Capacitive Sensor MCU

Capacitive Touch Noise Immunity Guide

Introduction

The Renesas Capacitive Touch Sensor Unit (CTSU) can be susceptible to noise in its surrounding environment because it can detect minute changes in capacitance, generated by unwanted spurious electrical signals (noise). The effect of this noise can depend on the hardware design. Therefore, taking countermeasures at the design stage will lead to a CTSU MCU that is resilient to environmental noise and an effective product development.

This application note describes ways to improve noise immunity for products using the Renesas Capacitive Touch Sensor Unit (CTSU) in accordance with the IEC's noise immunity standards (IEC61000-4).

Target Device

RX Family, RA Family, RL78 Family MCUs and Renesas Synergy™ embedding the CTSU

(CTSU, CTSU2, CTSU2L, CTSU2La, CTSU2SL)

Standards covered in this application note

- IEC-61000-4-3

Contents

1. Overview

The CTSU measures the amount of static electricity from the electric charge when an electrode is touched. If the potential of the touch electrode changes due to noise during measurement, the charging current also changes, affecting the measured value. Specifically, a large fluctuation in the measured value may exceed the touch threshold, causing the device to malfunction. Minor fluctuations in the measured value may affect applications that require linear measurements.

Knowledge about CTSU capacitive touch detection behavior and board design are essential when considering noise immunity for CTSU capacitive touch systems. We recommend first time CTSU users to familiarize yourself with the CTSU and capacitive touch principles by studying the following related documents.

- Basic information regarding capacitive touch detection and CTSU
  Capacitive Touch User's Guide for Capacitive Sensor MCUs (R30AN0424)

- Information regarding hardware board design
  Capacitive Sensor Microcontrollers - CTSU Capacitive Touch Electrode Design Guide (R30AN0389)

- Information regarding CTSU driver (CTSU module) software
  RA Family Renesas Flexible Software Package (FSP) User's Manual (Web Version - HTML)
  API Reference > Modules > CapTouch > CTSU (r_ctsu)
  RL78 Family CTSU Module Software Integration System (R11AN0484)
  RX Family QE CTSU Module Firmware Integration Technology (R01AN4469)

- Information regarding touch middleware (TOUCH module) Software
  RA Family Renesas Flexible Software Package (FSP) User's Manual (Web Version - HTML)
  API Reference > Modules > CapTouch > Touch (rm_touch)
  RL78 Family TOUCH Module Software Integration System (R11AN0485)
  RX Family QE Touch Module Firmware Integration Technology (R01AN4470)

- Information regarding QE for Capacitive Touch（capacitive touch application development support tool)
  Using QE and FSP to Develop Capacitive Touch Applications (R01AN4934)
  Using QE and FIT to Develop Capacitive Touch Applications (R01AN4516)
  RL78 Family Using QE and SIS to Develop Capacitive Touch Applications (R01AN5512)
  RL78 Family Using the Standalone Version of QE to Develop Capacitive Touch Applications (R01AN6574)

2. Noise Types and Countermeasures

2.1 EMC Standards

Table 2-1 provides a list of EMC standards. Noise can influence operations by infiltrating the system through air gaps and connection cables. This list introduces IEC 61000 standards as examples to describe the types of noise developers must be aware to ensure proper operations for systems using the CTSU. Please refer to the latest version of IEC 61000 for further details.

Table 2-1 EMC Testing Standards (IEC 61000)

Test Description	Overview	Standard
Radiated Immunity Test	Test for immunity to relatively high-frequency RF noise	IEC61000-4-3
Conducted Immunity Test	Test for immunity to relatively low-frequency RF noise	IEC61000-4-6
Electrostatic Discharge Test (ESD)	Test for immunity to electrostatic discharge	IEC61000-4-2
Electrical Fast Transient/Burst Test (EFT/B)	Test for immunity to continuous pulsed transient response introduced into power supply lines, etc.	IEC61000-4-4

Table 2-2 lists the performance criterion for immunity testing. Performance criteria are specified for EMC immunity tests, and results are judged based on the operation of the equipment during the test (EUT). Performance criteria are the same for each standard.

Table 2-2 Performance Criteria for Immunity Testing

Performance Criterion	Description
A	The equipment shall continue to operate as intended during and after the test. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer, when the equipment is used as intended.
B	The equipment shall continue to operate as intended during and after the test. No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer when the equipment is used as intended. During the test, degradation of performance is however allowed. No change of actual operating state or stored data is allowed.
C	Temporary loss of function is allowed, provided the function is self-recoverable or can be restored by the operation of the controls.

