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 (R30AN0424)

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.

Development environment covered in this document

· Renesas e^2 studio Integrated Development Environment (IDE) 2025-07 or later
· Renesas QE for Capacitive Touch V4.2.0 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, please see Web page below.

QE for Capacitive Touch: Development Assistance Tool for Capacitive Touch Sensors | Renesas

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.

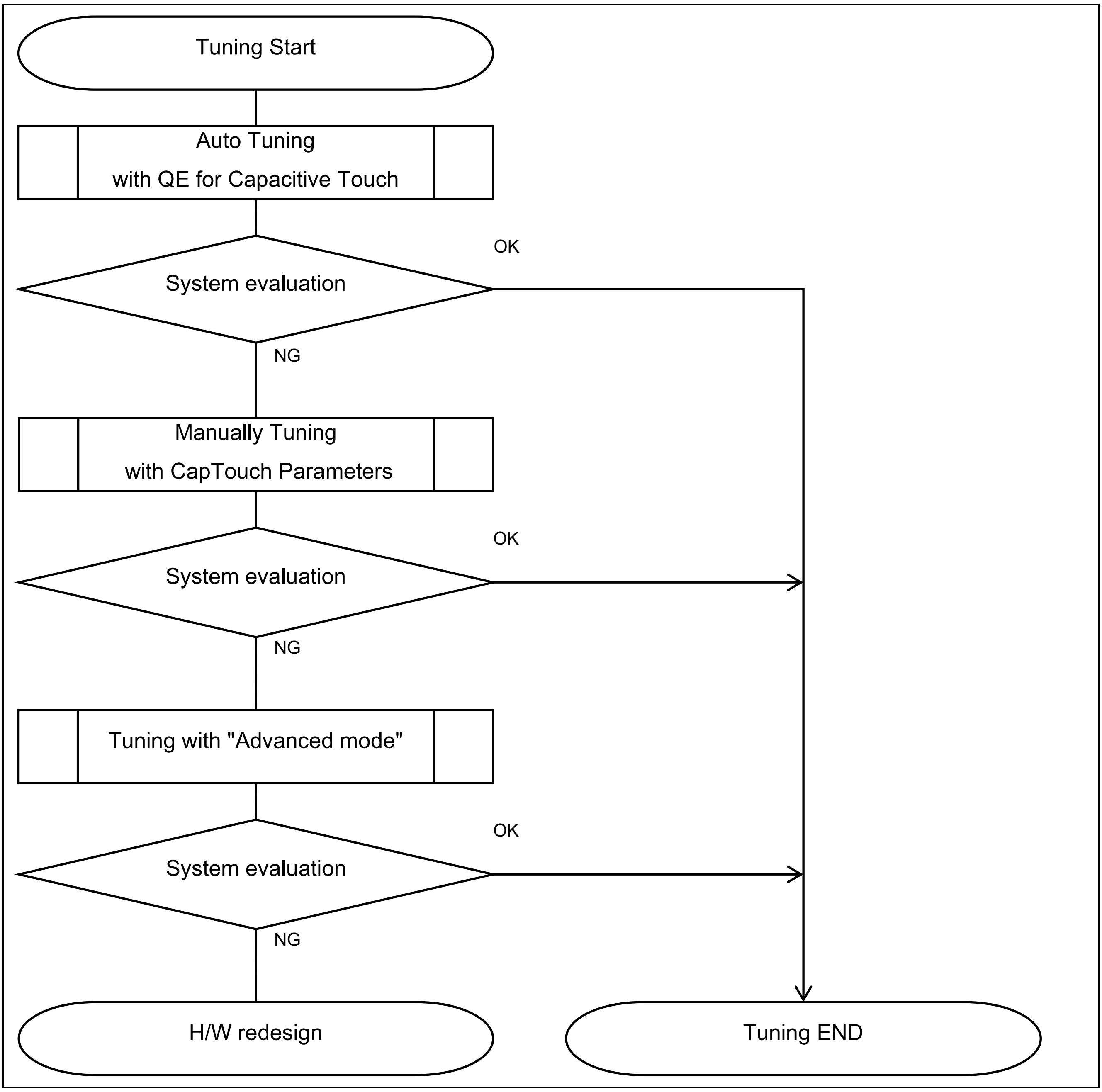


Figure 1-1 Tuning Flowchart

Table 1-1 lists the parameters that can be adjusted with Auto Tuning /Manual tuning with CapTouch parameters "Advanced mode" Tuning. Please refer to QE CTSU module/QE TOUCH module Application Notes for each device family of parameters.

Table 1-1 Tuning-adjustable parameters

Parameter	Auto tuning	Manually tuning with CapTouch parameters	Tuning with "Advanced mode"
Base Clock Frequency /Sensor Drive Pulse Frequency	✓	-	✓
Offset	✓	(Display only)	-
Touch Threshold	✓	✓	-
Hysteresis	✓	✓	-
Sample count for drift correction	-	✓	-
Continuous Touch Cancel Count	-	✓	-
Debouncing count of touch-on filter	-	✓	-
Debouncing count of touch-off filter	-	✓	-
Average sample count for moving average filter	-	✓	-
Measurement Count/Measurement Time	-	-	✓
Offset Tuning Target	-	-	✓
Current Range [*1]	-	-	✓
Non-measured TS Pin Output Select [*1]	-	-	✓
Transmit Power	-	-	✓
Judgment Type [*1]	–	–	✓
Multi-cock Measurement/Multiplication Ratio[*1]	-	-	✓
Touch Judgment (Software/Hardware) [*2]	–	–	✓
CCO Characteristics Correction (Software/Hardware) [*3]	–	–	(Display only)
Multi-clock Correction (Software/Hardware) [*3]	–	–	(Display only)
Measurement Voltage Setting [*1]	✓[*4]	–	✓[*4]

✓: Supported

Note1: This function can be adjusted only for CTSU2/CTSU2L/CTSU2La/CTSU2SL/CTSU2SLa. Please refer to "Capacitance Touch Introduction Guide" for the difference of each capacitance touch sensor and corresponding products.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (R30AN0424)

Note2: Hardware touch judgment (Auto Judgment) is a function available only for CTSU2L/CTSU2La/CTSU2SL/CTSU2SLa. However, for microcontrollers with a built-in SNOOZE mode sequencer (SMS), it can be realized by using it together with the SMS. When the MCU with built-in SMS is used, "SMS" is displayed instead of "Hardware" in Touch Judgment. It can be set from Smart Configurator/Touch Interface Configuration/Advanced Mode.

Note3: This function is only displayed on CTSU2SL/CTSU2SLa. It cannot be changed by the user because it is automatically set according to "Judgment Type" and "Touch Judgment".

Note4: When the microcontroller operating voltage setting is less than 2.4 V, the measurement voltage is automatically set to a lower voltage. 2.4 V or higher, the measurement voltage can still be set to a lower voltage 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 details, please refer to "7.2 Manually Tuning with CapTouch Parameters" in the document below.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (R30AN0424)

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.

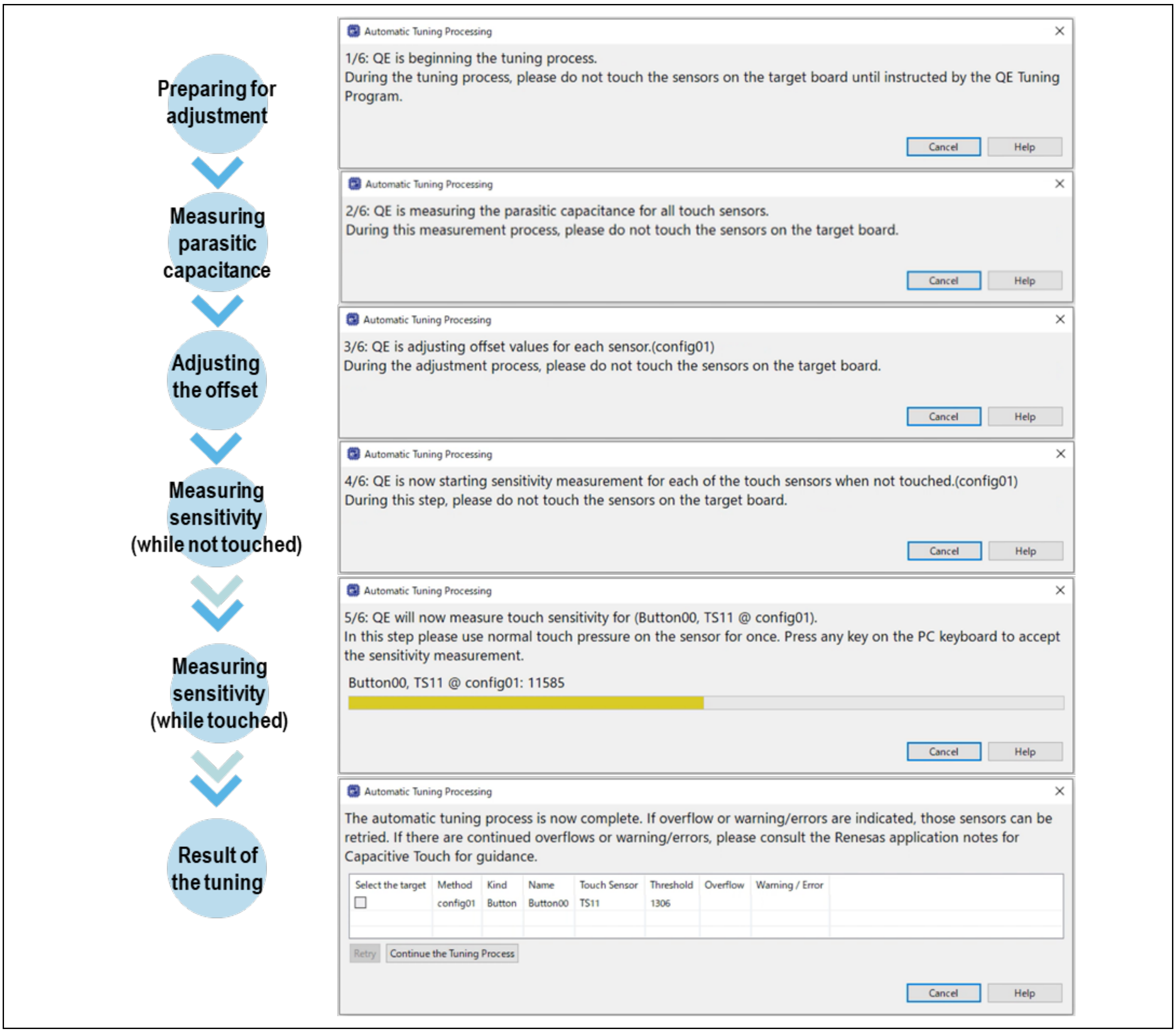


Figure 1-2 Flow of Auto tuning with QE for Capacitive Touch

Auto tuning adjusts the optimal parameters of touch sensor detection.
First, the capacitance at touch OFF is measured, and Base Clock Frequency/Sensor Drive Pulse Frequency is set according to the measurement result. Also, adjust the offset according to the offset tuning target. Then, the capacitance change of 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.

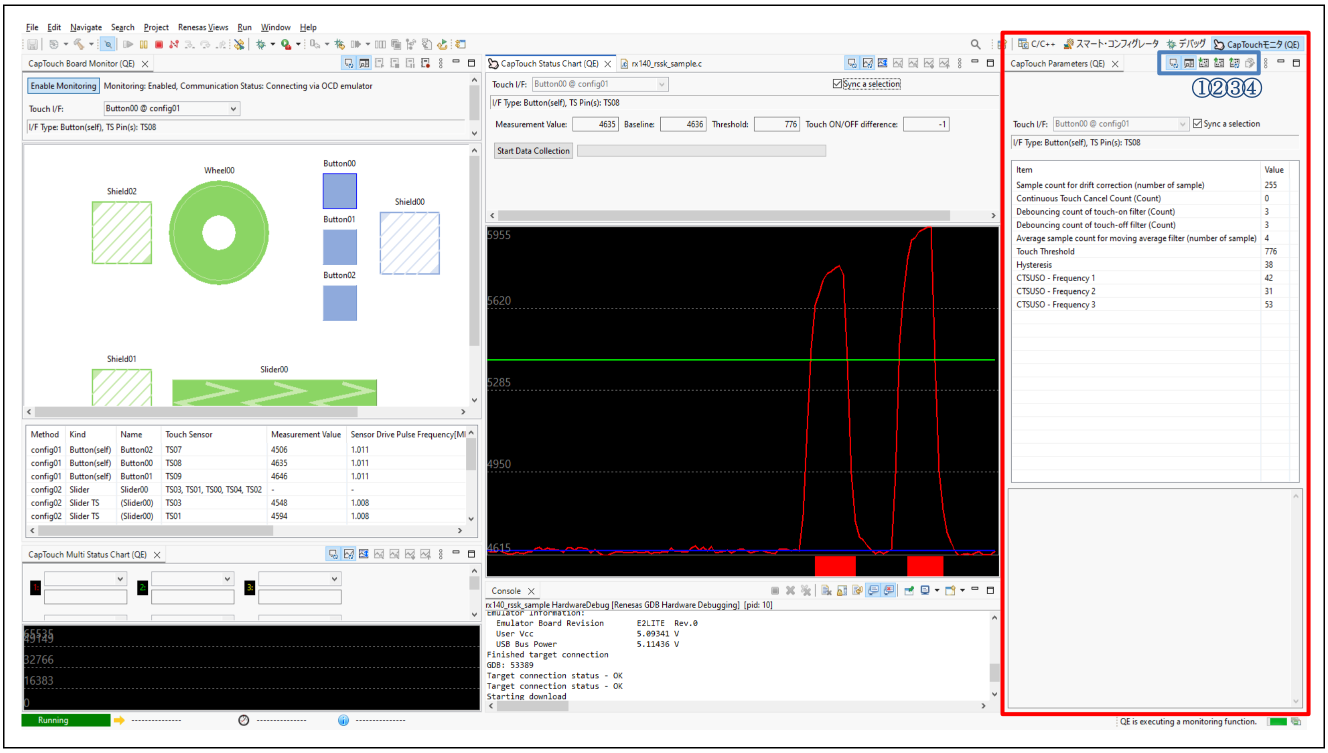


Figure 1-3 Manual Tuning with QE for Capacitive Touch

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. Please 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".

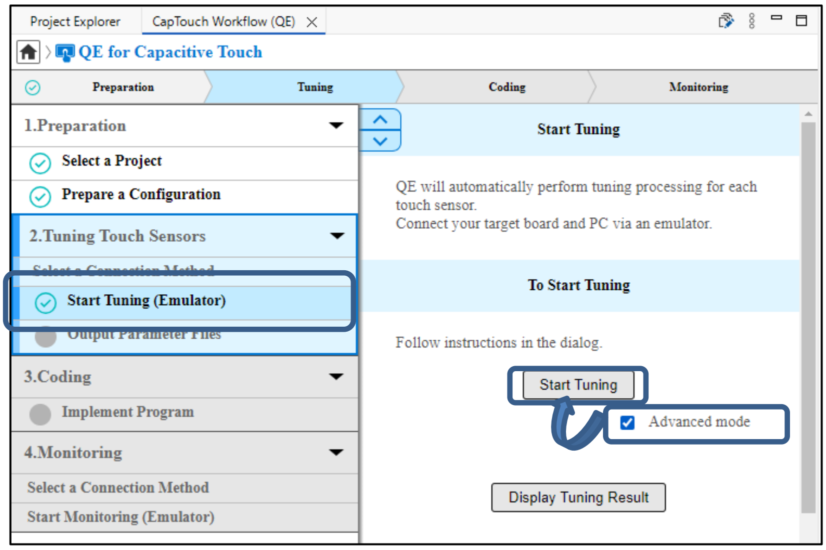
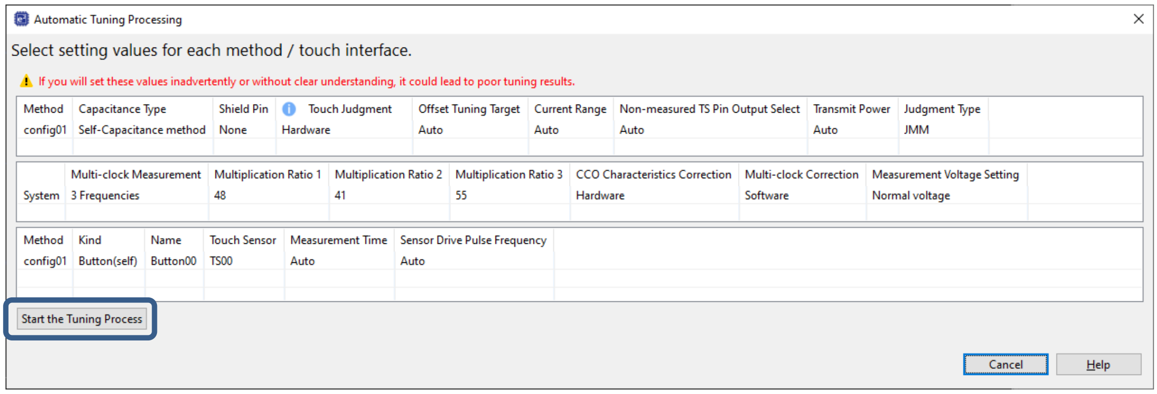


Figure 1-4 Tuning with "Advanced mode"

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, please 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.

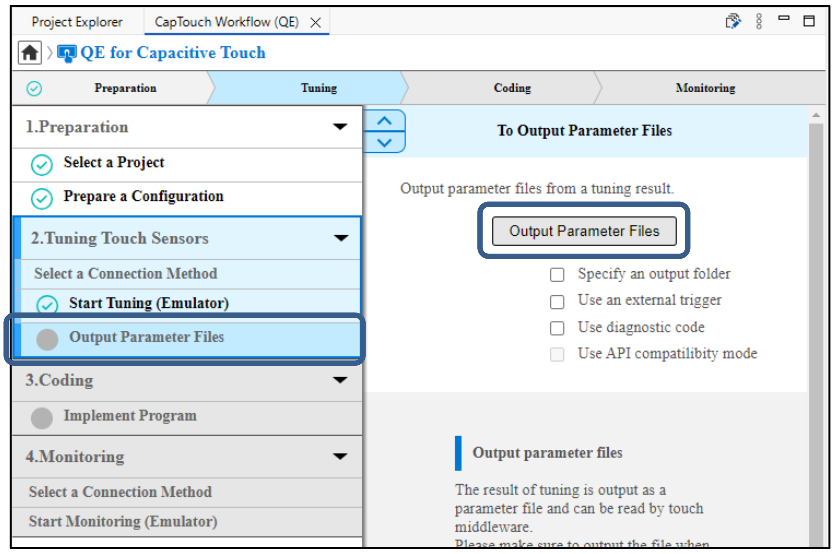


Figure 1-6 To Output Parameter Files

Click the Output File button to output the source file under the “qe_gen” folder. Table 1-4 shows the source files that are output.

