Capacitive Sensor MCU

QE for Capacitive Touch Advanced Mode Parameter Guide

Introduction

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 against 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, CTSU2SL, etc.)

Contents

1. Outline

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 tuning with QE for Capacitive Touch generates basic CapTouch parameters. If the required specifications are not met in evaluations using these parameter, 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.

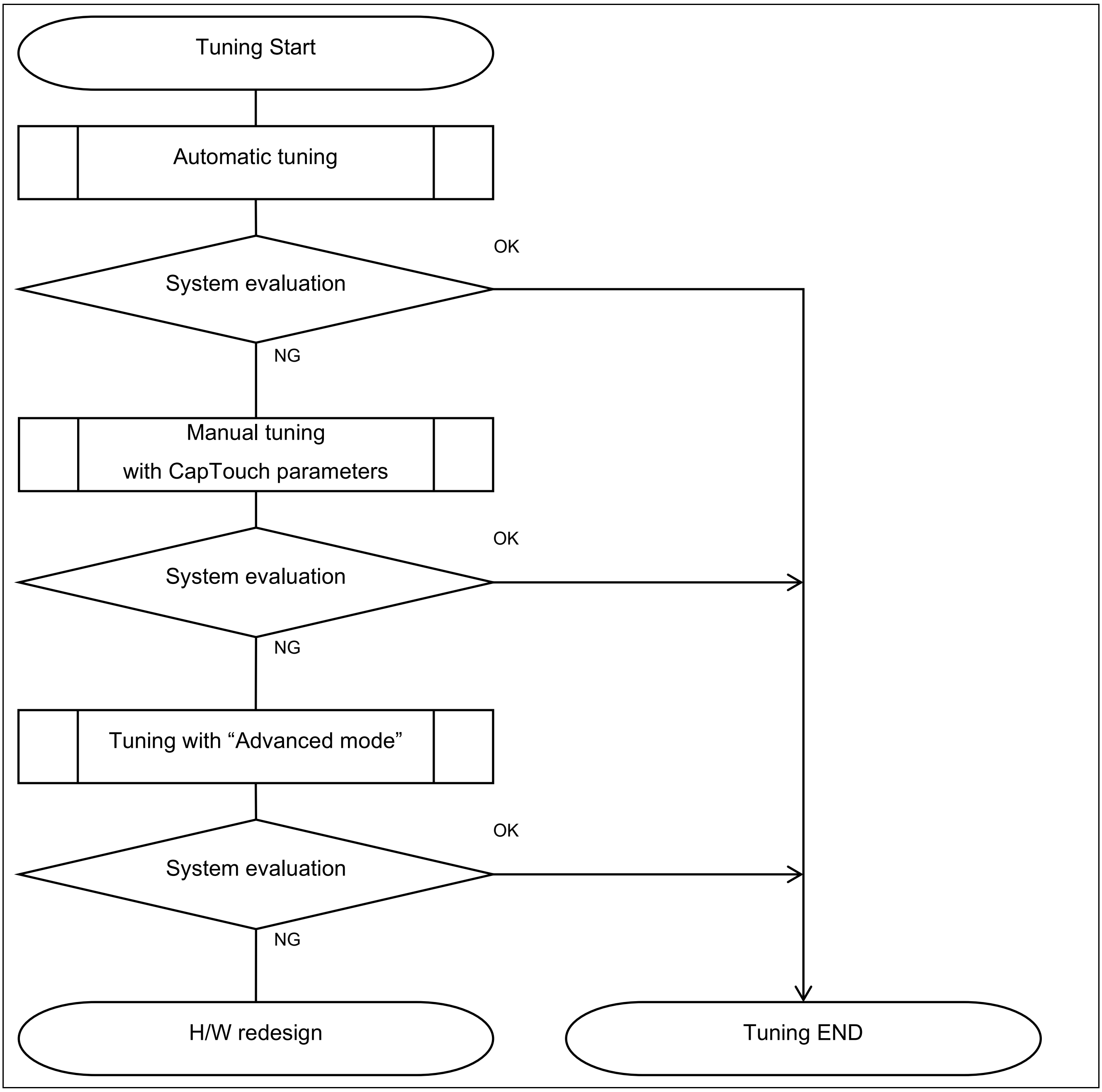


Figure 1-1 Tuning Flowchart

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*1	Manual tuning with CapTouch parameters *2	Tuning with “Advanced mode”
Measurement frequency	✓	-	✓
Offset	✓	-	-
Touch threshold	✓	✓	-
Hysteresis	✓	✓	-
Drift correction interval	-	✓	-
Long press cancel cycle	-	✓	-
Positive noise filter cycles	-	✓	-
Cycle of the negative noise filter	-	✓	-
Depth of the moving average filter	-	✓	-
Number of Measurements/Number of Time	-	-*4	✓
Target value of Offset Tuning	-	-*4	✓
Measured Current Range *3	-	-	✓
Non-Measured Channel Output Select*3	-	-	✓
Multi-Clock Measuring/Multiplier Rate*3	-	-*4	✓
Transmit Terminal Power	-	-	✓
Automatic Correction (Hardware)*3	-	-	✓

✓: Supported

Note: 1. In Auto tuning, QE for Capacitive Touch automatically adjusts parameter values and outputs the adjustment results to a source file.

Note: 2. For manual tuning with CapTouch parameters, see "CapTouch Parameters (QE)" in QE for Capacitive Touch for a list of parameters that can be changed. For details, please refer to "7.2 Manually Tuning with CapTouch Parameters" in the following document.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)

Note: 3. This function can be adjusted only for CTSU2/CTSU2L/CTSU2La/CTSU2SL. For CTSU2La/CTSU2L from the next page, refer to CTSU2. Also, please refer to the Introduction Guide for the difference between each capacitive touch sensor and compatible products.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)

Note: 4. The registers can be set from the "CapTouch Parameters (QE)", but do not change them, as they are parameters adjusted by the software to follow the environment.

If the “Auto tuning” or “Manual tuning with 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.

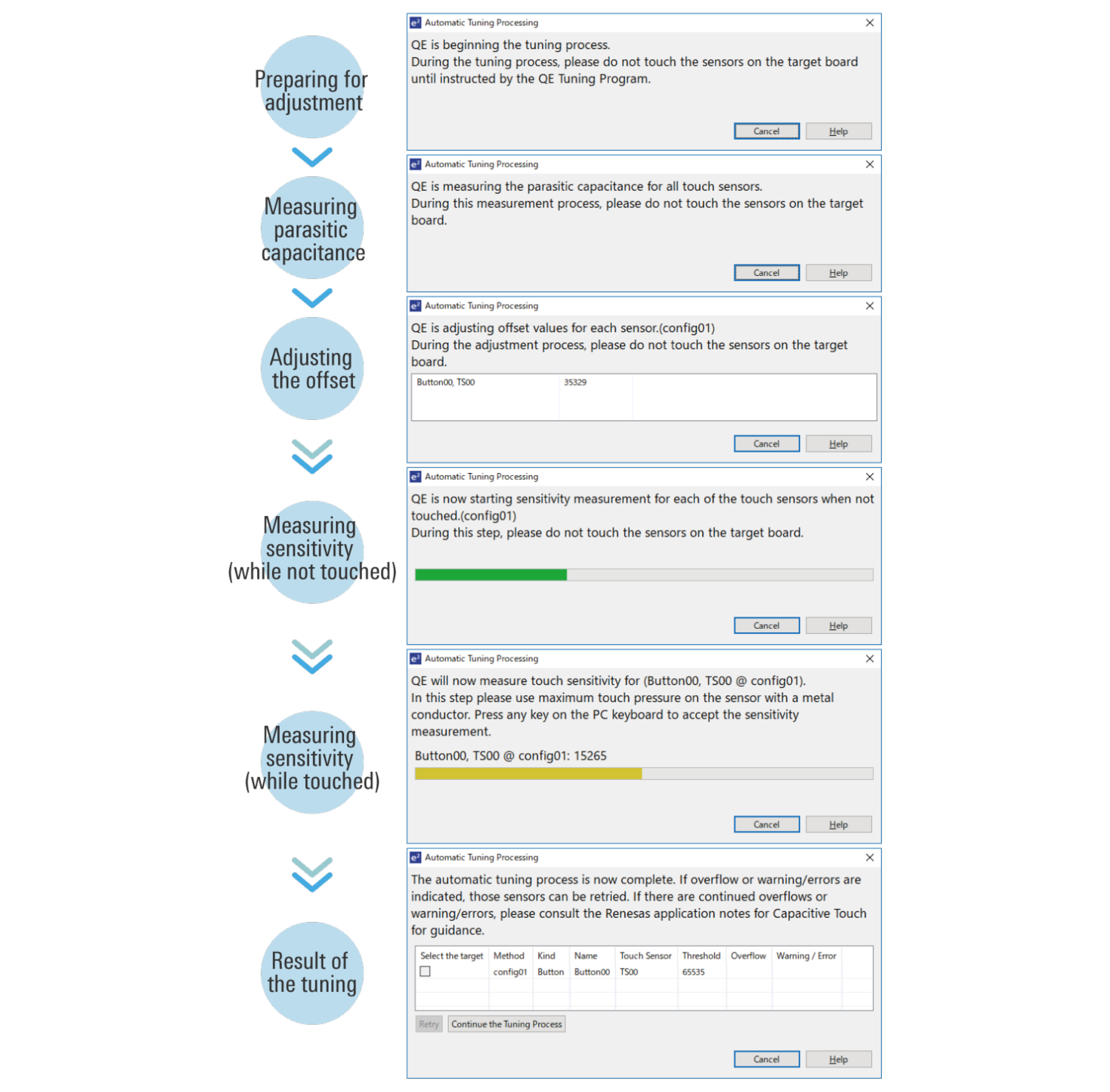


Figure 1-2 Flow of Auto tuning with QE for Capacitive Touch

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.

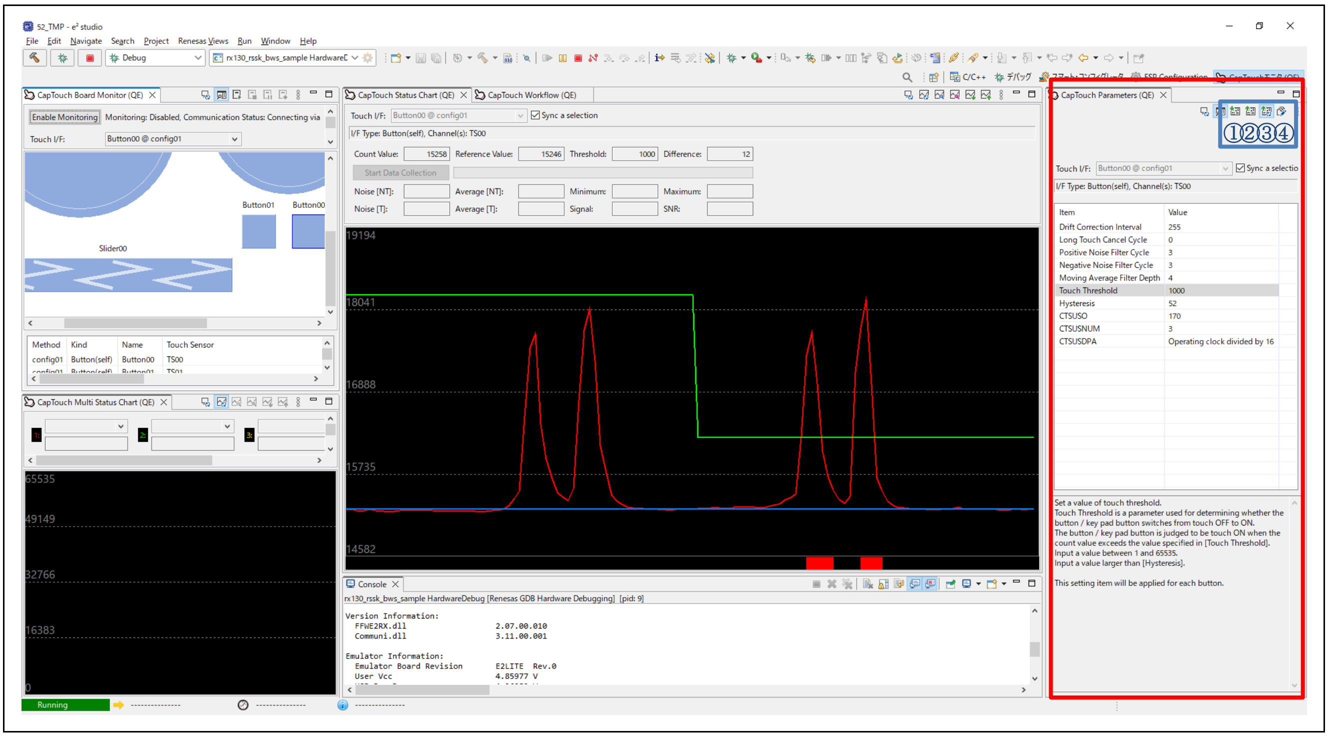


Figure 1-3 Manual Tuning with QE for Capacitive Touch

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”.

