Capacitive Sensor MCU

QE for Capacitive Touch Advanced Mode Parameter Guide

Introduction

This application note describes advanced mode and adjustable CTSU parameters using the Capacitive Touch Sensor Support Tool (QE for Capacitive Touch).

QE for Capacitive Touch is a tool that generates tuning data which is used by Renesas MCU which have the CTSU peripheral (Capacitive Touch Sensing Unit).

By default, QE for Capacitive Touch generates tuning data via “Auto Tuning” mode. However, to optimize touch performance and to mitigate unwanted behavior from environmental effects such as electrical noise, QE for Capacitive Touch supports an “Advanced mode” Tuning.

This application note describes "Advanced mode” Tuning and the CTSU parameters which can be adjusted.

If you are developing a Capacitive Touch for the first time, it is recommended that you read the Capacitive Touch Introduction Guide beforehand.

Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)

Target Device

CTSU mounted RX family, RA family, RL78 family MCU, Renesas Synergy ™

(CTSU includes CTSU2, CTSU2L, CTSU2La, CTSU2SL, CTSU2SLa, etc.)

In addition, refer to CTSU2x for CTSU2L/CTSU2La/CTSU2SL/CTSU2SLa after the next page.

Auto judgement using Value Majority Mode (VMM) of CTSU2SLa will be supported in future updates.

Development environment covered in this document

· Renesas e2 studio Integrated Development Environment (IDE) 2024-07 or later
· Renesas QE for Capacitive Touch V4.0.0 or later

Contents

1. Outline

This chapter describes the flow of parameter generation using QE for Capacitive Touch and the parameters that can be adjusted in tuning.

QE for Capacitive Touch measures the parasitic capacitance of the user's touch sensor and performs auto-tuning to optimize the parameters. For more information about QE for Capacitive Touch, see Web page below.

Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)

Auto judgement using Value Majority Mode (VMM) will be supported in future updates.

Auto tuning with QE for Capacitive Touch generates basic CapTouch parameters. If the required specifications are not met in evaluations using these parameters, perform manual tuning with CapTouch parameters. If further adjustment is required, perform “Advanced mode” Tuning. Figure 1-1 shows the tuning procedure in QE for Capacitive Touch.

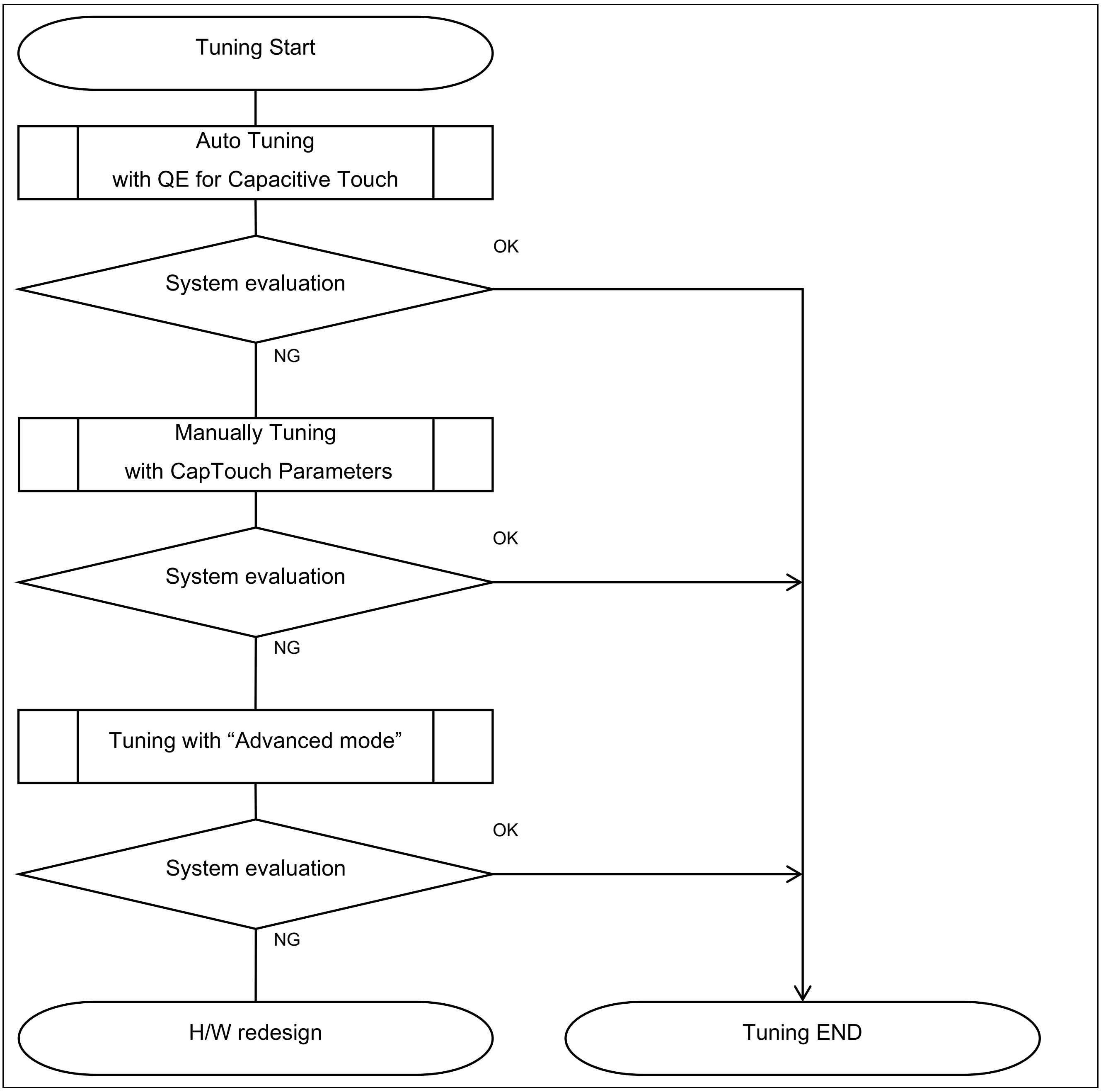


Figure 1-1 Tuning Flowchart

Table 1-1 lists the parameters that can be adjusted with Auto Tuning /Manual tuning with CapTouch parameters "Advanced mode" Tuning.

Table 1-1 Tuning-adjustable parameters

Parameter	Auto tuning	Manually tuning with CapTouch parameters	Tuning with “Advanced mode”
Measurement frequency	✓	-	✓
Offset	✓	(Display only)	-
Touch Threshold	✓	✓	-
Hysteresis	✓	✓	-
Drift Correction Interval	-	✓	-
Long Touch Cancel Judgement Count	-	✓	-
Positive Noise Filter Judgement Count	-	✓	-
Negative Noise Filter Judgement Count	-	✓	-
Moving Average Filter Depth	-	✓	-
Number of Measurements/Number of Time	-	-	✓
Target value of Offset Tuning	-	-	✓
Measured Current Range [*1]	-	-	✓
Non-Measured TS Terminal Output Select[*1]	-	-	✓
Transmit Terminal Power	-	-	✓
Judgement Type [*1]	–	–	✓
Multi-Frequency Scan/Multiplier Rate[*1]	-	-	✓
Auto Judgement/SMS [*2]	–	–	(Display only)
Automatic Interpolation (Hardware)[*3]	–	–	(Display only)
Automatic Multi-Frequency Correction (Hardware) [*3]	–	–	(Display only)
Low Voltage Operating Mode[*1]	✓[*4]	–	✓[*4]

✓: Supported

Note1: This function can be adjusted only CTSU2/CTSU2L/CTSU2La/CTSU2SL/CTSU2SLa. Refer to the Capacitance Touch Introduction Guide for the difference of each Capacitance Touch Sensor and corresponding products.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)
Note2: This function can be used only CTSU2L/CTSU2La/CTSU2SL/CTSU2SLa. SNOOZE-mode programmable controller (SMS) can be used together with SMS if it is a built-in MCU. It can be set from the Smart Configurator/Touch Interface configuration and is only displayed in Advanced mode. Refer to "Auto Judgement" for "Auto Judgement /SMS" on the following pages.
Auto judgement using Value Majority Mode (VMM) will be supported in future updates.
Note3: This function can be used only CTSU2SL/CTSU2SLa. It cannot be changed by the user because it is automatically set according to the touch Judgement method or Auto Judgement setting.
Note4: When the setting of the microcomputer operation voltage is less than 2.4V, Low Voltage Operating Mode is automatically enabled. Even in 2.4V or higher, Low Voltage Operating Mode can be enabled in advanced mode.

Auto Tune automatically adjusts the parameters using QE for Capacitive Touch, and outputs the adjusted parameters to the source file. For manual tuning of CapTouch parameters, those settings that can be changed using the "CapTouch Parameter List" in QE for Capacitive Touch are shown. For more information, refer to "Manually Tuning 7.2 Manually Tuning with CapTouch Parameters" in the document below.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)
If the manual tuning of auto tuning or CapTouch parameters does not meet the user's requirements for sensitivity/noise immunity, you can adjust the parameters in Advanced Mode.

1.1 Auto tuning

Figure 1-2 shows the flow of Auto tuning.

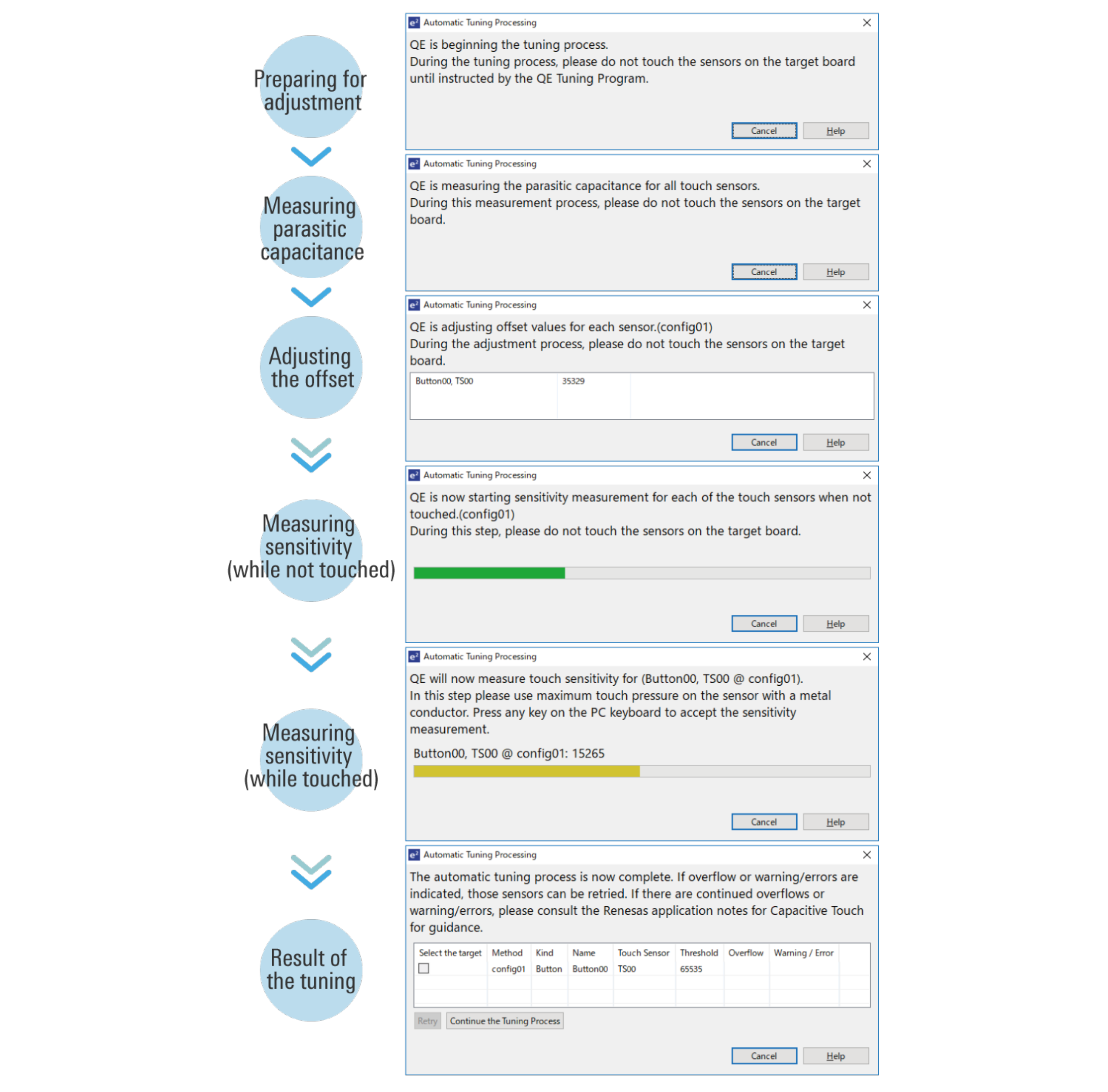


Figure 1-2 Flow of Auto tuning with QE for Capacitive Touch

Auto tuning adjusts the sensitivity of touch sensor detection to determine the optimal parameters.
First, the capacitance at touch OFF is measured, and the measurement frequency is set according to the measurement result. Also, adjust the offset according to the target value of offset tuning. Then, the capacitance of the touch ON/OFF status is measured, touch thresholds, etc. are set, and the tuning result is output to the source file.

1.2 Manual tuning with CapTouch parameters

For Manual tuning with CapTouch parameters, software parameters can be changed from "CapTouch Parameters (QE)". The touch behavior and the effect of changing the parameter values can be viewed in real time.

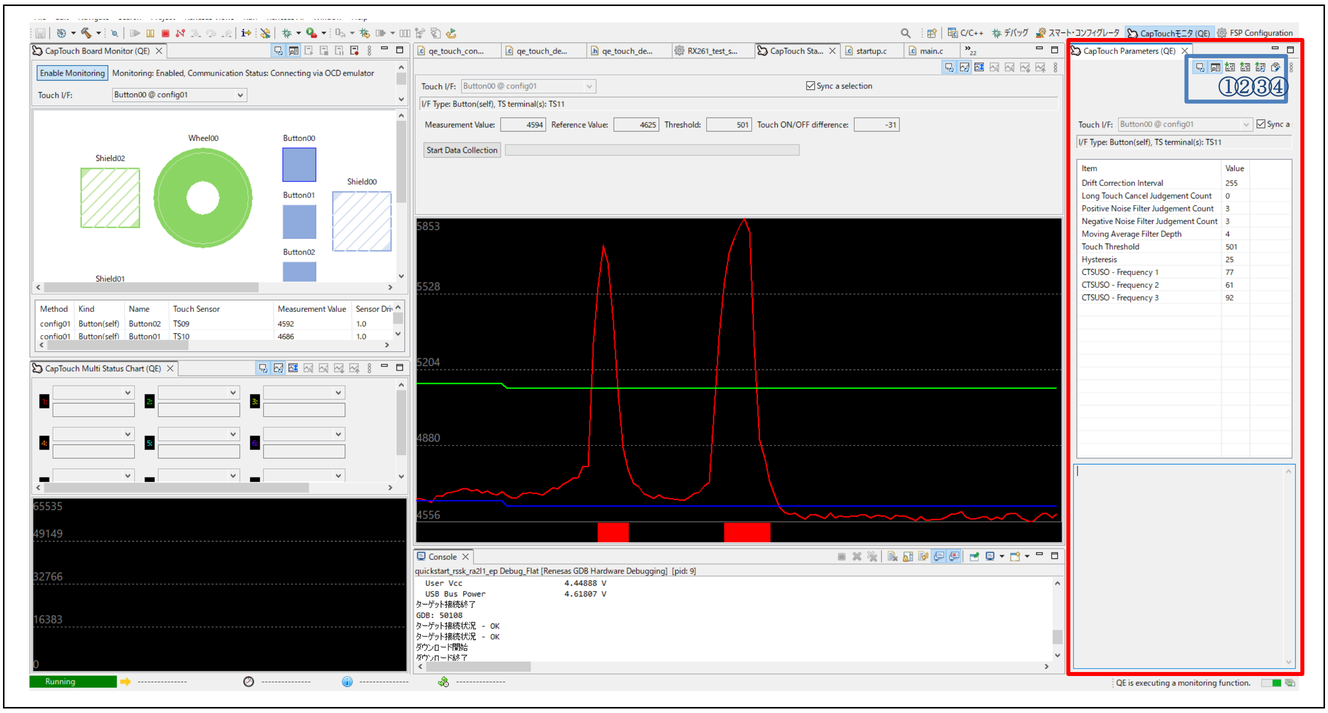


Figure 1-3 Manual Tuning with QE for Capacitive Touch

For Manual tuning , use the "CapTouch Parameters (QE)" in QE for Capacitive Touch (in red box in Figure 1-3).You can change the parameter and check the operation after adjusting it from the "CapTouch Status Chart (QE)" in real time. Parameters adjusted in this view can also be reflected in the source file. Refer to Table 1-2 for explanations of the functions of the "CapTouch Parameters (QE)" tool bar (in the blue frame in Figure 1-3) used when performing manual tuning. Parameters can be read and written to the application via the CapTouch Parameter icons.

Table 1-2 "CapTouch Parameters (QE)" tool bar function.

		Icon Description	Feature Overview
①		Read from target board	Reads parameter values from the target board.
②		Write to target board	Write the value of the edited parameter to the target board.
③		Write to target board in real time	Toggle button to switch whether the numerical value of the parameter is reflected to the target in real time.
④		Generate a parameter file	The parameter file is output based on the parameter information adjusted in this view.

"Generate parameter file" outputs the source file under the qe_gen folder. Table 1-3 shows the output source file. After outputting the source file, the operation of adjusted parameters can be checked by building and debugging.

Table 1-3 Source file output by "Generating a Parameter File"

File name	Description
qe_touch_config.c	File that holds parameter settings for each configuration (method)

Please refer to the QE for Capacitive Touch “Help” for details.

1.3 “Advanced mode” Tuning

In the “Advanced mode” Tuning, it is possible to adjust mainly hardware parameters such as the sensor drive pulse output for measuring capacitance. For details on the parameters that can be adjusted, please refer to the table below 2.3 Correspondence table for each capacitive touch sensor.

Figure 1-4 shows the Cap Touch workflow (QE). Tuning can be performed from "2. Tuning Touch Sensors”. Tuning by checking the “Advanced mode" checkbox under "Start Tuning”.

