RL78 Family

CTSU Module Software Integration System

Introduction

This application note describes CTSU Module.

Target Device

RL78/G23 Group
RL78/G22 Group
RL78/G16 Group
RL78/F25 Group
RL78/F22 Group
RL78/L23 Group

There are 4 types of CTSU peripherals, which are CTSUb, CTSU2L, CTSU2La and CTSU2SLa.These are functionally different. Versions of CTSU peripherals which each device is equipped with are shown below.

CTSU2SLa   : RL78/F25, RL78/F22
CTSU2La   : RL78/G22, RL78/L23
CTSU2L   : RL78/G23
CTSUb   : RL78/G16

CTSUb, CTSU2L, CTSU2La and CTSU2SLa have different features and for the explanation purposes, CTSU2L, CTSU2La and CTSU2SLa are described below.

・Common description for CTSUb, CTSU2L, CTSU2La and CTSU2SLa   -> CTSU
・Description only for CTSUb   -> CTSU1
・Common description for CTSU2L, CTSU2La and CTSU2SLa   -> CTSU2L
・Common description for CTSU2La and CTSU2SLa   -> CTSU2La
・Description only for CTSU2SLa   -> CTSU2SLa

To understand this document, it is recommended to refer to "Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide" and "Capacitive Touch Software Overview" beforehand.

When developing an application using the module, the use of QE for Capacitive Touch is recommended.

Related Documents

RL78 Family TOUCH Module Software Integration System (R11AN0485)
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (R30AN0424)
Capacitive Touch Sensor Microcontrollers Overview of Capacitive Touch Software (R30AN0470)

Contents

RENESAS

1. Overview

1.1   What is CTSU module

CTSU module is a driver for controlling CTSU peripheral.

By using configuration settings, CTSU module performs measurements corresponding to the electrodes connected to TS terminals and obtains the capacitance measurement values. Main functions are as follows:

- It controls CTSU peripheral, applies several correction processes to the measurement values obtained from CTSU, and calculates the final corrected measurement values. In addition, CTSU2L peripheral can measure current instead of capacitance.

- It obtains the button touch judgement result from CTSU2SL peripheral.

- It diagnoses the internal circuits to confirm that CTSU peripheral is operating correctly.

1.2   Position of CTSU module

The software configuration of a touch system is shown in Figure 1.1.

Normally, CTSU module controls CTSU peripheral and returns corrected measurement values. Therefore, to obtain button ON/OFF status or slider/wheel touch positions in an application, CTSU module should be used in combination with TOUCH module.

In that case, TOUCH module calls CTSU module and converts the corrected measurement values obtained from CTSU module into button ON/OFF status and touch positions. For details of the specific operation, refer to the application note for TOUCH module.

If you want to perform your own touch judgement based on the corrected measurement values obtained from CTSU module, refer to the subsequent chapters.

Furthermore, by combining the hardware judgement implemented in CTSU2SL peripheral (automatic judgement mode) with CTSU module, you can obtain touch ON/OFF results using CTSU module.

CTSU module can also be used to diagnose the internal circuits of CTSU peripheral and obtain the diagnosis results.
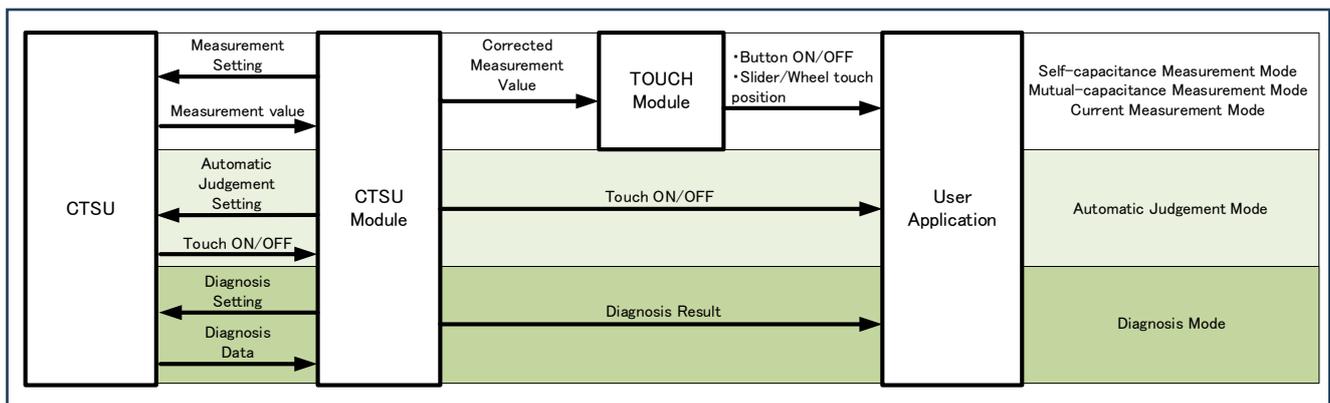
Figure 1.1 Relationship between CTSU module and user application

1.3   How to use CTSU module

Figure 1.2 shows an overview of the software system that illustrates how to use CTSU module.

CTSU module defines measurement modes using a combination of API call groups and the associated structure information. The API call groups used in self-capacitance / mutual-capacitance / current-measurement modes are treated as the basic operation model. For the operation models of automatic judgement and diagnosis modes, refer to Section 1.4.

In the basic operation model, you first call R_CTSU_Open() to initialize CTSU peripheral and to read the configuration settings and create the configuration information in the control structure. After that, by periodically calling R_CTSU_ScanStart() (measurement start processing) and R_CTSU_DataGet() (measurement result acquisition processing), you can perform periodic measurement processing.

During measurement, the following interrupts occur: INTCTSUWR (register setting request interrupt), INTCTSURD (measurement result readout request interrupt), and INTCTSUFN (measurement completion interrupt). These interrupts are generated by CTSU peripheral and processed by the module. After processing of INTCTSUFN completes, the module notifies the application of measurement completion via the callback function. After receiving the notification, perform the measurement result acquisition processing.

Note that INTCTSUWR and INTCTSURD processing can also use DTC. For details on using DTC, refer to Section 1.6.2.
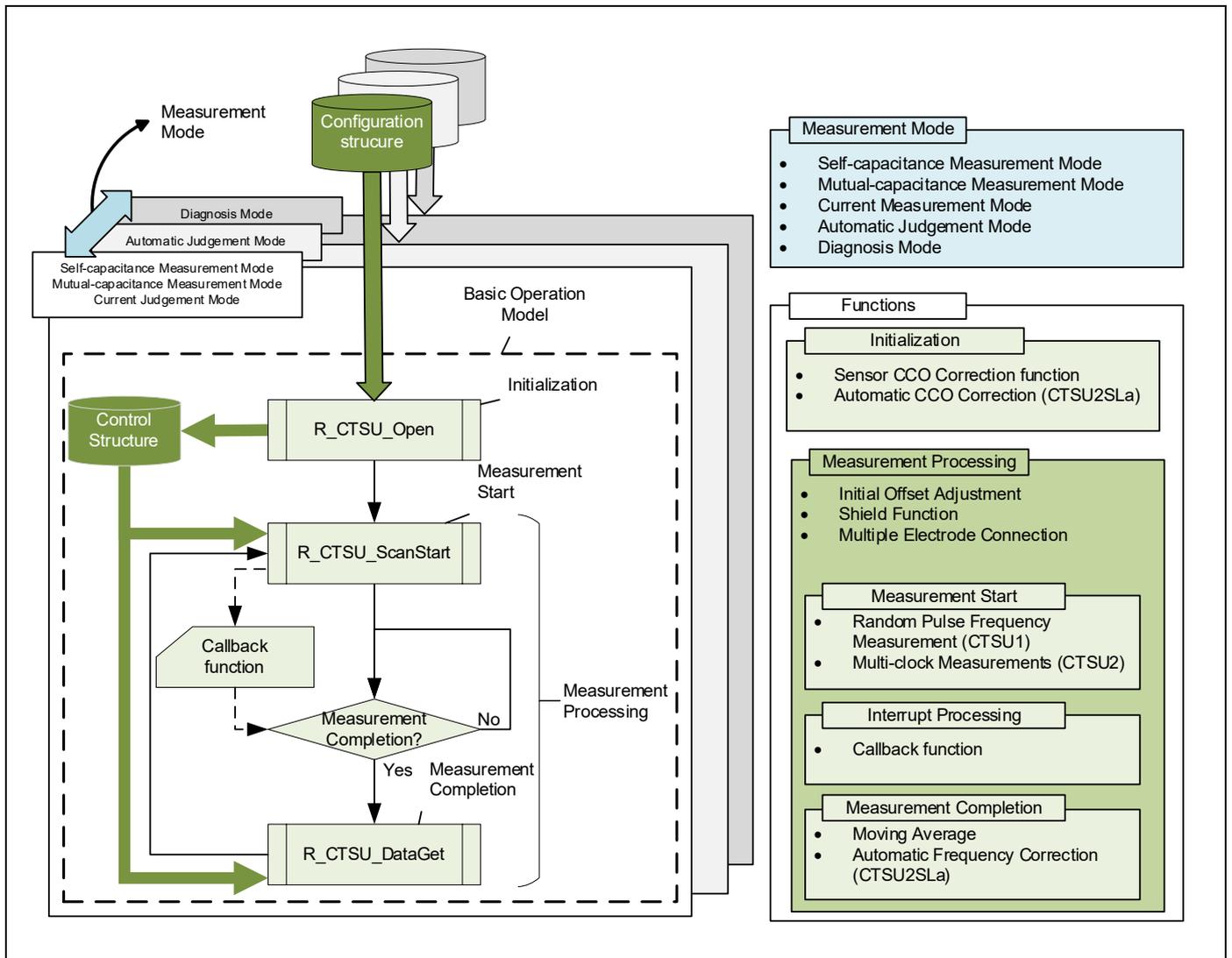
Figure 1.2 Overview of software system

In this module, data management is structured around two key data structures: the configuration structure and the control structure.

The configuration structure is used to set the measurement targets and measurement conditions. The target of a capacitance measurement is referred to as an element. In self-capacitance mode, TS terminal serves as the measurement target, while in mutual-capacitance measurement mode, the targets are the matrix of transmitter TS terminals and receiver TS terminals. The measurement conditions include various parameters required for executing measurements using CTSU peripheral, such as measurement mode, measurement time, measurement range, and trigger settings.

The measurement information defined in the configuration structure is copied into the control structure during the execution of R_CTSU_Open(). At the same time, buffers for storing measurement results are allocated, and internal flags and state information for managing measurement states are initialized. After initialization, only the control structure is referenced during the measurement process, enabling unified management of measurement settings, measurement states, and measurement results.

By preparing multiple sets of these structures, it becomes possible to run different measurement modes independently and in parallel, or to operate multiple measurement processes independently and in parallel even within the same measurement mode, provided the measurement targets and measurement conditions differ.

To simplify the configuration of these measurement settings, Renesas provides a development support tool called QE for Capacitive Touch. When creating applications that use this driver, it is recommended to use the touch interface configuration generated by QE for Capacitive Touch.

1.4   Measurement Mode

The term measurement mode collectively refers to the measurement processing determined by the measurement target, the measurement method, and the associated conditions. The available measurement modes differ depending on the functions of CTSU peripheral.

CTSU peripheral supports Self-capacitance Measurement Mode, mutual-capacitance measurement mode, and diagnosis mode.

In addition to these, CTSU2L peripheral supports current-measurement mode, and CTSU2SL peripheral supports auto-judgement mode.

Details of each measurement mode are described in Sections 1.4.1 and onward.

1.4.1   Self-capacitance Mode

Self-capacitance Measurement Mode is used to measure the capacitance of each terminal (TS).

CTSU peripheral measures the terminals in ascending order according to 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.
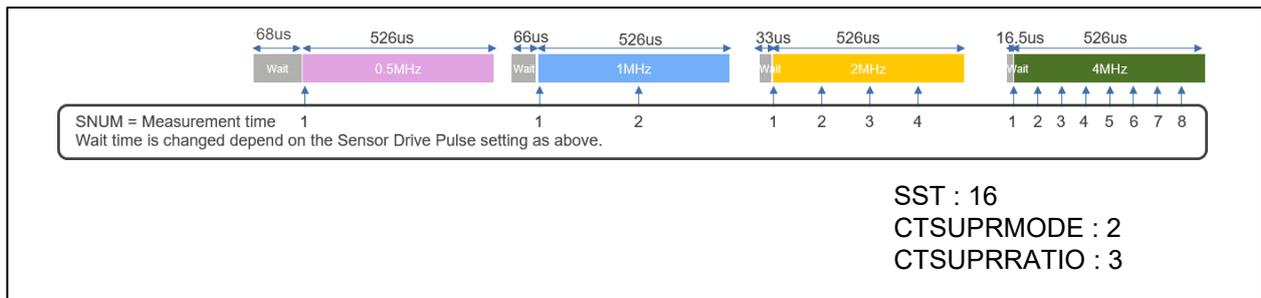
Figure 1.3 Self-capacitance Measurement Period (CTSU1)

[CTSU2L]

In default settings, the measurement period for each TS is approximately 576us.
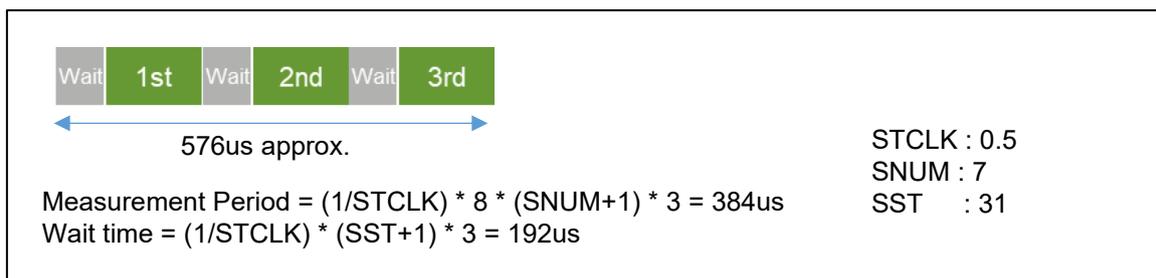
Figure 1.4 Self-capacitance Measurement Period (CTSU2L)

1.4.2   Mutual-capacitance Mode

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

CTSU2L peripheral measures all specified combinations of Rx and Tx. For example, when Rx is TS10 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 measurement generated between electrodes, CTSU2L peripheral performs the measurement process on the same electrode twice.