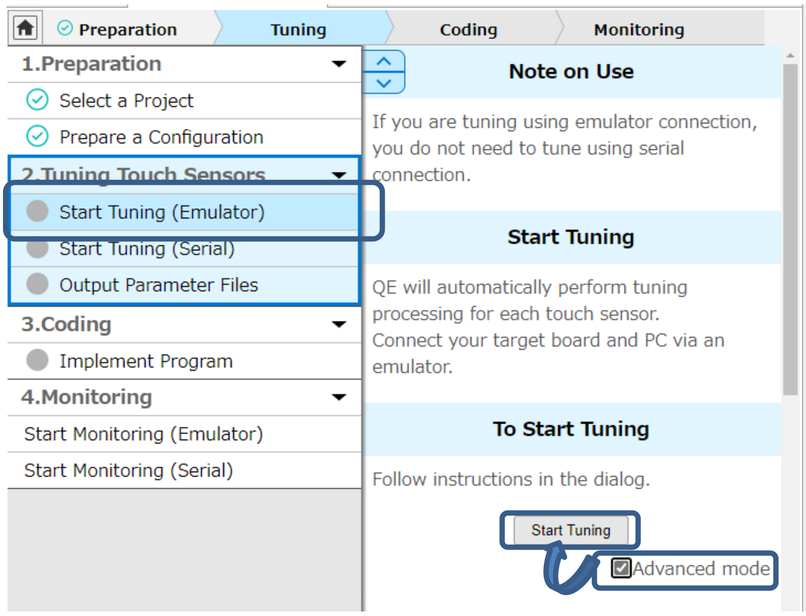
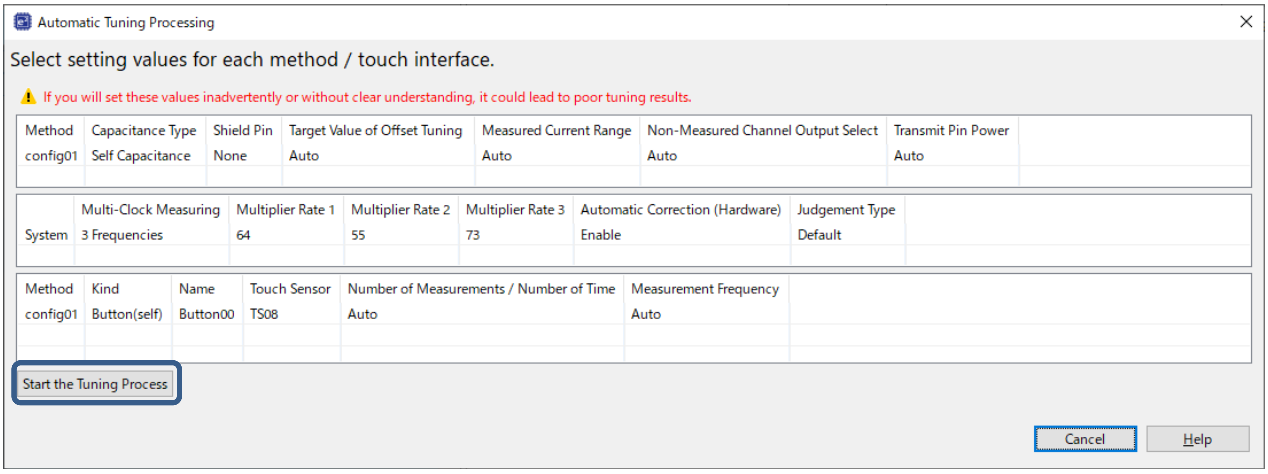


Figure 1-4 Tuning with "Advanced mode"

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 CTSU2SL

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.

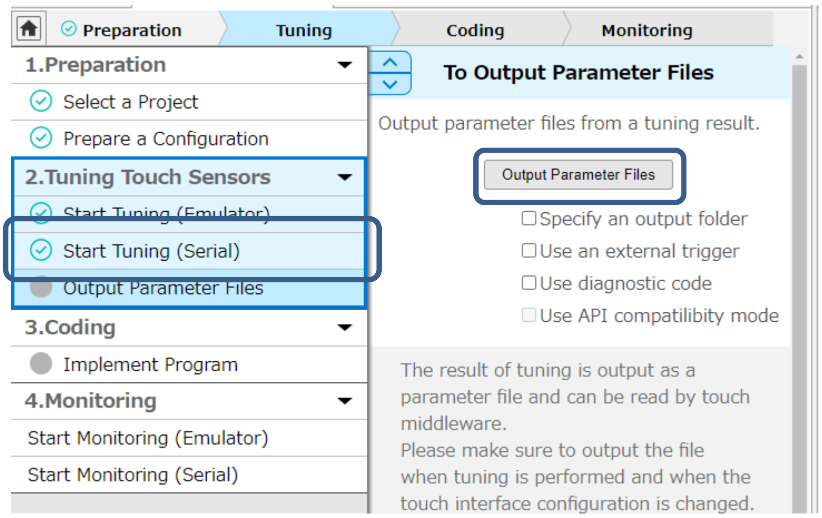


Figure 1-6 To Output Parameter Files

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.

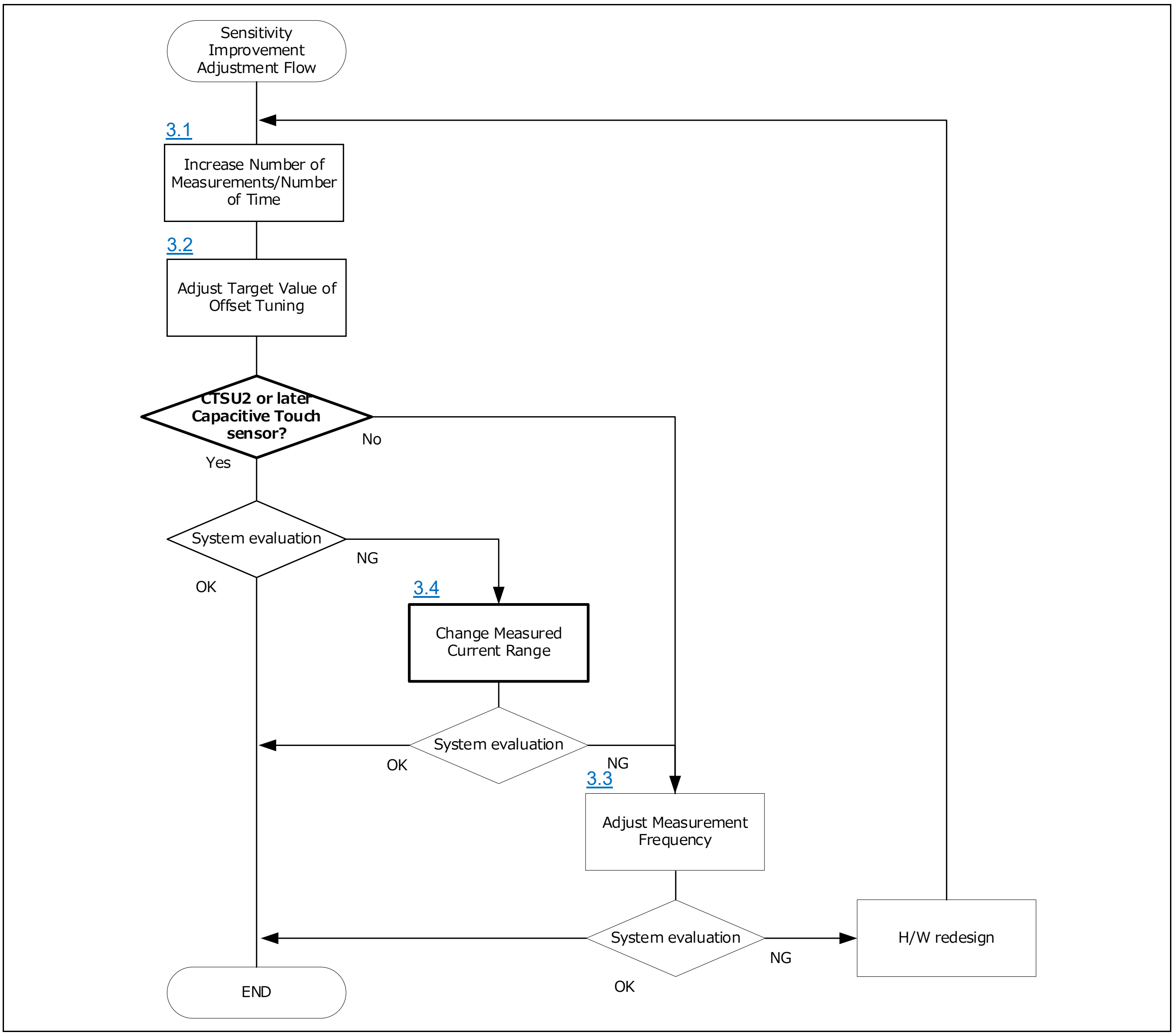


Figure 2-1 Sensitivity improvement adjustment flow

2.2 Noise suppression adjustment flow

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

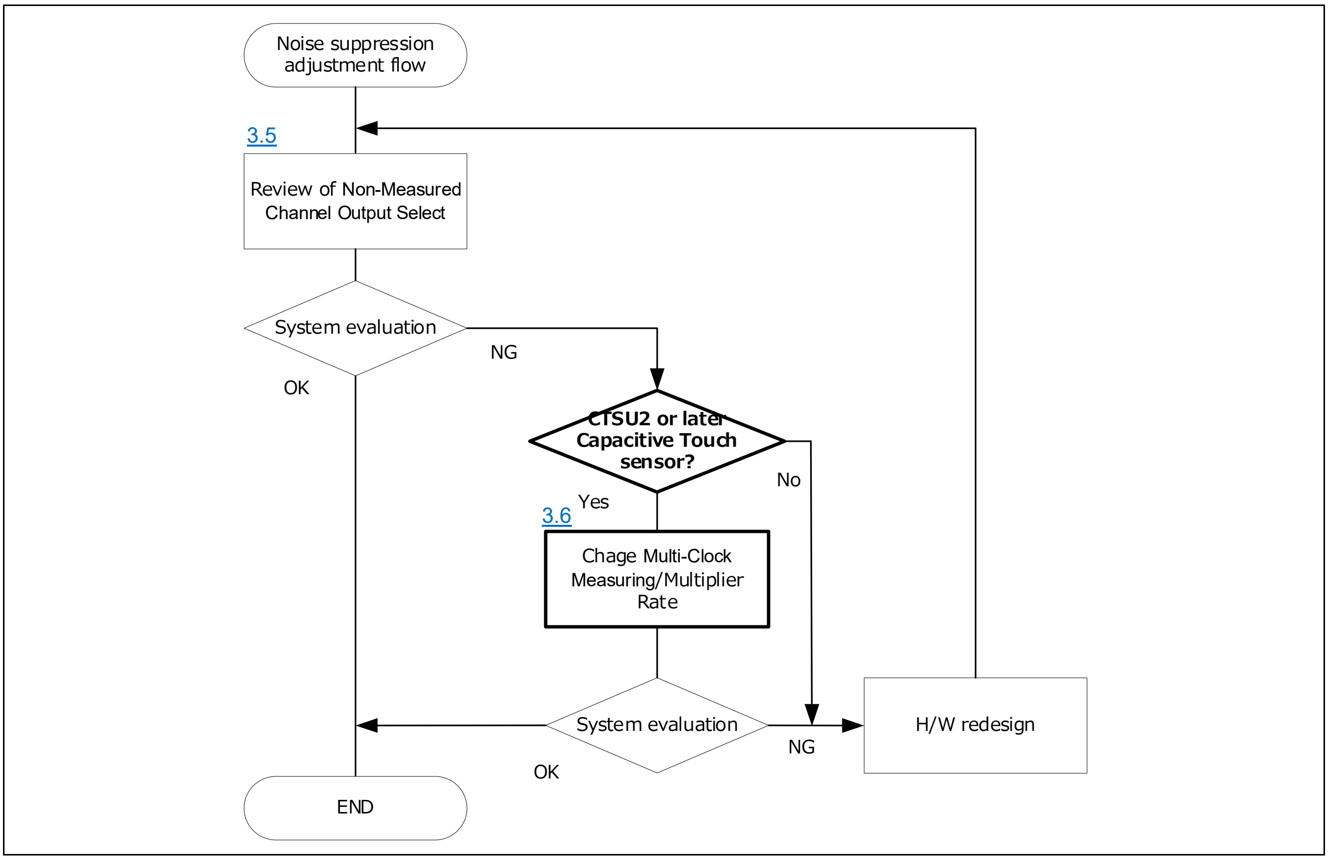


Figure 2-2 Noise suppression adjustment flow

2.3 Correspondence table for each capacitive touch sensor

Table 2-1 Correspondence table of capacitive touch sensors

Table 2-1 Correspondence table of capacitive touch sensors.

