maximum fine trim step is 128 Hz. This means that the closest that you can get to 1 kHz with certainty is ±128/2 = ±64 Hz or ±6.4%.

The effective accuracy of the trim procedure depends on the cumulative error from the 3 sources just discussed. Adding the three, the total error expected for PSoC 3 is less than ±7.5%.Thus, you can trim the ILO to within a range of (925, 1075) Hz.

7.1.5 Trim Procedure

The trim procedure implementation is completely in firmware:

Start Function: Starts all the Components, but disables the CorrectionISR. Similar to Components in the Cypress Component catalog, there are associated Stop, Sleep and Wakeup functions.

BeginTrimming Function: Enables the CorrectionISR.

CorrectionISR: Is an interrupt service routine triggered every second timer capture. These two capture values are used to calculate the edgeCount. The edgeCount is then compared to the upper (+6.5% + Ref_Error%) and lower (-6.5% – Ref_Error%) bounds for counted edges. If the edgeCount is outside this range, then the frequency of the ILO is adjusted by a unit trim step based on the sign of the error. If the edgeCount is within this range, then the CorrectionISR disables itself. For simplicity, a sequential search method is employed instead of a binary/proportional search algorithm.

CheckStatus Function: Checks whether the ILO frequency has drifted outside the optimal frequency range. If it has, the BeginTrimming function can be called.

CheckError Function: Similar to the CheckStatus function, but calculates the ILO error in parts per thousand.

7.2 IMO Trim Design Considerations

When trimming the IMO, the FAST_CLK is an IMO-sourced clock (either the IMO directly or via the PLL/clock dividers) and the SLOW_CLK is the 32 kHz crystal oscillator output. The design considerations for the IMO trim Component are very similar to that of the ILO.

7.2.1 Accuracy Attainable

The accuracy attainable by the IMO trim Component depends on the same three factors as the ILO trim Component:

- Ratio of IMO_CLK to the 32 kHz clock
- Accuracy of the 32 kHz crystal
- Resolution of trim registers

7.2.2 Ratio of IMO_CLK to 32-kHz Clock

Assume that the edges of the IMO are counted for every n (Averaging_Duration) cycles of the 32 kHz clock. Then:

$$edgeCount = \frac{\text{IMO\_CLK}}{\frac{\text{32kHz\_CLK}}{\text{n}}}$$

Let error of the IMO_CLK be z%, where z is small and can be either negative or positive. Then:

$$edgeCount = \text{IMO\_CLK} \times (1 + \text{z}) \times \frac{\text{n}}{\text{32kHz\_CLK}}$$

If you denote the ratio of IMO_CLK to 32kHz_CLK by k,

$$edgeCount = \text{k} \times \text{n} \times (1 + \text{z})$$

Or

$$edgeCount = \text{k} \times \text{n} + \text{k} \times \text{n} \times \text{z}$$

Note that k×n is the ideal number of edges which would be counted if the IMO were perfectly accurate. The term k×n×z arises due to the IMO error. For the timer to be able to resolve its impact on edgeCount, k×n×z must be greater than 1. For example, if you need to resolve an IMO error of z=±0.01%, then k×n should be greater than 10,000 so that k×n×z is greater than 1. In the Component, n (Averaging_Duration) is a user-supplied parameter, while k depends on the frequency used for the IMO_CLK input.

7.2.3 Accuracy of the 32 kHz Crystal

The error of the 32 kHz crystal directly adds to the minimum error output from the trim procedure. Most crystals have an effective error in the range of ±0.01%.

7.2.4 Resolution of Trim Registers

As shown in *Figure 3*, there are 11 trim bits for the IMO. From empirical data, the step size (kHz/bit) across frequency, voltage and temperature is 0.06% of the IMO frequency per LSB of trim. This means that the closest you can get to a selected IMO frequency is ±0.03%.

Adding the three error sources, you can expect the accuracy of the IMO when using the trim Component to be better than ±0.05%.