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

Measurement Period = (1/STCLK) * 8 * (SNUM+1) * 3 * 2 = 768us
Wait time = (1/STCLK) * (SST+1) * 3 * 2 = 384us

STCLK : 0.5
SNUM : 7
SST   : 31

Figure 1.5   Mutual-capacitance Measurement Period (CTSU2L)

1.4.3   Current Measurement Mode (CTSU2L)

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

The order of measurement and data storage is the same as that of 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 SST is set to 63.

Measurement Period = (1/STCLK) * 8 * (SNUM+1) = 128us
Wait time = (1/STCLK) * (SST+1) = 128us

STCLK : 0.5
SNUM : 7
SST   : 63

Figure 1.6 Current Measurement Period

1.4.4 Automatic Judgement Mode (CTSU2SLa)

In automatic judgement mode, CTSU2SL peripheral is controlled to obtain touch-judgement results. Since touch-judgement processing is performed by CTSU2SL peripheral, touch judgement can be executed without using CPU processing. The DTC module is mandatory because DTC transfer are necessary to process the interrupts that occur during measurement. For details on DTC, refer to Section 1.6.3.

The operation flow of automatic judgement mode is shown below. First, initial offset tuning is performed using R_CTSU_ScanStart() and R_CTSU_OffsetTuning(). For details on initial offset tuning, refer to Section 1.5.4. After initial offset tuning completes, automatic judgement measurement processing is performed using R_CTSU_ScanStart() and R_CTSU_AutoJudgementDataGet(). Note that the processing for the first measurement is different from that for the second and subsequent measurements:

First measurement:

The baseline for touch judgement is set. The first corrected measurement value is used as the baseline, and the touch judgement result is OFF.

Second and subsequent measurements:

Measurements are performed according to the measurement settings in the control structure, and touch judgement results are obtained.

By combining automatic judgement mode with measurement started by external triggers, you can create applications that perform touch judgement with low-power consumption. For more details and notes in that case, refer to 1.4.4(1). If you need more details on automatic judgement, refer to 1.4.4(2).
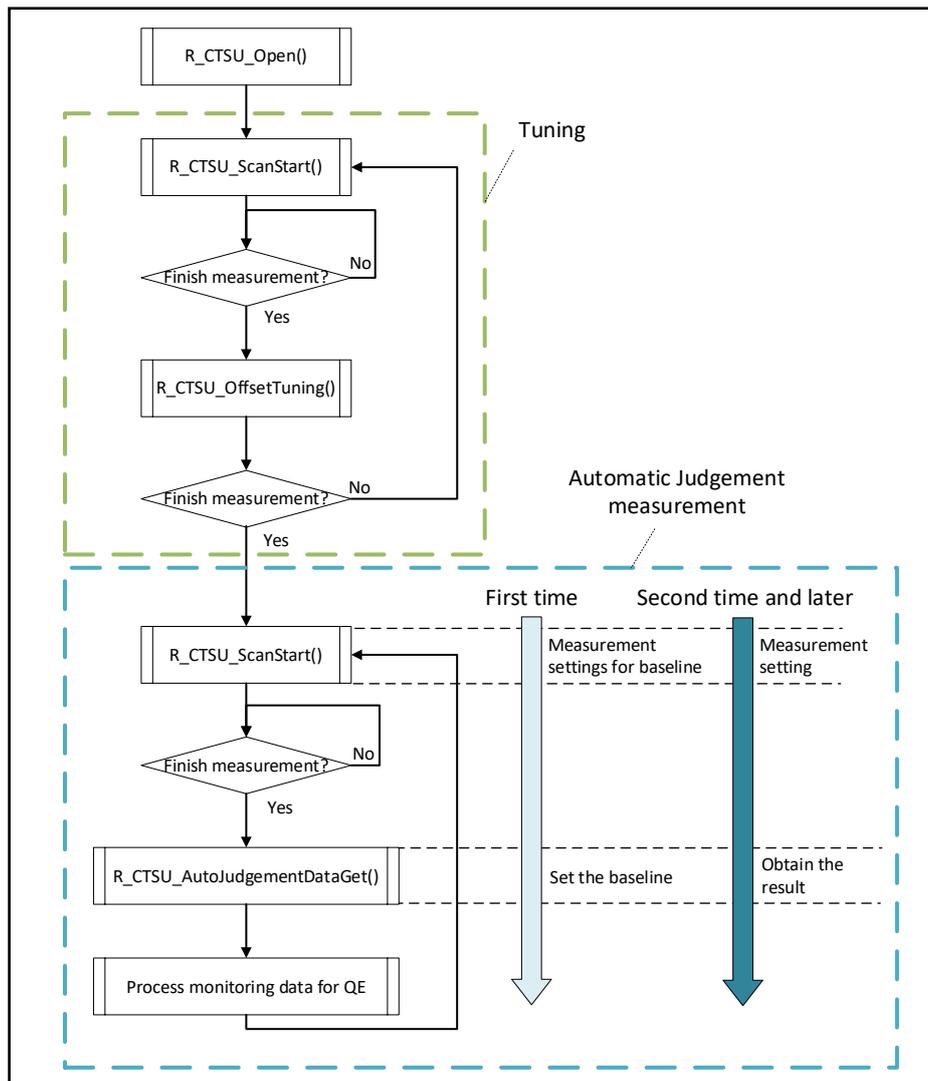

Figure 1.7 Basic operation model of auto judgement mode

(1)　　Notes for low-power touch judgement

In low-power touch applications that combine CPU Snooze mode or Software Standby mode with automatic judgement mode, it is possible to keep CPU in a low-power state while performing touch judgement and wake up CPU only when a touch judgement result is ON.
However, CPU processing is required until the baseline is set. Therefore, switch to the low-power operation mode after executing the first R_CTSU_ScanStart() and R_CTSU_AutoJudgementDataGet().
For concrete operation examples, refer to "Smart Wakeup Solution" application note.

(2)　　Functions and settings

When using the automatic judgement mode, in addition to the standard measurement settings, it is necessary to modify certain macro definitions and configure the configuration structure for automatic judgement mode. These settings differ depending on the automatic judgement method, JMM or VMM.

First, to enable the automatic judgement feature, set CTSU_CFG_AUTO_JUDGE_ENABLE = 1. At the same time, enable the automatic CCO correction function by setting CTSU_CFG_AUTO_CORRECTION_ENABLE = 1. For VMM, also enable the automatic frequency correction function by setting CTSU_CFG_AUTO_MULTI_CLOCK_CORRECTION_ENABLE = 1.

Next, an example of configuration structure settings required in addition to the standard measurement settings is shown below for JMM. When using VMM, set jc = 0 and majirimd = 1.

```
    .tlot = 2,      // Non-touch  judgment continuous count : 3 times
    .thot = 2,      // Touch judgment continuous count : 3 times
    .jc = 1,        // Judgement by two or more frequency
    .ajmmat = 2,    // Moving average : 2²times
    .ajbmat = 7,    // Baseline average count : 2⁷⁺¹times
    .majirimd = 0,  // JMM
    .mtucfen = 1,   // Enable mutual-capacitance calculation
    .ajfen = 1,     // Enable automatic judgement
```

The following (a) to (e) describe the automatic judgment and its setting. In the case of JMM, (a) ~ (e) settings are set for each multi-clock measurement.

(a) Measurement mode

Select self-capacitance or mutual-capacitance measurement 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 corrected 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) Touch 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 CTSUAJTHR register.

Figure 1.8 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.
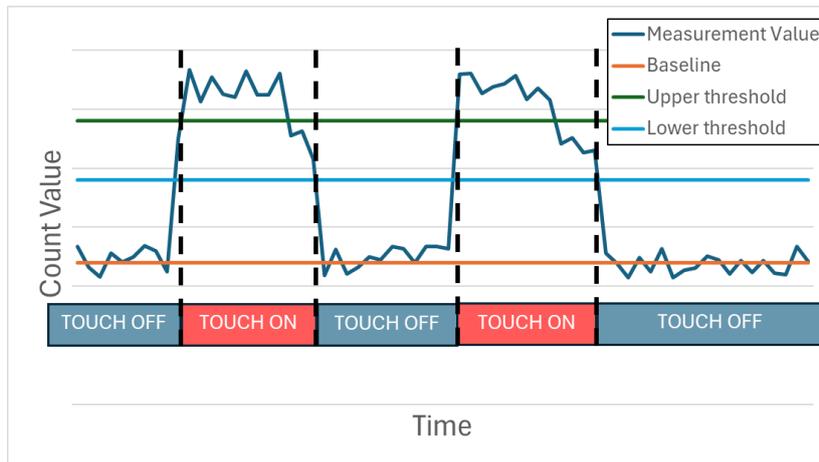
Figure 1.8 Self-capacitance judgement

Figure 1.9 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.
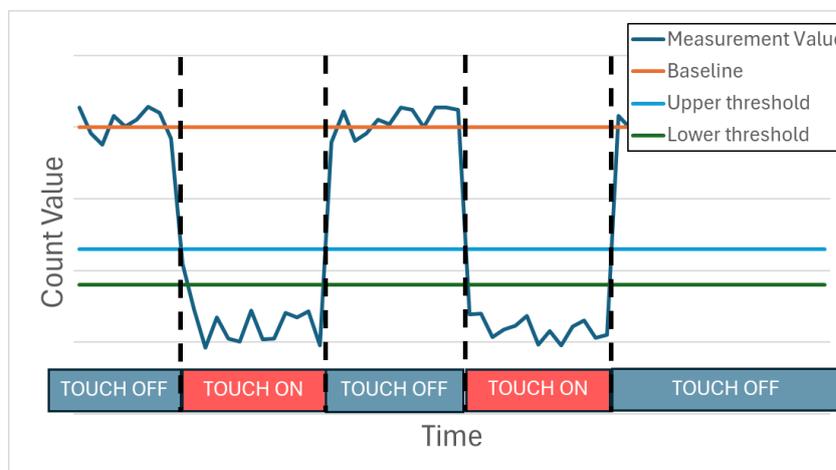
Figure 1.9 Mutual-capacitance judgement

(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.

(e) 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 1.10 shows the button judgment operation described above.
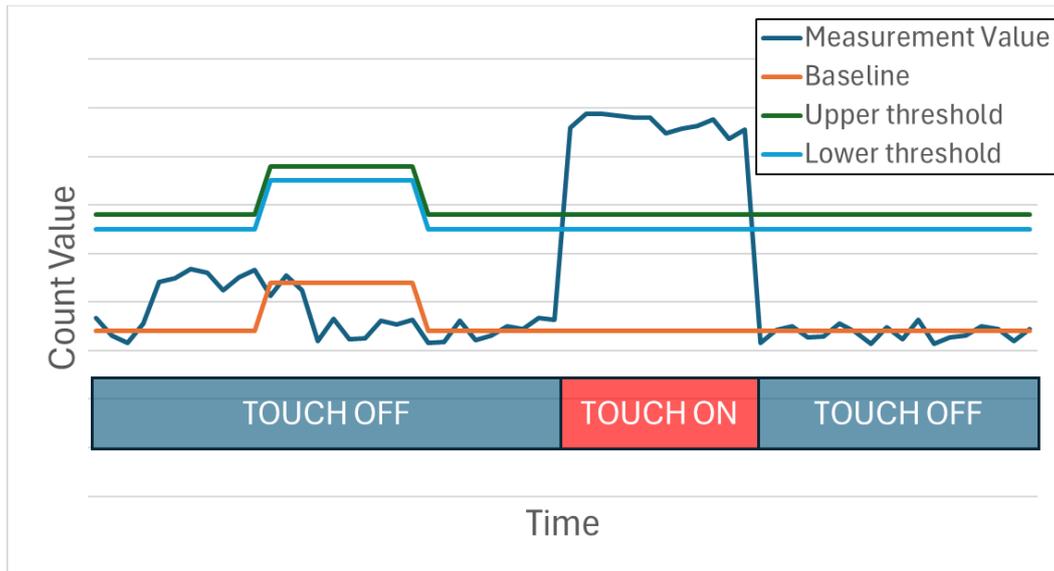
Figure 1.10 Button judgement

When enabling this mode, the lower 8 bits of the variables assigned to the repeat area must be set to 00H because DTC repeat transfer is used. Therefore, the variables shown in Table 1.1 are assigned to fixed addresses. In addition to these, there are DTC control-data areas; refer to 1.6.2. Furthermore, because the repeat area has a size limit of 255 bytes, it is not possible to configure an element count that causes these areas to exceed 255 bytes.