	Parameter	Purpose	CTSU2SL	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 Channel 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-measurement terminals.
6	Multi-Clock Measuring/Multiplier Rate	Noise Suppression	✓	✓	-	Set the number of times to be measured in multi-Clock measurement and the multiplier rate of multiple types of frequencies to be used for measurement. Multi-Clock Measurement allows you to measure multiple drive frequencies to avoid synchronous noise
7	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.
8	Automatic Correction (Hardware)	Process reduction Low power consumption	✓	-	-	Sets whether to process the compensation computation with CTSU peripheral. Hardware processing eliminates the need for wake-up for each measurement and contributes to power consumption reduction.

✓: Supported

3. Overview of each parameter

3.1 Number of Measurements/Number of Time

In "Number of Measurements/Number of Time", you can set how many times the charge/discharge is accumulated repeatedly to perform one touch detection, and determine the measurement time for one touch detection. 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.

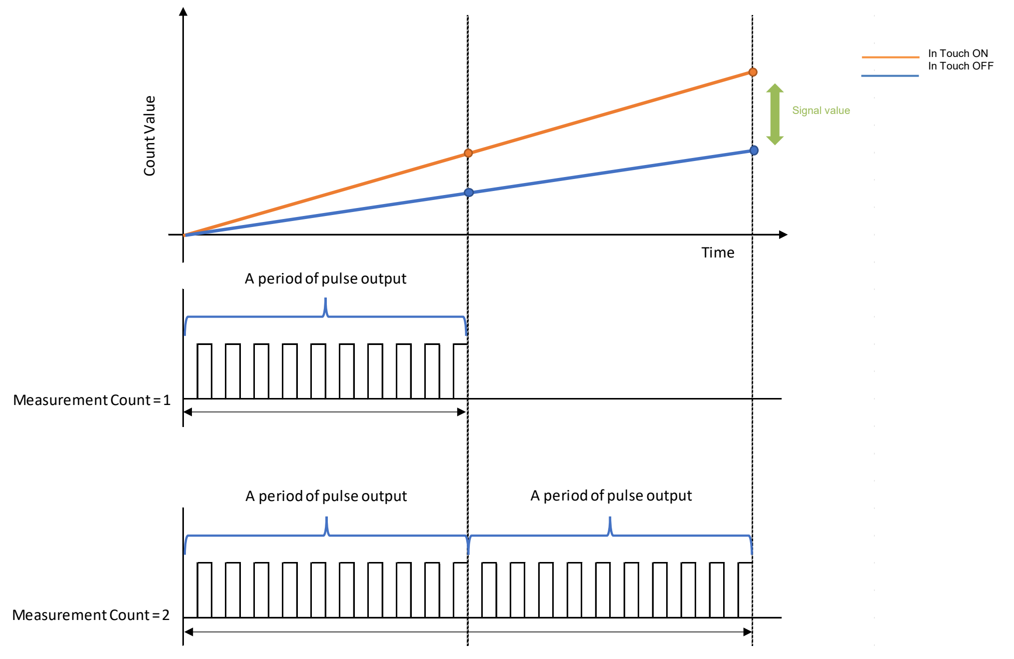


Figure 3-1 Image of measurement time and measurement value based on the number of measurements

Table 3-1 shows the default number of measurements.

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/CTSU2SL (Sample RX140)	-	8	128 *2

Note: 1. Refer to the respective capacitive touch sensor hardware manual for more information on SNUM. By CTSU2/CTSU2SL, the number of measurements is fixed at 8.

Note: 2. The measurement time of one frequency is described.

The stabilization wait time and measurement time also vary depending on the number of measurements. The formulas for calculating the stabilization wait time and measurement time for CTSU1, CTSU2/CTSU2SL 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/CTSU2SL (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/CTSU2SL 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 [384 + 192]

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.2.20 (renesas.com)

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

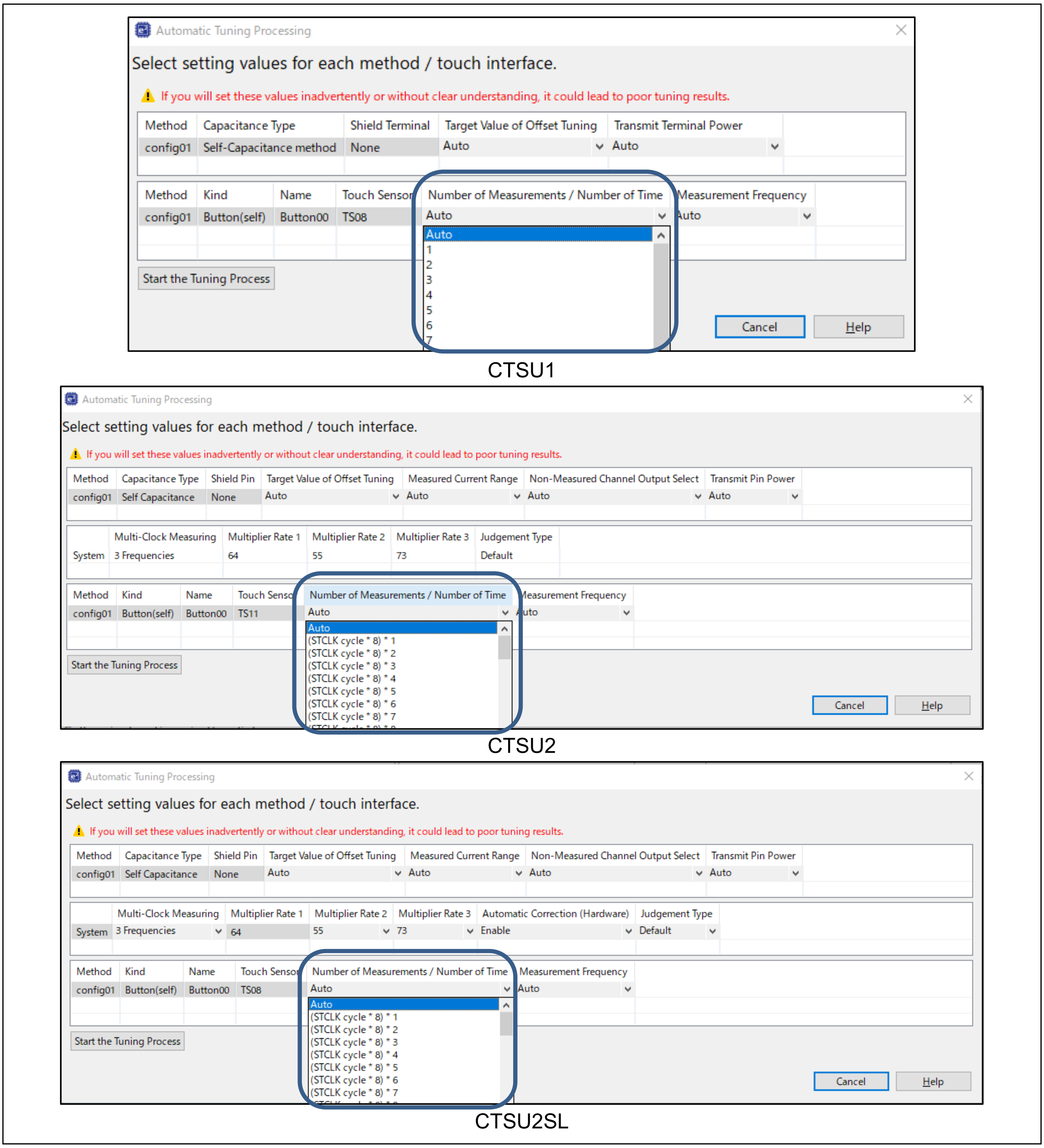


Figure 3-2 Setting of "Number of Measurements/Number of Time"

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 Impact 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 CTSU2SL(RX140) Self-capacitance 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	Stabilization wait time + Measurement time
8	37.5%	15388	17186	1798	17.8	576 µs
12	25%	15354	18279	2925	30.4	768 µs
15	20%	15339	19124	3785	36	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.

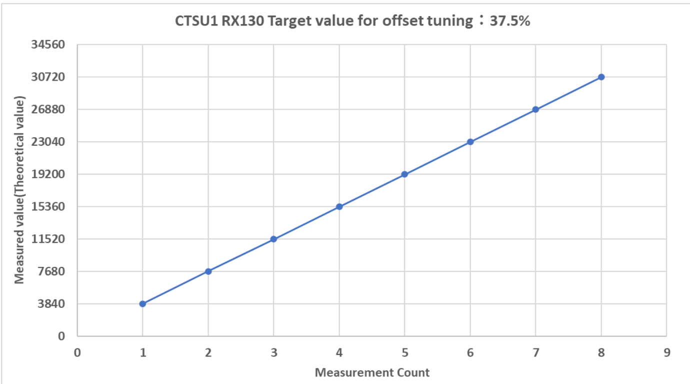
3.1.2 Necessity of Offset Tuning Adjustment when Changing Number of Measurements

When the number of measurements is changed, the sensor counter register becomes 0x0FFFF and the measurement value exceeds 65535. 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 RX**13**0 (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/CTSU2SL.

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

Capacitance Touch Evaluation System with CTSU2SL(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]	Measurement value (theoretical value)
1 [(STCLK cycle* 8) * 1]	192	48	240	1920
2 [(STCLK cycle* 8) * 2]	192	96	288	3840
3 [(STCLK cycle* 8) * 3]	192	144	336	5760
:	:	:	:	:
8 [(STCLK cycle* 8) * 8]	192	384	576	15360
:	:	:	:	:
16 [(STCLK cycle* 8) * 16]	192	768	960	30720
:	:	:	:	:

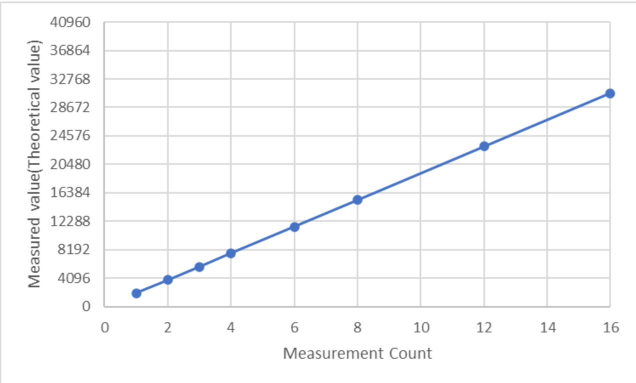


Figure 3-4 Measurement value (theoretical value) for "Number of Measurements/Number of Time" with RX140

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 30720. 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.

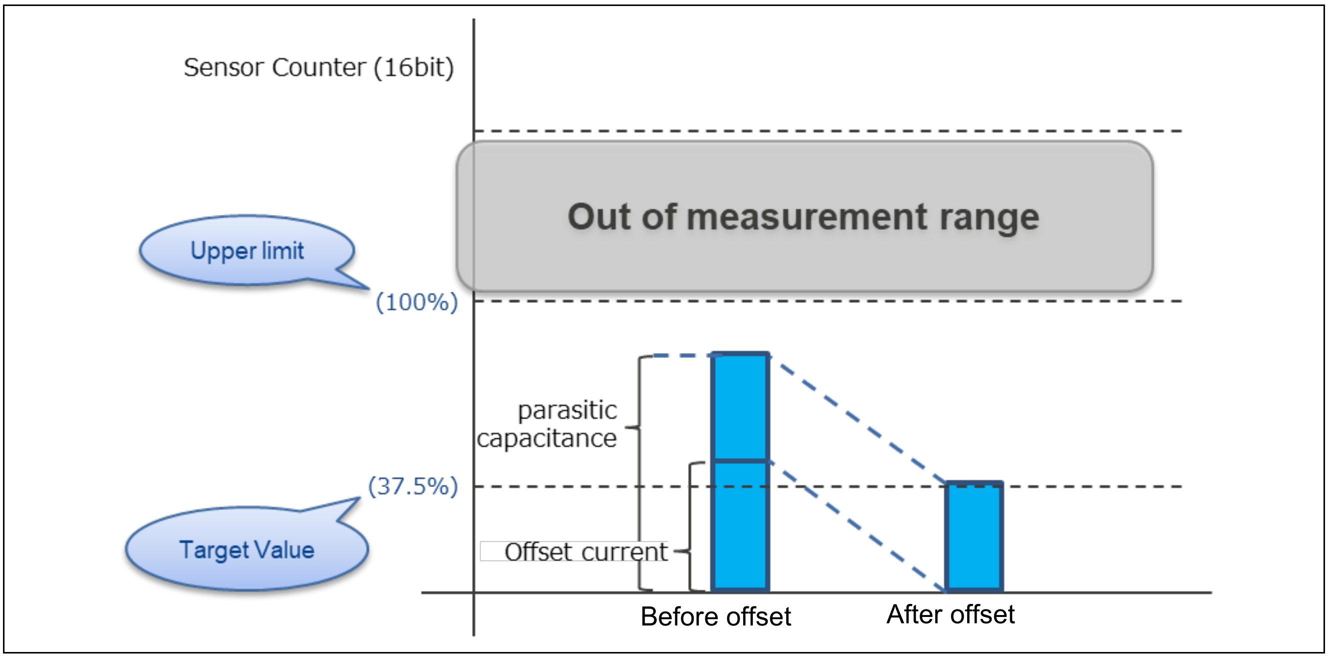


Figure 3-5 Offset Tuning Process of Self-Capacitance Method

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 Method

	When self-capacitance method is used	When using mutual capacitance method	When using active shield
CTSU1	15360 (37.5%)	10240 (25%)	-
CTSU2/CTSU2SL*	15360 (37.5%)	10240 (25%)	6144 (15%)

Note: In the actual measurement, the sum of the two adopted frequency measurement results out of the three frequency measurement results (128 + 128 = 256 μs) is the final measurement result. Offset tuning uses the value of the measurement time doubled at the first frequency (128 × 2 = 256 μs) for tuning.

