QTouch® Modular Library Peripheral Touch Controller User's Guide

Description

The Microchip QTouch® Peripheral Touch Controller (PTC) offers built-in hardware for capacitive touch measurement on sensors that function as buttons, sliders, and wheels. The PTC supports both mutual and self-capacitance measurements without the need for any external component. It offers superb sensitivity and noise tolerance, as well as self-calibration, and minimizes the sensitivity tuning effort by the user. It also extends the support for capacitive touch surface and gesture functionality.

The PTC is intended for autonomously performing capacitive touch sensor measurements. The external capacitive touch sensor is typically formed on a PCB, and the sensor electrodes are connected to the analog charge integrator of the PTC using the device I/O pins. The PTC supports mutual capacitance sensors organized as capacitive touch matrices in different X-Y configurations, including Indium Tin Oxide (ITO) sensor grids. In Mutual Capacitance mode, the PTC requires one pin per X-line (driveline) and one pin per Y-line (sense line). In Self-Capacitance mode, the PTC requires only one pin with a Y-line driver for each self-capacitance sensor.

Features

- Implements Low-Power, High-Sensitivity, Environmentally Robust Capacitive Touch Buttons
- Supports Mutual Capacitance and Self-Capacitance Sensing
- Up to 46 Buttons in Self-Capacitance mode
- Up to 529 Buttons in Mutual Capacitance mode
- Supports Lumped Mode Configuration
- One Pin Per Electrode
- Load Compensating Charge Sensing
- Parasitic Capacitance Compensation for Mutual Capacitance mode
- Adjustable Gain for Superior Sensitivity
- Zero Drift Over the Temperature and V_{DD} Range
- No Need for Temperature or V_{DD} Compensation
- Hardware Noise Filtering and Noise Signal De-Synchronization for High Conducted Immunity
- Atmel Start QTouch Configurator Support – Wizard Guided Touch Project Creation

Product Support

For assistance related to QTouch capacitive touch sensing software libraries and related issues, contact your local Microchip sales representative or visit https://www.microchip.com/support/.

Table of Contents

1. Introduction

The QTouch® Modular Library (QTML) provides the touch-sensing functionality of a QTouch Library under a modular architecture. By dividing the library into functional units, an application developer can include only those modules which provide functionality relevant to the target application, thereby saving both device memory and processing time.

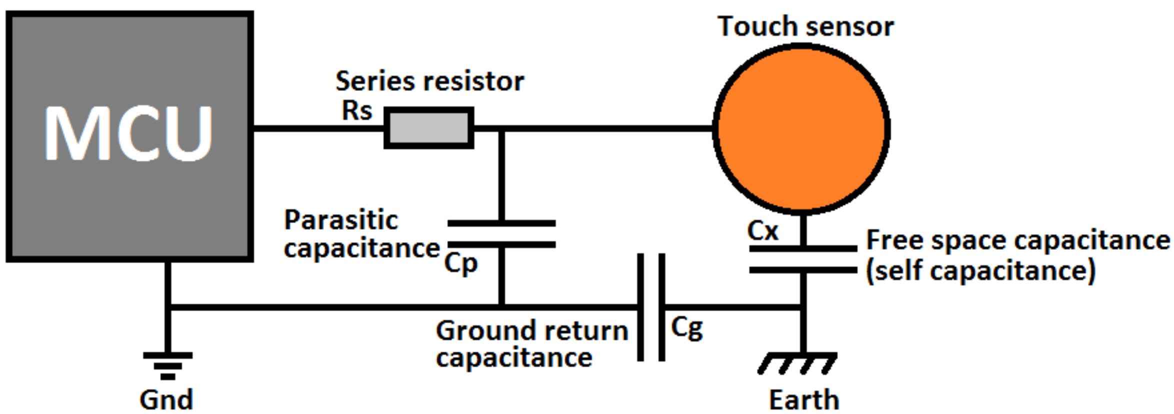
2. Capacitive Touch Measurement

The QTouch Modular Library supports PTC measurement of self-capacitance and mutual capacitance touch sensors on a selection of AVR®, Arm® Cortex-M0+, Arm Cortex-M23, and Arm Cortex-M4 microcontrollers.

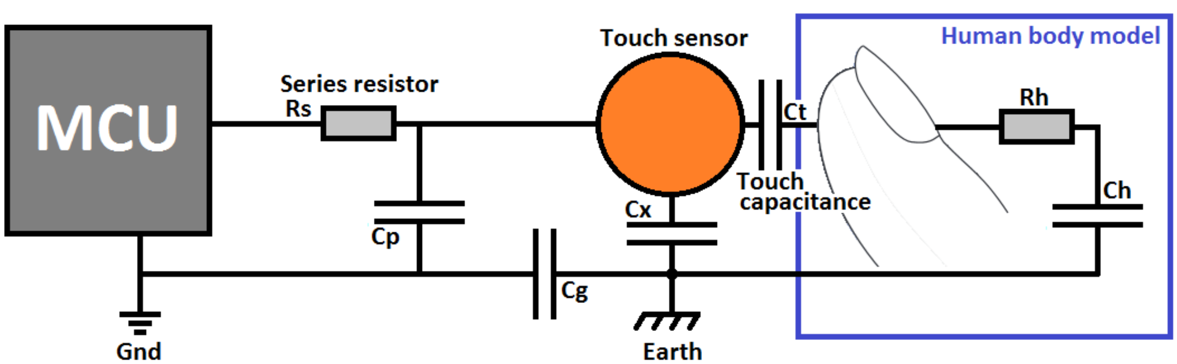
In all current capacitive touch measurement methods, one of two basic functional approaches is implemented: Self-capacitance or mutual capacitance.

2.1 Self-Capacitance

Self-capacitance refers to a capacitive measurement using a single sensor electrode to measure the apparent capacitance between the electrode and the DC ground of the touch sensor MCU circuit.



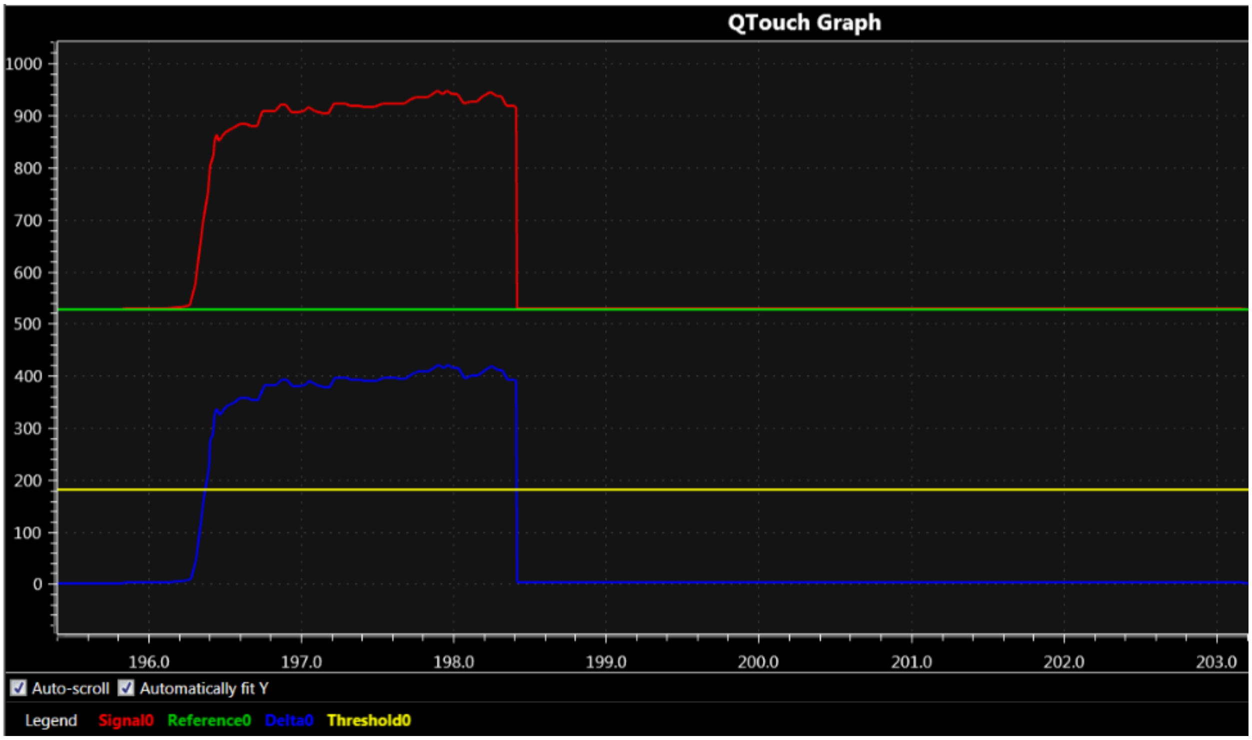
At power-on or Reset, a baseline measurement of the capacitance is recorded and assumed to be the *'Out Of Touch'* capacitance. Reference capacitance is the combination of Cp in parallel to the series pair Cg and Cx.



When a touch contact is applied, the capacitance is increased by the introduction of a parallel path to earth, via the series combination of Ct and Ch. The increase is compared to the touch threshold, and if exceeded, the sensor is indicated to be *'In Touch'*.

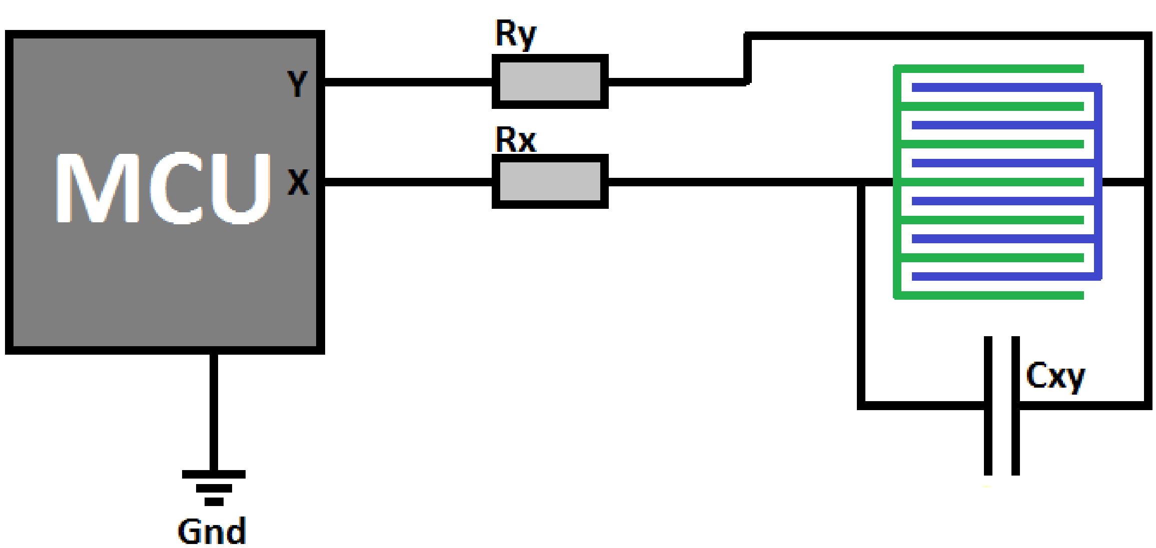
Note: Cx, the human body capacitance, varies by person and surroundings and is typically in the order of 100 pF to 200 pF. The touch contact Ct, however, is more consistent and much smaller at typically 1 pF to 5 pF, depending primarily on the design and construction of the touch sensor and secondly on the size of the finger used to activate the sensor.

As the dominant component in a pair of series capacitors is the smaller one, in this case, Ct, a well-designed and tuned sensor shows very consistent sensitivity to touch contact with little dependence on the user.

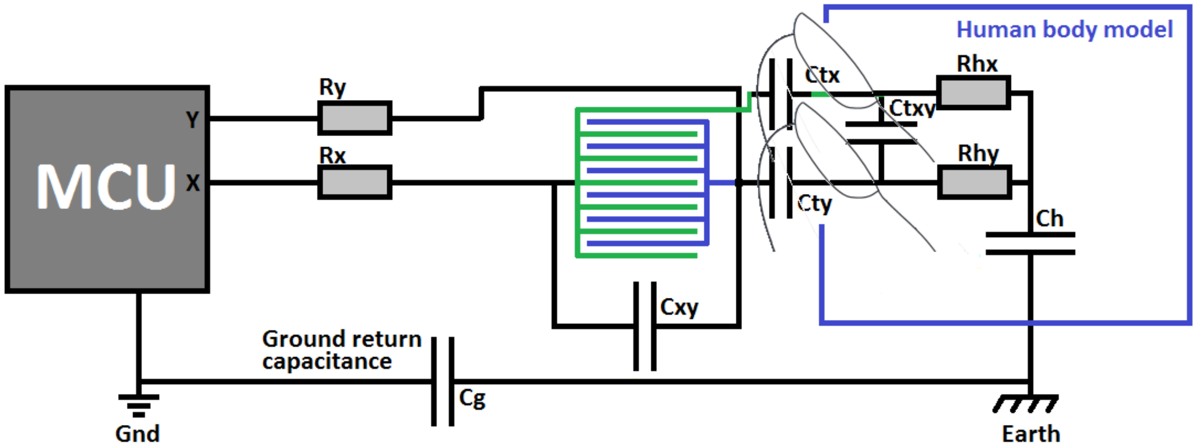


2.2 Mutual Capacitance

Mutual capacitance refers to a capacitive measurement using a pair of sensor electrodes to measure the apparent capacitance between them. Typically, one electrode acts as the Driver (X), while the other is the receiver (Y). Each physical location where an X electrode transfers charge to a Y electrode is a sensor node, and this is the location of touch sensitivity.



As with self-capacitance, a baseline measurement of the capacitance is recorded and assumed to be the *'Out Of Touch'* capacitance. Reference capacitance is the apparent capacitance between the X electrode and the Y electrode. Unlike self-capacitance, the reference capacitance does not depend on an earth return.



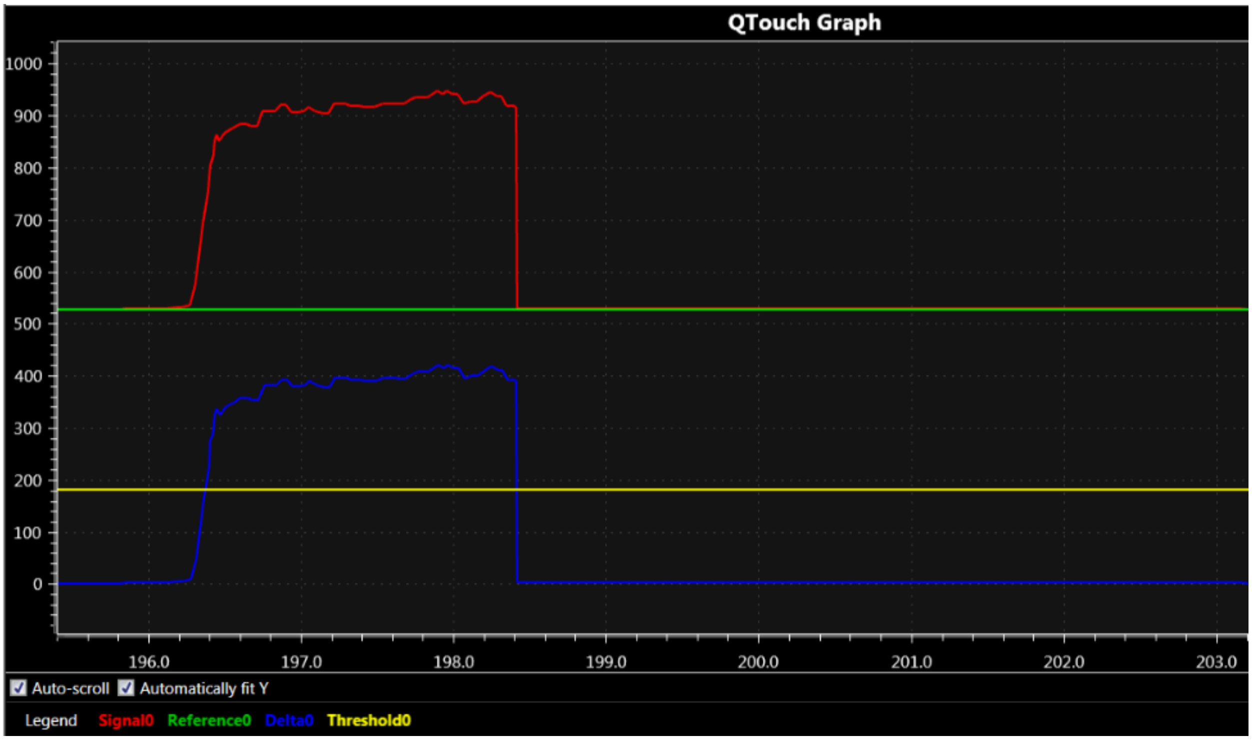
Interaction between a mutual capacitance sensor and the human body is more complex. It may be modeled by considering two separate touch contacts to the X and Y electrodes, where each is capacitively coupled to the body, resistively connected to each other inside the body and capacitively coupled to earth via the human body capacitance.

A touch contact has two competing effects:

- The introduction of a conductive plate (finger) to both X and Y electrodes increases the capacitance between X and Y. This occurs if any conductive part is placed over the sensor.
- The addition of another capacitance (Ch + Cg) at the XY node provides an alternative path for the energy emitted by the X electrode, reducing the amount of charge accumulated on the sensor. This effect is manifested as an apparent reduction in the XY capacitance and occurs only if the body of material connected to the conductive part has a significant self-capacitance.

When a real touch contact is placed, the second (reducing) effect is much greater than the first (increasing) effect, and so a touch contact on a mutual capacitance sensor is indicated by an apparent reduction in sensor capacitance.

This apparent change in capacitance (delta) is compared to the configured touch threshold, and if it exceeds the threshold, then the sensor is deemed to be in detect.


QTouch Graph
1000
900
800
700
600
500
400
300
200
100
0
196.0
197.0
198.0
199.0
200.0
201.0
202.0
203.0
Auto-scroll
Automatically fit Y
Legend
Signal0
Reference0
Delta0
Threshold0

3. Touch Sensors

Capacitive sensors may be implemented to simply detect contact as a button replacement, or functionally extended to provide a relative measurement of distance (proximity), 1D position (slider or wheel), 2D position (QTouch Surface), or 3D position (QTouch Surface with proximity).

In each case, the modular library detects a touch contact by a change in capacitance exceeding a pre-configured threshold. Once a contact has been confirmed, the various post-processing modules use the calculated touch delta to interpolate amongst neighboring sensors and calculate the location of the touch position or relative proximity.

3.1 Buttons

The simplest implementation of a capacitive sensor is a button, where the sensor consists of a single node (one electrode for self-capacitance, one pair of electrodes for mutual capacitance) and is interpreted as a binary state; In Detect or Out of Detect.

3.2 Proximity Sensor

An extension of the button is a proximity sensor. A single sensor node is monitored for a change in capacitance exceeding a pre-configured threshold. In the same way as the button, the sensor is considered to be *'In Detect'* when that threshold is exceeded. Once in detect, a relative measurement of the contact distance is made by scaling the touch delta between two thresholds - the initial *'Detect'* threshold and a second *'Full Contact'* threshold.

Note: As the proximity sensor relies on the capacitive load of a distant object, the 'apparent distance' to the contact will depend on the shape and size of the contact.

I.e., an open hand in proximity at 10 cm will 'appear' closer than an extended finger at 10 cm, as it has a larger influence on capacitance due to a larger surface area at the same distance.

Capacitance (C) is proportional to Area (A) and inversely proportional to distance (d). Also, the grounding has a significant impact on sensitivity, and so does the range.

$$C \propto \frac{A}{d}$$

3.3 Lumped Sensor

A Lumped sensor is implemented as a combination of multiple sense lines (self-capacitance measurement) or multiple drive and sense lines (mutual capacitance measurement) to act as one single sensor. This provides the application developer with greater flexibility in the touch sensor implementation.

- Improve the touch sensor responsiveness by reducing the number of measurements and therefore, the time required for initial touch detection
- Fast position resolution by binary search
- Improved moisture rejection through 'All but one' key lumping in a touch button application
- Provide wake-on-touch functionality on any key (up to maximum capacitance limits) with significantly lower power consumption as only one sensor measurement is required for all keys
- Dual-purpose sensor electrodes – e.g., individual keys may be lumped together to form a proximity sensor

Touch detection on a lumped sensor is implemented in the same way as a single node touch button. The capacitance of the lump sensor is equal to or more than the sum of the individual sensors' capacitance. Lumping too many sensor may result in saturation. In general, the capacitance of the self-capacitance sensor is higher than the mutual capacitance sensor. The number of sensor electrodes that can be lumped is relatively less for self-capacitance designs.

3.4 Interpolated Sensors

An interpolated sensor utilizes the touch delta of two or more adjacent sensor nodes arranged in a row to calculate the position of a touch contact along that row. The sensor layout is designed and the threshold configured in such a way that a contact anywhere along the sensor will cause:

1. **A touch delta exceeding the threshold on at least one sensor node.** The node with the strongest touch delta is determined to be the center node of the touch contact and identified the approximate location of the touch contact.
2. **Some touch delta on neighboring nodes, used for position interpolation between nodes.** The relative delta on the nodes to the left and right of the center node are used to adjust the calculated touch position towards the side with the strongest delta.

An interpolated sensor may be formed into any physical shape, with or without a wrap-around from the last sensor to the first. A sensor with wrap-around is configured as a *'Wheel'*, while one without is configured as a *'Slider'*. In the case of the wheel, a touch contact centered on the 1^{st} key uses the last key for *'left'* interpolation and vice versa while the slider option implements a dead band at the ends.

3.5 2D Position Sensors

Where a linear sensor is physically implemented as a line of keys, the same approach may be extended to 2D position detection through a grid of keys. The keys are designed such that interpolation may be made in either the vertical or horizontal direction, and two separate touch contacts may be individually resolved in their interpolated positions.

3.6 Mix and Match

The QTouch Modular Library allows an unprecedented degree of combinations implementing different sensor types and measurement technology, in many cases utilizing the same sensor electrodes in multiple ways and within the same firmware application.

For example, a 2D position sensor using mutual capacitance key sensors may be lumped or partially lumped in Mutual Capacitance mode to provide proximity measurements and the Y lines individually measured in Self-Capacitance mode to improve moisture immunity.

4. PTC

4.1 Overview

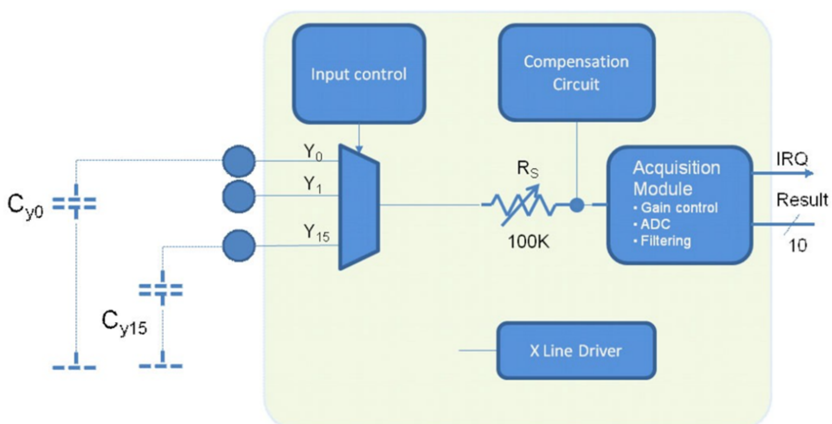
The Microchip QTouch® Peripheral Touch Controller (PTC) offers built-in hardware for capacitive touch measurement on sensors that function as buttons, sliders, and wheels. The PTC supports both mutual and self-capacitance measurements without the need for any external components. It offers superb sensitivity and noise tolerance, as well as self-calibration, and minimizes the sensitivity tuning effort by the user.

The PTC is intended for autonomously performing capacitive touch sensor measurements. The external capacitive touch sensor is typically formed on a PCB, and the sensor electrodes are connected to the analog charge integrator of the PTC using the device I/O pins. The PTC supports mutual capacitance sensors organized as capacitive touch matrices in different X-Y configurations, including Indium Tin Oxide (ITO) sensor grids.

4.2 Self-Capacitance

In Self-Capacitance mode, the PTC requires only one pin with a Y-line driver for each self-capacitance sensor.

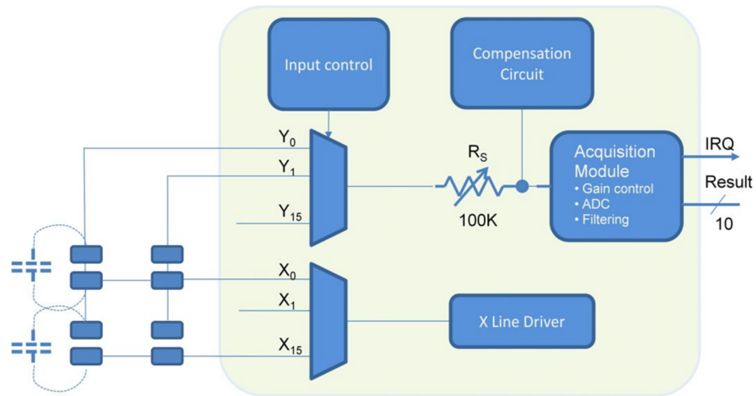
Figure 4-1. Self-Capacitance PTC Measurement



4.3 Mutual Capacitance

In Mutual Capacitance mode, the PTC requires one pin per X-line (driveline) and one pin per Y-line (sense line).

Figure 4-2. Mutual Capacitance PTC Measurement



5. QTouch® Modular Library

5.1 Introduction

The QTouch Modular Library provides the touch-sensing functionality of a QTouch Library under the redesigned modular architecture. By dividing the library into functional units, it is possible for an application developer to include only those modules which provide functionality relevant to the target application, thereby saving both device memory and processing time.

5.2 QTouch® Library Modules

QTouch Library modules can be classified into three types based on the functionality, as shown below.