7.2.5 Trim Procedure

The firmware structure for trimming the IMO is exactly the same as that for the ILO. The only difference is in the values (frequencies, accuracy range) used within the routines.

8 Component Performance

Table 2 and Table 3 list the performance of the two trim Components in terms of accuracy, lock-time, and resource usage.

Table 2. kHz_ILO_Trim Performance

Performance		
CPU cycles per iteration	314 (PSoC 3), 148 (PSoC 5LP)	
CPU percentage used*	0.65% (PSoC 3) 0.31% (PSoC 5LP)	
Accuracy wrt Ref_Clk	±6.5%	
Lock Time**	32 ms	
Code (bytes)	776 (Flash) + 23 (RAM)	
Resources	**Fraction**	**Percentage**
Datapath	2 of 24	8.3%
Status cells	1 of 24	4.2%
Control/count7 cells	1 of 24	4.2%
PLDs	2 of 48	4.2%
Macrocells	6 of 192	3.1%
Interrupts	1 of 32	3.1%
Digital clock dividers	0 of 8	0.0%
Sync blocks	1 of 92	2.2%

*Assuming 1 fine trim iteration every 2nd ILO cycle

** Worst lock time – from +100% error to minimum error

Table 3. IMO_Trim Performance

Performance	
CPU cycles per iteration	312 (PSoC 3), 147 (PSoC 5LP)
CPU %age used*	0.31% (PSoC 3) 0.14% (PSoC 5LP)
Accuracy wrt Ref_Clk	±0.05%
Lock Time**	125 ms
Code (bytes)	929 (Flash) + 26 (RAM)

Resources	Fraction	Percentage
Datapath	2 of 24	8.3%
Status cells	1 of 24	4.2%
Control/count7 cells	2 of 24	8.3%
PLDs	3 of 48	6.3%
Macrocells	8 of 192	4.2%
Interrupts	1 of 32	3.1%
Digital clock dividers	0 of 8	0.0%
Sync blocks	1 of 92	2.2%

*Assuming 1 trim iteration every 140 32 kHz cycles

** Worst lock time – from +1% error to minimum error

9 Summary

The PSoC contains two internal clock sources – the ILO and IMO. Using the Components presented in this application note, both the ILO and IMO can be trimmed during run time to improve their accuracy. The ILO was shown to achieve ±6.5% accuracy with respect to the reference clock, while the IMO could be trimmed down to ±0.05%. This adds a powerful feature to the unique, flexible clocking system in PSoC.

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10 Appendix A – IMO and ILO Frequency Variation Graphs