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

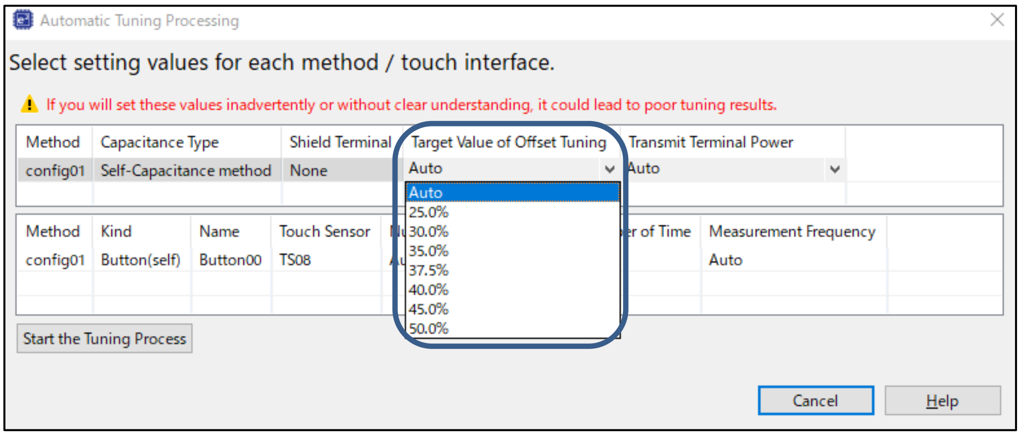
Target values are shown in Table 3-9. for setting the target value during offset-tuning in CTSU2/CTSU2SL.

Table 3-9 Target value for "Target Value of Offset Tuning" in CTSU2/CTSU2SL

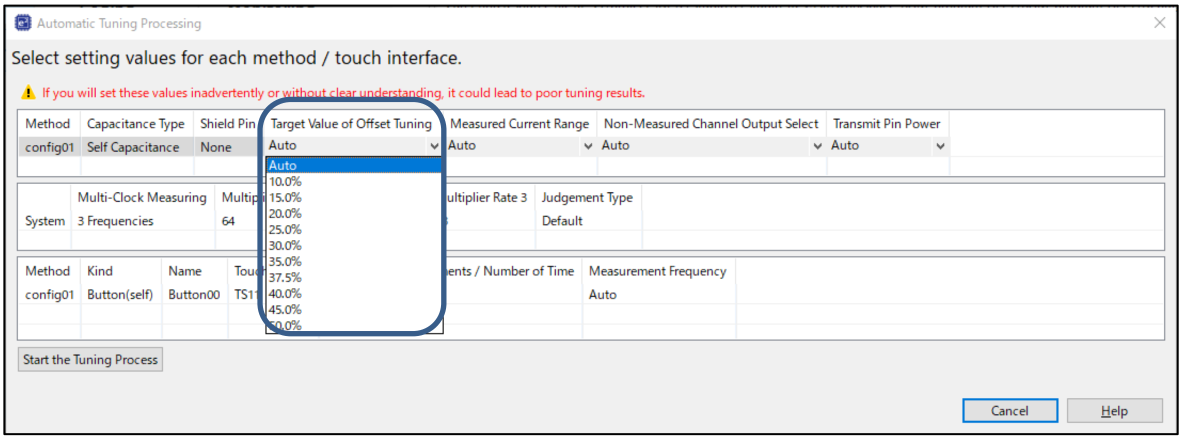
Target value of Offset Tuning	Target value*
10.0%	4096
15.0%	6144
20.0%	8192
25.0%	10240
30.0%	12288
35.0%	14336
37.5%	15360
40.0%	16384
45.0%	18432
50.0%	20480

Note: The value after the two-frequency sum of the three-frequency measurement results.

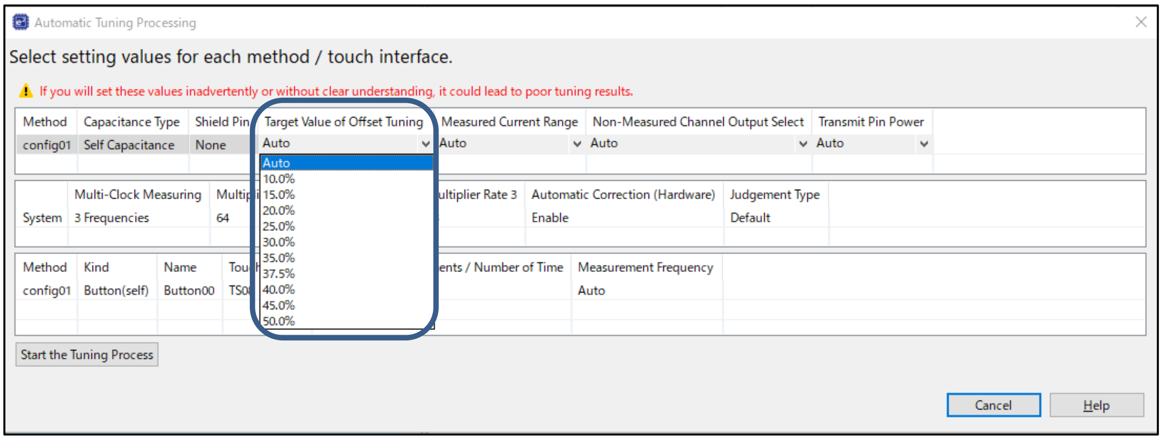
Figure 3-6 shows an example window for setting "Target value of Offset Tuning" with “Advanced mode”.



CTSU1



CTSU2



CTSU2SL

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

The number of measurements can be changed only with CTSU2/CTSU2SL. 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.

Measurement value = (Target value of Offset Tuning [%] × 40960*)/100 × (number of measurements/default number of measurements)

Note: 40960 is the value when the Target value of Offset Tuning is 100%.

Table 3-10 and Figure 3-7 show the measurement values (theoretical values) at touch OFF with respect to the setting of the target value at offset tuning when the Number of measurements in CTSU2/CTSU2SL.

Table 3-10 Measurement values for "Target values of offset tuning" when the number of measurements is changed (theoretical values)

Target value of Offset Tuning	Target value*	Measurement value at touch OFF (theoretical value)*	
		Number of measurements: 8 (default)	Number of measurements: 16
10.0%	4096	4096	8192
15.0%	6144	6144	12288
20.0%	8192	8192	16384
25.0%	10240	10240	20480
30.0%	12288	12288	24576
35.0%	14336	14336	28672
37.5%	15360	15360	30720
40.0%	16384	16384	32768
45.0%	18432	18432	36864
50.0%	20480	20480	40960

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

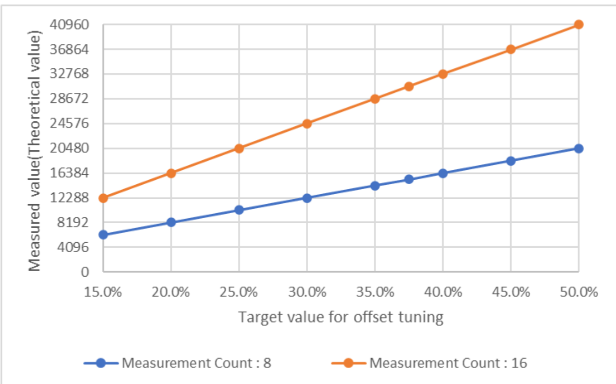


Figure 3-7 Measurement value (theoretical value) with respect to "Target value of Offset Tuning" when the number of measurements is changed

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 particular 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.

Change the number of measurements. If the measurement value differs from the expected value, refer to Table 3-10 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 it does not reach the target value set by the offset tuning process.

Note: As an example, assume the maximum possible capacity addition state, 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 is shown below.

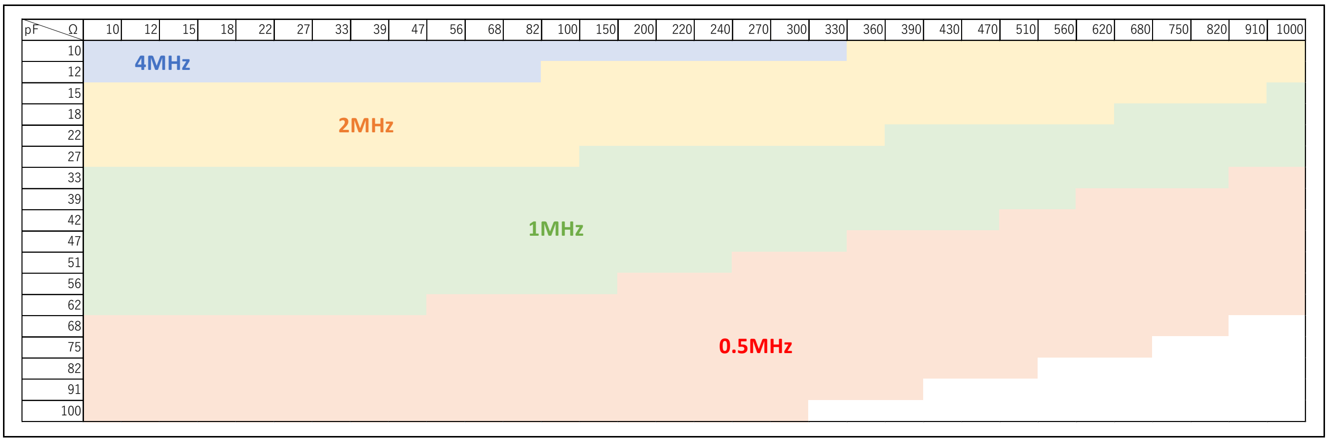


Figure 3-8 Parasitic capacitance/damping resistance of RX130 (receiving electrode 1.6V) vs. measurement frequency

Figure 3-9 shows the relation between the parasitic capacitance/damping resistor of RX140 and the measurement frequency. A typical example of CTSU2/CTSU2SL is shown below.