Table 1.1 Variables Assigned to Fixed Addresses (Automatic Judgement)

Start address	Variable	Size [bytes]	Description
CTSU_CFG_CTSUWR_ADDRESS (Default : 0xFF300)	ctsu_ctsuwr_t g_ctsu_ctsuwr[]	Number of elements × number of multi-clock	CTSUWR register configuration data
CTSU_CFG_SELF_RAW_ADDRESS (Default : 0xFF400)	ctsu_self_buf_t g_ctsu_self_raw[]	Number of self-capacitance elements × number of multi-clock	To read CTSUSC register when self-capacitance elements are present
CTSU_CFG_MUTUAL_RAW_ADDRESS (Default : 0xFF500)	ctsu_mutual_buf_t g_ctsu_mutual_raw[]	Number of mutual-capacitance elements × number of multi-clock	To read CTSUSC register when mutual-capacitance elements are present
CTSU_CFG_AJTHR_ADDRESS (Default : 0xFF600)	uint32_t g_ctsu_ajthr[]	JMM: Number of automatic judgement elements × number of multi-clocks VMM: Number of automatic judgement elements	CTSUAJTHR register configuration data
CTSU_CFG_AJMMAR_ADDRESS (Default : 0xFF700)	uint32_t g_ctsu_ajmmar[]	JMM: Number of automatic judgement elements × number of multi-clocks VMM: Number of automatic judgement elements	CTSUAJMMAR register configuration data
CTSU_CFG_AJBLACT_ADDRESS (Default : 0xFF800)	uint32_t g_ctsu_ajblact[]	JMM: Number of automatic judgement	CTSUAJBLACT register configuration data

		elements × number of multi-clocks VMM: Number of automatic judgement elements	
CTSU_CFG_AJBLAR_ADDRESS (Default : 0xFF900)	uint32_t g_ctsu_ajblar[]	JMM: Number of automatic judgement elements × number of multi-clocks VMM: Number of automatic judgement elements	CTSUAJBLAR register configuration data
CTSU_CFG_AJRR_ADDRESS (Default : 0xFFA00)	uint32_t g_ctsu_ajrr[]	JMM: Number of automatic judgement elements × number of multi-clocks VMM: Number of automatic judgement elements	CTSUAJRR register configuration data
CTSU_CFG_MCACT1_ADDRESS (Default : 0xFFB00)	uint32_t g_ctsu_mcact1[]	Number of elements × number of multi-clock	(VMM only) CTSUMCACT1 register configuration data
CTSU_CFG_MCACT2_ADDRESS (Default : 0xFFC00)	uint32_t g_ctsu_mcact2[]	Number of elements × number of multi-clock	(VMM only) CTSUMCACT2 register configuration data

1.4.5 Diagnosis Mode

CTSU peripheral has a function to diagnose its internal circuits. Diagnosis mode provides APIs that diagnose whether the internal circuits are operating correctly.

In this mode, CTSU internal circuits are diagnosed and, if an abnormality occurs, the result can be obtained as an error.

The diagnosis contents differ between CTSU1 and CTSU2L, and therefore the operation model (API call sequence) also differs.

To enable diagnosis mode, set CTSU_CFG_DIAG_SUPPORT_ENABLE = 1.

(1) CTSU1

(a) Diagnosis items

The diagnosis items of CTSU1 are shown in Table 1.2.

Table 1.2 Diagnosis items (CTSU1)

Order	Diagnosis items
1	Output Voltage Diagnosis
2	Over Voltage Detection Diagnosis
3	CCO High Diagnosis
4	CCO Low Diagnosis
5	SSCG Oscillator Diagnosis
6	Sensor Offset Diagnosis

(b)   Use case

For CTSU1, measurement and measurement-data processing are performed for a diagnosis instance using the basic model. If the return value of R_CTSU_DataGet() indicates normal completion, the diagnosis API is called to perform diagnosis processing, as shown in Figure 1.11.

If you want to use other measurement modes after diagnosis mode, start touch measurements after a wait time of about 1 ms following diagnosis-mode measurement.

Figure 1.11 Example flow when using diagnosis mode (CTSU1)

(c)   Configuration Settings

In the configuration structure for this mode, set the member md to CTSU_MODE_DIAGNOSIS_SCAN.

(2)   CTSU2L

(a)   Diagnosis items

The diagnosis items of CTSU2L are shown in Table 1.3.

Table 1.3   Diagnosis items (CTSU2L)

Order	Diagnosis items	Onetime / Repeat (※1)
1	Output Voltage Diagnosis	Repeat
2	Over Voltage Detection Diagnosis	One-time
3	Over Current Detection Diagnosis	One-time
4	Load Resistance Diagnosis	Repeat
5	Current Offset Diagnosis	One-time
6	SENSCLK Frequency Diagnosis	Repeat
7	SUCLK Frequency Diagnosis	Repeat
8	SUCLK Clock Recovery Diagnosis	Repeat

※1 "One-time" assumes diagnosis is performed once after reset. "Repeat" assumes periodic measurements.

(b)   Use case

In CTSU2L diagnosis mode, the diagnosis is typically executed once at system startup or reset, before starting any other measurement modes. Even while other measurement modes are in use, you can periodically diagnose internal circuits by using this mode.
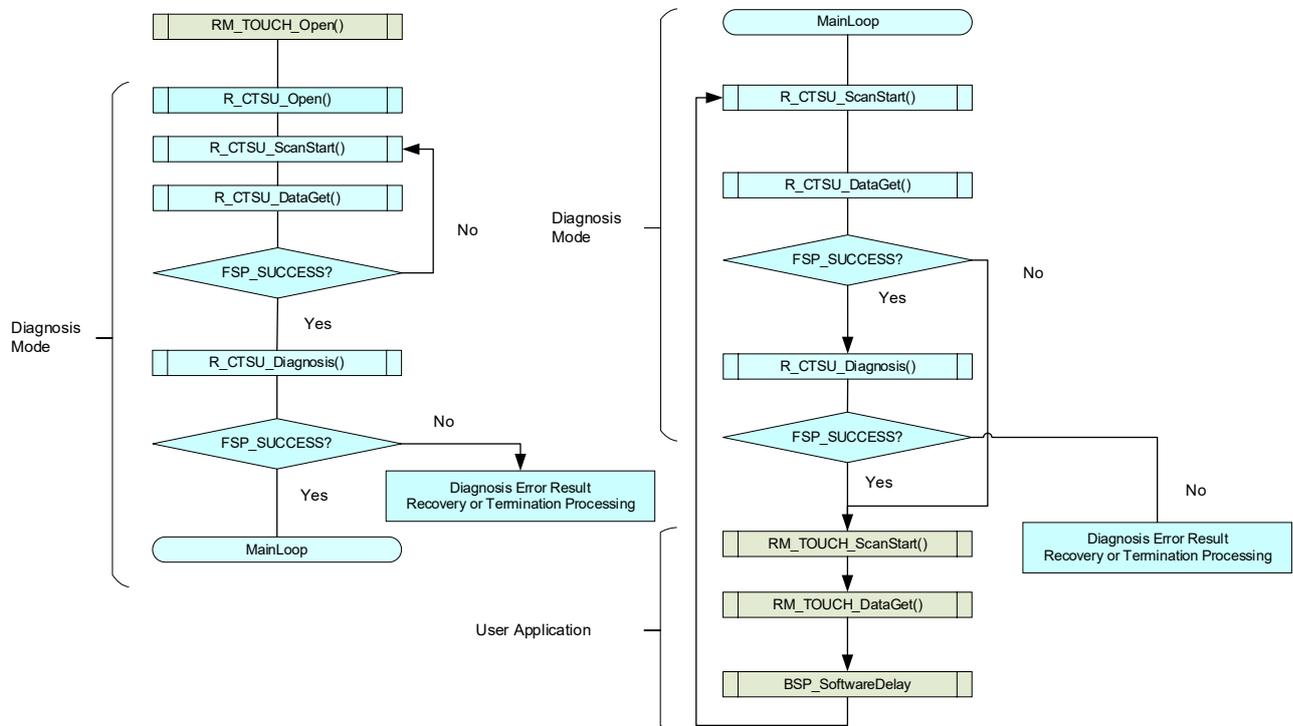

Figure 1.12 Example flow when using diagnosis mode (CTSU2)

(c)   Configuration Settings

The required settings for the members of the diagnosis mode configuration structure are shown below.

These settings are automatically generated when using QE for Capacitive Touch. If not using QE for Capacitive Touch, refer to section 1.4.5(2)(d).

Table 1.4   Configuration Settings for Diagnosis Mode (CTSU2L)

Member Name	Setting
ctsu_element_cfg_t	
so	0x00
snum	0x07
sdpa	Measurement setting for overcurrent detection
ctsu_cfg_t	
md	CTSU_MODE_DIAGNOSIS_SCAN
ctsuchacN (N=0～4)	Measurement terminal for overcurrent detection

(d)   Notes on configuration

In diagnosis mode, to verify overcurrent-detection operation, one TS terminal is selected from TS terminals used for normal measurement, and that TS terminal is set to ctsuchacN in the configuration structure. After this setting, the sensor-drive pulse frequency is adjusted according to the procedure below so that a current level that enables overcurrent detection is generated inside CTSU2SL peripheral connected to TS terminal.

1.   Calculate the current flowing in TS terminal

A measurement is performed for the selected TS terminal with an arbitrary sensor-drive pulse frequency f and TSCAP voltage V, and the parasitic capacitance C of the terminal is obtained.

The current I flowing inside CTSU2SL peripheral is calculated using the following formula:

$$I = fCV$$

2.   Set SDPA for diagnosis

The sensor-drive pulse is configured to meet the condition in which overcurrent can be detected.

Let $SDPA_0$ be SDPA value used during parasitic-capacitance measurement and I_0 be the current calculated in step 1.

Using these values, the diagnosis SDPA ($SDPA_1$) is determined as follows:

$$SDPA_1 = \frac{(SDPA_0 + 1)I_0}{100} - 1$$

Make sure that the sensor-drive pulse frequency set by $SDPA_1$ provides enough time to charge and discharge the target TS terminal.

1.5   Functions

CTSU module supports the following functions.

1.5.1   Random Pulse Frequency Measurement (CTSU1)

The drive pulse used for the measurement is a pulse with phase shifting and frequency spreading applied to the configured base clock.

The base-clock setting generally uses the value tuned with QE for Capacitive Touch.

This module is fixed at initialization and sets the following.

   CTSUSOFF = 0, CTSUSSMOD = 0, CTSUSSCNT = 3

The base clock is calculated as below.

It is determined by f_{CLK} 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 f_{CLK} =32MHz, CTSUCLK = PLCK/2, and CTSUSDPA = 1/16, then base clock is 0.5MHz. CTSUSDPA can change for each TS port.
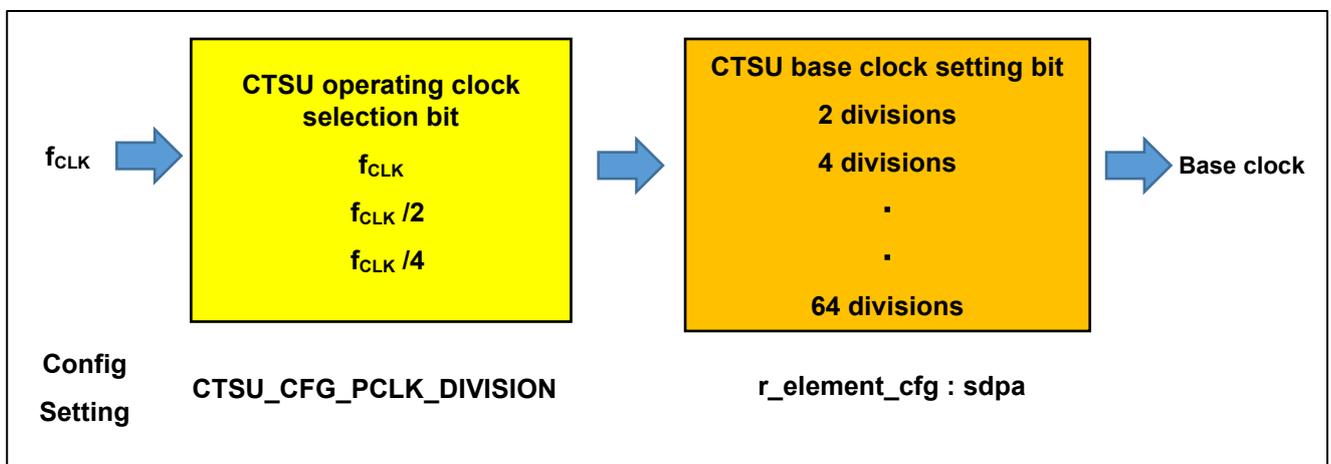

Figure 1.13 Base clock settings (CTSU1)

1.5.2   Multi-Clock Measurements (CTSU2L)

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

By default, this module measures at three different frequencies and makes a majority judgement on the three measurement results obtained.

Figure 1.14 Multi-clock Measurements

There are two types of majority judgement modes for the three measurement results: JMM (Judgement Majority Mode) and VMM (Value Majority Mode). JMM only supports self-capacitance buttons and mutual-capacitance buttons.

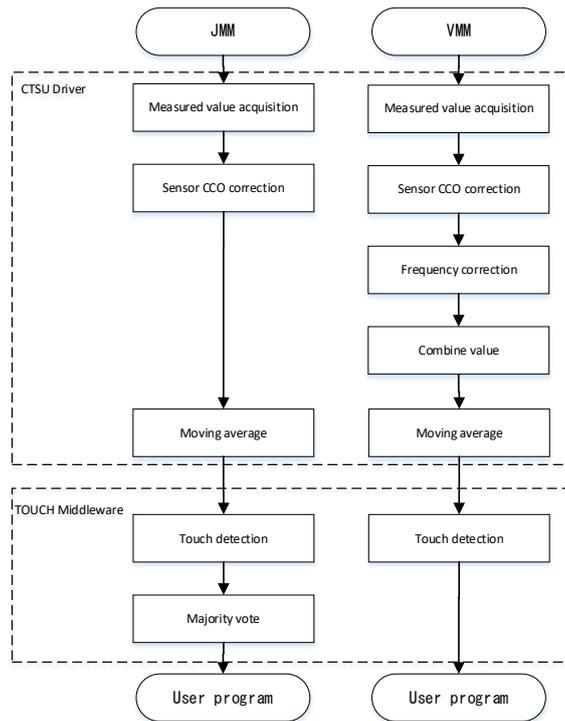Figure 1.15 shows the flowchart of JMM and VMM with Touch module.

Figure 1.15 Flowchart of JMM and VMM

JMM performs CCO correction on the three measurement values, then makes a touch judgment for each of them, and determines the final touch result by majority vote of the three judgments.

VMM performs CCO correction on the three measurement values, applies frequency correction to convert them to the measurement value at the first frequency, and then selects the two values that are close to each other. These two values are added together, and the result is treated as a measurement value with double the measurement time. Touch judgment is made based on this corrected measurement value.

Example VMM Calculations

From the frequency-corrected measurement values 1, 2, and 3, the difference values 1, 2, and 3 for each pair are calculated, and the smaller pair is selected by comparing the absolute values of the difference values. To prevent variation in the corrected measurement values, a combination of value 1 and value 2 is given a weight to be selected. When comparing value 3, multiply the difference value 2 by 2 and multiply the difference value 3 by 1.5.

