RX Family

QE CTSU module Firmware Integration Technology

Introduction

This application note describes the CTSU module.

Target Device

- RX113 Group
- RX130 Group
- RX230 Group
- RX231 Group
- RX23W Group
- RX671 Group
- RX140 Group

When using this application note with other Renesas MCUs, careful evaluation is recommended after making modifications to comply with the alternate MCU.

Related Documents

Firmware Integration Technology User's Manual (R01AN1833)
Board Support Package Firmware Integration Technology Module (R01AN1685)
Adding Firmware Integration Technology Module to Projects (R01AN1723)
RX100 Series VDE Certified IEC60730 Self-Test Code (R01AN2061ED)
RX v2 Core VDE Certified IEC60730 Self-Test Code for RX v2 MCU (R01AN3364EG)

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1. Overview

The CTSU module is a CTSU driver for the Touch module. The CTSU module assumes the access from the Touch middleware layer, and it is also accessible from a user application.

The CTSU peripheral has three versions: CTSU, CTSU2L, and CTSU2SL. Each MCU devices are equipped with the following version of CTSU peripherals.

CTSU2SL：RX140-256KB, RX140-128KB

CTSU2L：RX140-64KB

CTSU：RX113, RX130, RX230, RX231, RX23W, RX671

These are functionally different, so these are described in this application note as below.

- Common description for CTSU, CTSU2L, CTSU2SL -> CTSU
- Description only for CTSU -> CTSU1
- Common Description for CTSU2L and CTSU2SL -> CTSU2L
- Description only for CTSU2SL -> CTSU2SL

1.1 Functions

The CTSU module supports the following functions.

1.1.1 QE for Capacitive Touch Usage

The module provides various capacitive touch measurements based on configuration settings generated by QE for Capacitive Touch.

As a part of the configuration settings, the touch interface configuration displays the combination of terminals to be measured (referred to as TS) and the corresponding measurement mode. Multi-touch interface configurations are necessary when the development product has a combination of different measurement modes or when the active shield is used.

1.1.2 Measurements and Obtaining Data

Measurements can be started by a software trigger or by an external event triggered by the Event Link Controller (ELCL).

As the measurement process is carried out by the CTSU2L peripheral, it does not use up main processor processing time.

The CTSU module processes INTCTSUWR and INTCTSURD if generated during a measurement. The data transfer controller (DTC) can also be used for these processes.

When the measurement complete interrupt (INTCTSUFN) process is complete, the application is notified in a callback function. Make sure you obtain the measurement results before the next measurement is started as internal processes are also executed when a measurement is completed.

Start the measurement with API function R_CTSU_ScanStart().

Obtain the measurement results with API function R_CTSU_DataGet().

1.1.3 Sensor ICO Correction function

The CTSU2L peripheral has a built-in correction circuit to handle the potential microvariations related to the manufacturing process of the sensor ICO MCU.

The module temporarily transitions to the correction process during initialization after power is turned on. In the correction process, the correction circuit is used to generate a correction coefficient (factor) to ensure accurate sensor measurement values.

When temperature correction is enabled, an external resistor connected to a TS terminal is used to periodically update the correction coefficient. By using an external resistor that is not dependent on temperature, you can even correct the temperature drift of the sensor ICO.

1.1.4 Initial Offset Adjustment

The CTSU2L peripheral was designed with a built-in offset current circuit in consideration of the amount of change in current due to touch. The offset current circuit cancels enough of the parasitic capacitance for it to fit within the sensor ICO dynamic range.

This module automatically adjusts the offset current setting. As the adjustment uses the normal measurement process, R_CTSU_ScanStart() and R_CTSU_DataGet() must be repeated several times after startup. Because the ctsu_element_cfg_t member “so” is the starting point for adjustments, you can set the appropriate value for “so” in order to reduce the number of times the two functions must be run to complete the adjustment. Normally, the value used for “so” is a value adjusted by QE for Capacitive Touch.

For CTSU2L, this feature can be turned off in the config.

Default target value

Mode	Default target value
Self-capacitance	15360 (37.5%)
Self-capacitance using active shield	6144 (15%)
Mutual-capacitance	10240 (20%)

The percentage is for the CCO's input limit. 100% is the measured value 40960.The default target value is based on 526us(CTSU1) or 256us(CTSU2).When the measurement time is changed, the target value is adjusted by the ratio with the base time.

Example of target value in combination of CTSUSNUM and CTSUSDPA

CTSU1 (CTSU clock = 32MHz、Self-capacitance mode)

Target value	CTSUSNUM	CTSUSDPA	Measurement time
15360	0x3	0x7	526us
30720	0x7	0x7	1052us
30720	0x3	0xF	1052us
7680	0x1	0x7	263us
7680	0x3	0x3	263us

The measurement time changes depending on the combination of CTSUSNUM and CTSUSDPA.
In the above table, CTSUPRRTIO is the recommended value of 3, and CSTUPRMODE is the recommended value of 2. When changing CTSUPRRATIO and CTSUPRMODE from the recommended values, follow the Hardware Manual for the measurement time.

・CTSU2 (Self-capacitance mode)

Target value	Target value (multi frequency)	CTSUSNUM	Measurement time
7680	15360 (128us + 128us)	0x7	128us
15360	30720 (256us + 256us)	0xF	256us
3840	7680 (64us + 64us)	0x3	64us

The measurement time changes depending on CTSUSNUM. If STCLK cannot be set to 0.5MHz, it will not support the table above. When setting STCLK to other than 0.5MHz because the CTSU clock is not an integer, follow the hardware manual for the measurement time.

1.1.5 Random Pulse Frequency Measurement (CTSU1)

The CTSU1 peripheral measures at one drive frequency.

The drive frequency determines the amperage to the electrode and generally uses the value tuned with QE for Capacitive Touch.

The drive frequency is calculated as below.

It is determined by PCLK frequency input to CTSU, CTSU Count Source Select bit(CTSUCLK), and CTSU Sensor Drive pulse Division Control bit(CTSUSDPA). For example, If it is set PCLK =32MHz, CTSUCLK = PLCK/2, and CTSUSDPA = 1/16, then drive frequency is 0.5MHz. CTSUSDPA can change for each TS port.

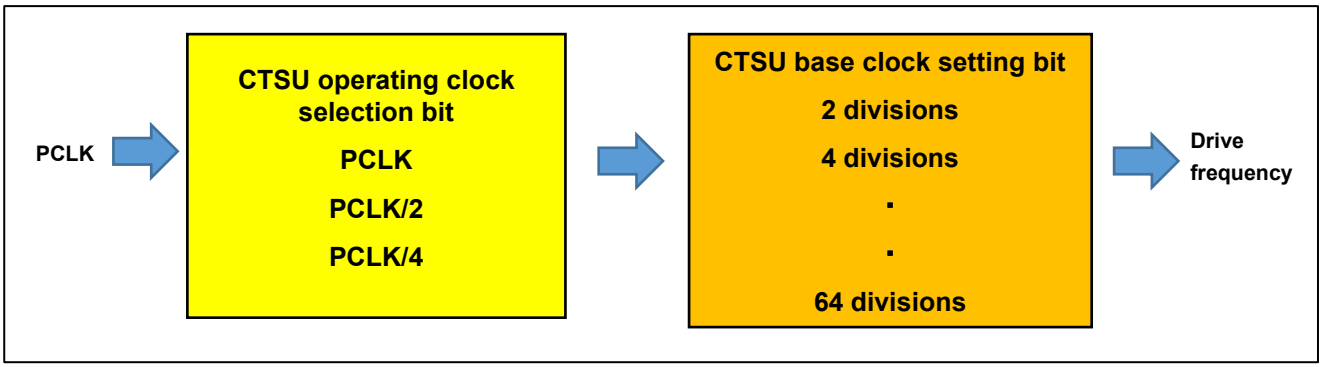

Figure 1 Drive Frequency Settings

The actual drive pulse is phase-shifted and frequency-spread with respect to the clock based on the drive frequency as a measure against external environmental noise. This module is fixed at initialization and sets the following.

CTSUSOFF = 0, CTSUSSMOD = 0, CTSUSSCNT = 3

1.1.6 Multi-frequency Measurements (CTSU2L)

The CTSU2L peripheral can measure in one of four drive frequencies to avoid synchronous noise.

With the default settings, the module takes measurements at three different frequencies. After standardizing the results obtained at the three frequencies in accordance with the first frequency reference value, the measured value is determined based on majority in a process referred to as “normalization.”

When this normalization is turned off in the config settings, the user can use the results of these three frequencies as noise filters. However, the three frequencies cannot be tied with the Touch module.

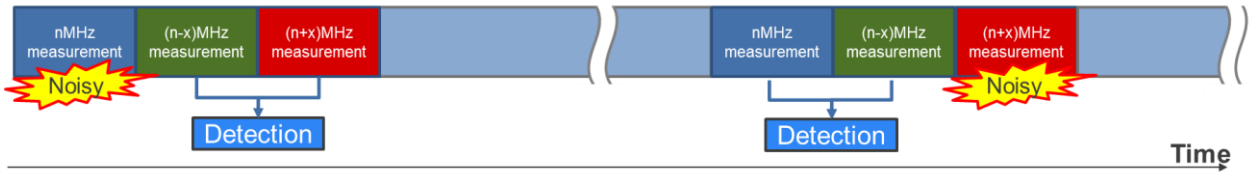

Figure 2 Multi-frequency Measurements

Drive frequency is determined based on the config settings. The module sets registers according to the config settings, and sets the three drive frequencies.

Drive frequency is calculated in the following equation:

(PCLKB frequency / CLK / STCLK) x SUMULTIn / 2 / SDPA : n = 0, 1, 2

The figure below shows the settings for generating a 2MHz drive frequency when the PCLKB frequency is 32 MHz. SDPA can be set for each touch interface configuration.

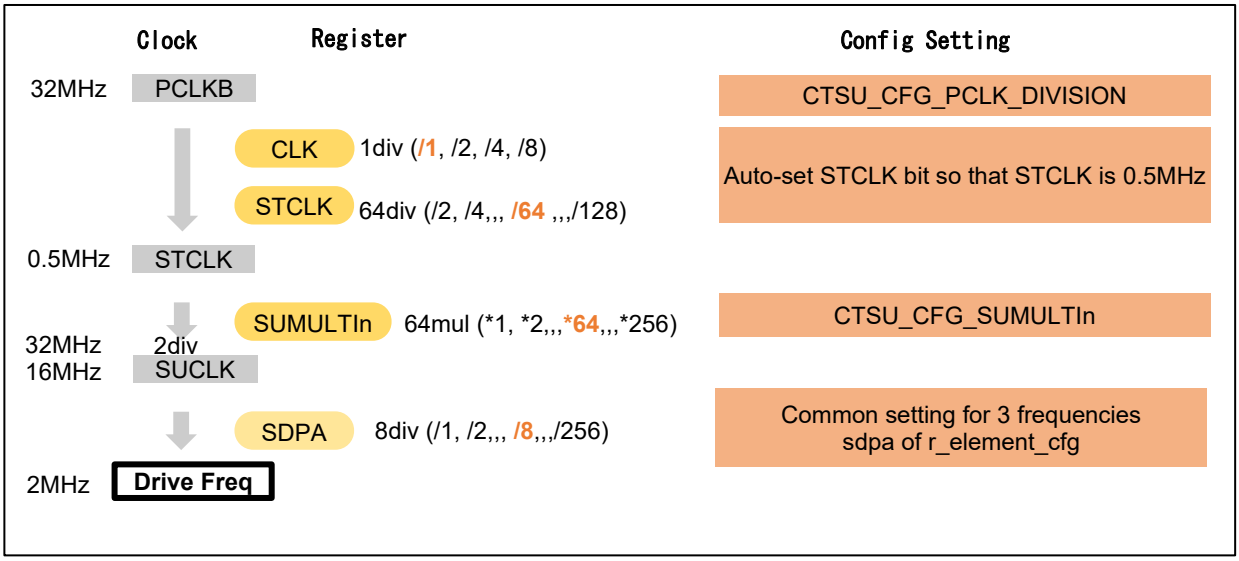

Figure 3 Drive Frequency Settings

1.1.7 Shield Function (CTSU2L)

The CTSU2L peripheral has a built-in function that outputs a shield signal in phase with the drive pulse from the shield terminal and the non-measurement terminal in order to shield against external influences while suppressing any increase in parasitic capacitance. This function can only be used during self-capacitance measurements.