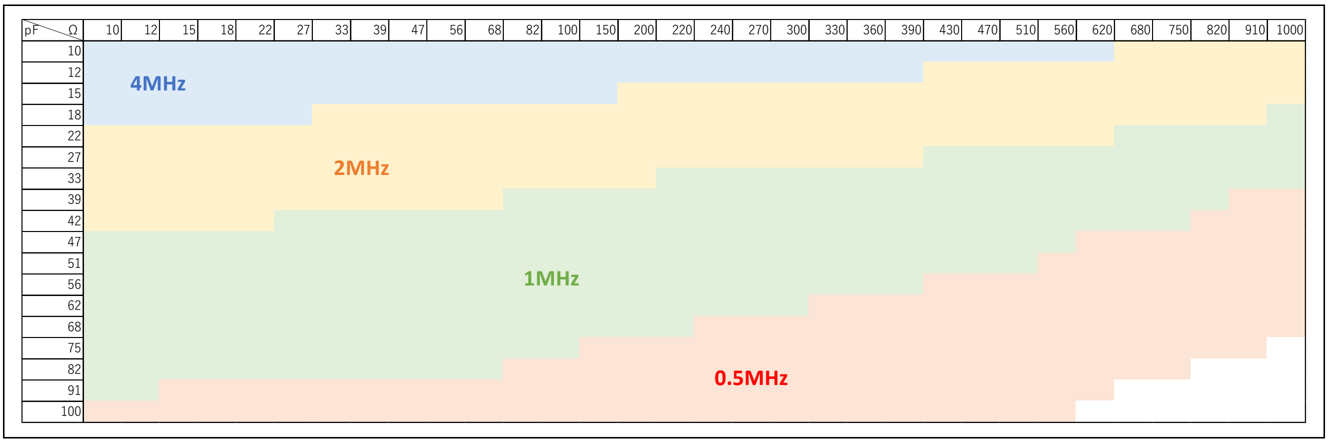
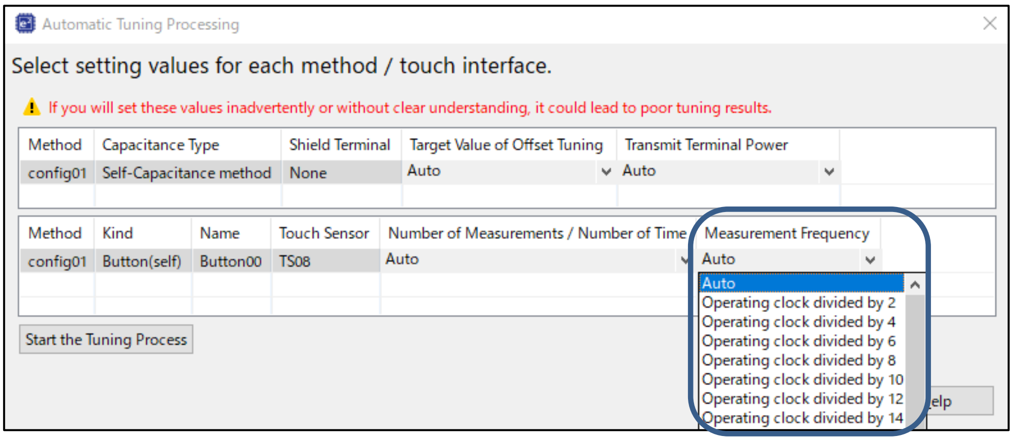


Figure 3-9 Parasitic capacitance/damping resistance of RX140 (receiving electrode 1.5V) vs. measurement frequency

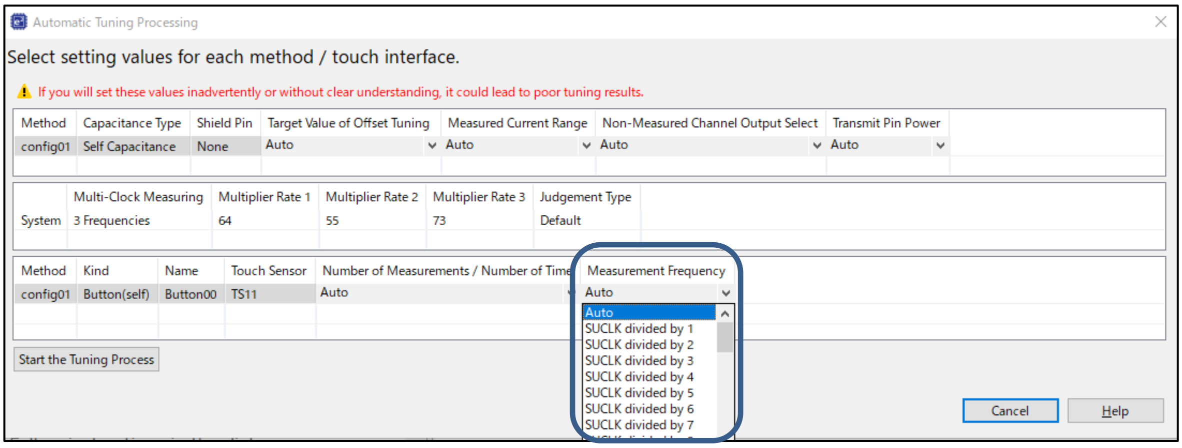
The higher the parasitic capacitance, the lower the measurement frequency is set. If the measurement frequency is set to a high value when the parasitic capacitance is large, the charge/discharge may not be satisfactorily performed and measurement error may occur when outputting sensor drive pulses from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

In addition, in CTSU2/CTSU2SL, the frequency set in "Measurement frequency" is determined as the 1st frequency in multi-clock measurement. Refer to 3.6 Multi-Clock Measuring/Multiplier Rate for the setting method of the 2nd/3rd Frequency.

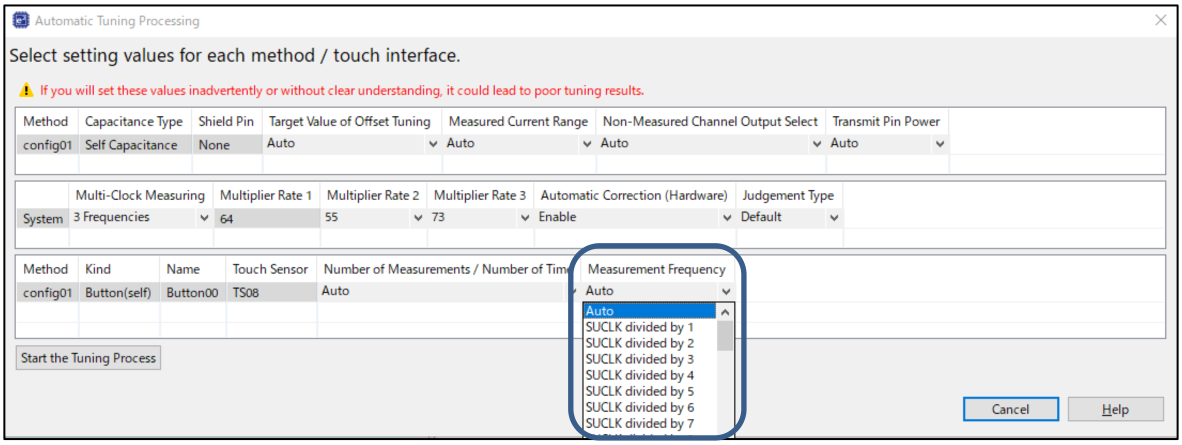
Figure 3-10 shows a window example for setting "Measurement Frequency" with “Advanced mode”.



CTSU1



CTSU2



CTSU2SL

Figure 3-10 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 "8 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 Influence on Sensitivity by Changing Measurement Frequency

Table 3-11 shows the measurement values (actual measurement examples) when RX140 mounted capacitance touch evaluation system is used when the measurement frequency is changed.

Table 3-11 Measurement values when the measurement frequency is changed (actual measurement example)

Capacitance Touch Evaluation System with CTSU2SL(RX140) Self-capacitance 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
4MHz	15359	18914	3555	30.2
2MHz	15408	17217	1809	18.2
1MHz	15371	16306	935	14.2
0.5MHz	10882	11357	475	12.6

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 may occur during touch ON. If the measurement frequency is increased forcibly when the parasitic capacitance is large, a measurement error may occur.

Figure 3-11 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.

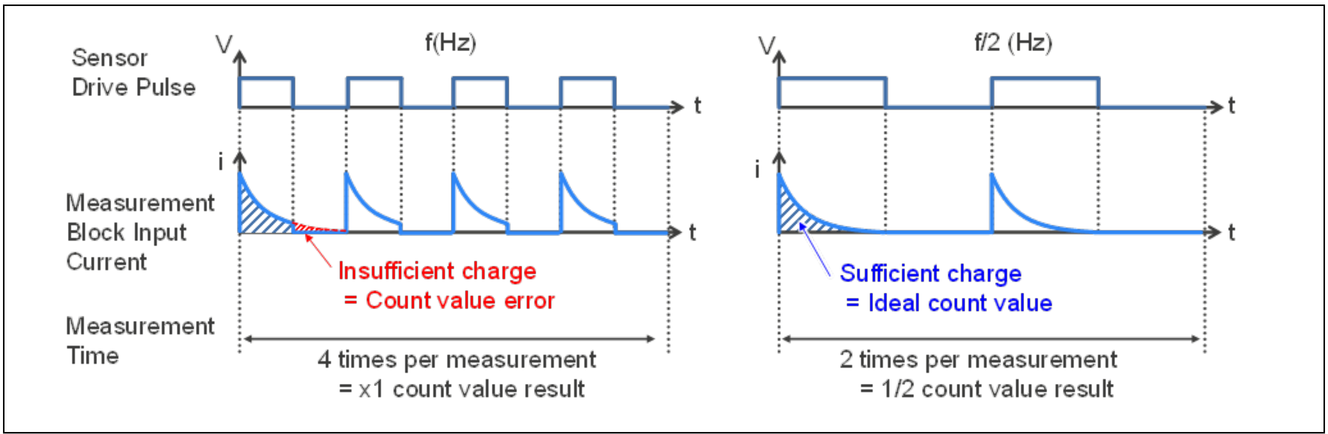


Figure 3-11 Image of CTSU measurement

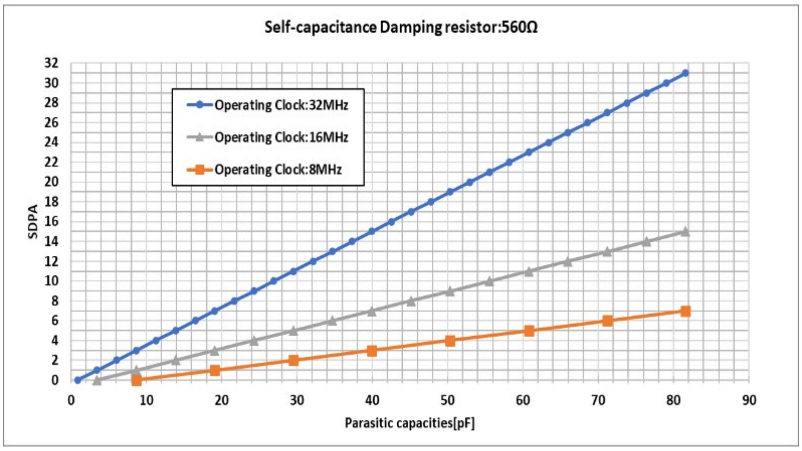
When set to 0.5MHz, if the parasitic capacitance is small, the average value at touch OFF may not be set near the offset tuning target value. The reason is that the measurement value does not reach the target value because the current supplied from VDC is small because the parasitic capacitance is small 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 make adjustments 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 3-12 shows the relation between parasitic capacitance and SDPA when a damping resistor of 560 Ω is used in RX130 that is CTSU1.



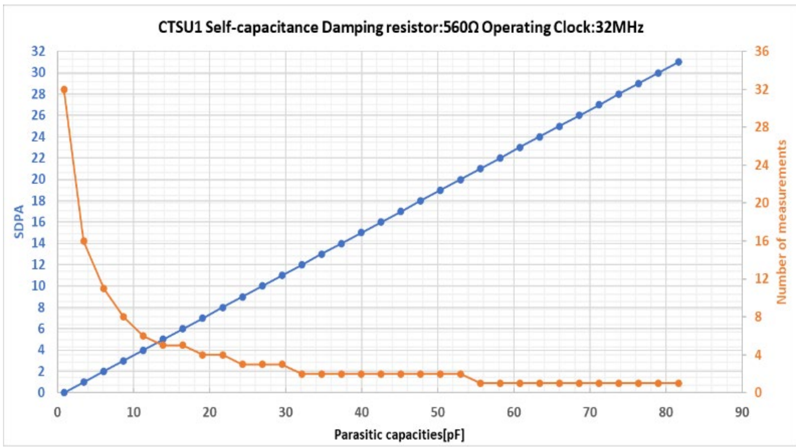
Note: Recommended values are set for PRMODE and PRRATIO.

Figure 3-12 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 3-13 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 3-13 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 3-14 shows the parasitic capacitance versus SDPA when the default setting of "Multi-frequency measurement/multiplication ratio" is used in RX140 that is CTSU2 and the damping resistor 560 Ω is used.