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 Signal value improvement adjustment flow

Figure 2-1 shows the adjustment steps to improve signal value, which represents the measurement difference between touch ON and OFF states, through "Advanced mode" Tuning.

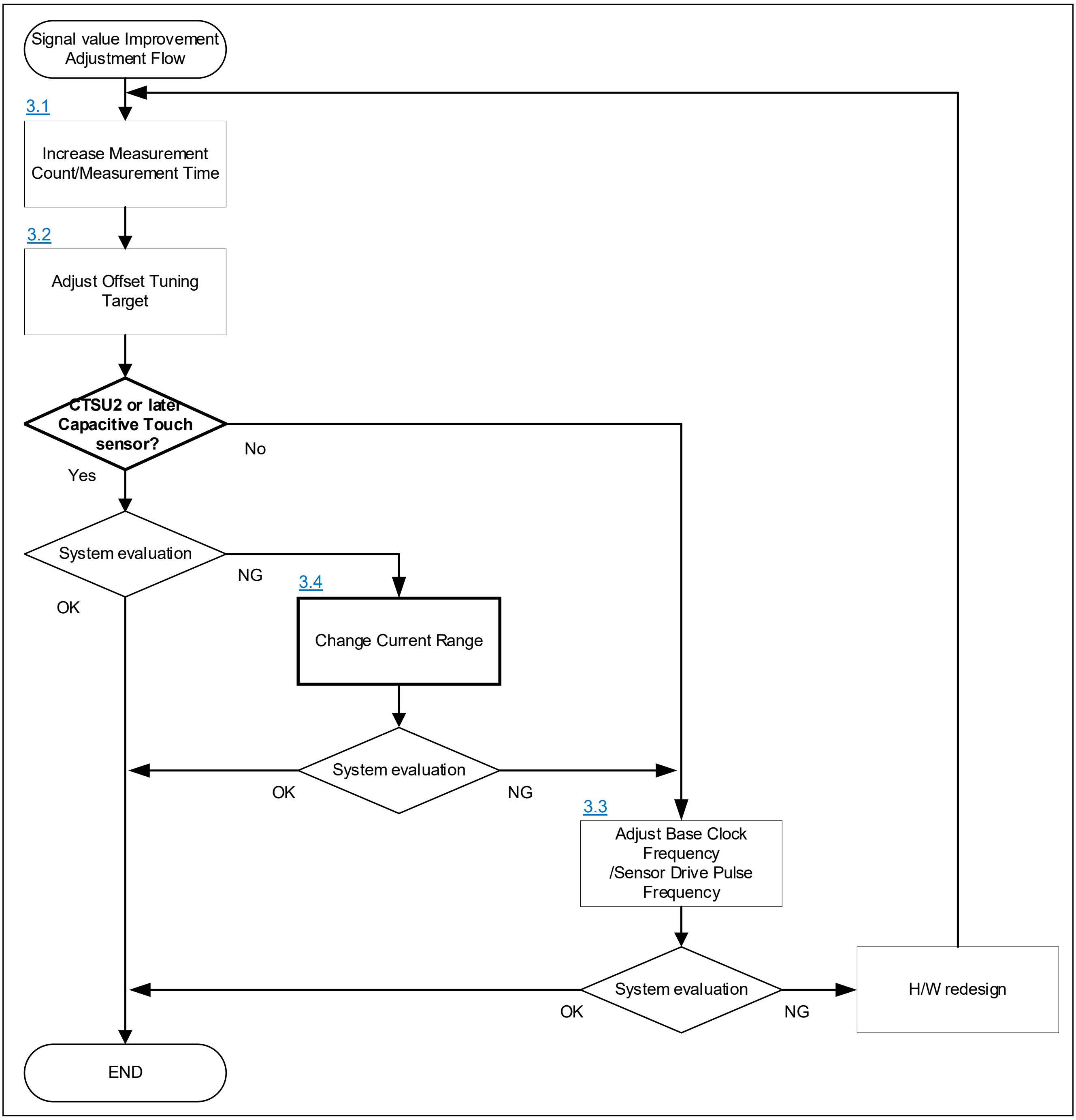


Figure 2-1 Signal value improvement adjustment flow

2.2 Noise suppression adjustment flow

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

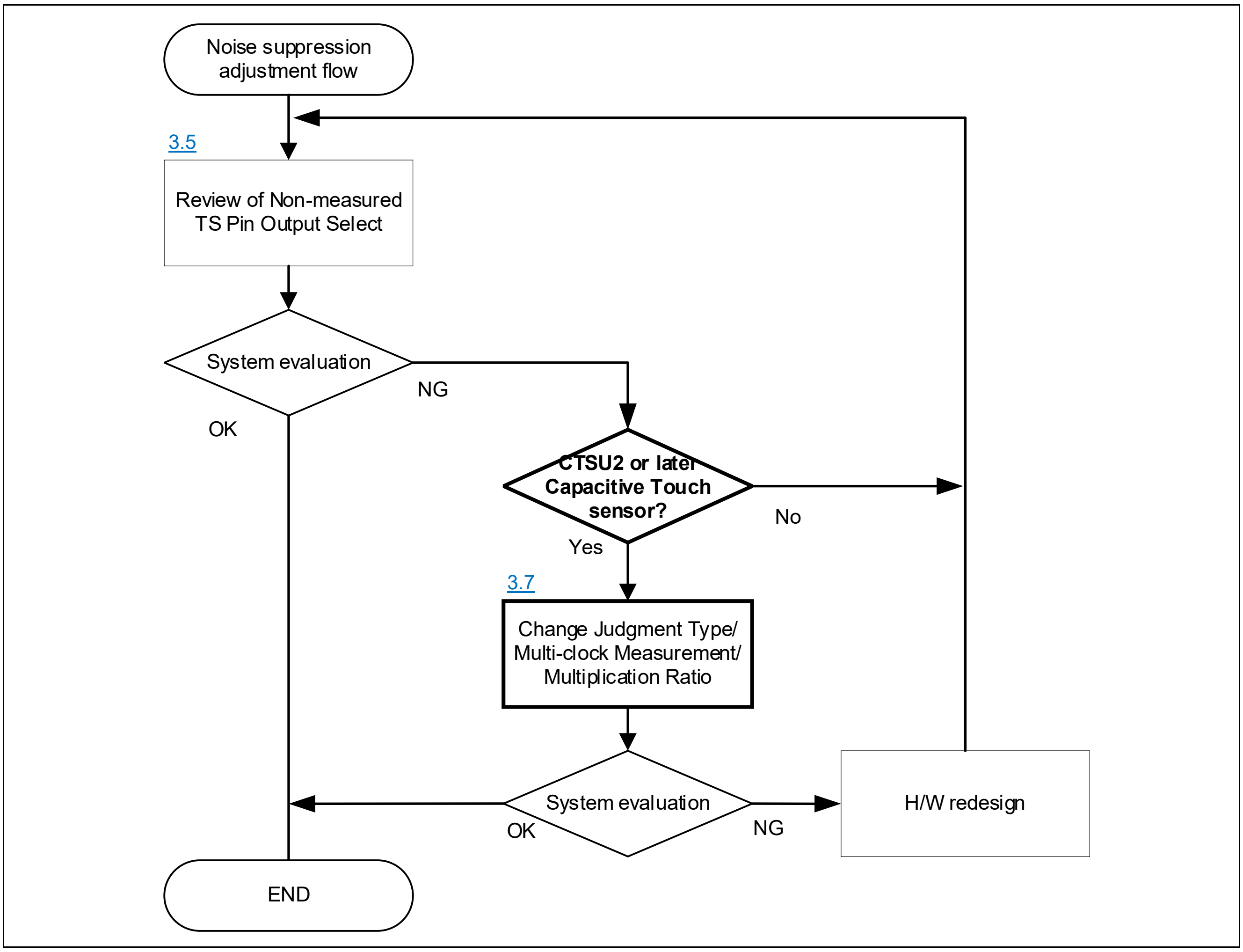


Figure 2-2 Noise suppression adjustment flow

2.3 Correspondence table for each capacitive touch sensor

Table 2-1 shows the parameters displayed in "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	Measurement Count/Measurement Time	Improved signal value	✓	✓	✓	Set the measurement count and determine the measurement time. The signal value can be improved by integrating the measurement value.
2	Offset Tuning Target	Improved signal value	✓	✓	✓	Set the target value (%) of the offset current so that the measured value at touch OFF becomes the target. Adjust this when the measurement time is changed.
3	Base Clock Frequency/Sensor Drive Pulse Frequency	Improved signal value	✓	✓	✓	Sets the frequency division ratio of the frequency output to the touch sensor. The higher Base Clock Frequency/Sensor Drive Pulse Frequency, the better the signal value can be seen. However, a measurement error occurs when the parasitic capacitance is large. For details, please see Figure 3-8 to Figure 3-13.
4	Current Range	Improved signal value	✓	✓	-	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 current range increases the signal value. This is because CCO input current at touch ON increases.
5	Non-measured TS Pin Output Select	Noise Suppression	✓	✓	-	These bits set the handling of non-measurement pins other than the measurement pins during the measurement interval of the pin s set in TS pin. Noise suppression can be achieved by appropriately processing the non-measured pins.
6	Transmit Power	Pin Setting	✓	✓	✓	Selects I/O power supply of the pins set to the transmit pins 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	Judgment Type	Noise Suppression	✓	✓	-	Judgment Type includes Value Majority Mode (VMM) and Judgment 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-frequency. JMM is a method in which the judgment result of each of the 3-frequency measurements is judged by majority decision.
8	Multi-clock Measurement/ Multiplication Ratio	Noise Suppression	✓	✓	-	Set the measurement times to be measured in Multi-clock Measurement and the Multiplication Ratio of multiple types of frequencies to be used for measurement. Multi-clock Measurement allows you to measure multiple drive frequencies to avoid synchronous noise
9	Touch Judgment	Process reduction Low power consumption	✓	-	-	This function sets whether touch judgment is performed by hardware or software. Low-power consumption can be achieved when touch judgment is set to hardware. However, in the case of a microcontroller with a built-in SNOOZE mode sequencer (SMS), this function can be realized by using it together with the SMS. It can be set from Smart Configurator/Touch Interface Configuration/Advanced Mode.
10	CCO Characteristics Correction	Process reduction Low power consumption	✓	-	-	This function sets whether CCO characteristics correction is performed by hardware or software. It is set to hardware when hardware touch judgment is enabled. Hardware processing eliminates the need for wake-up for each measurement and contributes to lower power consumption. This function is only displayed on CTSU2SL/CTSU2SLa. It cannot be changed by the user because it is automatically set according to "Judgment Type" and "Touch Judgment".
11	Multi-clock Correction	Process reduction Low power consumption	✓	-	-	This function sets whether multi-clock correction is performed in hardware or software. It is set to hardware when VMM)is used and hardware touch judgment is enabled. This function is only displayed on CTSU2SL/CTSU2SLa. It cannot be changed by the user because it is automatically set according to "Judgment Type" and "Touch Judgment".
12	Measurement Voltage Setting	Process reduction Low power consumption	✓	✓	-	Set TSCAP voltage to be used. If the microcontroller operating voltage is less than 2.4 V, the measurement voltage is automatically set to a lower voltage and the TSCAP voltage is 1.2 V. This function is used when VCC/VDD is less than 2.4 V during battery operation.

✓: Supported

3. Overview of each parameter

3.1 Measurement Count/Measurement Time

In "Measurement Count/Measurement Time" setting, the measurement time is determined by configuring the measurement count. In CTSU1, it is displayed as "Measurement Count" and in CTSU2, it is displayed as "Measurement Time".

1. CTSU1: The measurement time for a single cycle is determined by CTSUPRMODE, CTSUPRRATIO, and the base clock cycle. The number of repetitions for the measurement is configured using the “Measurement Count” setting. For detailed information on CTSUPRMODE and CTSUPRRATIO, please refer to the hardware manual for each capacitive touch sensor microcontroller.
2. CTSU2/CTSU2x: “Measurement time” is configured based on (STCLK cycle × 8). This setting defines the measurement time for 1 frequency in the 3-frequency measurement process. For detailed information on STCLK, please refer to the hardware manual for each capacitive touch sensor microcontroller.

Signal value* can be improved by increasing "Measurement Count/Measurement Time". However, since the measurement time is also extended at the same time, adjustment according to the user's specifications is required. Also, when changing "Measurement Count/Measurement Time", please adjust the offset tuning target using the "Offset Tuning Target" to prevent overflow. Please refer to 3.2 Offset Tuning Target 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 measurement count and the measured value at the time of touch ON/OFF.

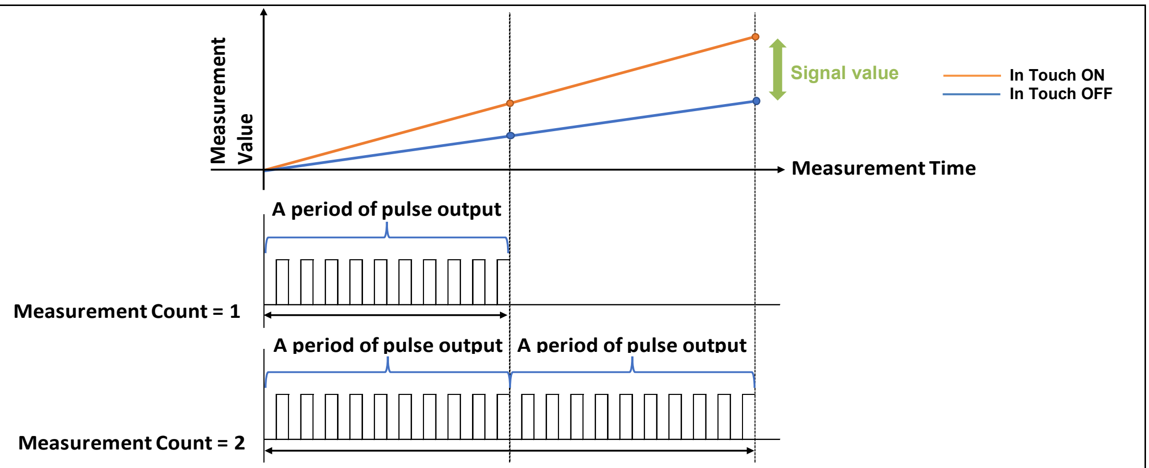


Figure 3-1 Image of Measurement Time and measurement value based on Measurement Count

Table 3-1 shows the default "Measurement Count/Measurement Time" when using self-capacitance method. In CTSU1, Measurement Count is determined based on the base clock frequency so that Measurement Time is fixed at 526 μs. In CTSU2/CTSU2x, Measurement Count is fixed at 8 to ensure a consistent Measurement Time of 128 μs.

Table 3-1 Default "Measurement Count" Setting

	Base Clock Frequency/Sensor Drive Pulse Frequency [MHz]	**Measurement Count** *1	**Measurement Time [μs]**
CTSU1 (Sample RX130)	4	8	526
	2	4	
	1	2	
	0.5	1	
CTSU2/CTSU2x (Sample RX140)	-	8	128 *2

Note1: For details about SNUM, please refer to the hardware manual for each capacitive touch sensor microcontroller.
Note2: The measurement time of one frequency is described.

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

- CTSU1 (RX130)

$$\text{Stabilization wait time } [\mu\text{s}] = 34 \cdot \frac{1}{\text{Base Clock Frequency}}$$

$$\text{Measurement time } [\mu\text{s}] *= 263 \cdot \frac{1}{\text{Base Clock Frequency}} \cdot \text{Measurement count}$$

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

Base Clock Frequency [MHz]	Measurement count	Stabilization wait time [μs]	Measurement time [μs]*	Total (Stabilization wait time + Measurement time) [μs]
4	8	8.5	526	534.5
2	4	17.0	526	543.0
1	2	34.0	526	560.0
0.5	1	68.0	526	594.0

Note: This indicates the measurement time when using the recommended settings for CTSUPRRATIO and CTSUPRMODE. Changing this value is deprecated. For details, please refer to the hardware manual for each capacitive touch sensor microcontroller.

- CTSU2/CTSU2x (RX140)

$\text{Stabilization wait time } [\mu\text{s}] = 64 \cdot 3$ [for 3-frequency measurement]

$\text{Measurement time } [\mu\text{s}] *= 16 \cdot \text{Measurement count} \cdot 3$ [for 3-requency 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 the measurement time when using self-capacitance method with RX140 (3-frequency measurement)

Measurement count	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. The example below shows the measurement time when using the recommended value of 0.5 MHz (2 μs).

The stabilization wait time and the 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 (R01AN4469)

Figure 3-2 shows an example when setting "Measurement Count/Measurement Time" with "Advanced mode".