This module allows the user to set a shield for each touch interface configuration.

For example, for the electrode configuration shown in, the members of ctsu_cfg_t should be set as follows. Other members have been omitted for the example.

```
.txvsel      = CTSU_TXVSEL_INTERNAL_POWER,
.txvsel2     = CTSU_TXVSEL_MODE,
.md          = CTSU_MODE_SELF_MULTI_SCAN,
.posel       = CTSU_POSEL_SAME_PULSE,
.ctsuchac0   = 0x0F,
.ctsuchtrc0  = 0x08,
```

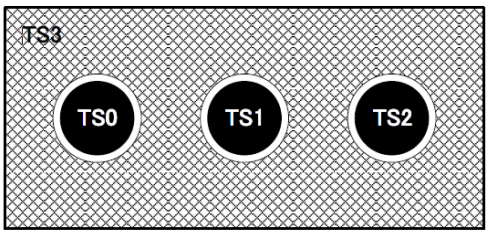

Figure 4 Example of Shield Electrode Structure

1.1.8 Measurement Error Message

When the CTSU2L peripheral detects an abnormal measurement, it sets the status register bit to 1.

In the measurement complete interrupt process, the module reads ICOMP1, ICOMP0, and SENSOVF of the status register and notifies the results in the callback function. The status register is reset after the contents are read. For more details on abnormal measurements, refer to “member event” in the ctsu_callback_args_t callback function argument.

1.1.9 Moving Average

This function calculates the moving average of the measured results.

Set the number of times the moving average should be calculated in the config settings.

1.1.10 Diagnosis Function

The CTSU peripheral has a built-in function that diagnoses its own inner circuit. This diagnosis function provides the API for diagnosing the inner circuit.

The diagnostic requirements are different for CTSU1 and CTSU2L providing 5 types of diagnosis for CTSU1 and 9 types for CTSU2L.

The diagnosis function is executed by calling the API function. This is executed independently from the other measurements and does not affect them.

To enable the diagnosis function, set CTSU_CFG_DIAG_SUPPORT_ENABLE to 1.

For CTSU1, 27pF condenser should be connected externally. After diagnostic function measurement, wait about 1ms before starting touch scanning.

For CTSU2L, use ADC FIT (r_s12ad_rx). If an error occurs in the ADC module used for Diagnosis mode, return FSP_ERR_ABORTED as the return value of R_CTSU_DataGet().For ADC module errors, see ADC FIT (r_s12ad_rx).

Consider the following three points when using the diagnostic function of CTSU2L.

1. When using the CTSU2L diagnostic function, CTSU driver must measure ADC. Therefore, when using ADC FIT on an application, be sure to close ADC FIT before using the diagnostic function.

2. If you did not close the ADC FIT, CTSU driver return value of FSP_ERR_ABORTED. Please refer to the sample below and close the ADC FIT so that the ADC measurement in the CTSU driver can be performed when the next diagnostic function is executed.

```
R_CTSU_ScanStart(g_qe_ctsu_instance_diagnosis.p_ctrl);
while (0 == g_qe_touch_flag) {}
g_qe_touch_flag = 0;

err = R_CTSU_DataGet(g_qe_ctsu_instance_diagnosis.p_ctrl, &dummyD);
if (FSP_SUCCESS == err)
{
    diag_err = R_CTSU_Diagnosis(g_qe_ctsu_instance_diagnosis.p_ctrl);
    if ( FSP_SUCCESS == diag_err )
    {
        /* TODO: Add your own code here. */
    }
}
else if (FSP_ERR_ABORTED == err)
{
    adc_err = R_ADC_Close(0);
    if (ADC_SUCCESS != adc_err)
    {
        while (true) {}
    }
}
```

3. When creating an RTOS application, consider the scheduling of diagnostic functions tasks for the CTSU module and tasks for the ADC module.

1.1.11 MEC Function (CTSU2SL)

The CTSU2SL peripheral has MEC (Multiple Electrode Connection) function that connects multiple electrodes and measures them as a single electrode. This feature is only available in self capacitance mode.

This is an example when using three electrodes. In normal times, normal measurement is performed, and 3 channels are measured to get each measured value. In power saving, MEC measurement is performed, and one channel is measured by combining three channels to acquire one measured value.

Figure 5 shows a compare of time of normal measurement and MEC measurement. Since multi channels are measured at the same time, the measurement time is shortened.

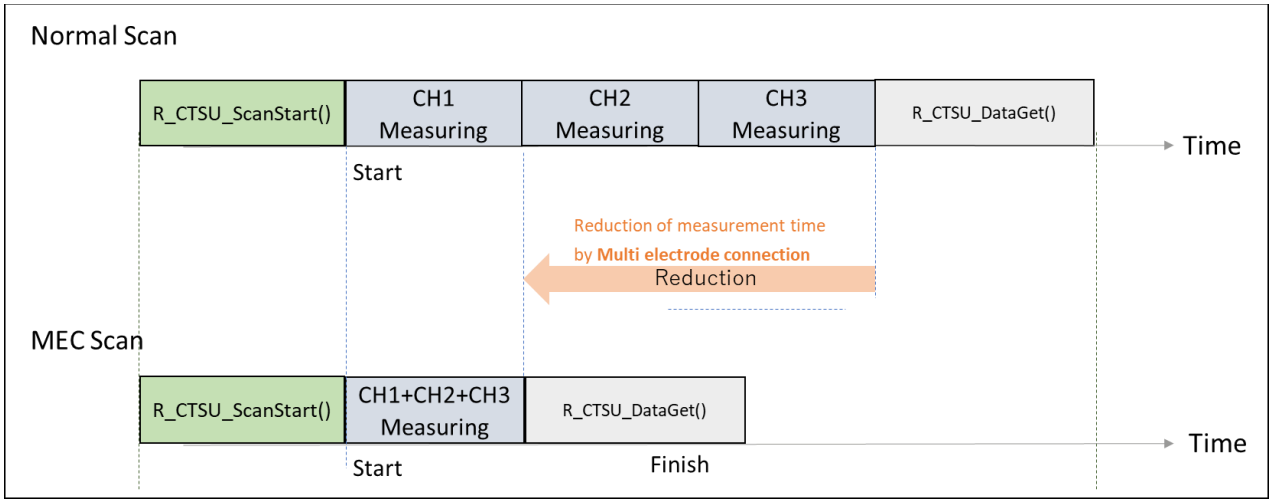

Figure 5 Compare of time between normal measurement and MEC measurement

To enable the code for the MEC feature, set CTSU_CFG_MULTIPLE_ELECTRODE_CONNECTION_ENABLE to 1.

When using MEC, create a touch interface configuration different from the normal touch interface configuration for the same TS. The following settings are required for the touch interface configuration for MEC measurement.

To enable MEC for touch interface configurations by setting tsod in ctsu_cfg_t to 1.

Set mec_ts of ctsu_cfg_t to one of the TS numbers to be measured.

If you want to use the shield function at the same time, set the TS number of the shield terminal in mec_shield_ts of ctsu_cfg_t. In this case, only one TS can be used as a shield terminal.

Set num_rx of ctsu_cfg_t to 1.

For example, in the case of the electrode configuration shown in Figure 6, set the members of ctsu_cfg_t as shown below. Other members are omitted here.

```
.tsod = 1,
.mec_ts = 0,
.mec_shield_ts = 3,
.num_rx = 1,
```

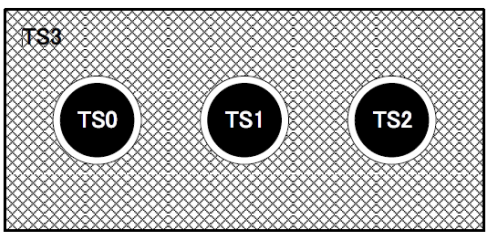

Figure 6 Example of MEC and shield electrode configuration

1.1.12 Automatic Correction (CTSU2SL)

CTSU2SL peripheral has an automatic correction that correct the sensor ICO by hardware. Refer to Section 1.1.3 for more information on sensor ICO correction.

CTSU2SL peripheral processes the correction calculation. ICO correction data can be calculated without using the correction calculation processing of the software. The processing time of the main processor is not consumed.

Set CTSU_CFG_AUTO_CORRECTION_ENABLE to 1 to enable the auto-correction feature.

1.1.13 Automatic Judgement (CTSU2SL)

CTSU2SL peripheral has an automatic judgement that judges the touch of a button by hardware.

CTSU2SL peripheral processes the touch judgment of the button. The processing time of the main processor is not consumed.

Measurements and Judgements can be initiated either by software triggers or external events triggered by the Event Link Controller (ELCL). Please use the API function R_CTSU_ScanStart ().

This module processes INTCTSUWR and INTCTSURD generated during measurement. Since DTC is used for these processes, DTC is required.

A callback function notifies the application when the processing of INTCTSUFN is completed. Get the judgment result before the next measurement. Please use the API function R_CTSU_AutoJudgeDataGet ().

The judgement result is the result of majority voting of the results of multi-frequency measurement.

1st Frequency	2nd Frequency	3rd Frequency	Judgement Result
“touch”	“touch”	“touch”	“touch”
“touch”	“touch”	“non-touch”	“touch”
“touch”	“non-touch”	“touch”	“touch”
“non-touch”	“touch”	“touch”	“touch”
“touch”	“non-touch”	“non-touch”	“non-touch”
“non-touch”	“touch”	“non-touch”	“non-touch”
“non-touch”	“non-touch”	“touch”	“non-touch”
“non-touch”	“non-touch”	“non-touch”	“non-touch”

Set CTSU_CFG_AUTO_JUDGE_ENABLE = 1 to enable the automatic judgement.

The following (a) to (f) describe the automatic judgment and its setting. Set (a) to (f) for each of the multi-frequency measurements.

(a) Measurement mode

Select self-capacitance or mutual-capacitance with “mtucfen” of ctsu_auto_button_cfg_t. Set the self-capacitance to 0. Set the mutual capacitance to 1.

(b) Baseline

Set the baseline from the measurement result in the non-touch state. After completing the initial offset adjustment with R_CTSU_OffsetTuning (), the baseline is initially set (set BLINI bit) when R_CTSU_ScanStart () is called for the first time. After that, when R_CTSU_AutoJudgementDataGet () is called, the baseline initialization is canceled (clear BLINI bit) and the baseline update process is started.

The baseline is updated every set number of measurements to follow changes in the surrounding environment. If “non-touch” state continues for the set number of measurements, the baseline is updated to the average value. When judgement result is “touch”, the number of counts is cleared.

Set the number of measurements (baseline update interval) with “ajbmat” of ctsu_cfg_t. Common to all buttons in the touch interface configuration. Adjusts the ability to follow changes in the surrounding environment.

(c) Threshold

Judgment is made using a threshold with an arbitrary offset from the baseline.

The threshold is set by adding hysteresis. Chattering is prevented by giving hysteresis to the transition from “touch” to “non-touch”. Increasing the hysteresis value is more effective in preventing chattering, but be aware that it will be more difficult to transition from “touch” to “non-touch”.

Set the threshold and hysteresis for each button with threshold and hysteresis of ctsu_auto_button_cfg_t. This module calculates the upper threshold and the lower threshold from these and sets them in the CTSUAJTHR register.