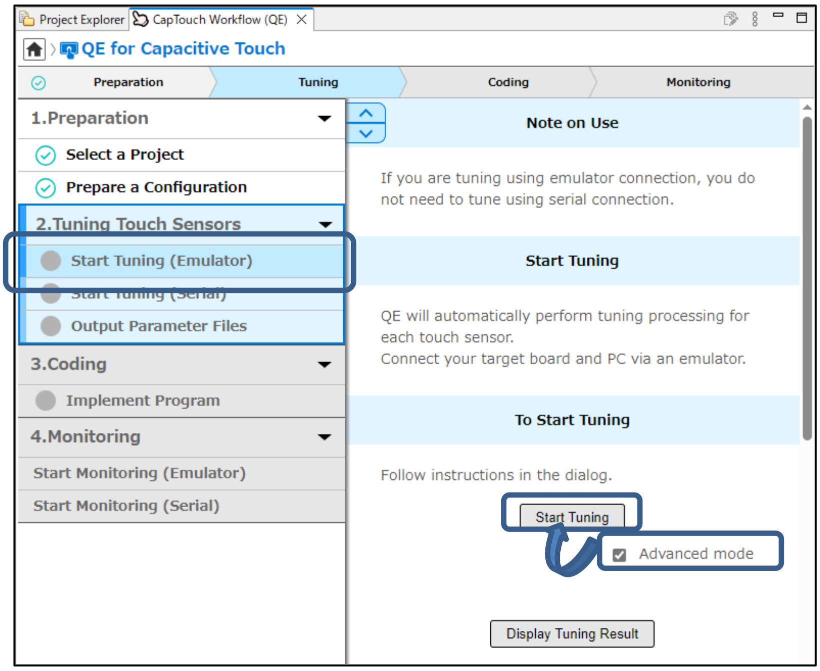
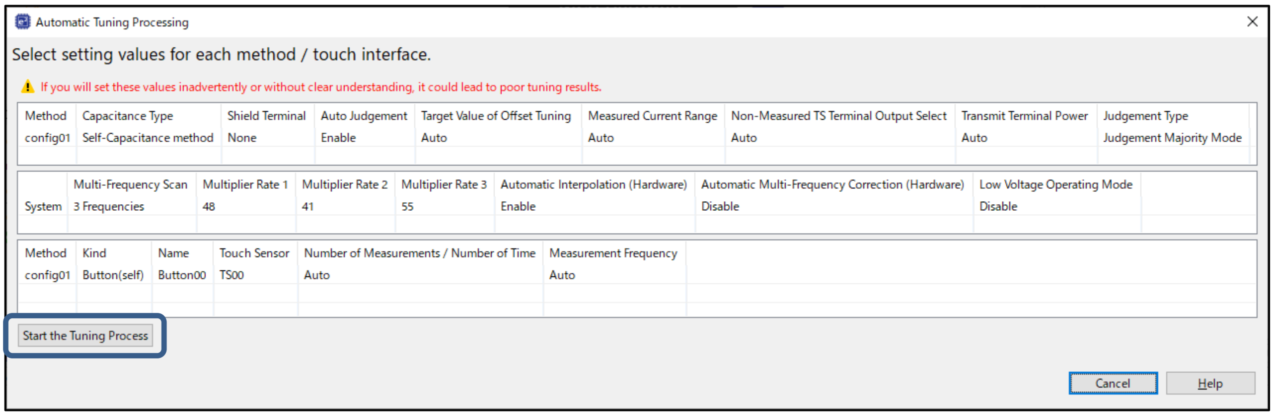


Figure 1-4 Tuning with "Advanced mode"

When tuning with "Advanced mode" Tuning is started, a window as shown in Figure 1-5 is displayed and each parameter can be adjusted. After desired parameters are adjusted, click the "Start the Tuning Process" button in the blue frame in Figure 1-5 to start tuning.



Using CTSU2x

Figure 1-5 "Advanced mode" Tuning window

The parameters that can be adjusted in "Advanced mode" Tuning vary depending on the device. For details, see 2.3 Correspondence table for each capacitive touch sensor.

After tuning in the “Advanced mode”, you can reflect the results of parameter adjustment in the source file by clicking the "Output Parameter Files" button shown in Figure 1-6 from the "To Output Parameter Files" menu.

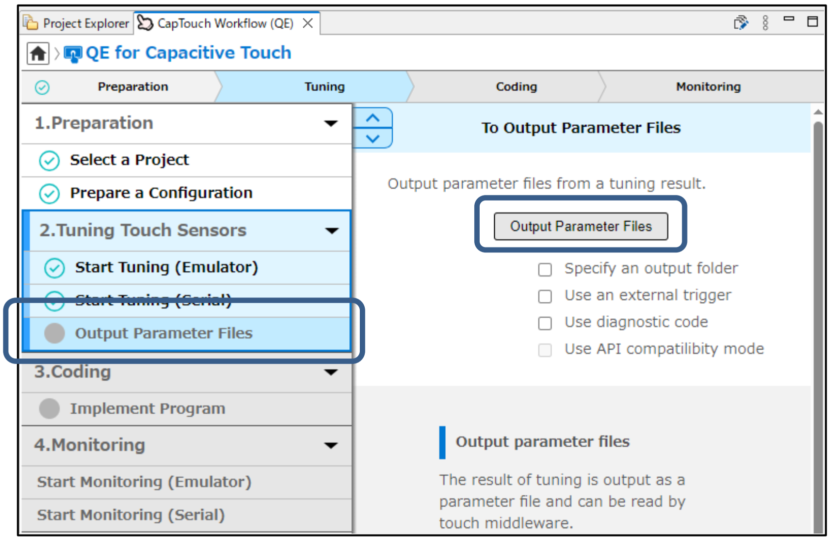


Figure 1-6 To Output Parameter Files

Click the Output File button to output the source file under the “qe_gen” folder.
Table 1-4 Source files output by the "Output Parameter Files" button

Table 1-4 Source files output by the "Output Parameter Files" button

File name	Description
qe_touch_define.h	Macro information file used by the touch middleware
qe_touch_config.h	Files to include from user programs
qe_touch_config.c	File that holds parameter settings for each configuration (method)

After outputting the source file, the operation of adjusted parameters can be checked by building and debugging.

Setting these values incorrectly or without a clear understanding may result in poor adjustment results. Adjust the value after sufficiently evaluating it to suit the environment in which it is used.

2. "Advanced mode" settings

2.1 Sensitivity improvement adjustment flow

Figure 2-1 shows the adjustment steps to improve sensitivity through "Advanced mode" Tuning.

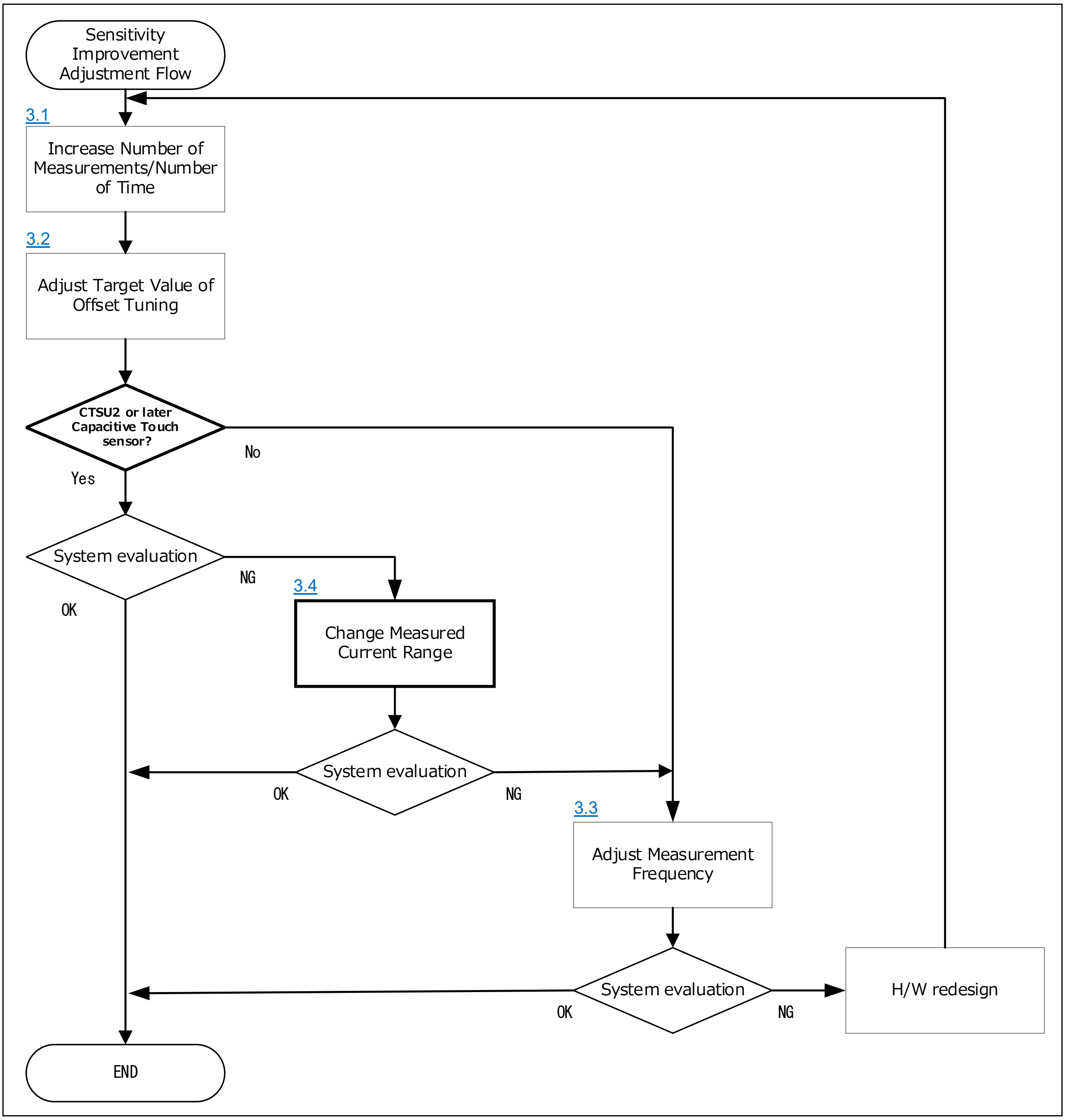


Figure 2-1 Sensitivity improvement adjustment flow

2.2 Noise suppression adjustment flow

Figure 2-2 shows the adjustment steps for improving noise immunity through “Advanced mode” Tuning.

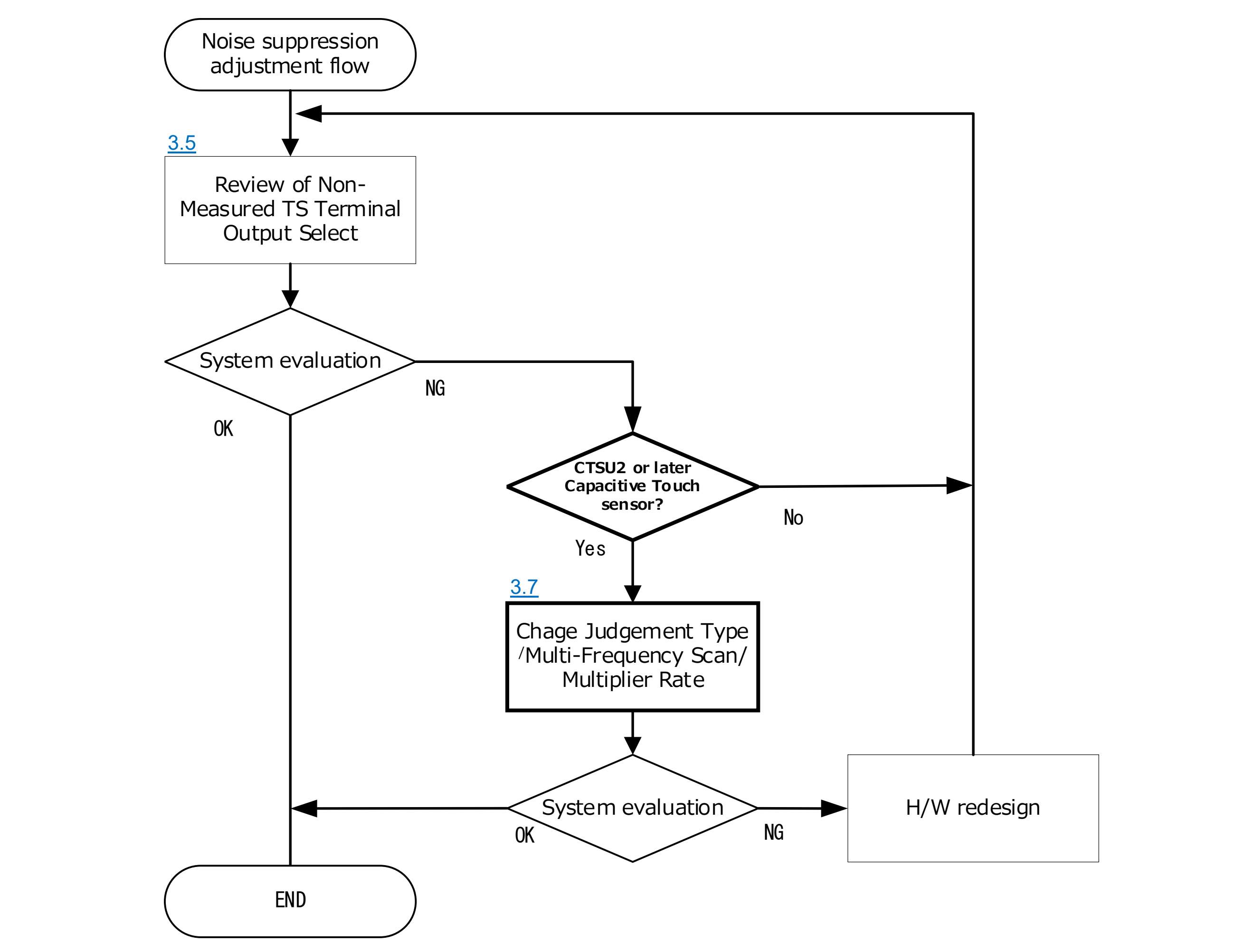


Figure 2-2 Noise suppression adjustment flow

2.3 Correspondence table for each capacitive touch sensor

Table 2-1 shows the parameters that can be changed in the advanced mode and the corresponding table for each capacitive touch sensor.

Table 2-1 Correspondence table of capacitive touch sensor

	Parameter	Purpose	CTSU2x	CTSU2	CTSU1	Feature Overview
1	Number of Measurements/ Number of Time	Improved sensitivity	✓	✓	✓	Set the number of measurements and determine the measurement time. The signal value can be improved by integrating the number of measurements.
2	Target value of Offset Tuning	Improved sensitivity	✓	✓	✓	Set the target value (%) of the offset current so that the measured value at touch OFF becomes the target value. Adjust this when the measurement time is changed.
3	Measurement frequency	Improved sensitivity	✓	✓	✓	Sets the frequency division ratio of the frequency output to the touch sensor. The higher the measurement frequency, the better the sensitivity can be seen. However, a measurement error occurs when the parasitic capacitance is large.
4	Measured Current Range	Improved sensitivity	✓	✓	-	Sets the power supply capability from VDC and determines the current mirror ratio between the measured power supply current and the input current of the current-controlled oscillator. Setting a low measuring current range increases the sensitivity. This is because CCO input current at touch ON increases.
5	Non-Measured TS Terminal Output Select	Noise Suppression	✓	✓	-	These bits set the handling of non-measurement terminals other than the measurement terminals during the measurement interval of the terminals set in TS terminal. Noise suppression can be achieved by appropriately processing the non-measured terminals.
6	Transmit Terminal Power	Terminal Setting	✓	✓	✓	Selects I/O power supply of the terminals set to the transmit terminals when the mutual capacitance method is used or the active-shield is used. This value uses the default setting and should not be changed.
7	Judgement Type	Noise Suppression	✓	✓	-	Judgement Type include Value Majority Mode (VMM) and Judgement Majority Mode (JMM). VMM is a method to judge by adding two measured values which are close in value from the measured results of 3 frequencies. JMM is a method in which the judgement result of each of the 3 frequency measurements is judged by majority decision. Auto judgement using Value Majority Mode (VMM) will be supported in future updates.
8	Multi-Frequency Scan/Multiplier Rate	Noise Suppression	✓	✓	-	Set the number of times to be measured in Multi-Frequency Scan and the multiplier rate of multiple types of frequencies to be used for measurement. Multi-Frequency Scan allows you to measure multiple drive frequencies to avoid synchronous noise
9	Auto Judgement	Process reduction Low power consumption	✓	-	-	Touch-judging is performed using a CTSU that supports auto-judging. Therefore, low power consumption operation can be realized. It can be set from the Smart Configurator/Touch Interface configuration. Auto judgement using Value Majority Mode (VMM) will be supported in future updates.
10	Automatic Interpolation (Hardware)	Process reduction Low power consumption	✓	-	-	This function performs CCO compensation computation using a CTSU that supports auto compensation. Hardware processing eliminates the need for wake-up for each measurement and contributes to power consumption reduction. Can be set when Auto judgement is enabled.
11	Automatic Multi-Frequency Correction (Hardware)	Process reduction Low power consumption	✓	-	-	This function performs frequency correction after 3 frequencies are measured with a CTSU that supports Automatic Multi-Frequency Correction. Auto judgement is enabled, and it can be used only in the measurement Value Majority Mode (VMM). Auto judgement using Value Majority Mode (VMM) will be supported in future updates.
12	Low Voltage Operating Mode	Process reduction Low power consumption	✓	✓	-	Set TSCAP voltage to be used. When the operating voltage is less than 2.4V, Low Voltage Operating Mode is automatically enabled and TSCAP voltage is turned 1.2V. This function is used when VCC/VDD is less than 2.4V during battery operation.

✓: Supported

3. Overview of each parameter

3.1 Number of Measurements/Number of Time

In "Number of Measurements/Number of Time", set the number of charge/discharge times to perform one measurement, and determine the time for one measurement. Signal value* can be improved by increasing the number of measurements. By increasing the number of measurements, the signal value* can be increased, leading to improved sensitivity. However, since measurement time is also extended at the same time, adjustment according to the user's specifications is required. In addition, adjust the offset tuning target by the target value of offset tuning to prevent overflow when the number of measurements is changed. Refer to 3.2 Target value of Offset Tuning for details of offset tuning target adjustment.
Note: The signal value indicates the difference value at touch ON/OFF.

Figure 3-1 shows the image of the measurement times by the number of measurements and the measured value at the time of touch ON/OFF.