Figure 12. PSoC 3 ILO Frequency Variation vs. V_{DDD}

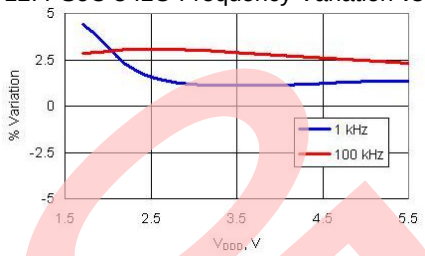


Figure 13. . PSoC 3 ILO Frequency Variation vs. T

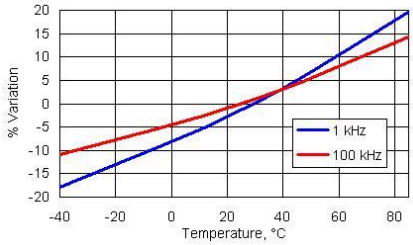


Figure 14. . PSoC 3 IMO Frequency Variation vs. V_{CCD}

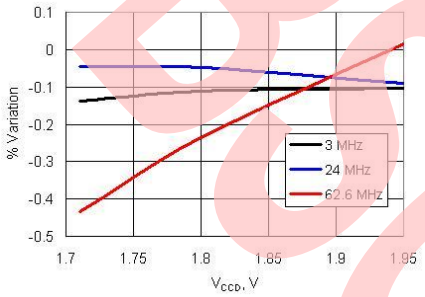


Figure 15. . PSoC 3 IMO Frequency Variation vs. T

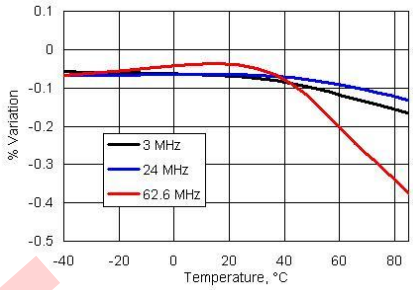


Figure 16. PSoC 5LP ILO Frequency Variation vs. V_{DDD}

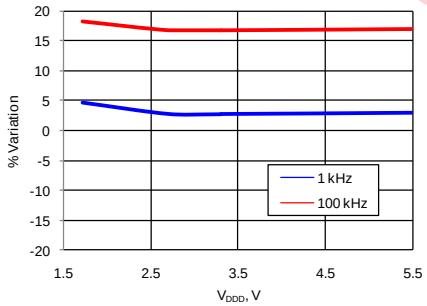


Figure 17. PSoC 5LP ILO Frequency Variation vs. T

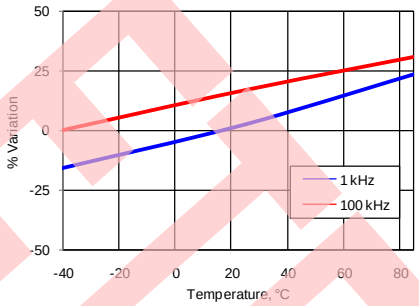


Figure 18. PSoC 5LP IMO Frequency Variation vs. V_{CCD}

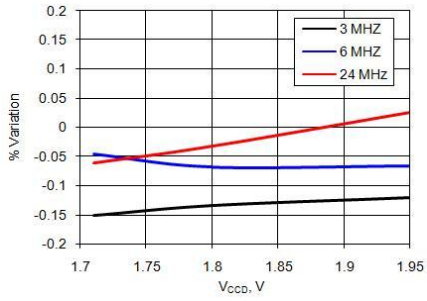
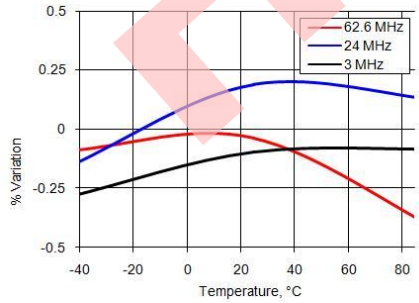


