Application Report
SLAA321A – August 2006 – Revised August 2018

MSP430FW42x Scan Interface SIFDACR Calibration

MSP430 Applications

ABSTRACT

This application report helps the reader become familiar with the features of the Scan Interface module on MSP430™ microcontrollers (MCUs) that relate to calibration of the SIFDACRx threshold limits for the channel input comparator control circuitry. This application report describes two methods of calibration, *Text Cycle Insertion* and *Direct Comparator Measurement*.

Related source code is available from www.ti.com/lit/zip/slaa321.

Contents

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1 Scan Interface Calibration Methodology

When an application uses the Scan Interface (SIF) module, proper calibration of the SIFDACRx registers is critical for correct interpretation of the compare or channel input applied to the SIF comparator. Without proper calibration (or recalibration), sensor drift or system noise can corrupt data interpretation, thus creating inaccurate or erroneous results.

Two primary methods of calibration are implemented in the scan interface module. Selecting the appropriate method for calibration depends on the types of circuitry used and the types of signals being compared. Knowing this information, the appropriate calibration methodology can be selected. The first calibration method, and the only one that is 100% integrated into the scan interface module, is the Test Cycle Insertion (TCI). The second calibration methodology is the Direct Comparator Measurement (DCM).

The TCI method uses built-in control circuitry to insert a test-cycle operation within a normal scan cycle. The DCM performs direct timing analysis of the resulting comparator signal by interfacing the scan interface comparator output to the capture/compare inputs of the Timer1_ A.

2 Scan Interface Configuration Overview

Before you begin the calibration methodology, set up some basic configuration. First, identify the applied inputs and configure them properly. Next, identify which type of sensor input is applied, and choose the appropriate scan interface configuration setting using SIFCTL2. Finally, configure the scan frequency using SIFCTL4, and generate the measurement timing using SIFTSMx.

2.1 Scan Interface Input Configuration

Before proceeding into the appropriate calibration operation, first select the input interface requirements. If using either the excitation (for LC sensors) or sample-and-hold (for half-bridge sensors like GMR) interfaces, SIFCH.0 to SIFCH.3 can be used. If using a direct comparator input, SIFCI.0 to SIFCI.3 can be used. When selecting the appropriate input, enable the alternate function of the ports and define the port direction as input.

2.2 Scan Interface Register Configuration

The primary configuration concerns relate to the operation configuration for the SIFCH.x channel input configuration for LC excitation or resistive-sensor sample-and-hold circuits, or for the SIFCI.x direct comparator input. SIFCTL2 maintains the differences in configuration. If the direct comparator inputs SIFCI.x are used, then SIFCAX = 1. If the LC excitation or resistive-sensor sample-and-hold circuits on SIFCH.x are used, then SIFCAX = 0.

Table 1 lists the settings for the LC excitation, resistive-sensor sample-and-hold circuits, and direct comparator inputs.

Table 1. Excitation, Sample/Hold, and Direct Comparator Input Configurations

Name	Value SIFCTL2	Description
LC excitation sensors	SIFCAX = 0 SIFSH = 0 SIFVCC2 = 1	SIFCH.x channel inputs applied Excitation circuitry enabled Vmid generator for LC sensor active
Resistive sample-and-hold sensors	SIFCAX = 0 SIFSH = 1 SIFVCC2 = 0	SIFCH.x channel inputs applied Sample/hold circuitry active Vmid generator for inactive (not necessary for sample-and-hold)
Direct comparator inputs	SIFCAX = 1 SIFSH = 0 SIFVCC2 = 0	SIFCI.x or SIFCI inputs are applied directly to the comparator, as controlled by SIFCISEL, SIFCACI3, and SIFCHx.