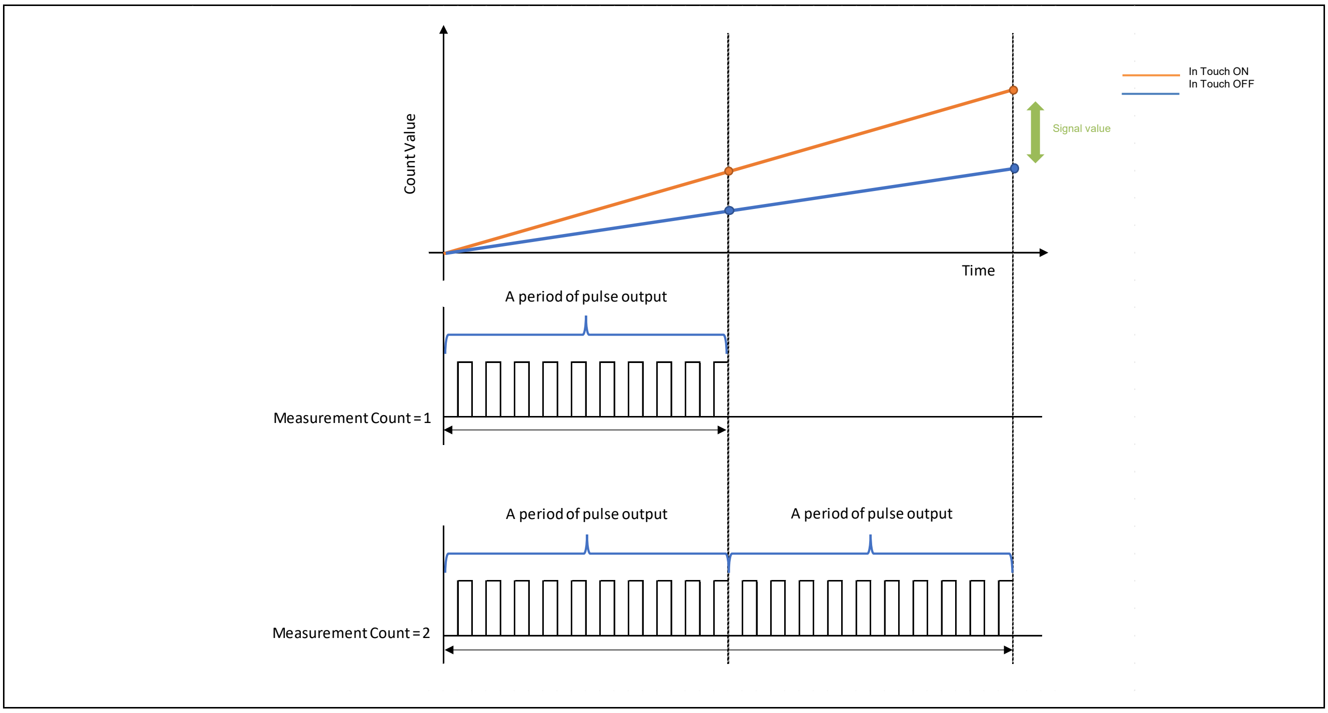


Figure 3-1 Image of measurement time and measurement value based on the number of measurements

Table 3-1 shows the default number of measurements. By CTSU2/CTSU2x, the number of measurements is fixed at 8.

Table 3-1 Default "Number of measurements" Setting

	Measurement frequency (sensor drive pulse frequency)	Number of measurements *1	Measurement time [μs]
CTSU1 (Sample RX130)	4 MHz	8	526
	2 MHz	4	
	1 MHz	2	
	0.5 MHz	1	
CTSU2/CTSU2x (Sample RX140)	-	8	128 *2

Note1: Refer to the respective capacitive touch sensor hardware manual for more information on SNUM.
Note2: The measurement time of one frequency is described.

The formulas for calculating the stabilization wait time and measurement time for CTSU1, CTSU2/CTSU2x are shown below.

- CTSU1 (RX130)

Stabilization wait time [μs] = 34 × (1/sensor drive pulse frequency)

Measurement time [μs] = 263 × (1/sensor drive pulse frequency) × (number of measurements)

Table 3-2 shows a typical example of the measurement time and stabilization wait time when the self-capacitance method is used in RX130 as a typical CTSU1.

Table 3-2 Stabilization Wait Time and measurement time when using self-capacitance method on RX130

Sensor drive pulse frequency [MHz]	Number of measurements	Stabilization wait time [μs]	Measurement time [μs]	Total (Stabilization wait time + Measurement time) [μs]
4	8	8.5	526	534.5
2	4	17	526	543
1	2	34	526	560
0.5	1	68	526	594

Note: Recommended CTSUPRRTIO, CTSUPRMODE are used. Changing this value is deprecated. For details, refer to the hardware manual of each capacitive touch sensor.

- CTSU2/CTSU2x (RX140)

Stabilization wait time [μs] = (64 × 3 [for 3 frequency measurement])

Measurement time [μs] = (16 × (number of measurements) × 3 [for 3 frequency measurement])

Table 3-3 shows a typical CTSU2/CTSU2x for the measurement time and stabilization wait time when the self-capacitance method is used in RX140.

Table 3-3 Stabilization wait time and measurement time when using self-capacitance method with RX140 (3 frequency measurement)

Number of measurements	Stabilization wait time [μs]	Measurement time [μs]	Total (Stabilization wait time + Measurement time) [μs]
8 [(STCLK cycle* 8) * 8]	192 [64 × 3]	384 [128 × 3]	576 [192 + 384]

Note: STCLK cycling is a reference clock for measuring times. It is set to the recommended 0.5MHz (2μs).

The stabilization wait time and measurement time when each capacitive touch sensor is used vary depending on the operation clock. Please refer to the hardware manual of each capacitive touch sensor and the following documents.

RX Family QE CTSU Module Using Firmware Integration Technology Rev.3.00 (renesas.com)

Figure 3-2 shows a window example when setting "Number of Measurements/Number of Time" with “Advanced mode”.

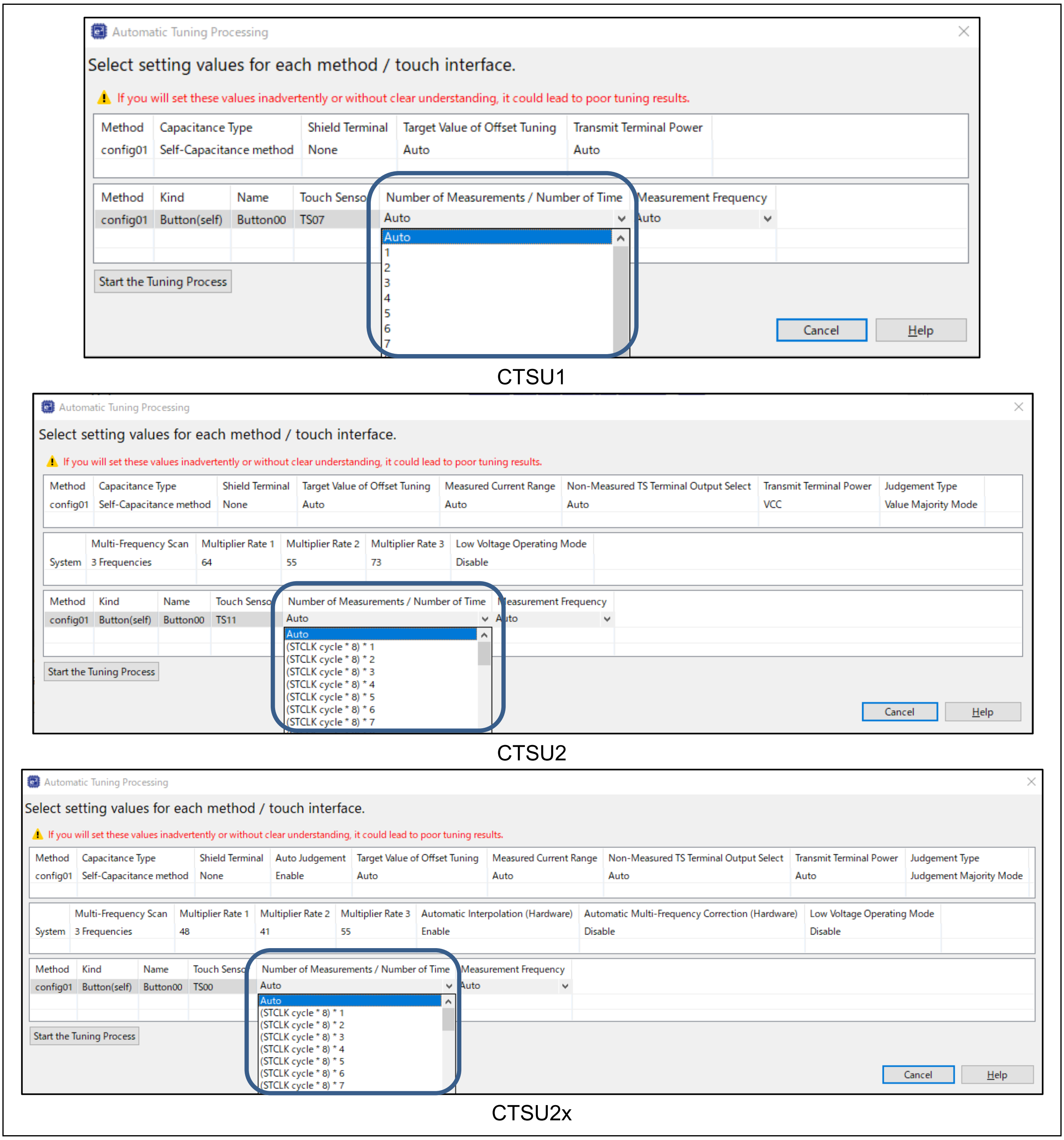


Figure 3-2 Setting of "Number of Measurements/Number of Time"

For the set value, the value of Number of measurements -1 is reflected to "snum" of the qe_touch_config.c. If "(STCLK Cycle* 8) * 8" is selected in "Number of Measurements/Number of Time", it is set as "snum = 0x07".

```
const ctsu_element_cfg_t g_qe_ctsu_element_cfg_config01[] =
{
    { .ssdiv = CTSU_SSDIV_4000, .so = 0x12B, .snum = 0x07, .sdpa = 0x07 },
};
```

Note: Refer to the respective capacitive touch sensor hardware manual for more information on SNUM.

3.1.1 Effects on sensitivity and precautions due to changes in the Number of measurements/Number of time

Table 3-4 shows the measurement values (actual measurement examples) when RX140 mounted capacitance touch evaluation system is used when the number of measurements/Number of Time is changed.

Table 3-4 Measurement values when the number of measurements/Number of Time is changed (actual measurement example)

Capacitance Touch Evaluation System with CTSU2x(RX140) Self-capacitance method, VMM method, Measurement frequency: 2MHz, measurement current range: 40μA, button 1ch (averaged five times)							
Number of measurements	Target value for offset tuning	Avg. at touch OFF A	Avg. at touch ON **B**	Signal value (Difference of touch ON/OFF) B - A	Avg. at touch OFF Noise value	SNR	Stabilization wait time + Measurement time
8	37.5%	11545	13514	1969	17.78	17.85	576 μs
12	25%	11666	14586	2920	22.76	20.96	768 μs
16	20%	11435	14994	3559	27.12	21.12	912 μs

Note: The actual measurement was obtained from QE for Capacitive Touch's "CapTouch Status Chart (QE) View" function. For more information, refer to e^{2}studio “Help”.

Accumulation of the number of measurements increases the signal value. At the same time, however, the measurement value may overflow or the measurement time may not satisfy the user's required specifications. In such cases, please consider adjusting the target value of offset adjustment, reducing the number of measurements, or changing the measurement current range or frequency. These can be adjusted individually.

Also, increasing the number of measurements can cause CTSU to consume more power during low-power operation. Please adjust the number of measurements after thorough evaluation according to the specifications required by the user.

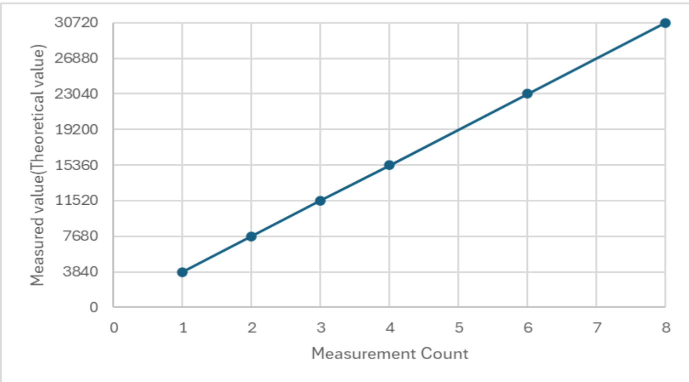
3.1.2 Necessity of Offset Tuning Adjustment when Changing Number of Measurements

If you change the number of measurements, you need to adjust the offset tuning to prevent the measurement value from exceeding the maximum value of 65535 and overflowing. In order to prevent overflow, offset tuning must be adjusted and the measurement value adjusted. Refer to 3.2 Target value of Offset Tuning for offset tuning adjustment.

Table 3-5 and Figure 3-3 show the measurements of "measurement count/measurement time" in RX130 as a typical CTSU1.

Table 3-5 Measurement value for "Number of Measurements/Number of Time" with RX130 (theoretical value)

Capacitance Touch Evaluation System with CTSU1(RX130) Self-Capacitance System PCLKB:32MHz Driving Pulse Frequency: 2MHz Target value of Offset Tuning: 37.5% Key 1ch				
Number of measurements	stabilization wait time [μs]	Measurement time [μs]	Total (stable waiting time + measurement time) [μs]	Measurement value (theoretical value)
1	17	131.5	148.5	3840
2	17	263	280	7680
3	17	394.5	411.5	11520
4	17	526	543	15360
5	17	657.5	674.5	19200
6	17	789	806	23040
:	:	:	:	:



Note: Recommended values are set for PRMODE and PRRATIO.

Figure 3-3 Measurement value (theoretical value) for "Number of Measurements/Number of Time" with RX130

For instance, if the number of measurements is increased to eight by the self-capacitance method, the measurement value at touch OFF will be around 30720. Increasing the number of measurements may cause overflow of measurements during touch ON. The offset-tuning target value must be adjusted so that the measurement value is within the range of good output-linearity characteristics of the current-controlled oscillator (CCO).

Table 3-6 and Figure 3-4 show typical measurements for "Number of Measurements/Number of Time" in RX140 as a CTSU2/CTSU2x.

Table 3-6 measurement value for "Number of Measurements/Number of Time" with RX140 (theoretical value)

Capacitance Touch Evaluation System with CTSU2x(RX140) Self-Capacitance System PCLKB:32MHz Driving Pulse Frequency: 2MHz Target value of Offset Tuning: 37.5% Key 1ch				
Number of measurements	stabilization wait time [μs]	Measurement time [μs]	Total (stable waiting time + measurement time) [μs]	Measured value per frequency (theoretical value)
1 [(STCLK cycle* 8) * 1]	192	48	240	720
2 [(STCLK cycle* 8) * 2]	192	96	288	1440
3 [(STCLK cycle* 8) * 3]	192	144	336	2880
:	:	:	:	:
8 [(STCLK cycle* 8) * 8]	192	384	576	5760
:	:	:	:	:
16 [(STCLK cycle* 8) * 16]	192	768	960	11520
:	:	:	:	:

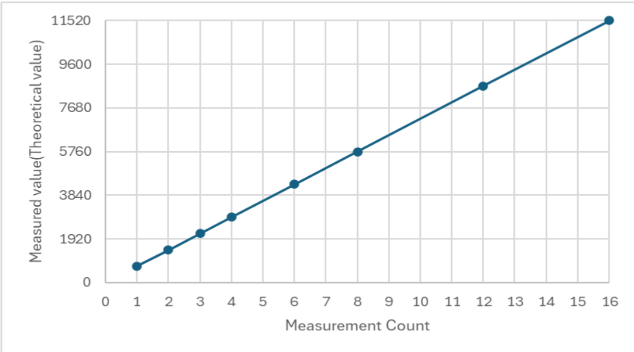


Figure 3-4 Measurement value (theoretical value) for "Number of Measurements/Number of Time" with RX140

For instance, if the number of measurements is increased to 16 when using the self-capacitance method, the measurement value at touch OFF will be around 11520. Increasing the number of measurements may cause overflow of measurements during touch ON. It is necessary to adjust the target value of offset tuning so that the measurement value fits within the good range of the output linearity characteristic of the current controlled oscillator (CCO).

3.2 Target value of Offset Tuning

In "Target value of Offset Tuning", adjust the offset current setting for each method so that the measurement value at touch OFF becomes the target value. This adjustment is made when the measurement time is changed and the measurement value overflows, or when the parasitic capacitance is large and the measurement value does not reach the target value for measurement value when the active shield is used. For details, refer to "2.2.2 Measurement Range" in the following document.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)

Figure 3-5 shows an image of offset-tuning when using the self-capacitance method in RX130. The sensor counter register ranges from 0 to 65535 for 16bit registers. However, when using the sensor counter register, measurement must be performed within the current measurement range (100% or less of the upper limit of the current range). CTSU is equipped with a sensor offset adjustment register. By tuning the offset current, the measured value of the parasitic capacitance component can be controlled and adjusted to the targeted value.

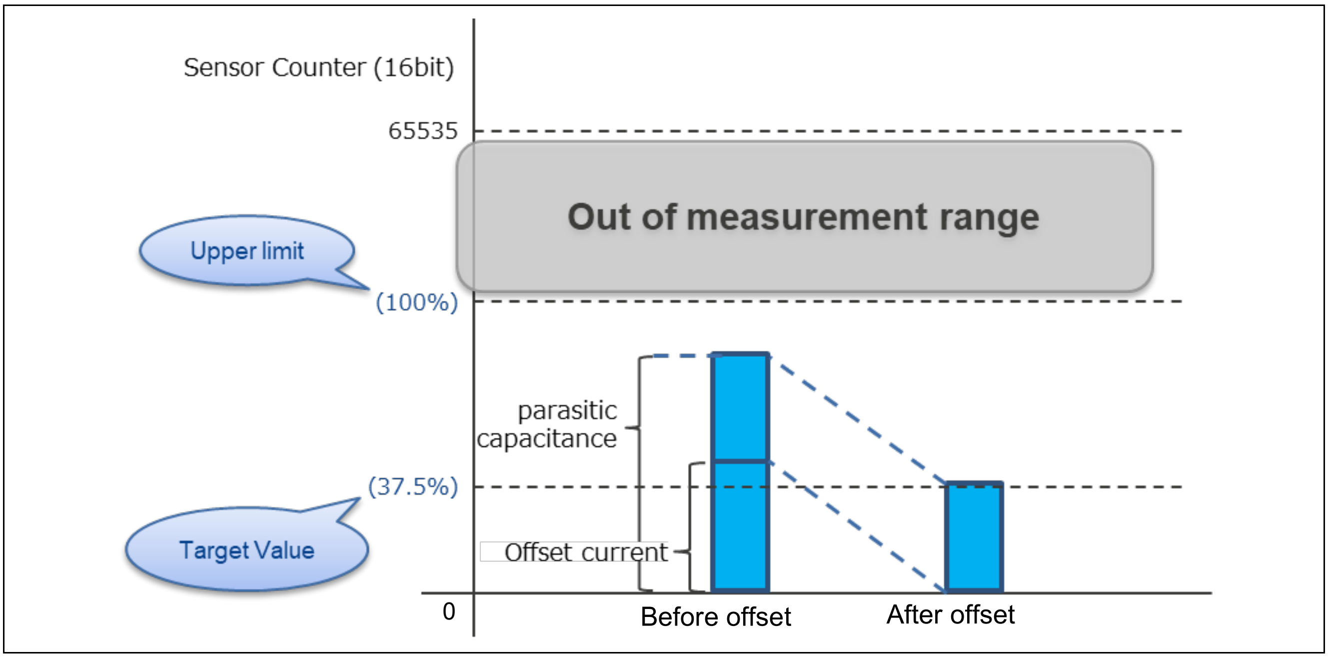


Figure 3-5 Offset Tuning Process of Self-Capacitance Method

Table 3-7 shows the target values for the default number of measurements. For the default "Number of measurements" see Table 3-1 setting.