Corrected Measurement Value 1	Corrected Measurement Value 2	Corrected Measurement Value 3	Difference value 1	Difference value 2	Difference value 3	Result	Added Value
7734	7734	7663	0	71	71	Value 1+2	15468
7689	7739	7666	50	23	73	Value 1+3	15355
7734	7679	7664	55	70	15	Value 2+3	15343
7721	7719	7694	2	27	25	Value 1+2	15440
7716	7747	7693	31	23	54	Value 1+2	15463

You can set JMM or VMM for each touch interface configuration. If the ctsu_cfg_t member "majority_mode" is set to 1, it works in JMM, and if it is set to 0, it works in VMM.

R_CTSU_DataGet () can get the data after conducting the moving average. To retrieve the data for each of the previous processes R_CTSU_SpecificDataGet use (). These data can also be used to determine the data with its own noise filter in Touch module. See Chapters 3.8 and 3.9 for more information.

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

Drive pulse frequency is calculated in the following equation:

$$f_{DrivePulse} = \frac{F_{PCLKB}}{2^{CLK} \times 2(STCLK + 1)} \frac{SUMULTIn + 1}{2(SDPA + 1)}, \; n = 0, 1, 2$$

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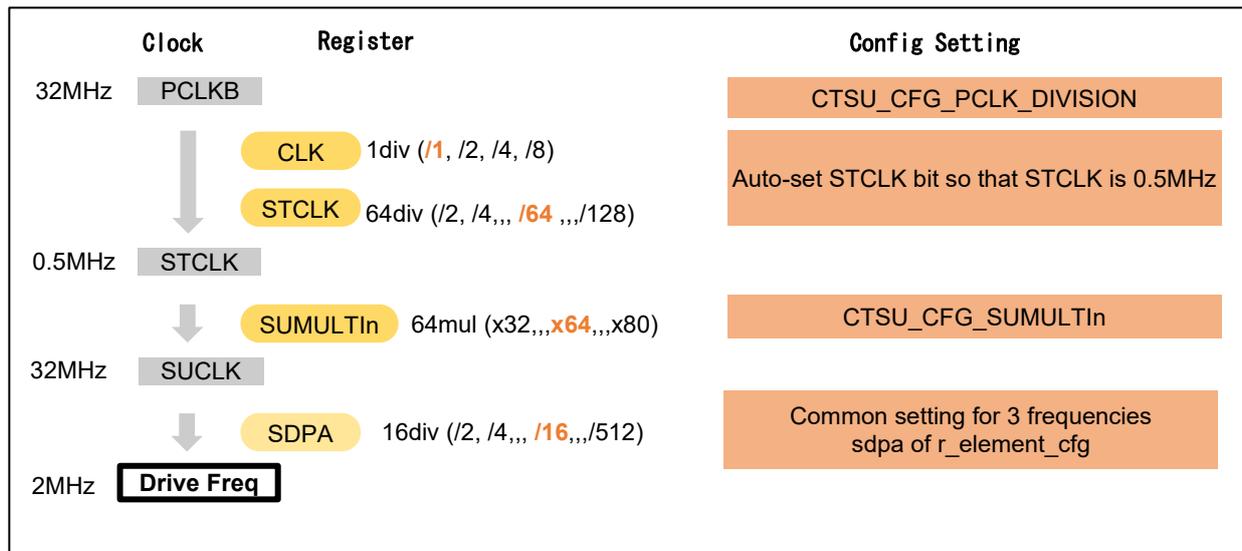

Figure 1.16 Drive Pulse Frequency Settings

1.5.3   Sensor CCO Correction function

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

This module uses the correction circuit during initialization after power-on to generate a correction coefficient to ensure accurate sensor measurement values. This correction coefficient is used to correct the measurement value.

1.5.4   Initial Offset Adjustment

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 CCO dynamic range.

This module adjusts the offset current setting so that the corrected measurement value reaches the target value. 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 (CTSU)

Mode	CTSU1 target value	CTSU2L target value
Self-capacitance	15360 (37.5%)	11520 (37.5%)
Self-capacitance using active shield	-	4608 (15%)
Mutual-capacitance	10240 (25%)	7680 (25%)

The percentage is based on 100% being the maximum input current applied to CCO.
CTSU1 : 100% is the measured value 40960 when the measurement time is 526us(base time).
CTSU2L : 100% is the measured value 30720 when the measurement time is 256us(base time).
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 Measurement 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.
Recommended CTSUPRRTIO, CTSUPRMODE are used. Changing this value is deprecated. For details,
refer to the hardware manual of each capacitive touch sensor.

・CTSU2L (Self-capacitance Measurement Mode)

Target value	Target value (multi-clock)	CTSUSNUM	Measurement time
5760	11520 (128us + 128us)	0x7	128us
11520	23040 (256us + 256us)	0xF	256us
2880	5760 (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. Regarding STCLK, refer to the hardware manual.

1.5.5　　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.

1.5.6　　Callback function

When an abnormal condition is detected during measurement, the CTSU peripheral sets the corresponding
status register. In the measurement-completion interrupt handler, the module reads CTSUSOVF from the
status register and CTSUICOMP from the error status register for CTSU1, and reads ICOMP1, ICOMP0, and
SENSOVF from the status register for CTSU2L. After the registers are read, the status registers are cleared.
The details of the abnormal condition can be checked by referring to the event member of the
ctsu_callback_args_t structure passed to the callback function.

1.5.7 Shield Function (CTSU2L)

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 Measurement.

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

For example, for the electrode configuration shown in Figure 1.17, 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,
```
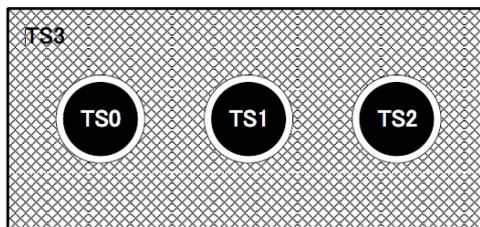

Figure 1.17 Example of Shield Electrode Structure

1.5.8 Multiple Electrode Connection (MEC) Function (CTSUb, CTSU2La)

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 Measurement Mode.

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

1.5.8 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.
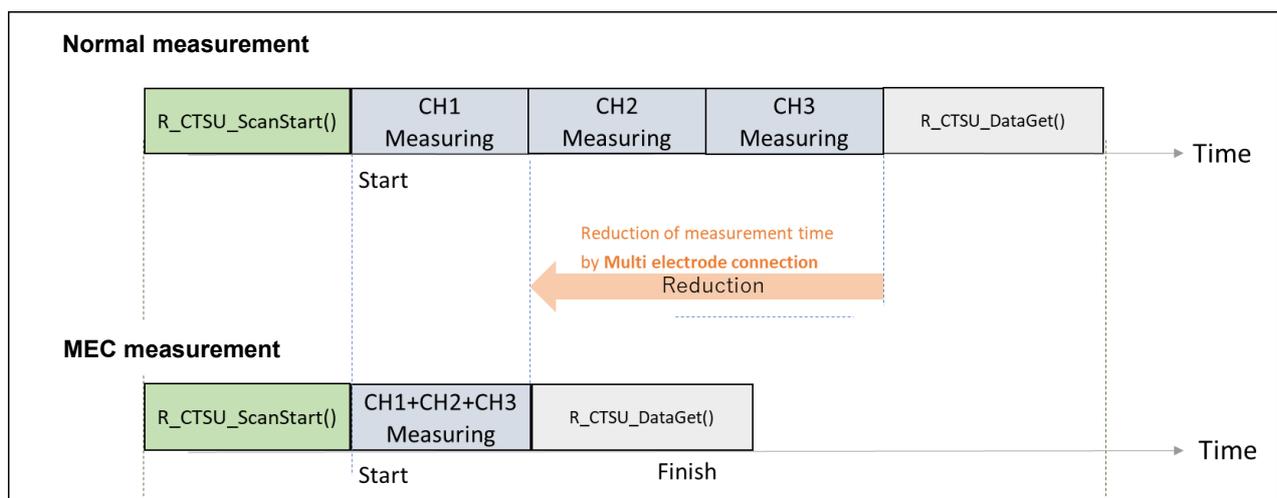

Figure 1.18 Compare of time between normal measurement and MEC measurement

To enable the code for 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 TS numbers to be measured.

If you want to use the shield function at the same time, set 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 1.19, 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,
```
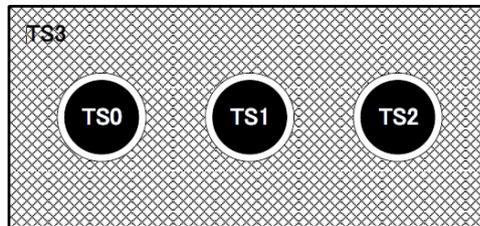

Figure 1.19 Example of MEC and shield electrode configuration

1.5.9   Automatic CCO Correction (CTSU2SLa)

The automatic CCO correction function is a feature that performs sensor CCO correction calculations inside CTSU2SL peripheral. For details on sensor CCO correction, refer to section1.5.3.

Because CTSU2SL peripheral processes the sensor CCO correction calculation internally, the corrected data can be obtained without using software-based correction processing, and no processing time is consumed on the main processor.

To enable the automatic CCO correction function, set CTSU_CFG_AUTO_CORRECTION_ENABLE to 1.

1.5.10   Automatic Frequency Correction (CTSU2SLa)

The automatic frequency-correction function is a feature that performs multi-clock correction inside CTSU2SLa peripheral.

Because CTSU2SLa peripheral processes the multi-clock correction calculation internally, the corrected data can be obtained without using software-based correction processing, and no processing time is consumed on the main processor.

To enable the automatic frequency correction function, set CTSU_CFG_AUTO_MULTI_CLOCK_CORRECTION_ENABLE to 1.

When using the automatic frequency-correction function, also enable the automatic CCO correction function.

1.5.11 Automatic judgement measurement using SMS (RL78/G22, RL78/G23, RL78/L23)

For more details on this function, refer to 'Development of Low-Power Capacitive Touch Applications for the RL78 Family (Using SMS)'. This chapter describes an overview of the function and supplementary explanations.

This function uses SNOOZE Mode Sequencer (SMS) to operate from measurement to touch judgement without CPU operation. Since the CPU is in either STOP mode or SNOOZE mode during measurement, it can measure with low power consumption. To enable this function, set CTSU_CFG_SMS_SUPPORT_ENABLE to 1.

Differences from the basic operation model (refer to 0 to verify the meaning of the basic operation model)

- For the external trigger, use the 32-bit interval timer with f_{SXP} selected as the operating clock.

- From initialization through initial offset tuning, perform the operations according to the basic operation model.

- After calling R_CTSU_SmsSet(), use R_CTSU_ScanStart() to wait for the measurement-start trigger.
- Start the timer count and execute STOP instruction to transition to STOP mode.

- When touch-ON condition is detected, INTSMSE interrupt occurs, which calls the same callback function used in normal measurement and clears SMS measurement settings. At that time, the application can obtain the measurement results using R_CTSU_DataGet(), as in normal operation.

Note

- While using this function, SMS cannot be used for other processes in the system.

- This function only supports JMM.

- To enabling this function, the lower 8 bits of the variables assigned to the repeat area must be set to 00H, as DTC repeat transfer is used. Therefore, the variables shown in Table 1.5 are assigned to fixed RAM addresses. In addition to these variables, there are other DTC control-data areas. Refer to section 1.6.2.

Table 1.5   A variable mapped to a fixed address (SMS)

Start address	Variable	Size [bytes]	Description
CTSU_CFG_SMS_TRANSFER_ADDRESS (Default : 0xFF500)	ctsu_sms_transfer_t g_ctsu_sms_transfer[]	Self-capacitance: 480 Mutual-capacitance: 544	These are the transfer data used for SMS. Although the repeat area has a size limitation of 255 bytes, SMS program rewrites the DTC information so that the operation complies with this limitation.
CTSU_CFG_SMS_CTSUWR_ADDRESS (Default : 0xFF800)	ctsu_sms_ctsuwr_t g_ctsu_sms_ctsuwr[]	Number of elements × 12	SMS measurement setting data
0xFF900	uint8_t __near g_ctsu_sms_trigger_bit_clr	1	RL78/G22 only: Port clear data
0xFFA00	uint8_t __near g_ctsu_sms_trigger_bit_set	1	RL78/G22 only: Port set data

- For RL78/G23, SMS measurement with 22 or more terminals cannot be performed due to the transfer size limitation of the DTC.

- For RL78/G22, RAM may become insufficient depending on the number of elements. If RAM becomes insufficient, RAM mapping should be reviewed and the memory sections should be optimized as necessary.

- For RL78/G22, additional settings are required to perform this process.

Figure 1.20 shows the start-up sequence for SMS measurement on RL78/G22. CTSURD interrupt of CTSU2L module triggers the DTC to output a signal from the port. The signal output from the port generates an interrupt signal, and this interrupt triggers ELC to start the SMS processing.

Therefore, connect the port terminal and the external-interrupt terminal that are used during DTC transfer. Since these terminals cannot be connected inside the MCU, connect them using an external circuit.
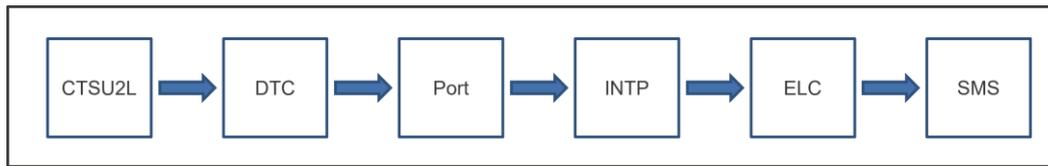
Figure 1.20 Module flow used for SMS measurement with RL78/G22

When performing automatic judgement measurement using SMS on RL78/G22, configure the port settings and external-interrupt settings as follows:

① Port Settings

  Set the port register to CTSU_CFG_SMS_EXTRIGGER_PORT.

  Set the register bit to be used for CTSU_CFG_SMS_EXTRIGGER_BIT. For example, when using P140, set CTSU_CFG_SMS_EXTRIGGER_PORT to P14 and set CTSU_CFG_SMS_EXTRIGGER_BIT to 1.

  Before starting measurement, configure the port to be used as an output port and set it to a low level.