Figure 7 shows the self-capacitance judgement. Since the electrode capacitance of the self-capacitance button increases when touched, it is judged “touch” when the upper threshold is exceeded.

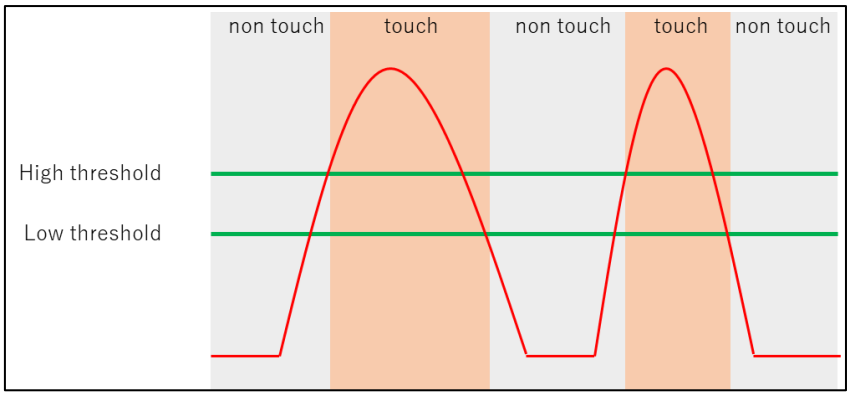

Figure 7 Self-capacitance judgement

Figure 8 shows the mutual-capacitance judgement. Since the mutual capacitance button reduces the capacitance between electrodes when touched, it is judged as "touch" when the lower threshold is exceeded.

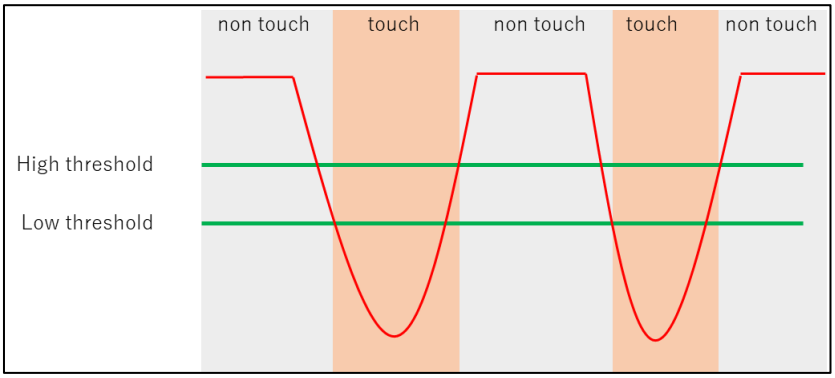

Figure 8 Mutual-capacitance judgement

(d) The number of consecutive “non-touch” and “touch” detections

This is a filter function to judge"touch" or "non-touch" when "touch" or "non-touch" state continues for a certain number of times.

Set the number of times with “tlot” and “thot” of ctsu_cfg_t. Common to all buttons in the touch interface configuration. Increasing the number of consecutive times will be more effective against chattering, but be aware that the reaction speed will decrease.

(f) Moving average

With the automatic judgment function, Set the number of moving averages with “ajmmat” of ctsu_cfg_t. Common to all buttons in the touch interface configuration.

Figure 9 shows the button judgment operation described above.

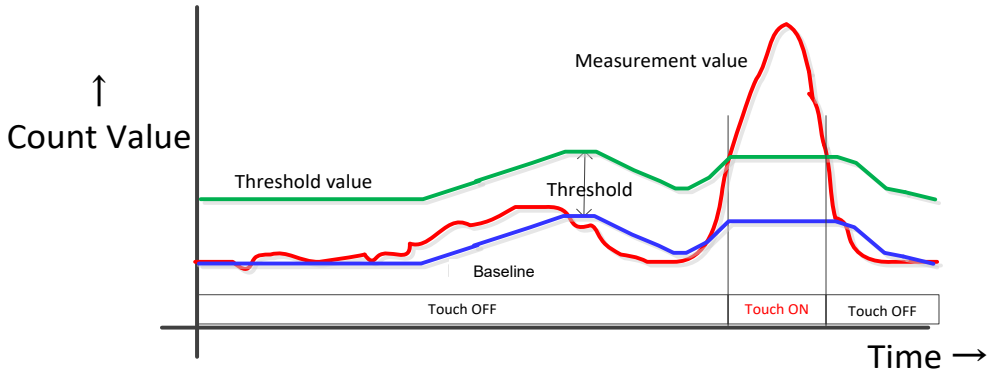

Figure 9 Button judgement

Set the members of ctsu_cfg_t as shown below. Other members are omitted here.

```
.tlot = 2,          // Non-touch  judgment continuous count : 3 times
.thot = 2,          // Touch judgment continuous count : 3 times
.jc = 1,            // Judgement by two frequency
.ajmmat = 2,        // Moving average : 2^2times
.ajbmat = 7,        // Baseline average count : 2^7times
.mtucfen = 1,       // Mutual-capacitance
.ajfen = 1,         // Enable automatic judgement
```

1.2 Measurement Mode

This module supports all three modes offered by the CTSU2L peripheral: self-capacitance, mutual capacitance, and current measurement modes. The temperature correction mode is also offered as a mode for updating the correction coefficient.

1.2.1 Self-capacitance Mode

The self-capacitance mode is used to measure the capacitance of each terminal (TS).

The CTSU2L peripheral measures the terminals in ascending order according to the TS numbers, then stores the data. For example, even if you want to use TS5, TS8, TS2, TS3 and TS6 in your application in that order, they will still be measured and stored in the order of TS2, TS3, TS5, TS6, and TS8. Therefore, you will need to reference buffer indexes [2], [4], [0], [1], and [3].

[CTSU1]

In default settings, the measurement period for each TS is wait-time plus approximately 526us.

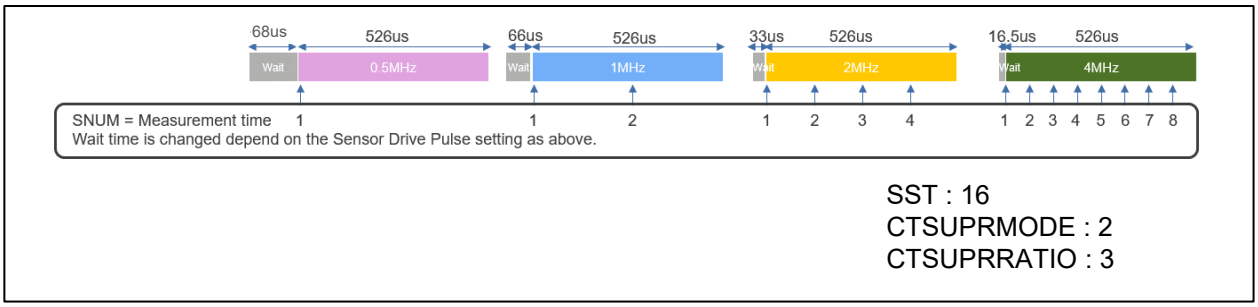

Figure 10 Self-capacitance Measurement Period (CTSU1)

[CTSU2L]

In default settings, the measurement period for each TS is approximately 576us.

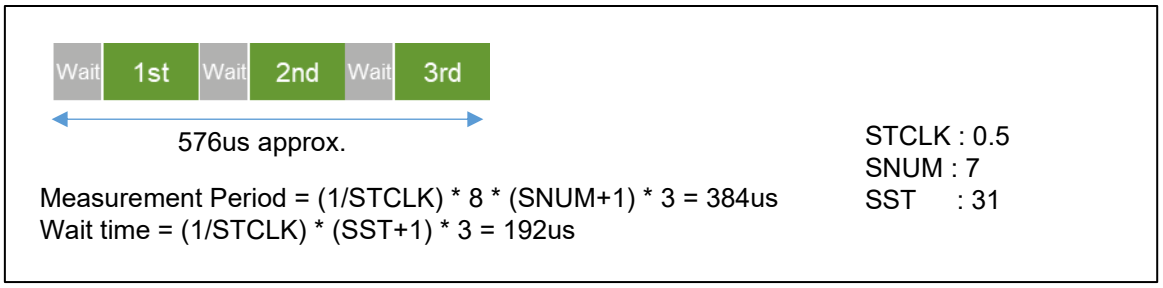

Figure 11 Self-capacitance Measurement Period (CTSU2L)

1.2.2 Mutual Capacitance Mode

The mutual capacitance mode is used to measure the capacitance generated between the receive TS (Rx) and transmit TS (Tx), and therefore requires at least two terminals.

The CTSU2L peripheral measures all specified combinations of Rx and Tx. For example, when Rx is TS1 and TS3, and Tx is TS2, TS7 and TS4, the combinations are measured in the following order and the data is stored.

TS3-TS2, TS3-TS4, TS3-TS7, TS10-TS2, TS10-TS4, TS10-TS7

To measure the mutual capacitance generated between electrodes, the CTSU2L peripheral performs the measurement process on the same electrode twice.

The mutual capacitance is obtained by inverting the phase relationship of the pulse output and switched capacitor in the primary and secondary measurements, and calculating the difference between the two measurements. This module does not calculate the difference, but outputs the secondary measured result.

[CTSU1]

In default settings, the measurement period for each TS is twice of wait-time plus approximately 526us.

[CTSU2L]

In default settings, the measurement period for each TS is approximately 1152us.

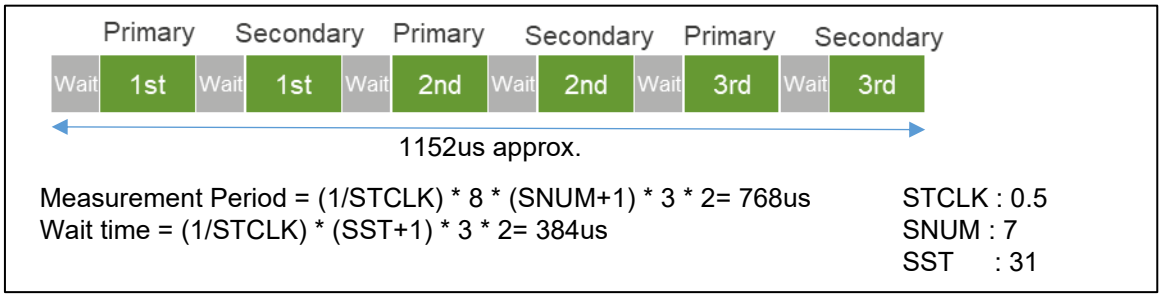

Figure 12 Mutual Capacitance Measurement Period (CTSU2L)

1.2.3 Current Measurement Mode(CTSU2L)

The current measurement mode is used to measure the minute current input to the TS terminal.

The order of measurement and data storage is the same as that of the self-capacitance mode.

As this does not involve the switched capacitor operation, the measurement is only performed once. The measurement period for one TS under default settings is approximately 256us. The current measurement mode requires a longer stable wait time than the other modes, so the SST is set to 63.

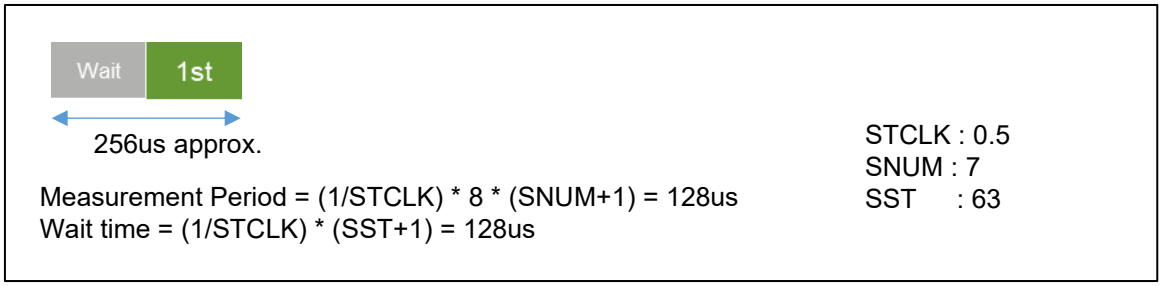

Figure 13 Current Measurement Period

1.2.4 Temperature Correction Mode(CTSU2L)

The temperature correction mode is used to periodically update the correction coefficient using an external resistor connected to a TS terminal. This involves three processes as described below. Also refer to the timing chart in Figure 14 Temperature Correction Measurement Timing Chart.