Table 3-7 Default "Target value of Offset Tuning" Setting for Each measurement

	Judgement Type	ATUNE0	Self-capacitance method	Mutual capacitance system	Active shield
CTSU1	-	Normal mode	15360 (37.5%)	10240 (25%)	-
CTSU2/ CTSU2x	Value Majority Mode (VMM)	Normal mode	11520 (37.5%)	7680 (25%)	4608 (15%)
		Low voltage mode	9216 (37.5%)	6144 (25%)	-
	Judgement Majority Mode (JMM)	Normal mode	5760 (37.5%)	3840 (25%)	2304 (15%)
		Low voltage mode	4608(37.5%)	3072 (25%)	-

Note: VMM is used, the total value (128 + 128 = 256 μs) of the selected 2-frequency measurement result from the 3-frequency measurement result is used as the final measurement result. When JMM is used, the measured value is one frequency (128 μs).

Target values are shown in Table 3-8 for setting the target value during offset-tuning in CTSU1.

Table 3-8 Target value for "Target Value of Offset tuning" in CTSU1

Target value of Offset Tuning	Target value
25.0%	10240
30.0%	12288
35.0%	14336
37.5%	15360
40.0%	16384
45.0%	18432
50.0%	20480

Target values for CTSU2/CTSU2x differ depending on the version of QE for Capacitive Touch. Table3-9 shows the target values when the offset-tuning target values are changed by CTSU2/CTSU2x when QE for Capacitive Touch prior to v3.5.0 is used after v4.0.0 and Table3-10.

Table3-9 Target value for "Offset tuning target value" CTSU2/CTSU2x
(QE for Capacitive Touch v4.0.0 or later)

Offset tuning target value	JMM target value*		VMM target value*	
	Normal mode	Low voltage mode	Normal mode	Low voltage mode
10.0%	1536	1229	3072	2458
15.0%	2304	1843	4608	3686
20.0%	3072	2458	6144	4915
25.0%	3840	3072	7680	6144
30.0%	4608	3686	9216	7373
35.0%	5376	4301	10752	8602
37.5%	5760	4608	11520	9216
40.0%	6144	4915	12288	9830
45.0%	6912	5530	13824	11059
50.0%	7680	6144	15360	12288

Note: When VMM is used, it is the sum of two frequencies (256 μs) of the three-frequency measurement. When JMM is used, it is equivalent to one frequency (128 μs).

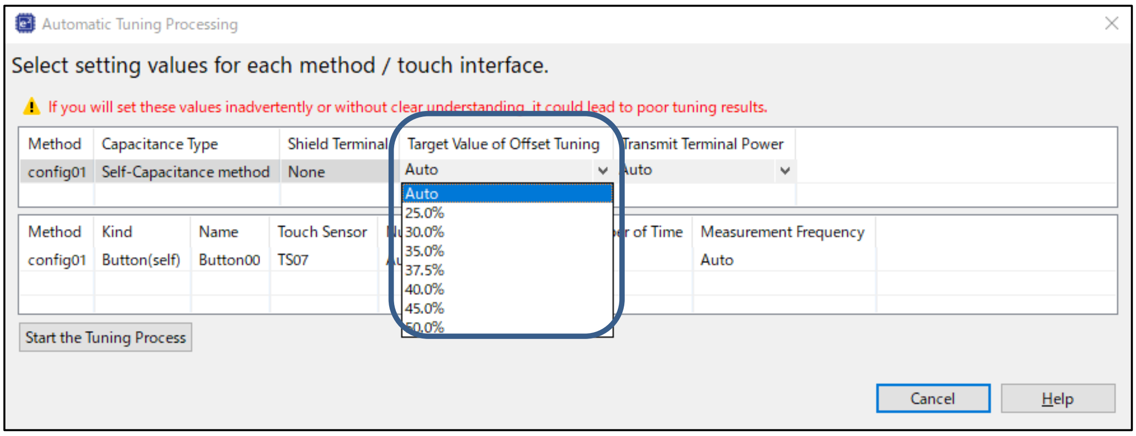
Table3-10 Target value for "Offset tuning target value" CTSU2/CTSU2x
(QE for Capacitive Touch v3.5.0 or earlier)

Offset tuning Desired value	Target value* (QE for Capacitive Touch v3.3.0 or earlier)	Target value* (QE for Capacitive Touch v3.5.0)
10.0%	4096	3072
15.0%	6144	4608
20.0%	8192	6144
25.0%	10240	7680
30.0%	12288	9216
35.0%	14336	10752
37.5%	15360	11520
40.0%	16384	12288
45.0%	18432	13824
50.0%	20480	15360

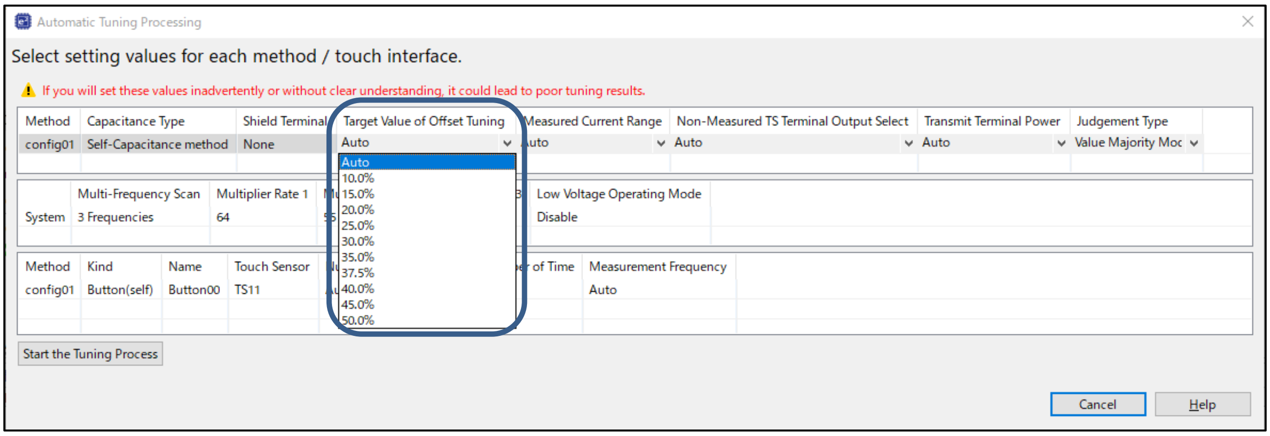
Note: The value after the sum of two frequencies (256 μs) of the 3-frequency measurement result.

The target value depends on the version of QE for Capacitive Touch at tuning. This application note uses the target values in Table3-9. It is recommended that the latest QE for Capacitive Touch be used in the evaluation.

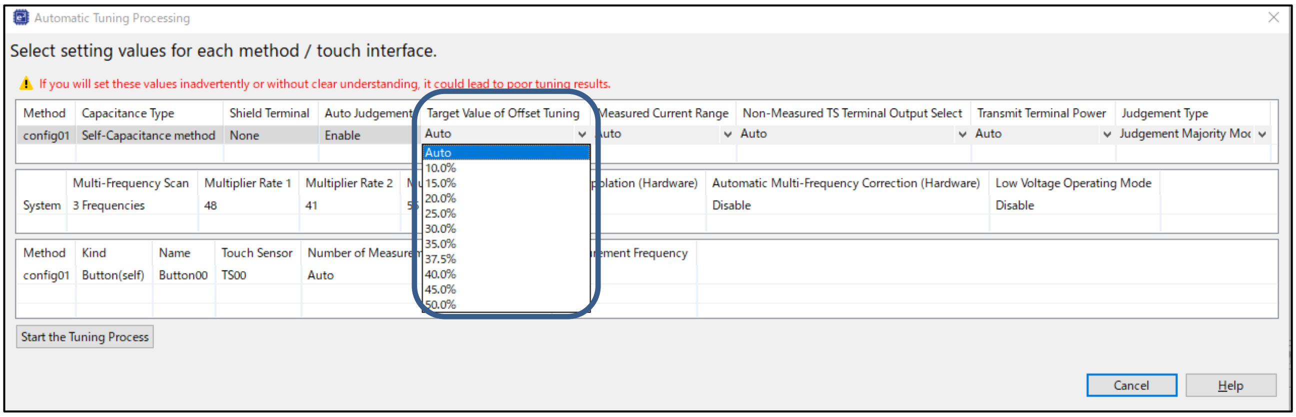
Figure 3-6 shows an example window for setting "Target value of Offset Tuning" with “Advanced mode”.



CTSU1



CTSU2



CTSU2x

Figure 3-6 Setting of "Target value of Offset Tuning"

The settings are reflected in the qe_touch_config.c. The following is an example of target values for the self capacitance method/mutual capacitance method when RX130 is used. It is not recommended to rewrite this value directly.

```
#if (CTSU_TARGET_VALUE_CONFIG_SUPPORT == 1)
    .tuning_self_target_value   = 15360,
    .tuning_mutual_target_value = 10240,
#endif
```

3.2.1 Effects on Target value of Offset Tuning and Number of measurements Change on Measurement Value

The number of measurements can be changed only with CTSU2/CTSU2x. The measurement value changes according to the number of times of measurement, and if the number of times of measurement is set to double the default setting, the measurement value is also doubled.

CTSU1:

Measured value = (offset tuning target value [%] × 40960*)/100 × (number of measurements/default number of measurements)
Note: 40960 is the value when the offset tuning target value is 100%.

CTSU2:

When using VMM:

In Normal mode:

Measured value = (offset tuning target value [%] × 30720*)/100 × (number of measurements/default number of measurements)
Note: 30720 is the offset tuning target value of 100% at a measurement time of 256 μs.

In Low Voltage Operating Mode:

Measured value = (offset tuning target value [%] × 24576*)/100 × (number of measurements/default number of measurements)
Note: 24576 is the offset tuning target value of 100% at a measurement time of 256 μs.

Indicates the measured value (theoretical value) at touch OFF when VMM is used with respect to the setting of the offset-tuning target value when the number of measurements in Table 3-11 and Figure 3-7 show CTSU2/CTSU2x is changed.

Table 3-11 Measurement values for "Target values of offset tuning" when the number of measurements is changed (theoretical values)

Target value of Offset Tuning	Target value when using VMM*	Measured value (theoretical value) when VMM is used in touch OFF*	
		Number of measurements: 8 (default)	Number of measurements: 16
10.0%	3072	3072	6144
15.0%	4608	4608	9216
20.0%	6144	6144	12288
25.0%	7680	7680	15360
30.0%	9216	9216	18432
35.0%	10752	10752	21504
37.5%	11520	11520	23040
40.0%	12288	12288	24576
45.0%	13824	13824	27648
50.0%	15360	15360	30720

Note: The value after the 2 frequency sum of the 3 frequency measurement results.

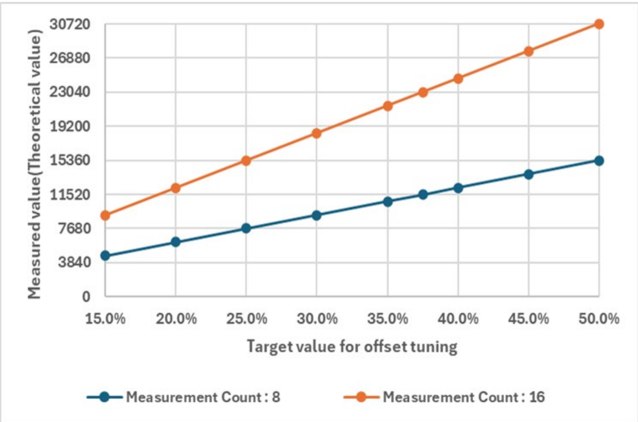


Figure 3-7 Measurement value (theoretical value) with respect to "Target value of Offset Tuning" when the number of measurements is changed

Changing the offset tuning target value may cause the count value to overflow. Set the target value and measurement time so that the measurement value at the maximum capacitance-added state* assumed when the system (product) is operating falls within the good range of output linearity characteristics of the current-controlled oscillator (CCO). If there is no need to change, set the target value and measurement time for offset tuning to the target value for each method, referring to Table 3-7.

If the measurement value differs from the expected value, refer to Table3-9 to set the target value for offset tuning. Set the target value for offset tuning lower than the default setting when the measurement value is larger than the target value, and higher than the default setting when the measurement value is smaller than the target value. When the parasitic capacitance of the electrode is small or the active shield is used, set these target values again when measurement value does not reach the target value set by the offset tuning process.

Note: As an example, assume the maximum possible added capacitance, including non-normal operation, when water is spilled over the touch buttons.

3.3 Measurement frequency

"Measurement frequency" (sensor drive pulse frequency) sets the frequency division of the frequency output to the touch sensor. The higher the measurement frequency, the better the sensitivity will be. However, measurement errors will occur if the parasitic capacitance is large.
CTSU outputs a sensor drive pulse from TS terminal and measures the capacitance from the charge current. For details, refer to the following document.
[Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)]

The measurement frequency is set to an appropriate frequency in Auto tuning by the parasitic capacitance and the set damping resistance. In addition, the measurement frequency varies depending on the operation clock. For details, refer to the hardware manual of each capacitive touch sensor. Figure 3-8 shows the relation between the parasitic capacitance/damping resistor of RX130 set by auto tuning and the measurement frequency. A typical example of CTSU1 (TSCAP voltage 1.6V) is shown below.

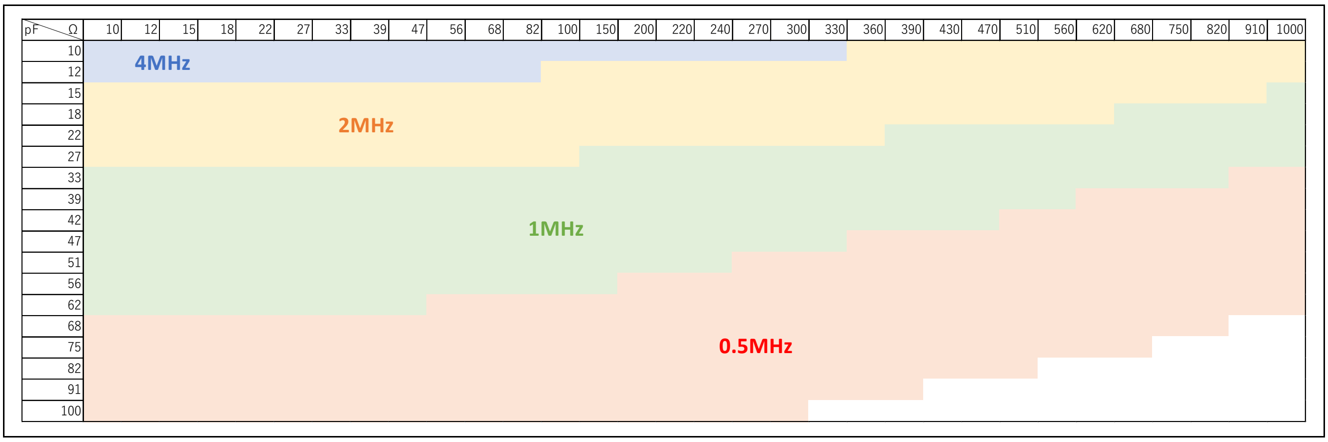


Figure 3-8 Parasitic capacitance/damping resistance of RX130 (receiving electrode 1.6V) vs. measurement frequency

Figure 3-9 shows a typical CTSU1 (TSCAP voltage 1.18V) between the parasitic capacitance/damping resistor of RX671 and the measurement frequency set by auto-tuning. The figure below shows 30 MHz of the operation clocks.

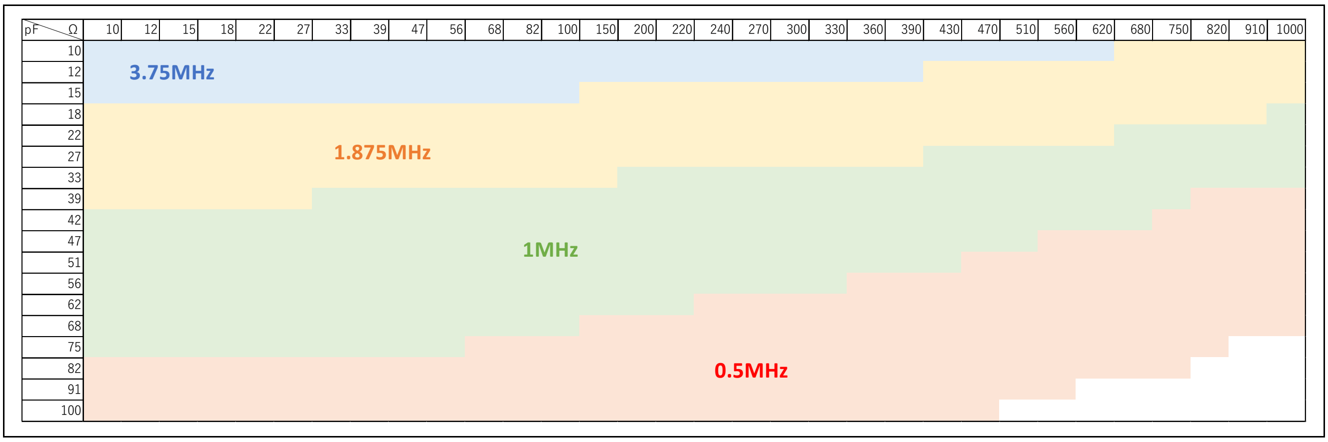


Figure 3-9 Parasitic capacitance/damping resistance of RX671 (receiving electrode 1.18V) vs. measurement frequency

Figure 3-10 shows the relation between the parasitic capacitance/damping resistor of RX140 and the measurement frequency. A typical example of CTSU2/CTSU2x is shown below.

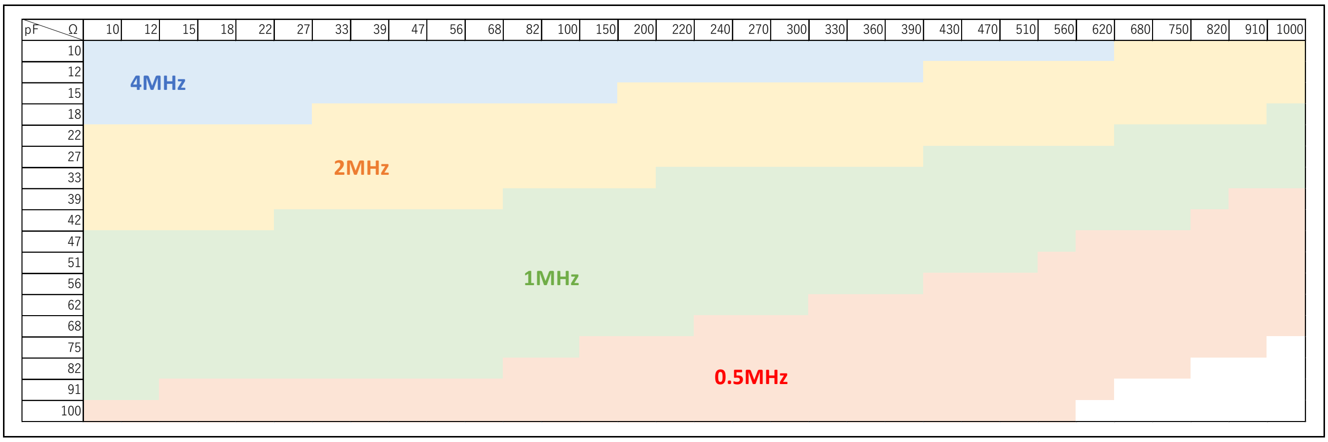


Figure 3-10 Parasitic capacitance/damping resistance of RX140 (receiving electrode 1.5V) vs. measurement frequency

The higher the parasitic capacitance, the lower the measurement frequency is set. If the measurement frequency is set to a high value when the parasitic capacitance is large, the charge/discharge may not be satisfactorily performed, and measurement error may occur when outputting sensor drive pulses from TS terminal. In Auto-tuning sets the optimum measurement frequency where no measurement error occurs.