Figure 19. PSoC 5LP IMO Frequency Variation vs. T



11 Appendix B – Identifying Nominal Clock Frequencies

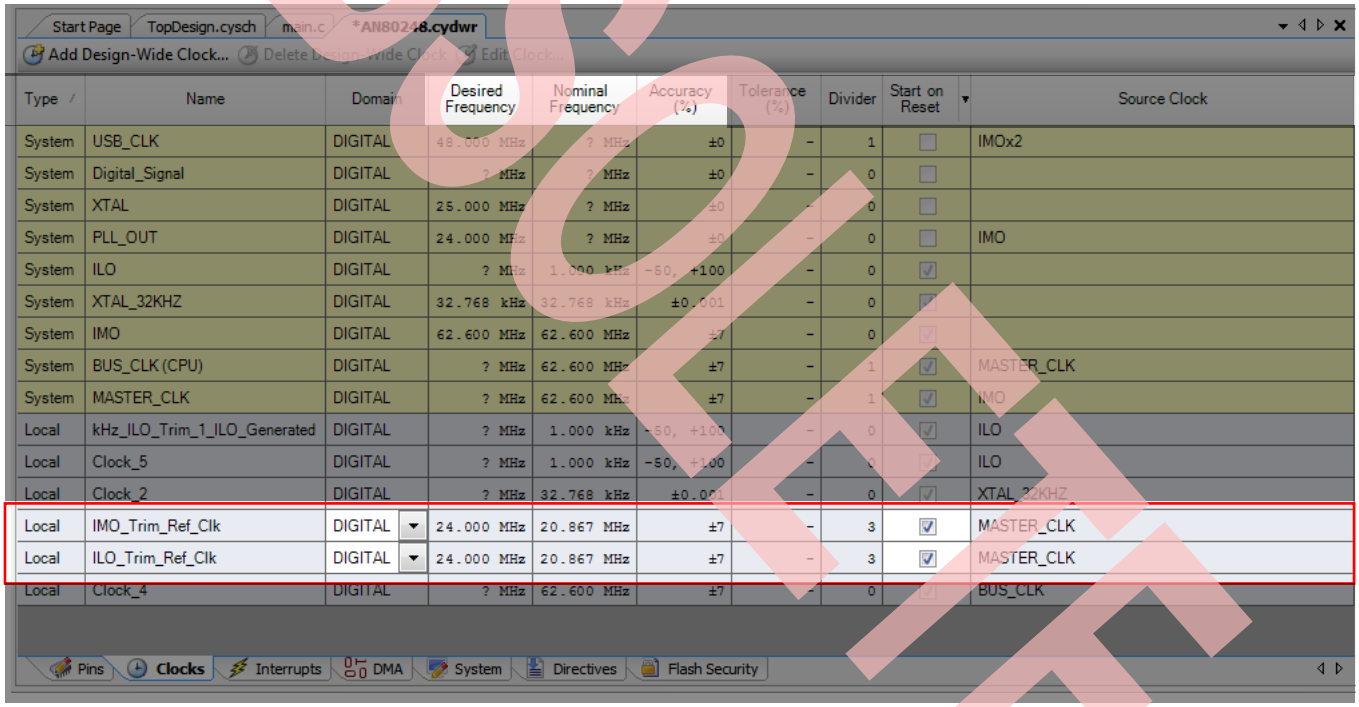
Figure 20 shows the Clocks tab of the design-wide resources file. The actual frequencies of all the clocks in your design appear under the **Nominal Frequency** column. There is also a **Desired Frequency** column which displays the expected/desired frequency of all fixed-frequency clocks in the system. If the desired frequency for a user-defined clock can be obtained through a 16-bit integer division of any of the enabled source clocks (MASTER_CLK, PLL, IMO, ILO, XTALs), then the desired and nominal frequency will be equal.

For the purpose of illustration, the IMO is set to 62.6 MHz, and the MASTER_CLK is sourced directly from the IMO. The PLL is disabled. As you can see in the figure, though the desired frequency for both IMO_Trim_Ref_Clk and ILO_Trim_Ref_Clk is 24 MHz, the nominal frequency is 20.867 MHz. The frequency value entered in the Component customizer must be this *nominal frequency*.

Another important piece of information conveyed by *Figure 20* is clock accuracy in percentage values. For each clock in your system, there is a corresponding accuracy value listed under the **Accuracy** column.

Note: To make the desired and nominal frequencies the same in this case, set the desired frequency to an integer-divided MASTER_CLK value. One example of such a setting is IMO_Trim_Ref_Clk and ILO_Trim_Ref_Clk configured for 31.3 MHz which is MASTER_CLK/2.