2.3 Scan Interface Scan Frequency

Whenever using the scan interface, the scan frequency must be defined. This frequency is always derived from the ACLK clock frequency and is controlled by two divider stages in the scan interface module, SIFDIV3Ax and SIFDIV3Bx within SIFCTL4. For initial calibration, the scan frequency setting can be increased to result in faster completion. For recalibration, TI recommends that the application maintain the normal scan frequency with the test cycle. It is possible to recalibrate without using the test cycle insertion, but it is not recommended, as adjustment to the SIFDACx thresholds are required during the active state of the recalibration. This requires that the application deactivate the SIFCNT operation during the recalibration.

2.4 Timing State-Machine Configuration

With any operation of the scan interface, the timing state machine must be generated. When defining the timing state machine operation, the sensor type, DAC, and comparator settling time (typically 2.5 µs by design), and the sample capture time must all be considered.

If using an LC sensor, the LC sensor's excitation requirement, damping response, and sample time are most important. With the generation of the excitation pulse for the LC sensor, it is important to minimize the excitation period to achieve a peak amplitude that just clips the supply voltage. A longer excitation period defined by SIFEX (located in the SIFTSMx control register) has no additional benefit, as a clamping diode limits the energy output to the inductor. Following the excitation pulse, the LC oscillation decay period must be specified. In most cases, for a single LC sensor, this corresponds most effectively to 31 µs or 62 µs from excitation until the sample measurement. These times have been identified for most LC sensors to produce the largest delta between a damped and undamped condition. Finally, the sample capture time, SIFRSON (located in SIFTSMx control register), must be defined. Because damping material has a direct impact to the LC oscillation frequency, it is important to sample over two or three periods of oscillation. Following the excitation, decay, and sample of the first LC sensor, the same timing procedure must be applied for each additional sensor.

Unlike the procedure with LC sensors, when using the sampling/hold circuitry with resistive sensors, all sensors are measured at the same time. In this case, the SIFEX (located in SIFTSMx control register) defines the time when the resistive sensor is applied to an internal sampling capacitor. Upon completion of the sample, each channel can be applied as input to the comparator and compared to an appropriate SIFDACRx threshold. Because there are not any decay requirements, the operation can occur very quickly.

Finally, when using the direct comparator inputs, no SIFEX (located in SIFTSMx control register) pulse is required. The signal under observation is applied directly to the input of the comparator. In this case, only the measurement sample and channel switching times are relevant.

3 Test Cycle Insertion (TCI) Scan Interface

As indicated in Section 1, TCI utilizes additional control logic within the scan interface module to insert a test cycle into the scan period where a normal channel scan operation occurs. However, before proceeding into the details of the insertion methodology, first identify the operation conditions that call for this method of calibration. Only after identifying these criteria, proceed into the configuration, activation, and interpretation phases of the TCI operation. After identifying these conditions, the following sections discuss the advantages and disadvantages of this method for SIFDACRx calibration.

3.1 TCI Criteria

When considering using the TCI calibration methodology, three primary factors must be considered.

The first criterion for the TCI is the dynamic range of the signal that is to be measured by the comparator. If this range is very large, then this method may not be the most efficient method to use. In fact, it is possible that no calibration requirement may be needed at all.

The next criterion is the type of interface selection: GMR sensor, LC sensor, or normal comparator input. In most cases, with bridge sensor structure such as GMR, this is the only method possible. With LC sensors, if high accuracy is needed, this method may not be the ideal method. However, if drift adjustment is needed, this method can be applied in a very effective manner. With the normal comparator input, the tested signal behavior determines if this method is possible.

The last main criterion is signal drift. If the signal on the channel or comparator input selected is likely to be highly impacted by temperature or voltage, the need for recalibration may be desirable. In many cases, the TCI method is ideal for this operation.

3.2 TCI Advantages and Disadvantages

As with all calibration methods, the TCI has advantages and disadvantages. When considering using TCI, it is important to take these into consideration, as system operation and resources are impacted.

The primary benefit of TCI is that it is completely integrated into the scan interface module. This means that the power consumption of the operation is confined to just the scan interface module for the measurement acquisition. Additional CPU processing is required to interpret the measurement acquisition; however, this is also the case for all other calibration methods.