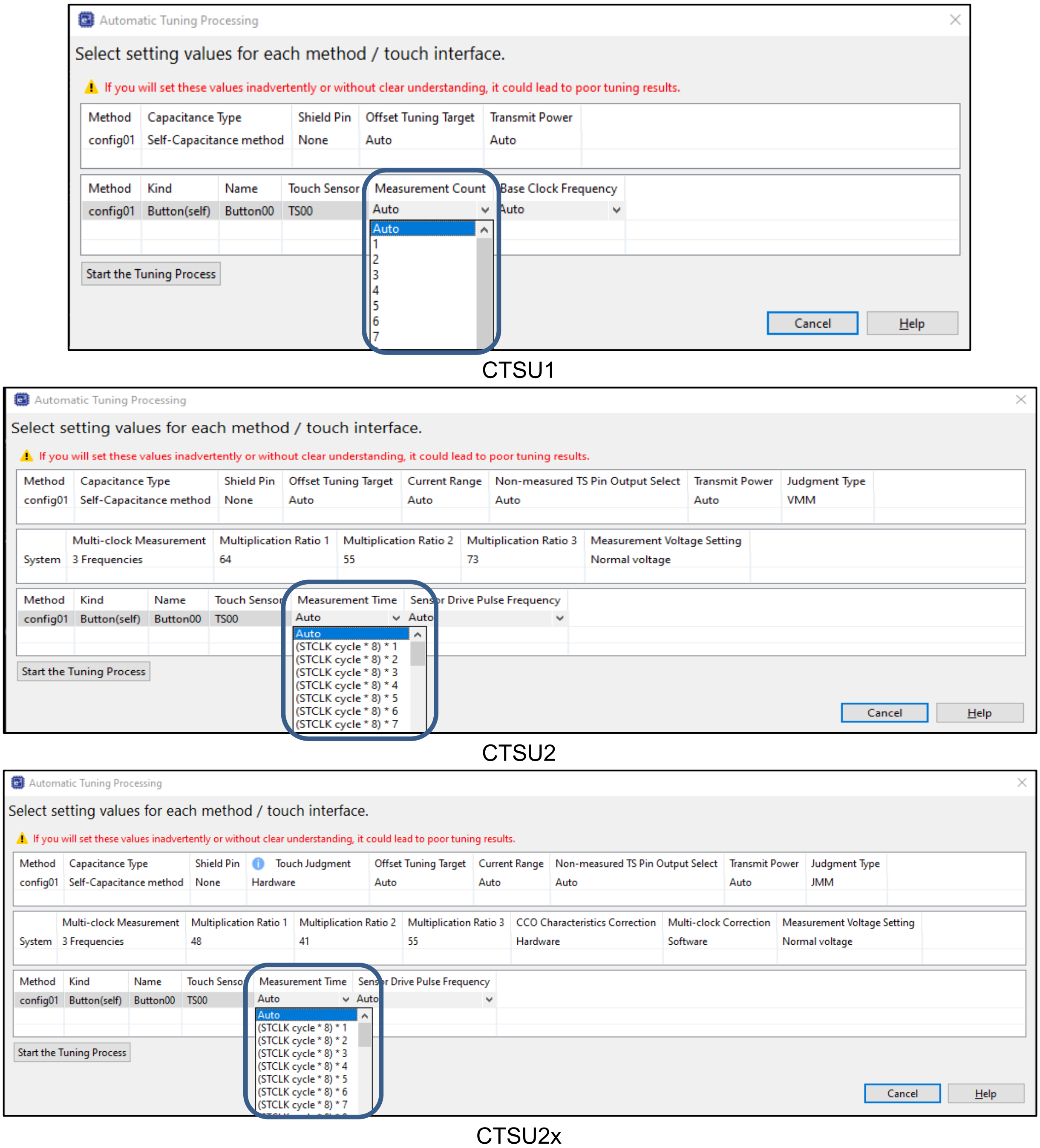


Figure 3-2 Setting of "Measurement Count/Measurement Time"

For the set value, the value of Measurement Count -1 is reflected to "snum" of the qe_touch_config.c. If "(STCLK Cycle* 8) * 8" is selected in "Measurement Count/Measurement 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: For details about SNUM, please refer to the hardware manual for each capacitive touch sensor microcontroller.

3.1.1 Effects on Signal value / SNR and precautions due to changes in the Measurement Count/Measurement Time

Table 3-4 shows the measurement values (actual measurement examples) when RX140 mounted capacitance touch evaluation system is used when "Measurement Count/Measurement Time" is changed.

Table 3-4 Measurement values when "Measurement Count/Measurement Time" is changed (actual measurement example)

Capacitance Touch Evaluation System with CTSU2x(RX140) Self-capacitance method, VMM method, Sensor Drive Pulse Frequency: 2 MHz, Current Range: 40 μA, Button 1 ch (averaged five times)							
Measurement count	Offset tuning target	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	25.0%	11666	14586	2920	22.76	20.96	768 μs
16	20.0%	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".

If the noise has a standard distribution, increasing the measurement count/measurement time will increase the signal value because the number of integrated touch measurements will increase, but the noise will be averaged, thus improving the SNR.

Accumulation of the measurement count 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 measurement count, or changing the current range or frequency. These can be adjusted individually.

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

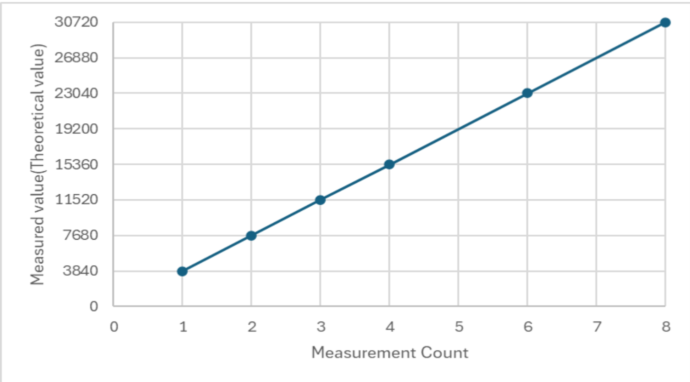
3.1.2 Necessity of Offset Tuning Adjustment when Changing Measurement Count

If you change the "Measurement Count", 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. Please refer to 3.2 Offset Tuning Target 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 "Measurement Count/Measurement Time" with RX130 (theoretical value)

Capacitance Touch Evaluation System with CTSU1(RX130) Self-Capacitance System, PCLKB:32 MHz, Sensor Drive Pulse Frequency: 2 MHz, Offset Tuning Target: 37.5 %, Key 1ch				
Measurement count	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	263.0	280.0	7680
3	17	394.5	411.5	11520
4	17	526.0	543.0	15360
5	17	657.5	674.5	19200
6	17	789.0	806.0	23040
:	:	:	:	:



Note: Recommended values are set for PRMODE and PRRATIO.

Figure 3-3 Measurement value (theoretical value) for "Measurement Count/Measurement Time" with RX130

For instance, if the measurement count is increased to eight by the self-capacitance method, the measurement value at touch OFF will be around 30720. Increasing the measurement count may cause overflow of measurements during touch ON.

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

Table 3-6 measurement value for "Measurement Count/Measurement Time" with RX140 (theoretical value)

Capacitance Touch Evaluation System with CTSU2x(RX140) Self-Capacitance System, PCLKB: 32 MHz, Sensor Drive Pulse Frequency: 2 MHz, Offset Tuning Target: 37.5 %, Key 1 ch				
Measurement count	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
:	:	:	:	:

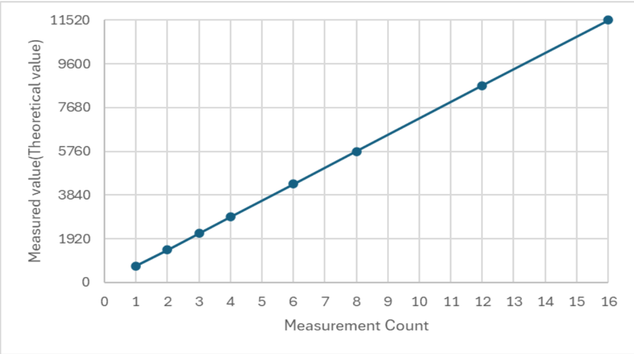


Figure 3-4 Measurement value (theoretical value) for "Measurement Count/Measurement Time" with RX140

For instance, if the measurement count is increased to 16 when using the self-capacitance method, the measurement value at touch OFF will be around 11520. Increasing the measurement count may cause overflow of measurements during touch ON.

3.2 Offset Tuning Target

In "Offset Tuning Target", 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, please refer to "2.2.2 Measurement Range" in the following document.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (R30AN0424)

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 16 bit 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.

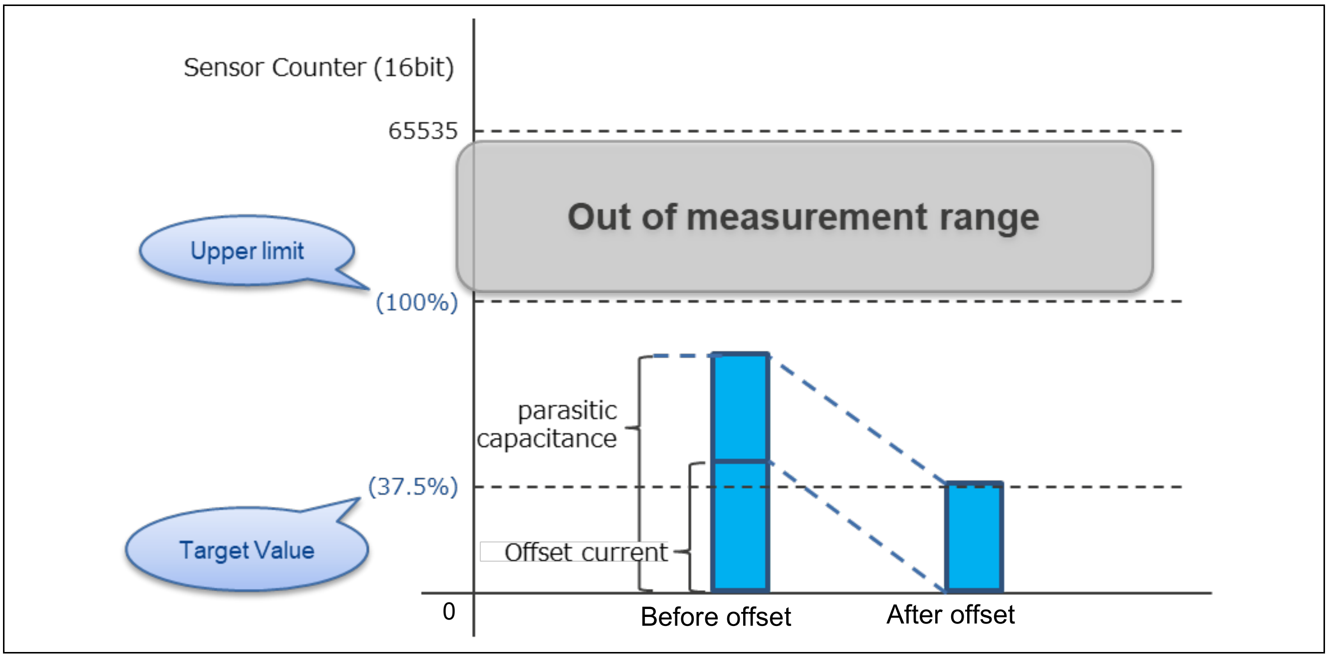


Figure 3-5 Offset Tuning Process of Self-Capacitance Method

Table 3-7 shows the target values for the default "Measurement Count". For the default "Measurement Count" please see Table 3-1 setting.

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

	Judgment Type *	ATUNE0	Self-capacitance method	Mutual capacitance system	Active shield
CTSU1	-	Normal Voltage	15360 (37.5 %)	10240 (25 %)	-
CTSU2/ CTSU2x	Value Majority Mode (VMM)	Normal Voltage	11520 (37.5 %)	7680 (25 %)	4608 (15 %)
		Low Voltage	9216 (37.5 %)	6144 (25 %)	-
	Judgment Majority Mode (JMM)	Normal Voltage	5760 (37.5 %)	3840 (25 %)	2304 (15 %)
		Low Voltage	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 "Offset Tuning Target" in CTSU1

Offset Tuning Target	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 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" CTSU2/CTSU2x (QE for Capacitive Touch v4.0.0 or later)

Offset Tuning Target	JMM target value*		VMM target value*	
	Normal Voltage	Low Voltage	Normal Voltage	Low Voltage
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 3-frequency measurement. When JMM is used, it is equivalent to one frequency (128 μs).

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

Offset Tuning Target	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 when setting "Offset Tuning Target" with "Advanced mode".

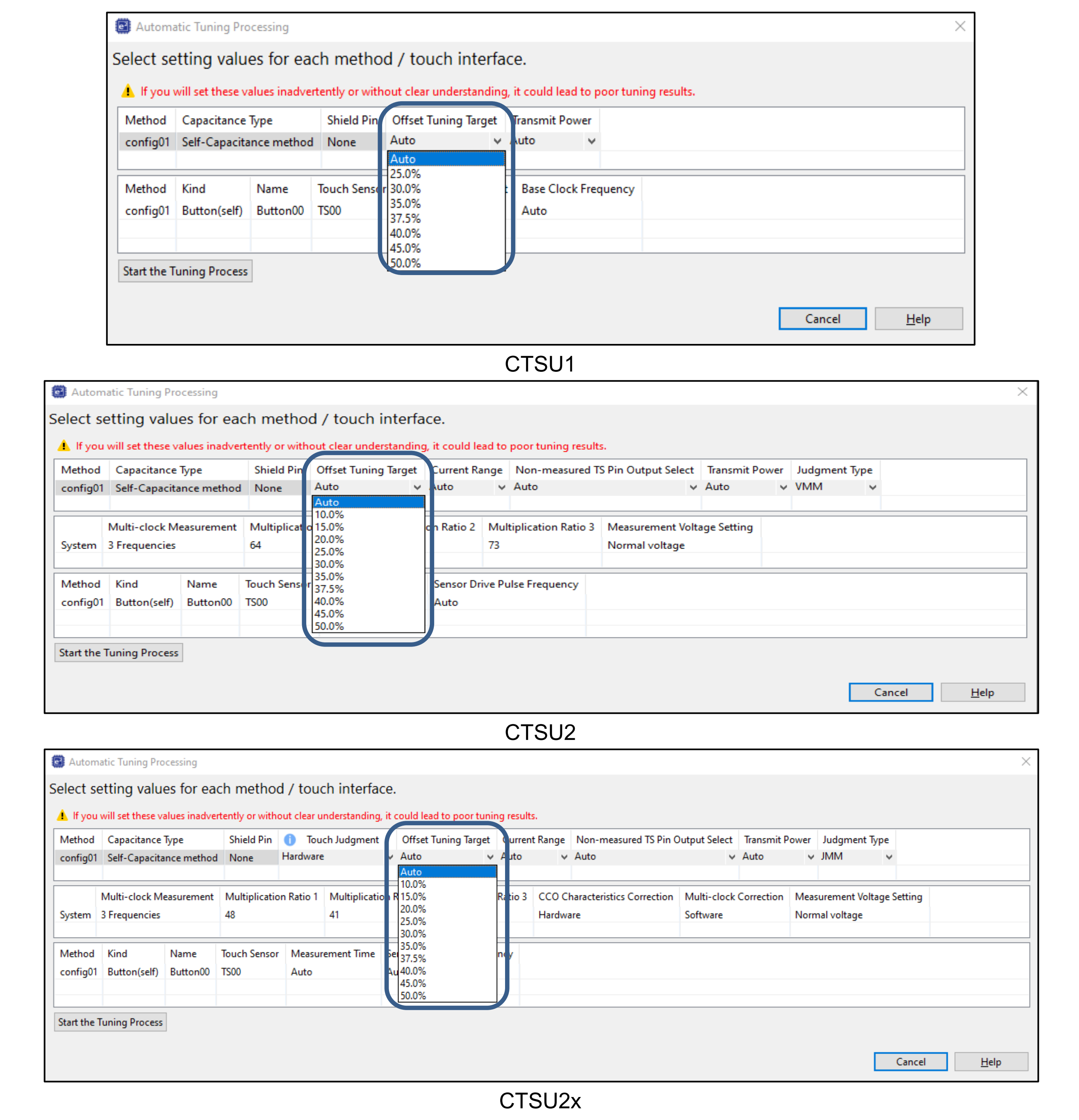


Figure 3-6 Setting of "Offset Tuning Target"

The setting is 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 Offset Tuning Target and Measurement Count Change on Measurement Value

The measured value changes depending on the measurement count. If the measurement count is set to twice the default setting, the measured value also doubles.

1. CTSU1:

Measured value = (Offset tuning target [%] × 40960*)/100 × (Measurement count/Default Measurement count)

Note: 40960 is the value when the offset tuning target is 100%.

2. CTSU2:

- When using VMM:

Measurement Voltage Setting: Normal Voltage

Measured value = (Offset tuning target [%] × 30720*)/100 × (Measurement count/default Measurement count)

Note: 30720 is the value when the offset tuning target is 100% at the measurement time of 256 µs.

Measurement Voltage Setting: Low Voltage

Measured value = (Offset tuning Target [%] × 24576*)/100 × (Measurement count/default Measurement count)

Note: 24576 is the value when the offset tuning target is 100% at the measurement time of 256 µs.

- When using JMM:

Measurement Voltage Setting: Normal Voltage

Measured value = (Offset tuning target [%] × 15360*)/100 × (Measurement count/default Measurement count)

Note: 15360 is the value when the offset tuning target is 100% at the measurement time of 128 µs.

Measurement Voltage Setting: Low Voltage

Measured value = (Offset tuning Target [%] × 12288*)/100 × (Measurement count/default Measurement count)

Note: 12288 is the value when the offset tuning target is 100% at the measurement time of 128 µs.

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

Table 3-11 Measurement values for "Offset Tuning Target " when the measurement count is changed (theoretical values)

Offset Tuning Target	Target value when using VMM*	Measured value (theoretical value) when VMM is used in touch OFF*	
		Measurement Count: 8 (default)	Measurement Count: 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.

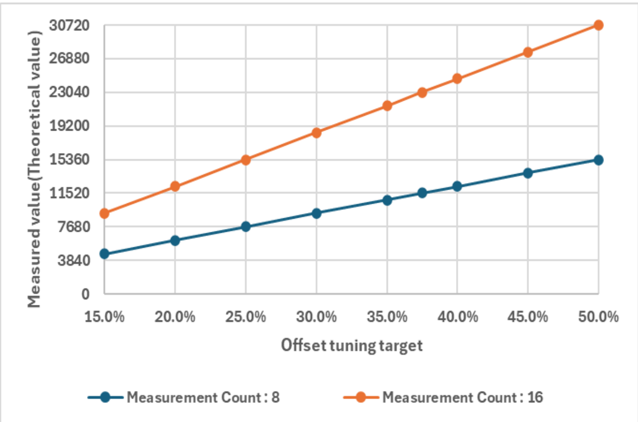


Figure 3-7 Measurement value (theoretical value) with respect to "Offset Tuning Target" when the Measurement Count is changed

Changing the Offset Tuning Target may cause the measurement value to overflow. Please set the target value and measurement count so that the measured values do not overflow during the system (product) operation under the maximum capacitance-added state*. If there is no need to change, set the target value and the 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 Table 3-11 to set the offset tuning target. Set the offset tuning target 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 Base Clock Frequency/Sensor Drive Pulse Frequency

"Base Clock Frequency/Sensor Drive Pulse Frequency" sets the frequency division of the frequency output to the touch sensor. In CTSU1, it is displayed as "Base Clock Frequency," and in CTSU2, it is displayed as "Sensor Drive Pulse Frequency." For details, please refer to the hardware manual of each capacitive touch sensor.