Acquisition Module	Signal Conditioning module	Post processing module
Acquisition auto tune module Acquisition run-time module	Frequency Hop module Frequency Hop Auto tune module	Touch Key module Scroller module
• Touch measurement • Channel sequencing • CC calibration • Auto/manual calibration of prescalar/series resistor/charge share delay	• Hop frequency • Median filter • Noise measurement • Change frequency based on noise	• Buttons post processing • Drifting, Detect integration • AKS groups • Slider/Wheel position • Touch active/inactive status • Hysteresis, IIR filtering

5.3 Module Naming Conventions

The naming conventions followed on the QTouch Library modules are given below.

```
qtm _ <module_name_identifier> _ <device_architecture> _ <module_ID> .
<file extension>
```

`qtm / libqtm`	An acronym that indicates QTouch module. All QTouch modules begin with "`qtm_`" for easy identification. For GCC modules, "`lib`" is prepended to the module name, thus it would be "`libqtm`".

module_name_identifier	acq – acquisition module with auto-tune acq_runtime – acquisition module without auto-tune code freq_hop – frequency hop module freq_hop_auto_tune – frequency hop with auto-tune module
device_architecture	cm0p – for all Cortex M0+ post processing modules cm4 – for all Cortex M4F post processing modules samd1x – SAM D10/D11 acquisition modules only t81x – all modules of AVR ATtiny817 device families t161x - all modules of AVR ATtiny1617 device families t321x - all modules of AVR ATtiny3217 device families m328pb - all modules of AVR ATmega328PB device m324pb- all modules of AVR ATmega324PB device saml21 - SAM L21 acquisition module only saml22 - SAM L22 acquisition module only samc21 - SAM C21 acquisition module only samc20 - SAM C20 acquisition module only samd21 - SAM D21 acquisition module only samda1 - SAM DA1 acquisition module only samha1 - SAM HA1 acquisition module only samd20 - SAM D20 acquisition module only saml10 - SAM L10 acquisition module only saml11 - SAM L11 acquisition module only cm23 – for all Cortex M23 post processing modules
module_id	Unique 16-bit identifier for each module
file_extension	.a – GCC modules of AVR® and Arm® devices, IAR modules of Arm devices .r90 – IAR modules of all AVR modules

See examples below:

Table 5-1. Acquisition Module of AVR® ATmega328PB Device

GCC module	`libqtm_acq_m328pb_0x0001.a`
IAR module	`qtm_acq_m328pb_0x0001.r90`

Touch Keys Processing Module of SAM D2x, SAM DA1, SAM HA1, SAM D1x, SAM L2x, SAM C2x Devices

GCC module	`libqtm_touch_key_cm0p_0x0002.a`
IAR module	`qtm_touch_key_cm0p_0x0002.a`

Touch Keys Processing Module of SAM L1x Devices

GCC module	`libqtm_touch_key_cm23_0x0002.a`
IAR module	`qtm_touch_key_cm23_0x0002.a`

5.4 QTouch® Library Application Interface

In addition to library modules, the various components that are required to build the complete touch application are given below.

1. Module API files.
2. `Touch.c` and `Touch.h` files.
3. `Common_components_api.h`.
4. `Touch_api_ptc.h`.
5. Module reburst flag.
6. Binding layer module.

5.4.1 Module API files

The API for each module is defined in its associated header file. Dependencies between modules are minimized and implemented at the application level. This allows for easy porting of application code from one device to another – only the hardware-dependent module configurations must be adjusted. The acquisition auto-tune and acquisition manual tune modules have the same API file. All the other modules have their API file that needs to be linked to the user application.

5.4.2 `Touch.c` and `Touch.h` files

User options for each module are configured in application code, typically `touch.h` and `touch.c`, and shared with the library module by pointer reference. Similarly, arrays are created in application code for modules' run-time data and provided to the module via a pointer.

Configurations may be modified on-the-fly by application code in between measurement sweeps of the touch sensors. All run-time data is available to the application code.

5.4.3 `Common_components_api.h`

The application requires structures and definitions common to all modules. The common definitions, macros, and the data structures are placed in the file **"*qtm_common_components_api.h*"**.

5.4.4 `Touch_api_ptc.h`

This file contains all the module API files included in the content, and thus this single file is sufficient to be included on the application source files wherever necessary.

5.4.5 Module Reburst Flag

Module configuration and functionality are unique to each module, but any module may require a repeated measurement of specific sensors. To achieve this, a signal conditioning module may temporarily change the acquisition configuration, e.g., to disable those sensors not requiring reburst.

This is indicated to the application by the implementation of a common *'Status'* byte at the first location of the signal conditioning group data structure. A `'1'` in bit 7 indicates that the application should re-start measurement on the sensor group without waiting for the measurement cycle time-out.

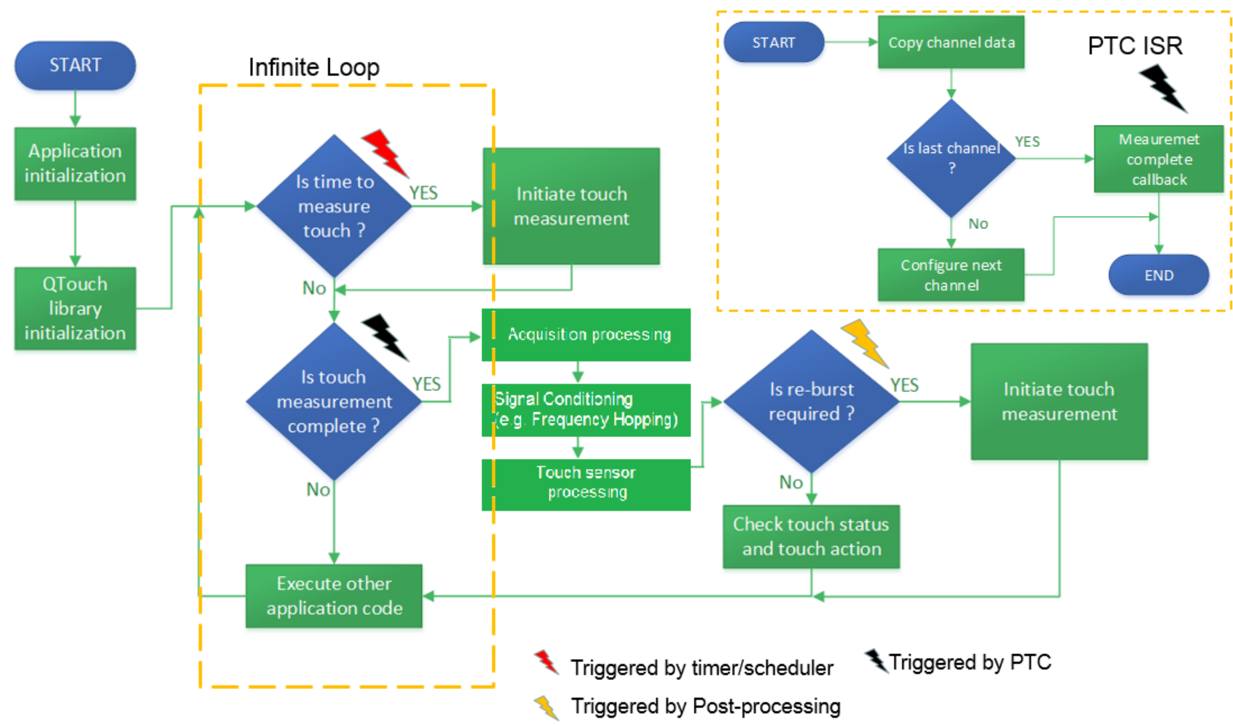
Figure 5-1. `uint8_t qtm_xxx_status`

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
Re-burst	Module specific status flags						

5.4.6 Binding Layer Module

The binding layer module provides an easy interface of QTouch modules to the user application. The binding layer binds all the configured modules in the appropriate sequence using minimal API functions. It takes care of the initialization of modules, synchronizes the calling procedures, and handles the error statuses.

5.5 Application Flow



5.6 MISRA Compliance

QTouch Library modules source code is compliant with the *'Required'* rule set of MISRA 2004, with the following exceptions:

Table 5-2. AVR® MCU Acquisition Modules and Exceptions

Acquisition Modules of ATmega32xPB, ATtiny81x, ATtiny161x, ATtiny321x Devices		
MISRA Rule	Definition	Remarks
1.1	All code shall conform to ISO 9899:1990 Programming languages – C, amended and corrected by ISO/IEC 9899/COR1:1995, ISO/IEC 9899/AMD1:1995, and ISO/IEC 9899/COR2:1996	The compiler is configured to allow extensions
8.5	There shall be no definitions of objects or functions in a header file	Inline functions are used in the header files
17.4	Array indexing shall be the only allowed form of pointer arithmetic	The pointer of module data structures is passed as a parameter and individual object data are fetched by iterating the data structure as an array index

Table 5-3. AVR® Postprocessing Modules and Exceptions

Touch_key, Binding Layer, Frequency Hop Auto Tune, Frequency Hop, Scroller, 2D Touch Surface and Gesture		
MISRA Rule	Definition	Remarks
17.4	Array indexing shall be the only allowed form of pointer arithmetic	The pointer of module data structures is passed as a parameter and individual object data are fetched by iterating the data structure as an array index

Table 5-4. Arm® Acquisition Modules and Postprocessing Modules

Modules		
MISRA Rule	Definition	Remarks
1.1	All code shall conform to ISO 9899:1990 Programming languages – C, amended and corrected by ISO/IEC 9899/COR1:1995, ISO/IEC 9899/AMD1:1995, and ISO/IEC 9899/COR2:1996	The compiler is configured to allow extensions
17.4	Array indexing shall be the only allowed form of pointer arithmetic	The pointer of module data structures is passed as a parameter and individual object data are fetched by iterating the data structure as an array index

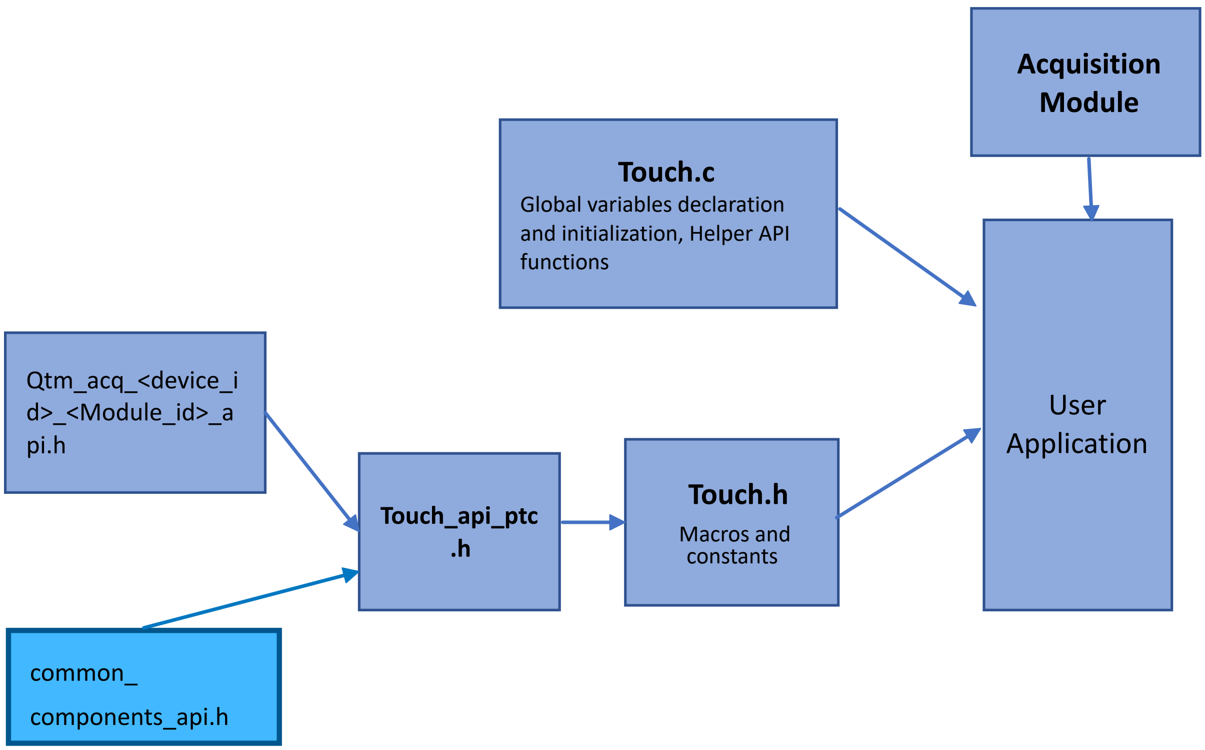
6. Acquisition Module

6.1 Overview

The minimum requirement for a touch sensor application is an acquisition module, which implements all hardware-dependent operations for configuration and measurement of capacitive touch or proximity sensors.

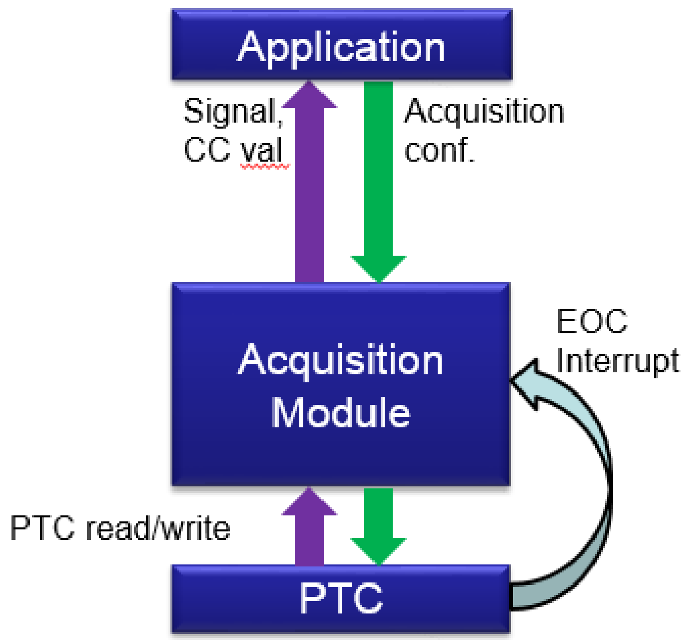
6.2 Interface

The data structure definitions and the API declarations are included in the API file "`qtm_acq_<device_id>_<module_id>_api.h`". The data structure covers all the configurations and output data variables. This file should be included on the common API '`touch_ptc_api.h`' file.



6.3 Functional Description

Acquisition modules are target specific, each having a hardware configuration structure depending on the touch sensing technology and method applied.



Features Implemented in this Acquisition Module

- Hardware Calibration for Sensor Nodes
  - Calibration of Prescaler/Resistor/Charge share delay to compensate for a time constant of sensor electrodes
  - Calibration of internal compensation circuit to match sensor load
- Self-Capacitance and Mutual Capacitance Sensor Touch Measurement with Normal Sequencing
- Low-Power Mode of Automated Scanning Using Event System (Currently not Supported on Atmel Start Configurator)

6.4 Configuration

6.4.1 Data Structures

The acquisition module implements all functionality required for making relative measurements of sensor capacitance. This is the only module uniquely built for an individual device, as it must access and control the pins used for touch sensor implementation.

As devices have different hardware features available, different configuration options are available on each device. For the most efficient use of system resources – ROM and RAM – different sensor configuration structures are required.

However, where the same variable name is used within the structure, the functionality controlled by that variable is identical. Any dependent function should utilize a reference to the variable, and NOT rely on a reference to the structure and pointer arithmetic.

Acquisition Group Configuration
A reference by a pointer to '`&ptc_qtlib_acq_gen1.freq_option_select`' will always point to the correct memory location, regardless of the device. However, any implementation based on pointer arithmetic will require re-factoring if code is to be re-used from one device for another.

Parameter	Size	Range/Options	Usage
`num_sensor_nodes`	16-bit	0 to 65535	The number of sensor nodes configured in the group
`acq_sensor_type`	8-bit	`NODE_SELFCAP` `NODE_MUTUAL`	Defines the measurement method applied to this group of nodes

`calib_option_select`	1 byte	**Bits 3:0**
		Calibration type:
		`CAL_AUTO_TUNE_NONE`
		`CAL_AUTO_TUNE_RSEL`
		`CAL_AUTO_TUNE_PRSC`
		`CAL_AUTO_TUNE_CSD`*
			The calibration type selects which parameter should be automatically tuned for optimal charge transfer

		Bits 7:4
		Calibration target:
		`CAL_CHRG_2TAU`
		`CAL_CHRG_3TAU`
		`CAL_CHRG_4TAU`
		`CAL_CHRG_5TAU`
			The calibration target applies a limit to the charge transfer loss allowed, where a higher setting of a target ensures a greater proportion of full charge is transferred

`freq_option_select`	1 byte	`FREQ_SEL_0` to `FREQ_SEL_15` Or `FREQ_SEL_SPREAD`	`FREQ_SEL_0` to `FREQ_SEL_15` inserts a delay cycle between measurements during oversampling, where 0 is the shortest delay, 15 the longest. `FREQ_SEL_SPREAD` varies this delay from 0 to 15 in a sawtooth manner during the oversampling set.
`PTC_interrupt_priority`**	1 byte	1 to 3	Interrupt priority level for the PTC

Note: * - Not available on all devices.
** - Applicable for Arm® Cortex devices only.

Node Configuration
Similarly, node configuration structures vary depending on which device is used.

- Number of X lines
- Number of Y lines
- Feature availability

Parameter	Size	Range/Options	Usage
`node_xmask`	1/2/4/8 bytes	(Bit field)	Set the bit(s) at location(s) corresponding to X line number(s). **Example:** X0 only = `0b00000001` = 0x01 X0 and X2 = `0b00000101` = 0x05 1 byte is used for devices with up to 8 "X" lines. 2 bytes, 4 bytes, 8 bytes are used for devices up to 16, 32 and 46* "X" lines, respectively. **Note:** *Can support up to 64 X lines.
`node_ymask`	1/2/4/8 bytes	(Bit field)	Set the bit(s) at location(s) corresponding to Y line number(s). **Example:** Y5 only = `0b00100000` = 0x20 Y1, Y2 and Y7 = `0b10000110` = 0x86 1 byte is used for devices with up to 8 "Y" lines 2 bytes, 4 bytes, 8 bytes are used for devices up to 16, 32, and 46* "Y" lines, respectively. **Note:** *Can support up to 64 Y lines.
`node_csd`*	1 byte	0 to 255	The number of delay cycles to ensure charging of sensor node capacitances. (Applicable for AVR® ATtiny, ATmega, Arm® SAM E54, SAMCx, SAM L22 family only.)

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Parameter	Size	Range/Options	Usage
node_rsel_prsc	1 byte	**Bits 7:4 = RSEL** RSEL_VAL_0 RSEL_VAL_3* RSEL_VAL_6* RSEL_VAL_20 RSEL_VAL_50 RSEL_VAL_70* RSEL_VAL_75* RSEL_VAL_80* RSEL_VAL_100 RSEL_VAL_120* RSEL_VAL_200*	Internal Y line series resistor selection. * May not be available for all devices. SAM E5x, SAM D5x: 3 kΩ, 6 kΩ, 75 kΩ, 200 kΩ SAM L22: 75 kΩ, 200 kΩ AVR-DA: 70 kΩ, 80 kΩ, 120 kΩ, 200 kΩ
		Bits 3:0 = PRSC PRSC_DIV_SEL_1 PRSC_DIV_SEL_2 PRSC_DIV_SEL_4 PRSC_DIV_SEL_6* PRSC_DIV_SEL_8 PRSC_DIV_SEL_12* PRSC_DIV_SEL_14* PRSC_DIV_SEL_16* PRSC_DIV_SEL_32* PRSC_DIV_SEL_64 * PRSC_DIV_SEL_128*	**Clock Prescaler** The acquisition clock is derived and scaled from CPU clock for AVR® devices. *May not be available for all devices. SAM E5x, SAM D5x, ATtiny: 16 kΩ, 32 kΩ, 64 kΩ, 128 kΩ AVR-DA: 6, 12, 14 ** **The numbers correspond to the prescaler value.
node_gain	1 byte	**Bits 7:4 = Analog Gain** GAIN_1 GAIN_2 GAIN_4 GAIN_8 GAIN_16	**Analog Gain Setting** Integration capacitor adjusted to control integrator gain.
		Bits 3:0 = Digital Gain GAIN_1 GAIN_2 GAIN_4 GAIN_8 GAIN_16	**Digital Gain Setting** The accumulated sum is scaled to digital gain.

...........continued

Parameter	Size	Range/Options	Usage
node_oversampling	1 byte	FILTER_LEVEL_1 FILTER_LEVEL_2 FILTER_LEVEL_4 FILTER_LEVEL_8 FILTER_LEVEL_16 FILTER_LEVEL_32 FILTER_LEVEL_64 FILTER_LEVEL_128* FILTER_LEVEL_256* FILTER_LEVEL_512* FILTER_LEVEL_1024*	The number of samples to accumulate for each measurement. **Note**: Oversampling must be configured to be greater than or equal to digital gain for correct operation. (Higher filter level values > 64 are available only on Arm® SAM E54 family only.)
Note: * - Not available on all devices.			

6.4.2 Status and Output Data

While different target hardware requires that the configuration structure for sensor nodes varies from one device to another, all acquisition modules conform to a standard sensor node data structure. Processed module output data are stored in this data structure during run-time.

The outputs/status information may be used by other post-processing modules or by the application.

Parameter	Size	Range/Options	Usage
node_acq_status	1 byte	Bit 7	Indicates node calibration error NODE_CAL_ERROR
		Bit 6	Rise Time calibration complete
		Bit 5	-
		Bit <4:2> (three bits) **Node calibration state** NODE_MEASURE NODE_CC_CAL NODE_PRSC_CAL NODE_RSEL_CAL NODE_CSD_CAL	Indicates whether a calibration is ongoing and its current stage
		Calibration Request	Write to ‘1’ to trigger calibration sequence on this node. (Reset to ‘0’ by module once actioned.)
		Enabled	Write to ‘1’ to enable this node for measurement
node_acq_signals	2 bytes	Most recent measurement for this sensor node.	16-bit unsigned value Accumulated and scaled as per node_oversampling and node_gain_digital settings.
node_comp_caps	2 bytes	Hardware calibration data	Indicates the tuning of the compensation circuit for this node

Table 6-1. `node_acq_status`

Bit	7	6	5	4	3	2	1	0
	Node Calibration Error	Rise time calibration complete	-		Node State		Calibrate request	Enabled

NODE_MEASURE	0
NODE_CC_CAL	1
NODE_PRSC_CAL	2
NODE_RSEL_CAL	3
NODE_CSD_CAL*	4
Note: * - CSD calibration is not available on SAM D10/D11, SAM D2x, SAM L21 devices.	

Acquisition Library State

Table 6-2. `touch_lib_state_t`

TOUCH_STATE_NULL	0
TOUCH_STATE_INIT	1
TOUCH_STATE_READY	2
TOUCH_STATE_CALIBRATE	3
TOUCH_STATE_BUSY	4

Return Parameter

Table 6-3. `touch_ret_t` **Common Return Type, Used by All QTML Modules**

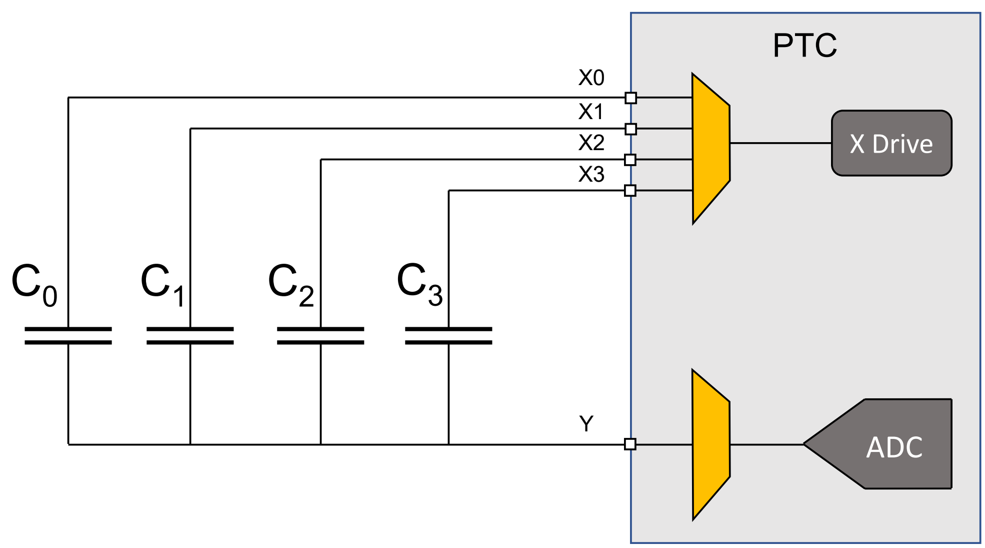
TOUCH_SUCCESS	0
TOUCH_ACQ_INCOMPLETE	1
TOUCH_INVALID_INPUT_PARAM	2
TOUCH_INVALID_LIB_STATE	3
TOUCH_INVALID_POINTER	11
TOUCH_LIB_NODE_CAL_ERROR	14
Note: Other values are reserved for future use.	

7. Boost Mode

7.1 Introduction

The PTC, on selected devices, includes a feature to acquire four channels simultaneously in Mutual Capacitance mode. To resolve each channel's node measurement, a minimum of four simultaneous measurements are required. This has the effect of combining both analog and digital oversampling with the net effect of an overall improvement in SNR or a reduction in response time.

Figure 7-1. Parallel X Drive



By using Boost mode, one of the following benefits can be achieved:

- Since a given node is measured four times, SNR improves by two times (square root of oversample times). In a noisy system, SNR is improved by two times without compromising on response time.
- The response time can be reduced to one quarter by reducing the analog oversamples to 1/4th to retain the same SNR. Example: By enabling the Boost mode, the filter level can be reduced from 32 to 8 without compromising on SNR.

Supported devices:

- SAM L1x
- ATtiny81x
- ATtiny161x
- ATtiny321x
- AVR-DA

7.2 Configuration

Sensor nodes are arranged for Boost mode in groups of 4X 1Y, depending on the application requirements. This module supports only mutual capacitance 4P measurements.