  Note:

  DTC rewrites the port register (Pxx) in 8-bit units. Therefore, while SMS-based automatic judgement measurement is running, the port register (Pxx) used as DTC transfer destination cannot be used by other functions. Select a port register (Pxx) that does not conflict with other system functions

② External-interrupt settings

  The external-interrupt that receives the port signal must be configured. Set the external-interrupt number to be used in CTSU_CFG_SMS_ELC_INTP. For example, when using INTP1, set CTSU_CFG_SMS_ELC_INTP to 1. Before starting measurement, enable the external interrupt that is used for the measurement start trigger.

1.6 Cooperation with other SIS modules

CTSU module can cooperate with peripheral functions and other SIS modules.

Table 1.6 Peripheral Functions Used

Peripheral function	Usage	Cooperation method
Timer	Start measurement with external trigger	Add the component to be used with the timer. Configure the timer according to the application. For RL78/F22 and RL78/F25, configure CTSUTRG register.
ELC	RL78/G22 External trigger measurement start	Configure according to the timer used in the application.
ELCL	RL78/G23, RL78/L23 External trigger measurement start	Configure according to the timer used in the application.
DTC	Writes on INTCTSUWR and reads on INTCTSURD during measurement	Add DTC component. ADC is already set inside CTSU module.
ADC	RL78/G22, RL78/G23, RL78/L23 Output Voltage Diagnosis in Diagnosis Mode(CTSU2L)	Add DTC component. ADC is already set inside CTSU module.
S12ADC	RL78/F22, RL78/F25 Output Voltage Diagnosis in Diagnosis Mode(CTSU2L)	Add S12ADC component. S12ADC is already set inside CTSU module.
SMS	RL78/G22, RL78/G23, RL78/L23 Creating a low-power capacitive-touch application	Add the SMS component. SMS is already configured within the CTSU module Refer to 1.5.11 for details.

1.6.1 Trigger for Measurement Start

Measurement can be started by either a software trigger or an external trigger. Select according to your system requirements.

Software trigger

Measurement starts when R_CTSU_ScanStart() sets the measurement-start bit to 1. Since configuration for the touch interface is performed before setting this bit, there is a small delay between the API call and the actual start of measurement. However, this delay is very small compared with the measurement time, so the software trigger, which is simpler to configure, is generally recommended.

External trigger

After R_CTSU_ScanStart() sets the measurement-start trigger-selection bit and the measurement-start bit to 1, CTSU enters a trigger-wait state. Measurement starts upon receiving an event. Generally, timers are used to measure periodically. Use this method when the small delay of the software trigger cannot be tolerated or when low-power operation is required. When using multiple measurement modes with external triggers, configure the next measurement mode by calling R_CTSU_ScanStart() after measurement of one mode completes.

1.6.2 Data Transfer

CTSU module allows Data Transfer Controller (DTC) to be used instead of CPU for handling the INTCTSUWR and INTCTSURD interrupts that occur during measurement.

In automatic judgement mode and SMS-based measurement, the use of DTC is mandatory, while in other measurement modes DTC can be enabled optionally.

To use DTC, set CTSU_CFG_DTC_SUPPORT_ENABLE to 1. This enables DTC configuration code.

The method of configuring DTC is selected by CTSU_CFG_DTC_USE_SC.

- When CTSU_CFG_DTC_USE_SC = 1, DTC configuration generated by Smart Configurator is used. Refer to 2.7 "CTSU_CFG_DTC_USE_SC" for details.

- When CTSU_CFG_DTC_USE_SC = 0, the internal DTC configuration of CTSU module is used.

When using DTC, the following structure definition for DTC control/data and the variable definitions for DTC control/data area become valid.

```
typedef struct
{
    uint8_t  dtccr;
    uint8_t  dtbls;
    uint8_t  dtcct;
    uint8_t  dtrld;
    uint16_t dtsar;
    uint16_t dtdar;
}st_dtc_data;
```

The DTC control and data areas for each MCU are shown below.

(1) RL78/G22

Start address	Variables	Size[bytes]	Description
0xFFB00	uint8_t __near dtc_vectortable[40]	40	DTC vector table
0xFFBE0	st_dtc_data __near dtc_controldata_20	8	When SMS function is enabled
0xFFBE8	st_dtc_data __near dtc_controldata_21	8	CTSUWR
0xFFBF0	st_dtc_data __near dtc_controldata_22	8	CTSURD
0xFFBF8	st_dtc_data __near dtc_controldata_23	8	When SMS function is enabled

(2) RL78/G23

Address	Section	Size[bytes]	Description
0xFFD00	uint8_t __near dtc_vectortable[40]	40	DTC vector table
0xFFDE8	st_dtc_data __near dtc_controldata_21	8	When SMS function is enabled
0xFFDF0	st_dtc_data __near dtc_controldata_22	8	CTSUWR
0xFFDF8	st_dtc_data __near dtc_controldata_23	8	CTSURD

(3) RL78/L23

Address	Section	Size[bytes]	Description
0xFFD00	uint8_t __near dtc_vectortable[56]	56	DTC vector table
0xFFDE8	st_dtc_data __near dtc_controldata_21	8	When SMS function is enabled
0xFFDF0	st_dtc_data __near dtc_controldata_22	8	CTSUWR
0xFFDF8	st_dtc_data __near dtc_controldata_23	8	CTSURD

(4) RL78/F22, RL78/F25

Address	Section	Size[bytes]	Description
0xFFD00	uint8_t __near dtc_vectortable[40]	40	DTC vector table

0xFFD90	st_dtc_data __near dtc_controldata_10	8	When Automatic Frequency Correction is enabled
0xFFD98	st_dtc_data __near dtc_controldata_11	8	When Automatic Frequency Correction is enabled
0xFFDA0	st_dtc_data __near dtc_controldata_12	8	When Automatic Judgement Mode is enabled
0xFFDA8	st_dtc_data __near dtc_controldata_13	8	When Automatic Judgement Mode is enabled
0xFFDB0	st_dtc_data __near dtc_controldata_14	8	When Automatic Judgement Mode is enabled
0xFFDB8	st_dtc_data __near dtc_controldata_15	8	When Automatic Judgement Mode is enabled
0xFFDC0	st_dtc_data __near dtc_controldata_16	8	When Automatic Judgement Mode is enabled
0xFFDC8	st_dtc_data __near dtc_controldata_17	8	When Automatic Judgement Mode is enabled
0xFFDD0	st_dtc_data __near dtc_controldata_18	8	When Automatic Judgement Mode is enabled
0xFFDD8	st_dtc_data __near dtc_controldata_19	8	When Automatic Judgement Mode is enabled
0xFFDE0	st_dtc_data __near dtc_controldata_20	8	When Automatic Judgement Mode is enabled
0xFFDE8	st_dtc_data __near dtc_controldata_21	8	When Automatic Judgement Mode is enabled
0xFFDF0	st_dtc_data __near dtc_controldata_22	8	CTSUWR
0xFFDF8	st_dtc_data __near dtc_controldata_23	8	CTSURD

1.6.3   Diagnosis function

Diagnosis mode (CTSU2L) includes timing in which ADC measurements are performed. Therefore, configure the settings for each MCU in Smart Configurator.

● RL78/F22, RL78/F25

From Components tab, add 12-bit A/D Single Scan and configure it.

The clock source is enabled to be set arbitrarily within the allowable range.

Refer to the following for the other items:

- Select "Internal reference voltage" for "Analog input channel setting"

- Select "Software trigger" for "Conversion start trigger setting"

- Do not enable "Enable AD conversion end interrupt (INTAD)" in "Interrupt setting"

- Select "Unused" for "Self diagnosis setting"

- Do not enable "Enable the disconnection detection assist function" in "Disconnection detection assist setting"

- Select "Right-alignment" for "Data register format" in "Data register setting"

- Select "Disable automatic clearing" for "Automatic clearing"

- Select "Average mode" for "Addition/average mode"

RENESAS

- Select "4-time (addition 3 times)" for "Addition counts"

- Select "5 µs" for "Internal reference voltage" in "Input sampling time setting"

● RL78/G22, RL78/G23, RL78/L23

From Components tab, add A/D Converter and configure it.

VREF(+) setting, VREF(-) setting, and conversion time may be set arbitrarily within the allowable range.

For RL78/G23 or RL78/L23 devices, select Standard 2 or Low Voltage 2 conversion time. For RL78/G22, configure the conversion time mode according to project requirements.

Refer to the following for the other items:

- Select "Stop" for "Comparator operation setting"

- [RL78/G22] Select "10 bits" for "Resolution setting"
  [RL78/G23, RL78/L23] Select "12 bits" for "Resolution setting"

- Select "Software trigger no wait mode" for "Trigger mode setting"

- Select "One-shot select mode" for "Operation mode setting"

- Select "Internal reference voltage output" for "A/D channel selection" in "Operation mode setting"

- Select "Generates an interrupt request (INTAD) when ADLL ≤ ADCR or ADLL ≤ ADUL" in "Conversion result upper/lower bound value setting"

- Set "Upper bound (ADUL) value" to 255 in "Conversion result upper/lower bound value setting"

- Set "Lower bound (ADLL) value" to 0 in "Conversion result upper/lower bound value setting"

- Do not enable "Use A/D interrupt (INTAD)" in "Interrupt setting"

1.7   API Overview

This module has the following API functions.

The first argument of all API functions must be a pointer to a control structure. If you pass pointers for other arguments, ensure that they are not NULL and that you have reserved the required size for each API. However, R_CTSU_CallbackSet() is an exception, so please refer to the detailed description of API functions 3.4.

Table 1.7   API function list

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.
R_CTSU_SmsSet()	Makes settings for automatic judgement measurement using SMS of the specified touch interface configuration.

2.   API Information

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

2.1   Hardware Requirements

The MCU used in the development must support the following function.

- CTSUb
- CTSU2L
- CTSU2La
- CTSU2SLa

2.2   Software Requirements

This driver depends on the following module:

- Board Support Package (r_bsp) v1.92

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

- Code generator DTC v1.00

This driver assumes use of the capacitive touch sensor development support tool:

- QE for Capacitive Touch V4.3.0

2.3   Supported Toolchains

Module operations have been confirmed on the following toolchains.

- Renesas CC-RL Toolchain v1.15.01

- IAR Embedded Workbench for Renesas RL78 v5.20.1

- LLVM for Renesas RL78 v17.0.1.202512

2.4   Restrictions

The module code is non-reentrant and protects simultaneous calls for multiple functions.
When using LLVM compiler in the RL78/G16 group, it is necessary to check the following CPU Options when creating a project. After the project is created, it can be set from the project properties.
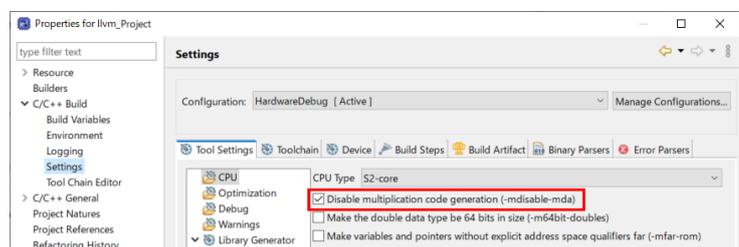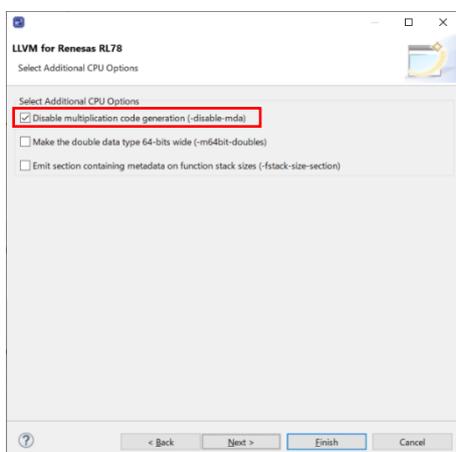
2.5   Header File

All interface definitions to be called and used in the API are defined in "r_ctsu_api.h".

Select "r_ctsu_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 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. "0": Omit parameter check process from code. "1": Include parameter check process in code. "BSP_CFG_PARAM_CHECKING_ENABLE": Selection depends on BSP setting.
CTSU_CFG_ DTC_SUPPORT_ENABLE *Default value: "0"	Select "1" to use DTC, rather than the main processor, to run CTSU2L's CTSUWR interrupt and CTSURD interrupt processes. Note: If DTC is used elsewhere in the application, it may compete with the use of this driver.
CTSU_CFG_DTC_USE_SC *Default value: "0"	When using DTC, select whether to use DTC settings of Smart Configurator. "0": DTC setting inside CTSU module is used. "1": DTC setting in Smart Configurator. When using DTC setting in the RL78/G23 group, assign CTSUWR to No.22 and CTSURD to No.23, and set normal mode and 16-bit transfer. When using DTC setting in the RL78/G22 group, assign CTSUWR to 21 and CTSURD to 22, set normal mode, 16-bit transfer, and DTC base address to 0xFFB00. Note: When the automatic judgement measurement function using SMS is enable, please set "0".
CTSU_CFG_AUTO_JUDGE_ENABLE *Default value: "0"	Select "1" to use the automatic-judgement code.
CTSU_CFG_CTSUWR_ADDRESS *Default value: "0xFF300"	Address specification for g_ctsu_ctsuwr
CTSU_CFG_SELF_RAW_ADDRESS *Default value: "0xFF400"	Address specification for g_ctsu_self_raw
CTSU_CFG_MUTUAL_RAW_ADDRESS *Default value: "0xFF500"	Address specification for g_ctsu_mutual_raw
CTSU_CFG_AJTHR_ADDRESS *Default value: "0xFF600"	Address specification for g_ctsu_ajthr
CTSU_CFG_AJMMAR_ADDRESS *Default value: "0xFF700"	Address specification for g_ctsu_ajmmar
CTSU_CFG_AJBLACT_ADDRESS *Default value: "0xFF800"	Address specification for g_ctsu_ajblact
CTSU_CFG_AJBLAR_ADDRESS *Default value: "0xFF900"	Address specification for g_ctsu_ajblar
CTSU_CFG_AJRR_ADDRESS *Default value: "0xFFA00"	Address specification for g_ctsu_ajrr