The higher Base Clock Frequency/Sensor Drive Pulse Frequency, the better the signal value will be. However, measurement errors will occur if the parasitic capacitance is large.

CTSU outputs a sensor drive pulse from TS pin and measures the capacitance from the charge current. For details, please refer to the following document.

Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (R30AN0424)

"Base Clock Frequency/Sensor Drive Pulse Frequency" is set to an appropriate frequency in Auto tuning by the parasitic capacitance and the set damping resistance. In addition, Base Clock Frequency/Sensor Drive Pulse Frequency varies depending on the operation clock. For details, please refer to the hardware manual of each capacitive touch sensor.

CTSU1 uses a parasitic capacitance/damping resistor to determine the final frequency from four different frequency 4 / 2 / 1 / 0.5 MHz.

Figure 3-8 shows the relation between the parasitic capacitance/damping resistor of RX130 set by Auto tuning and Base Clock Frequency. A typical example of CTSU1 (TSCAP voltage 1.6 V) is shown below.

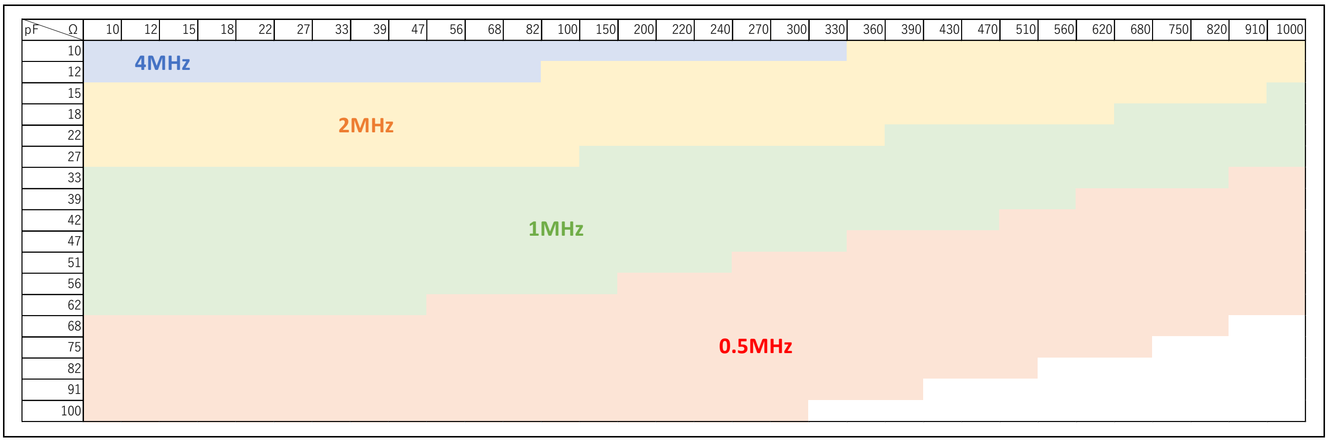


Figure 3-8 Parasitic capacitance/damping resistance of RX130 (receiving electrode 1.6V) vs. Base Clock Frequency

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

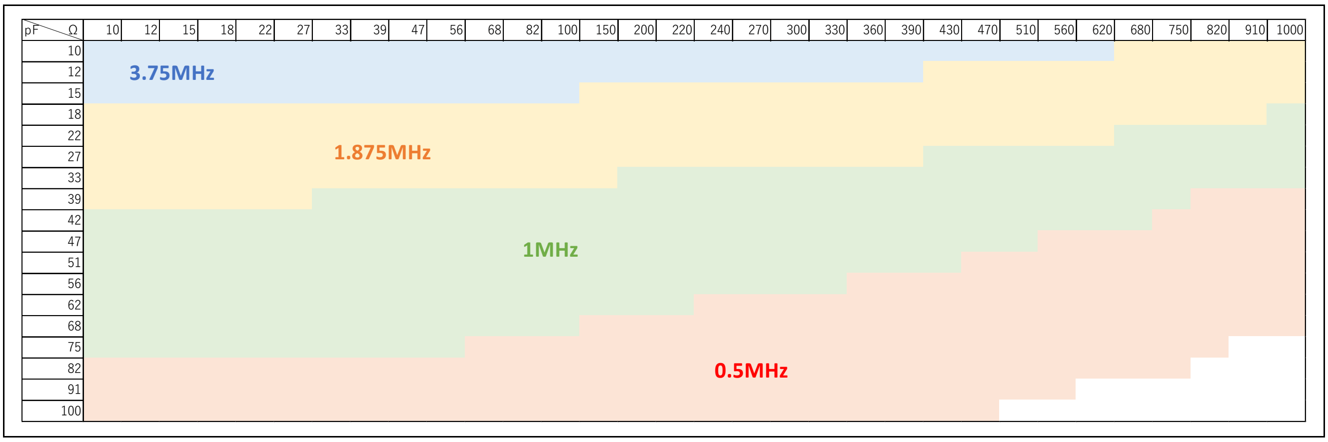


Figure 3-9 Parasitic capacitance/damping resistance of RX671 (receiving electrode 1.18 V) vs. Base Clock Frequency

The optimal upper limit of the sensor drive pulse frequency for CTSU2/CTSU2x is determined by the parasitic capacitance and damping resistor. Within this range, the highest of the 3-frequency is selected so that it remains below the upper frequency limit. Figure 3-10 to Figure 3-13 illustrate examples of the 1st frequency. For the first frequency among the 3-frequency measurements, please refer to section “3.7 Judgment Type/Multi-clock Measurement/Multiplication Ratio”.

Figure 3-10 shows the relation between the parasitic capacitance/damping resistor and the sensor drive pulse frequency (1st frequency) under normal voltage conditions set by Auto tuning, using RX140 (SUCLK upper limit: 40 MHz) as a representative example of CTSU2/CTSU2x.

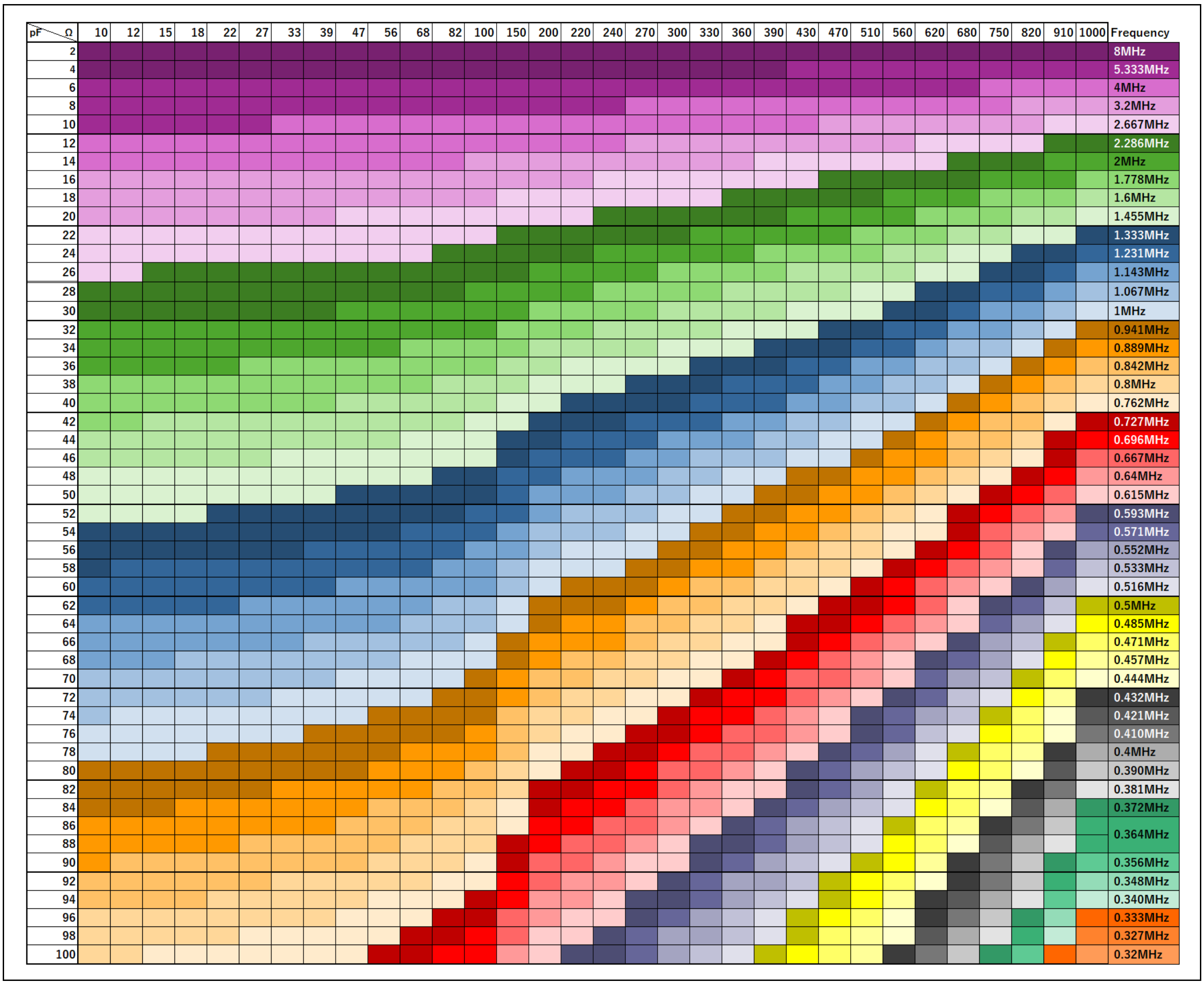


Figure 3-10 Relation between the parasitic capacitance/damping resistor of RX140 (Measurement Voltage Setting: Normal Voltage) and the sensor drive pulse frequency (1st frequency)

Figure 3-11 shows the relation between the parasitic capacitance/damping resistor and the sensor drive pulse frequency (1st frequency) under low voltage conditions set by Auto tuning, using RX140 (SUCLK upper limit: 40 MHz) as a representative example of CTSU2/CTSU2x.

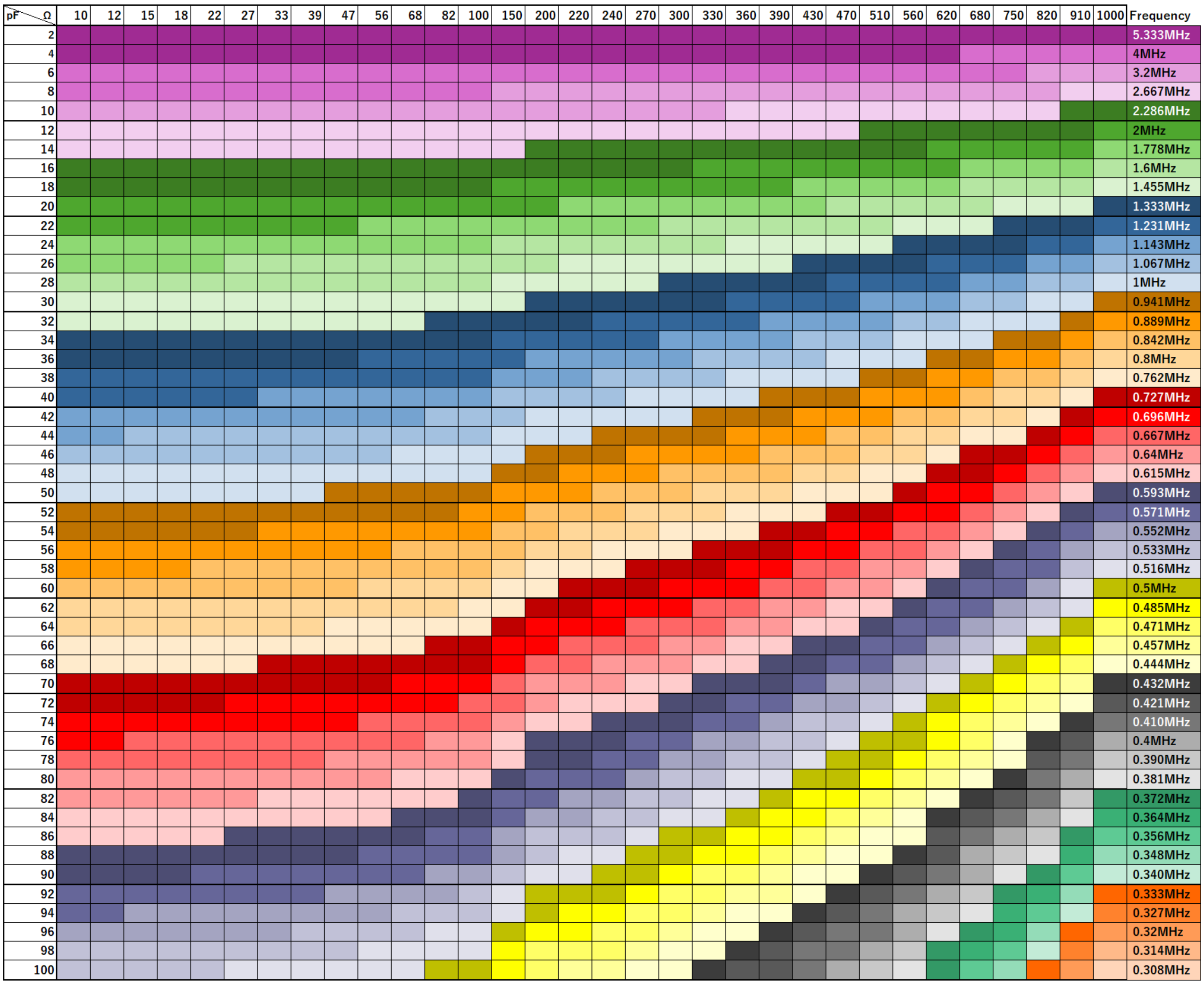


Figure 3-11 Relation between the parasitic capacitance/damping resistor of RX140 (Measurement Voltage Setting: Low Voltage) and the sensor drive pulse frequency (1st frequency)

Figure 3-12 shows the relation between the parasitic capacitance/damping resistor and the sensor drive pulse frequency (1st frequency) under normal voltage conditions set by Auto tuning, using RL78/G23 (SUCLK upper limit: 32 MHz) as a representative example of CTSU2/CTSU2x.

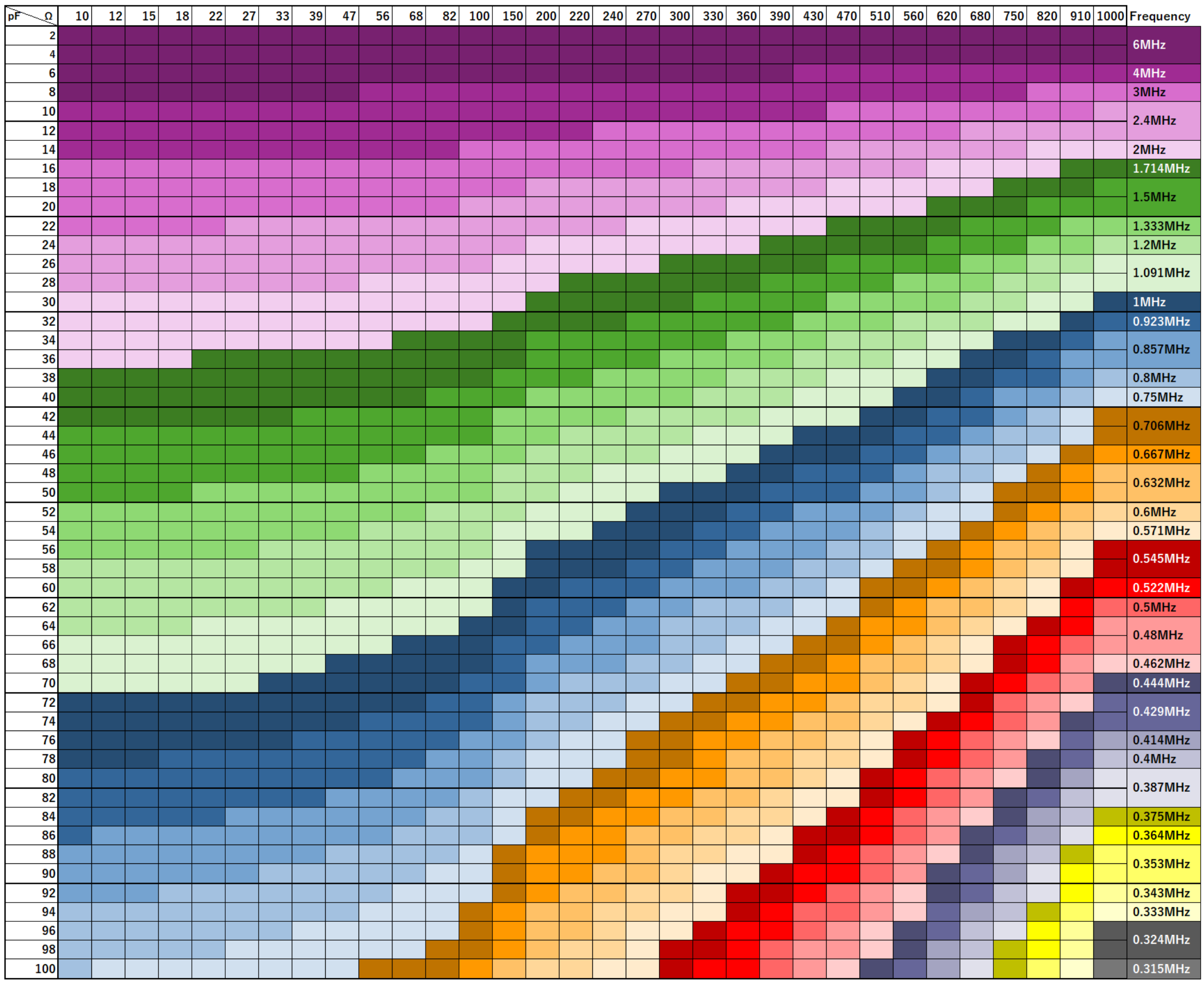


Figure 3-12 Relation between the parasitic capacitance/damping resistor of RL78/G23 (Measurement Voltage Setting: Normal Voltage) and the sensor drive pulse frequency (1st frequency)

Figure 3-13 shows the relation between the parasitic capacitance/damping resistor and the sensor drive pulse frequency (1st frequency) under low voltage conditions set by Auto tuning, using RL78/G23 (SUCLK upper limit: 32 MHz) as a representative example of CTSU2/CTSU2x.