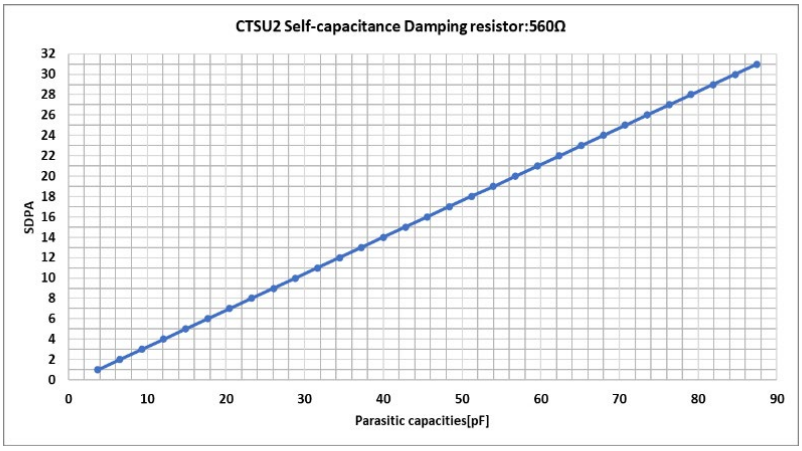


Figure 3-14 Parasitic capacitance that can be measured when RX140 is used

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 make adjustments 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/CTSU2SL.
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.

$$I = F\,C\,V$$

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 Principles of Detection" 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 3-15 shows the measurement image when "Measured Current Range" is changed.

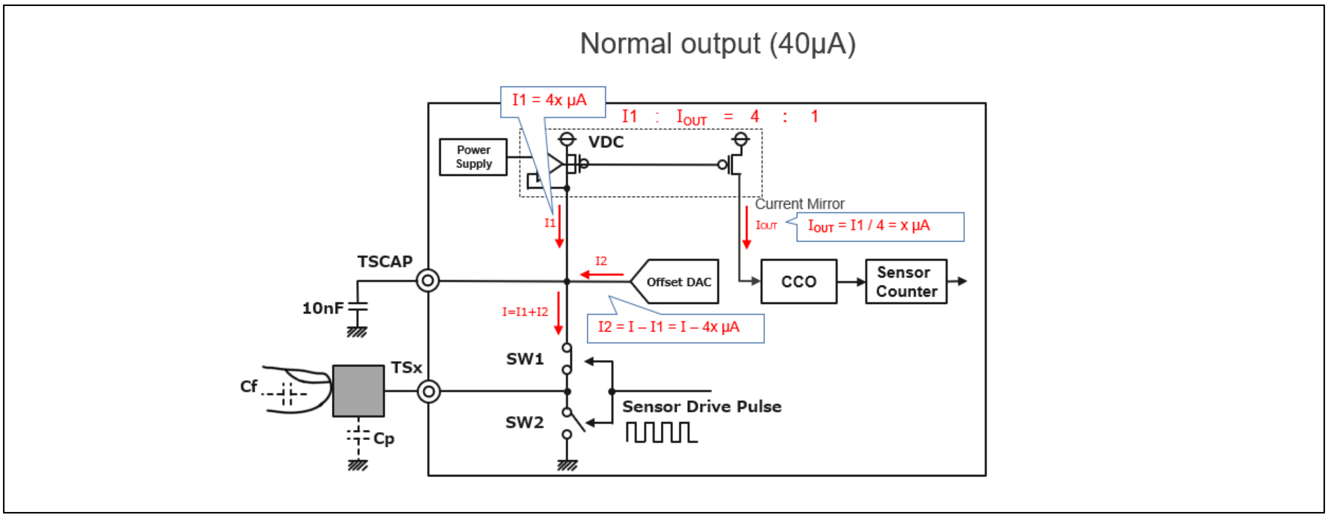


Figure 3-15 Measurement image when normal current (40μA) is used

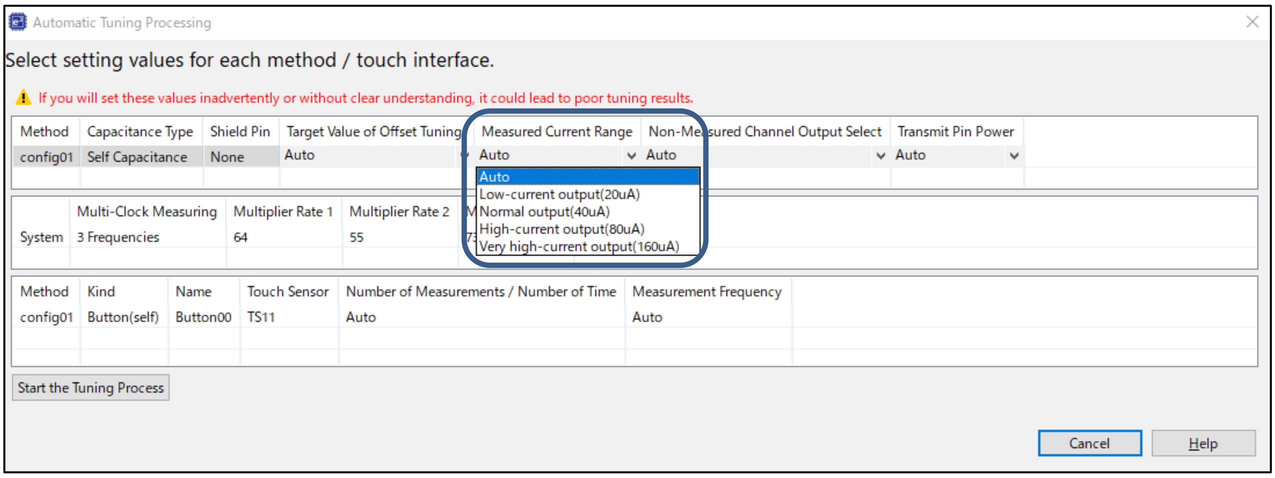
Table 3-12 shows the default settings.

Table 3-12 Default "Measured Current Range" settings

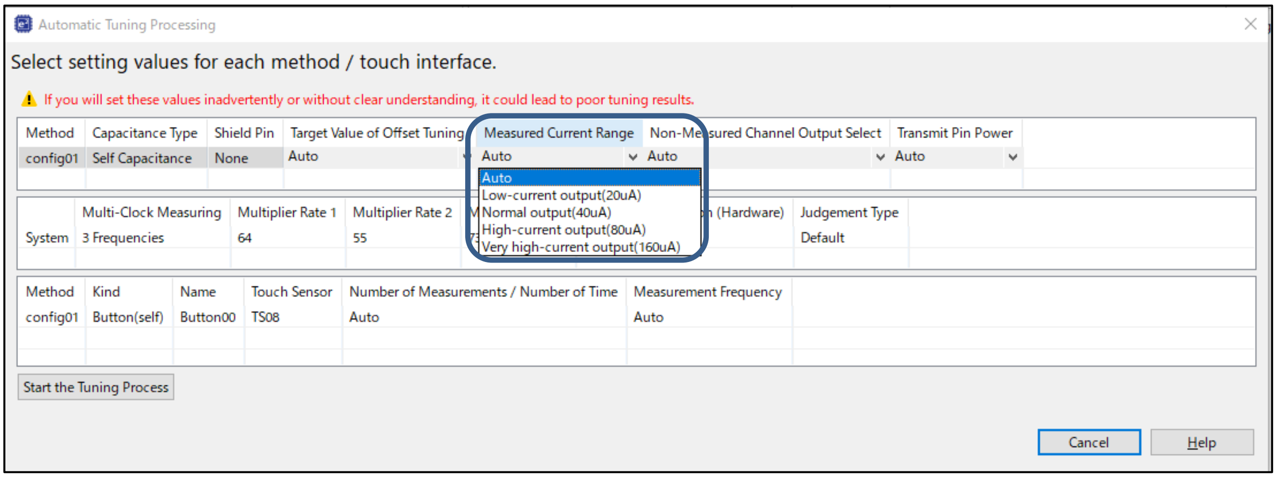
	When self-capacitance method is used	When using mutual capacitance method
CTSU2/CTSU2SL	Normal current (40μA)	High current (80μA)

In addition to the defaults, CTSU2/CTSU2SL can be set to low current (20μA) or high current (160μA).

Figure 3-16 shows an example window for setting "Measured Current Range" with “Advanced mode”.



CTSU2



CTSU2SL

Figure 3-16 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 3-13 shows the measurement values (actual measurement examples) when RX140 mounted capacitance touch evaluation system is used when the Measured Current Range is changed.

Table 3-13 Measurement values when the Measured Current Range is changed (actual measurement example)

Capacitance Touch Evaluation System with CTSU2SL(RX140) Self-capacitance method, Measurement frequency: 2MHz, easurement 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
20μA	15363	18897	3534	34.2
40μA	15429	17214	1785	19.4
80μA	15372	16255	883	11
160μA	10834	11271	437	8.2

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 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 3-17 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.

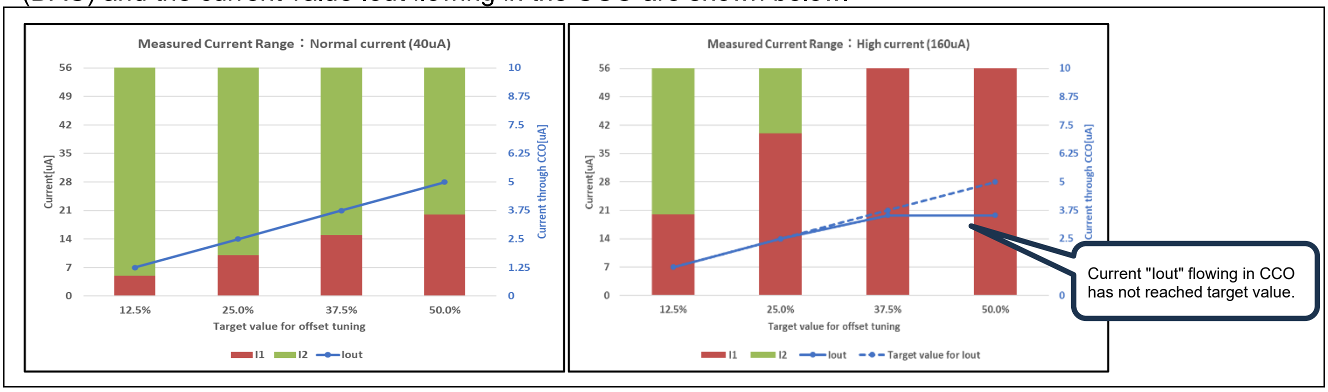


Figure 3-17 Current value when the target offset tuning value and measured current range are changed

The current flowing through the CCO is 1.25~10μA, and 10μA 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 / 4 = 3.75μA.

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 = I1/16 is approximately 3.5μA.

If the current mode is too large when the parasitic capacitance is small in this way, 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 to the user's required specifications.

3.5 Non-Measured Channel Output Select

The setting of "Non-Measured Channel Output Select" can be changed only with CTSU2/CTSU2SL.
In "Non-Measured Channel 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. In order 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 3-14 shows the default settings.

Table 3-14 Default "Non-Measured Channel Output Select" setting.

	When self-capacitance method is used	When using mutual capacitance method	When using active shield
CTSU2/CTSU2SL	Output low thorough GPIO	Output low thorough GPIO	Same phase pulse output as transmission channel through the power setting

Figure 3-19 shows an image of TS terminal measurement in a touch interface configuration as shown in Figure 3-18. 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.