In addition, in CTSU2/CTSU2x, the frequency set in "Measurement frequency" is determined as the 1st frequency in multi-frequency scan. Refer to 3.7 Judgement Type/Multi-Frequency Scan/Multiplier Rate for the setting method of the 2nd/3rd Frequency.

Figure 3-11 shows a window example for setting "Measurement Frequency" with “Advanced mode”.

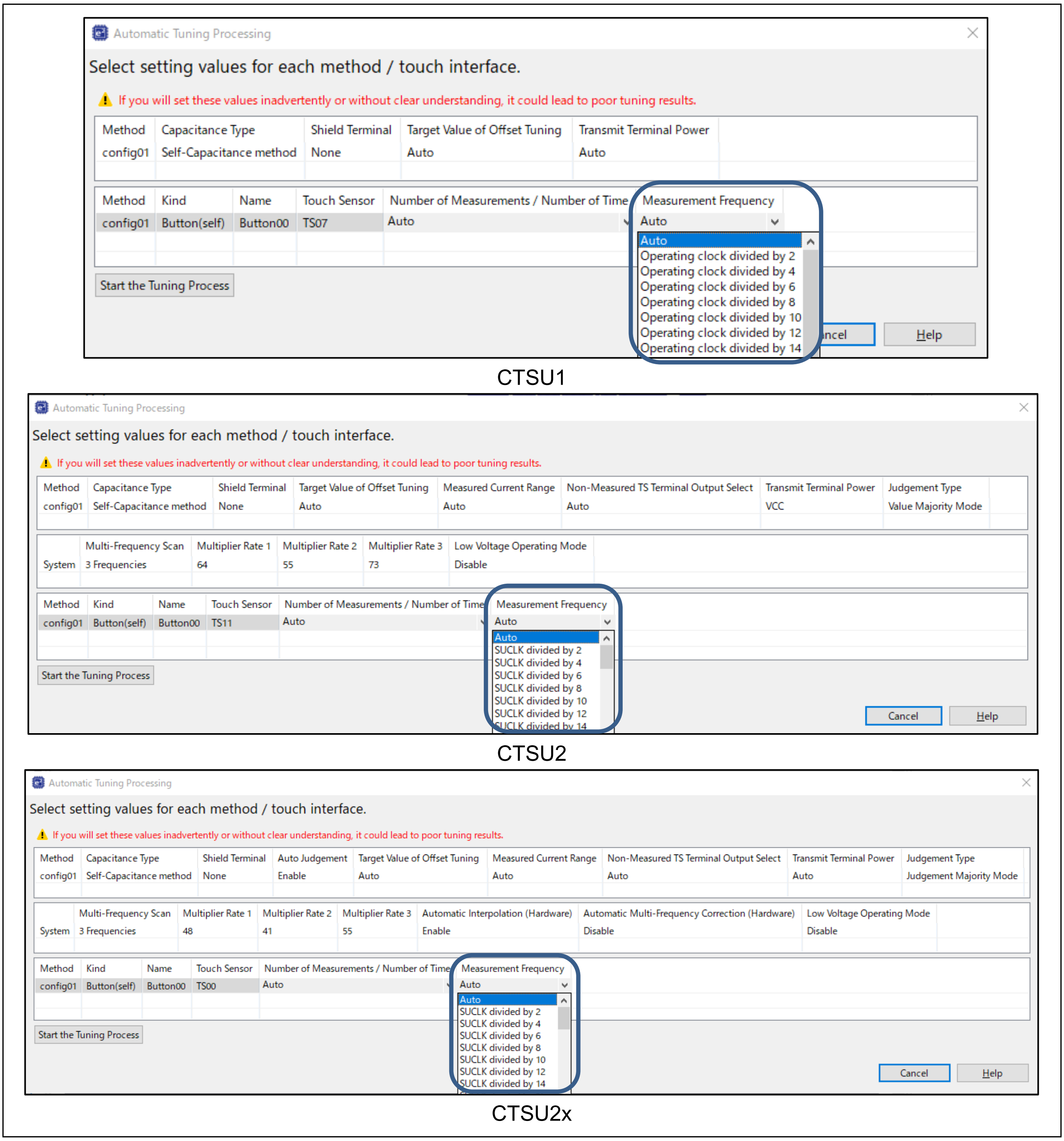


Figure 3-11 Setting of "Measurement Frequency"

The setting is reflected in "sdpa" of the qe_touch_config.c. For instance, when the Capacitance Touch Evaluation System with RX140 is used, if "16 division of SUCLK" is selected for the measurement frequency, "sdpa = 0x07" is set.

```
const ctsu_element_cfg_t g_qe_ctsu_element_cfg_config01[] =
{
    { .ssdiv = CTSU_SSDIV_4000, .so = 0x12B, .snum = 0x07, .sdpa = 0x07 },
};
```

Note: Refer to the respective capacitive touch sensor hardware manual for more information on SDPA.

3.3.1 Effects on Sensitivity by Changing Measurement Frequency

Table 3-12 shows the measurement values (actual measurement examples) when RX140 mounted capacitance touch evaluation system is used when the measurement frequency is changed.

Table 3-12 Measurement values when the measurement frequency is changed (actual measurement example)

Capacitance Touch Evaluation System with CTSU2x(RX140) Self-capacitance method, VMM method, Number of measurements: 8, Measurement current range: 40μA, Target value of Offset Tuning: 37.5% (averaged five times)					
Measurement Frequency	Avg. at touch OFF A	Avg. at touch ON B	Signal value (Difference of touch ON/OFF) B - A	Avg. at touch OFF Noise value	SNR
4MHz	11674	15322	3648	26.1	23.29
2MHz	11540	13376	1836	17.7	16.22
1MHz	11580	12513	932	13	11.29
0.5MHz	11550	12021	471	13.8	5.40

Note: The actual measurement was obtained from QE for Capacitive Touch's "CapTouch Status Chart (QE) View" function. For more information, refer to e^{2}studio “Help”.

When the measurement frequency is increased, the difference in the touch ON/OFF can be seen to be large. However, when the measurement frequency is increased, overflow of the measurement counter may occur during touch ON. If the measurement frequency is increased forcibly when the parasitic capacitance is large, a measurement error may occur.

Figure 3-12 shows the image of CTSU measurement when the parasitic capacitance is large and the measurement frequency is increased. If the output of the pulse is faster than the charging time and the parasitic capacitance is large at a higher frequency, charging/discharging may not be performed sufficiently. As a result, measurement errors may occur. Therefore, it is necessary to set the measurement frequency to match the parasitic capacitance.

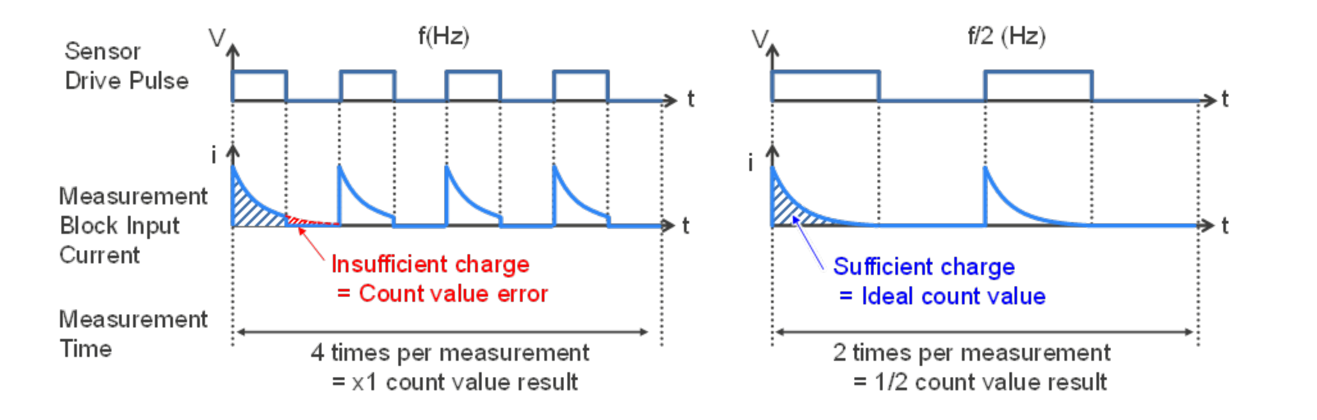


Figure 3-12 Image of CTSU measurement

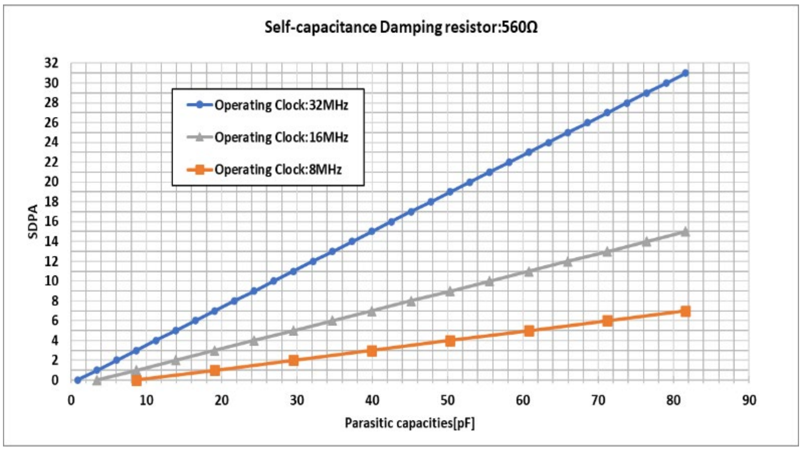
When set to 0.5MHz, if the parasitic capacitance is small, the average value at touch OFF may not be set near the offset tuning target value. The reason is that the measurement value does not reach the target value because the current supplied from VDC is small because the parasitic capacitance is small, and the current supplied to the current mirror circuit is also small. In this case, increase the measurement frequency or decrease the Target value of Offset Tuning.

In addition, considering that the charge/discharge times should be sufficiently secured, set the measurement frequency to be less than 4MHz.

Please adjust the measurement frequency after sufficiently evaluating it in accordance with the specifications required by the user.

3.3.2 How to adjust the measurement frequency using Advanced Mode

Automatic tuning sets the optimum measurement frequency where no measurement error occurs. Although the final measurement frequency is determined from the default 4 measurement frequencies, 4MHz, 2MHz, 1MHz, 0.5MHz by the parasitic capacitance, the margin of the measurement frequency set for the parasitic capacitance may be too large. In such a case, it is possible to change to a more detailed measurement frequency by using the advanced mode. Figure 3-13 shows the relation between parasitic capacitance and SDPA when a damping resistor of 560 Ω is used in RX130 that is CTSU1.



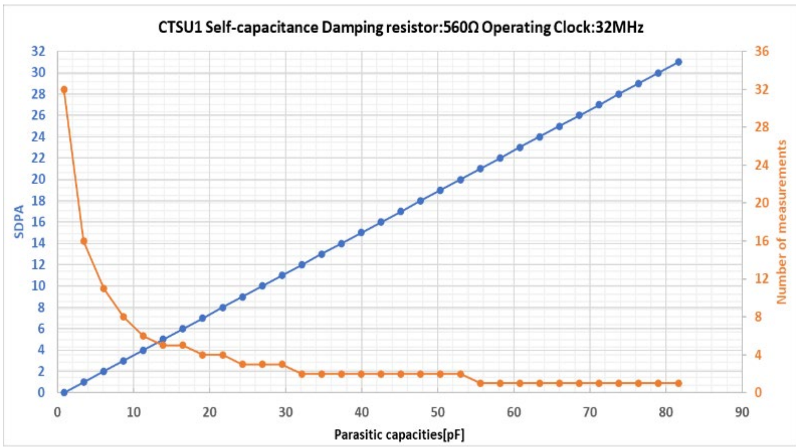
Note: Recommended values are set for PRMODE and PRRATIO.

Figure 3-13 Parasitic capacitance that can be measured when RX130 is used

When the parasitic capacitance is 30pF and the operating clocks (CTSUCLK) are 32MHz, the optimal SDPA is 11. The measurement frequency is calculated by the following formula.
Measurement frequency = CTSUCLK / ((SDPA + 1) × 2)

When the operating clock (CTSUCLK) is 32MHz and SDPA is 11, the measurement frequency is as follows.
Measurement frequency: 32[MHz] / ((11 + 1) × 2) = 1.333MHz

In RX130, the measurement time is set to be 526μs as the result of auto-tuning. However, if the measurement frequency is manually changed using this Advanced mode, the measurement time also changes. For details, please see 3.1 Number of Measurements/Number of Time.
Figure 3-14 shows the relation between SDPA and the number of measurements when the operating clock 32MHz is used when the value is set to around 526μs.



Note: Because the setting value of the number of measurement times is limited to an integer, there are cases where the measurement time deviates significantly from 526μs, even with the optimal number of measurements, depending on the SDPA.

Figure 3-14 SDPA and number of measurements when 526μs equivalent measurement times are set when RX130 (operation clock 32MHz) is used

When changing the measurement time, adjust it to the user's required specifications to prevent an overflow error from occurring. Depending on the operation clock, the setting may be set to other than 4/2/1/0.5MHz depending on the auto-tuning. For instance, if the operating clocks are 30MHz, they cannot be set to 4/2MHz because of the frequency division relation. In such cases, 4/2MHz is set to a lower 3.75/1.875MHz.

Figure 3-15 shows the parasitic capacitance versus SDPA when the default setting of "Multi-frequency measurement/Multiplier Rate" is used in RX140 that is CTSU2 and the damping resistor 560 Ω is used.

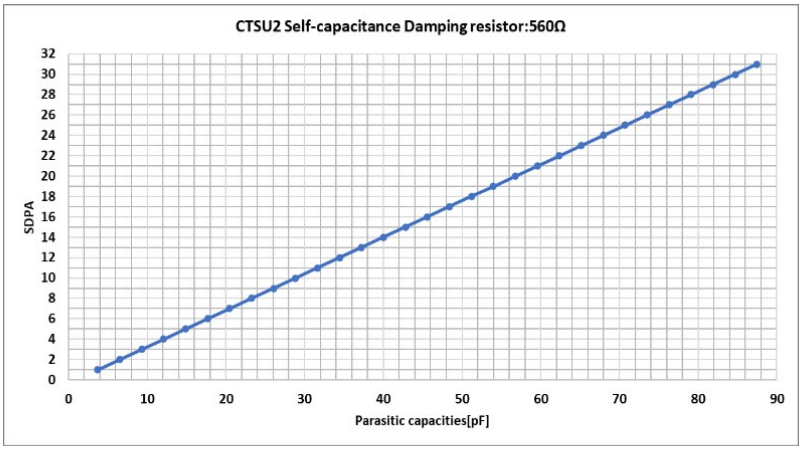


Figure 3-15 Parasitic capacitance that can be measured when RX140 is used

When the parasitic capacitance is 25pF, the optimal SDPA is 9.
The measurement frequency is calculated by the following formula.
Measurement frequency = (SUCLK* / 2) / (SDPA + 1)

Note: SUCLK = STCLK[0.5MHz] × SUMULTI is shown. For details on STCLK and SUMULTI, refer to the hardware manual for each capacitive touch sensor.

When SDPA is 9, the frequency at 3-frequency measurement is as follows.
Measurement frequency (multiplied by 64) : (32 [MHz] / 2) / (9 + 1) = 1.6MHz
Measurement frequency (multiplied by 55) : (27.5[MHz] / 2) / (9 + 1) = 1.38MHz
Measurement frequency (multiplied by 73) : (36.5[MHz] / 2) / (9 + 1) = 1.83MHz

Please adjust after sufficiently evaluating it in accordance with the specifications required by the user.

3.4 Measured Current Range

The "Measured Current Range" setting can be changed only with CTSU2/CTSU2x.
In “Measured Current Range", the current mirror ratio between the current supplied from the measurement VDC and the current flowing through the current controlled oscillator (CCO) via the current mirror circuit is set for each method. Setting a low "Measuring Current Range" increases the sensitivity. This is because CCO input current at the time of touch ON increases.
CTSU measures the capacitance by outputting a sensor drive pulse from TS terminal and measuring the charge/discharge current. The following equation is established when the electrode-side current I, sensor drive pulse frequency F, and parasitic capacitance are Cp, finger capacitance Cf, and sensor drive pulse voltage V.

$$I = F\,(Cp + Cf)\,V$$

Here, the current I is the sum of the current I1 supplied from the measurement VDC and the current I2 supplied from the offset current (DAC). For details, refer to "2.2.1 Detection Principle" in the following documents.
[Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)]

A current IOUT proportional to CCO is applied to the current I1 supplied from the measurement VDC through the current mirror. Set the power supply capability from VDC and the current mirror ratio is automatically determined according to the setting. Increasing the measurement current range increases the current I1 supplied from VDC for measurement.

Figure 3-16 shows the measurement image when "Measured Current Range" is changed.

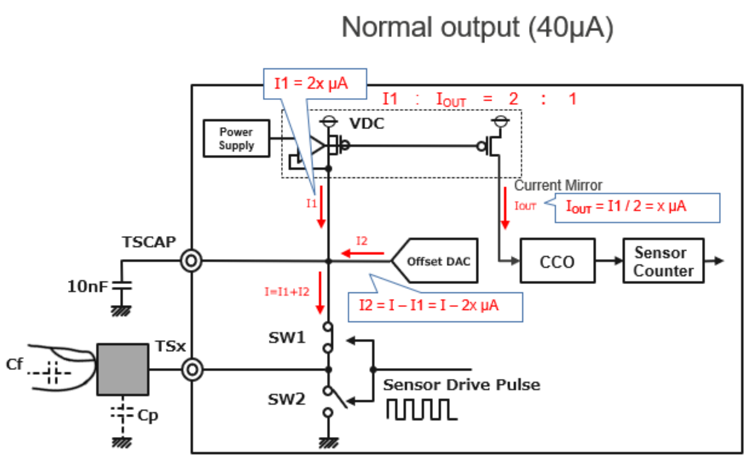


Figure 3-16 Measurement image when normal current (40μA) is used

Table 3-13 shows the default settings.

Table 3-13 Default "Measured Current Range" settings

	When self-capacitance method is used	When using mutual capacitance method
CTSU2/CTSU2x	Normal current (40μA)	High current (80μA)

In addition to the defaults, CTSU2/CTSU2x can be set to low current (20μA) or high current (160μA).

Figure 3-17 shows an example window for setting "Measured Current Range" with “Advanced mode”.