Additionally, with TCI, the insertion of the test cycle occurs within the normal cycle period. This is important, because it allows for easy integration of calibration to occur without impacting the normal measurement cycle. As seen in Figure 1, when setting SIFTESTD (located in SIFCTL1 control register) within the next normal cycle, a test cycle is also inserted. Interrupt generation possibilities exist for the test cycle, just as they exist for the normal cycle.

Furthermore, when using TCI, both measurement acquisition data and normal capture data is always valid. Integrated into the scan interface, along with the four normal capture registers (SIF0OUT, SIF1OUT, SIF2OUT, and SIF3OUT located in SIFCTL3), are two test capture registers (SIFTCH0OUT and SIFTCH1OUT located in SIFCTL2). These two test capture registers are updated only at the end of the test cycle and can be processed as needed.

The main disadvantage of using TCI is the speed of the calibration method. Because the test measurement acquisition is a sampled state, additional processing steps may be necessary to achieve the desired resolution result. This can be partly compensated by increasing the scan frequency, thus speeding up the TCI occurrence.

3.3 TCI Configuration

After confirming that the TCI method meets the calibration needs, first configure the scan interface module for handling this calibration operation. The primary control signal for the test-cycle insertion is SIFTESTD located in SIFCTL1. Upon setting this bit, a synchronized condition occurs that inserts a test cycle in the same period as a normal cycle.

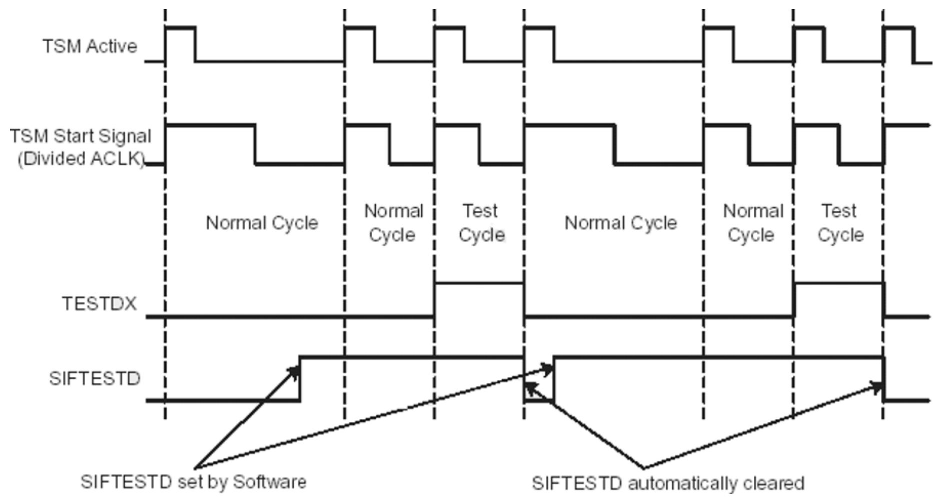

Figure 1. TCI Synchronization

3.4 TCI System Implementation

System implementation (see associated code files) uses two LC sensors interfaced to the scan interface excitation circuitry SIFCH.0 and SIFCH.1. When the TCI is applied by setting the SIFTESTD bit in SIFCTL1, the test cycle is inserted into a period along with a normal cycle. It is important that the normal cycle also occurs at the normal scanning interval. This ensures continuous resolution scanning for the normal cycle state captures. Figure 2 shows the system configuration used with this TCI example.