1. Measure the correction circuit. One set comprises twelve measurements.

2. Measure the current when TSCAP voltage is applied to the external resistor to create a correction coefficient based on an external resistor that does not depend on temperature. Execute the next measurement after the previous measurement set is completed (as described in step 1).

3. Flow offset current to the external resistor and measure the voltage with the ADC. This will adjust the RTRIM register and handle the temperature drift of the internal reference resistor. In the config settings, set the number of times step 2 should be executed before carrying out this measurement.

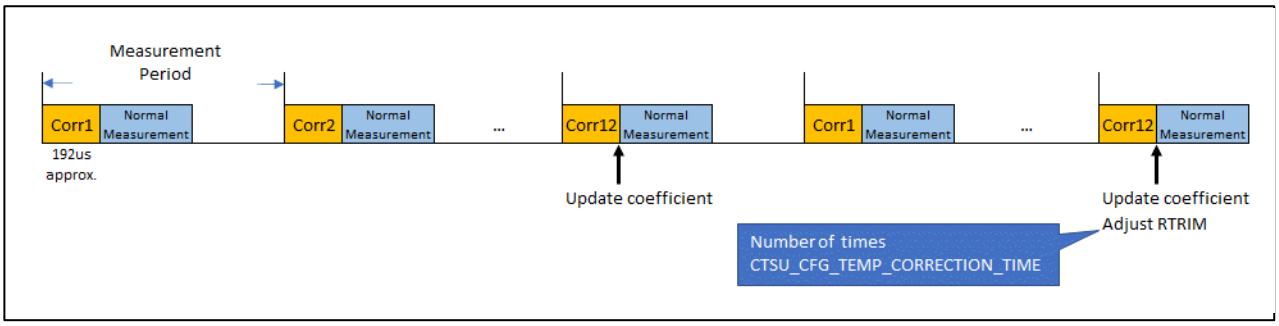

Figure 14 Temperature Correction Measurement Timing Chart

For CTSU2L, use ADC FIT (r_s12ad_rx). If an error occurs in the ADC module used for temperature correction mode, return FSP_ERR_ABORTED as the return value of R_CTSU_DataGet().For ADC module errors, see ADC FIT (r_s12ad_rx).

Consider the following three points when using the temperature correction function of CTSU2L.

1. When using the CTSU2L temperature correction function, CTSU driver must measure ADC. Therefore, when using ADC FIT on an application, be sure to close ADC FIT before using the temperature correction function.

2. If you did not close the ADC FIT, CTSU driver return value of FSP_ERR_ABORTED. Please refer to the sample below and close the ADC FIT so that the ADC measurement in the CTSU driver can be performed when the next temperature correction function is executed.

```
R_CTSU_ScanStart(g_qe_ctsu_instance_temp_correction.p_ctrl);
while (0 == g_qe_touch_flag) {}
g_qe_touch_flag = 0;

err = R_CTSU_DataGet(g_qe_ctsu_instance_temp_correction.p_ctrl, &dummyD);
if (FSP_SUCCESS == err)
{
    /* TODO: Add your own code here. */
}
else if (FSP_ERR_ABORTED == err)
{
```

```
            adc_err = R_ADC_Close(0);
            if (ADC_SUCCESS != adc_err)
            {
                while (true) {}
            }
        }
```

3. When creating an RTOS application, consider the scheduling of temperature correction functions tasks for the CTSU module and tasks for the ADC module.

1.2.5 Diagnosis Mode

The diagnosis mode is a mode in which various internal measurement values are scanned by using this diagnosis function. The details are described in 1.1.10.

1.3 Measurement Timing

As explained in section 1.1.2, measurements are initiated by a software trigger or an external event which is triggered by the Event Link Controller (ELCL).

The most common method is using a timer to carry out periodic measurements. Make sure to set the timer interval to allow the measurement and internal value update processes to complete before the next measurement period. The measurement period differs according to touch interface configuration and measurement mode. See section 1.2 for details.

The execution timing of software triggers and external triggers differ slightly.

Since a software trigger sets the start flag after setting the touch interface configuration with R_CTSU_ScanStart (), there is a slight delay after the timer event occurrence. However, as the delay is much smaller than the measurement period, a software trigger is recommended for most instances as it is easy to set.

An external trigger is recommended for applications in which this slight delay is not acceptable or that require low-power consumption operations. When using an external trigger with multiple touch interface configurations, use R_CTSU_ScanStart() to set another touch interface configuration after one measurement is completed.

1.4 API Overview

The CTSU module includes the following functions.

Function	Description
R_CTSU_Open()	Initializes the specified touch interface configuration.
R_CTSU_ScanStart()	Starts measurement of specified touch interface configuration.
R_CTSU_DataGet()	Gets measured values of specified touch interface configuration.
R_CTSU_CallbackSet()	Set callback function of specified touch interface configuration.
R_CTSU_Close()	Closes specified touch interface configuration.
R_CTSU_Diagnosis()	Executes diagnosis.
R_CTSU_ScanStop()	Stops measurement of specified touch interface configuration.
R_CTSU_SpecificDataGet()	Read the measurements for the specified data type for the specified touch interface.
R_CTSU_DataInsert()	Inserts the specified data in buffer of touch measurement results for the specified touch interface configuration.
R_CTSU_OffsetTuning()	Adjusts the offset register (SO) for the specified touch interface configuration.
R_CTSU_AutoJudgementDataGet()	Use the automatic judgement function to get all the button judgment results of the specified touch interface configuration.

2. API Information

Operations of this FIT module have been confirmed under the following conditions.

2.1 Hardware Requirements

The MCU used in the development must support one of the following functions:

- CTSU1
- CTSU2L
- CTSU2SL

2.2 Software Requirements

This driver depends on the following FIT modules:

- Board support package module (r_bsp) v6.10 or newer

According to the configuration settings, the driver may also depend on the following modules:

- DTC module r_dtc v3.80 or newer (In case of using DTC transfer)
  When using DTC transfer, set the Heap size of the r_bsp property to 0x1000 or more.
  Heap size of 0x1600 is recommended when using the GCC compiler.
- ADC module r_s12ad_rx_v4.90 or newer (In case of using Temperature correction mode or diagnosis mode)

This driver also assumes the use of following tool:

- Renesas QE for Capacitive Touch V3.1.0 or newer

2.3 Supported Toolchains

Module operations have been confirmed on the following toolchains:

- Renesas CC-RX Toolchain v3.04.00
- IAR RX Toolchain v4.20.3
- GCC RX Toolchain v 8.3.0.202202

2.4 Restrictions

The module code is non-reentrant and protects simultaneous calls for multiple function.

2.5 Header File

All interface definitions to be called and used in the API are defined in “r_ctsu_qe_if.h”.

Select “r_ctsu_qe_config.h” as the configuration option in each build.

2.6 Integer Type

This driver uses ANSI C99. The types are defined in stdint.h.

2.7 Compilation Settings

The following table provides the names and setting values for the configuration option settings used the CTSU module.

r_ctsu_config.h Configuration Options	
CTSU_CFG_PARAM_CHECKING_ENABLE *Default value: “BSP_CFG_PARAM_CHECKING_ENABLE”	Selects whether to include the parameter check process in the code. Selecting “0” allows the user to omit the parameter check process from the code to shorten the code size. “1”: Omit parameter check process from code. “2”: Include parameter check process in code. “BSP_CFG_PARAM_CHECKING_ENABLE”: Selection depends on BSP setting.
CTSU_CFG_USE_DTC *Default value: “0”	Select “1” to use the DTC, rather than the main processor, to run the CTSU2L’s CTSUWR interrupt and CTSURD interrupt processes. Note: If the DTC is used elsewhere in the application, it may compete with the use of this driver.
CTSU_CFG_AUTO_JUDGE_ENABLE	Set to 1 to enable the automatic judgment code.
CTSU_CFG_INTCTSUWR_PRIORITY_LEVEL *Default value: “2”	Sets the CTSUWR interrupt priority level (also necessary when using the DTC). The priority level range is from 0 (high) to 3 (low).
CTSU_CFG_INTCTSURD_PRIORITY_LEVEL *Default value: “2”	Sets the CTSURD interrupt priority level (also necessary when using the DTC). The priority level range is from 0 (high) to 3 (low).
CTSU_CFG_INTCTSUFN_PRIORITY_LEVEL *Default value: 2	Sets the CTSUFN interrupt priority level. The priority level range is from 0 (high) to 3 (low).
CTSU_CFG_DTC_USE_SC	
The following configurations depend on the touch interface configuration and cannot be set using Smart Configurator. These configurations are set when using QE for Capacitive Touch. In this case, QE_TOUCH_CONFIGURATION is defined in the project. Although r_ctsu_config.h becomes invalid, qe_touch_define.h is defined instead.	Sets the total number of TS for self-capacitance, current measurement, and temperature correction.
CTSU_CFG_NUM_SELF_ELEMENTS	Sets the total number of matrixes for mutual capacitance
CTSU_CFG_NUM_MUTUAL_ELEMENTS	Enables/disables the low voltage mode. This value is set in the CTSUCRAL register’s ATUNE0 bit.
CTSU_CFG_LOW_VOLTAGE_MODE	Sets the PCLK frequency division rate. This value is set in the CTSUCRAL register’s CLK bit.
CTSU_CFG_PCLK_DIVISION	Sets the TSCAP port. Example: For P30, set 0x0300.
CTSU_CFG_TSCAP_PORT	Sets the VCC (voltage). Example: for 5.00V, set 5000.
CTSU_CFG_VCC_MV	Sets the number of multi-frequency measurements.
CTSU_CFG_NUM_SUMULTI	Sets the multiplication factor for the first frequency in a multi-frequency measurement. Recommended: 0x3F
CTSU_CFG_SUMULTI0	Sets the multiplication factor for the second frequency in a multi-frequency measurement. Recommended: 0x36

CTSU_CFG_SUMULTI1	Sets the multiplication factor for the third frequency in a multi-frequency measurement. Recommended: 0x48
CTSU_CFG_SUMULTI2	Enables/disables temperature correction.
CTSU_CFG_TEMP_CORRECTION_SUPPORT	Sets the temperature correction terminal number.
CTSU_CFG_TEMP_CORRECTION_TS	Sets the update interval for the correction coefficient of the temperature correction. Assuming 13 measurements per set in the temperature correction mode, indicate the number of sets per update.
CTSU_CFG_TEMP_CORRECTION_TIME	Enables/disables RTRIM correction for temperature correction. The ADC must be selected to operate with RTRIM correction enabled.
CTSU_CFG_DIAG_SUPPORT_ENABLE	Enables/disables diagnosis function.
CTSU_CFG_DIAG_DAC_TS	Sets the number of TS pin to be used for diagnosis in CTSU1.
CTSU_CFG_AUTO_CORRECTION_ENABLE	Select whether to enable or disable the automatic correction process.
CTSU_CFG_MULTIPLE_ELECTRODE_CONNECTION_ENABLE	Select to enable or disable the MEC feature.

2.8 Code Size

ROM (code and constants) and RAM (global data) size are determined according to the configuration options as described in “section 2.7 Compilation Setting” during a build. The values shown are reference values when the compile option is the default for C compiler listed in “section 2.3 Supported Toolchains”. The default of compile options is as follows: the optimization level is 2, the optimization type is size priority, and the data-endian is a little endian. The code size varies according to the C compiler version or the compile options.