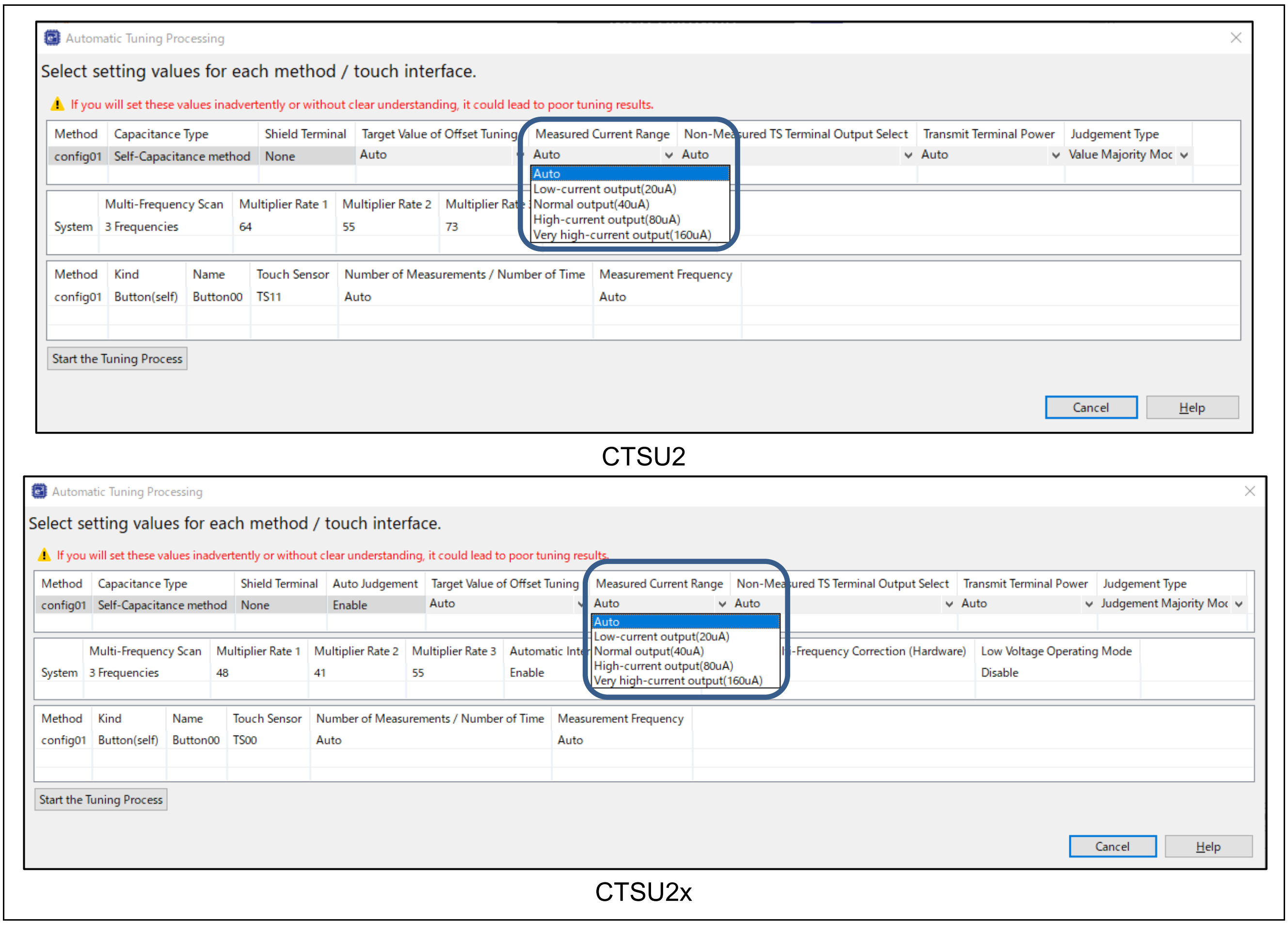


Figure 3-17 Setting of "Measured Current Range"

The settings are reflected in the qe_touch_config.c. Normal current (40μA) is shown below.

```
.atune12= CTSU_ATUNE12_40UA,
```

Note: Refer to the respective capacitive touch sensor hardware manual for more information on ATUNE.

3.4.1 Effects on Sensitivity by Changing the Measured Current Range

Table 3-14 shows the measurement values (actual measurement examples) when RX140 mounted capacitance touch evaluation system is used when the Measured Current Range is changed.

Table 3-14 Measurement values when the Measured Current Range is changed (actual measurement example)

Capacitance Touch Evaluation System with CTSU2x(RX140) Self-capacitance method, VMM method, Measurement frequency: 2MHz, measurement count: 8, Target value of Offset Tuning: 37.5% (averaged five times)					
Measured Current Range	Avg. at touch OFF A	Avg. at touch ON B	Signal value (Difference of touch ON/OFF) B - A	Avg. at touch OFF Noise value	SNR
20µA	11653	15508	3855	38.32	16.216
40µA	11566	13513	1947	16.96	17.672
80µA	11513	12484	970	11.46	14.288
160µA	11360	11840	480	9.94	7.49

Note: The actual measurement was obtained from QE for Capacitive Touch's "CapTouch Status Chart (QE) View" function. For more information, refer to e²studio “Help”.

When the measured current range is low, the difference in the touch ON/OFF can be seen to be large, but when the current range is low, overflow may occur during touch ON. Perform adjustment after sufficiently evaluating the offset tuning to meet the user's required specifications. Also, if the current-mode is too large when the parasitic capacitance is small, the mean value at touch OFF may not be set near the offset-tuning target value. The reason is that the measurement value does not reach the target value because the current supplied from VDC is small because the parasitic capacitance is small and the current supplied to the current mirror circuit is also small. In this case, lower the measured current range or decrease the target value of the measurement value.

Figure 3-18 shows, as an example, the current I1 supplied from the VDC for measurement and the current I2 supplied from the offset current (DAC) to the target offset tuning value when the measurement current range is normal current (40µA) / high current (160µA) when the measurement frequency is 2MHz and an electrode with a parasitic capacitance of approximately 18.8pF is used. current I2 supplied from the current (DAC) and the current value Iout flowing in the CCO are shown below.

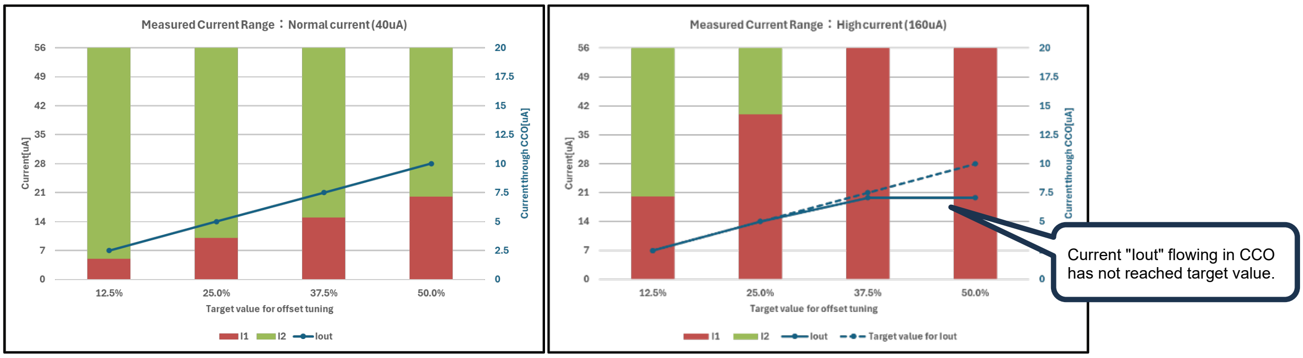


Figure 3-18 Current value when the target offset tuning value and measured current range are changed

The current flowing through the CCO is 2.5~20µA, and 20µA flows when the offset tuning target value is 100%. When the normal current (40µA) is used, I1 = approx. 15µA, I2 = approx. 41µA when the offset-tuning target is 37.5%. The current IOUT flowing through CCO is determined by the current mirror rate with the current I1 supplied from VDC for measurement and is therefore calculated as IOUT = I1 / 2 = 7.5µA.

When high current (160µA) is used, I1 = approx. 56µA, I2 = 0µA when offset-tuning target is 37.5%. Since the current IOUT flowing through CCO is determined by the current mirror rate with the current I1 supplied from the measurement VDC, IOUT = I1/8 is approximately 7µA.

If the current mode is too large when the parasitic capacitance is small, the current supplied to the current mirror circuit will also be small and the measurement value will not reach the target value.

Adjust the target value for current range and offset tuning after fully evaluating the user's required specifications.

3.5 Non-Measured TS Terminal Output Select

The setting of "Non-Measured TS Terminal Output Select" can be changed only with CTSU2/CTSU2x. In "Non-Measured TS Terminal Output Select", the processing of non-measurement terminals other than the measurement terminals during the measurement period is set for each method.

Noise suppression is possible by appropriately processing non-measurement terminals. It is recommended to set TS terminal which is not measured to GPIO Low output for noise-suppression. To shield the external influence while suppressing the increase of the parasitic capacitance when using the active shield, set the non-measurement terminal to the common-mode pulse output which is the setting to output the shield signal in the same phase as the sensor drive pulse during the measurement period. Table 3-15 shows the default settings.

Table 3-15 Default "Non-Measured TS Terminal Output Select" setting.

	When self-capacitance method is used	When using mutual capacitance method	When using active shield
CTSU2/CTSU2x	Output low thorough GPIO	Output low thorough GPIO	Same phase pulse output as transmission channel through the power setting

Figure 3-20 shows an image of TS terminal measurement in a touch interface configuration as shown in Figure 3-19. Since the active shield is set for the behavior of TS terminal during config01 measurement period, the other terminal TS01, TS02 is in-phase pulsing while TS00 is being measured. During config02 measurement, TS04 that TS03 is being measured is turned Low.

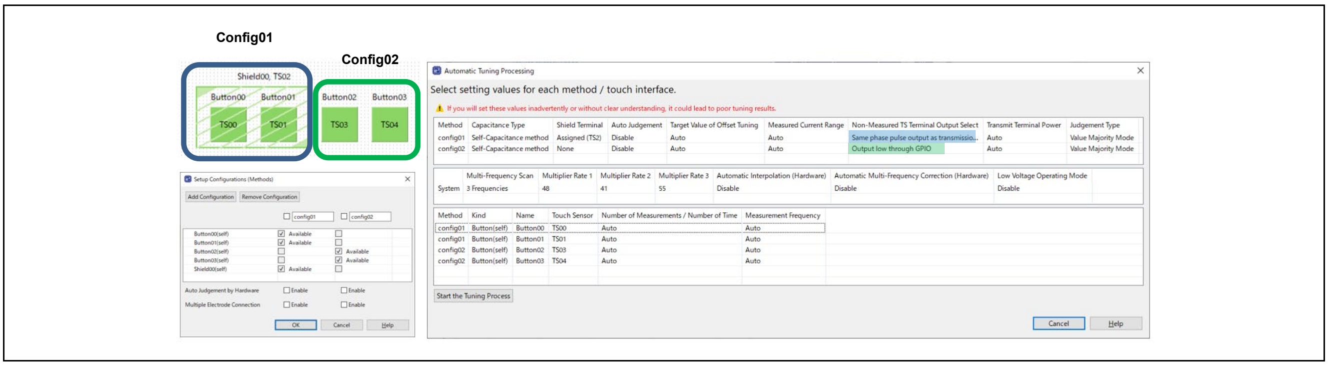


Figure 3-19 Example touch interface configuration

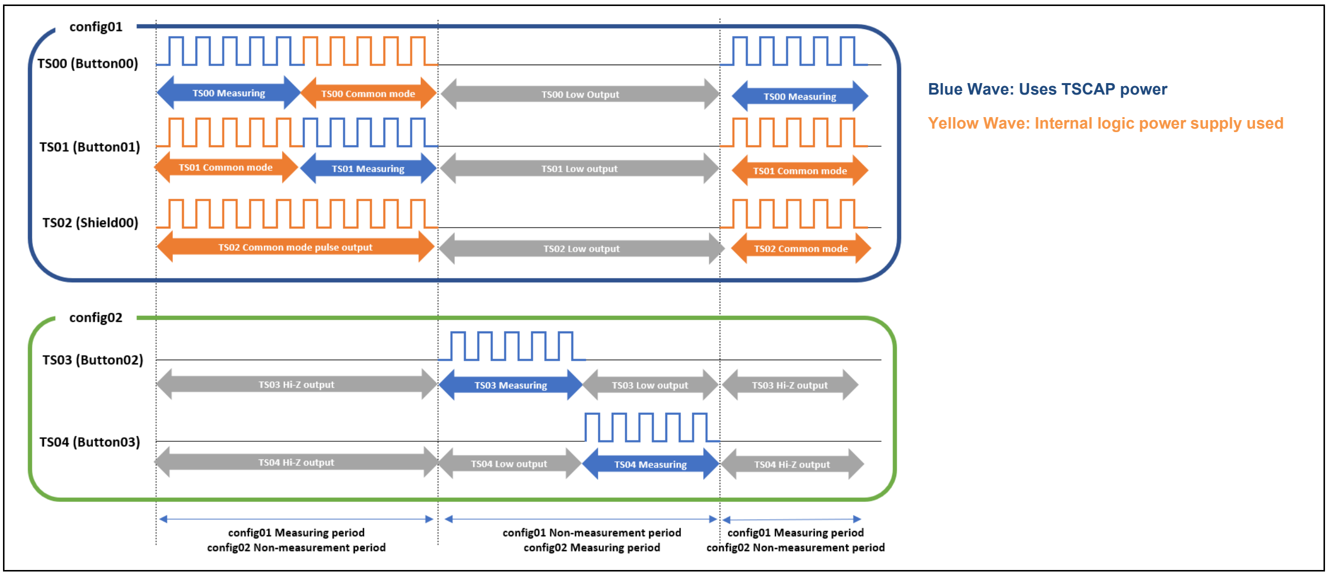


Figure 3-20 Image of TS terminal measurement

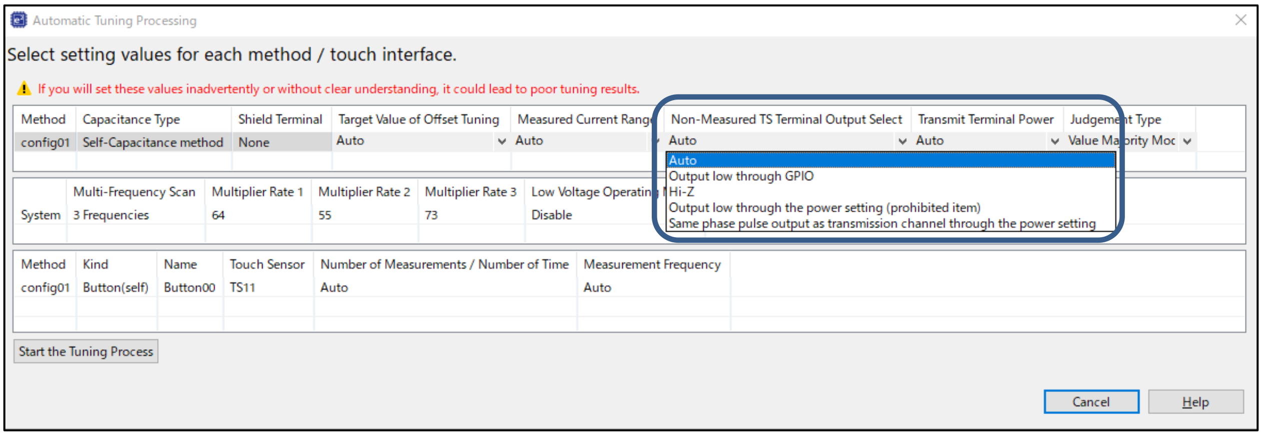
This is an example of a Non-Measured TS Terminal Output Select. Please refer to the following documents.
[RL78 Family Capacitive Touch Sensing Unit (CTSU2L) Operation Explanation Rev.1.00 (renesas.com)]

Table 3-16 shows an overview of each process setting.

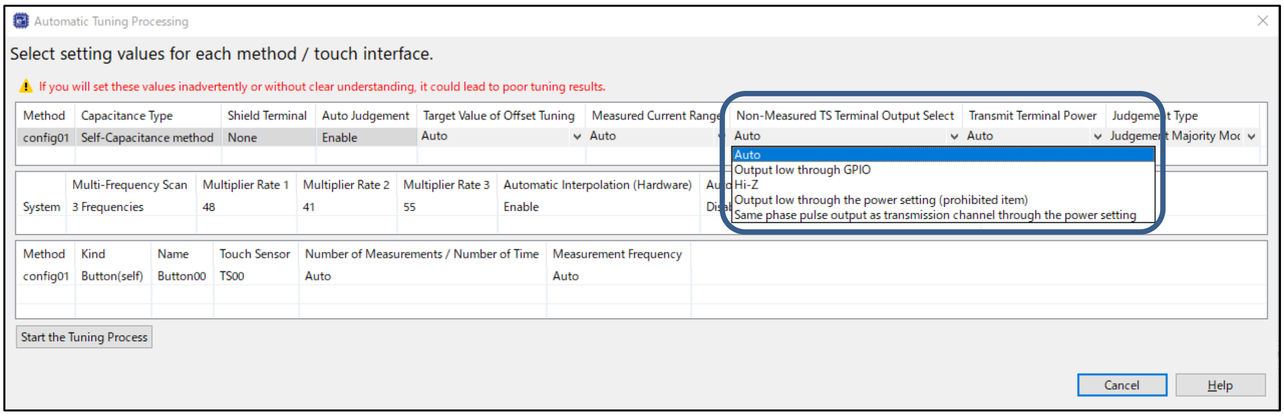
Table 3-16 Overview of processing settings

Non-Measured TS Terminal Output Select setting	Overview
Output low thorough GPIO	This setting is used to output a Low from the non-measurement terminal during measurement.
Hi-Z	This setting is used to output a Hi-Z from the non-measurement terminal during measurement.
Same phase pulse output as transmission channel through the power setting	This setting outputs a shield signal in phase with the sensor drive pulse from the non-measurement terminal during the measurement period.

Figure 3-21 shows an example window for setting "Non-Measured TS Terminal Output Select" with “Advanced mode”.



CTSU2



CTSU2x

Figure 3-21 Setting of "Non-Measured TS Terminal Output Select"

The settings are reflected in the qe_touch_config.c. Below is an example of setting from GPIO to L-output.

```
.posel  = CTSU_POSEL_LOW_GPIO,
```

Note: Refer to the respective capacitive touch sensor hardware manual for more information on POSEL.

3.6 Transmit Terminal Power

When the mutual capacitance method is used, I/O power supply of the terminals set in the transmit terminal is selected for each method in the "Transmit Terminal Power". The selected power supply is also used for the self-capacitance active shield electrode.
This value uses the default setting and should not be changed. For details, refer to the following document.

RL78 Family Capacitive Touch Sensing Unit (CTSU2L) Operation Explanation Rev.1.00 (renesas.com)

Table 3-17 lists the default settings.