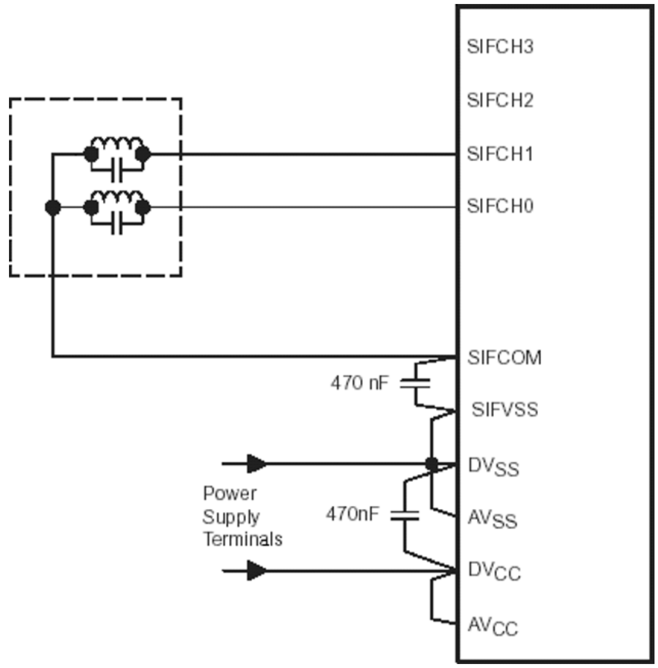

Figure 2. TCI System Configuration Example

Control for the TCI is maintained with the SIFTESTD bit in the SIFCTL1 register. Channel 1 in Figure 3 displays the SIFTESTD bit to the SIFIFG1 and SIFIFG2. Following the setting of SIFTESTD, the next scan cycle first consists of a normal cycle, then a test cycle. It is only at the completion of this test cycle that the SIFTCH0OUT and SIFTCH1OUT capture states are stored.

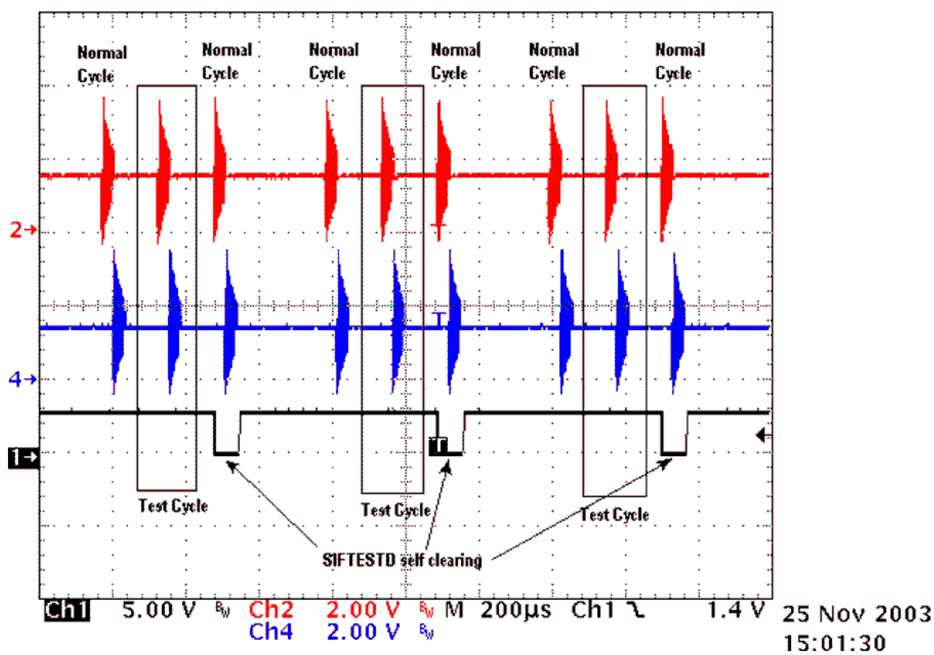

Figure 3. TCI LC Sensor Example

4 Direct Comparator Measurement (DCM) Scan Interface

Unlike TCI, an additional module is used when using the DCM. This module is Timer1_A. Specifically the Timer1_A capture/compare channels 2, 3, and 4 are used. With the DCM method, three signals are output from the scan interface to the Timer1_A capture/compare inputs. For additional details, see the scan interface module section internal signal connections to TimerA1_5 in the MSP430x4xx Family User's Guide.