[CTSU1]

ROM and RAM Usage the configuration options with Self-capacitance 1element	
CTSU_CFG_PARAM_CHECKING_ENABLE 0 CTSU_CFG_DTC_SUPPORT_ENABLE 0	ROM: 2569 bytes RAM: 61 bytes

ROM and RAM Usage Size of each mode, amount of increase by adding elements				
Mode and element num	Self-capacitance 1 element	+ 1 element	Mutual capacitance 1 element	+1 element
ROM	2569 bytes	+16 bytes	2836 bytes	+12 bytes
RAM	61 bytes	+21 bytes	71 bytes	+31 bytes

[CTSU2L]

ROM and RAM Usage the configuration options with Self-capacitance 1element	
CTSU_CFG_PARAM_CHECKING_ENABLE 0 CTSU_CFG_DTC_SUPPORT_ENABLE 0	ROM: 4199 bytes RAM: 195 bytes

ROM and RAM Usage Size of each mode, amount of increase by adding elements				
Mode and element num	Self-capacitance 1 element	+ 1 element	Mutual capacitance 1 element	+1 element
ROM	4199 bytes	+16 bytes	4335 bytes	+22 bytes
RAM	195 bytes	+35 bytes	211 bytes	+51 bytes

2.9 Arguments

The following are the structures and enums used as arguments of the API functions. Many of the parameters used in the API functions are defined by the enums, which provides a way to check types and reduce errors. These structures and enums are defined inr_ctsu_qe.h, r_ctsu_qe_api.h.

The following is the control structure for the touch interface configuration. This does not need to be set in the application. Using QE allows the variables corresponding to the touch interface configuration to be output by qe_touch_config.c. Make sure to set qe_touch_config.c in the module's first API argument.

```
typedef struct st_ctsu_instance_ctrl
{
    uint32_t                open;               ///< Whether or not driver is open.
    volatile ctsu_state_t    state;              ///< CTSU run state.
    ctsu_cap_t               cap;                ///< CTSU Scan Start Trigger Select
    ctsu_md_t                md;                 ///< CTSU Measurement Mode Select(copy to cfg)
    ctsu_tuning_t            tuning;             ///< CTSU Initial offset tuning status.
    uint16_t                 num_elements;       ///< Number of elements to scan
    uint16_t                 wr_index;           ///< Word index into ctsuwr register array.
    uint16_t                 rd_index;           ///< Word index into scan data buffer.
#if (BSP_FEATURE_CTSU_VERSION == 2)
    uint8_t * p_frequency_complete_flag;         ///< Pointer to complete flag of each frequency. g_ctsu_frequency_complete_flag[] is set by Open API.
#endif
    int32_t               * p_tuning_diff;      ///< Pointer to difference from base value of each element. g_ctsu_tuning_diff[] is set by Open API.
    uint16_t                 average;            ///< CTSU Moving average counter.
    uint16_t                 num_moving_average; ///< Copy from config by Open API.
    uint8_t                  ctsucr1;            ///< Copy from (atune1 << 3, md << 6) by Open API. CLK, ATUNE0, CSW, and PON is set by HAL driver.
    ctsu_ctsuwr_t         * p_ctsuwr;           ///< CTSUWR write register value. g_ctsu_ctsuwr[] is set by Open API.
    ctsu_self_buf_t       * p_self_raw;         ///< Pointer to Self raw data. g_ctsu_self_raw[] is set by Open API.
    uint16_t              * p_self_corr;        ///< Pointer to Self correction data. g_ctsu_self_corr[] is set by Open API.
    ctsu_data_t           * p_self_data;        ///< Pointer to Self moving average data. g_ctsu_self_data[] is set by Open API.
    ctsu_mutual_buf_t     * p_mutual_raw;       ///< Pointer to Mutual raw data. g_ctsu_mutual_raw[] is set by Open API.
    uint16_t              * p_mutual_pri_corr;  ///< Pointer to Mutual primary correction data. g_ctsu_self_corr[] is set by Open API.
    uint16_t              * p_mutual_snd_corr;  ///< Pointer to Mutual secondary correction data. g_ctsu_self_corr[] is set by Open API.
    ctsu_data_t           * p_mutual_pri_data;  ///< Pointer to Mutual primary moving average data. g_ctsu_mutual_pri_data[] is set by Open API.
    ctsu_data_t           * p_mutual_snd_data;  ///< Pointer to Mutual secondary moving average data. g_ctsu_mutual_snd_data[] is set by Open API.
    ctsu_correction_info_t * p_correction_info; ///< Pointer to correction info
    ctsu_txvsel_t            txvsel;             ///< CTSU Transmission Power Supply Select
    ctsu_txvsel2_t           txvsel2;            ///< CTSU Transmission Power Supply Select 2 (CTSU2 Only)
    uint8_t                  ctsuchac0;          ///< TS00-TS07 enable mask
    uint8_t                  ctsuchac1;          ///< TS08-TS15 enable mask
    uint8_t                  ctsuchac2;          ///< TS16-TS23 enable mask
    uint8_t                  ctsuchac3;          ///< TS24-TS31 enable mask
    uint8_t                  ctsuchac4;          ///< TS32-TS39 enable mask
    uint8_t                  ctsuchtrc0;         ///< TS00-TS07 mutual-tx mask
    uint8_t                  ctsuchtrc1;         ///< TS08-TS15 mutual-tx mask
    uint8_t                  ctsuchtrc2;         ///< TS16-TS23 mutual-tx mask
    uint8_t                  ctsuchtrc3;         ///< TS24-TS31 mutual-tx mask
    uint8_t                  ctsuchtrc4;         ///< TS32-TS39 mutual-tx mask
    uint16_t                 self_elem_index;    ///< self element index number for Current instance.
    uint16_t                 mutual_elem_index;  ///< mutual element index number for Current instance.
    uint16_t                 ctsu_elem_index;    ///< CTSU element index number for Current instance.
#if (BSP_FEATURE_CTSU_VERSION == 2)
    uint8_t * p_selected_freq_self;              ///< Frequency selected by self-capacity
    uint8_t * p_selected_freq_mutual;            ///< Frequency selected by mutual-capacity
#endif
#if (BSP_FEATURE_CTSU_VERSION == 1)
 #if (CTSU_CFG_DIAG_SUPPORT_ENABLE == 1)
    ctsu_diag_info_t * p_diag_info;              ///< pointer to diagnosis info
 #endif
#endif

#if (BSP_FEATURE_CTSU_VERSION == 2)
    ctsu_range_t range;                           ///< According to atune12. (20uA : 0, 40uA : 1, 80uA : 2, 160uA : 3)
    uint8_t      ctsucr2;                         ///< Copy from (posel, atune1, md) by Open API. FCMODE and SDPSEL and LOAD is set by HAL driver.
 #if (CTSU_CFG_NUM_CFC != 0)
```

```
    uint64_t             cfc_rx_bitmap;          ///< Bitmap of CFC receive terminal.
    ctsu_corrcfc_info_t * p_corrcfc_info;        ///< pointer to CFC correction info
 #endif
 #if (CTSU_CFG_DIAG_SUPPORT_ENABLE == 1)
    ctsu_diag_info_t * p_diag_info;              ///< pointer to diagnosis info
 #endif
#endif
#if (CTSU_CFG_AUTO_JUDGE_ENABLE == 1)
    ctsu_auto_judge_t * p_auto_judge;             ///< Array of automatic judgement register write variables. g_ctsu_auto_judge[] is set by Open API.
    uint32_t            adress_auto_judge;        ///< Automatic judgement Variable start address
    uint32_t            adress_ctsuwr;            ///< CTSUWR variable start address for automatic judgement
    uint32_t            adress_self_raw;          ///< Self raw variable start address for automatic judgement
    uint32_t            adress_mutual_raw;        ///< Mutual raw variable start address for automatic judgement
    uint32_t            count_auto_judge;         ///< Automatic judgement transfer count
    uint32_t            count_ctsuwr_self_mutual; ///< CTSUWR, Self raw, Mutual raw transfer count for automatic judgement
    uint8_t             blini_flag;               ///< Flags for controlling baseline initialization bit for automatic judgement
    uint8_t             ajmmat;                   ///< Copy from config by Open API for automatic judgement
    uint8_t             ajbmat;                   ///< Copy from config by Open  for automatic judgement
 #endif
#endif
    ctsu_cfg_t const * p_ctsu_cfg;               ///< Pointer to initial configurations.
    void (* p_callback)(ctsu_callback_args_t *); ///< Callback provided when a CTSUFN occurs.
    uint8_t               interrupt_reverse_flag;///< Flag in which read interrupt and end interrupt are reversed
    ctsu_event_t          error_status;          ///< error status variable to send to QE for serial tuning.
    ctsu_callback_args_t * p_callback_memory;    ///< Pointer to non-secure memory that can be used to pass arguments to a callback in non-secure memory.
    void const          * p_context;             ///< Placeholder for user data.
    bool     serial_tuning_enable;               ///< Flag of serial tuning status.
    uint16_t serial_tuning_mutual_cnt;           ///< Word index into ctsuwr register array.
    uint16_t tuning_self_target_value;           ///< Target self value for initial offset tuning
    uint16_t tuning_mutual_target_value;         ///< Target mutual value for initial offset tuning
    uint8_t                   tsod;              ///< Copy from tsod by Open API.
    uint8_t                   mec_ts;            ///< Copy from mec_ts by Open API.
    uint8_t                   mec_shield_ts;     ///< Copy from mec_shield_ts by Open API.
} ctsu_instance_ctrl_t;
```

The following is the configuration setting structure for the touch interface configuration.

Using QE for Capacitive Touch allows the variables and initialization values corresponding to the touch interface configuration to be output by qe_touch_config.c. Make sure to set qe_touch_config.c in the second argument of R_CTSU_Open().

```
typedef struct st_ctsu_cfg
{
    ctsu_cap_t                cap;                  ///< CTSU Scan Start Trigger Select
    ctsu_txvsel_t             txvsel;               ///< CTSU Transmission Power Supply Select
    ctsu_txvsel2_t            txvsel2;              ///< CTSU Transmission Power Supply Select 2 (CTSU2 Only)
    ctsu_atune1_t             atune1;               ///< CTSU Power Supply Capacity Adjustment (CTSU Only)
    ctsu_atune12_t            atune12;              ///< CTSU Power Supply Capacity Adjustment (CTSU2 Only)
    ctsu_md_t                 md;                   ///< CTSU Measurement Mode Select
    ctsu_posel_t              posel;                ///< CTSU Non-Measured Channel Output Select (CTSU2 Only)
    uint8_t                   tsod;                 ///< TS all terminal output control for multi electrode scan
    uint8_t                   mec_ts;               ///< TS number used when using the MEC function
    uint8_t                   mec_shield_ts;        ///< TS number of active shield used when using MEC function
    uint8_t                   tlot;                 ///< Number of consecutive judgements exceeding the threshold L for automatic judgement
    uint8_t                   thot;                 ///< Number of consecutive judgements exceeding the threshold H for automatic judgement
    uint8_t                   jc;                   ///< judgement condition for automatic judgement
    uint8_t                   ajmmat;               ///< Measured value moving average number of times for automatic judgement
    uint8_t                   ajbmat;               ///< Average number of baselines for automatic judgement
    uint8_t                   mtucfen;              ///< Mutual capacity operation for automatic judgement
    uint8_t                   ajfen;                ///< Automatic judgement function enabled for automatic judgement
    uint8_t                   autojudge_monitor_num;///< Method number for QE monitor for automatic judgement
    uint8_t                   ctsuchac0;            ///< TS00-TS07 enable mask
    uint8_t                   ctsuchac1;            ///< TS08-TS15 enable mask
    uint8_t                   ctsuchac2;            ///< TS16-TS23 enable mask
    uint8_t                   ctsuchac3;            ///< TS24-TS31 enable mask
    uint8_t                   ctsuchac4;            ///< TS32-TS39 enable mask
    uint8_t                   ctsuchtrc0;           ///< TS00-TS07 mutual-tx mask
    uint8_t                   ctsuchtrc1;           ///< TS08-TS15 mutual-tx mask
    uint8_t                   ctsuchtrc2;           ///< TS16-TS23 mutual-tx mask
    uint8_t                   ctsuchtrc3;           ///< TS24-TS31 mutual-tx mask
```

```
    uint8_t                   ctsuchtrc4;             ///< TS32-TS39 mutual-tx mask
    ctsu_element_cfg_t const * p_elements;            ///< Pointer to elements configuration array
    uint8_t                   num_rx;                 ///< Number of receive terminals
    uint8_t                   num_tx;                 ///< Number of transmit terminals
    uint16_t                  num_moving_average;     ///< Number of moving average for measurement data
    bool tunning_enable;                              ///< Initial offset tuning flag
    void (* p_callback)(ctsu_callback_args_t * p_args); ///< Callback provided when CTSUFN ISR occurs.
    void const * p_context;                           ///< User defined context passed into callback function.
    void const * p_extend;                            ///< Pointer to extended configuration by instance of interface.
    uint16_t     tuning_self_target_value;            ///< Target self value for initial offset tuning
    uint16_t     tuning_mutual_target_value;          ///< Target mutual value for initial offset tuning
} ctsu_cfg_t;
```