Table 3-17 Default "Transmit Terminal Power" settings

	When self-capacitance method is used	When using mutual capacitance method	When using active shield
CTSU1	VCC	VCC	-
CTSU2/CTSU2x	VCC	VCC (private)	Internal logic power supply (Power supply for active shield)

Table 3-18 outlines the settings in CTSU1.

Table 3-18 Overview of "Transmit Terminal Power " settings for CTSU1

	Power setting of transmit terminal	TXVSEL	Overview
When self-capacitance method is used	VCC	0	Only the receive terminal is used during measurement and the transmit terminal is not used. The receiving terminal uses TSCAP power supply.
When using mutual capacitance method	VCC	0	The transmission terminal is also used during measurement. Sensitivity changes depending on the voltage of the transmission terminal. The receiving terminal uses TSCAP power supply.

When using CTSU1, do not set TXVSEL = 1.

Table 3-19 outlines the settings in CTSU2/CTSU2x.

Table 3-19 Overview of "Transmit Terminal Power " settings for CTSU2/CTSU2x

	Power setting of transmit terminal	TXVSEL	TXVSEL2	Overview
When self-capacitance method is used	VCC	0	0	Only the receive terminal is used during measurement and the transmit terminal is not used. The receiving terminal uses TSCAP power supply.
When using mutual capacitance method	VCC (private)	0 / 1	1	The transmission terminal is also used during measurement. Sensitivity changes depending on the voltage of the transmission terminal. The receiving terminal uses TSCAP power supply.
When using active shield	Internal logic power supply (Power supply for active shield) RX,RA:VCL RL:REGC	1	0	The transmit terminal is used for the output of the shield pulse. It can act as a shield by outputting pulses of the same phase and potential as the receiving terminal from the transmitting terminal. The receiving terminal uses TSCAP power supply.

Note: For details, refer to "2.3.1 Detection Principle" in the following documents.

Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)

Figure 3-22 shows an example window for setting "Transmit Terminal Power" with “Advanced mode”.

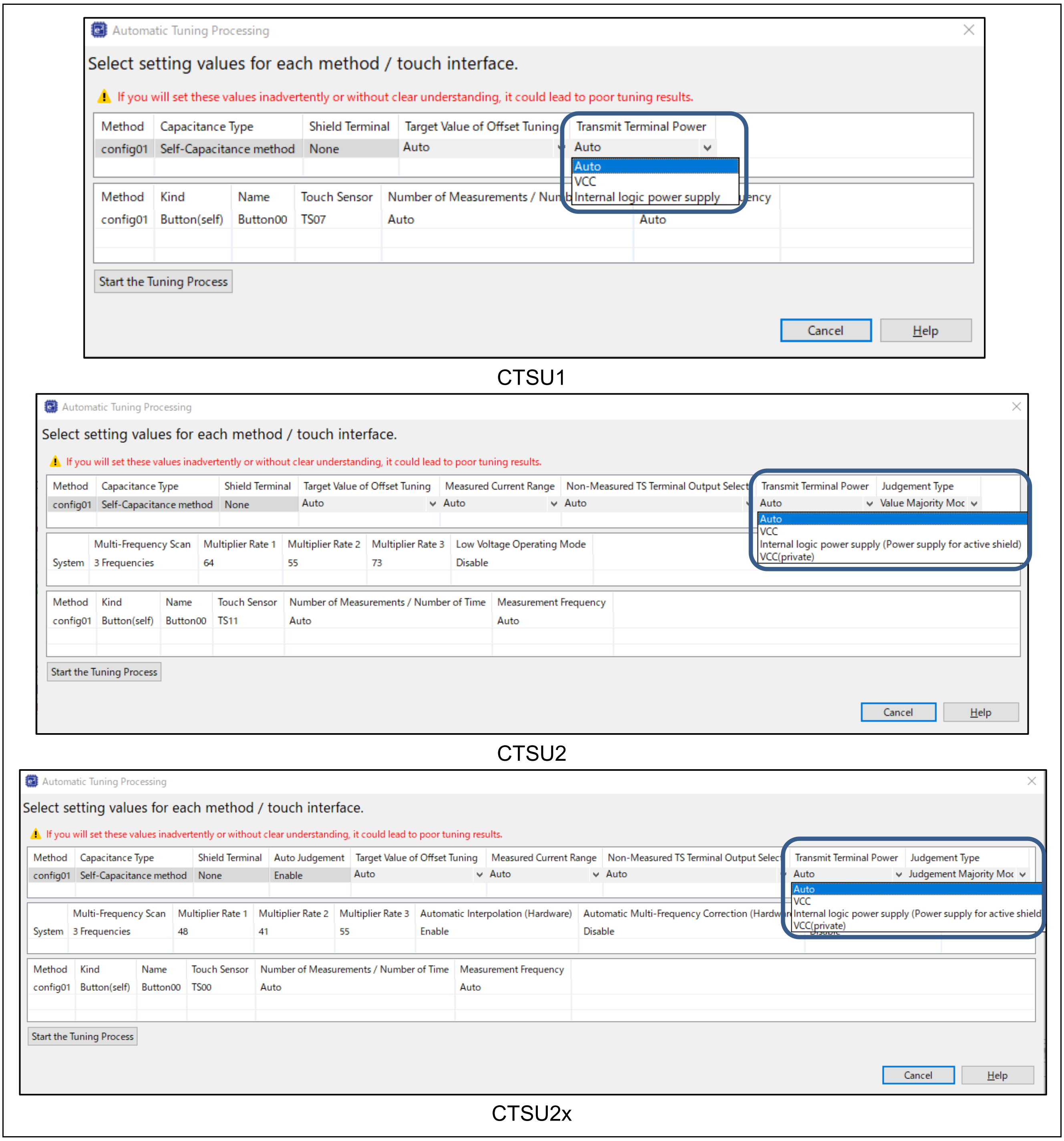


Figure 3-22 Setting of "Transmit Terminal Power"

The settings are reflected in the qe_touch_config.c.

Below is a sample of CTSU1.

- When self-capacitance method/mutual capacitance method used

```
.txvsel = CTSU_TXVSEL_VCC,
```

Below is a sample of CTSU2/CTSU2x.

- When self-capacitance method is used

```
.txvsel = CTSU_TXVSEL_VCC,
.txvsel2= CTSU_TXVSEL_MODE,
```

- When mutual capacitance method is used

```
.txvsel = CTSU_TXVSEL_VCC,
.txvsel2= CTSU_TXVSEL_VCC_PRIVATE,
```

- When active shield is used

```
.txvsel = CTSU_TXVSEL_INTERNAL_POWER,
.txvsel2= CTSU_TXVSEL_MODE,
```

3.7 Judgement Type/Multi-Frequency Scan/Multiplier Rate

The settings for "Judgement Type" and "Multi-Frequency Scan" and "Multiplier Rate" can be changed only with CTSU2/CTSU2x.
Multi-Frequency Scan can be performed with multiple sensor drive pulse frequencies to avoid synchronous noise. By default, it measures at 3 different frequencies and uses the results of measurements at each of the 3 frequencies to make touch judgements. "Judgement Type" can be set for each method, and "Multi-Frequency Scan" and "Multiplier Rate" can be set for each system.

The touch judgement method is shown below.

1. Value Majority Mode

Measured value majority (Value Majority Mode: VMM) is the result of two measurements that are close to the measured value of three frequencies.
Touch judgement is performed with the value obtained by adding. Figure3-23 shows the operation image when VMM is used.

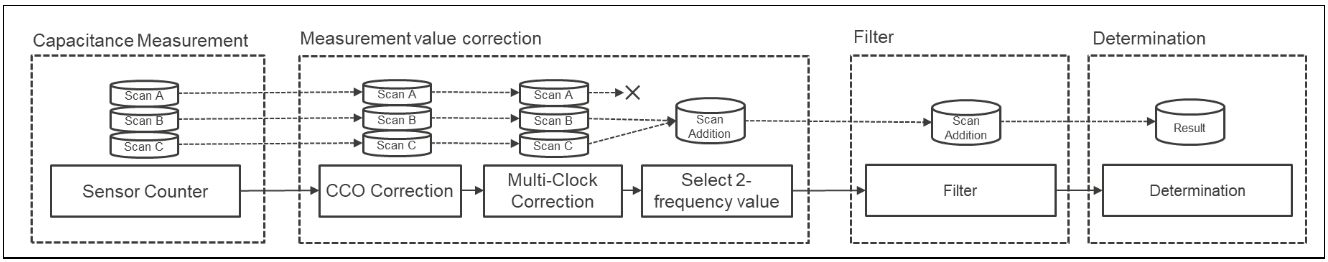


Figure3-23 Image of operation when VMM is used

2. Judgement Majority Mode

Majority Decision Mode (Judgement Majority Mode: JMM) is a method to make the final touch-judgement by majority decision based on the judgement result of each of the three-frequency measurements. Only the self-capacitance and mutual capacitance buttons are supported. Figure 3-24 shows the operation image when JMM is used.

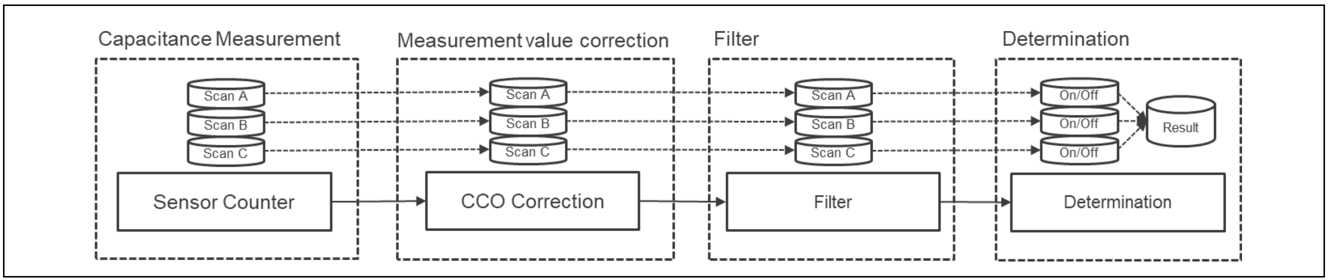


Figure 3-24 Image of operation when JMM is used

Refer to the following document for details of the touch judgement method.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)

Table3-20 shows examples of default settings for "Judgement Type" and "Multi-frequency Measurement" when buttons are used.

Table3-20 Default "Judgement Type/Multi-frequency measurement" settings

	Auto judgement	Judgement Type	Multi-frequency Scan
CTSU2	-	Value Majority Mode	3 frequency
CTSU2x	Enable	Judgement Majority Mode	3 frequency
	Disable	Value Majority Mode	3 frequency

The measurement frequency according to the set Multiplier Rate is displayed as shown in Figure 3-25.

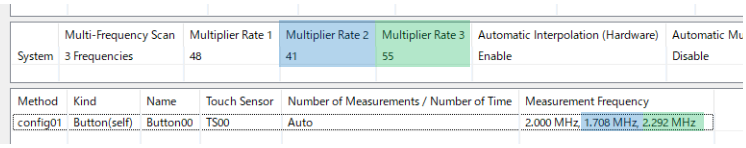


Figure 3-25 Measurement Frequency by Setting the Multiplier Rate

In the advanced mode setting, the Multi-Frequency Scan is measured by three sensor drive pulse frequencies respectively. The 1st frequency is the value set by "Measurement frequency" (sensor drive pulse frequency). Its Multiplier Rate is fixed to 48 or 64 by the device. The Multiplier Rate of the 2nd and 3rd frequencies can be changed to an arbitrary value.

Table 3-21 shows the default setting of the "Multiplier Rate" and the lower and upper limits that can be set.

Table 3-21 Default "Multiplier Rate" settings

Device	1st frequency Multiplier rate[*1]	2nd frequency Multiplier rate[*2]	3rd frequency Multiplier rate[*2]
RL78/G22 RL78/G23	48	41 [32~60]	Normal：55 [32~60] Low voltage operating：46 [32~60]
RX260 RX261	48	41 [32~64]	Normal：55 [32~64] Low voltage operating：46 [32~64]
Other Device	64	Normal：55 [32~80] Low voltage operating：55 [32~64]	Normal：73 [32~80] Low voltage operating：46 [32~64]

Note1: The multiplication factor of the 1st frequency differs depending on the upper limit of SUCLK. For more information on SUCLK, refer to the Hardware Manual for the respective Capacitive Touch Sensor MCUs.
Note2: For details on the Low Voltage Operating Mode, see "3.9 Low Voltage Operating Mode".

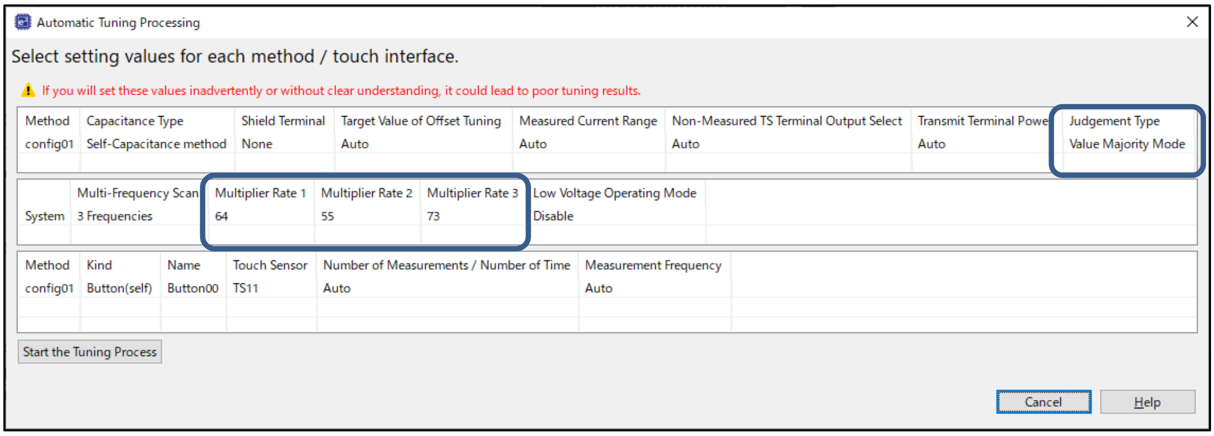
The formulas for calculating the measurement frequencies of the 2nd and 3rd frequencies when the multiplier rate is changed are shown below.

Measurement frequency [2nd frequency] = Measurement frequency [1st frequency] × Multiplier rate [2nd frequency]/Multiplier rate [1st frequency]

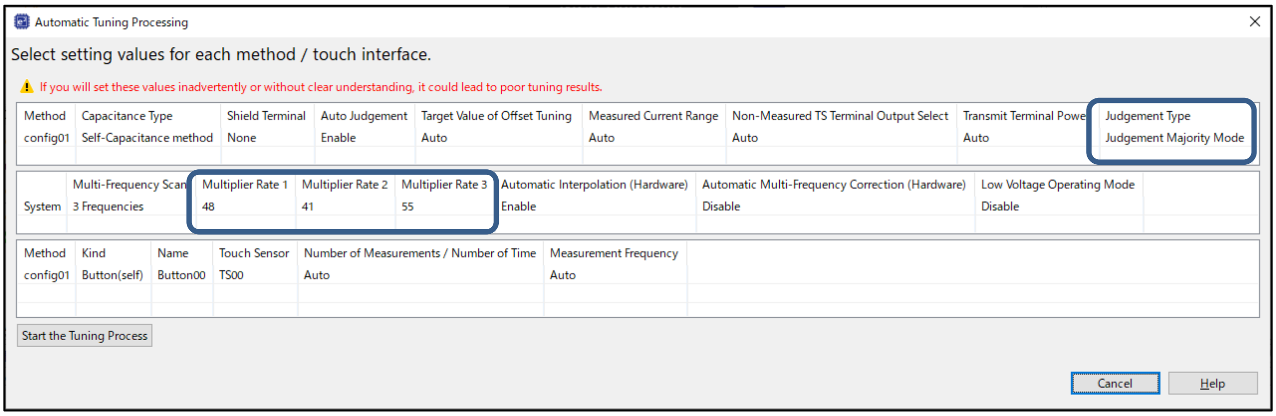
Measurement frequency [3rd frequency] = Measurement frequency [1st frequency] × Multiplier rate [3rd frequency]/Multiplier rate [1st frequency]

Increasing the frequency difference for 3-frequency measurement tends to increase the dispersion of the measurement value.
In addition, the multiplier rate should be set so that the measurement value does not overflow. The multiplier rate should be set after thorough evaluation.

Figure 3-26 shows an example window for setting the "Judgement Type/Multi-Frequency Scan/Multiplier Rate" in advanced mode.



CTSU2



CTSU2x

Figure 3-26 Setting of "Judgement Type/Multi-Frequency Scan/Multiplier Rate"

The settings for "Judgement Type" are reflected in the qe_touch_define.h. The following is a sample setting when VMM is used.

```
#define CTSU_CFG_MAJORITY_MODE (1)
```

The setting of "Multi-Frequency Scan/Multiplier Rate" is reflected on the qe_touch_define.h. Below is an example of setting when the upper limit of SUCLK is 40MHz.

```
#define CTSU_CFG_NUM_SUMULTI    (3)
#define CTSU_CFG_SUMULTI0       (0x3F)
#define CTSU_CFG_SUMULTI1       (0x36)
#define CTSU_CFG_SUMULTI2       (0x48)
```

Note: Refer to the respective capacitive touch sensor hardware manual for more information on SUMULTI.

3.8 Auto Judgement/Automatic Interpolation (Hardware)/Automatic Multi-Frequency Correction (Hardware)

The "Auto Judgement" and "Automatic Interpolation (Hardware)" and "Automatic Multi-Frequency Correction (Hardware)" settings are applicable to CTSU2x. "Auto Judgement", "Automatic Interpolation (Hardware)", and "Automatic Multi-Frequency Correction (Hardware)" are functions for performing touch judgements, CCO corrections, and multi-frequency corrections on hardware. This eliminates the need for software processing, reducing power consumption and processing time for the main processor. In Advanced Mode, the "Automatic Interpolation" and "Automatic Multi-Frequency Correction " settings are set automatically by referring to the "Auto Judgement" settings. Auto judgement using Value Majority Mode (VMM) will be supported in future updates. Table3-22 shows a description of each function.

Table3-22 Function overview of "Auto judgement/Automatic multi-frequency correction (Hardware)/Automatic Interpolation (Hardware)"

Function	Function overview
Auto judgement	This function is used to judge the touch of a button using hardware. This function is only available for buttons. SNOOZE-mode programmable controller (SMS) can be used together with SMS if it is a built-in MCU. When SMS is used, only the Judgement Majority Mode (JMM) is available. Auto judgement using Value Majority Mode (VMM) will be supported in future updates.
Automatic Interpolation (Hardware)	This function performs CCO compensation computation with hardware.
Automatic Multi-Frequency Correction (Hardware)	This function performs frequency correction after 3 frequencies are measured by hardware. Frequency correction process after 3-frequency measurement and the results of 2 frequencies with close values from the 3-frequency measurement are selected for the final measurement result. Available only when Value Majority Mode (VMM) is used. Auto judgement using Value Majority Mode (VMM) will be supported in future updates.

Figure 3-27 shows the operation image of the functions when VMM is used. Auto judgement using VMM will be supported in future updates.