7.2.1 Sensor Node Group

`qtm_acquisition_control_t`

- A top-level container for an acquisition group
- Contains pointers to group and node memory containing configurations and run-time data

Structure	Contents
qtm_acquisition_control_t	qtm_acq_node_group_config_t (*qtm_acq_node_group_config);
	qtm_acq_4p_saml10_config_t (*qtm_acq_node_config);
	qtm_acq_node_data_t (*qtm_acq_node_data);

`qtm_acq_node_group_config_t`

- Common parameters, applied to all sensor nodes in the group

Parameter	Size	Range/Options	Usage
num_sensor_nodes	16-bit	4 to 65532	The total number of sensor nodes configured in the group, for example, a number of 4P sets X4.
acq_sensor_type	8-bit	NODE_MUTUAL_4P	Parallel sets of 4 mutual capacitance sensor nodes. Each set contains 4x PTC X masks and 1x PTC Y masks for the measurement of XY capacitance.
calib_option_select	1 byte	**Bits 3:0 Calibration type**	**Selects which parameter is auto-tuned for charge transfer.**
		CAL_AUTO_TUNE_NONE	No auto-tune for charge transfer
		CAL_AUTO_TUNE_RSEL	Series resistor tuned to the largest value that allows full charge transfer
		CAL_AUTO_TUNE_PRSC	Prescaler tuned to the lowest (fastest) value that allows full charge transfer
		CAL_AUTO_TUNE_CSD	Charge share delay tuned to the lowest value that allows full charge transfer
		Bits 7:4 Calibration target	**Target charge time for sensor capacitance.**
		CAL_CHRG_2TAU	Sensor charged for 2 x Time constant
		CAL_CHRG_3TAU	Sensor charged for 3 x Time constant
		CAL_CHRG_4TAU	Sensor charged for 4 x Time constant
		CAL_CHRG_5TAU	Sensor charged for 5 x Time constant

...........continued

Parameter	Size	Range/Options	Usage
`freq_option_select`	1 byte	`FREQ_SEL_0` to `FREQ_SEL_15`	`FREQ_SEL_0` to `FREQ_SEL_15` inserts a delay cycle between measurements during oversampling, where 0 is the shortest delay, 15 the longest
		`FREQ_SEL_SPREAD`	`FREQ_SEL_SPREAD` varies this delay from 0 to 15 in a sawtooth manner during the oversampling set
`ptc_interrupt_priority`	1 byte	1 to 3	Arm® NVIC Interrupt priority

`qtm_acq_saml10_node_config_t`

Note: This data structure is the specific configuration for SAM L10 PTC hardware.

Parameter	Size	Range/Options	Usage
`node_xmask[4]`	4x4 bytes (16 bytes) 4x8* bytes (32 bytes) *AVR-DA	Array/bit field	Select X pin masks for `NODE_MUTUAL_4P`. Set the bit(s) at location(s) corresponding to X line number(s). For example: X0 only = `0b00000001` = `0x01` X0 and X2 = `0b00000101` = `0x05`
`node_ymask`	4 bytes 8* bytes *AVR-DA	(bit field)	Select Y pin mask. Set the bit(s) at location(s) corresponding to Y line number(s). For example: Y5 only = `0b00100000` = `0x20` Y1, Y2 and Y7 = `0b10000110` = `0x86`
`node_csd`	1 byte	For SAM L1x: 0 to 255 For ATtiny81x,161x, 321x: 0 to 31	The number of delay cycles to ensure the charging of the sensor node capacitances **Note:** If auto-tune is enabled, this value is used for initial compensation capacitor calibration. Ensure it allows sufficient time to charge the sensor.

...........continued

Parameter	Size	Range/Options	Usage
`node_rsel_prsc`	1 byte	**Bits 7:4 = RSEL** RSEL_VAL_0 RSEL_VAL_20 RSEL_VAL_50 RSEL_VAL_70* RSEL_VAL_80* RSEL_VAL_100 RSEL_VAL_120* RSEL_VAL_200	Internal Y line series resistor selection * May not be available for all devices AVR-DA: 70 kΩ, 80 kΩ, 120 kΩ, 200 kΩ
		Bits 3:0 = PRSC PRSC_DIV_SEL_1 PRSC_DIV_SEL_2 PRSC_DIV_SEL_4 PRSC_DIV_SEL_6* PRSC_DIV_SEL_8 PRSC_DIV_SEL_12* PRSC_DIV_SEL_14* PRSC_DIV_SEL_16	**Clock Prescaler** Acquisition clock is derived and scaled from CPU clock for AVR® devices. * May not be available for all devices. AVR-DA: 6 , 12, 14 ** **The numbers correspond to the prescaler value.
`node_gain`	1 byte	**Bits 7:4 = Analog Gain** GAIN_1 GAIN_2 GAIN_4 GAIN_8 GAIN_16	**Analog Gain Setting** Integration capacitor adjusted to control integrator gain.
		Bits 3:0 = Digital Gain GAIN_1 GAIN_2 GAIN_4 GAIN_8 GAIN_16	**Digital Gain Setting** The accumulated sum is scaled to Digital Gain.

...........continued

Parameter	Size	Range/Options	Usage

`node_oversampling`	1 byte	`FILTER_LEVEL_1`
		`FILTER_LEVEL_2`
		`FILTER_LEVEL_4`
		`FILTER_LEVEL_8`
		`FILTER_LEVEL_16`
		`FILTER_LEVEL_32`
		`FILTER_LEVEL_64`
			The number of samples to accumulate for each measurement.
			Note: Oversampling must be configured to be greater than or equal to Digital Gain for correct operation.

`qtm_acq_node_data_t`

- Individual node run-time data (array)

Parameter	Size	Range/Options	Usage
`node_acq_status`	1 byte	Bit 7	`1` = `NODE_CAL_ERROR` The sensor node capacitance exceeds the maximum compensation capacitance supported.
		Bit 6	`1` = Charge transfer tuning complete
		Bit 5	`1` = Calibration state set

		Bit 4: Bit 2 (3 Bits)
		Node calibration state
		`NODE_MEASURE`
		`NODE_CC_CAL`
		`NODE_PRSC_CAL`
		`NODE_RSEL_CAL`
		`NODE_CSD_CAL`
			Indicates whether calibration is ongoing and its current stage

		Bit 1: Calibration Request	Write a ‘`1`’ to trigger calibration sequence on this node. (Reset to ‘`0`’ by module once actioned.)
		Bit 0: Enabled	Write a ‘`1`’ to enable this node for measurement.
`node_acq_signals`	2 bytes	Most recent measurement for this sensor node.	This is a 16-bit unsigned value. Accumulated and scaled as per `node_oversampling` and `node_gain_digital` settings.
`node_comp_caps`	2 bytes	Hardware calibration data	Indicates tuning of the compensation circuit for this node

7.2.2 4P Parallel Acquisition Modules

SAM L1x Modules:

- `libqtm_acq_4p_saml1x_0x0033.a`
- `qtm_acq_4p_saml1x_0x0033.a`

ATtiny161x Modules:

- `libqtm_acq_4p_t161x_0x001b.a`
- `qtm_acq_4p_t161x_0x001b.r90`

ATtiny321x Modules:

- `libqtm_acq_4p_t321x_0x001b.a`
- `qtm_acq_4p_t321x_0x001b.r90`

AVR-DA Modules:

- `libqtm_acq_4p_avr_da_0x0038.a`
- `qtm_acq_4p_avr_da_0x0038.r90`

8. Frequency Hop Module

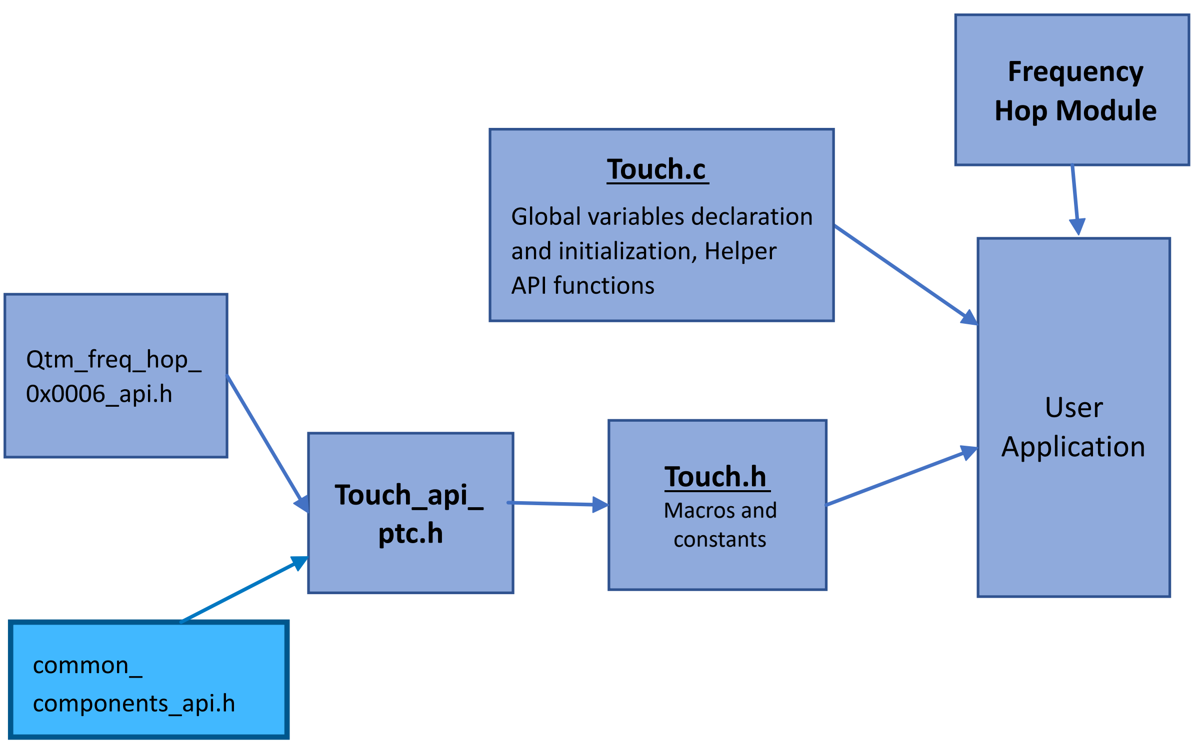
8.1 Overview

The Frequency Hop module provides a way of filtering the noise during the sensor measurement by varying the frequency of bursting the sensors. Module ID for frequency hop module is 0x0006 and the module name is in the format given below.

GCC compiler	`libqtm_freq_hop_xxxxx_0x0006.a`
IAR compiler (AVR® MCU)	`qtm_freq_hop_xxxxx_0x0006.r90`
IAR compiler (Arm® MCU)	`qtm_freq_hop_xxxxx_0x0006.a`
Note: "xxxxx" – string based on the device architecture that the module is built.	

8.2 Interface

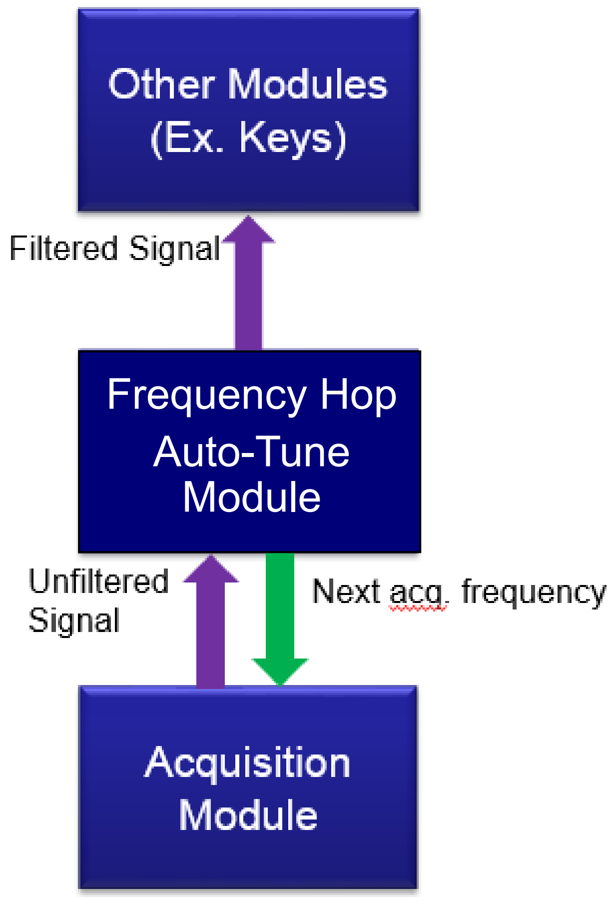
The data structure definitions and the API declarations are included in the API file '`qtm_freq_hop_0x0006_api.h`'. The data structure covers all the configurations and output data variables. This file should be included on the common API '`touch_ptc_api.h`' file.



The default values of configurations should be defined on the `touch.c` and `touch.h` files. Global variables of the data structures have to be initialized in the `touch.c` file, and the reference of the structure has to be used on the application files.

8.3 Functional Description

The Frequency Hop module is interfaced between the Acquisition module and the rest of the post-processing modules, as shown below.



The Frequency Hop module applies a configurable cyclic frequency hopping algorithm, such that on each measurement cycle a different sampling frequency is used. The module is initialized with predefined frequencies, which are set by cyclic order during the consecutive measurement cycles.

The measured raw signal values from the acquisition module are then passed through **"Median filter"**. Finally, the filtered value is stored back on the memory for further processing by the post-processing modules.

A number of frequencies provides effective filtering by processing more samples. However, this also increases the buffer size used by the median filter and takes a number of measurement cycles to report filtered value. So, the number of frequencies should be configured based on the RAM memory available.

8.4 Configuration

8.4.1 Data Structures

Parameter	Size	Range/Options	Usage
`num_sensors`	1 byte	0-255	The number of sensors to buffer data for median filter
`num_freqs`	1 byte	3-to-7	The number of frequencies to cycle/depth of median filter
`*freq_option_select`	2/4 bytes	N/A	The pointer to the acquisition library frequency selection parameter
`*median_filter_freq`	2/4 bytes	N/A	The pointer to the array of selected frequencies

8.4.2 Status and Output Data

Parameter	Size	Range/Options	Usage
`module_status`	1 byte	N/A	Module status – N/A
`current_freq`	1 byte	0-to-15	Current frequency step
`*filter_buffer`	2/4 bytes	N/A	The pointer to the filter buffer array for measured signals
`*qtm_acq_node_data`	2/4 bytes	N/A	The pointer to the node data structure of the acquisition group

Table 8-1. List of Supported Frequencies

PTC Clock = 4 MHz		
PTC Frequency Delay Cycles		Frequency [kHz]
0	`FREQ_SEL_0`	66.67
1	`FREQ_SEL_1`	62.5
2	`FREQ_SEL_2`	58.82
3	`FREQ_SEL_3`	55.56
4	`FREQ_SEL_4`	52.63
5	`FREQ_SEL_5`	50
6	`FREQ_SEL_6`	47.62
7	`FREQ_SEL_7`	45.45
8	`FREQ_SEL_8`	43.48
9	`FREQ_SEL_9`	41.67
10	`FREQ_SEL_10`	40
11	`FREQ_SEL_11`	38.46
12	`FREQ_SEL_12`	37.04

...........continued

PTC Clock = 4 MHz		
PTC Frequency Delay Cycles		Frequency [kHz]
13	FREQ_SEL_13	35.71
14	FREQ_SEL_14	34.48
15	FREQ_SEL_15	33.33
16	FREQ_SEL_SPREAD	Variable frequencies

9. Frequency Hop Auto-Tune Module

9.1 Overview

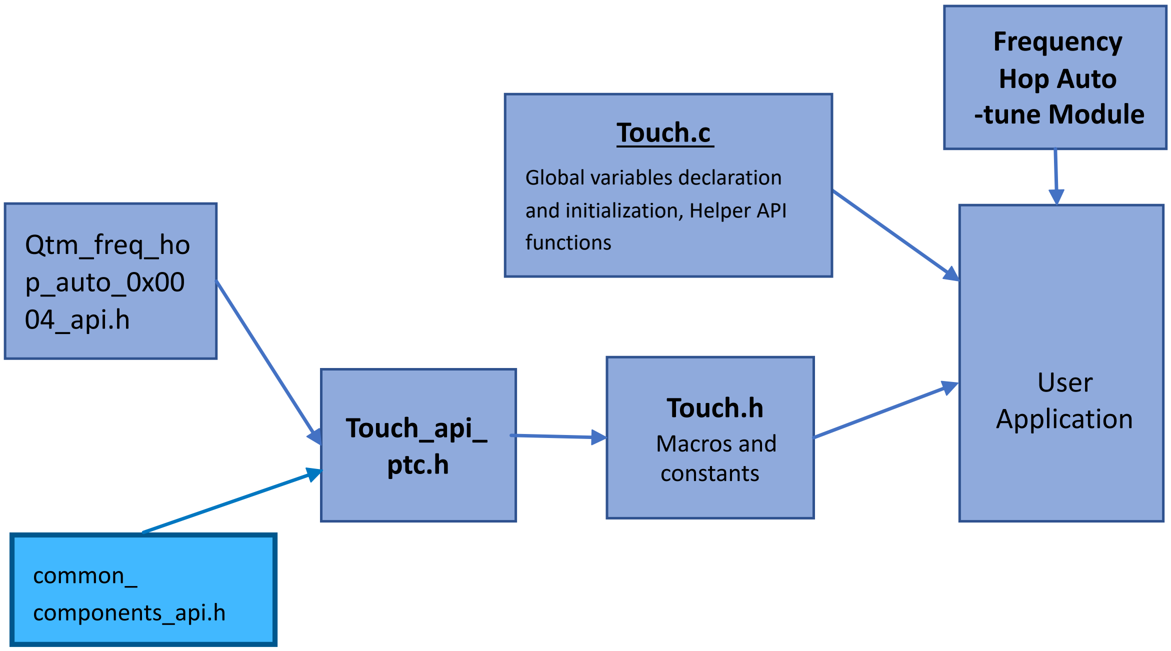
The frequency hop auto-tune module is the superset of the frequency hop module with additionally providing noise monitoring and tuning the frequency according to the measured noise factor.

The Module ID for the frequency hop auto-tune module is '0x0004', and the module name is in the format given below.

GCC compiler	`libqtm_freq_hop_auto_xxxxx_0x0004.a`
IAR compiler (AVR® MCU)	`qtm_freq_hop_auto_xxxxx_0x0004.r90`
IAR compiler (Arm® MCU)	*`qtm_freq_hop_auto_xxxxx_0x0004.a`*
Note: "xxxxx" – string based on the device architecture that the module is built.	

9.2 Interface

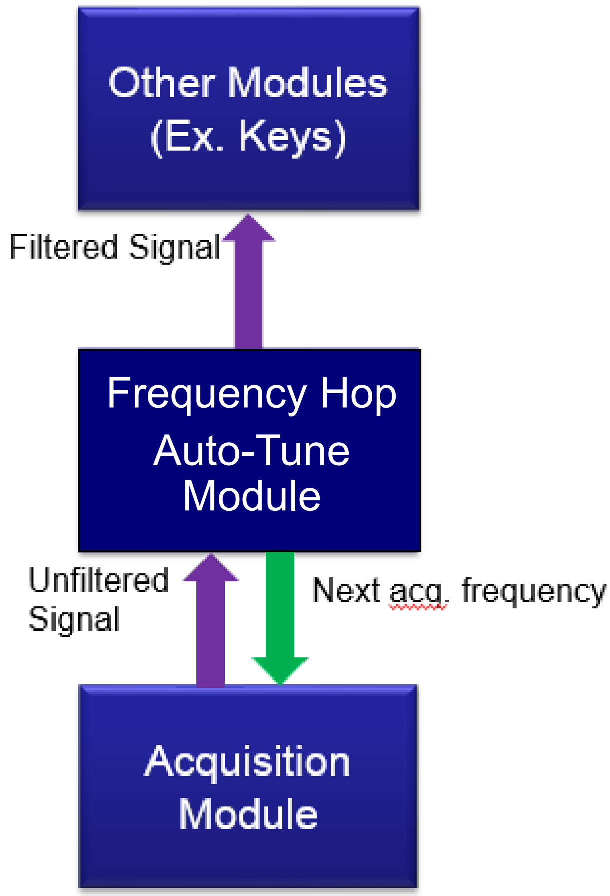
The data structure definitions and the API declarations are included in the API file '`qtm_freq_hop_auto_0x0004_api.h`'. The data structure covers all the configurations and output data variables. This file should be included on the common API `touch_ptc_api.h` file.



The default values of the configurations should be defined on the `touch.c` and `touch.h` files. Global variables of the data structures have to be initialized in the `touch.c` file, and the reference of the structure has to be used on the application files.

9.3 Functional Description

The frequency hop auto-tune module is interfaced between the acquisition module and the rest of the post-processing modules, as shown below.



The frequency hop auto-tune module applies a configurable cyclic frequency-hopping algorithm, such that on each measurement cycle a different sampling frequency is used. Several preconfigured frequencies are implemented in turn during consecutive measurement cycles.

Where 'n' frequencies are included in the cycle, an 'n'-point median filter is applied to the output data.

To perform auto-tuning, the signals measured on each sensor node are recorded for each selected frequency. When one frequency shows greater variance than the others, that frequency is removed from the measurement sequence and replaced with another.

9.4 Configuration

9.4.1 Data Structures

Parameter	Size	Range/ Options	Usage
`num_sensors`	1 byte	0 – 255	The number of sensors to buffer data for the median filter
`num_freqs`	1 byte	3-to-7	The number of frequencies to cycle/depth of the median filter

...........continued

Parameter	Size	Range/ Options	Usage
*freq_option_select	Pointer 2/4 bytes	Pointer	The pointer to the acquisition library frequency selection parameter
*median_filter_freq	Pointer 2/4 bytes	Pointer	The pointer to the array of selected frequencies
enable_freq_autotune	1 byte	0 or 1	Disable (0) or enable (1) automatic retuning of hop frequencies
max_variance_limit	1 byte	1-to-255	Signal variance required to trigger returning of hop frequency
Autotune_count_in	1 byte	1-to-255	The number of occurrences of max_variance_limit to trigger retuning of hop frequency

9.4.2 Status and Output Data

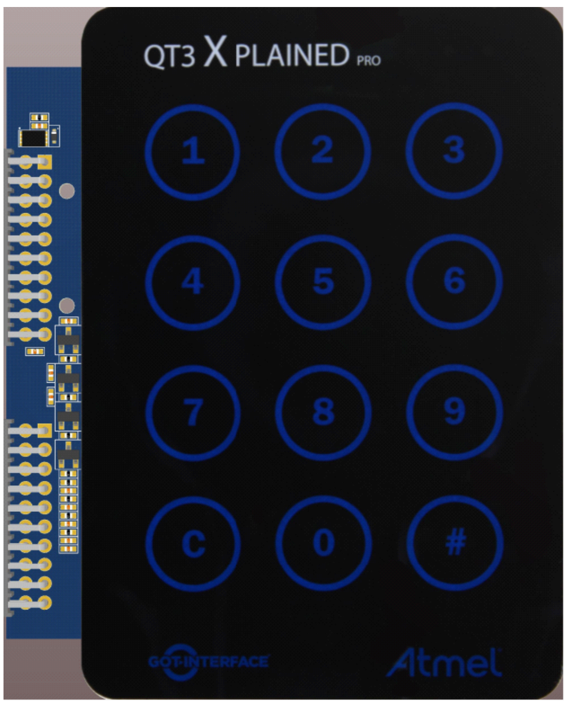
Parameter	Size	Range/Options	Usage
module_status	1 byte	N/A	Module status – N/A
current_freq	1 byte	0-to-15	Current frequency step
*filter_buffer	Pointer 2/4 bytes	Pointer	The pointer to the filter buffer array for measured signals
*qtm_acq_node_data	Pointer 2/4 bytes	Pointer	The pointer to the node data structure of the acquisition group
*freq_tune_count_ins	Pointer 2/4 bytes	Pointer	Pointing to the counter array to trigger frequency change

10. Touch Key Module

10.1 Overview

The Touch Key module implements functionality that can handle the key sensors, also called as one-dimensional touch sensors. The module receives the raw output from the acquisition module, processes them and provides the touch status of key sensors. The processing includes signal post-processing, environmental drift, touch detection, touch state machine, and timing management for the implementation of application touch sensors. Reference touch sensor designs are provided to assist the users to evaluate and design their custom sensor boards. The touch sensor board view and the sensor design of the QT3 XPlained Pro sensor board are shown below.

QT3 Sensor Board Overlay



QT3 Sensor Board Design

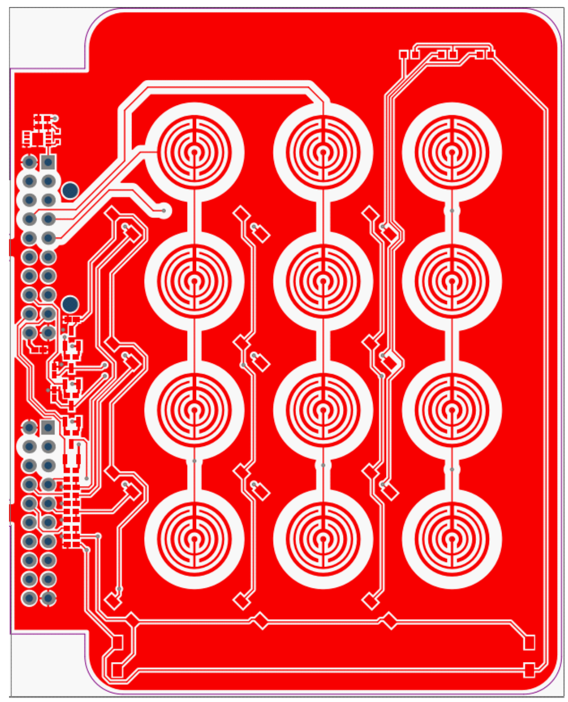
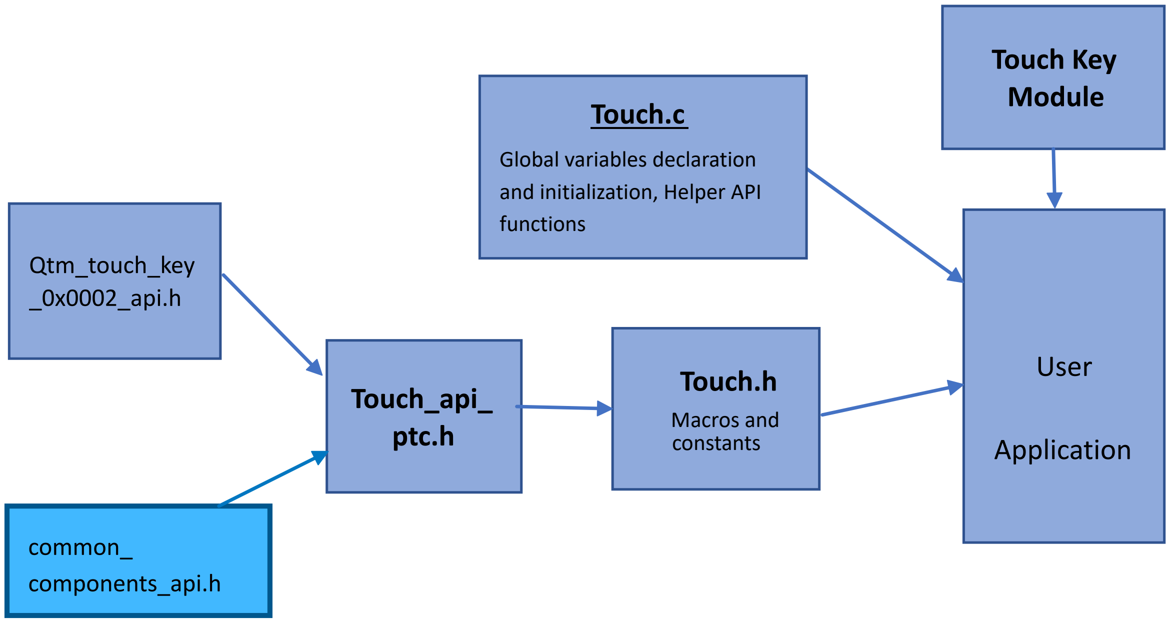


Table 10-1. Module Format

GCC compiler	`libqtm_touch_key_xxxxx_0x0002.a`
IAR compiler (AVR® MCU)	`qtm_touch_key_xxxxx_0x0002.r90`
IAR compiler (Arm® MCU)	`qtm_touch_key_xxxxx_0x0002.a`

10.2 Interface

The data structure definitions and the API declarations are included in the API file '`qtm_touch_key_0x0002_api.h`'. The data structure covers all the configurations and output data variables. This file should be included on the common API `touch_ptc_api.h` file.