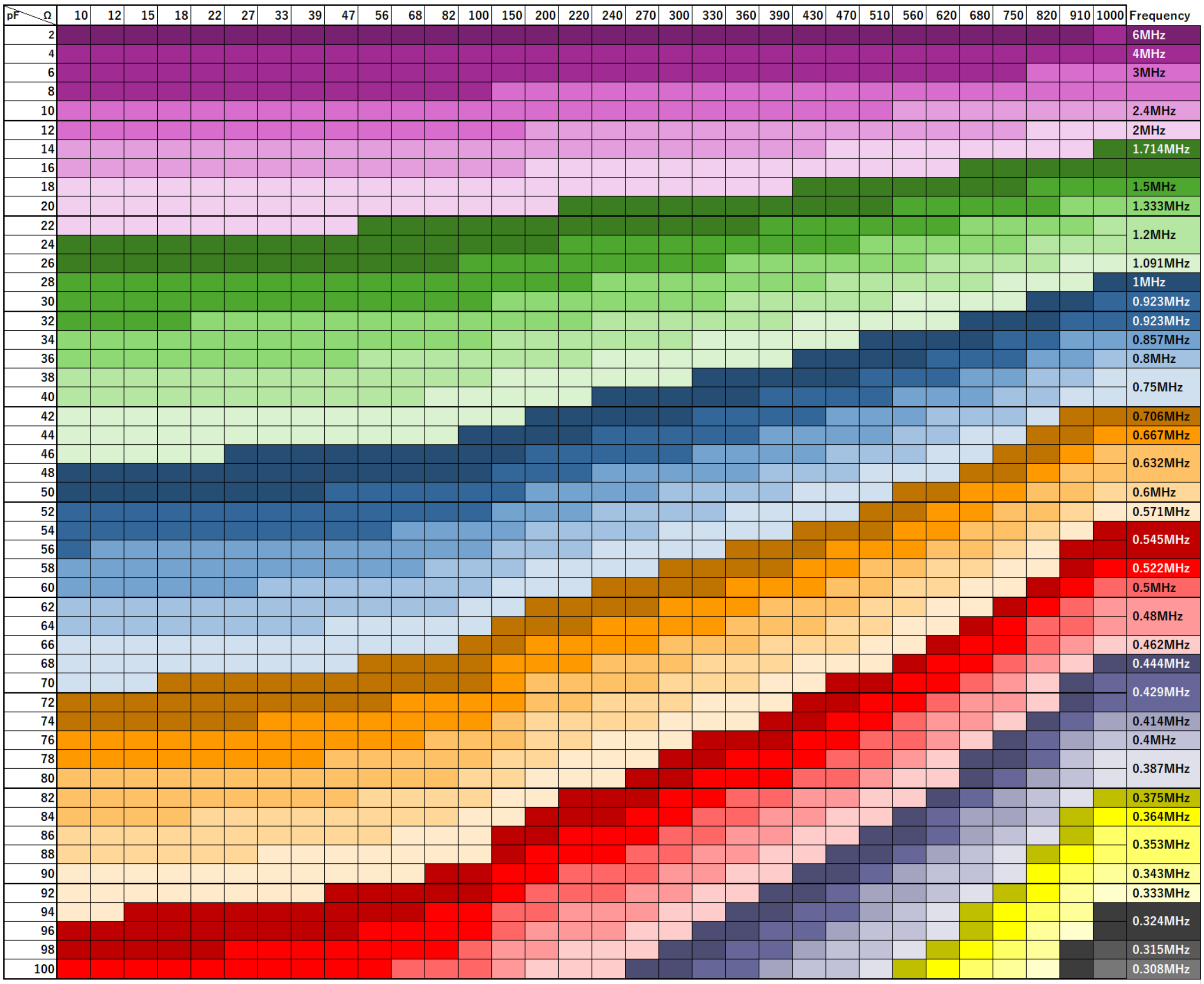


Figure 3-13 Relation between the parasitic capacitance/damping resistor of RL78/G23 (Measurement Voltage Setting: Low Voltage) and the sensor drive pulse frequency (1st frequency)

The higher the parasitic capacitance, the lower Base Clock Frequency/Sensor Drive Pulse Frequency is set. If Base Clock Frequency/Sensor Drive Pulse 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 pin. Therefore, in Auto tuning sets the optimum frequency where no measurement error occurs.

If the sensor drive pulse frequency varies between electrodes and this variation affects system performance, the frequency should be adjusted accordingly. For example, it may be appropriate to align all electrodes to the lowest frequency. Please adjust Base Clock Frequency/Sensor Drive Pulse Frequency after thorough evaluation according to the specifications required by the user.

Figure 3-14 shows an example when setting "Base Clock Frequency/Sensor Drive Pulse Frequency" with "Advanced mode".

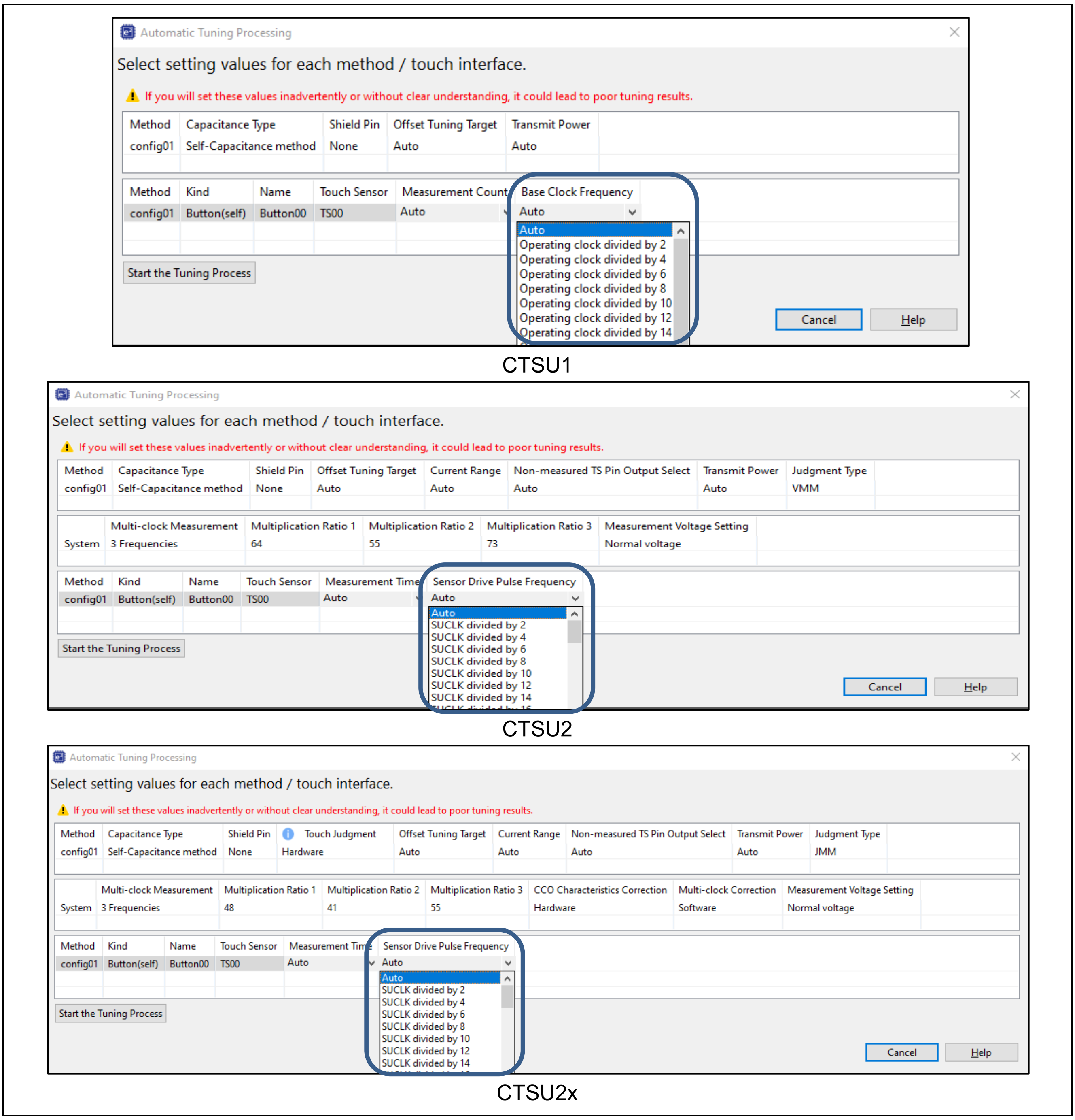


Figure 3-14 Setting of "Base Clock Frequency/Sensor Drive Pulse Frequency"

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 "SUCLK divided by 16" is selected for Base Clock Frequency/Sensor Drive Pulse 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: For details about SDPA, please refer to the hardware manual for each capacitive touch sensor microcontroller.

3.3.1 Effects on Signal value / SNR by Changing Base Clock Frequency/Sensor Drive Pulse Frequency

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

Table 3-12 Measurement values when Sensor Drive Pulse Frequency is changed (actual measurement example)

Capacitance Touch Evaluation System with CTSU2x(RX140) Self-capacitance method, VMM method, Measurement Count: 8 (Stabilization wait time + Measurement time: 576μs), Current Range: 40μA, Offset Tuning Target: 37.5% (averaged five times)					
Sensor Drive Pulse 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	13.0	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 e² studio "Help".

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

Figure 3-15 shows the image of CTSU measurement when the parasitic capacitance is large and Base Clock Frequency/Sensor Drive Pulse 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 frequency to match the parasitic capacitance.

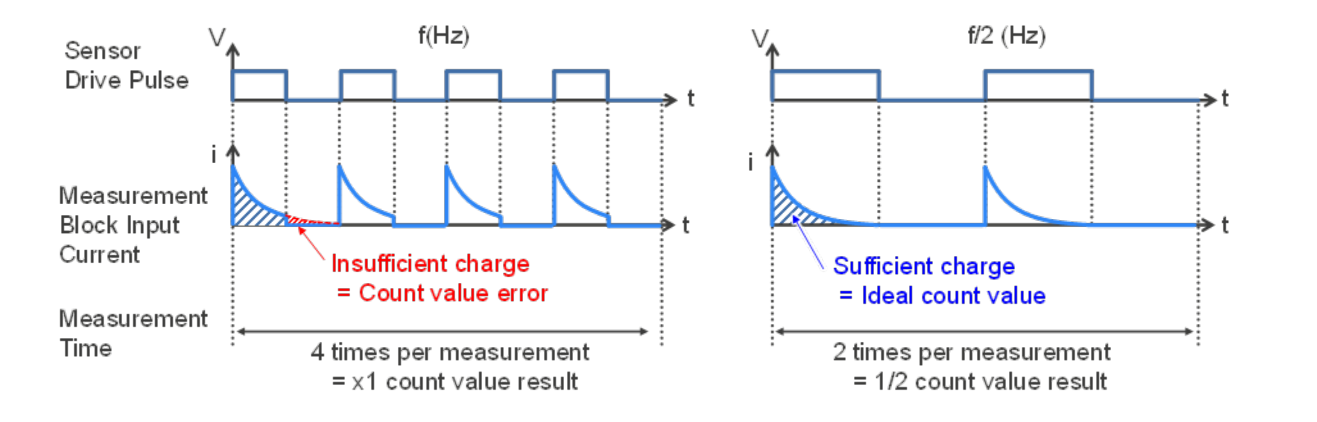


Figure 3-15 Image of CTSU measurement

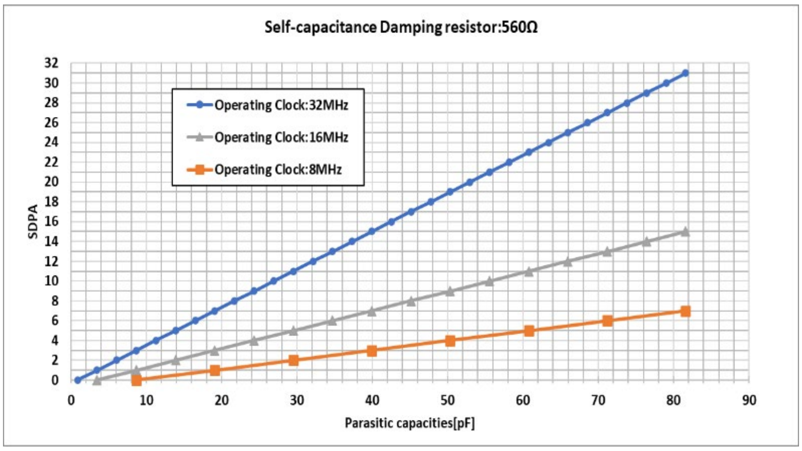
When set to 0.5 MHz, if the parasitic capacitance is small, the average value at touch OFF may not be set near the offset tuning target. The reason is that the measurement value does not reach the target value because the current supplied from VDC is small because the parasitic capacitance is small, and the current supplied to the current mirror circuit is also small. In this case, increase Base Clock Frequency/Sensor Drive Pulse Frequency or decrease the offset tuning target.

Also, considering to ensure enough charge/discharge times, set the base clock frequency/sensor drive pulse frequency by referring Figure 3-10 to Figure 3-13.

Please adjust Base Clock Frequency/Sensor Drive Pulse Frequency after sufficiently evaluating it in accordance with the specifications required by the user.

3.3.2 How to adjust the Base Clock Frequency/Sensor Drive Pulse Frequency using Advanced Mode

Auto tuning sets the optimum Base Clock Frequency/Sensor Drive Pulse Frequency where no measurement error occurs. Although the final frequency is determined from the default 4 measurement frequencies, 4 MHz, 2 MHz, 1 MHz, 0.5 MHz by the parasitic capacitance in CTSU1, the margin of the frequency set for the parasitic capacitance may be too large. In such a case, it is possible to change to a more detailed frequency by using Advanced mode. Figure 3-16 shows the relation between parasitic capacitance and SDPA when a damping resistor of 560 Ω is used in RX130 that is CTSU1.

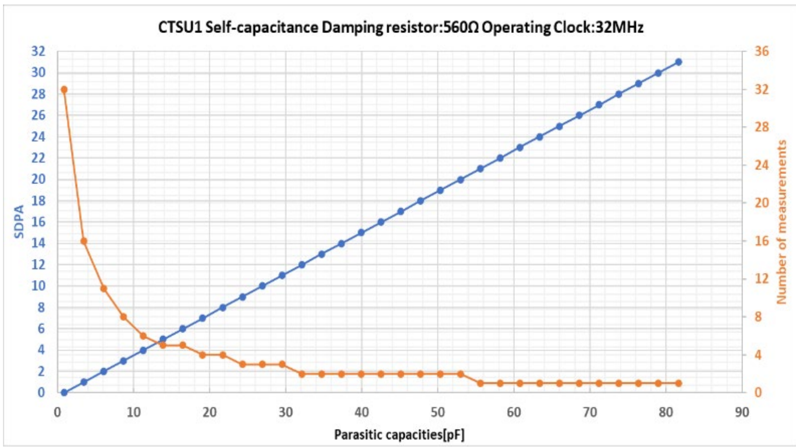


Note: Recommended values are set for PRMODE and PRRATIO.

Figure 3-16 Parasitic capacitance that can be measured when RX130 is used

When the parasitic capacitance is 30 pF and the operating clocks (CTSUCLK) are 32 MHz, the optimal SDPA is 11. Base Clock Frequency is calculated by the following formula.
Base Clock Frequency = CTSUCLK / ((SDPA + 1) × 2)
When the operating clock (CTSUCLK) is 32 MHz and SDPA is 11, Base Clock Frequency is as follows.
Base Clock Frequency: 32[MHz] / ((11 + 1) × 2) = 1.333 MHz

In RX130, the measurement time is set to be 526 µs as the result of Auto tuning. However, if Base Clock Frequency is manually changed using this Advanced mode, the measurement time also changes. For details, please see 3.1 Measurement Count/Measurement Time. Figure 3-17 shows the relation between SDPA and the measurement count when the operating clock 32 MHz is used when the value is set to around 526 µs.



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 Measurement Count, depending on the SDPA.

Figure 3-17 SDPA and Measurement Count when 526 µs equivalent Measurement Times are set when RX130 (operation clock 32 MHz) 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 4/2/1/0.5 MHz depending on the Auto tuning. For instance, if the operating clocks are 30 MHz, they cannot be set to 4/2 MHz because of the frequency division relation. In such cases, 4/2 MHz is set to a lower 3.75/1.875 MHz.

Figure 3-18 shows the parasitic capacitance versus SDPA when the default setting of "Multi-clock measurement/ Multiplication Ratio" is used in RX140 that is CTSU2 and the damping resistor 560 Ω is used.

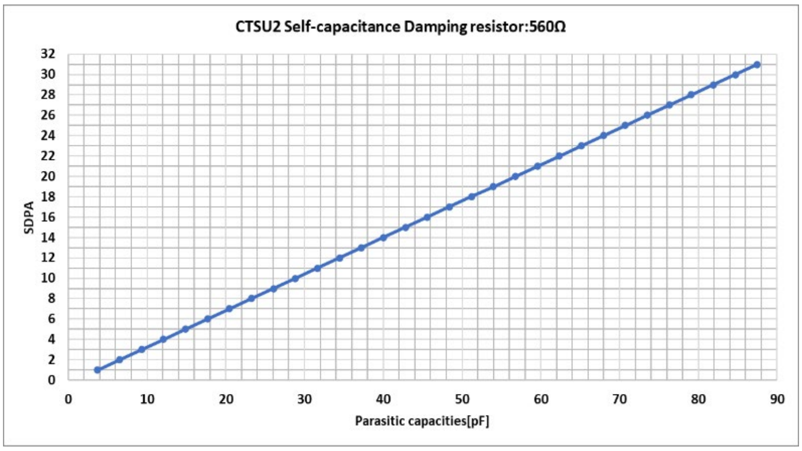


Figure 3-18 Parasitic capacitance that can be measured when RX140 is used

When the parasitic capacitance is 25 pF, the optimal SDPA is 9.
The Sensor Drive Pulse Frequency is calculated by the following formula.
Sensor Drive Pulse Frequency = (SUCLK* / 2) / (SDPA + 1)

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

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

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

3.4 Current Range

The "Current Range" setting can be changed only with CTSU2/CTSU2x.