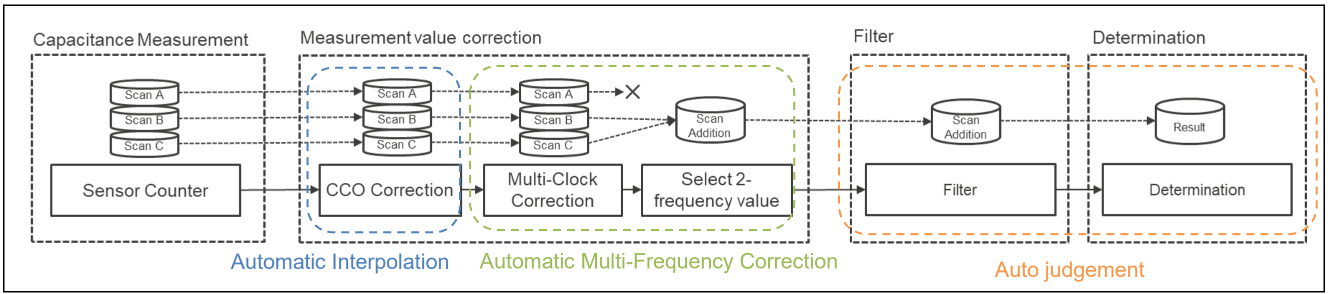


Figure 3-27 Image of operation when VMM is used

Figure 3-28 shows the operation image of the functions when JMM is used. Multi-Frequency Correction is not available when JMM is used.

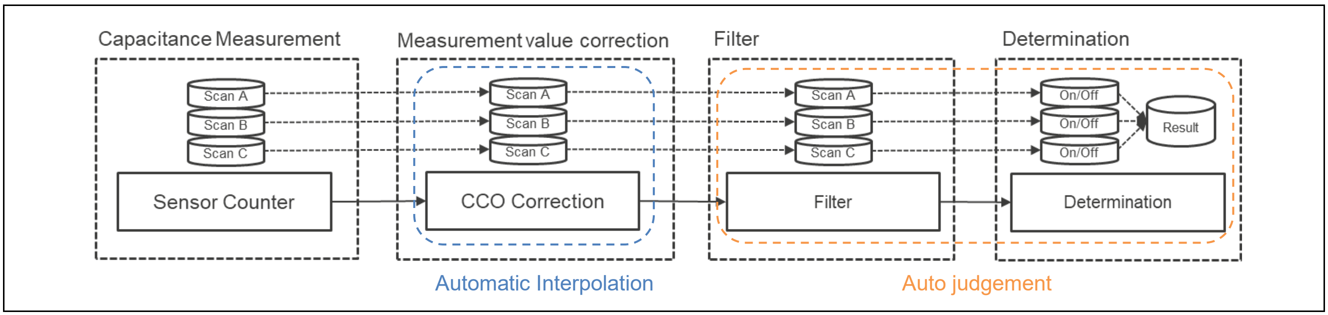


Figure 3-28 Image of operation when JMM is used

Table3-23 shows examples of default settings for each function when auto judgement is enabled or disabled.

Table3-23 “Default Settings for "Automatic Interpolation (Hardware)/Automatic Multi-Frequency Correction (Hardware)"

Auto judgement	Automatic Interpolation (Hardware)	Automatic Multi-Frequency Correction (Hardware)
Enable	Enable	When using VMM*: Enable When JMM is used: Disable
Disable	Disable	Disable

Note: Auto judgement using VMM will be supported in future updates.

If the auto judgement function is enabled for any method in the system, Automatic Interpolation is enabled as the system. If VMM is used when the auto judgement is enabled, the automatic multi-frequency correction is also enabled. Figure 3-29 shows the flow for determining the "Auto Judgement/Automatic Interpolation (Hardware)/Automatic Multi-Frequency Correction (Hardware)" setting.

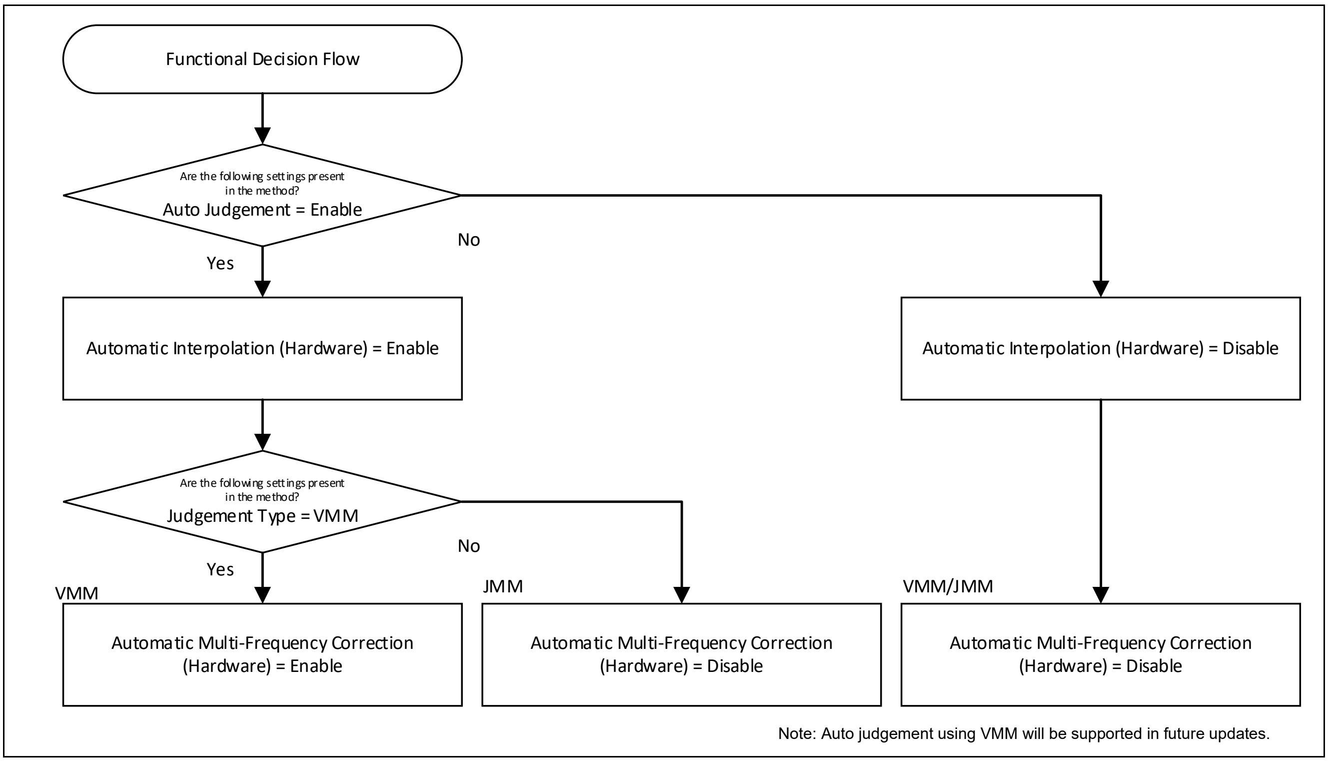
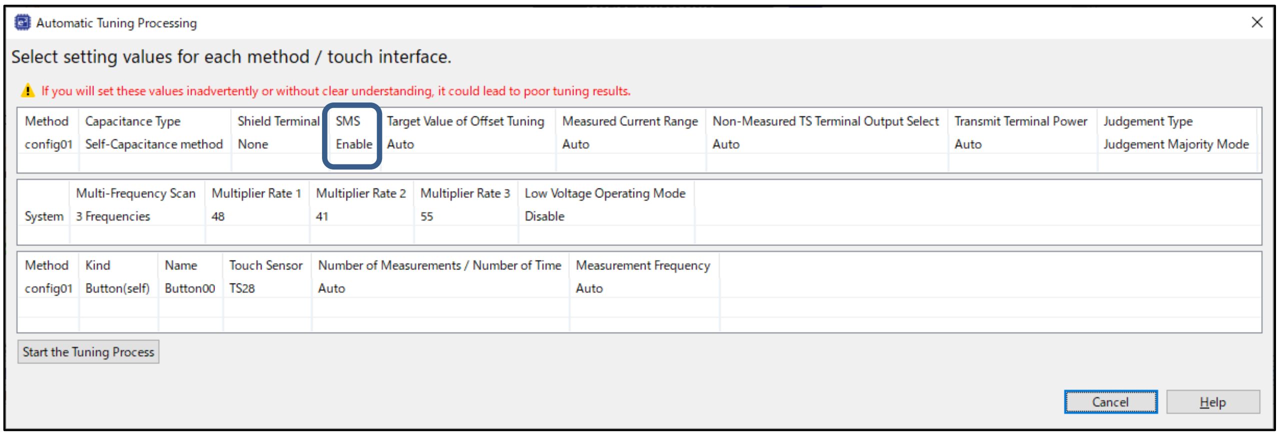
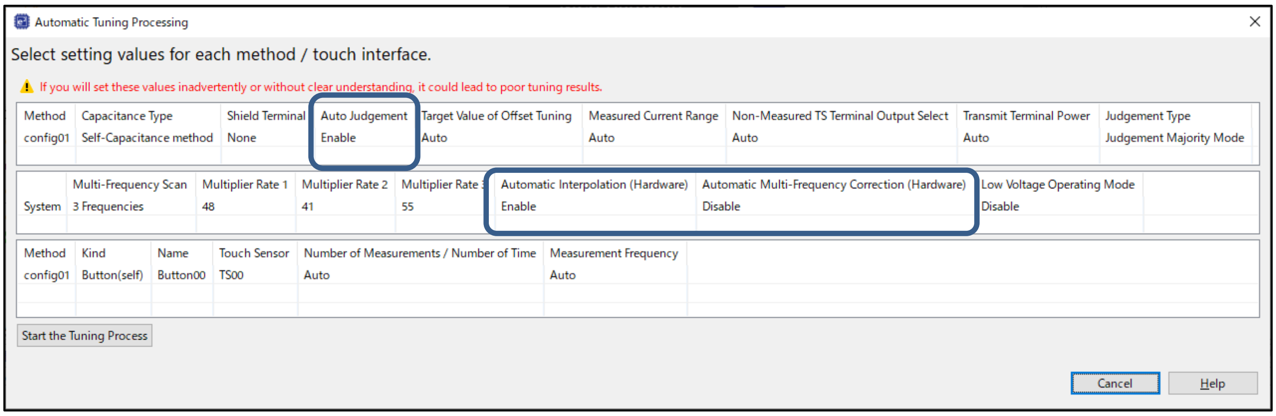


Figure 3-29 Flowchart for Determining "Auto Judgement/Automatic Interpolation (Hardware)/ Automatic Multi-Frequency Correction (Hardware)"

Figure3-30 shows a window example when setting "Auto Judgement/Automatic Interpolation (Hardware)/Automatic Multi-Frequency Correction (Hardware)" in Advanced Mode. When the MCU with built-in SMS is used, "SMS" is displayed for "Auto Judgement". Auto judgement using VMM will be supported in future updates.



CTSU2L/CTSU2La



CTSU2SL/CTSU2SLa

Figure3-30 Setting of "Auto Judgement/Automatic Interpolation (Hardware)/Automatic Multi-Frequency Correction (Hardware)"

The "Auto Judgement" setting is reflected in the r_ctsu_qe_config.h. The following is an example when Auto judgement is enabled.

```
#define CTSU_CFG_AUTO_JUDGE_ENABLE          (1)
```

The setting of "Automatic Interpolation (Hardware)/Automatic Multi-Frequency Correction (Hardware)" is reflected in the qe_touch_define.h. The following is an example of when Auto Judgement is enabled when JMM is used.

```
#define CTSU_CFG_AUTO_CORRECTION_ENABLE       (1)
#define CTSU_CFG_AUTO_MULTI_CLOCK_CORRECTION_ENABLE  (0)
```

Note: For details of each function, refer to the hardware manual of each capacitive touch sensor.

3.9 Low Voltage Operating Mode

The "Low Voltage Operating Mode" setting can be changed only with CTSU2/CTSU2x.

In “Low Voltage Operating Mode”, TSCAP voltage to be used can be set for each system. When the operating voltage of the microcontroller is less than 2.4V,” Low Voltage Operating Mode” is automatically enabled and TSCAP voltage is 1.2V. This function is used when the microcomputer operating voltage becomes less than 2.4V during battery operation. In addition, “Low Voltage Operating Mode” can be used only when buttons, sliders and wheels are used. Switching TSCAP voltage during MCU operation is not supported.

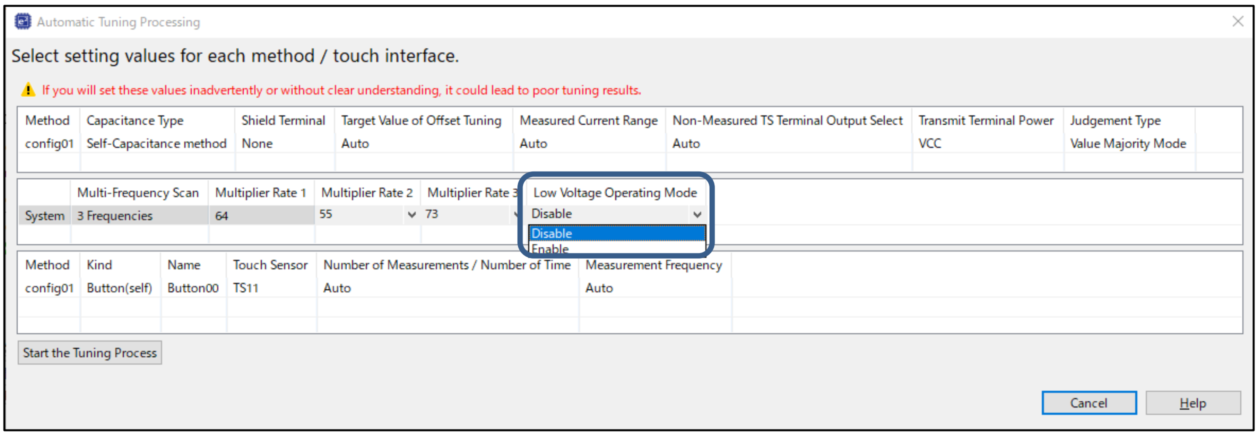
Table 3-24 shows an example of the default settings for “Low Voltage Operating Mode” with operating voltage.

Table 3-24 Default Settings for Low Voltage Operating Mode with Operating Voltage

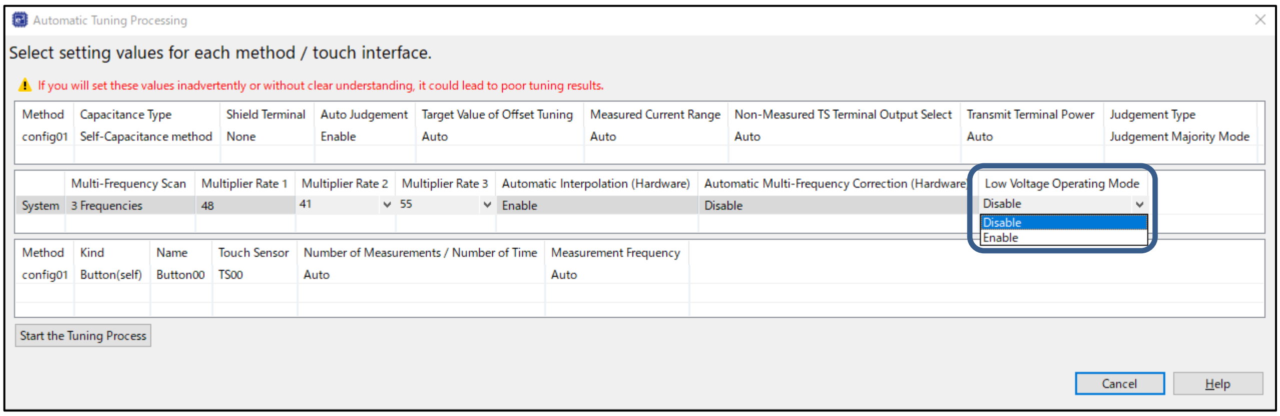
Operating voltage *	Low Voltage Operating Mode	TSCAP voltage
More than 2.4V	Disable	1.5V
Less than 2.4V	Enable	1.2V

Note: For configurable operating voltage, refer to the hardware manual of each capacitive touch sensor microcomputer.

Figure3-31 shows an example window for setting "Low Voltage Operating Mode" in Advanced Mode.



CTSU2



CTSU2x

Figure3-31 Setting of "Low Voltage Operating Mode"

The settings are reflected in the qe_touch_define.h. An example is shown below.

- When Low Voltage Operating Mode is disabled in the operating voltage 5.0V (TSCAP voltage: 1.5V)

```
#define CTSU_CFG_VCC_MV           (5000)
#define CTSU_CFG_LOW_VOLTAGE_MODE (0)
```

- When Low Voltage Operating Mode is enabled in the operating voltage 5.0V (TSCAP voltage: 1.2V)

```
#define CTSU_CFG_VCC_MV           (5000)
#define CTSU_CFG_LOW_VOLTAGE_MODE (1)
```

- When Low Voltage Operating Mode is enabled in the operating voltage 1.8V (TSCAP voltage: 1.2V)

```
#define CTSU_CFG_VCC_MV           (1800)
#define CTSU_CFG_LOW_VOLTAGE_MODE (1)
```

Note: For details on the low voltage operating mode, refer to the hardware manual of each capacitive touch sensor microcomputer.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Jun.20.23	-	First edition issued
2.00	Dec.25.23	P26	Added explanation on how to adjust measurement frequency
		P30	Added an image diagram of the amount of current change relative to the offset target value when the measured current range is changed.
		P38	Added image diagrams when Automatic Correction (Hardware) is enabled/disabled.
3.00	Oct.22.24	-	New feature information added ・Judgement Type ・Auto Judgement/Automatic Multi-Frequency Correction (Hardware) ・Low Voltage Operating Mode
		-	The diagram was changed with the change of the workflow after QE for Capacitive Touch v4.0.0 and the view design for monitoring.
		-	Changed figures because the available items have been renamed for the advanced dialogs from QE for Capacitive Touch v4.0.0 onwards.
		P1	Add CTSU2La, CTSU2SLa to the operation check device.
		P11	Updated Capacitive Touch Sensor Correspondence Table
		P15,26,31	Updated data as offset-tuning target value-updated in QE for Capacitive Touch v4.0.0
		P18	Corrected with offset-tuning target value updated in QE for Capacitive Touch v4.0.0
		P19	Table3-10 lists QE for Capacitive Touch v3.3.0 and v3.5.0 tuning targets
		P23	Added a chart of the relation between parasitic capacitance/damping resistor and measurement frequency, taking RX671 as an example.
		P29	Corrected the rated current value flowing through the Current Control oscillator (CCO).
		P34	Replace chapters 3.6 and 3.7 from the previous edition
		P37	Modified the title of chapter 3.7
		P40	Added explanation of Auto Judgement and Automatic Multi-Frequency Correction (Hardware)
		P43	Added explanation of Low Voltage Operating Mode

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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.
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