The followings are the enums used for the above listed structures.

```
/** CTSU Events for callback function */
typedef enum e_ctsu_event
{
    CTSU_EVENT_SCAN_COMPLETE = 0x00,   ///< Normal end
    CTSU_EVENT_OVERFLOW      = 0x01,   ///< Sensor counter overflow (CTSUST.CTSUSOVF set)
    CTSU_EVENT_ICOMP         = 0x02,   ///< Abnormal TSCAP voltage (CTSUERRS.CTSUICOMP set)
    CTSU_EVENT_ICOMP1        = 0x04    ///< Abnormal sensor current (CTSUSR.ICOMP1 set)
} ctsu_event_t;

/** CTSU Scan Start Trigger Select */
typedef enum e_ctsu_cap
{
    CTSU_CAP_SOFTWARE,                 ///< Scan start by software trigger
    CTSU_CAP_EXTERNAL                  ///< Scan start by external trigger
} ctsu_cap_t;

/** CTSU Transmission Power Supply Select */
typedef enum e_ctsu_txvsel
{
    CTSU_TXVSEL_VCC,                   ///< VCC selected
    CTSU_TXVSEL_INTERNAL_POWER         ///< Internal logic power supply selected
} ctsu_txvsel_t;

/** CTSU Transmission Power Supply Select 2 (CTSU2 Only) */
typedef enum e_ctsu_txvsel2
{
    CTSU_TXVSEL_MODE,                  ///< Follow TXVSEL setting
    CTSU_TXVSEL_VCC_PRIVATE,           ///< VCC private selected
} ctsu_txvsel2_t;

/** CTSU Power Supply Capacity Adjustment (CTSU Only) */
typedef enum e_ctsu_atune1
{
    CTSU_ATUNE1_NORMAL,                ///< Normal output (40uA)
    CTSU_ATUNE1_HIGH                   ///< High-current output (80uA)
} ctsu_atune1_t;

/** CTSU Power Supply Capacity Adjustment (CTSU2 Only) */
typedef enum e_ctsu_atune12
{
    CTSU_ATUNE12_80UA,                 ///< High-current output (80uA)
    CTSU_ATUNE12_40UA,                 ///< Normal output (40uA)
    CTSU_ATUNE12_20UA,                 ///< Low-current output (20uA)
    CTSU_ATUNE12_160UA                 ///< Very high-current output (160uA)
} ctsu_atune12_t;

/** CTSU Measurement Mode Select */
typedef enum e_ctsu_mode
{
    CTSU_MODE_SELF_MULTI_SCAN  = 1,    ///< Self-capacitance multi scan mode
    CTSU_MODE_MUTUAL_FULL_SCAN = 3,    ///< Mutual capacitance full scan mode
    CTSU_MODE_MUTUAL_CFC_SCAN  = 7,    ///< Mutual capacitance cfc scan mode (CTSU2 Only)
    CTSU_MODE_CURRENT_SCAN     = 9,    ///< Current scan mode (CTSU2 Only)
    CTSU_MODE_CORRECTION_SCAN  = 17,   ///< Correction scan mode (CTSU2 Only)
    CTSU_MODE_DIAGNOSIS_SCAN   = 33    ///< Diagnosis scan mode
} ctsu_md_t;
```

```
/** CTSU Non-Measured Channel Output Select (CTSU2 Only) */
typedef enum e_ctsu_posel
{
    CTSU_POSEL_LOW_GPIO,                ///< Output low through GPIO
    CTSU_POSEL_HI_Z,                    ///< Hi-Z
    CTSU_POSEL_LOW,                     ///< Output low through the power setting by the TXVSEL[1:0] bits
    CTSU_POSEL_SAME_PULSE               ///< Same phase pulse output as transmission channel through the power setting by the TXVSEL[1:0] bits
} ctsu_posel_t;

/** CTSU Spectrum Diffusion Frequency Division Setting (CTSU Only) */
typedef enum e_ctsu_ssdiv
{
    CTSU_SSDIV_4000,                    ///< 4.00 <= Base clock frequency (MHz)
    CTSU_SSDIV_2000,                    ///< 2.00 <= Base clock frequency (MHz) < 4.00
    CTSU_SSDIV_1330,                    ///< 1.33 <= Base clock frequency (MHz) < 2.00
    CTSU_SSDIV_1000,                    ///< 1.00 <= Base clock frequency (MHz) < 1.33
    CTSU_SSDIV_0800,                    ///< 0.80 <= Base clock frequency (MHz) < 1.00
    CTSU_SSDIV_0670,                    ///< 0.67 <= Base clock frequency (MHz) < 0.80
    CTSU_SSDIV_0570,                    ///< 0.57 <= Base clock frequency (MHz) < 0.67
    CTSU_SSDIV_0500,                    ///< 0.50 <= Base clock frequency (MHz) < 0.57
    CTSU_SSDIV_0440,                    ///< 0.44 <= Base clock frequency (MHz) < 0.50
    CTSU_SSDIV_0400,                    ///< 0.40 <= Base clock frequency (MHz) < 0.44
    CTSU_SSDIV_0360,                    ///< 0.36 <= Base clock frequency (MHz) < 0.40
    CTSU_SSDIV_0330,                    ///< 0.33 <= Base clock frequency (MHz) < 0.36
    CTSU_SSDIV_0310,                    ///< 0.31 <= Base clock frequency (MHz) < 0.33
    CTSU_SSDIV_0290,                    ///< 0.29 <= Base clock frequency (MHz) < 0.31
    CTSU_SSDIV_0270,                    ///< 0.27 <= Base clock frequency (MHz) < 0.29
    CTSU_SSDIV_0000                     ///< 0.00 <= Base clock frequency (MHz) < 0.27
} ctsu_ssdiv_t;

/** CTSU select data type for slect data get */
typedef enum e_ctsu_specific_data_type
{
    CTSU_SPECIFIC_RAW_DATA,
    CTSU_SPECIFIC_CORRECTION_DATA,
    CTSU_SPECIFIC_SELECTED_FREQ,
} ctsu_specific_data_type_t;

/** Callback function parameter data */
typedef struct st_ctsu_callback_args
{
    ctsu_event_t event;                 ///< The event can be used to identify what caused the callback.
    void const * p_context;             ///< Placeholder for user data. Set in ctsu_api_t::open function in ::ctsu_cfg_t.
} ctsu_callback_args_t;

/** CTSU Control block. Allocate an instance specific control block to pass into the API calls.
 * @par Implemented as
 * - ctsu_instance_ctrl_t
 */
typedef void ctsu_ctrl_t;

/** CTSU Configuration parameters. */
/** Element Configuration */
typedef struct st_ctsu_element
{
    ctsu_ssdiv_t ssdiv;                 ///< CTSU Spectrum Diffusion Frequency Division Setting (CTSU Only)
    uint16_t     so;                    ///< CTSU Sensor Offset Adjustment
    uint8_t      snum;                  ///< CTSU Measurement Count Setting
    uint8_t      sdpa;                  ///< CTSU Base Clock Setting
} ctsu_element_cfg_t;
```

2.10 Return Values

The following provides return values for the API functions. The enum is defined in fsp_common_api.h.

```
/** Common error codes */
typedef enum e_fsp_err
{
    FSP_SUCCESS = 0,

    FSP_ERR_ASSERTION               = 1,                    ///< A critical assertion has failed
    FSP_ERR_INVALID_POINTER         = 2,                    ///< Pointer points to invalid memory location
    FSP_ERR_INVALID_ARGUMENT        = 3,                    ///< Invalid input parameter
    FSP_ERR_INVALID_CHANNEL         = 4,                    ///< Selected channel does not exist
    FSP_ERR_INVALID_MODE            = 5,                    ///< Unsupported or incorrect mode
    FSP_ERR_UNSUPPORTED             = 6,                    ///< Selected mode not supported by this API
    FSP_ERR_NOT_OPEN                = 7,                    ///< Requested channel is not configured or API not open
    FSP_ERR_ABORTED                 = 18,                   ///< An operation was aborted

    /* Start of CTSU Driver specific */
    FSP_ERR_CTSU_SCANNING               = 6000,     ///< Scanning.
    FSP_ERR_CTSU_NOT_GET_DATA           = 6001,     ///< Not processed previous scan data.
    FSP_ERR_CTSU_INCOMPLETE_TUNING      = 6002,     ///< Incomplete initial offset tuning.
    FSP_ERR_CTSU_DIAG_NOT_YET           = 6003,     ///< Diagnosis of data collected no yet.
    FSP_ERR_CTSU_DIAG_LDO_OVER_VOLTAGE = 6004,      ///< Diagnosis of LDO over voltage failed.
    FSP_ERR_CTSU_DIAG_CCO_HIGH          = 6005,     ///< Diagnosis of CCO into 19.2uA failed.
    FSP_ERR_CTSU_DIAG_CCO_LOW           = 6006,     ///< Diagnosis of CCO into 2.4uA failed.
    FSP_ERR_CTSU_DIAG_SSCG              = 6007,     ///< Diagnosis of SSCG frequency failed.
    FSP_ERR_CTSU_DIAG_DAC               = 6008,     ///< Diagnosis of non-touch count value failed.
    FSP_ERR_CTSU_DIAG_OUTPUT_VOLTAGE    = 6009,     ///< Diagnosis of LDO output voltage failed.
    FSP_ERR_CTSU_DIAG_OVER_VOLTAGE      = 6010,     ///< Diagnosis of over voltage detection circuit failed.
    FSP_ERR_CTSU_DIAG_OVER_CURRENT      = 6011,     ///< Diagnosis of over current detection circuit failed.
    FSP_ERR_CTSU_DIAG_LOAD_RESISTANCE   = 6012,     ///< Diagnosis of LDO internal resistance value failed.
    FSP_ERR_CTSU_DIAG_CURRENT_SOURCE    = 6013,     ///< Diagnosis of Current source value failed.
    FSP_ERR_CTSU_DIAG_SENSCLK_GAIN      = 6014,     ///< Diagnosis of SENSCLK frequency gain failed.
    FSP_ERR_CTSU_DIAG_SUCLK_GAIN        = 6015,     ///< Diagnosis of SUCLK frequency gain failed.
    FSP_ERR_CTSU_DIAG_CLOCK_RECOVERY    = 6016,     ///< Diagnosis of SUCLK clock recovery function failed.
    FSP_ERR_CTSU_DIAG_CFC_GAIN          = 6017,     ///< Diagnosis of CFC oscillator gain failed.
} fsp_err_t;
```

2.11 Adding the FIT Module to Your Project

2.11.1 Adding source tree and project include paths

This module must be added to each project in which it is used. Renesas recommends using “Smart Configurator” described in (1) or (3). However, “Smart Configurator” only supports some RX devices. Please use the methods of (2) or (4) for unsupported RX devices.