4.1 DCM Criteria

The DCM methodology is intended to provide an alternate method for performing channel calibration. With DCM, it is possible to directly observe the comparator output for up to two selected channels. This is primarily optimized for LC sensor operation to detect oscillation peak occurrences above a specified SIFDACRx reference level.

As with TCI, DCM is also affected by the type of interface selection: GMR sensor, LC sensor, or normal comparator input. In most cases with a bridge sensor structure like GMR, this method is neither possible nor practical. With LC sensors, if achieving high accuracy is needed, this method is perhaps more ideal. As with TCI, if signal drift adjustment is needed, this method can also be applied in an effective manner. When using the normal comparator input, the sensor input signal type (static or dynamic) determines if this method is possible.

The last main criterion is signal drift. If the signal on the channel or comparator input selected is likely to be highly impacted by temperature or voltage, the need for recalibration may be desirable. In many cases, the DCM is possible, but perhaps the TCI method is more ideal for this operation as it utilizes measurement acquisition registers dedicated for calibration. Performing DCM occurs using the normal capture register SIFDACRx thresholds. Adjustment here could impact the normal measurement operation.

4.2 DCM Advantages and Disadvantages

As with TCI, DCM has advantages and disadvantages. When considering using DCM, it is important to consider these advantages and disadvantages, as they affect system operation and resources.

The primary benefit of DCM is the ability to directly observe the scan interfaces comparator output. This allows flexibility in determining resolution adjustments that are to be made to the reference SIFDACRx threshold levels.

The next benefit is that with SIFDACRx, it is possible to calibrate more than two channels simultaneously. However, when performing such an operation, timing is critical and CPU intensive.

Finally, when using DCM, measurements are performed, along with the normal cycle execution. As observed with TCI, one full normal cycle is always inserted after the second normal cycle.

The primary disadvantage with DCM is that the Timer1_A module is required. This means additional system resources and CPU processing is required. When using the Timer1_A, it requires an active reference clock. This also consumes additional power and, in many cases, also requires calibration. There are some special features built into the scan interface and Timer1_A that can eliminate/reduce these additional requirements. These are discussed in the following sections.

4.3 DCM Configuration

After identifying that the DCM method meets the calibration needs, first configure the scan interface module for handling this calibration operation. The control signal outputs SIFO0, SIFO1, and SIFO2 (shown in Figure 4 and described in Table 2) are applied to the Timer1_A capture/compare inputs 2, 3, and 4. These control signals are SIFCS (located in SIFCTL3) and SIFTESTS1 (located in SIFTSMx).