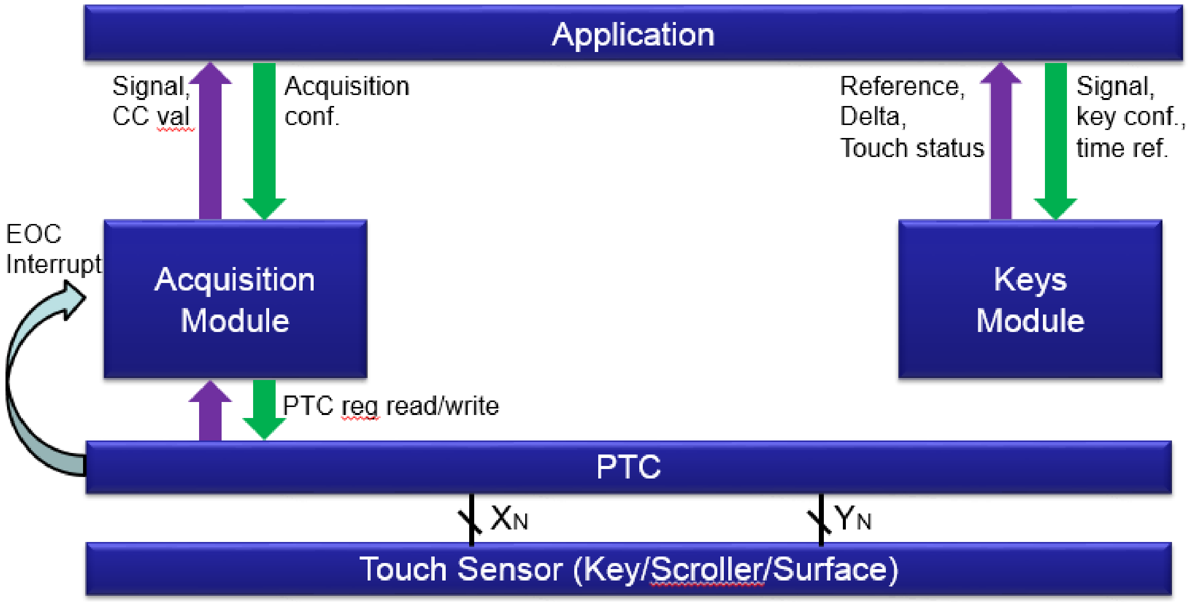


10.3 Functional Description

The touch key module is responsible for the detection of a touch contact, where higher-level module(s) carry out position interpolation, gesture recognition, contact tracking, etc.

Features implemented in the touch key module:

- Timing Management for Detecting Towards Touch, Away from Touch
- Software Calibration
  - Reference signal
  - Reference drift
- Touch Detection State Machine



10.4 Configuration

10.4.1 Data Structures

Table 10-2. Group Configuration

Parameter	Size	Range/Options	Usage
`num_key_sensors`	2 bytes	1-to-65535	The number of sensor keys in the group
`sensor_touch_di`	1 byte	0-to-255	The number of repeat measurements to confirm touch detection and out-of-touch detection
`sensor_max_on_time`	1 byte	0 (Disabled), 1-to-255	The number of timer periods with sensor In Detect before automatic 'recal'
`sensor_anti_touch_di`	1 byte	0 (Disabled), 1-to-255	The number of repeat measurements to confirm anti-touch recalibration required
`sensor_anti_touch_recal_thr`	1 byte	0-to-5	Scale-down of touch threshold to set anti-touch threshold. 0 = 100% Touch Threshold 1 = 50% 2 = 25% 3 = 12.5% 4 = 6.25% 5 = Maximum Recalibration
`sensor_touch_drift_rate`	1 byte	0 (Disabled), 1-to-255	The number of timer periods to countdown between towards touch drifts

...........continued

Parameter	Size	Range/Options	Usage
`sensor_anti_touch_drift_rate`	1 byte	`0` (Disabled), 1-to-255	The number of timer periods to countdown between away from touch drifts
`sensor_drift_hold_time`	1 byte	`0` (Disabled), 1-to-255	The number of timer periods to stop drifting after touch event
`sensor_reburst_mode`	1 byte	0 = None 1 = Unresolved (Quick reburst) 2 = All	None – Reburst is never set, measurements according to application schedule. Unresolved – Reburst is set, all sensors suspended except those in same AKS as the target sensor. All – Reburst is set, no sensors are suspended.

Table 10-3. Individual Sensor Configuration

Parameter	Size	Range/Options	Usage
`channel_threshold`	1 byte	0-to-255	Minimum signal delta indicating touch contact
`channel_hysteresis`	1 byte	0 (50%)-to-4 (3.125%)	Reduction of touch threshold to de-bounce when filtering out removed touch contact
`channel_aks_group`	1 byte	0-to-255	Grouping of key sensors controlling simultaneous touch detect.

10.4.2 Status and Output Data

Table 10-4. Group Data

Parameter	Size	Range/Options	Usage
`qtm_keys_status`	1 byte	Bit 7: Reburst required Bit 6-1: Reserved Bit 0: Touch Detection	Indicates the current state of the Touch Key Group
`acq_group_timestamp`	2 bytes	0-to-65535	Timestamp of last drift period processed
`dht_count_in`	1 byte	0-to-'`sensor_drift_hold_time`'	Countdown to drift hold release after a touch event
`tch_drift_count_in`	1 byte	0-to-'`sensor_touch_drift_rate`'	Countdown to next towards a touch drift period
`antitch_drift_count_in`	1 byte	0-to-'`sensor_anti_touch_drift_rate`'	Countdown to the next away from a touch drift period

Individual Key Sensor Data

The individual key sensor data is required by other post processing modules like Scroller. So, this data structure definition is placed on the `common_compoenents_api.h` file.

Parameter	Size	Range/Options	Usage
`sensor_state`	1 byte	Bit field	Touch key sensor state
`sensor_state_counter`	1 byte	0-to-255	The number of repeat measurements to confirm a touch detection and an out-of-touch detection

...........continued

Parameter	Size	Range/Options	Usage
*node_data_struct_ptr	2/4 bytes	Pointer	Pointer to node data structure array
Channel_reference	2 bytes	0-to-65535	Reference measurement, baseline for touch detection

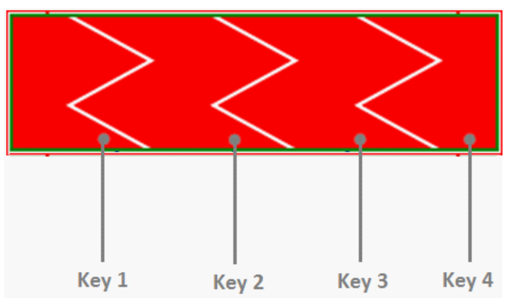
sensor_state	Value
QTM_KEY_STATE_DISABLE	0x00
QTM_KEY_STATE_INIT	0x01
QTM_KEY_STATE_CAL	0x02
QTM_KEY_STATE_NO_DET	0x03
QTM_KEY_STATE_FILT_IN	0x04
QTM_KEY_STATE_DETECT	0x85
QTM_KEY_STATE_FILT_OUT	0x86
QTM_KEY_STATE_ANTI_TCH	0x07
QTM_KEY_STATE_SUSPEND	0x08
QTM_KEY_STATE_CAL_ERR	0x09
Note: Bit 7 (0x80u) is set in each state where the touch key sensor is 'In Detect'.	

11. Scroller Module

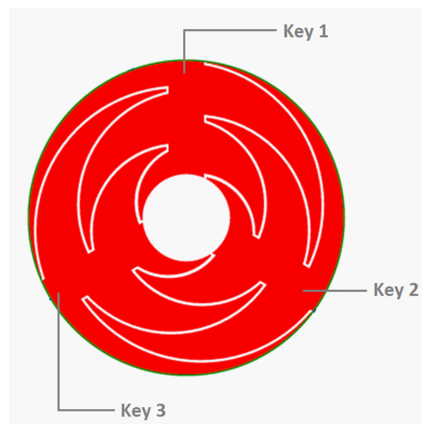
11.1 Overview

The scroller module processes the group of touch sensors constructed either as a linear slider or circular wheel, as shown in the figure below. The slider/wheel sensors, also known as one-dimensional surface sensors, track the touch movement scrolled over them and report the state and the position to the user application. The size of the slider/wheel is the underlying number of the touch key sensors that form the linear/circular surface.

Slider Sensor



Wheel Sensor

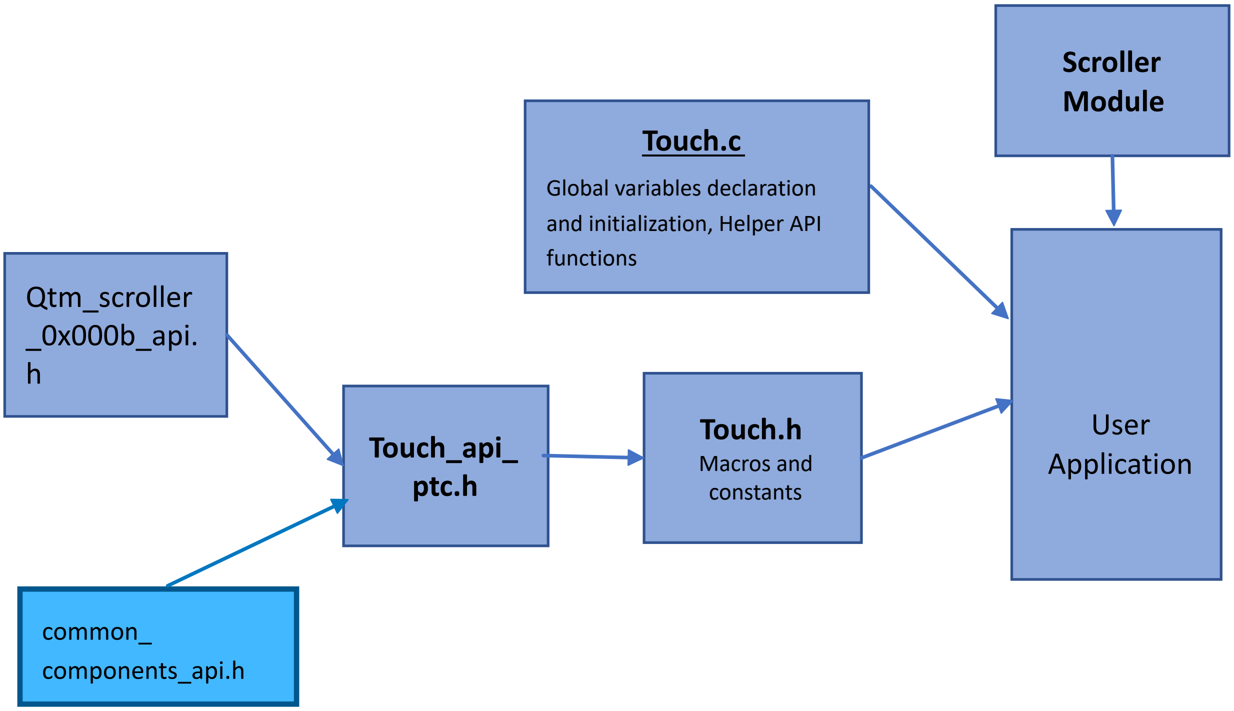


The slider/wheel can be formed by using both self-capacitance and mutual capacitance sensors. The figure above shows the 4-channel slider and 3-channel wheel sensors based on self-capacitance technology. To get good linearity on the reported touch positions when the touch is scrolled over the sensor surface, the touch keys should be interleaved, as shown in the figure above.

GCC compiler	`libqtm_scroller_xxxxx_0x000B.a`
IAR compiler (AVR® MCU)	`qtm_scroller_xxxxx_0x000B.r90`
IAR compiler (Arm® MCU)	`qtm_scroller_xxxxx_0x000B.a`

11.2 Interface

The data structure definitions and the API declarations are included in the API file '`qtm_scroller_0x000b_api.h`'. The data structure covers all the configurations and output data variables. This file should be included on the common API `touch_ptc_api.h` file.



11.3 Functional Description

The scroller module processing is dependent on the touch key module output. After the keys are processed and statuses are updated in the data structures, they are checked by the slider module. Based on the key status, the slider/wheel position is calculated from the current signal values available on the acquisition module variables.

The possible use cases and the sequence of operations under each use case are given below.

Use Case 1: Touch contact made on slider/wheel sensor

1. The module checks the status of all keys in the scroller for touch contact detection.
2. If any key is in the detect state, the touch position is calculated using the signal values of three adjacent keys.
3. Both raw position and filtered position are calculated.
4. The scroller state comes to “TOUCH_ACTIVE”, and the scroller reburst flag is set.
5. The “`POSITION_CHANGE`” flag is set now. The flag is cleared on the next measurement cycle if the touch is stationary and no change in touch position.

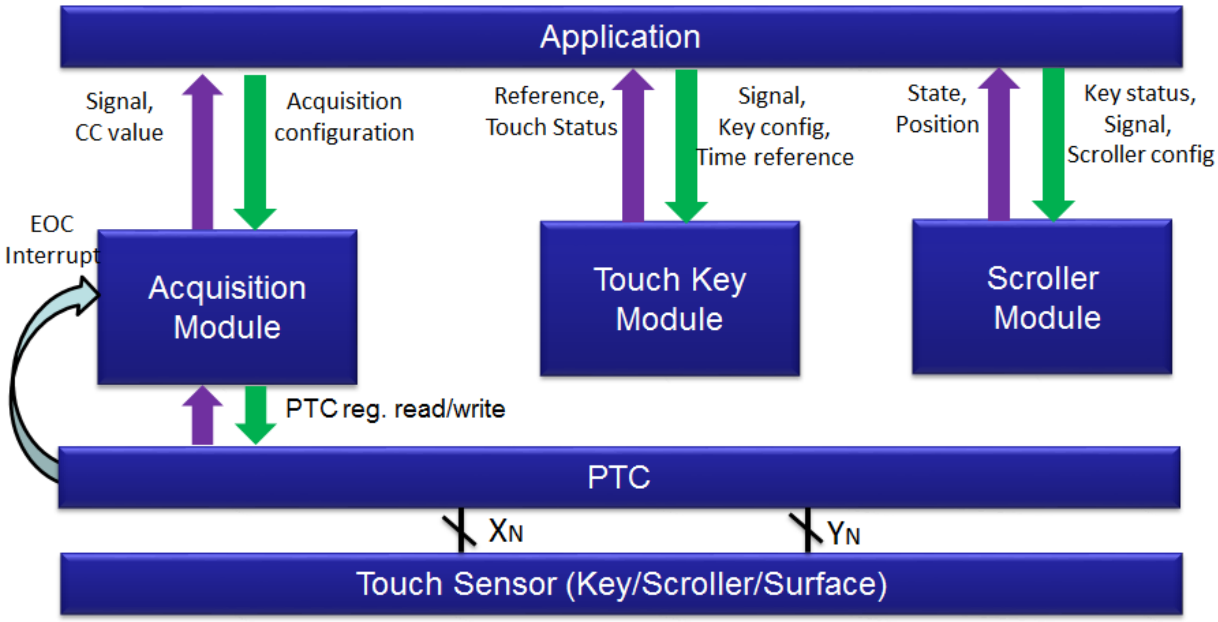
Use Case 2: Touch contact scrolling over the slider/wheel surface

1. The module checks all keys for touch contact.
2. If no key is in detect, the module searches for a pair of neighboring keys whose touch delta exceeds the minimum contact threshold.
3. If such a contact is found, then the new position is calculated.
   Or
4. If no such contact is found, the scroller returns to ‘No Detect’ condition.

Use Case 3: Touch contact removed from slider/wheel sensor

1. The module checks the status of all keys in the scroller for touch contact detection.

2. If no key is in detect, the module searches for a pair of neighboring keys whose touch delta exceeds the minimum contact threshold.
3. If such a contact is found, then the new position is calculated.
Or
4. If no such contact is found, the scroller returns to 'No Detect' condition. That is the flag "TOUCH_ACTIVE" is cleared.



11.4 Configuration

11.4.1 Data Structures

Table 11-1. Group Configuration

Parameter	Size	Range/Options	Usage
`*qtm_touch_key_data`	Pointer 2/4 bytes	`qtm_touch_key_data_t`	Pointer to touch key data for the underlying set of touch keys
`num_scrollers`	1 byte	1-to-255*	The number of scrollers implemented in this group

Table 11-2. Individual Sensor Configuration

Parameter	Size	Range/Options	Usage
`type`	1 byte	0 = Linear Slider 1 = Wheel	Type of scroller
`start_key`	2 bytes	0-to-65535*	The key number which forms the first component key of the scroller

...........continued

Parameter	Size	Range/Options	Usage
number_of_keys	1 byte	2-to-255	The number of component keys to form the scroller. The minimum number of keys required to make a slider is two and the minimum number of keys to make a wheel is three.
resol_deadband	1 byte	Bits 7:4 = Resolution 2 to 12 bits	Full scale position resolution reported for the scroller
		Bits 3:0 = Dead band 0% to 15% (each side)	The size of the edge correction dead bands as a percentage of the full scale range
position_hysteresis	1 byte	0-to-255	The minimum travel distance to be reported after contact or direction change
contact_min_threshold	2 bytes	0-to-65535	The minimum contact size measurement for persistent contact tracking. The contact size is the sum of two neighboring keys' touch deltas forming the touch contact

11.4.2 Status and Output Data

Table 11-3. Group Data

Parameter	Size	Range/Options	Usage
scroller_group_status	1 byte	Bit field Bit 7: Reburst required Bit 0: Touch detection	Reburst Required = 1 Indicates that one or more scrollers in the group require a reburst of sensors. Touch Detection = 1 Indicates that one or more scrollers in the group are in 'Touch Detect'

Individual Key Sensor Data

Parameter	Size	Range/Options	Usage
scroller_status	1 byte	Bit field Bit 7: Reburst required Bit 1: Contact moved Bit 0: Touch detection	Reburst Required = 1 Indicates that one or more scrollers in the group require a reburst of sensors. Touch contact reported position has changed Touch Detection = 1 Indicates that one or more scrollers in the group are in 'Touch Detect'
right_hyst	1 byte	Hysteresis limit	Indicates when a contact is moving 'Right', i.e., the direction of increasing touch position
left_hyst	1 byte	Hysteresis limit	Indicates when a contact is moving 'Left', i.e., the direction of reducing touch position
raw_position	2 bytes	0-to-4095	The calculated location of the touch contact prior to motion filtering
position	2 bytes	0-to-4095	The calculated location of the touch contact after motion filtering

...........continued

Parameter	Size	Range/Options	Usage
`contact_size`	2 bytes	0-to-65535	The sum of two neighbouring keys' touch deltas comprising the touch contact

12. 2D Surface (One-Finger Touch) CS Module

12.1 Overview

This module provides the functionality of a 2D touch surface with single contact support for touchscreen/touchpad applications.

- Touch Contact X and Y Position
- Up to 32x32 Sensors
  - Limited by maximum compensation capacitance per row/column
- Self-Capacitance
- Optimized Crossed Sliders Measurements
  - (MxN) sensor array measured in (M+N) acquisitions
- Persistent Contact Tracking
- Position Filtering
  - IIR
  - Median
  - Hysteresis
  - Dead band

The Surface CS module is intended for use with a grid of sensor keys which are arrayed over the surface area.

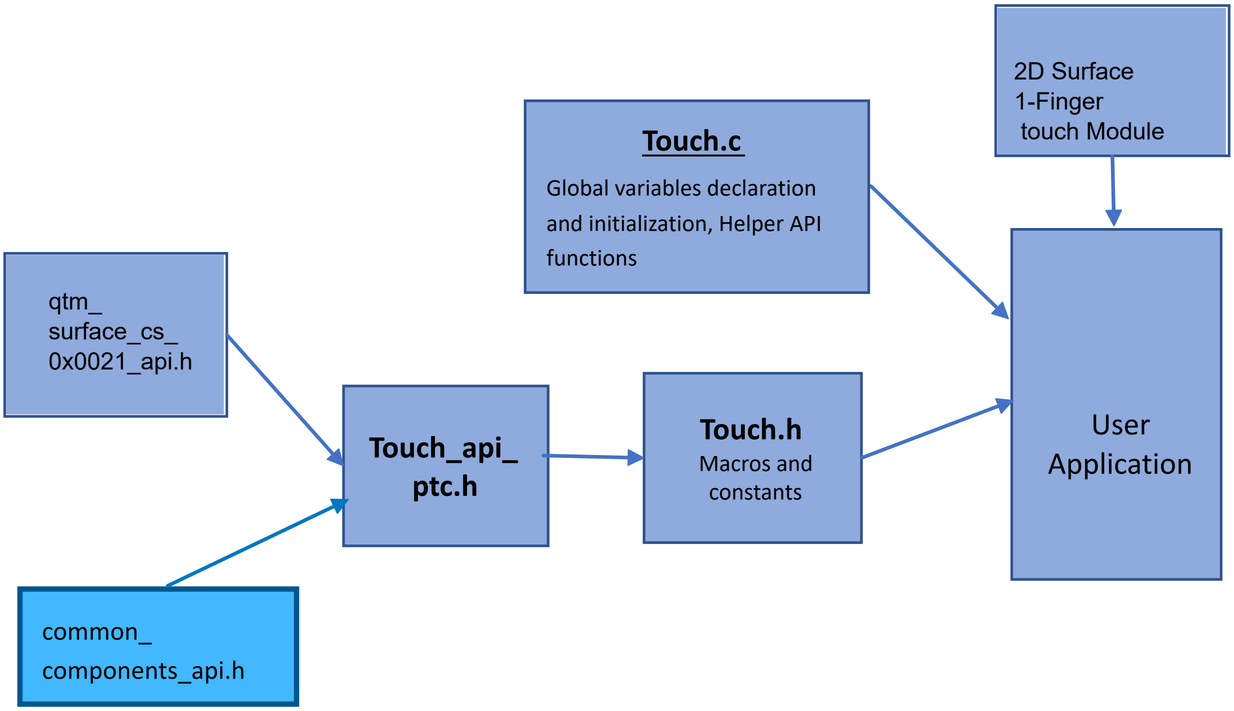
The Surface CS module is configured to interface with the QTML touch key module (0x0002) or a compatible touch detection module. Pointers are required to the location of touch key data in a standard format, as defined in the common API file.

Table 12-1. Module Files

GCC Compiler	E.g., Atmel Studio 7	`libqtm_surface_cs_xxxxx_0x0021.a` `libqtm_surface_cs_32x32_xxxxx_0x003b.a`
IAR Compiler	AVR® devices	`qtm_surface_cs_xxxxx_0x0021.r90` `qtm_surface_cs_32x32_xxxxx_0x003b.r90`
	Arm® devices	`qtm_surface_cs_xxxxx_0x0021.a` `qtm_surface_cs_32x32_xxxxx_0x003b.a`
Note: *"xxxxx" refers to the target processor or architecture.* Module with ID 0x0021: Supports up to a maximum of 16x16. Module with ID 0x003b: Supports up to a maximum of 32x32.		

12.2 Interface

All user options are configured in application code (`touch.h` / `touch.c`) and shared with the library module by pointer reference.



qtm_surface_cs_0x0021_api.h **qtm_surface_cs_0x003b_api.h**	This header file contains all API implementations relevant to the module. It must be included with the compiled module in the application project.
qtm_common_components_api.h	This header file contains API declarations that are accessible by all QTML modules, such as node and key data structures and `touch_ret_t` return codes.

12.3 Functional Description

Initialization
Data structures must be loaded with configurations before library usage. The '`surface_cs`' module is initialized by calling the '`qtm_init_surface_cs()`' API.