In “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 "Current Range" increases the signal value. 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 pin 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, please refer to "2.2.1 Detection Principle" in the following document.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (R30AN0424)

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 current range increases the current I1 supplied from VDC for measurement.

Figure 3-19 shows an image of the measurement when using normal current (40 μA).

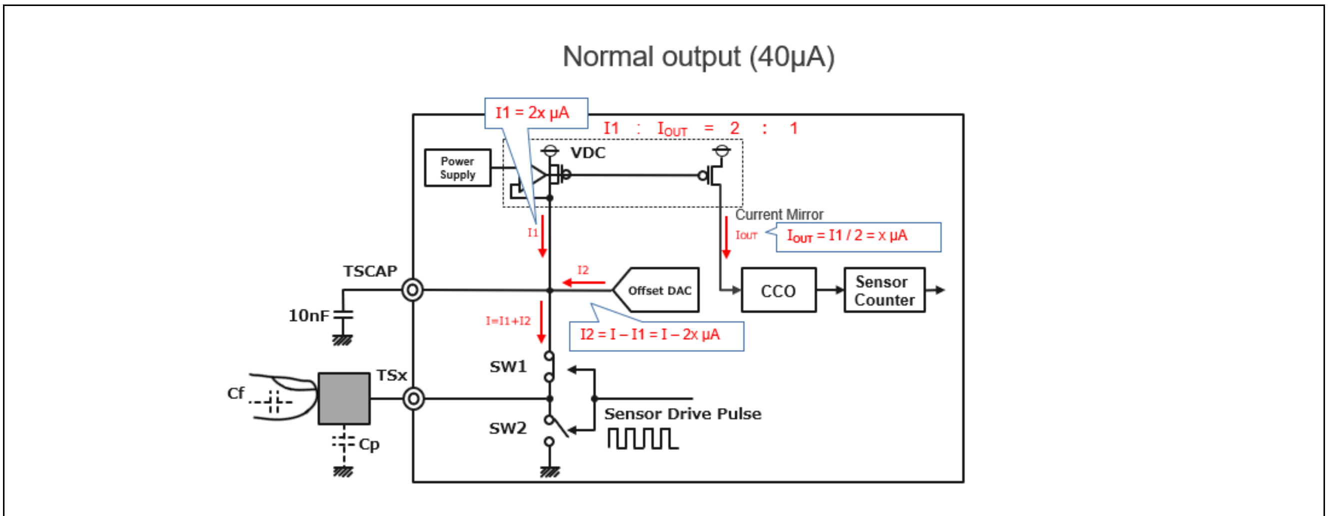


Figure 3-19 Measurement image when normal current (40 μA) is used

Table 3-13 shows the default settings.

Table 3-13 Default "Current Range" settings

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

Table 3-14 outlines the settings in CTSU2/CTSU2x.

Table 3-14 Overview of "Current Range" settings for CTSU2/CTSU2x

Current Range	ATUNE1	ATUNE2	Current mirror ratio
Low-current output (20 μA)	0	1	1
Normal current output (40 μA)	1	0	2
High-current output (80 μA)	0	0	4
Very high-current output (80 μA)	1	1	8

Figure 3-20 shows an example when setting "Current Range" with "Advanced mode".

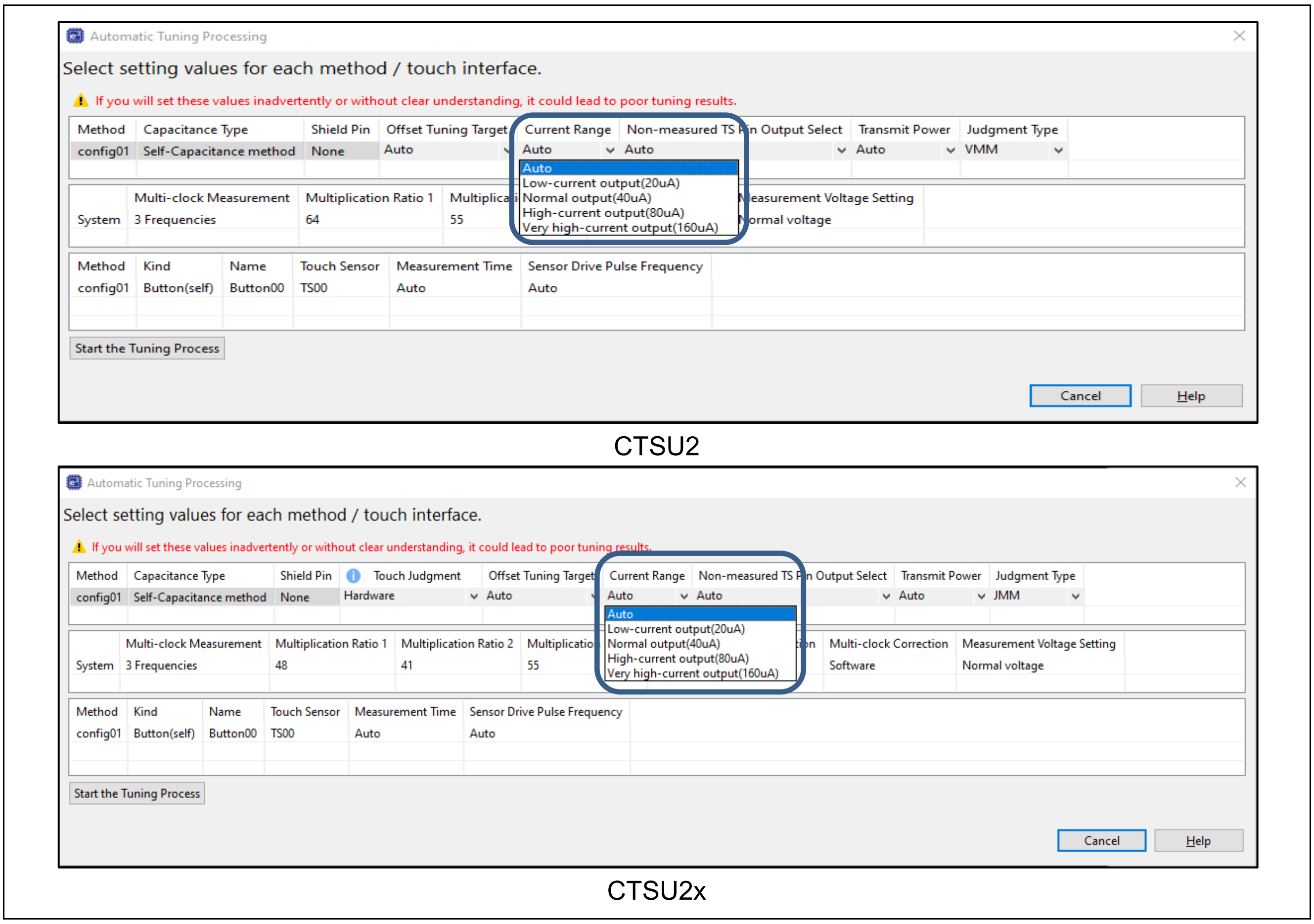


Figure 3-20 Setting of "Current Range"

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

```
    .atune12= CTSU_ATUNE12_40UA,
```

Note: For details about ATUNE, please refer to the hardware manual for each capacitive touch sensor microcontroller.

3.4.1 Effects on Signal value / SNR by Changing the Current Range

Table 3-15 shows the measurement values (actual measurement examples) when RX140 mounted capacitance touch evaluation system is used when the Current Range is changed.

Table 3-15 Measurement values when the Current Range is changed (actual measurement example)

Capacitance Touch Evaluation System with CTSU2x(RX140) Self-capacitance method, VMM method, Sensor Drive Pulse Frequency: 2MHz, Measurement Count: 8 (Stabilization wait time + Measurement time: 576 μs), Offset Tuning Target: 37.5 % (averaged five times)					
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	16.29
40μA	11566	13513	1947	16.96	17.67
80μA	11513	12484	970	11.46	14.29
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 e[2] studio "Help".

When the current range is low, the difference in 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. 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 current range or decrease the target value of the measurement value.

Figure 3-21 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 offset tuning target when the current range is normal current (40 μA) / very high current (160 μA) when the Sensor Drive Pulse Frequency is 2 MHz 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.

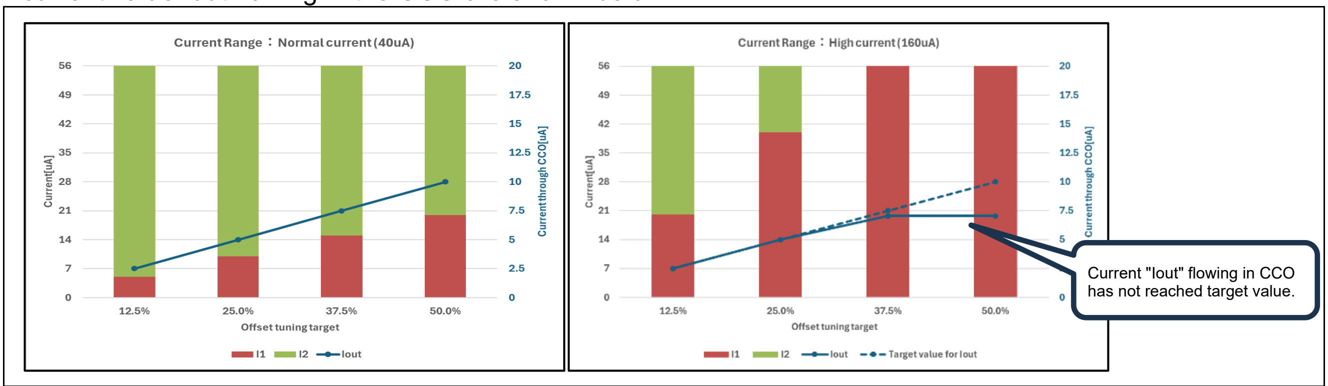


Figure 3-21 Current value when the offset tuning taeget and current range are changed

The current flowing through the CCO is 2.5~20 μA, and 20 μA flows when the offset tuning target is 100 %. When the normal current (40 μA) is used, I1 = approx. 15 μA, I2 = approx. 41 μA 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 = 7.5 μA.

When high current (160 μA) is used, I1 = approx. 56 μA, I2 = 0 μA when the 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 7 μA.

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 Pin Output Select

The setting of "Non-measured TS Pin Output Select" can be changed only with CTSU2/CTSU2x.

In "Non-measured TS Pin Output Select", the processing of non-measurement pins other than the measurement pins during the measurement period is set for each method.
Noise suppression is possible by appropriately processing non-measurement pins. It is recommended to set TS pin 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 pin 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 3-16 shows the default settings.

Table 3-16 Default "Non-measured TS Pin 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 3-23 shows an image of TS pin measurement in a touch interface configuration as shown in Figure 3-22. Since the active shield is set for the behavior of TS pin during config01 measurement period, the other pin TS01, TS02 is in-phase pulsing while TS00 is being measured. During config02 measurement, TS04 that TS03 is being measured is turned Low.

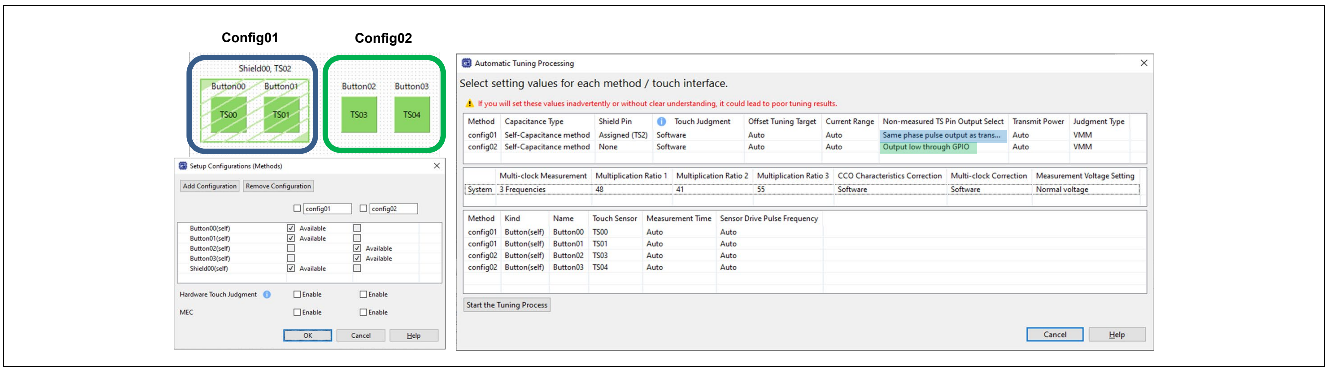


Figure 3-22 Example touch interface configuration

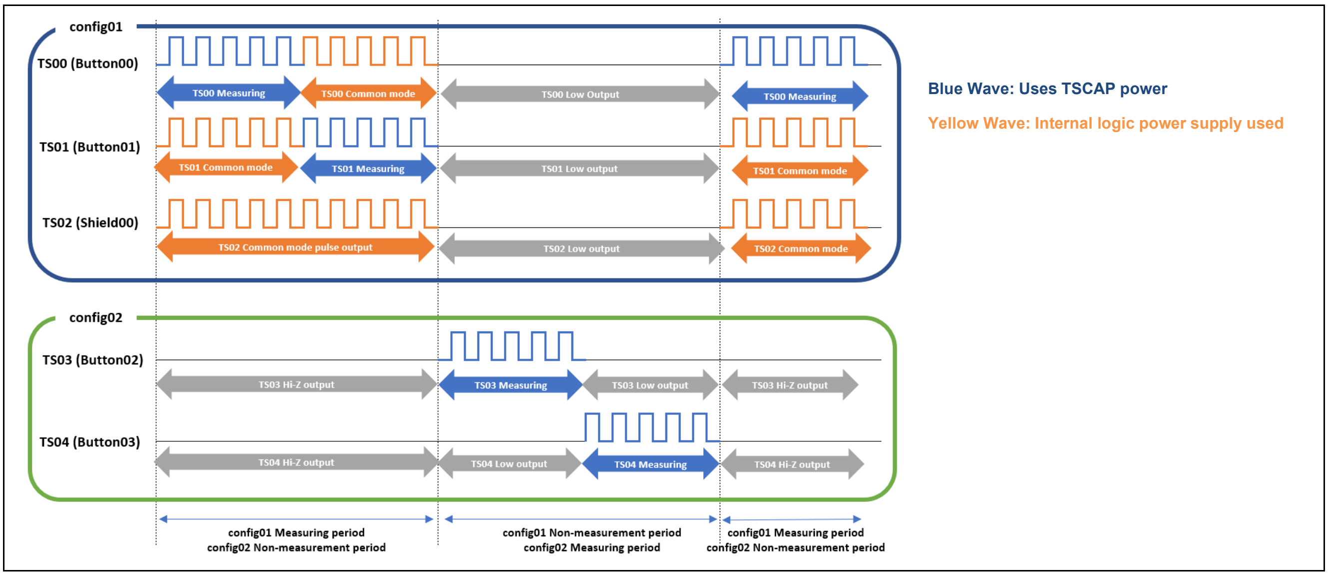


Figure 3-23 Image of TS pin measurement

This is an example of a Non-measured TS Pin Output Select. Please refer to the following documents.
RL78 Family Capacitive Touch Sensing Unit (CTSU2L) Operation Explanation (R01AN5744)

Table 3-17 shows an overview of each process setting.

Table 3-17 Overview of processing settings

Non-measured TS Pin Output Select setting	Overview
Output low thorough GPIO	This setting is used to output a Low from the non-measurement pin during measurement.
Hi-Z	This setting is used to output a Hi-Z from the non-measurement pin 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 pin during the measurement period.

Figure 3-24 shows an example when setting "Non-measured TS Pin Output Select" with "Advanced mode".

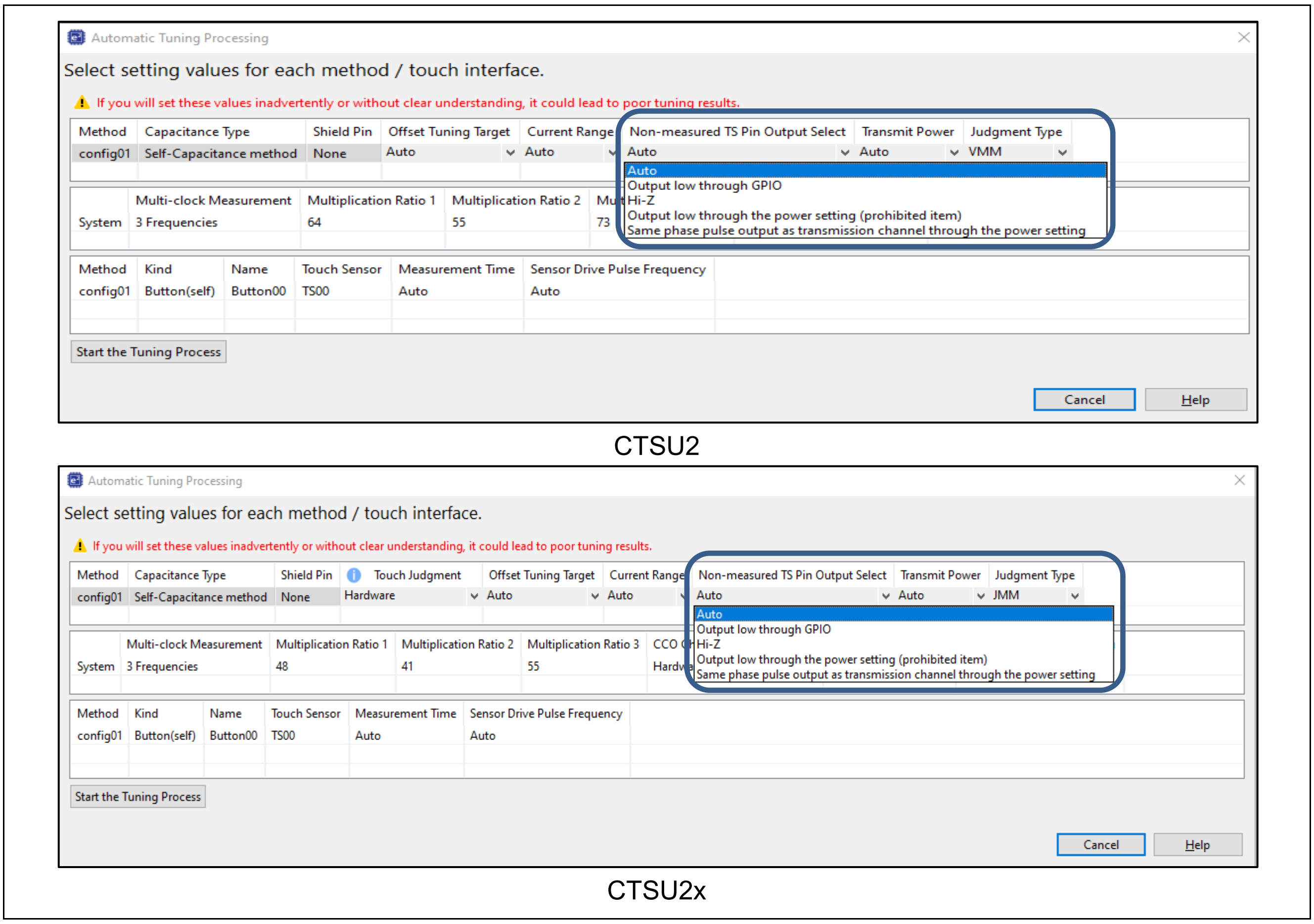


Figure 3-24 Setting of "Non-measured TS Pin Output Select"

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

```
    .posel  = CTSU_POSEL_LOW_GPIO,
```

Note: For details about POSEL, please refer to the hardware manual for each capacitive touch sensor microcontroller.