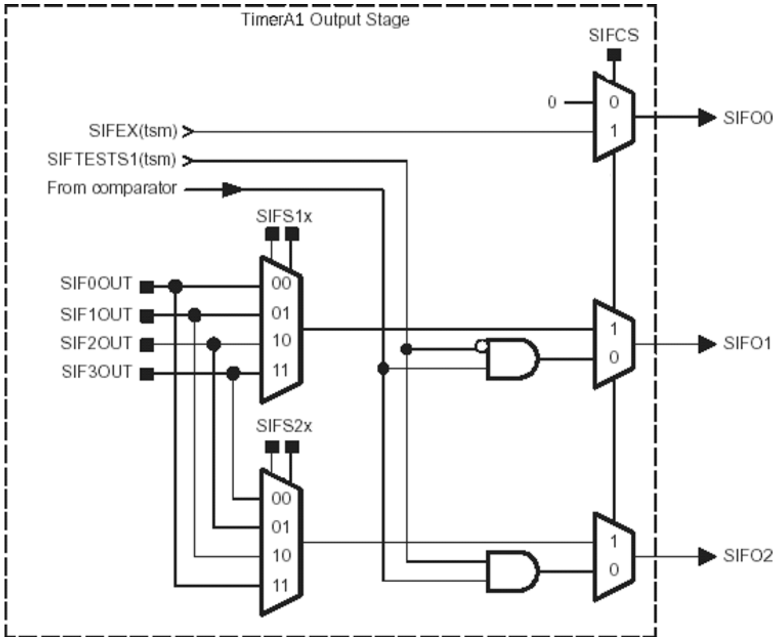

Figure 4. Timer1_A Output Stage From Scan Interface

Table 2. DCM Register Configuration

Name	Value SIFCTL2	Description
Comparator output configuration	SIFCS = 1, SIFTESTS1 = 0	SIFEX is applied to SIFO0. Scan interface comparator is applied to SIFO1.
	SIFCS = 1, SIFTESTS1 = 1	SIFEX is applied to SIFO0. Scan interface comparator is applied to SIFO2.
Measurement acquisition states	SIFCS = 0 SIFS1 = 00 SIFS2 = 01	SIFO0 = 0 SIFO1 = SIF0OUT, SIF1OUT, SIF2OUT, or SIF3OUT SIFO2 = SIF0OUT, SIF1OUT, SIF2OUT, or SIF3OUT

4.4 DCM System Implementation

Just like the TCI, the DCM system implementation uses two LC sensors interfaced to the scan interface excitation circuitry SIFCH.0 and SIFCH.1 (see Figure 2).

Unlike TCI, DCM uses the Timer1_A for measuring comparator activity. Therefore, in addition to configuration in the scan interface module, also configure the Timer1_A. However, before proceeding, it is necessary to understand the interface between the scan interface and Timer1_A. This was briefly described in Section 4.3, but is addressed in greater detail here.

The SIFO0, SIFO1, and SIFO2 signals are applied to the CCIxB inputs to the Timer1_A module. CCI2B is derived from SIFO0, CCI3B is derived from SIFO1, and CCI4B is derived from SIFO2.

In addition, operation of the Timer1_A is based upon a reference clock. This reference clock defines the resolution interval used by the Timer1_A counter. Because ACLK does not provide enough resolution when operating with a 32.768-kHz crystal, use TACLK or SMCLK. The selection of the Timer1_A clock source is controlled by the TASSELx bits in control register TA1CTL.

From here on, configuration of the Timer1_A directly follows the configuration described in the MSP430x4xx Family User's Guide.

4.5 DCM Calibration Calculation

Now that the interface between the scan interface module and the Timer1_A is understood, this section focuses on the DCM calibration methodology. Figure 5 shows the normal operation sequence that appears when observing the two LC sensor configurations of the scan interface module.