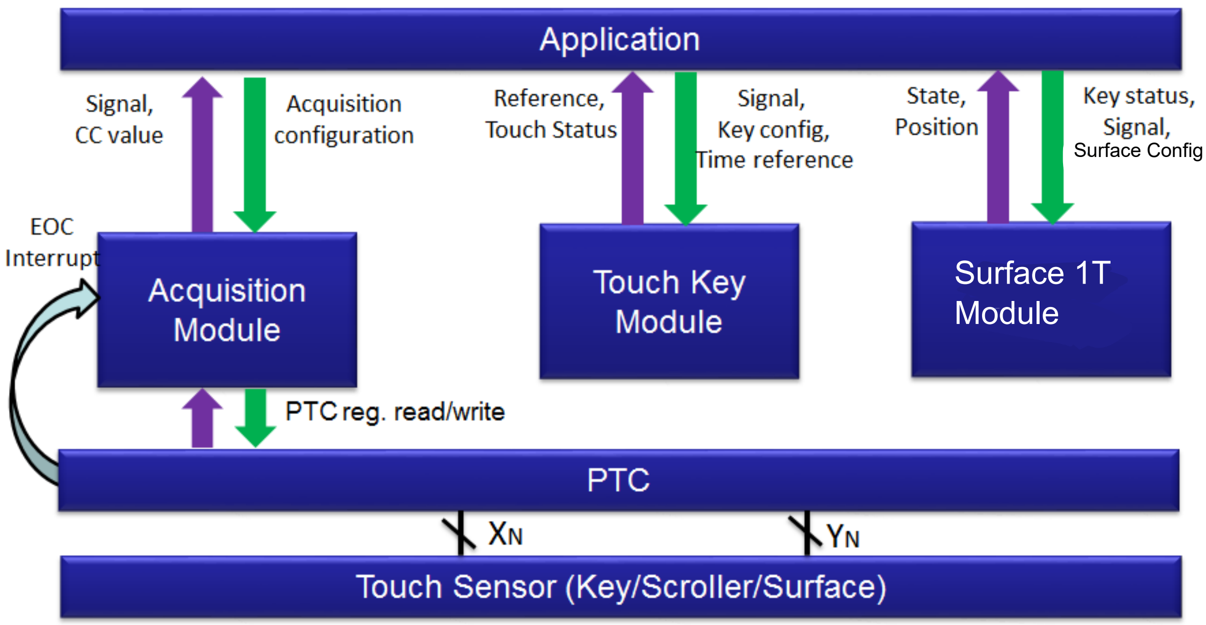
Supporting Modules
Sensor nodes ('`acquisition`' module) and keys ('`touch_key`' module) must be appropriately configured as required by the '`surface_cs`' module.

Sensor Node Configuration
Surface CS requires sensors configured and grouped to implement one horizontal and one vertical slider. If X pins are arranged horizontally, then the vertical slider is made up of (All X)/Each Y. Similarly, the horizontal slider is made up of Each X/(All Y).

Run-Time Operation
Surface CS functions as a top-level module providing touch contact information to the application. It utilizes a touch key library module for sensor calibration, signal drift, touch detection, and timed feature implementations. The touch key module itself uses a target-specific acquisition module to interface with the capacitive measurement hardware.

In a QTML application, the module processing order must be called correctly:

1. Acquisition of measurements of all sensor nodes - `qtm_ptc_start_measurement_seq();`
2. Acquisition processing for all sensor nodes - `qtm_acquisition_process();`
3. Touch Key processing for all keys - `qtm_key_sensors_process();`
4. Surface CS processing - `qtm_surface_cs_process();`



12.4 Operation

The API function '`qtm_surface_cs_process()`' is called after acquisition and touch key processing.

Making contact:

When contact is made with the surface sensor

1. The module checks all keys on the surface for touch contact detection.
2. If a key in detect is found, the position is calculated.
3. The contact size is calculated and compared against the minimum contact threshold.
4. The surface goes into the 'Detect' condition.

Tracking/Releasing contact:

1. The module checks all keys for touch contact.
2. If no key is in detect, the module searches for a pair of neighboring keys whose touch delta exceeds the minimum contact threshold.
3. If such a contact is found, then the new position is calculated.
   Or
4. If no such contact is found, the surface returns to 'No Detect' condition.

12.5 Configuration

The Surface CS module must be configured with operational parameters and with pointers to the key data set for the underlying touch keys.

12.5.1 Data Structures

qtm_surface_cs_control_t

- Top-level container for surface configuration
- Contains pointers to data and configuration structures

Struct	Contents
qtm_surface_cs_control_t	qtm_surface_contact_data_t *qtm_surface_contact_data;
	qtm_surface_cs_config_t *qtm_surface_cs_config;

qtm_surface_contact_data_t

- Run-time data for touch surface

Parameter	Size	Range/Options	Usage
qt_surface_status	1 byte	Bit field Bit 7: Reburst required	Reburst Required = 1 Indicates that further measurements are required to resolve/update contact status.
		Bit 6: —	—
		Bit 5: POS_V_DEC	Vertical position decreased
		Bit 4: POS_V_INC	Vertical position increased
		Bit 3: POS_H_DEC	Horizontal position decreased
		Bit 2: POS_H_INC	Horizontal position increased
		Bit 1: POS_CHANGE	Change in reported position
		Bit 0: Touch detection	Touch Detection = 1 Indicates that a touch contact is present on the surface
h_position_abs	2 bytes	0 to 4095	Apparent horizontal position
h_position	2 bytes	0 to 4095	Motion filtered horizontal position
v_position_abs	2 bytes	0 to 4095	Apparent vertical position
v_position	2 bytes	0 to 4095	Motion filtered vertical position
contact_size	2 bytes	—	Sum of touch deltas at contact location

qtm_surface_cs_config_t

- Configuration parameters for the touch surface

Parameter	Size	Range/Options	Usage
start_key_h	2 bytes	0 to 65534	Start key of horizontal axis
number_of_keys_h	1 byte	0 to 255	The number of keys forming horizontal axis
start_key_v	2 bytes	0 to 65534	Start key of vertical axis
number_of_keys_v	1 byte	0 to 255	The number of keys forming vertical axis
resol_deadband	1 byte	Bits 7:4 = Resolution 2 to 12 bits	Full-scale position resolution reported for the axis
position_hysteresis	1 byte	0 to 255	The minimum travel distance to be reported after contact or direction change. Applies to Horizontal and Vertical.

...........continued

Parameter	Size	Range/Options	Usage
position_filter	1 byte	Bits7:5: —	—
		Bit 4: Median Filter	Median filter enable
		Bit3 : —	—
		Bit 2: —	—
		Bits 1:0: IIR Config	IIR Config 0 = None 1 = 25% 2 = 50% 3 = 75%
contact_min_threshold	2 bytes	0 to 65535	The minimum contact size measurement for persistent contact tracking. Contact size is the sum of neighboring keys' touch deltas forming the touch contact.
*qtm_touch_key_data	Pointer 2/4 bytes	qtm_touch_key_data_t	Pointer to touch key data for the underlying set of touch keys.

13. 2D Surface (Two-Finger Touch) CS/2T Module

13.1 Overview

This module provides the functionality of a 2D touch surface with two-contact support for touchscreen/ touchpad applications.

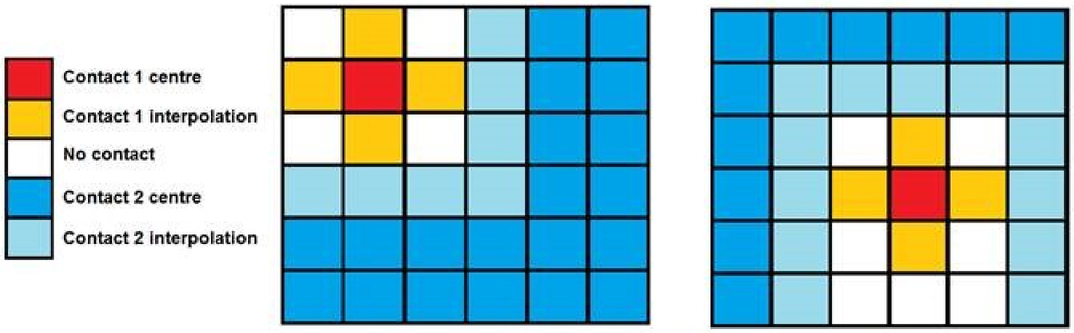
- Touch Contact X and Y Position
- Up to 32x32 Sensors
  – Limited by maximum compensation capacitance per row/column
- Mutual or Self-Capacitance
- Optimized Crossed Sliders Measurements
  – (MxN) sensor array measured in (M+N) acquisitions
- Persistent Contact Tracking
- Contact Path Extrapolation
- Position Filtering
  – IIR
  – Median
  – Hysteresis
  – Dead band

The Surface CS/2T module is intended for use with a grid of sensor keys which are arrayed over the surface area.

The Surface CS/2T module is configured to interface with the QTML touch key module (0x0002) or a compatible touch detection module. Pointers are required to the location of touch key data in a standard format, as defined in the common API file.

Important: The two positions outputted by this 2D Surface (Two-Finger Touch) CS/2T module can be used only for gesture detection. Therefore, it is not advisable to use this module without gesture support.

A minimum of eight sensors in each dimension is recommended to achieve reliable performance with two touch contacts. The use of fewer sensors severely restricts the isolation space for independent contacts.



6x6 Sensor - Few locations possible for second touch contact

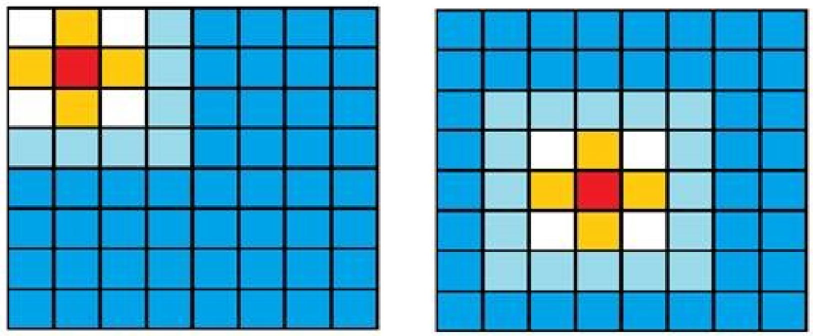
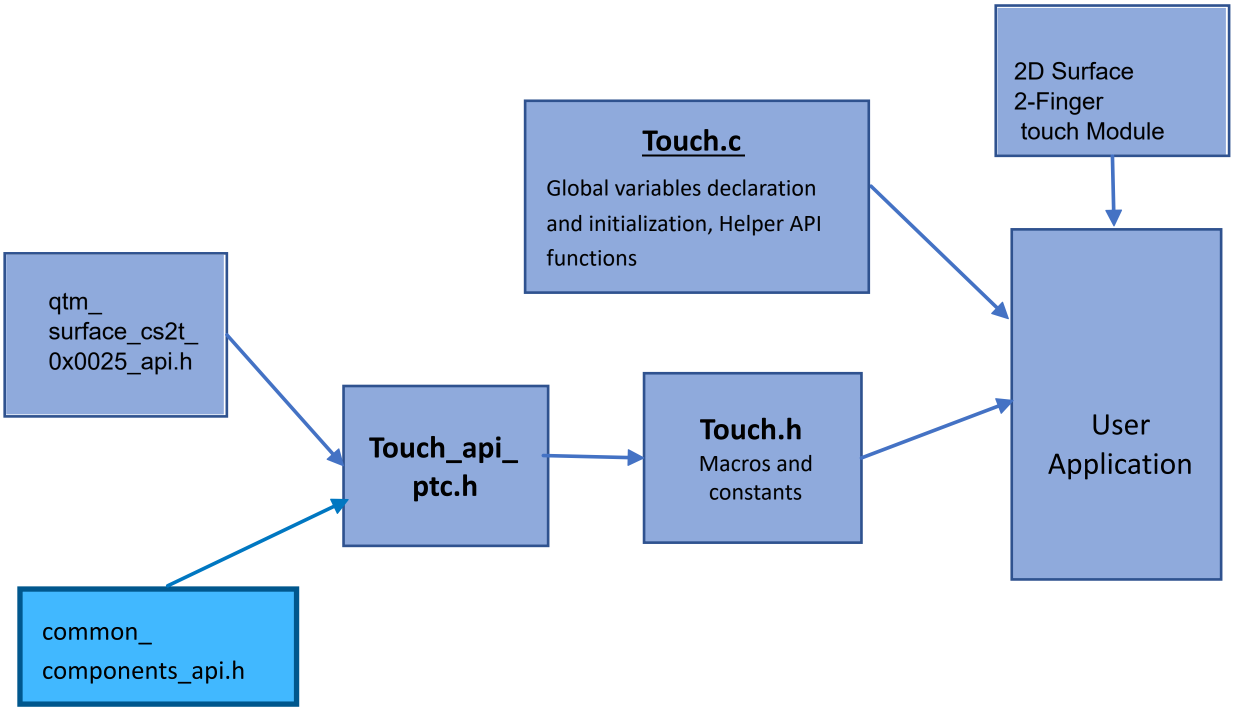

8x8 Sensor - More than double the available locations for second touch

Table 13-1. Module Files

GCC Compiler	E.g., Atmel Studio 7	`libqtm_surface_cs2t_xxxxx_0x0025.a` `libqtm_surface_cs2t_32x32_xxxxx_0x003c.a`
IAR Compiler	AVR® devices	`qtm_surface_cs2t_xxxxx_0x0025.r90` `qtm_surface_cs2t_32x32_xxxxx_0x003c.r90`
	Arm® devices	`qtm_surface_cs2t_xxxxx_0x0025.a` `qtm_surface_cs2t_32x32_xxxxx_0x003c.a`
Note: *"xxxxx" refers to the target processor or architecture.* Module with ID 0x0025: Supports up to a maximum of 16x16. Module with ID 0x003c: Supports up to a maximum of 32x32.		

13.2 Interface

All user options are configured in application code (`touch.h` / `touch.c`) and shared with the library module by pointer reference.



`qtm_surface_cs_0x0021_api.h` `qtm_surface_cs_0x003c_api.h`	This header file contains all API implementations relevant to the module. It must be included with the compiled module in the application project.
`qtm_common_components_api.h`	This header file contains API declarations that are accessible by all QTML modules, such as node and key data structures and `touch_ret_t` return codes.

13.3 Functional Description

Initialization
Data structures must be loaded with configurations before library usage. The '`surface_cs2t`' module is initialized by calling the '`qtm_init_surface_cs2t()`' API.

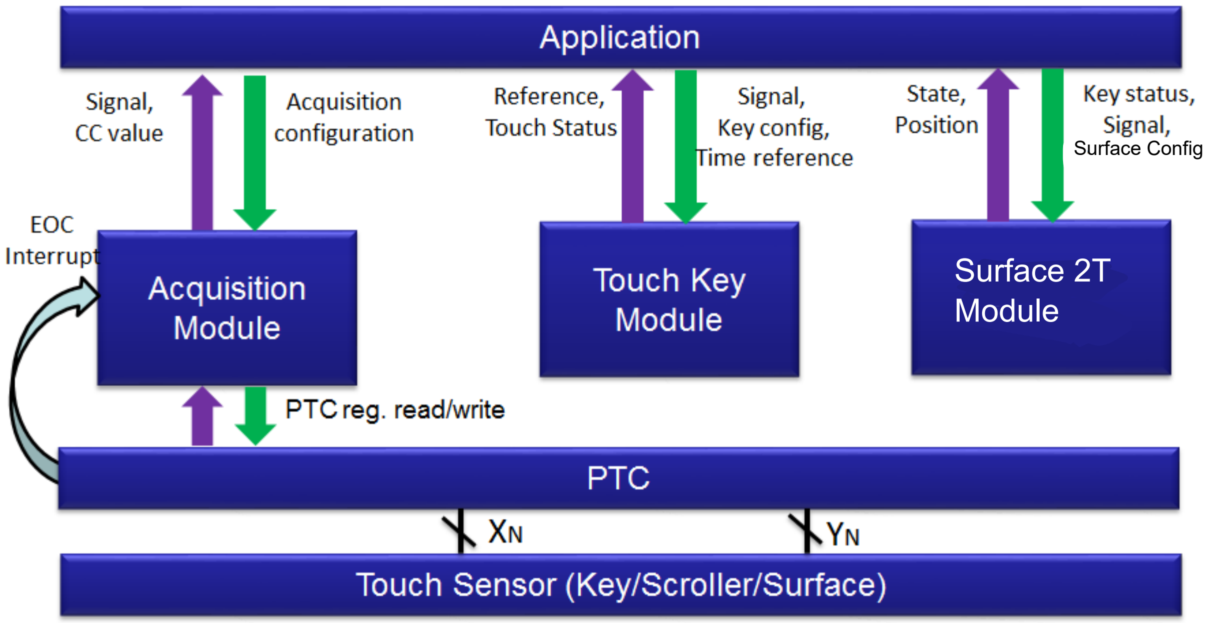
Supporting Modules
Sensor nodes ('`acquisition`' module) and keys ('`touch_key`' module) must be appropriately configured as required by the '`surface_cs`' module.

Sensor Node Configuration
Surface CS/2T requires sensors configured and grouped to implement one horizontal and one vertical slider. If the X pins are arranged horizontally, then the vertical slider is made up of (All X)/Each Y. Similarly, the horizontal slider is made up of Each X/(All Y).

Run-time Operation
Surface CS/2T functions as a top-level module providing touch contact information to the application. It utilizes a touch key library module for sensor calibration, signal drift, touch detection, and timed feature implementations. The touch key module itself uses a target-specific acquisition module to interface with the capacitive measurement hardware.

In a QTML application, the module processing order must be called correctly:

1. Acquisition of measurements of all sensor nodes - `qtm_ptc_start_measurement_seq();`
2. Acquisition processing for all sensor nodes - `qtm_acquisition_process();`
3. Touch Key processing for all keys - `qtm_key_sensors_process();`
4. Surface CS processing - `qtm_surface_cs2t_process();`



13.4 Operation

The API function '`qtm_surface_cs2t_process()`' is called after acquisition and touch key processing.

Making contact:

When contact is made with the surface sensor

1. The module checks all keys on the surface for touch contact detection.
2. If a key in detect is found, the position is calculated.
3. Contact size is calculated and compared against the minimum contact threshold
4. The surface goes into the 'Detect' condition.

Tracking/Releasing contact:

1. The module checks all keys for touch contact.
2. If no key is in detect, the module searches for a pair of neighboring keys whose touch delta exceeds the minimum contact threshold.
3. If such a contact is found, then the new position is calculated, **OR**
4. If no such contact is found, the surface returns to 'No Detect' condition.

13.5 Configuration

The Surface CS/2T module must be configured with operational parameters and with pointers to the key data set for the underlying touch keys.

13.5.1 Data Structures

qtm_surface_cs2t_control_t

- Top-level container for surface configuration
- Contains pointers to data and configuration structures

Struct	Contents
qtm_surface_cs2t_control_t	qtm_surface_cs2t_data_t *qtm_surface_cs2t_data;
	qtm_surface_contact_data_t *qtm_surface_contact_data;
	qtm_surface_cs_config_t *qtm_surface_cs_config;

qtm_surface_cs2t_data_t

- Run-time data for the Surface CS/2T module

Parameter	Size	Range/Options	Usage
qt_surface_cs2t_status	1 byte	Bit field Bit 7: Reburst required	Reburst Required = 1 Indicates that further measurements are required to resolve/update contact status.
		Bit 6: —	—
		Bit 5: POS_MERGED_V	Two contacts present, vertical positions too close to separate
		Bit 4: POS_MERGED_H	Two contacts present, horizontal positions too close to separate
		Bit 3 —	—
		Bit 2: —	—
		Bit 1: —	—
		Bit 0: Touch detection	Touch Detection = 1 Indicates that a touch contact is present on the surface.

qtm_surface_contact_data_t

- Runtime data for individual touch contacts (array)

Parameter	Size	Range/Options	Usage
qt_contact_status	1 byte	Bit field Bit 7: —	—
		Bit 6: —	—
		Bit 5: POS_V_DEC	Vertical position decreased
		Bit 4: POS_V_INC	Vertical position increased
		Bit 3: POS_H_DEC	Horizontal position decreased
		Bit 2: POS_H_INC	Horizontal position increased
		Bit 1: POS_CHANGE	Change in reported position
		Bit 0: Touch detection	Touch Detection = 1 Indicates that a touch contact is present on the surface.
h_position_abs	2 bytes	0 to 4095	Unfiltered horizontal position
h_position	2 bytes	0 to 4095	Filtered horizontal position
v_position_abs	2 bytes	0 to 4095	Unfiltered vertical position
v_position	2 bytes	0 to 4095	Filtered vertical position
contact_size	2 bytes	—	Sum of touch deltas at contact location

qtm_surface_cs_config_t

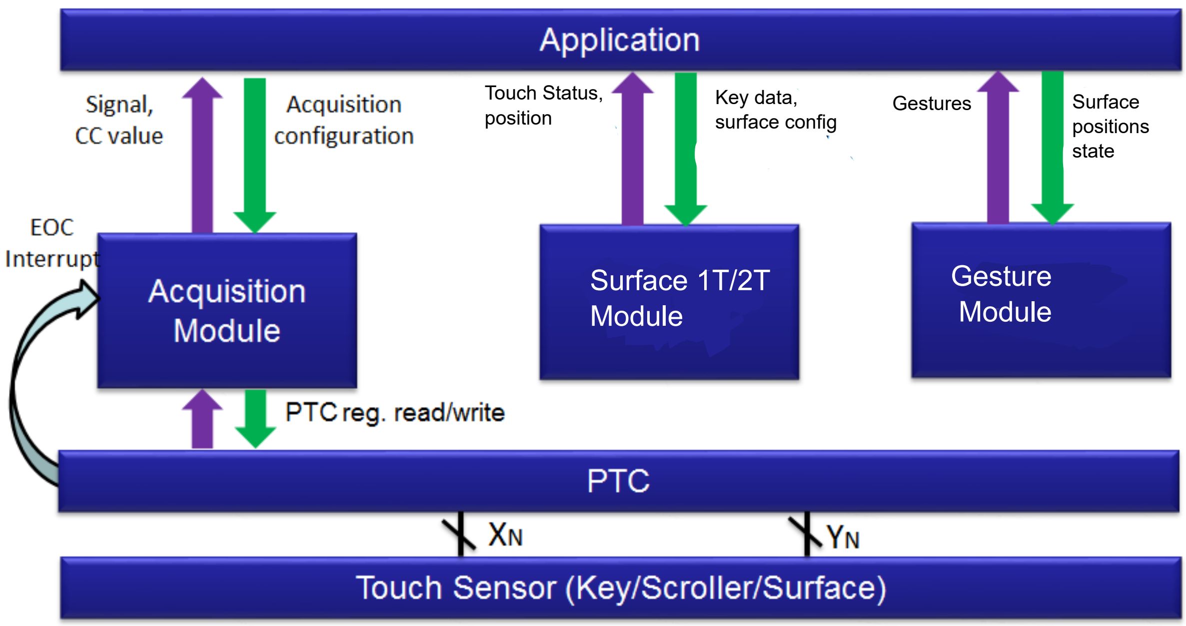
- Configuration parameters for the touch surface

Parameter	Size	Range/Options	Usage
start_key_h	2 bytes	0 to 65534	Start key of horizontal axis
number_of_keys_h	1 byte	0 to 255	Number of keys forming horizontal axis
start_key_v	2 bytes	0 to 65534	Start key of vertical axis
number_of_keys_v	1 byte	0 to 255	Number of keys forming vertical axis
resol_deadband	1 byte	Bits 7:4 = Resolution 2 to 12 bits	Full-scale position resolution reported for each axis
position_hysteresis	1 byte	0 to 255	The minimum travel distance to be reported after contact or direction change. Applies to horizontal and vertical.
position_filter	1 byte	Bits 7:5: —	—
		Bit 4: Median Filter	Median filter enable
		Bit 3: —	—
		Bit 2: —	—
		Bits 1:0: IIR Config	IIR Config 0 = None 1 = 25% 2 = 50% 3 = 75%
contact_min_threshold	2 bytes	0 to 65535	The minimum contact size measurement for persistent contact tracking. Contact size is the sum of neighboring keys' touch deltas forming the touch contact.
*qtm_touch_key_data	Pointer 2/4 bytes	qtm_touch_key_data_t	Pointer to touch key data for the underlying set of touch keys

14. Gestures Module

14.1 Overview

The gestures module identifies the gestures based on the touch positions received from the surface module and reports the detected gestures. This module processes the horizontal and vertical touch positions and reports if any gesture is identified.



The module is configured to interface with the QTouch surface module. Pointers to surface module contact data are needed for the identification of gestures.

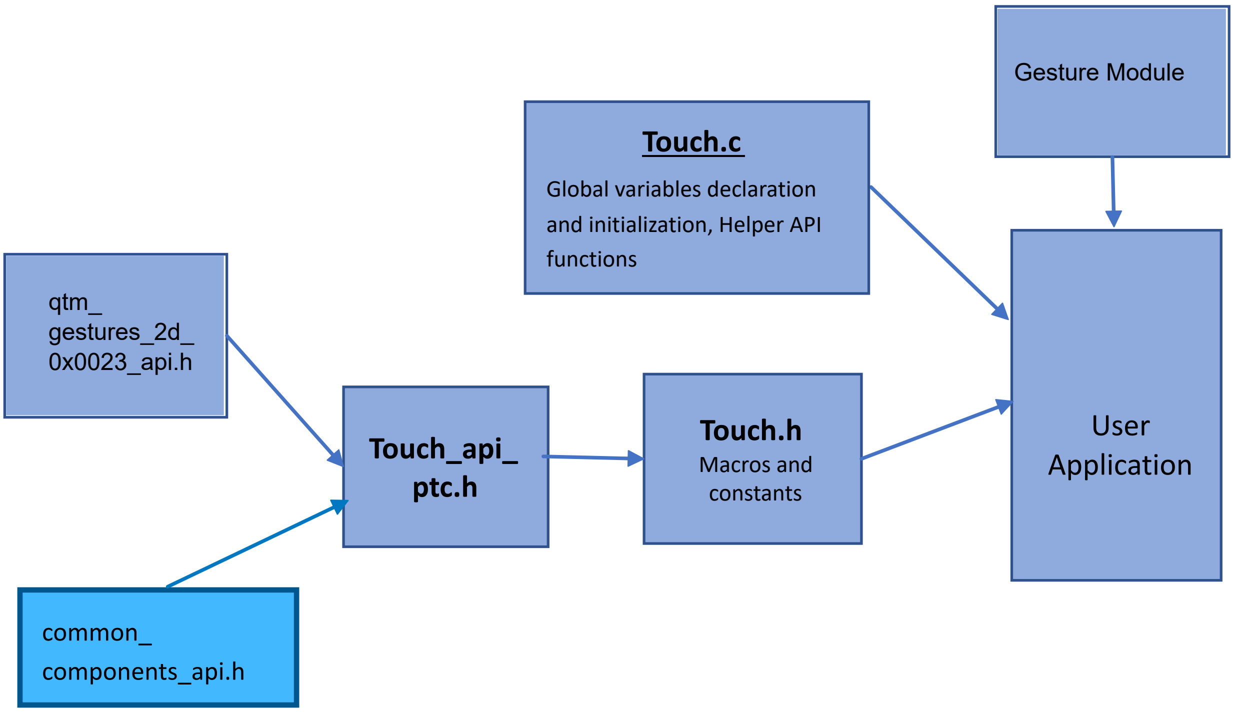
Table 14-1. Module Files

GCC Compiler	SAM devices	`libqtm_surface_gestures_cm0p_0x0023.a`
	AVR® devices	`libqtm_surface_gestures_t1614_0x0023.a`
		`libqtm_surface_gestures_t1616_0x0023.a`
		`libqtm_surface_gestures_t1617_0x0023.a`
		`libqtm_surface_gestures_t3214_0x0023.a`
		`libqtm_surface_gestures_t3216_0x0023.a`
		`libqtm_surface_gestures_t3217_0x0023.a`
IAR Compiler	SAM devices	`qtm_surface_gestures_cm0p_0x0023.r90`
	AVR® devices	`qtm_surface_gestures_t1614_0x0023.r90`
		`qtm_surface_gestures_t1616_0x0023.r90`
		`qtm_surface_gestures_t1617_0x0023.r90`
		`qtm_surface_gestures_t3214_0x0023.r90`
		`qtm_surface_gestures_t3216_0x0023.r90`
		`qtm_surface_gestures_t3217_0x0023.r90`

14.2 Interfaces to Module

As this module is dependent on the surface module, it needs a pointer to the surface contact data to read the surface touch positions and status for the processing of gestures.