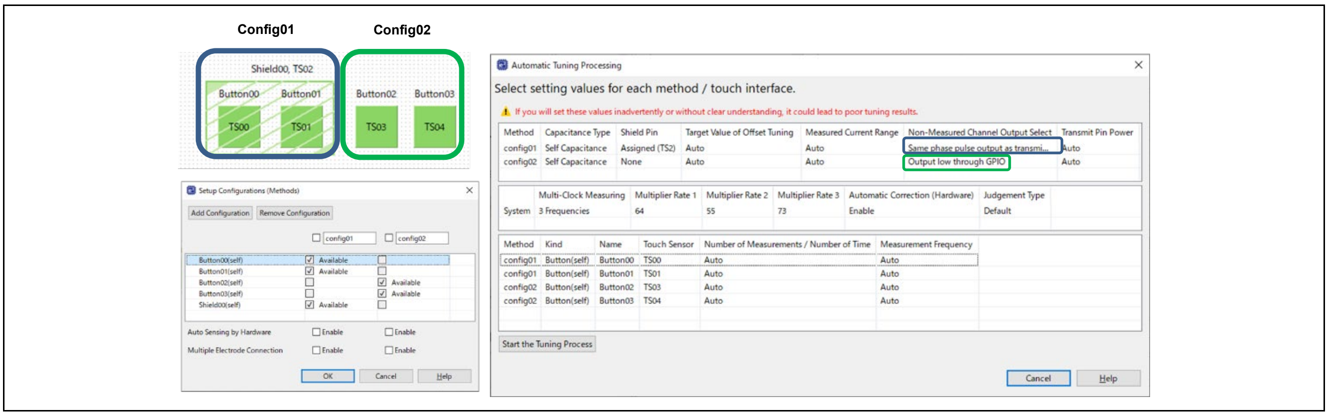


Figure 3-18 Example touch interface configuration

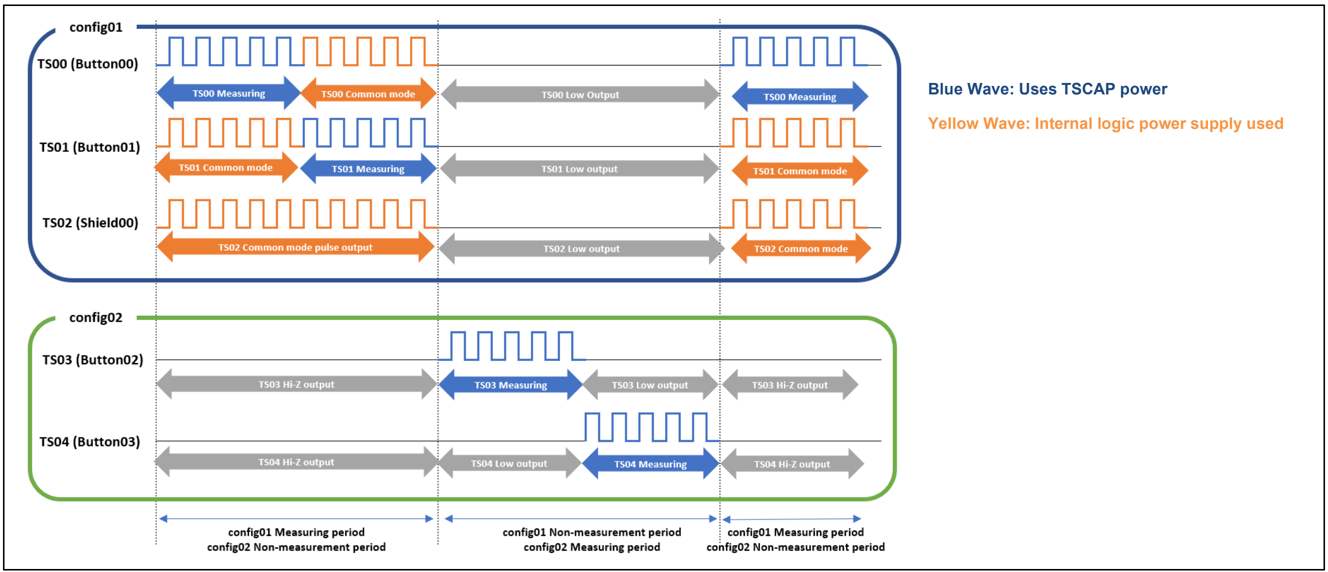


Figure 3-19 Image of TS terminal measurement

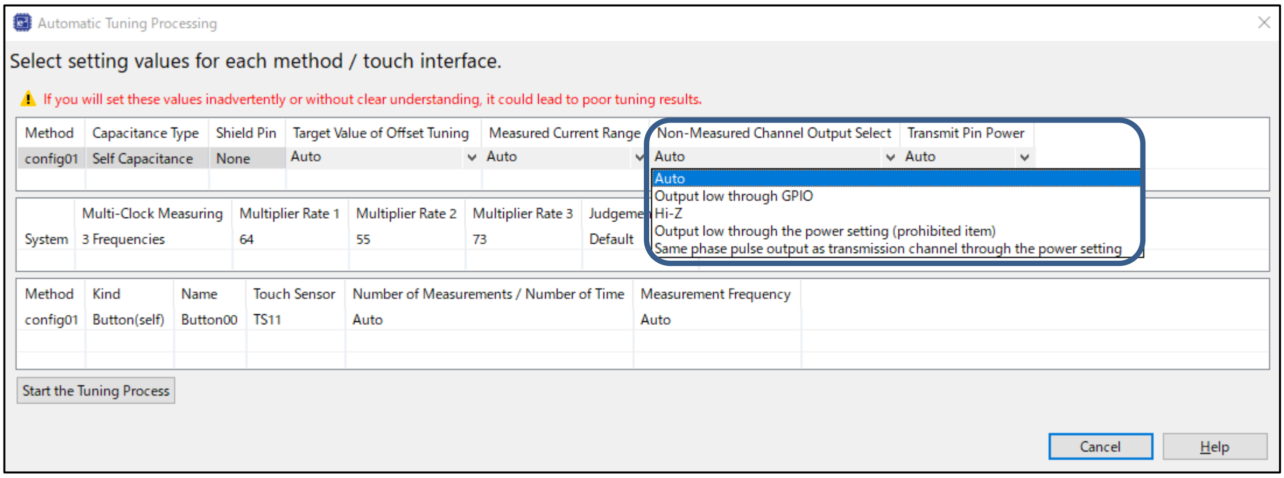
This is an example of a Non-Measured Channel Output Select. Please refer to the following documents.
RL78 Family Capacitive Touch Sensing Unit (CTSU2L) Operation Explanation Rev.1.00 (renesas.com)

Table 3-15 shows an overview of each process setting.

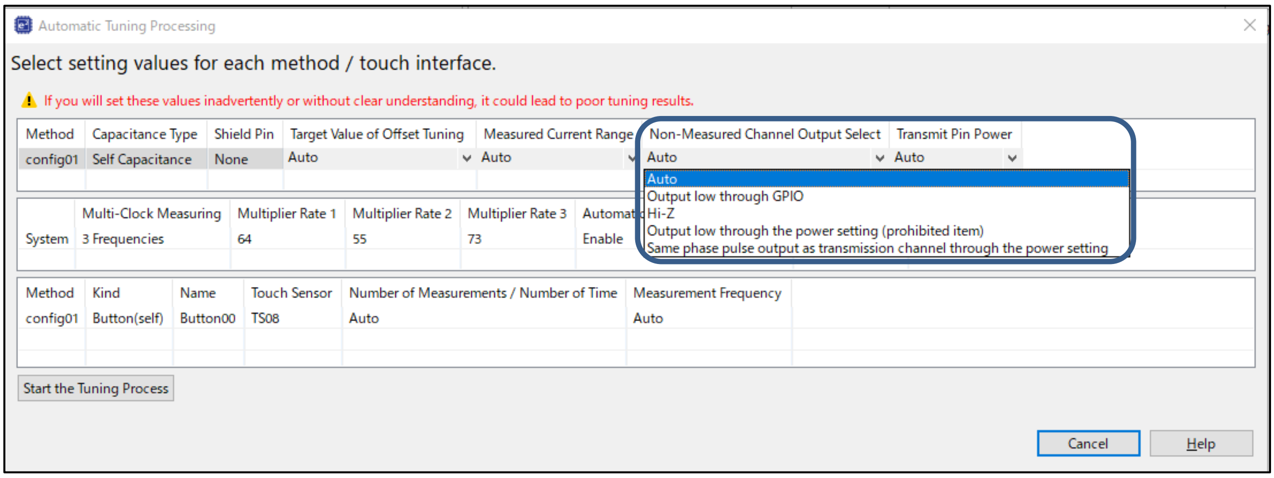
Table 3-15 Overview of processing settings

Non-Measured Channel 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 3-20 shows an example window for setting "Non-Measured Channel Output Select" with “Advanced mode”.



CTSU2



CTSU2SL

Figure 3-20 Setting of "Non-Measured Channel 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 Multi-Clock Measuring/Multiplier Rate

The "Multi-Clock Measuring/Multiplier Rate" setting can be changed only with CTSU2/CTSU2SL.
In "Multi-Clock Measuring/Multiplier Rate", the number of times of measurement and measurement frequency in multi-clock measurement are set from the multiplier rate.
Multi-Clock Measuring can be performed at multiple drive frequencies to avoid synchronous noise. By default, the instrument measures three frequencies and makes a majority decision on the result at the three frequencies to determine the measurement value. For 3-frequency measurement, the frequency set in "Measurement frequency" (sensor drive pulse frequency) is used as the first frequency, and the multiplying ratio of the 2nd/3rd frequencies can be changed to any value. For details, refer to the following document.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (renesas.com)

Figure 3-21 shows an image of multi-clock measurement (3-frequency measurement).

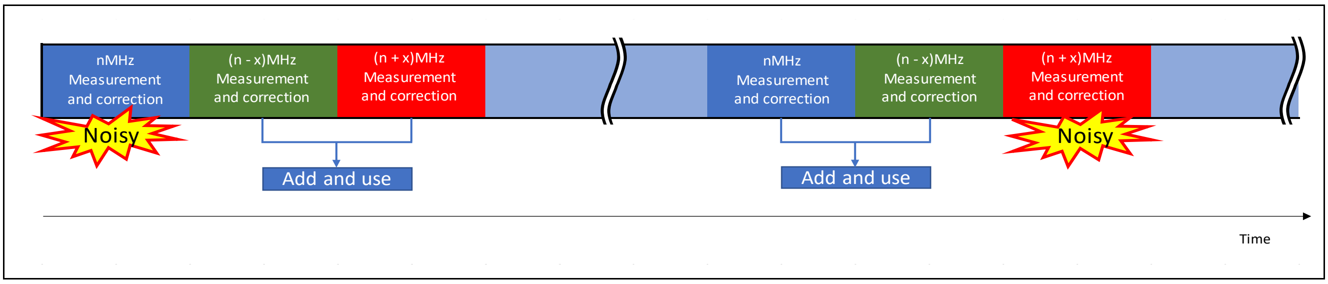


Figure 3-21 Image of multi-clock measurement (3-frequency measurement)

Table 3-16 lists the default settings.

Table 3-16 Default "Multi-Clock Measuring/Multiplier Rate" Settings

	Multi-Clock Measuring Frequency	1st frequency Multiplier Rate	2nd frequency Multiplier Rate	3rd frequency Multiplier Rate
CTSU2/CTSU2SL	3 Frequencies	64	55	73

The number of multi-clock measurements can be set at 1 frequency or 3 frequencies. Since majority operation is not performed when 1 frequency measurement is set, the measurement value is half that of 3 frequency measurement. For 3-frequency measurement, the multiplier rate of the 2nd/3rd frequency can be set within the range of 32 to 80. The multiplier rate of the 1st frequency is fixed at 64, and the frequency set in "Measurement frequency" is used. Refer to 3.3 Measurement frequency for details. The measurement frequency according to the set multiplier rate is displayed as shown in Figure 3-22.

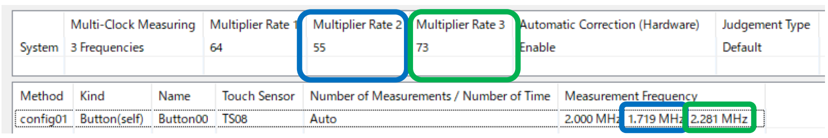


Figure 3-22 Measurement Frequency by Setting the Multiplier Rate

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 3-23 shows a window example for setting "Multi-Clock Measuring/Multiplier Rate" with "Advanced mode".

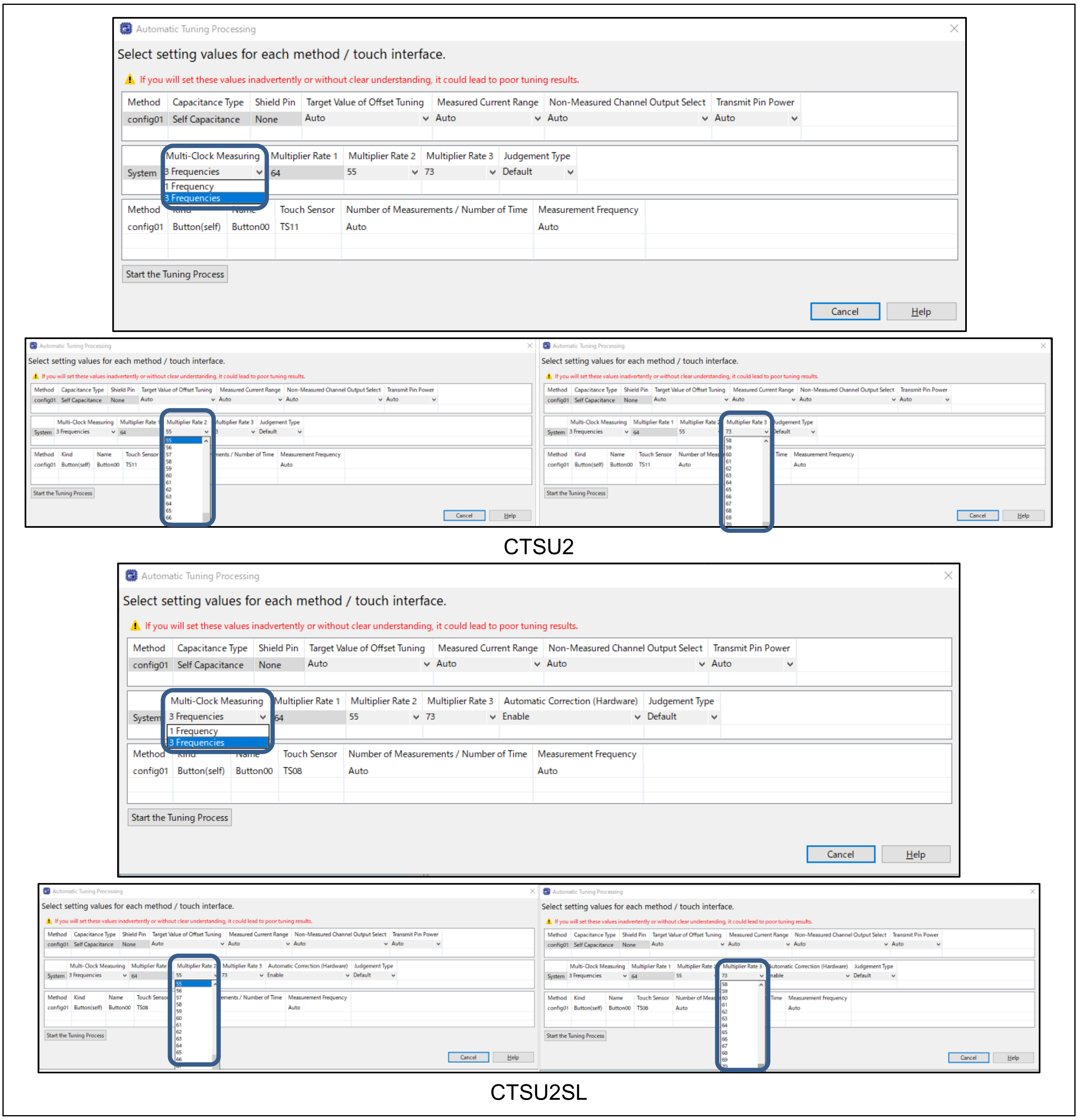


Figure 3-23 Setting of "Multi-Clock Measuring/Multiplier Rate"