(1) Adding the FIT module to your project using “Smart Configurator” in e2 studio
By using the “Smart Configurator” in e2 studio, the FIT module is automatically added to your project. Refer to “Renesas e2 studio Smart Configurator User Guide (R20AN0451)” for details.

(2) Adding the FIT module to your project using “FIT Configurator” in e2 studio
By using the “FIT Configurator” in e2 studio, the FIT module is automatically added to your project. Refer to “Adding Firmware Integration Technology Modules to Projects (R01AN1723)” for details.

(3) Adding the FIT module to your project using “Smart Configurator” on CS+
By using the “Smart Configurator Standalone version” in CS+, the FIT module is automatically added to your project. Refer to “Renesas e2 studio Smart Configurator User Guide (R20AN0451)” for details.

(4) Adding the FIT module to your project in CS+
In CS+, please manually add the FIT module to your project. Refer to “Adding Firmware Integration Technology Modules to CS+ Projects (R01AN1826)” for details.

2.11.2 Setting driver options when not using Smart Configurator

The Touch-specific options are found and edited in r_config¥r_touch_qe_config.h.

2.12 IEC 60730 Compliance

This module complies with both R.1 (IEC 60335-1) and software class B (IEC 60730-1). For the latest information on the support status, refer to the web page Functional Safety Solutions for Home Appliances (IEC/UL 60730).

3. API Functions

3.1 R_CTSU_Open

This function initializes the module and must be executed before using any of the other API functions. Please execute this function for each touch interface.

Format

```
fsp_err_t R_CTSU_Open (ctsu_ctrl_t * const p_ctrl,
                       ctsu_cfg_t const * const p_cfg)
```

Parameters

p_ctrl	Pointer to the control structure (normally generated by QE for Capacitive Touch)
p_cfg	Pointer to the config structure (normally generated by QE for Capacitive Touch)

Return Values

FSP_SUCCESS	*/* Successfully completed */*
FSP_ERR_ASSERTION	*/* Argument pointer not specified */*
FSP_ERR_ALREADY_OPEN	*/* Open() is called without calling Close() */*
FSP_ERR_INVALID_ARGUMENT	*/* Configuration parameters are invalid */*

Properties

Prototype is declared in r_ctsu_api.h

Description

This function enables control structure initialization, register initialization, and interrupt setting according to the argument p_cfg.

Also, the correction coefficient generation process is executed while processing the first touch interface structure. The process takes approximately 120ms.

The DTC is initialized if CTSU_CFG_USE_DTC is enabled when the first touch interface configuration is processed.

Example

```
fsp_err_t err;

/* Initialize pins (function created by Smart Configurator) */
R_CTSU_PinSetInit();

/* Initialize the API. */
err = R_CTSU_Open(&g_ctsu_ctrl, &g_ctsu_cfg);

/* Check for errors. */
if (err != FSP_SUCCESS)
{
    . . .
}
```

Special Notes:

The port must be initialized before calling this function. We recommend using the R_CTSU_PinSetInit() function generated by SmartConfigurator as the port initialization function

3.2 R_CTSU_ScanStart

This function starts measurement of the specified touch interface configuration.

Format

```
fsp_err_t R_CTSU_ScanStart (ctsu_ctrl_t * const p_ctrl)
```

Parameters

p_ctrl Pointer to the control structure (normally generated by QE for Capacitive Touch)

Return Values

FSP_SUCCESS	*/* Successfully completed */*
FSP_ERR_ASSERTION	*/* Argument pointer not specified */*
FSP_ERR_NOT_OPEN	*/* Called without calling Open() */*
FSP_ERR_CTSU_SCANNING	*/* Now scanning */*
FSP_ERR_CTSU_NOT_GET_DATA	*/* Did not obtain previous results */*

Properties

Prototype is declared in r_ctsu_api.h.

Description

When a software trigger occurs, this function sets and starts the measurement based on the touch interface configuration. With an external trigger, the function sets the measurement and goes to the trigger wait state.

If CTSU_CFG_USE_DTC is enabled, the function also sets the DTC.

The resulting value is notified in the callback generated from the INTCTSUFN interrupt handler.

When using the automatic judgement function, the measurement settings are initialized when this function is called for the first time after offset tuning is completed.

Example

```
fsp_err_t err;

/* Initiate a sensor scan by software trigger */
err = R_CTSU_ScanStart(&g_ctsu_ctrl);

/* Check for errors. */
if (err != FSP_SUCCESS)
{
    . . .
}
```

Special Notes:

None

3.3 R_CTSU_DataGet

This function reads all the values previously measured in the specified touch interface configuration.

Format

```
fsp_err_t R_CTSU_DataGet (ctsu_ctrl_t * const p_ctrl, uint16_t * p_data)
```

Parameters

p_ctrl	Pointer to the control structure (normally generated by QE for Capacitive Touch)
p_data	Pointer to the buffer that stores the measured value.

Return Values

FSP_SUCCESS */* CTSU initialization successfully completed */*

FSP_ERR_ASSERTION */* Argument pointer not specified */*

FSP_ERR_NOT_OPEN */* Called without calling Open() */*

FSP_ERR_CTSU_SCANNING */* scanning */*

FSP_ERR_CTSU_INCOMPLETE_TUNING */*Tuning initial offset */*

FSP_ERR_ABORTED */* Operate error of ADC data collection ,since ADC use other */*

Properties

Prototype is declared in r_ctsu_api.h.

Description

This function reads all previously measured values into the specified buffer. The required buffer size varies depending on the measurement mode. Prepare twice the number of TS for the self-capacitance and current measurement modes, and twice the number of matrixes for the mutual-capacitance mode. If normalization (majority frequency) is turned off, prepare multiple CTSU_CFG_NUM_SUMULTI terminals for each mode. The value measured in the temperature correction mode is not stored. When RTRIM adjustment is performed, the RTRIM value is stored. At this time, the ADC settings have been changed in this function, so perform the process to return to the ADC settings you are using. Otherwise, store 0xFFFF.

When initial offset adjustment is on, FSP_ERR_INCOMPLETE_TUNING is returned several times until the adjustment is complete. Measured values are not stored in the buffer at this time. For more details on initial offset adjustment, refer to section 1.1.6.

The measured value is the value resulting from the sensor ICO correction, normalization (when on), and moving average processes executed in this function.

Example:

```
fsp_err_t err;
uint16_t buf[CTSU_CFG_NUM_SELF_ELEMENTS];

/* Get all sensor values */
err = R_CTSU_DataGet(&g_ctsu_ctrl, buf);
```

Special Notes:

None

3.4 R_CTSU_CallbackSet

This function sets the function specified for the measurement completion callback function.

Format

```
fsp_err_t R_CTSU_CallbackSet (ctsu_ctrl_t * const p_api_ctrl,
                              void (* p_callback)(ctsu_callback_args_t *),
                              void const * const p_context,
                              ctsu_callback_args_t * const p_callback_memory)
```

Parameters

p_api_ctrl Pointer to the control structure (normally generated by QE for Capacitive Touch)

p_callback Pointer to callback function

p_context Pointer to send to callback function

p_callback_memory Set to NULL

Return Values

FSP_SUCCESS */* Successfully completed */*

FSP_ERR_ASSERTION */* Argument pointer not specified */*

FSP_ERR_NOT_OPEN */* Called without calling Open() */*

Properties

Prototype is declared in r_ctsu_api.h.

Description

This function sets the function specified for the measurement completion callback function. By default, the callback function is set to the function of member p_callback of ctsu_cfg_t, so use it when you want to change to another function during operation.

You can also set the context pointer. If not used, set p_context to NULL. Set p_callback_memory to NULL.

Example:

```
fsp_err_t err;

/* Set callback function */
err = R_CTSU_CallbackSet(&g_ctsu_ctrl, ctsu_callback, NULL, NULL);
```

Special Notes:

None

3.5 R_CTSU_Close

This function closes the specified touch interface configuration.

Format

```
fsp_err_t R_CTSU_Close (ctsu_ctrl_t * const p_ctrl)
```

Parameters

p_ctrl Pointer to the control structure (normally generated by QE for Capacitive Touch)

Return Values

FSP_SUCCESS */* Successfully completed */*

FSP_ERR_ASSERTION */* Argument pointer not specified */*

FSP_ERR_NOT_OPEN */* Called without calling Open() */*

Properties

Prototype is declared in r_ctsu_api.h.

Description

This function closes the specified touch interface configuration.

Example:

```
fsp_err_t err;

/* Shut down peripheral and close driver */
err = R_CTSU_Close(&g_ctsu_ctrl);
```

Special Notes:

None

3.6 R_CTSU_Diagnosis

This is the API function providing the function for diagnosis of the CTSU inner circuit.

Format

```
fsp_err_t R_CTSU_Diagnosis (ctsu_ctrl_t * const p_ctrl)
```

Parameters

p_ctrl Pointer to the control structure (normally, generated by QE for Capacitive Touch)

Return Values

FSP_SUCCESS */* All diagnoses are normal */*

FSP_ERR_ASSERTION */* Missing argument pointer */*

FSP_ERR_NOT_OPEN */* Called without calling Open() */*

FSP_ERR_CTSU_NOT_GET_DATA */*Not processed previous scan data. */*

FSP_ERR_CTSU_DIAG_LDO_OVER_VOLTAGE */* Diagnosis of LDO over voltage failed */*

FSP_ERR_CTSU_DIAG_CCO_HIGH */* Diagnosis of CCO into 19.2uA failed. */*

FSP_ERR_CTSU_DIAG_CCO_LOW */* Diagnosis of CCO into 2.4uA failed.*/*

FSP_ERR_CTSU_DIAG_SSCG */* Diagnosis of SSCG frequency failed. */*

FSP_ERR_CTSU_DIAG_DAC */* Diagnosis of non-touch count value failed. */*

FSP_ERR_CTSU_DIAG_OUTPUT_VOLTAGE */*Diagnosis of LDO output voltage failed. */*

FSP_ERR_CTSU_DIAG_OVER_VOLTAGE */*Diagnosis of over voltage detection circuit failed.*/*

FSP_ERR_CTSU_DIAG_OVER_CURRENT */*Diagnosis of over current detection circuit failed. */*

FSP_ERR_CTSU_DIAG_LOAD_RESISTANCE */*Diagnosis of LDO internal resistance value failed.*/*

FSP_ERR_CTSU_DIAG_CURRENT_SOURCE */*Diagnosis of Current source value failed.*/*

FSP_ERR_CTSU_DIAG_SENSCLK_GAIN */*Diagnosis of SENSCLK frequency gain failed.*/*

FSP_ERR_CTSU_DIAG_SUCLK_GAIN */*Diagnosis of SUCLK frequency gain failed.

FSP_ERR_CTSU_DIAG_CLOCK_RECOVERY */*Diagnosis of SUCLK clock recovery function failed.*/*

Properties

Prototyped in file “r_ctsu_qe.h

Description

This is the API function providing the function for diagnosis of the CTSU inner circuit

Call when the return value of the function R_CTSU_DataGet is FSP_SUCCESS.