Figure 20. System Clocks Tab in AN80248.cydwr File



12 Appendix C – main.c code for the Test Project

```
void main()
{
    int16 errIMO, errILO;   /* temporary variables to store IMO, ILO error */
    char dispError[8];            /* buffer to print to LCD display */

    LCD_Char_1_Start();

    LCD_Char_1_Position(0,0);
    LCD_Char_1_PrintString("IMO Err:");

    LCD_Char_1_Position(1,0);
    LCD_Char_1_PrintString("ILO Err:");

    IMO_Trim_1_Start();
    IMO_Trim_1_BeginTrimming();

    kHz_ILO_Trim_1_Start();
    kHz_ILO_Trim_1_BeginTrimming();

    /* The Components use interrupts - so enable global interrupts */
    CyGlobalIntEnable;

    for(;;)
        {
        errIMO = IMO_Trim_1_CheckError();       /* in parts per million */
        errILO = kHz_ILO_Trim_1_CheckError();   /* in parts per thousand */

        /* Similar to the CheckStatus function, the CheckError function returns
         * the value ISR_ON if the ISR is running, and NOT_READY if the Timer
         * FIFO is not full.
         */
        if((errIMO != IMO_Trim_1_ISR_ON) && (errIMO != IMO_Trim_1_NOT_READY))
        {
            /* Display IMO Error on LCD */
            LCD_Char_1_Position(0,8);
            sprintf(dispError, "%+.3f", (float)errIMO/10000); /* convert to % */
            LCD_Char_1_PrintString(dispError);
            LCD_Char_1_Position(0,14);
            LCD_Char_1_PrintString(" %");

            /* One method to ascertain whether trimming is required:
             * If the IMO accuracy is outside +/-0.05%, begin trimming.
             * IS_BETWEEN(VALUE, LOW, HIGH) is defined in the Component's .h file.
             * It checks whether value is between the low, high bounds specified.
             */
            if(!IS_BETWEEN(errIMO, -500, 500))
            {
                IMO_Trim_1_BeginTrimming();
            }
        }

        if((errILO != kHz_ILO_Trim_1_ISR_ON) && (errILO != kHz_ILO_Trim_1_NOT_READY))
        {
            /* Display ILO Error on LCD */
            LCD_Char_1_Position(1,8);
            sprintf(dispError, "%+.3f", (float)errILO/10);    /* convert to percent */
            LCD_Char_1_PrintString(dispError);
            LCD_Char_1_Position(1,13);
```

```
            LCD_Char_1_PrintString("%  ");
        }

        /* Give a sufficient delay between CheckError and CheckStatus */
        CyDelay(100);

        /* The other method which can be used to check whether trimming is
         * required is by using the CheckStatus function. If the return value
         * is IS_INACCURATE, the BeginTrimming() function is called.
         */
        if(kHz_ILO_Trim_1_CheckStatus() == kHz_ILO_Trim_1_IS_INACCURATE)
        {
            kHz_ILO_Trim_1_BeginTrimming();
        }

/* This delay allows us to observe the LCD clearly */
        CyDelay(500);
    }
}
```

Document History

Document Title: AN80248 - PSoC® 3 / PSoC 5LP Improving the Accuracy of Internal Oscillators

Document Number: 001-80248

Revision	ECN	Orig. of Change	Submission Date	Description of Change
**	3680731	ANTO	07/17/2012	New Application Note.
*A	3712498	ANTO	08/14/2012	Updated IMO Basics. Updated Component Usage (Updated kHz_ILO_Trim (Updated Parameters), updated IMO_Trim (Updated APIs), updated Test Project Description (Updated TopDesign Schematic, updated *main.c*, added Expected Output)). Updated Component Internal Implementation (Updated ILO Trim Design Considerations (Updated Trim Procedure)). Updated Component Performance. Updated Summary. Updated Appendix A – IMO and ILO Frequency Variation Graphs. Updated Appendix B – Identifying Nominal Clock Frequencies. Added Appendix C – main.c code for the Test Project.
*B	3793652	ANTO	09/25/2012	Updated AN document to clearly state that the ±1% spec for IMO is for CY8C36 and CY8C38 parts. Updated Components with bug fixes Uploaded a single example project for the AN
*C	3832945	ANTO	12/11/2012	Added two APIs to each of the Components, Updated Datasheets, Updated AN document and Components (project) for PSoC 5LP. Added the Trim_Components project to the AN80248 workspace
*D	3941636	ANTO	3/22/2013	Updated for PSoC Creator 2.2. Added GetTrim and SetTrim functions to Components.
*E	4828954	DRSW	07/10/2015	Removed note about legacy PSoC 5 support. Added note that ILO Trim Component is now in PSoC Creator (as of PSoC Creator 3.0). Updated to new template. Completing Sunset Review.
*F	5702274	AESATMP8	04/19/2017	Updated logo and Copyright.
*G	5775930	MKEA	06/16/2017	Obsolete document. Completing Sunset Review.

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