3.6 Transmit Power

When the mutual capacitance method is used, I/O power supply of the pins set in the transmit pin is selected for each method in the "Transmit 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, please refer to the following document.

RL78 Family Capacitive Touch Sensing Unit (CTSU2L) Operation Explanation (R01AN5744)

Table 3-18 lists the default settings.

Table 3-18 Default "Transmit 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 3-19 outlines the settings in CTSU1.

Table 3-19 Overview of "Transmit Power" settings for CTSU1

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

When using CTSU1, do not set TXVSEL = 1.

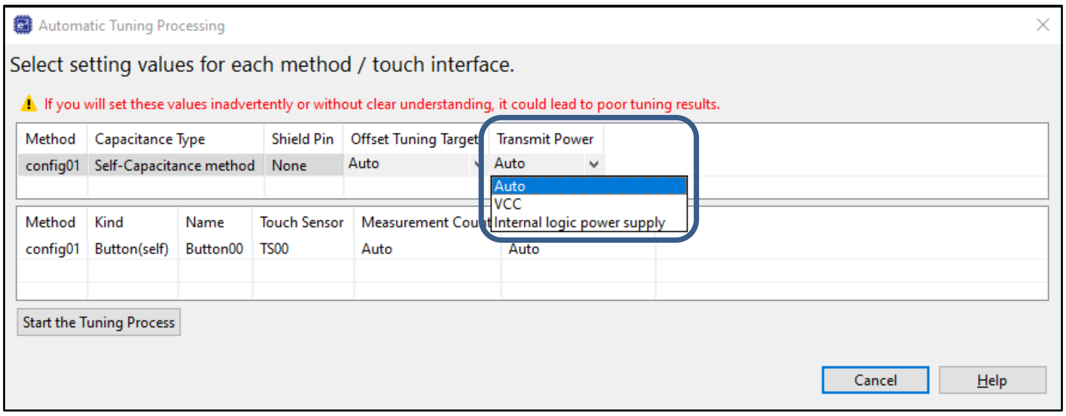
Table 3-20 outlines the settings in CTSU2/CTSU2x.

Table 3-20 Overview of "Transmit Power" settings for CTSU2/CTSU2x

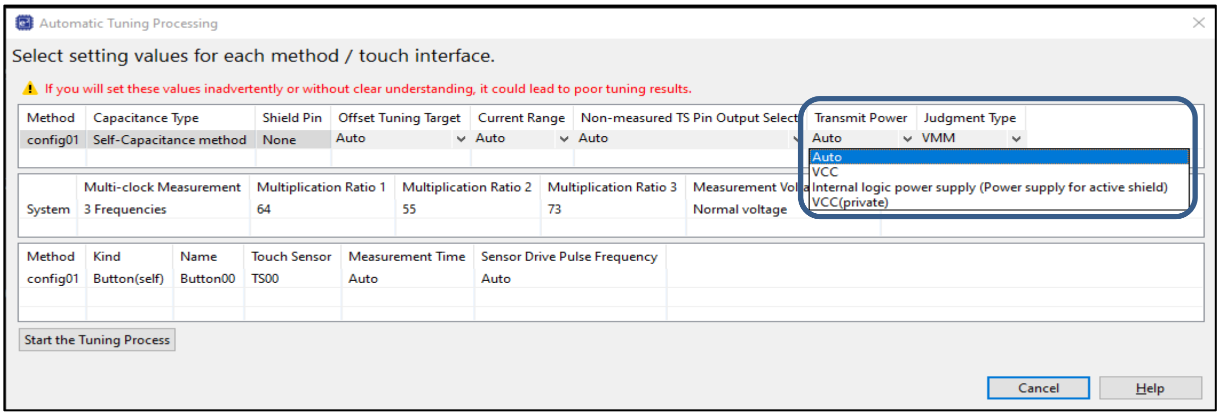
	Power setting of transmit pin	TXVSEL	TXVSEL2	Overview
When self-capacitance method is used	VCC	0	0	Only the receive pin is used during measurement and the transmit pin is not used. The receiving pin uses TSCAP power supply.
When using mutual capacitance method	VCC (private)	0 / 1	1	The transmission pin is also used during measurement. Signal value changes depending on the voltage of the transmission pin. The receiving pin 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 pin 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 pin from the transmitting pin. The receiving pin uses TSCAP power supply.

Note: For details, please refer to "2.3.1 Detection Principle" in the following document.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (R30AN0424)

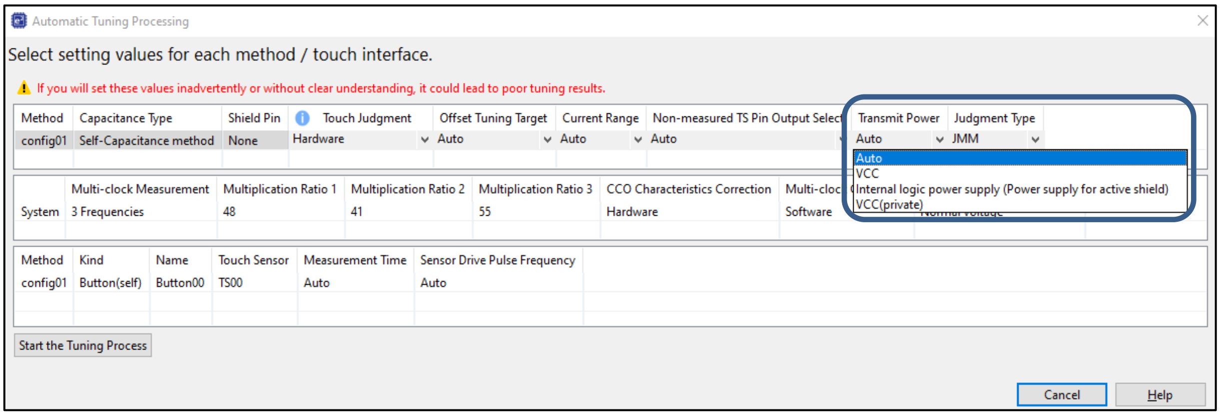
Figure 3-25 shows an example when setting "Transmit Power" with "Advanced mode".



CTSU1



CTSU2



CTSU2x

Figure 3-25 Setting of "Transmit Power"

The setting is 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 Judgment Type/Multi-clock Measurement/Multiplication Ratio

The settings for "Judgment Type" and "Multi-clock Measurement" and "Multiplication Ratio" can be changed only with CTSU2/CTSU2x.

Multi-clock Measurement 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-frequency to make touch judgments. "Judgment Type" can be set for each method, and "Multi-clock Measurement" and "Multiplication Ratio" can be set for each system.

The touch judgment method is shown below.

1. Value Majority Mode (VMM)

VMM is the result of two measurements that are close to the measured value of three frequencies. Touch judgment is performed with the value obtained by adding. Figure3-26 shows the operation image when VMM is used.

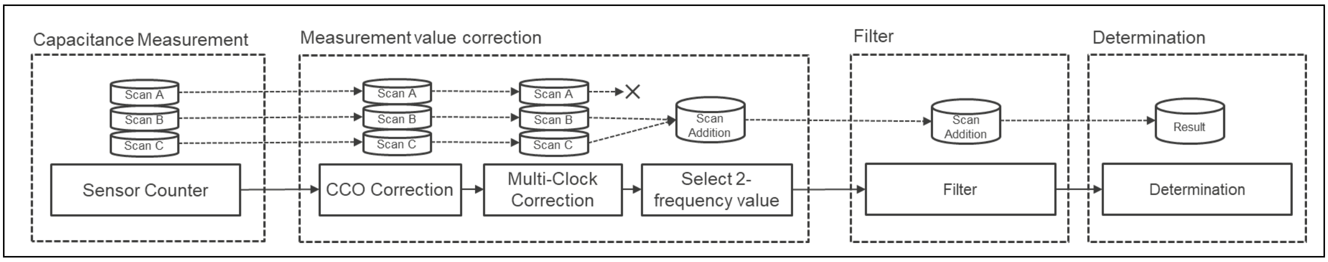


Figure3-26 Image of operation when VMM is used

2. Judgment Majority Mode (JMM)

JMM is a method to make the final touch judgment by majority decision based on the judgment result of each of the 3-frequency measurements. Only the self-capacitance and mutual capacitance buttons are supported. Figure 3-27 shows the operation image when JMM is used.

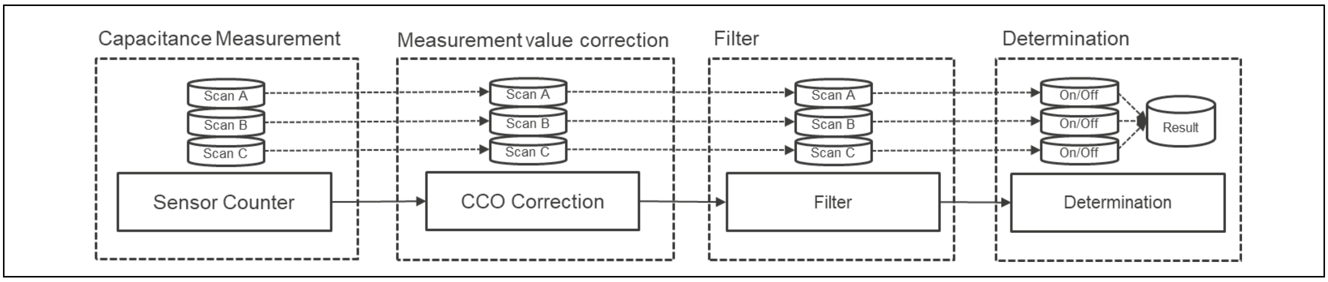


Figure 3-27 Image of operation when JMM is used

Please refer to the following document for details of the touch judgment method.
Capacitive Sensor Microcontrollers CTSU Capacitive Touch Introduction Guide (R30AN0424)

Table3-21 shows examples of default settings for "Judgment Type" and "Multi-clock Measurement" when buttons are used.

Table3-21 Default "Judgment Type/Multi-clock measurement" settings

	Touch Judgment	Judgment Type	Multi-clock Measurement
CTSU2	-	VMM	3-frequency
CTSU2x	Hardware	JMM	3-frequency
	Software	VMM	3-frequency

The Sensor Drive Pulse Frequency according to the set Multiplication Ratio is displayed as shown in Figure 3-28.

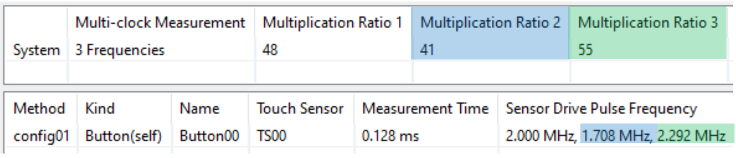


Figure 3-28 Sensor Drive Pulse Frequency by Setting the Multiplication Ratio

In Advanced mode setting, Multi-clock Measurement is measured by three sensor drive pulse frequencies respectively. The 1st frequency is the value set by "Sensor Drive Pulse Frequency". Its Multiplication Ratio is fixed to 48 or 64 by the device. Multiplication Ratio of the 2nd and 3rd frequencies can be changed to an arbitrary value.

Table 3-22 shows the default setting of "Multiplication Ratio" and the lower and upper limits that can be set.

Table 3-22 Default "Multiplication Ratio" settings

Device	**1st frequency Multiplication Ratio** *1	**2nd frequency Multiplication Ratio** *2 **[Configurable range]**	**3rd frequency Multiplication Ratio** *2 **[Configurable range]**
RL78/G22 RL78/G23 RL78/L23 RA0L1	48	41 [32~60]	Normal Voltage : 55 [32~60] Low Voltage : 46 [32~60]
RX260 RX261	48	41 [32~64]	Normal Voltage : 55 [32~64] Low Voltage : 46 [32~64]
RL78/F22 RL78/F25	64	55 [32~76]	73 [32~76]
Other Device	64	Normal Voltage : 55 [32~80] Low Voltage : 55 [32~64]	Normal Voltage : 73 [32~80] Low Voltage : 46 [32~64]

Note1: The multiplication factor of the 1st frequency differs depending on the upper limit of SUCLK. For more information on SUCLK, please refer to the hardware manual for each capacitive touch sensor microcontroller.

Note2: For details on the Measurement Voltage Setting, please see "3.9 Measurement Voltage Setting".

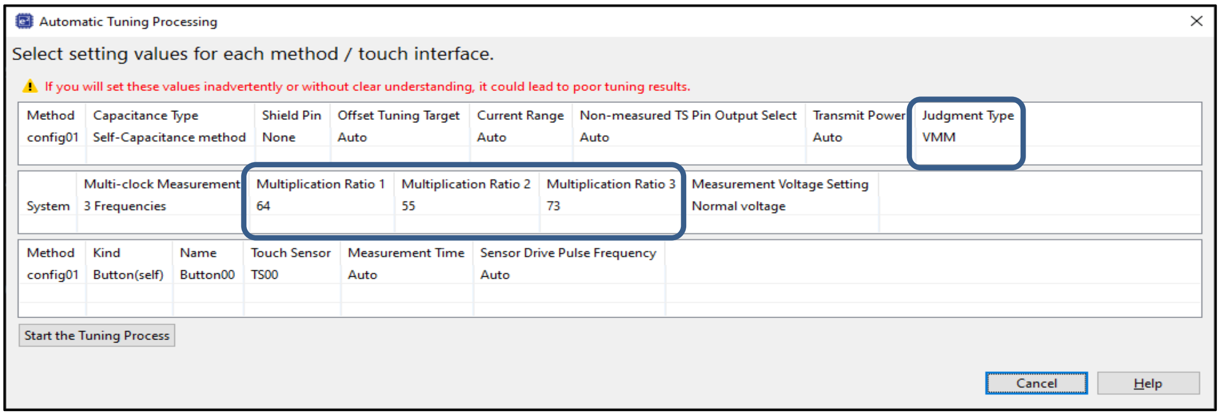
The formulas for calculating Sensor Drive Pulse Frequency of the 2nd and 3rd frequencies when the Multiplication Ratio is changed are shown below.

Sensor Drive Pulse Frequency [2nd frequency] = Sensor Drive Pulse Frequency [1st frequency] × Multiplication Ratio [2nd frequency]/Multiplication Ratio [1st frequency]

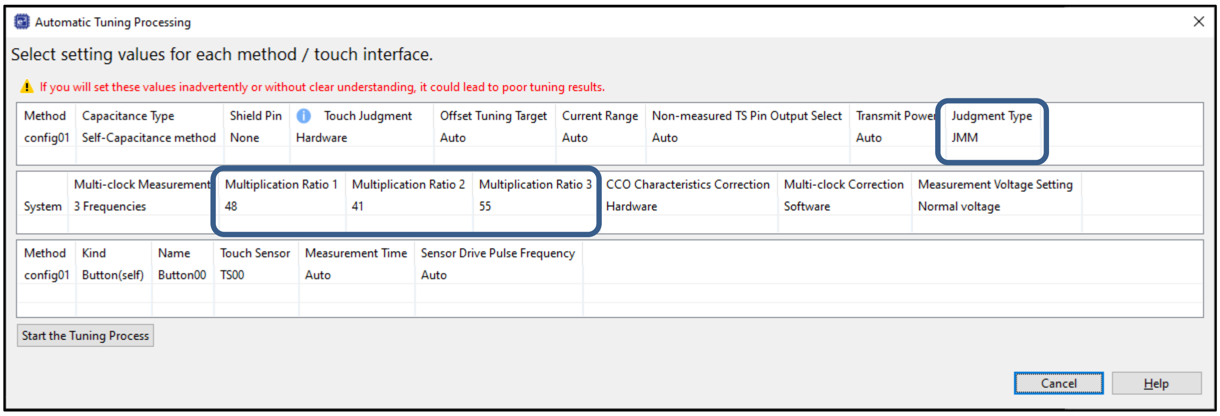
Sensor Drive Pulse Frequency [3rd frequency] = Sensor Drive Pulse Frequency [1st frequency] × Multiplication Ratio [3rd frequency]/Multiplication Ratio [1st frequency]

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

Figure 3-29 shows an example when setting the "Judgment Type/Multi-clock Measurement/Multiplication Ratio" in "Advanced mode".



CTSU2



CTSU2x

Figure 3-29 Setting of "Judgment Type/Multi-clock Measurement/Multiplication Ratio"

The setting of "Judgment Type" is 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-clock Measurement/Multiplication Ratio" is reflected on the qe_touch_define.h. Below is an example of setting when the upper limit of SUCLK is 40 MHz.