All user options are configured in application code (`touch.h` / `touch.c`) and shared with the library module by pointer reference.



`qtm_gestures_2d_0x0023_api.h`	This header file contains all API implementations related to the gesture module. It should be included with the compiled module in the application project.
`qtm_common_components_api.h`	This header file contains API declarations that are accessible by all QTML modules, such as node and key data structures and `touch_ret_t` return codes.

14.3 Configuration

14.3.1 Data Structures

`qtm_gestures_2d_control_t`

The `qtm_gestures_2d_control_t` data interface is a container structure which controls the input and output of this module.

Field	Unit	Range/Options	Parameter
`qtm_gestures_2d_data`	`qtm_gestures_2d_data _t*`	Pointer	Pointer to the gestures data structure
`qtm_gestures_2d_config`	`qtm_gestures_2d_config _t*`	Pointer	Pointer to the gestures config structure

qtm_gestures_2d_config _t

The qtm_gestures_2d_config _t data structure is the configuration structure passed to the module.

Field	Unit	Range/ Options	Parameter
horiz_position0	uint16_t	Pointer	Pointer to the horizontal contact 0 position
vertical_position0	uint16_t	Pointer	Pointer to the vertical contact 0 position
surface_status0	uint8_t	Pointer	Pointer to the status of contact 0
horiz_position1	uint16_t	Pointer	Pointer to the horizontal contact 1 position
vertical_position1	uint16_t	Pointer	Pointer to the vertical contact 1 position
surface_status1	uint8_t	Pointer	Pointer to the status of contact 1
surface_resolution	uint8_t	0 to 255	This parameter defines the resolution of surface
tapReleaseTimeout	uint8_t	0 to 255	This parameter limits the amount of time allowed between the initial finger press and the liftoff. Exceeding this value will cause the firmware to not consider the gesture as a tap gesture. **Note:** This value should be lesser than tapHoldTimeout and swipeTimeout
tapHoldTimeout	uint8_t	0 to 255	If a finger stays within the bounds set by TAP_AREA and is not removed, the firmware will report a Tap Hold gesture once the gesture timer exceeds this value. **Note:** This should be greater than the tapReleaseTimeout and swipeTimeout
swipeTimeout	uint8_t	0 to 255	This value limits the amount of time allowed for the swipe gesture (initial finger press, moving in a particular direction, crossing the distance threshold and the liftoff). **Note:** This should be greater than the tapReleaseTimeout and lesser than tapHoldTimeout
xSwipeDistanceThreshold	uint8_t	0 to 255	This controls the distance traveled in the X-axis direction for detecting Left and Right Swipe gestures.
ySwipeDistanceThreshold	uint8_t	0 to 255	This controls the distance traveled in the Y-axis direction for detecting Up and Down Swipe gestures
edgeSwipeDistanceThreshold	uint8_t	0 to 255	This controls the distance traveled for Edge Swipe gestures
tapDistanceThreshold	uint8_t	0 to 255	This parameter bounds the finger to an area it must stay within to be considered a Tap gesture when the finger is removed and Tap and Hold gesture if the finger is not removed for some time
seqTapDistanceThreshold	uint8_t	0 to 255	This parameter limits the allowable distance of the current touch's initial press from the liftoff position of the previous touch. It is used for multiple taps (double-tap, triple-tap, etc.). If the taps following the first are within this threshold, then the tap counter will be incremented. If the following tap gestures exceed this threshold, the previous touch is sent as a single tap, and the current touch will reset the tap counter.
edgeBoundary	uint8_t	0 to 255	The firmware can also be modified to define an edge region along the border of the touch sensor. With this defined, Swipe gestures that start in an edge region will be reported as Edge Swipe gestures in place of normal Swipe gestures.

...........continued

Field	Unit	Range/ Options	Parameter
`wheelPostscaler`	`int8_t`	-128 to 127	This parameter adjusts the rate at which the Wheel gesture is updated in the GUI
`wheelStartQuadrantCount`	`int8_t`	-128 to 127	The Wheel gesture movement can be broken down into 90° arcs. The firmware watches for a certain number of arcs to occur in a circular pattern before starting to report Wheel gesture information. The number of arcs that must be first detected is determined by this parameter. Lower values for this parameter make it faster to start a wheel gesture, but it also makes the firmware prone to prematurely reporting wheel gesture information.
`wheelReverseQuadrantCount`	`int8_t`	-128 to 127	This parameter functions like `wheelStartQuadrantCount`, except it is used when changing the direction of the wheel instead of starting it new. This is used to prevent quick toggling between directions.
`pinchZoomThreshold`	`uint8_t`	0 to 255	This parameter limits the allowable distance between the two fingers to detect the pinch and the zoom gestures. After crossing this parameter value, if the distance between the contacts is reducing, then the gesture is reported as "PINCH". After crossing this parameter value, if the distance between the contacts is increasing, then the gesture is reported as "ZOOM".

`qtm_gestures_2d_data_t`

The `qtm_gestures_2d_data_t` data structure is used internally within the module to identify the gesture and to store the status and information.

Field	Unit	Range/Options	Parameter
`gestures_status`	`uint8_t`	0 or 1	This indicates if a gesture has been decoded or not
`gestures_which_gesture`	`uint8_t`	0 to 255	This contains the current, decoded gesture
`gestures_info`	`uint8_t`	0 to 255	This contains the additional gesture information

15. Binding Layer Module

15.1 Overview

The binding layer is the generic framework that binds the QTouch library modules and automates the initialization and processing of modules. The binding layer is configured with data pointers and function pointers of the QTouch modules, which are used to execute the module API functions in the appropriate sequence. The binding module also provides callback on completion of every stage to the user application.

The binding includes the acquisition module, signal conditioning modules, and post processing modules. Controlling all the modules with a unified application interface reduces the complexity of handling multiple modules, their states, errors, callback functions. The user application code can also be built as a library module and automated using the binding layer provided the user module conforms to the QTouch modular library architecture.

Figure 15-1. Binding Layer Framework Block Diagram

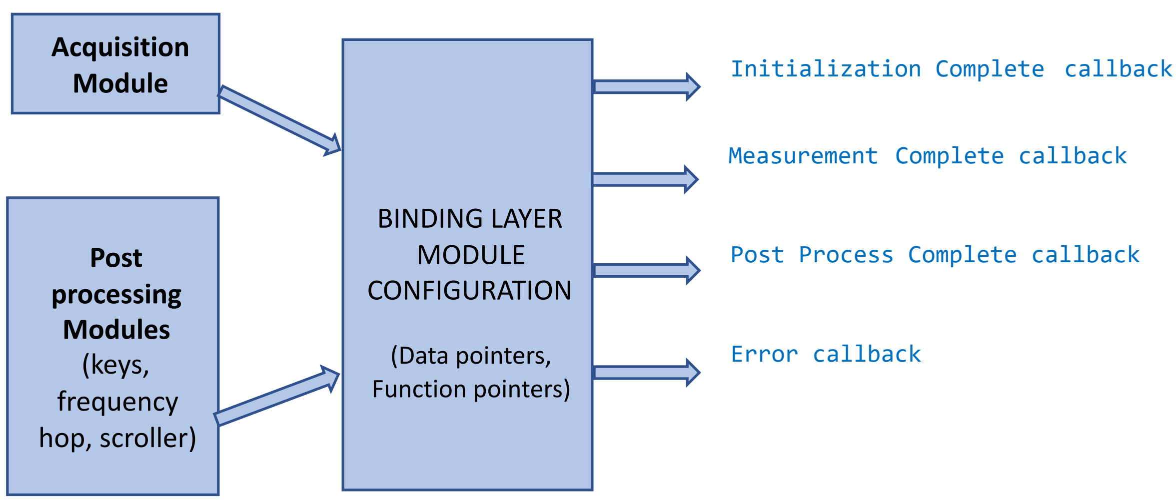
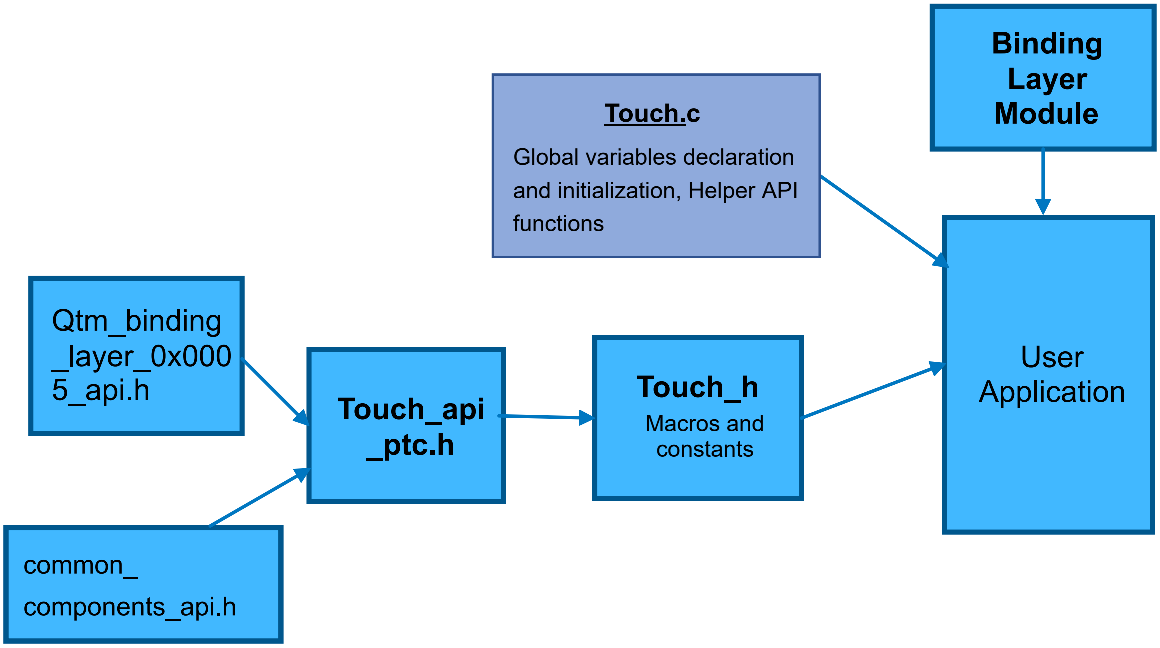


Table 15-1. Module Format

GCC compiler	`libqtm_binding_layer_xxxxx_0x0005.a`
IAR compiler (AVR® MCU)	`qtm_binding_layer_xxxxx_0x0005.r90`
IAR compiler (Arm® MCU)	`qtm_binding_layer_xxxxx_0x0002.a`

15.2 Interface

The data structure definitions and the API declarations are included in the API file '`qtm_binding_layer_0x0005_api.h`'. The data structure covers all the configurations and output data variables. This file should be included on the common API `touch_ptc_api.h` file.

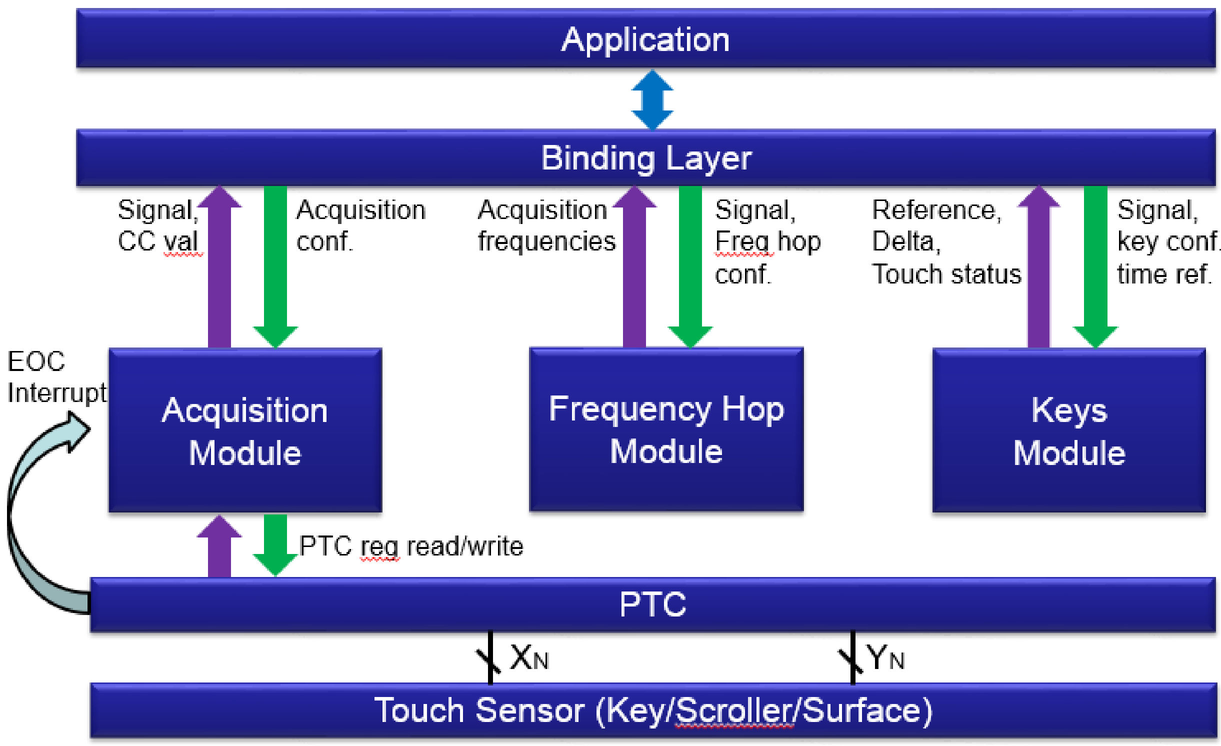


15.3 Functional Description

The binding layer automates the following processes of each module.

1. Module initialization.
2. Capture success/error and report through callback.
3. Module post-processing.
4. Capture success/error and report through callback.
5. Capture “module reburst” flag and retriggers the acquisition based on the ‘Reburst’ status.

Figure 15-2. Binding Layer-based QTouch® Application



Error handling support by binding layer module:
The individual module errors are validated inside the binding layer, and they are encoded and passed to the application as a single error code.

The error code is decoded in the touch.c file and displayed on the data visualizer software. The error code format is given below.

```
Acquisition Module Error codes: 0x8<error code>
    0x81 - Qtm init
    0x82 - start acq
    0x83 - cal sensors
    0x84 - cal hardware

Post processing Modules error codes: 0x4<process_id>
    0x40, 0x41, 0x42, ...
process_id is the sequence of process IDs listed in #define LIB_MODULES_PROC_LIST macro.
Process IDs start from zero and maximum is 15

        Examples:
        0x40 -> error in post processing module 1
        0x42 -> error in post processing module 3

Decoded Module_error_codes:
    Acquisition module error = 1
    post processing module1 error = 2
    post processing module2 error = 3
    ... and so on
```

15.4 Configuration

15.4.1 Data Structures

The container structure that holds the entire configuration of a binding layer is given below.

```
typedef struct qtm_control_tag
{
    uint8_t binding_layer_flags;

    module_init_t *library_modules_init;
    module_proc_t *library_modules_proc;
    module_acq_t  *library_modules_acq;

    module_arg_t *library_module_init_data_model;
    module_arg_t *library_module_proc_data_model;
    module_arg_t *library_modules_acq_dm;

    qtm_acq_pp_t *qtm_acq_pp;

    /*******************************/
    /* Callbacks for Binding layer */
    /*******************************/
    qtm_library_init_complete_t qtm_init_complete_callback;
    qtm_error_callback_t        qtm_error_callback;
    qtm_measure_complete_t      qtm_measure_complete_callback;
    qtm_pre_process_callback_t  qtm_pre_process_callback;
    qtm_post_process_callback_t qtm_post_process_callback;

} qtm_control_t;
```

Parameter	Description
`*library_modules_init`	Pointer to the array that contains the list of module initialization function pointers
`*library_modules_proc`	Pointer to the array that contains the list of module post-processing function pointers
`*library_modules_acq`	Pointer to the array that contains the list of acquisition module function pointers
`*library_module_init_data_model`	Pointer to the array which contains the Data Pointers of the acquisition modules
`*library_module_proc_data_model`	Pointer to the array which contains the Data Pointers of the post-processing modules
`*library_modules_acq_dm`	Pointer to the array which contains the pointers of acquisition groups
`qtm_init_complete_callback`	Callback provided by binding layer module after executing all the module initializations
`qtm_error_callback`	Callback function triggered only if there is any error encountered by the binding layer during the module processes
`qtm_measure_complete_callback`	Callback triggered by binding layer module after the completion of measurement and before post-processing
`qtm_pre_process_callback`	Callback triggered after the acquisition process and before post processing. This is provided to enable the user to implement custom filtering modules
`qtm_post_process_callback`	Callback triggered by binding layer module after the completion of all the post-processing of modules

15.4.2 Status and Output Data

Parameter	Description
binding_layer_flags	Three status flags are set inside the binding layer callback functions to perform further processing the Application. Three binding layer flags are supported in the current version as below.
	time_to_measure_touch: This flag is set on the timer ISR handler and when any module reburst is requested. This flag is used to trigger the measurement on either one of the above conditions met.
	node_pp_request: This flag is set in the measurement complete callback to indicate post processing is required. This flag is handled in the touch_process function.
	reburst_request: This flag is set in the post process complete callback and based on the individual module reburst flags. This flag is handled on the touch_process function.

16. Building Applications Using Atmel START

Atmel START helps the user to select and configure software components for the Microchip microcontrollers. The QTouch project can be created using Atmel START. The user can add sensors and configure QTouch parameters represented in graphical ways. The created project supports GCC and IAR compilers.

Refer to the following link for more information on how to create QTouch projects using the Amel START platform: http://microchipdeveloper.com/touch:introduction-to-qtouch-project-creation.

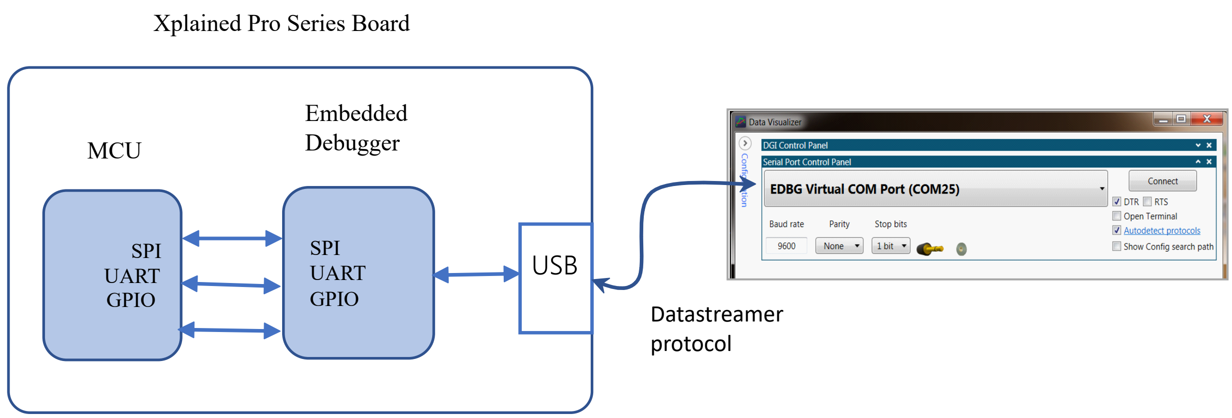
Refer to the following link for creating touch projects for SAM L1x devices using the START platform: http://microchipdeveloper.com/touch:generate-saml1x-touch-project.

17. Using Data Visualizer with QTouch® Applications

17.1 Overview

Data Visualizer (DV) is a program used for processing and visualization of run-time data from the target hardware. Data Visualizer can receive data from various sources such as the Embedded Debugger Data Gateway Interface (DGI) and serial port (COM port).

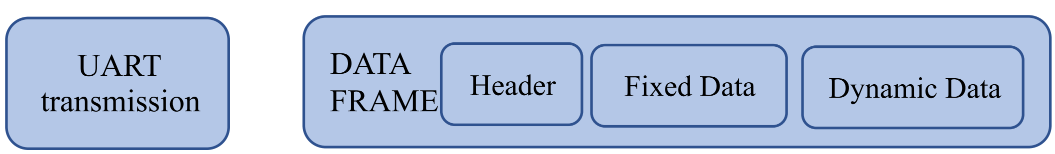
Typical connection models of the data visualizer with target hardware are shown below.



17.2 Datastreamer Module

The datastreamer module embeds with a simple mono-directional data transfer protocol and the data frame that is transmitted to the data visualizer software. The current version of the datastreamer provides support only for UART port communication.

Figure 17-1. Datastreamer Module Block Diagram



UART Transmission:
The UART transmission function is device-dependent, and the Atmel START automatically picks up the right driver and includes it on the user board/kit example project. Simple Asynchronous mode (non-interrupt driven) of the driver is used in all the devices.

Data frame:
The data frame contains a header, fixed module data, and dynamic module data bytes.

Header details:
The header contains 19 bytes and needs to be transmitted as part of the packet. The header need not be transmitted on every packet, rather transmitted once every 15 packet transmissions. The header packet details are listed below.

```
// uint8_t data[] =
// {
//     0x5F,
//     0xB4, 0x00, 0x86, 0x4A,
//     0x51, 0x54, 0x38, 0x31, 0x37, 0x54, 0x4F, 0x55, 0x43, 0x48, 0x55, 0xAA,
//     0xF9,
//     0xA0
// };
```

Bytes	Description
Byte 0	Start token. Contains fixed value ‘0x5F’
Bytes 1 to 14	Checksum type. Corresponds to LRC8 (XOR sum of packet, excluding start and end token)
Bytes 5 to 16	GUID, an identifier for the target hardware
Byte 17	Checksum of the header packet
Byte 18	End token. Contains fixed value ‘0xA0’

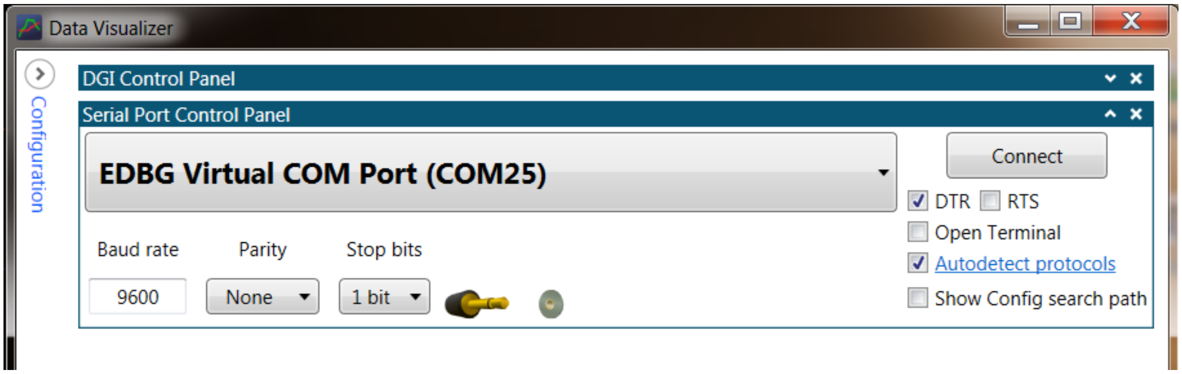
Fixed module data:
1. Basic button sensor data of all the configured button sensors.
2. Error status data.

Dynamic module data:
1. Acquisition auto-tune parameters are included when auto-tune is enabled in the Atmel START QTouch configurator.
2. Frequency hop auto-tune data is included as per the configurations done on Atmel START.
3. Scroller module parameters are transmitted when the Slider/Wheel sensors are configured on Atmel START.

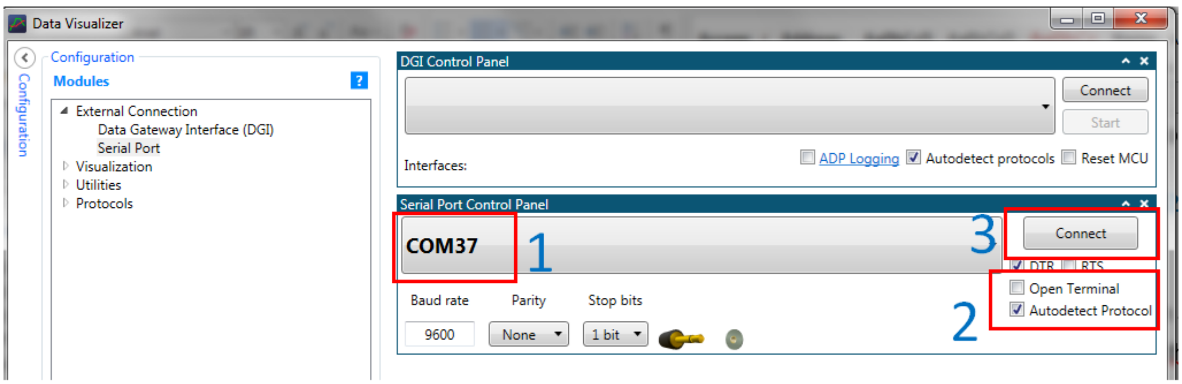
17.3 Debugging Using Data Visualizer

Data visualizer supports many widgets to visualize the data like terminal, label, graph, etc. The continuous data and their types are parsed and displayed on the appropriate elements using three scripts files having extensions of `*.db`, `*.ds`, `*.sc`. These script files are automatically generated by the Atmel START platform based on the project configuration. Only the path of the scripts needs to be configured on the data visualizer software. Data visualizer software is available both as a stand-alone installable version as well as an extension on Atmel Studio IDE and can be downloaded from the following link: https://gallery.microchip.com/policies/studio.