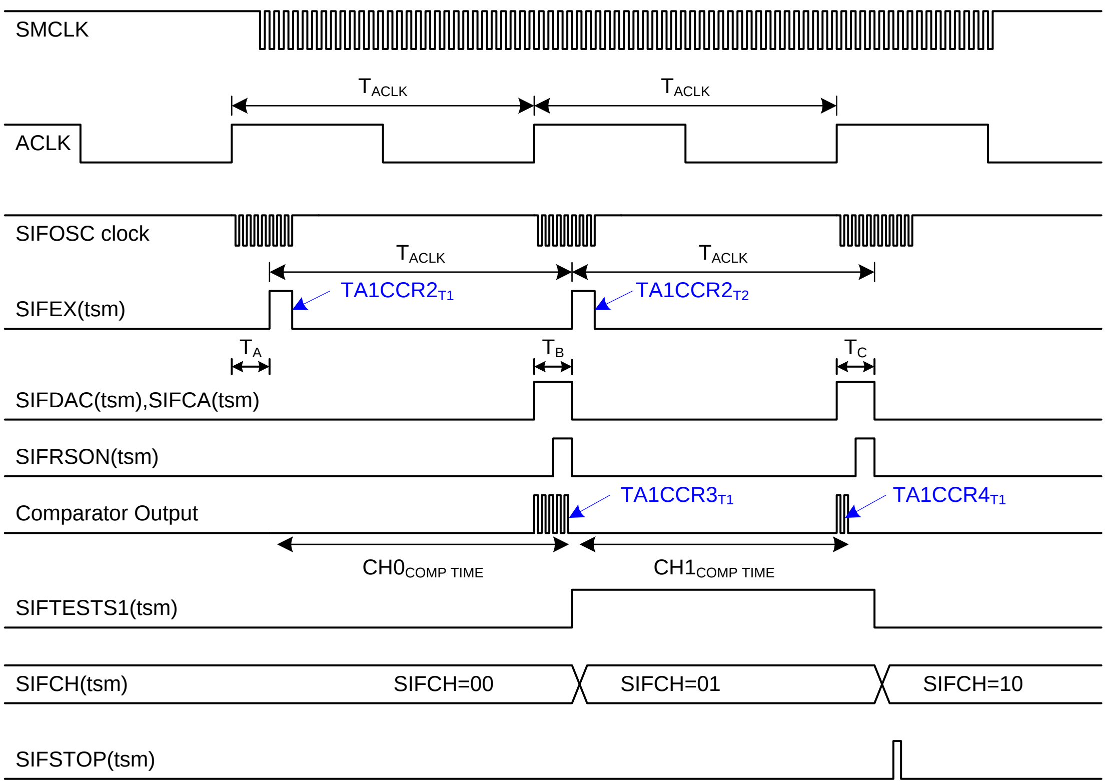

Figure 5. DCM Operation Example

There are two methods to use when using the SIFO signals with the Timer1_A for calibration. The first method is to use SMCLK for the clocking source for the Timer1_A. With this configuration, activation and deactivation of the SMCLK source must be maintained to minimize additional power consumption. In addition, if the internal DCO is used for SMCLK, calibration of this clock source is necessary to accurately measure comparator active states.

Knowing this, focus on another method of operation. This is using the Timer1_A TACLK clock source external to the device. However, the method requires no additional components, because the clock source that is used is generated by the scan interface. When using the SIFOSC generator for the scan interface high-frequency state machine resolution, it is possible to directly identify count intervals relative to the normal measurement capture, SIFRSON (located in SIFTSMx control register).

This is implemented by enabling the alternate function SIFCLKG output on P2.7 (device pin 30) and externally connecting this to the alternate function TA1CLK input on P2.5 (device pin 32). Doing this makes a stable reference clock to the SIFRSON (bit located in SIFTSMx control register) generation, which is ideal for calibration. Furthermore, for the measurements, the count location, rather than the time interval, is critical.

The following equations show the calculation required for determination of the channel comparator active times. Again, note that if SMCLK is used for Timer1_A source, calibration of SMCLK necessary for accurate measurement of channel comparator pulse active time.

$$T_{SMCLK} = 1 / (32768\ \text{Hz} \times (TA1CCR2_{T2} - TA1CCR2_{T1})) \quad (1)$$

$$CH0_{COMP\ ACTIVE\ TIME\ (from\ SIFEX(tsm))} = T_{SMCLK} \times (TA1CCR3_{T1} - TA1CCR2_{T1}) \quad (2)$$

$$CH1_{COMP\ ACTIVE\ TIME\ (from\ SIFEX(tsm))} = T_{SMCLK} - (TA1CCR4_{T1} - TA1CCR2_{T2}) \quad (3)$$

These equations require considerable additional calculation. Instead, if using the SIFCLKG TA1CLK input, these calculations can be eliminated, and sensor state determination can be performed, based on where the last captured comparator pulse has occurred. Because the SIFCLKG clock pulses are fixed for the scan measurement cycle, identification of when an LC sensor is 100% damped, compared to 100% undamped, is based purely upon the values contained in $TA1CCR3_{T1}$ and $TA1CCR4_{T1}$.

5 References

1. MSP430x4xx Family User's Guide
2. MSP430FW42x Mixed-Signal Microcontrollers data sheet
3. Rotation Detection With the MSP430 Scan Interface
4. MSP430FW42x Scan Interface SIFCLK Adjustment

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from August 1, 2006 to August 2, 2018	Page
• Editorial and formatting changes throughout document	1

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