The settings are reflected in the qe_touch_define.h. The following is an example of the default setting when 3-frequency measurement is used.

```
#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.

3.7 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/CTSU2SL	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/CTSU2SL.

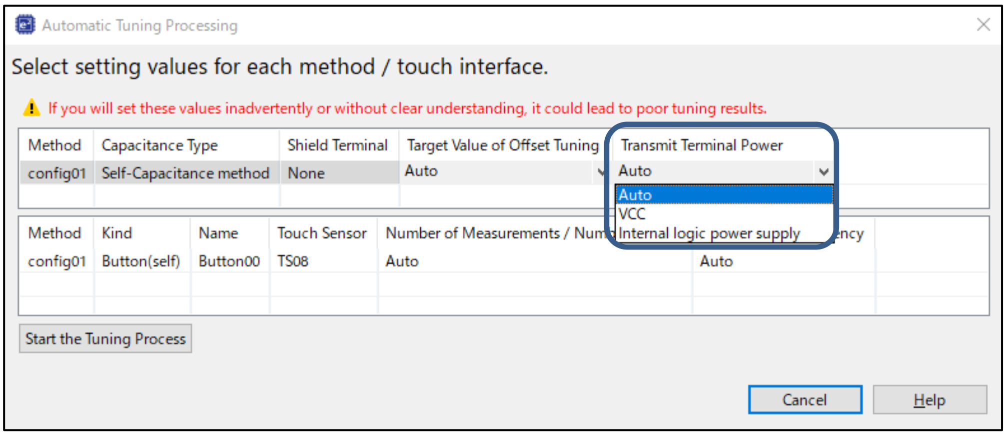
Table 3-19 Overview of "Transmit Terminal Power " settings for CTSU2/CTSU2SL

	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.

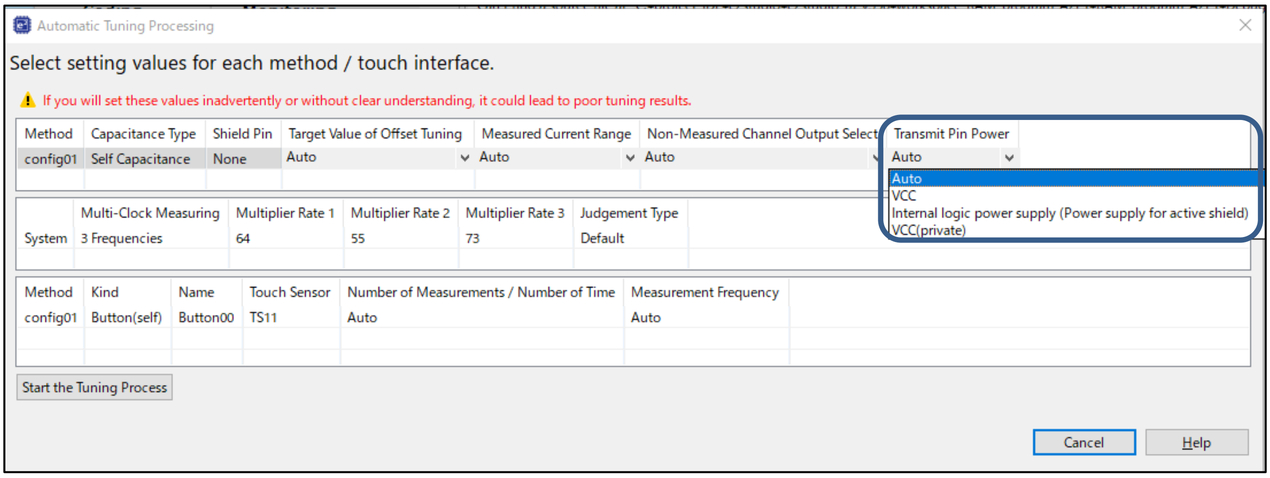
Note: For details, refer to "2.3.1 Principles of Detection" in the following documents.

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

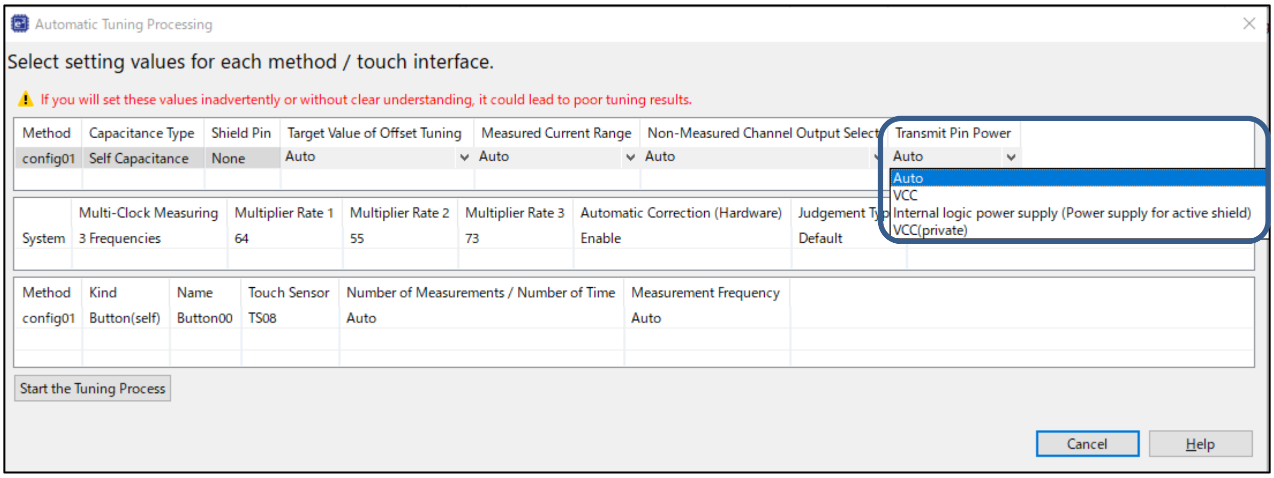
Figure 3-24 shows an example window for setting "Transmit Terminal Power" with “Advanced mode”.



CTSU1



CTSU2



CTSU2SL

Figure 3-24 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/CTSU2SL.

- 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,
```

3.8 Automatic Correction (Hardware)

The "Automatic Correction (Hardware)" setting can be changed only in CTSU2SL.
In "Automatic Correction (Hardware)", it is set whether to process the correction computation with CTSU peripheral. CTSU has built-in circuitry to compensate for the potential small variations in the current controlled oscillator (CCO) MCU manufacturing process. CTSU drivers or software temporarily shift to the compensation process at initialization after power-on. In the correction process, a correction circuit is used to generate a correction factor to ensure accurate sensor measurements. In the correction calculation, correction is calculated for the measurement value obtained by using this correction coefficient.
Hardware processing of correction calculation eliminates the need for wake-up for each measurement and contributes to power consumption reduction. For details, refer to the following document.

[RX Family QE CTSU Module Using Firmware Integration Technology Rev.2.20 (renesas.com)]

Enabled is the default setting. If it is set to "Disable", the correction calculation is executed by software.

Figure 3-25 shows the image of Automatic Correction (Hardware) disabled/enabled.

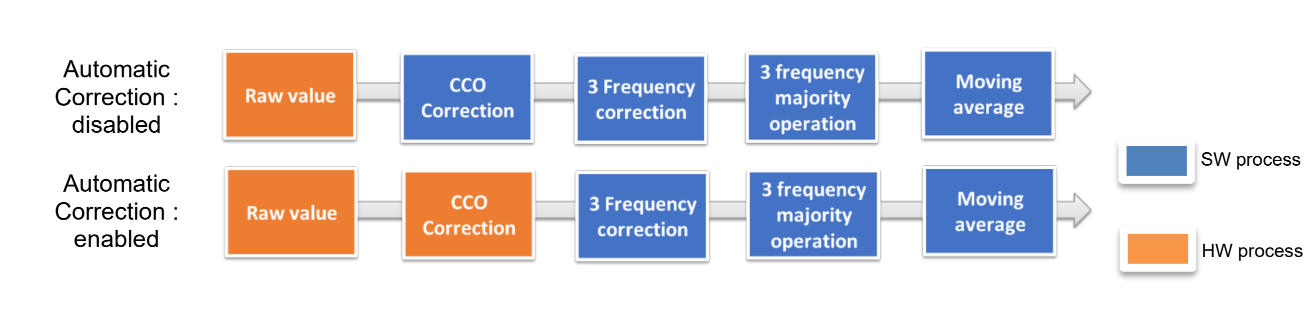
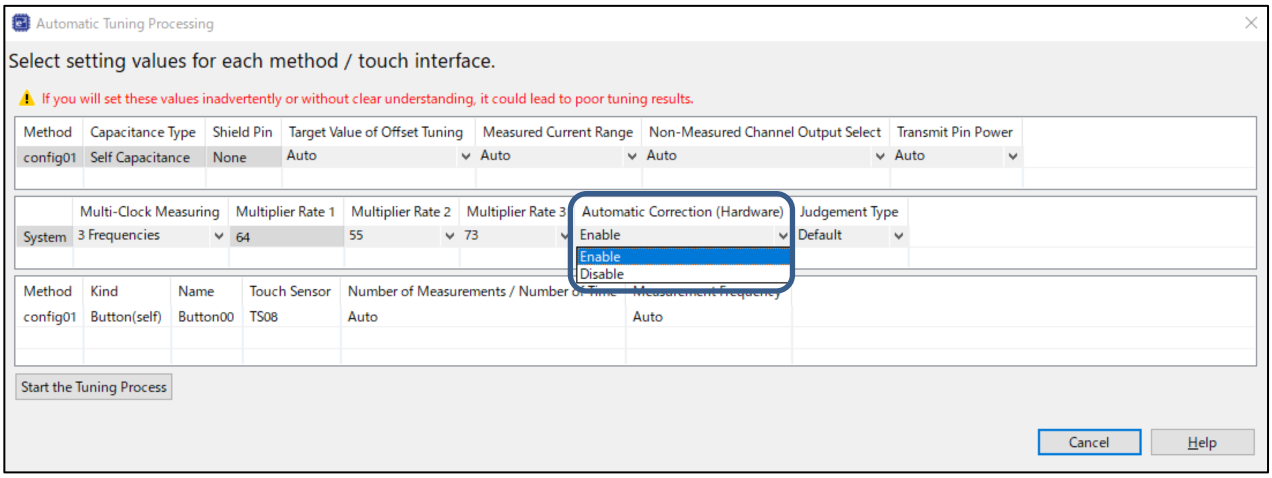


Figure 3-25 Operation image with Automatic Correction disabled/enabled

Figure 3-26 shows an example window for setting "Automatic Correction (Hardware)" with “Advanced mode”.



CTSU2SL

Figure 3-26 Setting of "Automatic Correction (Hardware)"

The settings are reflected in the qe_touch_define.h. The following is an example when Automatic Correction (Hardware) is enabled.

```
#define CTSU_CFG_AUTO_CORRECTION_ENABLE   (1)
```

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.

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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