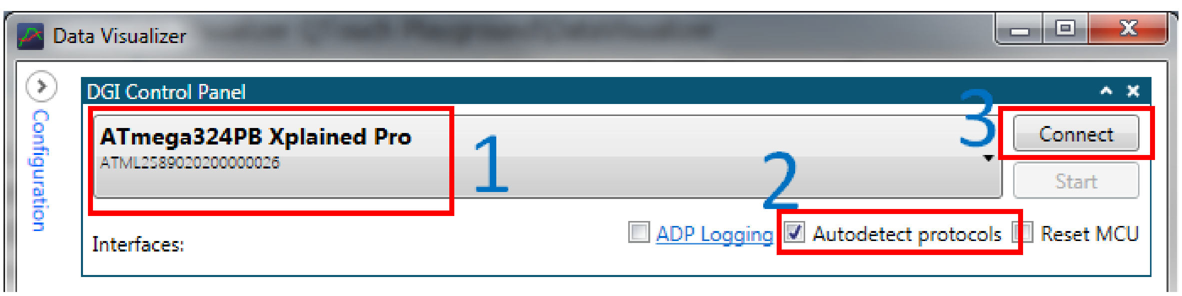
The sequence of steps used for debugging is given below.
1. Create a configuration folder “dv_config” for data visualizer in the desired location.
2. Copy the dashboard configuration (`.db`, `.ds`, `.sc`) files from “..\thirdparty\qtouch\datastreamer” project folder to “dv_config” folder.
   Note: These files are not source files. They will not be automatically extracted to the project folder. To extract these files, rename the `selfcap_3ch.atzip` file to `selfcap_3ch.zip`. Then extract the content.
3. Open **Data Visualizer**.
   Note: If QTouch Debug data is sent using SPI or I^2C interface, go to Step 6. If QTouch Debug data is sent using COM port, continue.
4. Double-click the serial port control panel and click the **Connect** button to make a connection to the target. Close the DGI control panel tab.



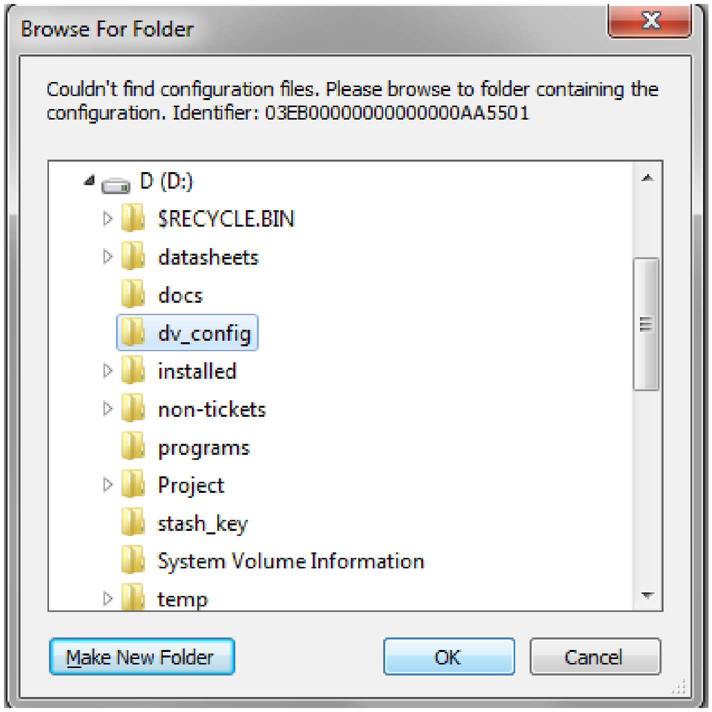
5. Another way to make the connection is through the **Configuration** option on the left side. Expand Configuration option and under **External Connection** option, double-click on the **Serial Port** option and click the "**Connect**" button on the serial port control panel. Restore the configuration option to a minimized state.



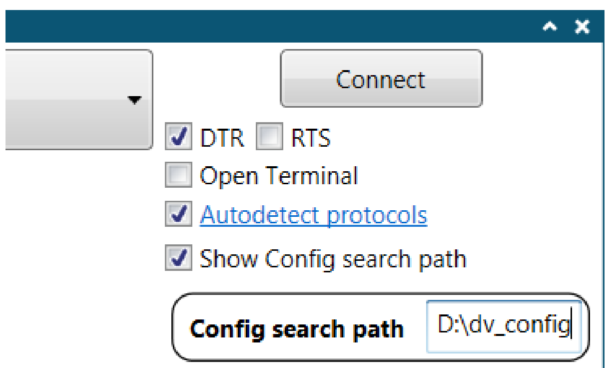
6. Select the desired kit, select then the **Autodetect protocol** check-box, and click **Connect**.



7. For the very first time, Data Visualizer will prompt the user to select the folder containing configuration information as follows. Browse and select the '`dv_config`' folder and click **OK**.



Alternatively, the path of the configuration folder ‘`dv_config`’ can be specified in the `config_path` tab as shown below. Click the check box option “**`show config search path`**” to enable the config path tab.

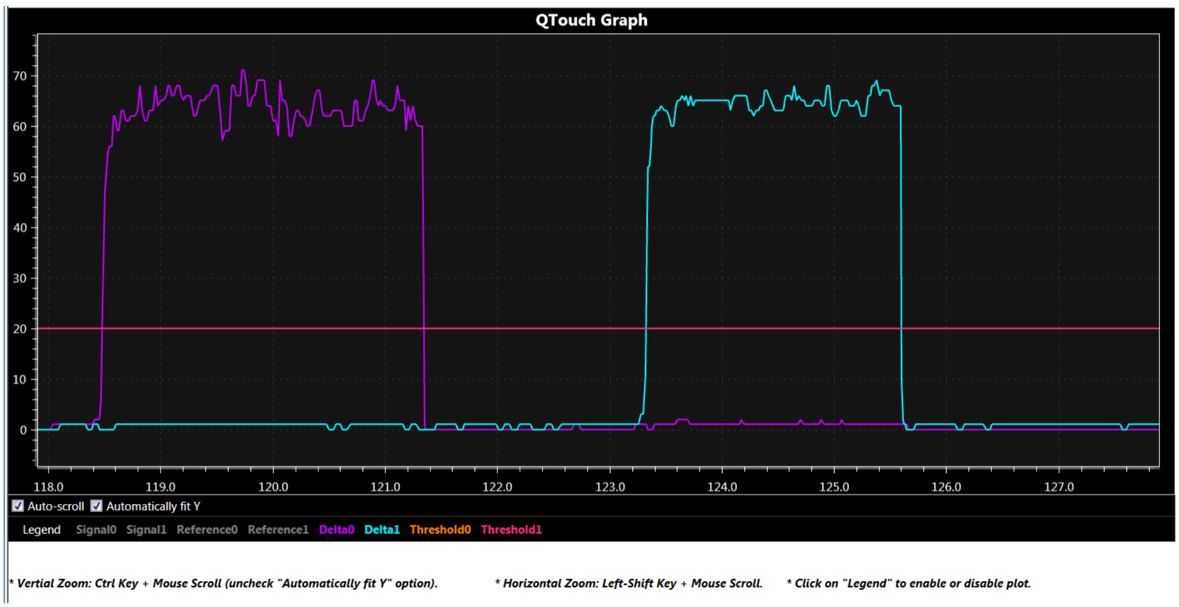


Note: The selected folder will be saved by the Data Visualizer. Data Visualizer will not prompt the user to select a folder for subsequent connections. If the sensor configuration is changed, the new dashboard configuration files from the Atmel START project need to be copied to this folder. Since the configuration file names are the same, the old files should be replaced with the new ones. The file names should not be modified.

8. The dashboard view contains three sections of data displayed. The first section converts the status information of all the configured buttons along with delta and threshold values.

Button Data				
Channel ID	**Sensor Type**	**State**	**Delta**	**Threshold**
0	**Button 0**	1	65	20
1	**Button 1**	0	2	20

9. Section 2 shows the graph view plotted with the signal, reference, and delta values of the configured channels, as shown below. The plots can be enabled/disabled by clicking on the legends at the bottom of the graph.



10. The third section displays the table of data from Noise Immunity modules, detailed sensor information, including Compensation Capacitance value, Error Status data.

Sensor Data

Channel ID	Sensor Type	Signal	Reference	Delta	Compensation
0	**Button 0**	509	508	1	11495
1	**Button 1**	515	513	2	7287

Compensation: Represents PTC compensation circuit value which is equivalent to sensor capacitance

"Compenstation" value can be used to check whether sensor is saturated. Refer to User Guide

Frequency Hop Data

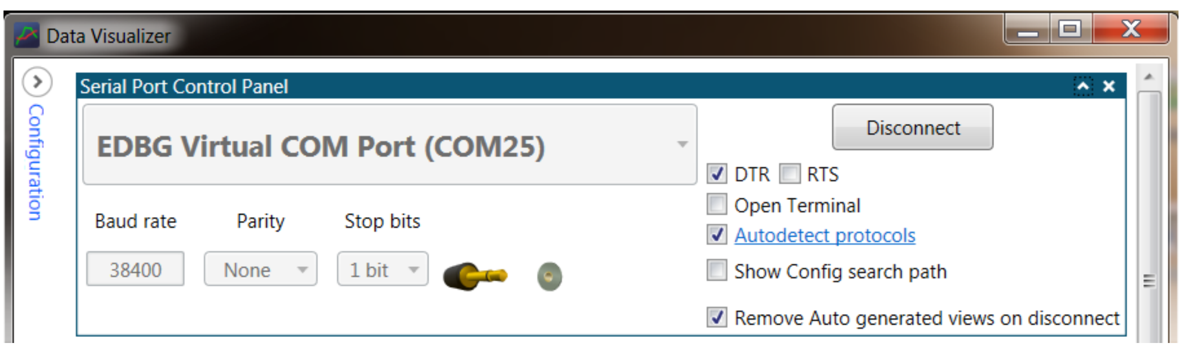
CurrentFrequency	1	HopFrequency0	0	HopFrequency1	1	HopFrequency2	2

Displayed frequencies are auto-tuned by QTouch Library based on noise levels

Debug Data

FrameCounter	41	***Counter for datastreamer packets. Missing count indicate packet drop***
QTouchLibError	0	***Indicates library error state. Zero: no error. Refer "Error Code" section in User Guide***

11. To disconnect the hardware, open the **Serial Port Control Panel** by double-clicking on the tab, and click the '**Disconnect**' button, as shown below:



17.4 Debugging Using 2D Touch Surface Utility

For debugging surface and gesture projects, a tool called "2D Touch Surface Utility" is used.

For more details about the tool and surface-gesture projects, see the following links:

- http://microchipdeveloper.com/touch:generate-qtouch-surface-gesture-project
- http://microchipdeveloper.com/touch:guide-for-surface-sensor-design-using-modular-library
- http://microchipdeveloper.com/touch:guide-to-connect-to-touch-surface-utility

18. Tuning Procedure

18.1 Tuning for Noise Performance

In any touch sensing application, the system designer must consider how electrical interference in the target environment may affect the performance of the sensors.

Touch sensors with insufficient tuning can show failures in tests of either radiated or conducted noise, which can occur in the environment or power domain of the application or may be generated by the application itself during normal operation.

In many applications, there are quality standards that must be met where EMC performance criteria are clearly defined. However, meeting the standards cannot be considered as proof that the system will never show EMC problems, as the standards include only the most commonly occurring types and sources of noise.

Noise immunity comes at the cost of increased touch response time and power consumption. The system designer must carry out a proper tuning of the touch sensors to ensure the least power consumption. The QTouch modular library has several user-configurable features that can be tuned to give the best balance between touch response time, noise immunity, and power consumption.

Noise Sources

Noise sources that affect touch sensor performance can occur in a wide variety of applications like:

- Motors
- Piezo buzzers
- PWM controls
- Fluorescent lamps
- Radio transmissions
- Inductive cook tops
- Power supply/chargers
- Mains supply

Applicable EMC standards

- Conducted Immunity EN61000-4-6
- Electrostatic Discharge (ESD) EN61000-4-2
- Electrical Fast Transient (EFT) EN61000-4-4

Noise Counter Measures

The effects of noise are highly dependent on the amplitude of the noise signal induced or injected onto the sensors, and the frequency profile of that noise signal.

Generally, this noise can be classified as:

- Broadband noise

or

- Narrow band noise

Broadband Noise Counter Measures

In broadband noise, most of the noise spectrum lies outside the sampling frequency. Provided that the maximum and minimum voltage levels of the acquisition signal combined with noise signals are within the input range of the measurement system and a sufficiently large number of samples are taken, broadband noise interference can be averaged out by setting a high value of oversampling.

Excessive noise amplitude can saturate the analog front end. In this case, the acquisition signals combined with the noise signals are outside the input range of the measurement circuit, which results in clipping of the measurements.

Often the clipping is not observable in the resolved measurement, as it occurs only on a portion of the measurement samples, but the presence of clipped samples prevents effective averaging of the sample points.

In this case, averaging of samples will not result in a noise-free measurement, even with large rates of oversampling. The resolved signal will show a shift from its correct level due to the asymmetry of signal clipping.

18.1.1 Step 1: Prevent Clipping

This requires the implementation of a hardware low-pass filter in order to reduce the scale of the noise combined with acquisition signal. The sensor capacitance is combined with a series resistor on the Y (Sense) line, which may be internal or external to the microcontroller.

Note: Internal series resistor is only available in Mutual Capacitance mode with PTC.

The external series resistor helps reduce the effect during ESD. Use at least one 1 kΩ external series resistor as close to the microcontroller pin on the sense lines as possible for both self-capacitance and mutual capacitance sensors.

18.1.2 Step 2: Charge Transfer Test

As an effect of adding a series resistor to form a low pass filter, the time constant for charging the sensors is increased. It is essential to ensure that the sensor capacitance is fully charged and discharged during each measurement sampling.

Insufficient charging can be observed as a reduced touch delta or compensation circuit calibration.

However, this problem may not be apparent in the touch sensor operation; the application may behave well even in the presence of low-level noise, but show much worse performance during noise tests with the addition of the resistor compared to a configuration which excludes the resistor.

Charge Transfer Calibration

The QTouch® Modular Library provides functionality to automatically adjust timing parameters to ensure full charge transfer.

Calibration may be configured to tune one of three parameters, depending on the target device and measurement technology.

`CAL_AUTO_TUNE_RSEL` Clock prescaler and CSD are maintained at the configured setting, while the internal series resistor is adjusted to the maximum value, which allows adequate charging for each sensor node.
- Only available with PTC Mutual capacitance acquisition

`CAL_AUTO_TUNE_PRSC` Series resistor and CSD are maintained at the configured setting, while the prescaler is adjusted to the minimum value, which allows adequate charging for each sensor node.
- Incrementing doubles the acquisition time, decrementing halves the acquisition time

`CAL_AUTO_TUNE_CSD` Both Prescaler and Resistor are maintained at the configured setting, and Charge Share Delay is adjusted to the minimum value, which allows adequate charging for each sensor node.
- Incrementing CSD adds one cycle to the charge transfer phase of the acquisition sequence

18.1.3 Step 3: Adjusting Oversampling

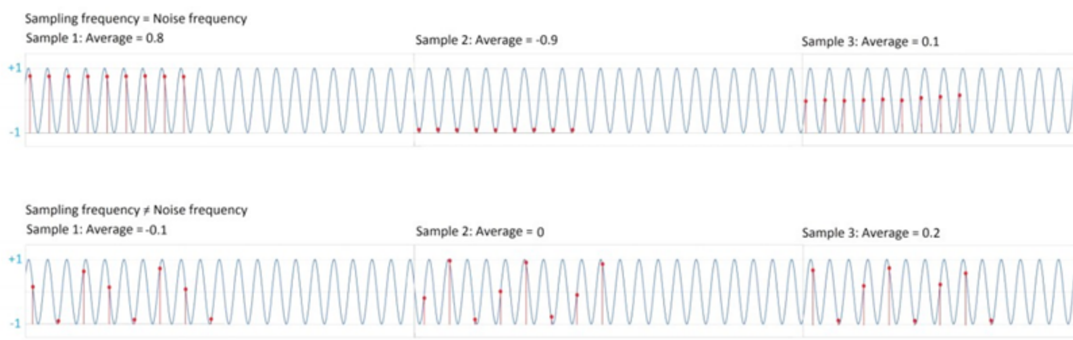
Once the clipping is prevented by hardware filtering and full charge transfer is ensured, the next step is to find the optimal settings for oversampling.

This is a trade-off between noise tolerance against response time and power consumption. More samples give better quality data but take longer to acquire.

Narrow Band Noise Counter Measures

If the noise includes a frequency component that is related to the capacitance measurement frequency, then no amount of oversampling will average out the noise effects. Any batch of measurement samples taken with the same sampling frequency will result in a measurement offset. The actual offset resulting from each measurement depends on the relative phase of the noise component and the sampling frequency.

This effect is illustrated in the following diagram, where the noise is represented by a sine wave.



18.1.4 Step 4: Select Frequency Mode

In the case where the noise is at (or close to) a frequency that is harmonically related to the sampling frequency then the noise issue becomes severe, as illustrated above. In this case, the oversampling frequency must be adjusted in order to avoid the noise.

This is particularly important in applications where a frequency sweep test is required, such as EN61000-4-6.

Acquisition Module (PTC)

Available Frequencies (4 MHz PTC Clk)	
Frequency Selection	**Frequency [kHz]**
`FREQ_SEL_0`	66.67
`FREQ_SEL_1`	62.5
`FREQ_SEL_2`	58.82
`FREQ_SEL_3`	55.56
`FREQ_SEL_4`	52.63
`FREQ_SEL_5`	50
`FREQ_SEL_6`	47.62
`FREQ_SEL_7`	45.45
`FREQ_SEL_8`	43.48
`FREQ_SEL_9`	41.67
`FREQ_SEL_10`	40
`FREQ_SEL_11`	38.46
`FREQ_SEL_12`	37.04
`FREQ_SEL_13`	35.71
`FREQ_SEL_14`	34.48
`FREQ_SEL_15`	33.33

...........continued

Available Frequencies (4 MHz PTC Clk)	
Frequency Selection	Frequency [kHz]
`FREQ_SEL_SPREAD`	Variable frequencies

The acquisition module provides two strategies for frequency selection:

1. A single acquisition frequency is selected, and oversampling takes place at this frequency only. `FREQ_SEL_0` provides the fastest measurements and `FREQ_SEL_15` the slowest. If no high-performance EMC standards are required, but the application equipment generates noise, which interferes with a particular acquisition frequency, the designer may simply change the frequency.
2. A variable frequency is used during oversampling. FREQ_SEL_SPREAD varies the frequency during the acquisition oversampling. The delay is varied from 0 to 15 in a sawtooth manner on successive samples during oversampling to apply a wider spectrum of sampling frequency. Compared to single frequency acquisition, the frequency spread option reduces the sensitivity to noise at a particular 'worst-case' frequency, but increases the range of noise frequencies around that worst-case frequency which will show harmonic interference – albeit with reduced severity of the noise effects. In many applications, `FREQ_SEL_SPREAD` is sufficient to achieve the required noise tolerance.

Frequency Hopping Module
Module ID: 0x0006

The frequency hopping module utilizes three or more base frequencies and a median filter to avoid using measurements taken with harmonic interference. The frequencies should be selected to minimize the set of crossover harmonics within the problem frequency band.

Each of the selected frequencies is used for acquisition oversampling during successive measurement cycles.

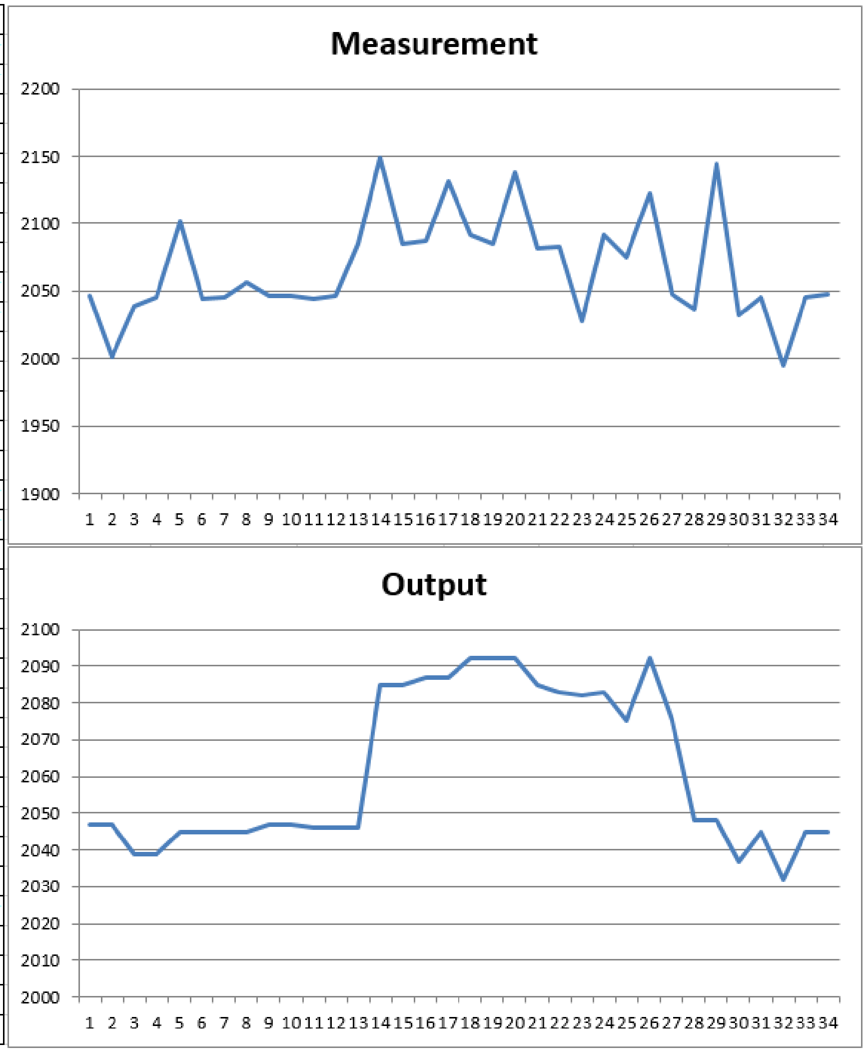
Example 18-1. Frequency Hopping with 3 Frequencies:

- **Cycle 1**: All sensors measured with Frequency 0
- **Cycle 2**: All sensors measured with Frequency 1
- **Cycle 3**: All sensors measured with Frequency 2
- **Cycle 4**: All sensors measured with Frequency 0
- **Cycle 5**: All sensors measured with Frequency 1

If Frequency 0 is related to the noise frequency, then the measurements taken with F0 will show high variation. By using a median filter, the outlying measurements will be rejected.

Figure 18-1. Measurements Taken at Frequency 1 are Affected by Noise

Cycle	Frequency	Measurement	Output
0	F0	2047	2047
1	F1	2001	2047
2	F2	2039	2039
3	F0	2045	2039
4	F1	2102	2045
5	F2	2044	2045
6	F0	2045	2045
7	F1	2056	2045
8	F2	2047	2047
9	F0	2046	2047
10	F1	2044	2046
11	F2	2046	2046
12	F0	2085	2046
13	F1	2149	2085
14	F2	2085	2085
15	F0	2087	2087
16	F1	2131	2087
17	F2	2092	2092
18	F0	2085	2092
19	F1	2138	2092
20	F2	2082	2085
21	F0	2083	2083
22	F1	2028	2082
23	F2	2092	2083
24	F0	2075	2075
25	F1	2122	2092
26	F2	2048	2075
27	F0	2037	2048
28	F1	2145	2048
29	F2	2032	2037
30	F0	2045	2045
31	F1	1995	2032
32	F2	2045	2045
33	F0	2048	2045



Common Harmonics

No matter which frequencies are chosen, the possibility of noise at higher frequencies which are harmonics of more than one of the selected frequencies, exists.

Further up the spectrum, there are frequencies which are harmonics of all available frequencies, but those superset harmonics are at higher frequencies and so are blocked by the low pass filter.

In some applications, the potential for exposure to noise frequencies may be an unknown and variable quantity.

For example, a device utilizing a USB charger may not always be plugged into the charger that it was supplied with. Inexpensive replacement chargers are often found to generate high levels of common-mode noise, and at variable frequencies – often in the same band as the acquisition frequencies.

A similar situation occurs with applications tested to EN61000-4-6 for conducted immunity. The test equipment sweeps through injected noise from 150 kHz to 80 MHz, in steps of 1%. This gives an excellent chance of hitting an interference frequency, which is a common harmonic of the HOP frequencies.

In both cases, no static selection of frequencies can ensure harmonic avoidance by the median filter.

Frequency Hopping with Auto-tune
Module ID: 0x0004

Frequency Hopping with auto-tune provides the cyclic frequency hopping with median filter functionality, extended to quantify the variance of signals as measured by each individual frequency.

The module is configured with a stability limit. When signals measured at a particular oversampling frequency show a repeated variance exceeding this limit, the module switches this frequency to another, searching for a better performing option.

18.2 Tuning the Slider/Wheel Sensor

For instance, two buttons and a three-channel self-capacitance slider are configured. Let the buttons B0, B1, and the Key sensors that form the slider sensor be Slider0[0], Slider0[1], and Slider0[2].

The Buttons, Slider/Wheel data are displayed in the data visualizer control panel view, as shown below.

Button Data

Channel ID	Sensor Type	State	Delta	Threshold
0	Button 0	0	0	20
1	Button 1	0	0	20
2	Slider 0[0]	0	1	70
3	Slider 0[1]	0	1	70
4	Slider 0[2]	0	0	70

Slider & Wheel Data

Sensor	State	SW Delta	SW Threshold	Position
Slider 0	0	0	60	0

The following steps describe the procedure for tuning the slider/wheel sensors.