CTSU_CFG_MCACT1_ADDRESS *Default value: "0xFFB00"	Address specification for g_ctsu_mcact1
CTSU_CFG_MCACT2_ADDRESS *Default value: "0xFFC00"	Address specification for g_ctsu_mcact2
CTSU_CFG_SMS_SUPPORT_ENABLE *Default value: "0"	Select whether to enable the automatic judgement measurement function using SMS. When this function is enabled, SMS cannot be used for other processes in the system.
CTSU_CFG_SMS_TRANSFER_ADDRESS *Default value: "0xFF500"	This is the address setting of the repeat area used for DTC repeat transfer for SMS. See Section 1.5.9.
CTSU_CFG_SMS_CTSUWR_ADDRESS *Default value: "0xFF800"	This is the address setting of the repeat area used for DTC repeat transfer for SMS. See Section 1.5.9.
CTSU_CFG_AUTO_JUDGE_ENABLE *Default value: "0"	Set to "1" to enable the automatic judgement code.
CTSU_CFG_INTCTSUWR_PRIORITY_LEVEL *Default value: "2"	Sets CTSUWR interrupt priority level (also necessary when using DTC). The priority level range is from 0 (high) to 3 (low).
CTSU_CFG_INTCTSURD_PRIORITY_LEVEL *Default value: "2"	Sets CTSURD interrupt priority level (also necessary when using DTC). The priority level range is from 0 (high) to 3 (low).
CTSU_CFG_INTCTSUFN_PRIORITY_LEVEL *Default value: 2	Sets CTSUFN interrupt priority level. The priority level range is from 0 (high) to 3 (low).
CTSU_CFG_SMS_EXTRIGGER_PORT *Default value: "P14"	Set the output port for calling SMS. The setting value is the group number of the port. The range is P0 ~ P7, P12 ~ P14 that can be set as an output port.
CTSU_CFG_SMS_EXTRIGGER_BIT *Default value: "1"	Sets the output port bitmap for calling SMS.
CTSU_CFG_SMS_ELC_INTP *Default value: "1"	Set the number of the interrupt input function (INTP) to call SMS. The range is 0 to 7.
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.	
QE_TOUCH_VERSION	QE version
CTSU_CFG_NUM_SELF_ELEMENTS	Sets the total number of TS for self-capacitance, current measurement, and temperature correction.
CTSU_CFG_NUM_MUTUAL_ELEMENTS	Sets the total number of matrixes for mutual-capacitance
CTSU_CFG_NUM_AUTOJUDGE_SELF_ELEMENTS	Sets the total number of TS for self-capacitance with automatic judgement.
CTSU_CFG_NUM_AUTOJUDGE_MUTUAL_ELEMENTS	Sets the total number of matrixes for mutual-capacitance with automatic judgement.
CTSU_CFG_LOW_VOLTAGE_MODE	Enables/disables the low voltage mode. This value is set in CTSUCRAL register's ATUNE0 bit. Note: This software does not support Low Voltage Mode on CTSU1, please set 0 using CTSU1.
CTSU_CFG_PCLK_DIVISION	Sets the f_{CLK} frequency division rate. This value is set in CTSUCRAL register's CLK bit.
CTSU_CFG_TSCAP_PORT	Sets TSCAP port. For example, P30 : "0x0300".
CTSU_CFG_VCC_MV	Sets V_{DD} voltage. For example, 5.00V : "5000".
CTSU_CFG_NUM_SUMULTI	Sets the number of multi-clock measurements.

CTSU_CFG_SUMULTI0	Sets the multiplication factor for the first frequency in a multi-clock measurement. Recommended: 0x2F (RL78/F25 and RL78/F22 : 0x3F)
CTSU_CFG_SUMULTI1	Sets the multiplication factor for the second frequency in a multi-clock measurement. Recommended: 0x28 (RL78/F25 and RL78/F22 : 0x36)
CTSU_CFG_SUMULTI2	Sets the multiplication factor for the third frequency in a multi-clock measurement. Recommended: 0x36 (RL78/F25 and RL78/F22 : 0x48)
CTSU_CFG_TEMP_CORRECTION_SUPPORT	Enables/disables temperature correction.
CTSU_CFG_TEMP_CORRECTION_TS	Sets the temperature correction pin number.
CTSU_CFG_TEMP_CORRECTION_TIME	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_CALIB_RTRIM_SUPPORT	Enables/disables RTRIM correction for temperature correction. ADC must be selected to operate with RTRIM correction enabled.
CTSU_CFG_DIAG_SUPPORT_ENABLE	Enables/disables diagnosis function.
CTSU_CFG_SMS_ELEMENT_NUM	Set the total number of elements to be measured by SMS.
CTSU_CFG_AUTO_CORRECTION_ENABLE	Select whether to enable or disable the automatic CCO correction process.
CTSU_CFG_AUTO_MULTI_CLOCK_CORRECTION_ENABLE	Select whether to enable or disable the automatic frequency correction process.
CTSU_CFG_MULTIPLE_ELECTRODE_CONNECTION_ENABLE	Select to enable or disable MEC feature.
CTSU_CFG_MAJORITY_MODE	Bitmap of majority judgement mode processing. The first bit is VMM, and the second bit is JMM. Set according to the touch interface configuration. "1" : VMM "2" : JMM "3" : VMM and JMM

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 CC-RL C compiler listed in "section 2.3 Supported Toolchains". The code size varies according to C compile version and compile options.

Depending on the application and the number of elements, your program may exceed RAM size. Please note that RL78/G16 group has 2KB of RAM.

Using Renesas CC-RL Toolchain v1.15.01, the following is the size at compilation settings.
Only settings related to size are shown.

- CTSU_CFG_PARAM_CHECKING_ENABLE 0
- CTSU_CFG_DTC_SUPPORT_ENABLE 0
- CTSU_CFG_LOW_VOLTAGE_MODE 0
- CTSU_CFG_TEMP_CORRECTION_SUPPORT 0
- CTSU_CFG_CALIB_RTRIM_SUPPORT 0
- CTSU_CFG_MULTIPLE_ELECTRODE_CONNECTION_ENABLE 0

The size of the self-capacitance and the mutual-capacitance are shown in one element, and the size is increased by adding one element. It also includes qe_touch_config.c output by QE.

[CTSU1]

- CTSU_CFG_NUM_SUMULTI 1

Mode and element num	Self-capacitance 1 element	+ 1 element	Mutual-capacitance 1 element	+1 element
ROM	3951 bytes	+6 bytes	4228 bytes	+6 bytes
RAM	156 bytes	+24 bytes	174 bytes	+26 bytes

[CTSU2L] VMM

- CTSU_CFG_NUM_SUMULTI 3
- CTSU_CFG_MAJORITY_MODE 1

Mode and element num	Self-capacitance 1 element	+ 1 element	Mutual-capacitance 1 element	+1 element
ROM	6798 bytes	+30 bytes	7308 bytes	+27 bytes
RAM	376 bytes	+40 bytes	410 bytes	+62 bytes

[CTSU2L] JMM

- CTSU_CFG_NUM_SUMULTI 3
- CTSU_CFG_MAJORITY_MODE 2

Mode and element num	Self-capacitance 1 element	+ 1 element	Mutual-capacitance 1 element	+1 element
ROM	7029 bytes	+30 bytes	7515 bytes	+27 bytes
RAM	384 bytes	+48 bytes	426 bytes	+78 bytes

RENESAS

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 in r_ctsu_api.h along with the prototype declaration.

Table 2.1 shows ctsu_ctrl_t structure (control structure) for the touch interface configuration. Please refer to r_ctsu_qe.h to see more about the data type used in this structure. This structure manages measurement settings and results of each touch interface configuration. Using QE for Capacitive Touch 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.

Table 2.1 ctsu_ctrl_t Structure

Data Type	Member	Description
uint32_t	open	Open flag
volatile ctsu_state_t	state	Measurement state
ctsu_cap_t	cap	Measurement trigger
ctsu_md_t	md	Measurement mode
ctsu_tuning_t	tuning	Initial offset tuning flag
uint16_t	num_elements	Number of elements
uint16_t	wr_index	Index of CTSUWR interrupt
uint16_t	rd_index	Index of CTSURD interrupt
uint8_t *	p_element_complete_flag	Pointer to the flag indicating the completion of offset tuning for the element
int32_t *	p_tuning_diff	Pointer to the difference from the target value
uint16_t	average	Number of moving average operations
uint16_t	num_moving_average	Number of samples used for moving average operation
uint8_t	ctsucr1	CTSUCR1 setting
ctsu_ctsuwr_t *	p_ctsuwr	CTSUWR setting
ctsu_self_buf_t *	p_self_raw	Pointer to the self-capacitance raw value buffer
uint16_t *	p_self_corr	Pointer to the self-capacitance corrected value buffer
uint16_t *	p_self_mfc	Pointer to the self-capacitance multi-clock corrected value buffer
ctsu_data_t *	p_self_data	Pointer to the self-capacitance measurement value buffer
ctsu_mutual_buf_t *	p_mutual_raw	Pointer to the mutual-capacitance raw value buffer
uint16_t *	p_mutual_pri_corr	Pointer to the mutual-capacitance primary corrected value buffer
uint16_t *	p_mutual_snd_corr	Pointer to the mutual-capacitance secondary corrected value buffer
uint16_t *	p_mutual_pri_mfc	Pointer to the mutual-capacitance primary multi-clock corrected value buffer
uint16_t *	p_mutual_snd_mfc	Pointer to the mutual-capacitance secondary multi-clock corrected value buffer
ctsu_data_t *	p_mutual_pri_data	Pointer to the mutual-capacitance primary measurement value buffer
ctsu_data_t *	p_mutual_snd_data	Pointer to the mutual-capacitance secondary measurement value buffer
ctsu_correction_info_t *	p_correction_info	Pointer to the correction information
ctsu_txvsel_t	txvsel	TXVSEL setting
ctsu_txvsel2_t	txvsel2	TXVSEL2 setting
uint8_t	ctsuchac0	CHAC0 setting
uint8_t	ctsuchac1	CHAC1 setting
uint8_t	ctsuchac2	CHAC2 setting
uint8_t	ctsuchac3	CHAC3 setting

Data Type	Member	Description
uint8_t	ctsuchac4	CHAC4 setting
uint8_t	ctsuchtrc0	CHTRC0 setting
uint8_t	ctsuchtrc1	CHTRC1 setting
uint8_t	ctsuchtrc2	CHTRC2 setting
uint8_t	ctsuchtrc3	CHTRC3 setting
uint8_t	ctsuchtrc4	CHTRC4 setting
uint16_t	self_elem_index	Index of the self-capacitance element
uint16_t	mutual_elem_index	Index of the mutual-capacitance element
uint16_t	ctsu_elem_index	Element index
ctsu_cfg_t const *	p_ctsu_cfg	Pointer to the configuration structure
void	(* p_callback) (ctsu_callback_args_t *)	Pointer to the callback function
uint8_t	interrupt_reverse_flag	Flag for indicating reversal of the order of interrupts
ctsu_event_t	error_status	Error state
ctsu_callback_args_t *	p_callback_memory	Callback function stored (for TrustZone)
void const *	p_context	Context pointer
bool	serial_tuning_enable	Flag for enabling serial tuning
uint16_t	serial_tuning_mutual_cnt	Serial tuning
uint16_t	tuning_self_target_value	Target value for self-capacitance offset tuning
uint16_t	tuning_mutual_target_value	Target value for mutual-capacitance offset tuning
uint8_t	tsod	TSOD setting
uint8_t	mec_ts	TS pin number to be used for MEC
uint8_t	mec_shield_ts	TS pin number to be used for MEC shield
CTSU_CFG_DIAG_SUPPORT_ENABLE == 1		
ctsu_diag_info_t *	p_diag_info	Pointer to the diagnostic information
BSP_FEATURE_CTSU_VERSION == 2		
uint8_t *	p_frequency_complete_flag	Pointer to the flag for indicating the completion of offset tuning for a multi-clock scan
uint8_t *	p_selected_freq_self	Pointer to the selected frequency number (self-capacitance)
uint8_t *	p_selected_freq_mutual	Pointer to the selected frequency number (mutual-capacitance)
ctsu_range_t	range	Current range
uint8_t	ctsucr2	CTSUCR2 setting
(BSP_FEATURE_CTSU_VERSION == 2 && CTSU_CFG_AUTO_JUDGE_ENABLE == 1)		
ctsu_auto_judge_t *	p_auto_judge	Pointer to the automatic judgement information
uint32_t	address_auto_judge	Address of p_auto_judge
uint32_t	address_ctsuwr	Address of p_ctsuwr
uint32_t	address_self_raw	Address of p_self_raw
uint32_t	address_mutual_raw	Address of p_mutual_raw
uint32_t	count_auto_judge	Number of DTC transfers in automatic judgement
uint32_t	count_ctsuwr_self_mutual	Number of CTSUWR interrupts in automatic judgement
uint8_t	blini_flag	BLINI setting flag
uint8_t	ajmmat	AJMMAT setting
uint8_t	ajbmat	AJBMAT setting
(BSP_FEATURE_CTSU_VERSION == 2 && CTSU_CFG_AUTO_MULTI_CLOCK_CORRECTION_ENABLE == 1)		
uint32_t	p_mcact1	Pointer to MCACT1 settings
uint32_t	p_mcact2	Pointer to MCACT2 settings
uint8_t	mcact_flag	Automatic Frequency Correction Setting Flag

Table 2.2 shows the ctsu_cfg_t structure (configuration setting structure).

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(). The configuration value is assumed to be set by "Smart Configurator" or "QE for Capacitive Touch", and this software does not check for errors to improve processing efficiency. Be careful if you want to modify the configs manually.