Example:

```
fsp_err_t err;
uint16_t  dummy;

/* Open Diagnosis function */
R_CTSU_Open(g_qe_ctsu_instance_diagnosis.p_ctrl,
g_qe_ctsu_instance_diagnosis.p_cfg);

/* Scan Diagnosis function */
R_CTSU_ScanStart(g_qe_ctsu_instance_diagnosis.p_ctrl);
while (0 == g_qe_touch_flag) {}
g_qe_touch_flag = 0;

err = R_CTSU_DataGet(g_qe_ctsu_instance_diagnosis.p_ctrl,&dummy);
if (FSP_SUCCESS == err)
{
   err = R_CTSU_Diagnosis(g_qe_ctsu_instance_diagnosis.p_ctrl);
   if ( FSP_SUCCESS  == err )
   {
      /* Diagnosis was succssed. */
   }
}
```

Special Notes:

3.7 R_CTSU_ScanStop

This function stops measuring the specified touch interface configuration.

Format

```
fsp_err_t R_CTSU_ScanStop (ctsu_ctrl_t * const p_ctrl)
```

Parameters

p_ctrl Pointer to the control structure (normally, generated by QE for Capacitive Touch)

Return Values

FSP_SUCCESS */* Successfully completed */*

FSP_ERR_ASSERTION */* Argument pointer not specified */*

FSP_ERR_NOT_OPEN */* Called without calling Open() */*

Properties

Prototype is declared in r_ctsu_api.h.

Description

This function stops measuring the specified touch interface configuration.

Reentrant

This function is non-reentrant.

Example:

```
fsp_err_t err;

/* Stop CTSU module */
err = R_CTSU_ScanStop(&g_ctsu_ctrl);
```

Special Notes:

None

3.8 R_CTSU_SpecificDataGet

This function reads the measurements for the specified data type for the specified touch interface configuration.

Format

```
fsp_err_t R_CTSU_SpecificDataGet (ctsu_ctrl_t * const      p_ctrl,
                                  uint16_t               * p_specific_data,
                                  ctsu_specific_data_type_t specific_data_type)
```

Parameters

p_ctrl	Pointer to the control structure (normally generated by QE for Capacitive Touch)
p_specific_data	Pointer to specific data array.
specific_data_type	Specific data type to get

Return Values

FSP_SUCCESS	*/* CTSU initialization successfully completed */*
FSP_ERR_ASSERTION	*/* Argument pointer not specified */*
FSP_ERR_NOT_OPEN	*/* Called without calling Open() */*
FSP_ERR_CTSU_SCANNING	*/* Scanning */*
FSP_ERR_CTSU_INCOMPLETE_TUNING	*/* Tuning initial offset */*
FSP_ERR_NOT_ENABLED	*/* CTSU_SPECIFIC_SELECTED_FREQ for CTSU1 */*

Properties

Prototype is declared in r_ctsu_api.h.

Description

When CTSU_SPECIFIC_RAW_DATA is set for specific_data_type, RAW data will be stored in p_specific_data. These are the data before the calculation of the sensor ICO correction in 1.1.3.

When CTSU_SPECIFIC_CORRECTION_DATA is set for specific_data_type, the corrected data is stored in p_specific_data. These are the data after the calculation of the sensor ICO correction in 1.1.3.

In CTSU2, these store the number of data obtained by multiplying the number of channels by the number of multi-frequency.

When CTSU_SPECIFIC_SELECTED_DATA is set for specific_data_type, p_specific_data stores the bitmap of the frequency used by the majority vote. Only valid for CTSU2. For example, store 0x05 if the 1st and 3rd frequencies were used.

Example:

```
fsp_err_t err;
uint16_t specific_data[CTSU_CFG_NUM_SELF_ELEMENTS * CTSU_CFG_NUM_SUMULTI]

/* Get Specific Data */
err = R_CTSU_SpecificDataGet(&g_ctsu_ctrl, &specific_data[0],
CTSU_SPECIFIC_CORRECTION_DATA);
```

3.9 R_CTSU_DataInsert

This function inserts the specified data in buffer of touch measurement results for the specified touch interface configuration.

Format

```
fsp_err_t R_CTSU_DataInsert (ctsu_ctrl_t * const p_ctrl,
                             uint16_t * p_insert_data)
```

Parameters

p_ctrl	Pointer to the control structure (normally generated by QE for Capacitive Touch)
p_insert_data	Pointer to insert data array.

Return Values

FSP_SUCCESS	*/* CTSU initialization successfully completed */*
FSP_ERR_ASSERTION	*/* Argument pointer not specified */*
FSP_ERR_NOT_OPEN	*/* Called without calling Open() */*
FSP_ERR_CTSU_SCANNING	*/* scanning */*
FSP_ERR_CTSU_INCOMPLETE_TUNING	*/*Tuning initial offset */*

Properties

Prototype is declared in r_ctsu_api.h.

Description

This function is supposed to process the data acquired by R_CTSU_SpecificDataGet () in the user application, such as noise suppression, and store the data in this function. Set the start address of the data array to be stored in p_insert_data. For self-capacity mode, store in p_ctrl-> p_self_data. For mutual capacity, store in p_ctrl-> p_mutual_pri_data and p_crtl-> p_mutual_snd_data.

Example:

```
fsp_err_t err;
uint16_t specific_data[CTSU_CFG_NUM_SELF_ELEMENTS * CTSU_CFG_NUM_SUMULTI]

/* Get Specific Data */
err = R_CTSU_DataGet(&g_ctsu_ctrl, &specific_data[0],
CTSU_SPECIFIC_CORRECTION_DATA);

/* Noise filter process */

/* Insert data */
err = R_CTSU_DataInsert(&g_ctsu_ctrl, &specific_data[0]);
```

Special Notes:

None

3.10 R_CTSU_OffsetTuning

This function adjusts the offset register (SO) for the specified touch interface configuration.

Format

```
fsp_err_t R_CTSU_OffsetTuning (ctsu_ctrl_t * const p_ctrl);
```

Parameters

p_ctrl

Pointer to the control structure (normally generated by QE for Capacitive Touch)

Return Values

FSP_SUCCESS	*/* CTSU successfully configured */*
FSP_ERR_ASSERTION	*/* Argument pointer not specified */*
FSP_ERR_NOT_OPEN	*/* Called without calling Open() */*
FSP_ERR_CTSU_SCANNING	*/* scanning */*
FSP_ERR_CTSU_INCOMPLETE_TUNING	*/*Tuning initial offset */*

Properties

Prototype is declared in r_ctsu_api.h.

Description

This function adjusts the offset using all the previously measured values. Call this function after the measurement is complete. Execute this function once, it returns FSP_ERR_CTSU_INCOMPLETE_TUNING until the offset adjustment is completed. Return FSP_SUCCESS when the offset adjustment is complete. Repeat the measurement and this function call until the offset adjustment is completed. See Chapter1.1.4 for offset adjustment. If automatic judgement is enabled, set the baseline initialization bit flag after offset adjustment is complete.

Example:

```
fsp_err_t err;
err = R_CTSU_ScanStart (g_qe_ctsu_instance_config01.p_ctrl);
while (0 == g_qe_touch_flag) {}
g_qe_touch_flag = 0;
err = R_CTSU_OffsetTuning (g_qe_ctsu_instance_config01.p_ctrl);
```

Special Notes:

None

3.11 R_CTSU_AutoJudgementDataGet

This function gets the result of the automatic judgement button for the specified touch interface configuration.

Format

```
fsp_err_t R_CTSU_AutoJudgementDataGet  (ctsu_ctrl_t * const p_ctrl,
                                uint64_t * p_button_status)
```

Parameters

p_ctrl

Pointer to the control structure (normally generated by QE for Capacitive Touch)

p_button_status

Pointer to a buffer that stores the button status

Return Values

FSP_SUCCESS	*/* CTSU successfully configured */*
FSP_ERR_ASSERTION	*/* Null pointer passed as a parameter */*
FSP_ERR_NOT_OPEN	*/* Module is not open */*
FSP_ERR_CTSU_SCANNING	*/* Scanning this instance */*
FSP_ERR_INVALID_MODE	*/*The mode of automatic judgement off is invalid。*/*

Properties

rPrototype is declared in r_ctsu_api.h。

Description

This function gets the result of the automatic judgement button. Call this function after the measurement is completed. The result is a 64-bit bitmap, stored in the order of TS numbers for the specified touch interface configuration.

When this function is called for the first time after offset tuning is completed, it is set to start the baseline mean calculation.

Example:

```
 fsp_err_t err;
 uint16_t buf[CTSU_CFG_NUM_SELF_ELEMENTS];

 /* Open Touch middleware */
 err = R_CTSU_Open (&g_ctsu_ctrl, &g_ctsu_cfg);

 /* Initial Offset Tuning */
 while (true)
 {
    err = R_CTSU_ScanStart (&g_ctsu_ctrl);
    while (0 == g_qe_touch_flag) {}
    g_qe_touch_flag = 0;

    err = R_CTSU_OffsetTuning (&g_ctsu_ctrl);
 }

 /* Main loop */
 while (true)
{
   /* for [CONFIG01] configuration */
   err = R_CTSU_ScanStart (&g_ctsu_ctrl);
   while (0 == g_qe_touch_flag) {}
   g_qe_touch_flag = 0;

   /* Get all sensor values */
   err = R_CTSU_AutoJudgementDataGet(&g_ctsu_ctrl, btn_status);
}
```

Special Notes:

This function is only supported with CTSU2SL.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Oct.04.18	—	First edition issued
1.10	Jul.09.19	1 3-5 9,12 21-22 8, 10-14 1,14	Added RX23W support. Added definitions for “correction” and “offset tuning”. Updated API return values. Added CTSU_CMD_GET_METHOD_MODE and CTSU_CMD_GET_SCAN_INFO Control() commands. Added #pragma section macros and configuration option to driver for Safety Module support (includes GCC/IAR support). Added IEC 60730 Compliance section.
1.11	Jan.09.20	4,5 26,27 — —	Added definition for “baseline” (Touch layer). Added CTSU_CMD_SNOOZE_ENABLE and CTSU_CMD_SNOOZE_DISABLE Control() commands. Fixed bug where a custom callback function was called twice after a scan completes. Fixed compile error for RX231 when PLL had multiplier of 13.5.
2.00	Jul.30.21	-	Full-fledged revision
2.01	Dec.17.21	4	Added description to 1.1.4 Initial offset adjustment
		5	Added description to 1.1.6 multi-measurement frequency (CTSU2L)
		6	Added description to 1.1.7 shield function (CTSU2L)
		9	Added description to 1.2.4 temperature compensation mode (CTSU2L)
		10	Added API to 1.4 API overview
		14	Fixed 2.8 Code size
		15~18	Update to 2.9 Arguments
		28	Added description to 3.6 R_CTSU_Diagnosis
		31~32	Create a new 3.8 R_CTSU_SpecifivDataGet
		33	Create a new 3.9 R_CTSU_DataInset
2.10	Apr.20.22	3	Add content to the overview
		7	Added 1.1.11 MEC function (CTSU2SL)
		7	Added 1.1.12 Automatic judgment function (CTSU2SL)
		7,8,9	Added 1.1.13 Automatic function (CTSU2SL)
		16	Added contents to 2.7 Compile settings
		19,20	Added content to 2.9 Argument
		37	Added 3.10 R_CTSU_OffsetTuning
		38	Added 3.11R_CTSU_AutoJudgmentDataGet
2.20	2022/1/20	3	Update 1 Overview
		7	Added to 1.1.10 Diagnosis Function
		12	Replaced figure at 1.2.1 Self-capacitance Mode
		14	Added to 1.2.4 Temperature Compensation Mode (CTSU2L)
		16	Updated 2.2 Software Requirements
		16	Updated 2.3 Supported Toolchains
		19	Updated 2.8 Code Size
		24	Updated 2.9 Arguments
		29	Updated 2.10 Return Value

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)
   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.
2. Processing at power-on
   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.
3. Input of signal during power-off state
   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.
4. Handling of unused pins
   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.
5. Clock signals
   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.
6. Voltage application waveform at input pin
   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).
7. Prohibition of access to reserved addresses
   Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.
8. Differences between products
   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

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