Step 1:
Make a touch on each key sensor Slider0[0], Slider0[1], and Slider0[2] and note the delta values. For example, the delta observed on slider0[0] is shown below.

Set the individual key sensor threshold to half the value of the delta value observed. In this case, the key threshold should be set to 60.

Slider0[0]

Button Data

Channel ID	Sensor Type	State
0	Button 0	0
1	Button 1	0
2	Slider 0[0]	1
3	Slider 0[1]	0
4	Slider 0[2]	0

Slider0[1]

Button Data

Channel ID	Sensor Type	State
0	Button 0	0
1	Button 1	0
2	Slider 0[0]	0
3	Slider 0[1]	1
4	Slider 0[2]	0

Slider0[2]

Button Dat

Channel ID	Sensor Type	State
0	Button 0	0
1	Button 1	0
2	Slider 0[0]	0
3	Slider 0[1]	0
4	Slider 0[2]	1

Step 2:
Set the calculated key threshold on Step 1 as the SW Threshold and verify the slider sensor goes to detect when the touch made on the individual sensors is as shown below.

Button Data

Channel ID	Sensor Type	State	Delta	Threshold
0	Button 0	0	10	20
1	Button 1	0	0	20
2	Slider 0[0]	1	123	60
3	Slider 0[1]	0	30	60
4	Slider 0[2]	0	8	60

Slider & Wheel Data

Sensor	State	SW Delta	SW Threshold	Position
Slider 0	1	149	60	4

Button Data

Channel ID	Sensor Type	State	Delta	Threshold
0	Button 0	0	11	20
1	Button 1	0	0	20
2	Slider 0[0]	0	10	60
3	Slider 0[1]	1	122	60
4	Slider 0[2]	0	35	60

Slider & Wheel Data

Sensor	State	SW Delta	SW Threshold	Position
Slider 0	1	152	60	157

Button Data

Channel ID	Sensor Type	State	Delta	Threshold
0	Button 0	0	15	20
1	Button 1	0	0	20
2	Slider 0[0]	0	2	60
3	Slider 0[1]	0	21	60
4	Slider 0[2]	1	121	60

Slider & Wheel Data

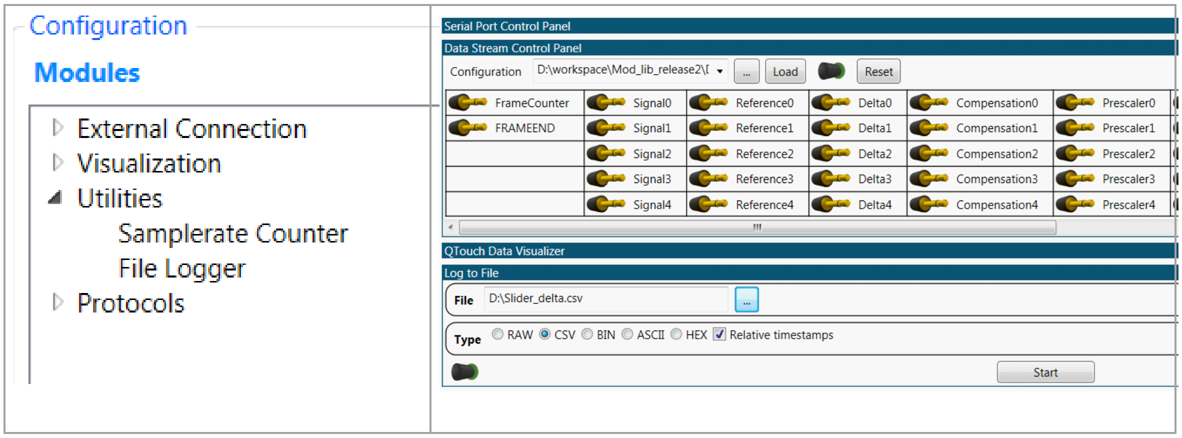
Sensor	State	SW Delta	SW Threshold	Position
Slider 0	1	137	60	255

Step 3:
Scroll over the slider sensor back and forth between start and end corners and record the SW delta on a CSV file using the File logger utility.

To use file logger, follow the instructions below:

1. Switch to Edit mode by checking the edit box at the bottom of the debug control panel.
2. Open the **File Logger** element *Configurations -> Utilities -> File Logger*.
3. Minimize the **QTouch Data Visualizer** view window by double-clicking on the title bar.

4. In the **File Logger** view, click the file browser and select the file name to log data.
5. Click the **SWDelta0** connector, drag and plug it to the file logger socket, as shown in the figure below.
6. Now click the **Start/Stop** button to log the data.
7. After logging complete, remove the SWDelta0 connection, uncheck the edit mode check box and close the File Logger.



Step 4:
Open the file log and identify the lowest SWDelta0 value from the samples. A few samples of the SWDelta0 collected from the Slider_delta.csv file are listed below.

103, 102, 101, 106, 98, 92, 86, 82, 78, 76, 78, 86, 0, 118, 113, 109, 105, 102, 100, 106, 102, 93, 86, 80, 76, 73, 72, 73, 79, 88, 90, 90, 89, 89, 89, 90, 94, 87, 81, 76, 72, 71, 69, 72, 81, 89, 94, 98, 100, 102

Set the SW threshold less than the identified minimal value “69”. In this case, the SW threshold is set about 15 counts less than the observed value, which is 54. Repeat step3 and step4 for a couple of iterations and tune the SW threshold based on the logs.

The Buttons, Slider/Wheel data after the tuning are given below.

Button Data				
Channel ID	**Sensor Type**	**State**	**Delta**	**Threshold**
0	Button 0	0	3	20
1	Button 1	0	0	20
2	Slider 0[0]	0	2	60
3	Slider 0[1]	0	49	60
4	Slider 0[2]	0	34	60

Slider & Wheel Data				
Sensor	**State**	**SW Delta**	**SW Threshold**	**Position**
Slider 0	1	80	54	192

19. Known Issues

Sl. No.	Issue Description	Category	Work Around Solution
1	When PTC is used in Self-Capacitance mode, the internal series resistor is not effective in reducing noise.	PTC	Recommended to use external series resistor
2	Some pins have higher parasitic capacitance. Refer to the *"Device Pin Capacitance"* sheet of https://microchip.wdfiles.com/local--files/touch:release-notes/QTouch_PTC_Information_7.1.xlsx for details.	PTC	1. Avoid these pins if alternate Y lines are available. 2. If it is required to use this pin for touch, then higher charge-time needs to be provided which might impact response time.

20. Appendix A - Revision History

Doc Rev.	Date	Comments
E	3/2020	Added support for AVR-DA devices. Added new content to section “7.1 Introduction”. Removing section “7.2 Parallel 4P – 1 From 4”. Updating table in section “6.4.1 Data Structures”. Updated table in sections “12.1 Overview”, “13.1 Overview”, “19. Known Issues”, and “18.1 Tuning for Noise Performance”. Other minor corrections.
D	3/2019	Added new section “4P Parallel Acquisition Module”.
C	6/2018	Updated “Module Naming Conventions” and “Appendix B” sections with new devices.
B	5/2018	Added 2D Touch Surface and Gesture module support.
A	12/2017	Microchip DS40001986 Revision A replaces Atmel 42805A. **Revised sections:** Updated the screen shots in the KIT example/user board project creation section with the latest QTouch Configurator GUI. Included picture for the Touch Key sensors and included graphs on the introduction section. **Additions:** New section “Known Issues” is added.
C	06/2017	**Revised sections:** Touch Library introduction, Data Visualizer, Atmel START Configurator. **Additions:** Acquisition module, Touch key module, Frequency hop module, Frequency Hop Auto-tune module, Slider/Wheel module, Binding Layer module, MISRA report, API Reference for each module, Kit example projects, Module naming conventions, API files interface.
B	02/2017	Added SAM D10/D11 Library information.
A	11/2016	Initial document release.

21. Appendix B - Acquisition Module API Reference

```
----------------------------------------------------------------------------
touch_ret_t qtm_acquisition_process(void)
----------------------------------------------------------------------------
Purpose: Signal capture and processing
Input  : (Measured signals, config)
Output : touch_ret_t
Notes  : Called by application after 'touch_measure_complete_callback'

----------------------------------------------------------------------------
touch_ret_t qtm_ptc_init_acquisition_module(qtm_acquisition_control_t* qtm_acq_control_ptr);
----------------------------------------------------------------------------
Purpose: Initialize the PTC & Assign pins
Input  : pointer to acquisition set
Output : touch_ret_t: TOUCH_SUCCESS or INVALID_PARAM
Notes  : ptc_init_acquisition module must be called ONLY once with a pointer to each config
set

----------------------------------------------------------------------------
touch_ret_t qtm_ptc_qtlib_assign_signal_memory(uint16_t* qtm_signal_raw_data_ptr);
----------------------------------------------------------------------------
Purpose: Assign raw signals pointer to array defined in application code
Input  : pointer to raw data array
Output : touch_ret_t: TOUCH_SUCCESS
Notes  : none

----------------------------------------------------------------------------
touch_ret_t qtm_enable_sensor_node(qtm_acquisition_control_t* qtm_acq_control_ptr, uint16_t
qtm_which_node_number);
----------------------------------------------------------------------------
Purpose:  Enables a sensor node for measurement
Input  :  Node configurations pointer, node (channel) number
Output : touch_ret_t:
Notes  : none

----------------------------------------------------------------------------
touch_ret_t qtm_calibrate_sensor_node(ptc_seq_acq_settings* qtm_acq_control_l_ptr, uint16_t
which_node_number)
----------------------------------------------------------------------------
Purpose:  Marks a sensor node for calibration
Input  :  Node configurations pointer, node (channel) number
Output : touch_ret_t:
Notes  : none

----------------------------------------------------------------------------
touch_ret_t qtm_ptc_start_measurement_seq(qtm_acquisition_control_t* qtm_acq_control_pointer,
void (*measure_complete_callback) (void));
----------------------------------------------------------------------------
Purpose:  Loads touch configurations for first channel and start,
Input  :  Node configurations pointer, measure complete callback pointer
Output : touch_ret_t:
Notes  : none

----------------------------------------------------------------------------
touch_ret_t qtm_autoscan_sensor_node(qtm_auto_scan_config_t* qtm_auto_scan_config_ptr, void
(*auto_scan_callback)(void));
----------------------------------------------------------------------------
Purpose: Configures the PTC for sleep mode measurement of a single node, with window
comparator wake
Input  : Acquisition set, channel number, threshold, scan trigger
Output : touch_ret_t
Notes  : none

----------------------------------------------------------------------------
touch_ret_t qtm_autoscan_node_cancel(void)
----------------------------------------------------------------------------
Purpose: Cancel auto-scan config
Input  : None
Output : touch_ret_t
Notes  : none

----------------------------------------------------------------------------
```

```
void qtm_ptc_de_init(void)
----------------------------------------------------------------------------
Purpose: Clear PTC Pin registers, set TOUCH_STATE_NULL
Input  : none
Output : none
Notes  : This API function is used to RESET the PTC during runtime without power cycle the
hardware. The application may include this function as part of other soft reset functions to
restart the application at runtime.

----------------------------------------------------------------------------
uint16_t qtm_<device_family>_acq_module_get_id(void)
Applicable <device_family> =
m328pb,m324pb,t81x,t161x,samd1x,samd20,samd21,samda1,same51,same53,same54,samd51,tiny321x,samc
20,samc21,saml21,saml22,samha1,saml10,saml11,avr_da
----------------------------------------------------------------------------
Purpose: Returns the module ID
Input  : none
Output : Module ID
Notes  : none

----------------------------------------------------------------------------
uint8_t qtm_<device_family>_acq_module_get_version(void);
Applicable <device_family> =
m328pb,m324pb,t81x,t161x,samd1x,samd20,samd21,samda1,same51,same53,same54,samd51,tiny321x,samc
20,samc21,saml21,saml22,samha1,saml10,saml11,avr_da
----------------------------------------------------------------------------
Purpose: Returns the module Firmware version
Input  : none
Output : Module ID - Upper nibble major / Lower nibble minor
Notes  : none

----------------------------------------------------------------------------
void qtm_ptc_clear_interrupt(void) -> ARM Cortex SAMD10,SAMD11,SAME51/E53/E54/D51
----------------------------------------------------------------------------
Purpose :  Clears the eoc/wcomp interrupt bits
Input   :  none
Output  :  none
Notes   :  none

----------------------------------------------------------------------------
void qtm_<device_family>_ptc_handler_eoc(void)
Applicable <device_family> =
m328pb,m324pb,t81x,t161x,samd1x,samd20,samd21,samda1,same51,same53,same54,samd51,tiny321x,samc
20,samc21,saml21,saml22,samha1,saml10,saml11,avr_da
----------------------------------------------------------------------------
Purpose :  Captures  the  measurement,  starts  the  next  or  End  Of  Sequence  handler
Input   :  none
Output  :  none
Notes   :  none

----------------------------------------------------------------------------
void qtm_<device_family>_ptc_handler_wcomp(void)
Applicable <device_family> =
m328pb,m324pb,t81x,t161x,samd1x,samd20,samd21,samda1,same51,same53,same54,samd51,tiny321x,samc
20,samc21,saml21,saml22,samha1,saml10,saml11,avr_da
----------------------------------------------------------------------------
Purpose :  Captures  the  measurement,  calls the callback
Input   :  none
Output  :  none
Notes   :  none
```

22. Appendix C - Frequency Hop Module API Reference

```
----------------------------------------------------------------------------
touch_ret_t qtm_freq_hop(qtm_freq_hop_control_t *qtm_freq_hop_control);
----------------------------------------------------------------------------
Purpose: Runs freq hop process
Input  : Pointer to container structure
Output : touch_ret_t
Notes  : none

----------------------------------------------------------------------------
uint16_t qtm_get_freq_hop_module_id(void)
----------------------------------------------------------------------------
Purpose: Returns the module ID
Input  : none
Output : Module ID
Notes  : none

----------------------------------------------------------------------------
uint8_t qtm_get_freq_hop_module_ver(void)
----------------------------------------------------------------------------
Purpose: Returns the module Firmware version
Input  : none
Output : Module ID - Upper nibble major / Lower nibble minor
Notes  : none

----------------------------------------------------------------------------
```

23. Appendix D - Frequency Hop Auto-tune Module API Reference

```
----------------------------------------------------------------------------
touch_ret_t qtm_freq_hop_autotune(qtm_freq_hop_autotune_control_t
*qtm_freq_hop_autotune_control);
----------------------------------------------------------------------------
Purpose: Runs freq hop auto tune process
Input  : Pointer to container structure
Output : touch_ret_t
Notes  : none

----------------------------------------------------------------------------
uint16_t qtm_get_freq_auto_module_id(void);
----------------------------------------------------------------------------
Purpose: Returns the module ID
Input  : none
Output : Module ID
Notes  : none

----------------------------------------------------------------------------
uint8_t qtm_get_freq_auto_module_ver(void);
----------------------------------------------------------------------------
Purpose: Returns the module Firmware version
Input  : none
Output : Module ID - Upper nibble major / Lower nibble minor
Notes  : none

----------------------------------------------------------------------------
```

24. Appendix E - Touch Key Module API Reference

```
----------------------------------------------------------------------------
touch_ret_t qtm_init_sensor_key(qtm_touch_key_control_t* qtm_lib_key_group_ptr, uint8_t
which_sensor_key, qtm_acq_node_data_t* acq_lib_node_ptr)
----------------------------------------------------------------------------
Purpose: Initialize a touch key sensor
Input  : Pointer to key group control data, key number, pointers to sensor node status and
signal
Output : TOUCH_SUCCESS
Notes  : none

----------------------------------------------------------------------------
touch_ret_t qtm_key_sensors_process(qtm_touch_key_control_t* qtm_lib_key_group_ptr)
----------------------------------------------------------------------------
Purpose: Sensor key post-processing (touch detect state machine)
Input  : Pointer to key group control data
Output : TOUCH_SUCCESS
Notes  : none

----------------------------------------------------------------------------
touch_ret_t qtm_key_suspend(uint16_t which_sensor_key, qtm_touch_key_control_t*
qtm_lib_key_group_ptr)
----------------------------------------------------------------------------
Purpose: Suspends acquisition measurements for the key
Input  : Key number, Pointer to key group control data
Output : TOUCH_SUCCESS
Notes  : Used to suspend the key temporarily, like to save the power by avoiding the
continuous scan on all the sensors. A single key can be defined to act as wake up sensor and
other key sensors can be suspended using this API. This API function works in association
with resume API function

----------------------------------------------------------------------------
touch_ret_t qtm_key_resume(uint16_t which_sensor_key, qtm_touch_key_control_t*
qtm_lib_key_group_ptr)
----------------------------------------------------------------------------
Purpose: Resumes acquisition measurements for the key
Input  : Key number, Pointer to key group control data
Output : TOUCH_SUCCESS
Notes  : Can be used along with suspend API function to avoid scanning of sensors
temporarily. For instance, some of the keys may be suspended from scanning during the idle
time and resumes based on touch on a defined key

----------------------------------------------------------------------------
void update_qtlib_timer(uint16_t time_elapsed_since_update)
----------------------------------------------------------------------------
Purpose: Updates local variable with time period
Input  : Number of ms since last update
Output : none
Notes  : none

----------------------------------------------------------------------------
uint16_t qtm_get_touch_keys_module_id(void)
----------------------------------------------------------------------------
Purpose: Returns the module ID
Input  : none
Output : Module ID
Notes  : none

----------------------------------------------------------------------------
uint8_t qtm_get_touch_keys_module_ver(void)
----------------------------------------------------------------------------
Purpose: Returns the module Firmware version
Input  : none
Output : Module ID - Upper nibble major / Lower nibble minor
Notes  : none

----------------------------------------------------------------------------
```

25. Appendix F - Scroller Module API Reference

```
----------------------------------------------------------------------------
touch_ret_t qtm_init_scroller_module(qtm_scroller_control_t *qtm_scroller_control)
----------------------------------------------------------------------------
Purpose: Initialize a scroller
Input  : Pointer to scroller group control data
Output : Touch return status value
Notes  : none

----------------------------------------------------------------------------
touch_ret_t qtm_scroller_process(qtm_scroller_control_t *qtm_scroller_control)
----------------------------------------------------------------------------
Purpose: Scroller position calculation and filtering
Input  : Pointer to scroller group control data
Output : Touch return status value
Notes  : none

----------------------------------------------------------------------------
uint16_t qtm_get_scroller_module_id(void)
----------------------------------------------------------------------------
Purpose: Returns the module ID
Input  : none
Output : Module ID
Notes  : none

----------------------------------------------------------------------------
uint8_t qtm_get_scroller_module_ver(void)
----------------------------------------------------------------------------
Purpose: Returns the module Firmware version
Input  : none
Output : Module ID - Upper nibble major / Lower nibble minor
Notes  : none
----------------------------------------------------------------------------
```

26. Appendix G - 2D Surface (One-Finger Touch) CS Module

```
/*============================================================================
touch_ret_t qtm_init_surface_cs(qtm_surface_cs_control_t *qtm_surface_cs_control);
------------------------------------------------------------------------------
Purpose: Initialize a scroller
Input  : Pointer to scroller group control data
Output : TOUCH_SUCCESS
Notes  : none
============================================================================*/
touch_ret_t qtm_init_surface_cs(qtm_surface_cs_control_t *qtm_surface_cs_control);

/*============================================================================
touch_ret_t qtm_surface_cs_process(qtm_surface_cs_control_t *qtm_surface_cs_control);
------------------------------------------------------------------------------
Purpose: Scroller position calculation and filtering
Input  : Pointer to scroller group control data
Output : TOUCH_SUCCESS
Notes  : none
============================================================================*/
touch_ret_t qtm_surface_cs_process(qtm_surface_cs_control_t *qtm_surface_cs_control);

/*============================================================================
uint16_t qtm_get_scroller_module_id(void)
------------------------------------------------------------------------------
Purpose: Returns the module ID
Input  : none
Output : Module ID
Notes  : none
============================================================================*/
uint16_t qtm_get_surface_cs_module_id(void);

/*============================================================================
uint8_t qtm_get_scroller_module_ver(void)
------------------------------------------------------------------------------
Purpose: Returns the module Firmware version
Input  : none
Output : Module ID - Upper nibble major / Lower nibble minor
Notes  : none
============================================================================*/
uint8_t qtm_get_surface_cs_module_ver(void);
```

27. Appendix H - 2D Surface (Two-Finger Touch) CS/2T Module

```
/*============================================================================
touch_ret_t qtm_init_surface_cs2t(qtm_surface_cs_control_t *qtm_surface_cs_control);
------------------------------------------------------------------------------
Purpose: Initialize a scroller
Input  : Pointer to scroller group control data
Output : TOUCH_SUCCESS
Notes  : none
============================================================================*/
touch_ret_t qtm_init_surface_cs2t(qtm_surface_cs2t_control_t *qtm_surface_cs2t_control);

/*============================================================================
touch_ret_t qtm_surface_cs_process(qtm_surface_cs_control_t *qtm_surface_cs_control);
------------------------------------------------------------------------------
Purpose: Scroller position calculation and filtering
Input  : Pointer to scroller group control data
Output : TOUCH_SUCCESS
Notes  : none
============================================================================*/
touch_ret_t qtm_surface_cs2t_process(qtm_surface_cs2t_control_t *qtm_surface_cs2t_control);

/*============================================================================
uint16_t qtm_get_surface_cs2t_module_id(void)
------------------------------------------------------------------------------
Purpose: Returns the module ID
Input  : none
Output : Module ID
Notes  : none
============================================================================*/
uint16_t qtm_get_surface_cs2t_module_id(void);

/*============================================================================
uint8_t qtm_get_surface_cs2t_module_ver(void)
------------------------------------------------------------------------------
Purpose: Returns the module Firmware version
Input  : none
Output : Module ID - Upper nibble major / Lower nibble minor
Notes  : none
============================================================================*/
uint8_t qtm_get_surface_cs2t_module_ver(void);
```

28. Appendix I - Gestures Module

```
----------------------------------------------------------------------------
void qtm_gestures_2d_clearGesture(void);

/*============================================================================
touch_ret_t qtm_init_gestures_2d(void);
------------------------------------------------------------------------------
Purpose: Initialize gesture tracking variables
Input : -
Output : TOUCH_SUCCESS
Notes : none
============================================================================*/
touch_ret_t qtm_init_gestures_2d(void);

/*============================================================================
touch_ret_t qtm_gestures_2d_process(qtm_gestures_2d_control_t *qtm_gestures_2d_control);
------------------------------------------------------------------------------
Purpose: Gesture engine processes updated touch info
Input : Gesture control struct pointer
Output : ?TOUCH_SUCCESS?
Notes : none
============================================================================*/
touch_ret_t qtm_gestures_2d_process(qtm_gestures_2d_control_t *qtm_gestures_2d_control);

/*============================================================================
void qtm_update_gesture_2d_timer(uint16_t time_elapsed_since_update);
------------------------------------------------------------------------------
Purpose: Updates local variable with time period
Input  : Number of ms since last update
Output : none
Notes  : none
============================================================================*/
void qtm_update_gesture_2d_timer(uint16_t time_elapsed_since_update);

/*============================================================================
uint16_t qtm_get_gesture_2d_module_id(void);
------------------------------------------------------------------------------
Purpose: Returns the module ID
Input : none
Output : Module ID
Notes : none
============================================================================*/
uint16_t qtm_get_gesture_2d_module_id(void);

/*============================================================================
uint8_t qtm_get_gesture_2d_module_ver(void);
------------------------------------------------------------------------------
Purpose: Returns the module Firmware version
Input : none
Output : Module ID - Upper nibble major / Lower nibble minor
Notes : none
============================================================================*/
uint8_t qtm_get_gesture_2d_module_ver(void);
----------------------------------------------------------------------------
```

29. Appendix J - Binding Layer Module API Reference

```
--------------------------------------------------------------------------------
void qtm_binding_layer_init(qtm_control_t *qtm_control);
--------------------------------------------------------------------------------
Purpose: This function internally executes the individual module initialization functions
using the pointers. Based on the initialization output, init_complete_callback or the
error_callback function is triggered.
Input  : Pointer to binding layer container structure
Output : none
Notes  : none

--------------------------------------------------------------------------------
void qtm_lib_start_acquisition(qtm_control_t *qtm_control);
--------------------------------------------------------------------------------
Purpose: This function internally executes the "qtm_ptc_start_measurement_seq" function to
start the measurement of sensors. The functions of multiple acquisition groups are executed
sequentially.
Input  : Pointer to binding layer container structure
Output : none
Notes  : none

--------------------------------------------------------------------------------
touch_ret_t qtm_lib_acq_process(void)
--------------------------------------------------------------------------------
Purpose: Executes the acquisition post process functions. The acquisition post process of
multiple groups is executed sequentially according to the configuration.
Input  : none
Output : Touch return status value
Notes  : none

--------------------------------------------------------------------------------
touch_ret_t qtm_lib_post_process(void)
--------------------------------------------------------------------------------
Purpose: Executes the individual module post processes. The sequence of post processes
executed is based on the configuration of qtm_config_t
Input  : none
Output : Touch return status value
Notes  : none

--------------------------------------------------------------------------------
qtm_control_t* qmt_get_binding_layer_ptr(void)
--------------------------------------------------------------------------------
Purpose: Returns the pointer to the binding layer container structure
Input  : none
Output : pointer to the binding layer container
Notes  : none

--------------------------------------------------------------------------------
uint16_t qtm_get_lib_state(void)
--------------------------------------------------------------------------------
Purpose: Returns the binding layer state
Input  : none
Output : Module state
Notes  : none

--------------------------------------------------------------------------------
uint16_t qtm_get_binding_layer_module_id(void)
--------------------------------------------------------------------------------
Purpose: Returns the module ID
Input  : none
Output : Module ID
Notes  : none

--------------------------------------------------------------------------------
uint8_t qtm_get_binding_layer_module_ver(void)
--------------------------------------------------------------------------------
Purpose: Returns the module Firmware version
Input  : none
Output : Module ID - Upper nibble major / Lower nibble minor
Notes  : none
```

30. Appendix K - Device Support

The latest device support list is provided in the link: http://microchipdeveloper.com/touch:release-notes.

The Microchip Website

Microchip provides online support via our website at http://www.microchip.com/. This website is used to make files and information easily available to customers. Some of the content available includes:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQs), technical support requests, online discussion groups, Microchip design partner program member listing
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

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ISBN: 978-1-5224-5703-9

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