Table 2.2 ctsu_cfg_t Structure

Data Type	Member Name	Description	Range of the Value
ctsu_cap_t	cap	Selects CTSU scan start trigger.	CTSU_CAP_SOFTWARE: software trigger. CTSU_CAP_EXTERNAL: external trigger.
ctsu_txvsel_t	txvsel	Selects the transmission power.	CTSU_TXVSEL_VCC: VCC is selected. CTSU_TXVSEL_INTERNAL_POWER: VDD is selected.
ctsu_txvsel2_t	txvsel2	Selects the transmission power 2. (only for CTSU2)	CTSU_TXVSEL_MODE: Power is selected by TXVSEL setting. CTSU_TXVSEL_VCC_PRIVATE: Dedicated VCC is selected.
ctsu_atune1_t	atune1	Adjusts the power capability. (only for CTSU)	CTSU_ATUNE1_NORMAL: Normal output CTSU_ATUNE1_HIGH: Large-current output
ctsu_atune12_t	atune12	Adjusts the power capability. (only for CTSU2)	CTSU_ATUNE12_80UA : 80uA mode CTSU_ATUNE12_40UA : 40uA mode CTSU_ATUNE12_20UA : 20uA mode CTSU_ATUNE12_160UA : 160uA mode
ctsu_md_t	md	Selects CTSU measurement mode.	CTSU_MODE_SELF_MULTI_SCAN: Self multi-scan mode CTSU_MODE_MUTUAL_FULL_SCAN: Mutual full-scan mode CTSU_MODE_MUTUAL_CFC_SCAN: Mutual simultaneous scan mode (only for CTSU2) CTSU_MODE_CURRENT_SCAN: Current-scan mode (only for CTSU2) CTSU_MODE_DIAGNOSIS_SCAN: Diagnosis scan mode
ctsu_posel_t	posel	Selects the output from non-measurement pins.	CTSU_POSEL_LOW_GPIO: Low level is output (GPIO). CTSU_POSEL_HI_Z: Hi-Z state CTSU_POSEL_LOW: Low level is output (TXVSEL or TXVSEL2 setting) CTSU_POSEL_SAME_PULSE: In-phase (transmission) pulses are output (TXVSEL or TXVSEL2 setting)
uint8_t	tsod	Selects measurement or fixed output from TS pins.	0: Electrostatic capacitance measurement mode 1: A fixed level (high or low) is output from TS pins.
uint8_t	mec_ts	TS pin number to be used for MEC function	0 to 35
uint8_t	mec_shield_ts	TS pin number of the active shield to be used for MEC function	0 to 35
uint8_t	tlot	Number of consecutive judgements of a value exceeding the low threshold in automatic judgement	0 to 255
uint8_t	thot	Number of consecutive judgements of a value exceeding the high threshold in automatic judgement	0 to 255

Data Type	Member Name	Description	Range of the Value
uint8_t	jc	Criteria for automatic judgement	0: Touch-ON is detected when the result of judgement is that the high threshold has been exceeded once. 1: Touch-ON is detected when the result of judgement is that the high threshold has been exceeded twice. 2: Touch-ON is detected when the result of judgement is that the high threshold has been exceeded three times. 3: Touch-ON is detected when the result of judgement is that the high threshold has been exceeded four times.
uint8_t	ajmmat	Number of moving average operations for the measurement values in automatic judgement	0 to 11 (2^ set value)
uint8_t	ajbmat	Number of average calculations for the baseline values in automatic judgement	0 to 15 (2^ (set value + 1). 0 indicates that updating of the baseline value is stopped.)
uint8_t	mtucfen	Calculation of mutual-capacitance in automatic judgement	0: No subtraction 1: The first measurement value is subtracted from the second measurement value.
uint8_t	ajfen	Enables or disables automatic judgement.	0: Automatic judgement is disabled. 1: Automatic judgement is enabled.
uint8_t	autojudge_monitor_num	QE monitoring configuration number for automatic judgement	0 to 7
uint8_t	ctsuchac0	Mask for enabling TS00 to TS07	0x00 to 0xFF
uint8_t	ctsuchac1	Mask for enabling TS08 to TS15	0x00 to 0xFF
uint8_t	ctsuchac2	Mask for enabling TS16 to TS23	0x00 to 0xFF
uint8_t	ctsuchac3	Mask for enabling TS24 to TS31	0x00 to 0xFF
uint8_t	ctsuchac4	Mask for enabling TS32 to TS35	0x00 to 0xFF
uint8_t	ctsuchtrc0	Mask for mutual-capacitance transmission TS00 to TS07	0x00 to 0xFF
uint8_t	ctsuchtrc1	Mask for mutual-capacitance transmission TS08 to TS15	0x00 to 0xFF
uint8_t	ctsuchtrc2	Mask for mutual-capacitance transmission TS16 to TS23	0x00 to 0xFF
uint8_t	ctsuchtrc3	Mask for mutual-capacitance transmission TS24 to TS31	0x00 to 0xFF
uint8_t	ctsuchtrc4	Mask for mutual-capacitance transmission TS32 to TS35	0x00 to 0xFF
ctsu_element_cfg_t *	p_elements	Element configuration pointer	—
uint8_t	num_rx	Number of receiving pins	0 to 36
uint8_t	num_tx	Number of transmitting pins	0 to 36
uint16_t	num_moving_average	Number of moving average operations for measured data	0 to 65535
bool	tunning_enable	Initial offset tuning flag	true: Enable false: Disable
void *	p_callback	CTSUFN interrupt callback	—

Data Type	Member Name	Description	Range of the Value
void *	p_context	Context pointer	—
void *	p_extend	Extended configuration pointer	—
uint16_t	tuning_self_target_value	Target value of self-capacitance initial offset	0 to 65535
uint16_t	tuning_mutual_target_value	Target value of mutual-capacitance initial offset	0 to 65535
ctsu_auto_button_cfg_t *	p_ctsu_auto_buttons	Pointer to the array of button settings for use in automatic judgement	—

The following 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;

/** 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;

/** 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;

/** Configration of each automatic judgement button */
typedef struct st_ctsu_auto_button_cfg
{
    uint8_t  elem_index;             ///< Element number used by this button fo automatic judgement.
    uint16_t threshold;              ///< Touch/non-touch judgement threshold for automatic judgement.
    uint16_t hysteresis;             ///< Threshold hysteresis for chattering prevention for
                                         automatic judgement.
} ctsu_auto_button_cfg_t;
```

2.10   Return Values

The following provides return values for the API functions. The enum is defined in fsp_common_api.h, along with the API function prototype declaration.

```
/** 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 is 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 not yet.
    FSP ERR CTSU DIAG LDO OVER VOLTAGE = 6004, ///< Diagnosis of Output Voltage failed.
    FSP ERR CTSU DIAG CCO HIGH      = 6005,   ///< Diagnosis of CCO High failed.
    FSP_ERR_CTSU_DIAG_CCO_LOW       = 6006,   ///< Diagnosis of CCO Low failed.
    FSP ERR CTSU DIAG SSCG          = 6007,   ///< Diagnosis of SSCG Oscillator failed.
    FSP ERR CTSU DIAG DAC           = 6008,   ///< Diagnosis of Sensor Offset failed.
    FSP ERR CTSU DIAG OUTPUT VOLTAGE = 6009,  ///< Diagnosis of Output Voltage failed.
    FSP ERR CTSU DIAG OVER VOLTAGE  = 6010,   ///< Diagnosis of Over Voltage Detection
                                                failed.
    FSP ERR CTSU DIAG OVER CURRENT  = 6011,   ///< Diagnosis of Over Current Detection
                                                failed.
    FSP ERR CTSU DIAG LOAD RESISTANCE = 6012, ///< Diagnosis of Load Resistance failed.
    FSP ERR CTSU DIAG CURRENT SOURCE = 6013,  ///< Diagnosis of Current Offset failed.
    FSP ERR CTSU DIAG SENSCLK GAIN  = 6014,   ///< Diagnosis of SENSCLK Frequency failed.
    FSP ERR CTSU DIAG SUCLK GAIN    = 6015,   ///< Diagnosis of SUCLK Frequency failed.
    FSP ERR CTSU DIAG CLOCK RECOVERY = 6016,  ///< Diagnosis of SUCLK Clock Recovery failed.
    FSP ERR CTSU DIAG CFC GAIN      = 6017,   ///< Diagnosis of CFC oscillator failed.
} fsp_err_t;
```

2.11   Callback function

This module calls the registered callback function when the processing of the measurement completion interrupt is completed. Set it to the member p_callback of the config structure. It has already been set in the output code of QE. It can also be set with R_CTSU_CallbackSet (). Please refer to 0.

The callback function should be provided by the application. When the tuning result is output using QE, the sample code of the callback function below is also output. The output function changes depending on the software judgement and the automatic judgement. If both configurations are present, both are output.

Software Judgement

```
void qe_touch_callback(touch_callback_args_t * p_args)
{
    g_qe_touch_flag = 1;
    g_qe_ctsu_event = p_args -> event;
}
```

Automatic Judgement

```
void qe_ctsu_auto_callback(ctsu_callback_args_t * p_args)
{
    g_qe_touch_flag = 1;
    g_qe_ctsu_event = p_args -> event;
}
```

As shown below, it is assumed that g_qe_touch_flag is polled between R_CTSU_ScanStart() and R_CTSU_DataGet().

```
R_CTSU_ScanStart(g_qe_ctsu_instance.p_ctrl);

while (0 == g_qe_touch_flag) {}
g_qe_touch_flag = 0;

R_CTSU_DataGet(g_qe_ctsu_instance.p_ctrl, &data);
```

For information about the arguments of the callback function, see the ctsu_callback_arg_t in 2.9. touch_call_back_arg_t is a typedef of ctsu_callback_args_t in Touch module. As explained in 1.5.6, you can check whether there is an error in the measurement by using the structure member event.

2.12   API Processing Time

This section provides reference values for API processing time.

The conditions under which the processing time was measured are shown below:

- **Compiler**   : Renesas CC-RL v1.15.01
- **Compiler optimization option**   : -Odefault
- **Main clock**   : 32 MHz

The API processing time for the basic-operation model is shown below.

For example, the table below shows the processing time for each API when measuring a single element in Self-capacitance Measurement Mode. Note that for R_CTSU_Open(), initialization operations such as reset processing are performed, including the creation of CCO correction coefficient table, so the processing time is relatively long.

Table 2.3 API Processing Time in Basic-Operation Mode

Function Name	Processing Time (µs)
R_CTSU_Open（1st）	104576
R_CTSU_Open（2nd and later）	49
R_CTSU_ScanStart	7
R_CTSU_DataGet	89

The API processing time when using diagnosis mode is shown below. R_CTSU_Open() is the same as in the basic-operation model.

In diagnosis mode, since the processing time differs between the first measurement and subsequent measurements, check both R_CTSU_ScanStart() and R_CTSU_DataGet() processing times. Since the diagnosis of Output Voltage does not use the R_CTSU_DataGet function, it is excluded from the measurement. In addition, the diagnosis item in Table 2.5   correspond to those in Table 1.2.

Table 2.4 API Processing Time During Execution in Diagnosis Mode

Function Name	Processing Time (µs)
R_CTSU_Diagnosis	1

Table 2.5 API Processing Time During Execution in Diagnosis Mode

Diagnosis Item	R_CTSU_ScanStart	R_CTSU_DataGet
Output Voltage Diagnosis	434	
Over Voltage Detection Diagnosis	12	7
Over Current Detection Diagnosis	12	7
Load Resistance Diagnosis	13	31
Sensor Offset Diagnosis	13	26
SENSCLK Frequency Diagnosis	13	7
SUCLK Frequency Diagnosis	13	7
SUCLK Clock Recovery Diagnosis	14	7

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 configuration.

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

Parameters

p_ctrl   [in] Pointer to the control structure
p_cfg   [in] Pointer to the config structure

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 100ms.
DTC is initialized if CTSU_CFG_DTC_SUPPORT_ENABLE 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.
When the touch interface configuration is in diagnosis mode, execute the R_CTSU_Open () of the other touch interface configuration first.

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   [in] Pointer to the control structure

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_DTC_SUPPORT_ENABLE is enabled, the function also sets 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   [in] Pointer to the control structure

p_data   [out] 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 */*
FSP_ERR_CTSU_DIAG_NOT_YET	*/* The collection of diagnostic data has not been completed */*

Properties
Prototype is declared in r_ctsu_api.h.

Description
This function reads all previously corrected measured values into the specified buffer(p_data).
   CTSU1: The value passed through sensor CCO correction and moving average.
   CTSU2L JMM: The value passed through sensor CCO correction and moving average.
   CTSU2L VMM: Sensor passed through sensor CCO correction, frequency correction and moving average.
The required buffer size varies depending on the measurement mode. Prepare the number of TS for the self-capacitance measurement and current measurement modes, and twice the number of matrixes for the mutual-capacitance measurement mode. In the case of CTSU2 JMM, data of 3 frequencies is stored, so prepare 3 times more.
In diagnosis mode, if data collection has not been completed, the function returns FSP_ERR_CTSU_DIAG_NOT_YET. If data collection is completed, it will return FSP_SUCCESS, so please call R_CTSU_Diagnosis() to check the diagnosis result. In addition, if an error occurs in ADC measurement during the output-voltage diagnosis, the function returns FSP_ERR_ABORTED.

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   [in] Pointer to the control structure

p_callback   [in] Pointer to callback function

p_context   [in] Pointer to send to callback function

p_callback_memory   [in] 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　　　　　[in] Pointer to the control structure

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:

When using this API together with the diagnosis mode, please note the following:

・ Do not call this API between executing R_CTSU_ScanStart() and calling R_CTSU_DataGet().

3.6   R_CTSU_Diagnosis

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

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

Parameters

p_ctrl   [in] Pointer to the control structure

Return Values

FSP_SUCCESS	*/* All diagnoses are success */*
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 Output Voltage failed */*
FSP_ERR_CTSU_DIAG_CCO_HIGH	*/* Diagnosis of CCO High failed */*
FSP_ERR_CTSU_DIAG_CCO_LOW	*/* Diagnosis of CCO Low failed */*
FSP_ERR_CTSU_DIAG_SSCG	*/* Diagnosis of SSCG Oscillator failed */*
FSP_ERR_CTSU_DIAG_DAC	*/* Diagnosis of Sensor Offset failed */*
FSP_ERR_CTSU_DIAG_OUTPUT_VOLTAGE	*/* Diagnosis of Output Voltage failed */*
FSP_ERR_CTSU_DIAG_OVER_VOLTAGE	*/* Diagnosis of Over Voltage Detection failed */*
FSP_ERR_CTSU_DIAG_OVER_CURRENT	*/* Diagnosis of Over Current Detection failed */*
FSP_ERR_CTSU_DIAG_LOAD_RESISTANCE	*/* Diagnosis of Load Resistance failed */*
FSP_ERR_CTSU_DIAG_CURRENT_SOURCE	*/* Diagnosis of Current Offset failed */*
FSP_ERR_CTSU_DIAG_SENSCLK_GAIN	*/* Diagnosis of SENSCLK Frequency failed */*
FSP_ERR_CTSU_DIAG_SUCLK_GAIN	*/* Diagnosis of SUCLK Frequency failed */*
FSP_ERR_CTSU_DIAG_CLOCK_RECOVERY	*/* Diagnosis of SUCLK Clock Recovery failed */*

Properties

Prototyped in file r_ctsu_api.h

Description

This is the API function providing the function for diagnosis of CTSU inner circuit. Please call the function when the return value of R_CTSU_DataGet is FSP_SUCCESS. If an abnormality is detected in any of the diagnosis items, the corresponding diagnosis error is returned. If all diagnosis is complete normally, FSP_SUCCESS is returned

Example:
```
/* For CTSU1 */
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 succeed. */
    }
}
```