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

Note: For details about SUMULTI, please refer to the hardware manual for each capacitive touch sensor microcontroller.

3.8 Touch Judgment/CCO Characteristics Correction/Multi-clock Correction

The "Touch Judgment" and "CCO Characteristics Correction" and "Multi-clock Correction" settings are applicable to CTSU2x.

These settings determine whether each process is performed in hardware or software. When processed by hardware, software processing is not required, resulting in low power consumption and reduced processing time for the main processor. In Advanced Mode, the "CCO Characteristics Correction " and "Multi-clock Correction" settings are set automatically by referring to "Touch Judgment" settings.
Table3-23 shows the description of each function.

Table3-23 Function overview of "Touch Judgment/Multi-clock Correction/CCO Characteristics Correction"

Function	Function overview
Touch Judgment	This function sets whether touch judgment is performed by hardware or software. Hardware touch judgment (Auto judgment) is available only for buttons. However, if your microcontroller has a built-in SNOOZE mode sequencer (SMS), you can use this function together with SMS. When SMS is used, only the majority decision mode (JMM) can be used.
CCO Characteristics Correction	This function sets whether CCO characteristics correction is performed by hardware or software. This function is only displayed on CTSU2SL/CTSU2SLa. It cannot be changed by the user because it is automatically set according to "Judgment Type" and "Touch Judgment".
Multi-clock Correction	This function sets whether multi-clock correction is performed in hardware or software. Multi-clock 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 VMM is used. This function is only displayed on CTSU2SL/CTSU2SLa. It cannot be changed by the user because it is automatically set according to "Judgment Type" and "Touch Judgment".

Figure 3-30 shows the operation image of the functions when VMM is used.

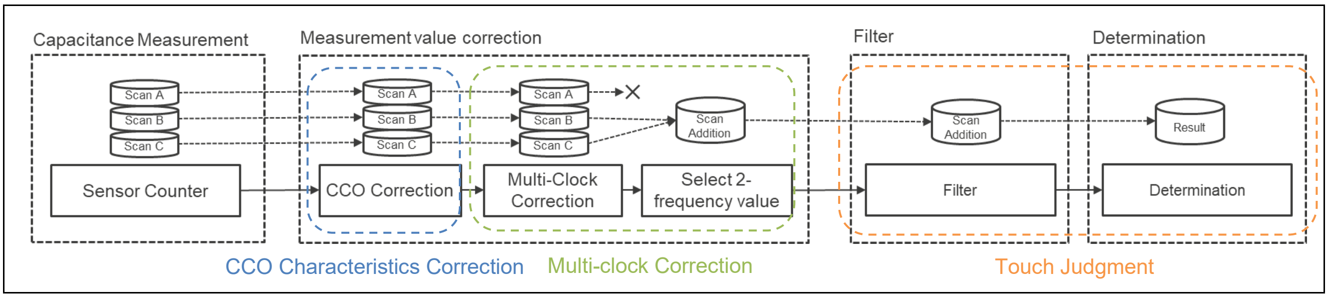


Figure 3-30 Image of operation when VMM is used

Figure 3-31 shows the operation image of the functions when JMM is used. Multi-clock Correction is not available when JMM is used.

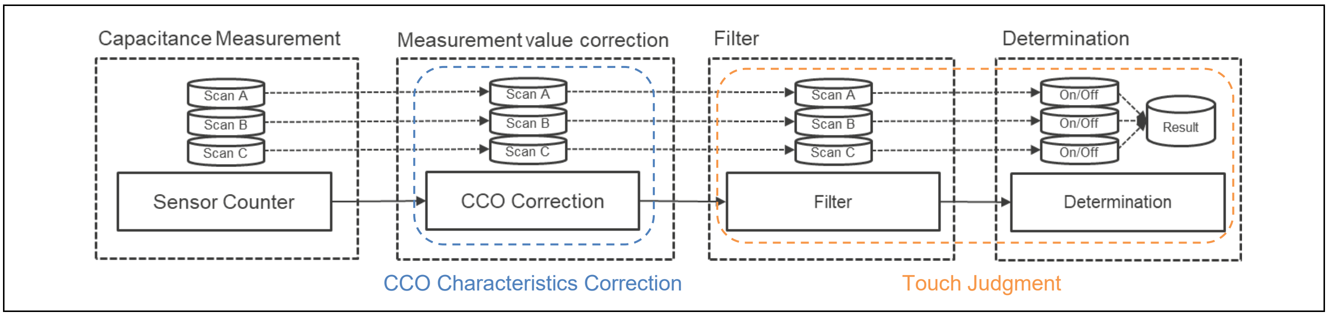


Figure 3-31 Image of operation when JMM is used

Table3-24 shows examples of default settings for each function when Touch Judgment is Hardware or Software.

Table3-24 Default Settings for "CCO Characteristics Correction/Multi-clock Correction"

Touch Judgment	CCO Characteristics Correction	Multi-clock Correction
Hardware	Hardware	When using VMM: Hardware When JMM is used: Software *
Software	Software	Software *

Note: Includes when Multi-clock Correction is disabled.

If the Touch Judgment is Hardware for any method in the system, CCO Characteristics Correction is Hardware as the system. If VMM is used when Touch Judgment is Hardware, the Multi-clock Correction is also Hardware. Figure 3-32 shows the flow for determining the "Touch Judgment/CCO Characteristics Correction/Multi-clock Correction" setting.

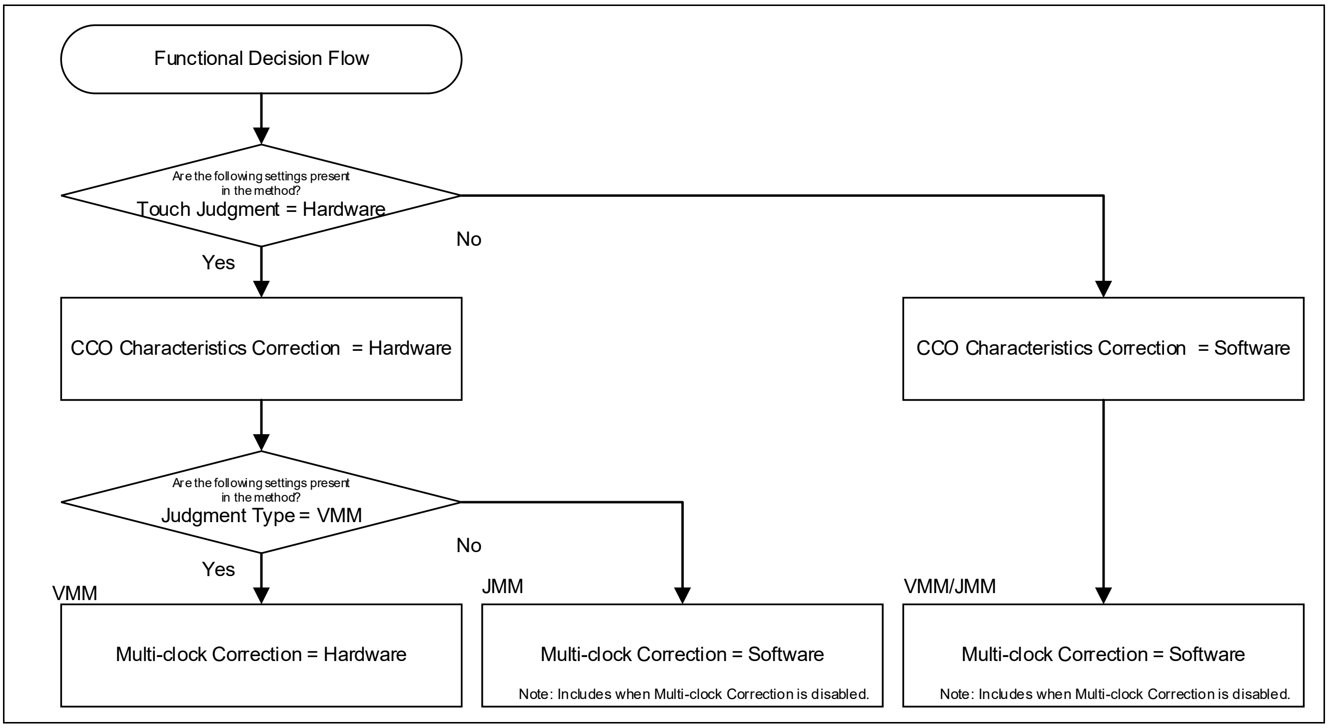
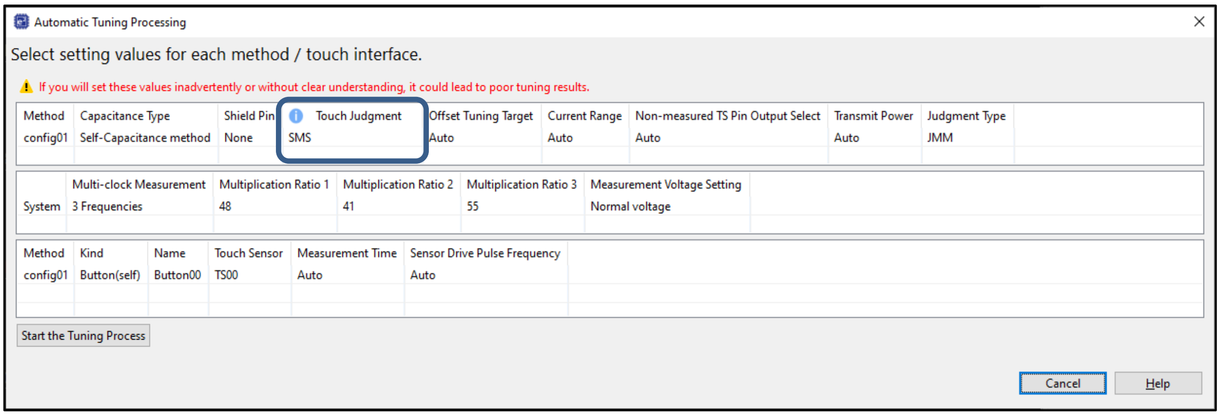
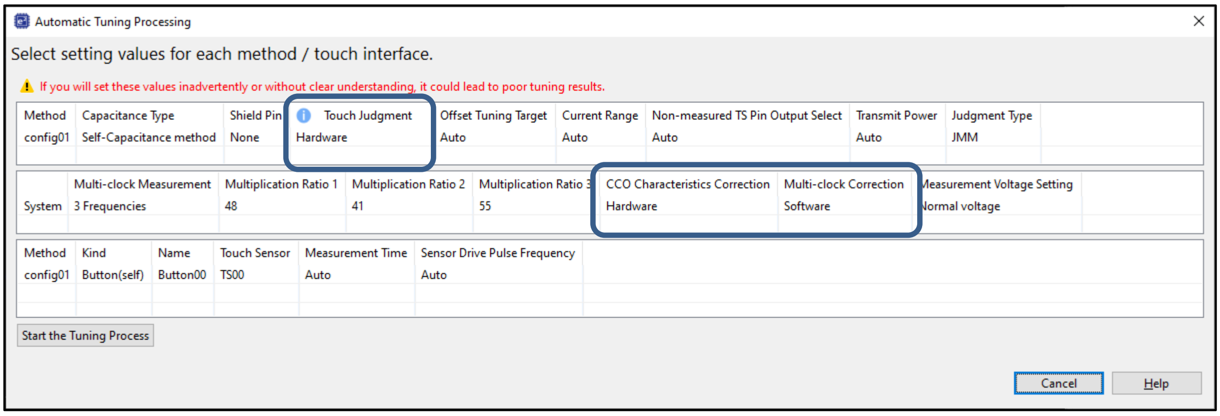


Figure 3-32 Flowchart for Determining "Touch Judgment/CCO Characteristics Correction/ Multi-clock Correction"

Figure3-33 shows an example when setting "Touch Judgment/CCO Characteristics Correction/Multi-clock Correction" in Advanced Mode. When the MCU with built-in SMS is used, "SMS" is displayed instead of "Hardware" in "Touch Judgment".



CTSU2L/CTSU2La



CTSU2SL/CTSU2SLa

Figure3-33 Setting of "Touch Judgment/CCO Characteristics Correction/Multi-clock Correction"

The setting of "Touch Judgment" is reflected in the r_ctsu_qe_config.h. The following is an example when Touch Judgment is hardware.

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

The setting of "CCO Characteristics Correction/Multi-clock Correction" is reflected in the qe_touch_define.h. The following is an example of when Touch Judgment is hardware 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, please refer to the hardware manual for each capacitive touch sensor microcontroller.

3.9 Measurement Voltage Setting

The " Measurement Voltage Setting" setting can be changed only with CTSU2/CTSU2x.

In "Measurement Voltage Setting", TSCAP voltage to be used can be set for each system. When the operating voltage of the microcontroller is less than 2.4 V, "Measurement Voltage Setting" is automatically set to a lower voltage and TSCAP voltage is 1.2 V. This function is used when the microcontroller operating voltage becomes less than 2.4 V during battery operation. In addition, "Measurement Voltage Setting" can be used only when buttons, sliders and wheels are used. Switching TSCAP voltage during MCU operation is not supported.

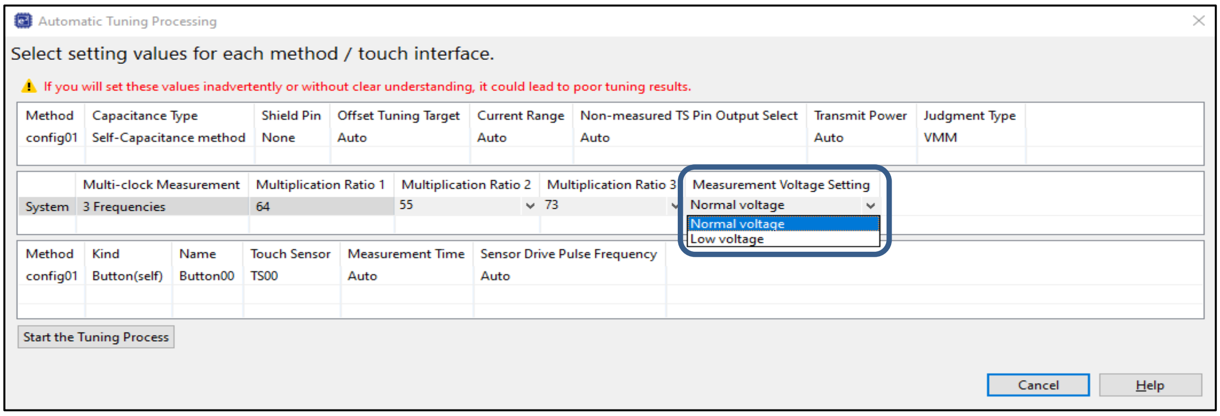
Table 3-25 shows an example of the default settings for "Measurement Voltage Setting" with operating voltage.

Table 3-25 Default Settings for "Measurement Voltage Setting" with Operating Voltage

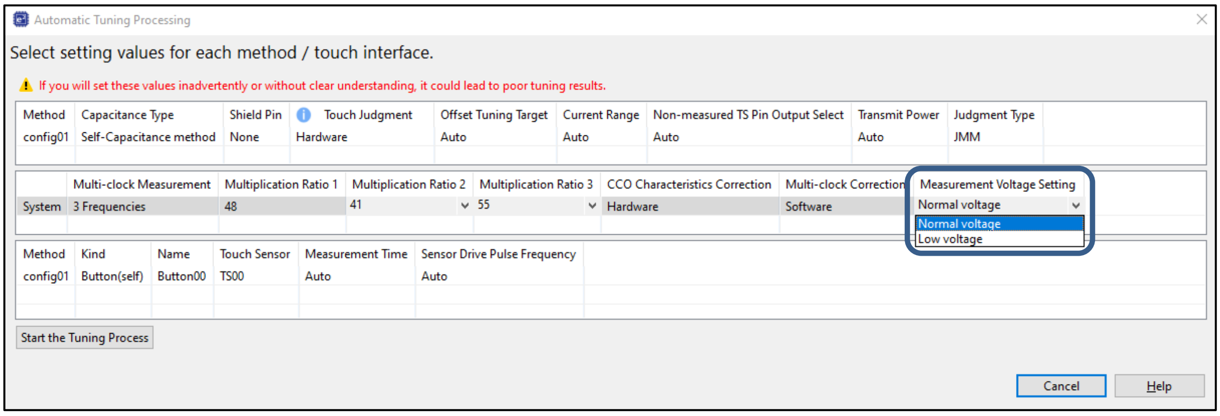
Operating voltage *	Measurement Voltage Setting	TSCAP voltage
More than 2.4V	Normal Voltage	1.5V
Less than 2.4V	Low Voltage	1.2V

Note: For configurable operating voltage, please refer to the hardware manual for each capacitive touch sensor microcontroller.

Figure3-34 shows an example when setting "Measurement Voltage Setting" in Advanced Mode.



CTSU2



CTSU2x

Figure3-34 Setting of "Measurement Voltage Setting"

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

- Measurement Voltage Setting : Normal Voltage (TSCAP voltage: 1.5 V)
  The microcontroller operating voltage 5.0 V

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

- Measurement Voltage Setting : Low Voltage (TSCAP voltage: 1.2 V)
  The microcontroller operating voltage 5.0 V

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

- Measurement Voltage Setting : Low Voltage (TSCAP voltage: 1.2 V)
  The microcontroller operating voltage 1.8 V

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

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

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
3.10	Feb.19.25	-	Terms have been revised in accordance with the terminology corrections in QE for Capacitive Touch v4.1.0.
		-	Figures have been updated in accordance with the terminology corrections in QE for Capacitive Touch v4.1.0.
		-	The text regarding usage restrictions has been removed as hardware judgment using VMM has become possible from QE for Capacitive Touch v4.1.0.
		P15	The text in section 3.1.1 has been updated.
3.20	Sep.24.25	-	The diagram was changed with the change of the workflow after QE for Capacitive Touch v4.2.0 and the view design for monitoring.
		P11	Corrected parameter description
		P12	Revised the explanation regarding "Measurement Count/Measurement Time."

		P23	Corrected the explanation and figure with the change of the adjustment method of sensor drive pulse frequency.
		P32	Added a table for Current Range and current mirror ratio.
		P41	RL78/L23, RA0L1, RL78/F25, RL78/F22 was added to the description of the multiplication ratio setting.

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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