```
/* For CTSU2 */
void R_CTSU_PinSetInit(void);
void qe_touch_main(void);
uint16_t dummyD;

void qe_touch_main(void)
{
    fsp_err_t err;
    uint8_t initial_diag_flag = 0;

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

    /* Open Touch middleware */
    err = RM_TOUCH_Open(g_qe_touch_instance_config01.p_ctrl, g_qe_touch_instance_config01.p_cfg);

    /* Open CTSU driver for [Diagnosis] */
    err = R_CTSU_Open(g_qe_ctsu_instance_diagnosis.p_ctrl, g_qe_ctsu_instance_diagnosis.p_cfg);

    /* Initial Diagnosis loop */
    while (0 == initial_diag_flag)
    {
        /* for [Diagnosis] configuration */
        err = 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)
        {
            err = R_CTSU_Diagnosis(g_qe_ctsu_instance_diagnosis.p_ctrl);
            if (FSP_SUCCESS == err)
            {
                initial_diag_flag = 1;
            } else {
                while(1);
            }
        }
    }

    /* Main loop */
    while (true)
    {
        /* for [CONFIG01] configuration */
        err = RM_TOUCH_ScanStart(g_qe_touch_instance_config01.p_ctrl);
        while (0 == g_qe_touch_flag) {}
        g_qe_touch_flag = 0;

        err = RM_TOUCH_DataGet(g_qe_touch_instance_config01.p_ctrl, &button_status, NULL, NULL);

        /* for [Diagnosis] configuration */
        err = 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)
        {
            err = R_CTSU_Diagnosis(g_qe_ctsu_instance_diagnosis.p_ctrl);
            if (FSP_SUCCESS != err)
            {
                while(1);
            }
        }

        /* FIXME: Since this is a temporary process, so re-create a waiting process yourself. */
        R_BSP_SoftwareDelay(TOUCH_SCAN_INTERVAL_EXAMPLE, BSP_DELAY_MILLISECS);
    }
}
```

Special Notes:
   None.

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   [in] Pointer to the control structure

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.

Example:
```
fsp_err_t err;

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

Special Notes:

When using this API together with the diagnosis mode, please note the following:

・ Do not call this API between executing R_CTSU_ScanStart() and calling R_CTSU_DataGet().

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   [in] Pointer to the control structure
p_specific_data   [out] Pointer to specific data array.
specific_data_type   [in] 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   /* Specify unsupported types */

Properties

Prototype is declared in r_ctsu_api.h.

Description

When CTSU_SPECIFIC_RAW_DATA is set to specific_data_type, the measurement value is stored in p_specific_data. Prepare a buffer that is the number of elements multiplied by the number of elements in CTSU1 and the number of elements multiplied by the number of frequencies in CTSU2.
When CTSU_SPECIFIC_CCO_CORRECTION_DATA is set to specific_data_type, the sensor CCO correction data is stored in p_specific_data. Prepare a buffer that is the number of elements multiplied by the number of elements in CTSU1 and the number of elements multiplied by the number of fequencies in CTSU2.
When CTSU_SPECIFIC_CORRECTION_DATA is set to specific_data_type, the p_specific_data stores multi-clock correction data. Only VMM of CTSU2 is valid. Prepare a buffer for the elements.
When CTSU_SPECIFIC_SELECTED_FREQ is set specific_data_type, p_specific_data contains a bitmap of the frequencies used in the majority vote. The first frequency corresponds to bit 0, the second frequency corresponds to bit 1, and the third frequency corresponds to bit 2. For example, if the first and third frequencies were used, store the 0x05. Only VMM of CTSU2 is valid.

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_RAW_DATA );
```

Special Notes:

When the specific_data_type is set to something other than CTSU_SPECIFIC_RAW_DATA, execute this API after calling R_CTSU_DataGet().

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   [in] Pointer to the control structure

p_insert_data   [in] 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. The data is stored in the corrected measurement buffer. (p_ctrl->p_self_data for Self-capacitance Measurement Mode, p_ctrl->p_mutual_pri_data and p_crtl->p_mutual_snd_data for mutual-capacitance)

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   [in] Pointer to the control structure

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	*/* Initial offset tuning in progress */*

Properties

Prototype is declared in r_ctsu_api.h.

Description

This function adjusts the offset using all the previously corrected 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 Chapter 1.5.4 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   [in] Pointer to the control structure
p_button_status   [out] 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   /* Called without calling Open() */
FSP_ERR_CTSU_SCANNING   /* Scanning this instance */
FSP_ERR_INVALID_MODE   /* The mode of automatic judgement off is invalid */

Properties
Prototype 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 average calculation.

Example:
```
fsp_err_t err;
uint64_t button_status;

/* Open CTSU Driver  */
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, &button_status);
}
```

Special Notes:
This function is only supported by CTSU2SLa.

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3.12   R_CTSU_SmsSet

This function configures the settings required to perform automatic judgement measurement using SMS for the specified touch interface.

Format
```
fsp_err_t R_CTSU_SmsSet (ctsu_ctrl_t * const p_ctrl,
                         uint16_t * p_threshold,
                         uint16_t * p_hysteresis,
                         uint16_t count_filter)
```

Parameters

p_ctrl : [in] Pointer to the control structure

p_threshold : [in] Pointer to the touch-judgement threshold value

p_hysteresis : [in] Pointer to the touch-judgement hysteresis value

count_filter : [in] Touch-count matching filter value (upper 8 bits for OFF, lower 8 bits for ON)

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 configures the following settings. The function uses the argument settings for touch-judgement processing.

- Disable CTSUFN interrupt

- Enable SMS module

- SMS configuration

- ELCL configuration (when using RL78/G23 Group or RL78/L23 Group)

- ELC configuration (when using RL78/G22 Group)

- Start SMS

To start automatic judgement measurement, call R_CTSU_ScanStart() for the same touch interface after calling this function. When a touch-ON judgement occurs, INTSMSE is generated, and CTSU module interrupt handler performs the following operations:
- Set the measurement status into the callback function argument
- Store the measurement value into variables
- Call the callback function
- Enable CTSUFN interrupt
Disable SMS module

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Example:

```
fsp_err_t err;
uint16_t threshold[3] = {1000, 1500, 2000};
uint16_t hysteresis[3] = {50, 75, 100};
uint16_t buf[3];

    /* Start SMS measurement */
    err = R_CTSU_SmsSet(&g_ctsu_ctrl, threshold, hysteresis[3], 0x0303);
    err = R_CTSU_ScanStart(&g_ctsu_ctrl);
    __stop();


    err = R_CTSU_DataGet(&g_ctsu_ctrl, buf);
```

Special Notes:

If it is called while the touch state is ON, the baseline will be set in the touch-ON state, and touch detection will not be possible until the baseline is updated by the baseline-drift function.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Apr.13.21	-	First edition issued
1.10	Aug.31.21	5	Added 1.1.9 Diagnosis Function
		5	Added 1.1.10 Automatic judgement measurement using SMS
		8	Added 1.2.5 Diagnosis Mode
		9	Updated 1.4 API overview
		11	Updated 2.7 Compilation settings
		13	Updated 2.8 Code size
		13	Updated 2.9 Arguments
		16	Updated 2.10 Return Values
		-	Deleted R_CTSU_VersionGet
		24	Added 3.5 R_CTSU_SmsSet
		27	Added 3.7 R_CTSU_Diagnosis
		29	Added 3.8 R_CTSU_ScanStop
1.11	Jan.18.22	3,4	Added 1.1.4 Initial offset adjustment
		5	Added 1.1.6 multi-measurement frequency (CTSU2L)
		9	Updated 1.4 API overview
		10	Updated 2.2 Software Requirements
			Updated 2.3 Supported Toolchains
		13	Updated 2.8 Code size
		13-14	Updated 2.9 Arguments
		30-31	Added 3.8 R_CTSU_SpecificDataGet
		31-32	Added 3.9 R_CTSU_DataInsert
1.20	Apr.20.22	6	Added 1.1.10 Automatic judgement measurement using SMS
		4,5	Fixed PCLKB to f_{CLK}
		9	Updated 1.4 API overview
		10	Update 2.2 Software Requirement
			Update 2.3 Supported Toolchain
		33	Added 3.11 R_CTSU_OffsetTuning
		24	Fixed Example: in 3.5 R_CTSU_SmsSet
1.30	Feb.14.23	1	Added RL78/G22 to Target Device
		6	Updated 1.5.11 Automatic judgement measurement using SMS (RL78/G22, RL78/G23, RL78/L23)
		7	Added 1.5.7 Shield Function (CTSU2L)
		12	Updated 2.2 Software Requirements
		12	Updated 2.3 Supported Toolchains
		13,14	Updated 2.7 Compilation Settings
		13	Updated 2.8 Code Size
		15,16	Updated 2.9 Arguments
		18	Updated 2.10 Return Values
		24	Updated 3.12 R_CTSU_SmsSet
1.40	Jun.14.23	1	Added RL78/G16 group to Target Device
		3	Added CTSU description to 1 Overview.
		3	Updated Measurements and Obtaining Data
		4	Added CTSU1 function description to 1.5.4 Initial Offset Adustment
		4	Added 1.5.1 Random Pulse Frequency Measurement (CTSU1)
		7	Added CTSU1 function description to 1.5.9 Diagnosis Function

RENESAS

		10,11	Added CTSU1 function description to 1.4 Measurement Mode
		14	Updated 2.1 Hardware Requirements
		14	Updated 2.2 Software Requirements
		14	Updated 2.4 Restrictions
		18	Updated 2.8 Code Size
		18	Updated 2.9 Arguments
		31	Updated 0 R_CTSU_Diagnosis
1.50	May.31.24	4	Updated 1.5.4 Initial offset adjustment
		6	Updated 1.5.2 multi-measurement frequency (CTSU2L)
		8	Updated 1.5.8 Multiple Electrode Connection (MEC) Function (CTSUb, CTSU2La)
		14	Updated 2.2 Software Requirements
		14	Updated 2.3 Supported Toolchains
		18	Updated 2.7 Compilation Settings
		18	Updated 2.8 Code Size
		29	Updated 3.12 R_CTSU_SmsSet
2.00	Oct.15.24	-	Changed "ICO" to "CCO" (applied to all documents)
		6	Added majority measurement (JMM/VMM) to 1.1.1
		29	Updated 2.2 Software Requirements
		29	Updated 2.3 Supported Toolchains
		31	Updated 2.7 Compilation Settings
		34	Updated 2.8 Code Size
		35	Updated 2.9 Arguments
		46	Updated description of 0 R_CTSU_DataGet
		52	Updated description of 0 R_CTSU_SpecificDataGet
2.10	Feb.19.25	16	Updated 1.5.1 Random Pulse Frequency Measurement (CTSU1)
		8	Updated 1.5.8 Multiple Electrode Connection (MEC) Function (CTSUb, CTSU2La)
		29	Updated 2.2 Software Requirements
		29	Updated 2.3 Supported Toolchains
		31	Updated 2.7 Compilation Settings
		34	Updated 2.8 Code Size
		35	Updated 2.9 Arguments
2.20	Jul.31.25	1	Added RL78/F25, RL78/F22, RL78/L23 to Target Device
		3	Added description to 1 Overview
		21	Added 1.5.9 Automatic CCO Correction (CTSU2SLa)Automatic CCO Correction (CTSU2SLa)
		21	Added 1.5.10 Automatic Frequency Correction (CTSU2SLa)Automatic Frequency Correction (CTSU2SLa)
		22	Added 1.5.11 Automatic judgement measurement using SMS (RL78/G22, RL78/G23, RL78/L23)
		28	Added description to API Overview
		29	Updated 2.2 Software Requirements
		29	Updated 2.3 Supported Toolchains
		31	Updated 2.7 Compilation Settings
		34	Updated 2.8 Code Size
		35	Updated 2.9 Arguments
		42	Added 2.11 Callback function
		44-54	Added input and output information to API function arguments.
		55	Added R_CTSU_AutoJudgementDataGet

2.30	Mar.24.26	3	Added 1.1 What is CTSU module
		3	Added 1.2 Position of CTSU module
		4	Added 1.3 How to use CTSU module
		28	Moved 1.7 API Overview
		8	Added 1.4.4 Automatic Judgement Mode (CTSU2SLa)
		12	Added 1.4.5 Diagnosis Mode
		16	Reorganized and reordered 1.5 Functions
		10	Added 1.6 Cooperation with other SIS modules
		-	Deleted the chapter on Temperature Compensation Mode (CTSU2L)
		29	Updated 2.2 Software Requirements
		29	Updated 2.3 Supported Toolchains
		34	Updated 2.8 Code Size
		22	Added 2.12 API Processing Time
		-	Deleted the chapter on IEC60730 compliance
		46	Added explanation of 3.3 R_CTSU_DataGet
		49	Added explanation of 3.6 R_CTSU_Diagnosis

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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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