2.2 RF Noise Countermeasures

RF noise indicates electromagnetic waves of radio frequencies used by television and radio broadcasting, mobile devices, and other electrical equipment. RF noise may directly seep into a PCB or it may enter through the power supply line and other connected cables. Noise countermeasures must be implemented on the board for the former and at the system level for the latter, such as via the power supply line. The CTSU measures capacitance by converting it into an electrical signal. Change in capacitance due to touch is extremely small, so to ensure normal touch detection, the sensor pin and the power supply of the sensor itself must be protected from RF noise.

Two tests with differing test frequencies are available to test for RF noise immunity: IEC 61000-4-3 and IEC 61000-4-6.

IEC61000-4-3 is a radiated immunity test and is used to evaluate noise immunity by directly applying a signal from the radio-frequency electromagnetic field to the EUT. The RF electromagnetic field ranges from 80MHz to 1GHz or higher, which converts to wave lengths of approximately 3.7m to 30cm. As this wavelength and the length of the PCB are similar, the pattern may act as an antenna, adversely affecting the CTSU measurement results. In addition, if the wiring length or parasitic capacitance differ for each touch electrode, the affected frequency may differ for each terminal. Refer to Table 2-3 for details regarding the radiated immunity test.

Table 2-3 Radiated Immunity Test

Frequency Range	Test Level	Test Field Strength
80MHz-1GHz Up to 2.7GHz or up to 6.0GHz, depending on test version	1	1 V/m
	2	3 V/m
	3	10 V/m
	4	30 V/m
	X	Specified individually

IEC 61000-4-6 is a conducted immunity test and is used to evaluate frequencies between 150kHz and 80MHz, a range lower than that of the radiated immunity test. This frequency band has a wavelength of several meters or more, and the wavelength of 150 kHz reaches about 2 km. Because it is difficult to directly apply an RF electromagnetic field of this length on the EUT, a test signal is applied to a cable directly connected to the EUT to evaluate the effect of low-frequency waves. Shorter wavelengths mainly affect power supply and signal cables. For example, if a frequency band causes noise that affects the power cable and the power supply voltage destabilizes, the CTSU measurement results may be affected by noise across all pins. Table 2-4 provides details of the conducted immunity test.

Table 2-4 Conducted Immunity Test

Frequency Range	Test Level	Test Field Strength
150kHz-80MHz	1	1 V rms
	2	3 V rms
	3	10 V rms
	X	Specified individually

Table 2-5 provides a list of countermeasures required for improving RF noise immunity. Most countermeasures are common to the improvement of both radiated immunity and conducted immunity. Please refer to the section of each corresponding chapter as listed for each development step.

Table 2-5 List of Countermeasures Required for RF Noise Immunity Improvements

Development Step	Countermeasures Required at Time of Design	Corresponding Sections
MCU selection (CTSU function selection)	Using an MCU embedded with CTSU2 is recommended when noise immunity is priority. ● Enable CTSU2 anti-noise countermeasure functions: — Multi-frequency measurement — Active shield — Set to non-measurement channel output when using active shield Or ● Enable CTSU anti-noise countermeasure functions: — Random phase shift function — High frequency noise reduction function	 3.3.1 Multi-frequency Measurement 3.3.2 Active Shield 3.3.3 Non-measurement Channel Output Selection 3.2.1 Random Phase Shift Function 3.2.2 High-frequency Noise Reduction Function (spread spectrum function)
Hardware design	● Board design using recommended electrode pattern ● Use power supply source for low-noise output ● GND pattern design recommendation: in a grounded system use parts for a common mode noise countermeasure ● Reduce noise infiltration level at the sensor pin by adjusting the damping resistor value. ● Place damping resistor on communication line	4.1.1 Touch Electrode Pattern Designs 4.1.2.1 Voltage Supply Design 4.1.2.2 GND Pattern Design 4.2.1 TS Pin Damping Resistance 4.2.2 Digital Signal Noise
Software implementation	Adjust the software filter to reduce the effect of noise on measured values ● IIR moving average (effective for most random noise cases) ● FIR moving average (for specified periodic noise)	 5.1 IIR Filter 5.2 FIR Filter

2.3 ESD Noise (electrostatic discharge)

Electrostatic discharge (ESD) is generated when two charged objects are in contact or located in proximity. Static electricity accumulated within the human body can reach electrodes on a device even through an overlay. Depending on the amount of electrostatic energy applied to the electrode, the CTSU measurement results may be affected, causing damage to the device itself. Therefore, countermeasures must be introduced at the system level, such as protection devices on the board circuit, board overlays, and protective housing for the device.

The IEC 61000-4-2 standard is used to test ESD immunity. Table 2-6 provides ESD test details. The target application and properties of the product will determine the required test level. For further details, refer to the IEC 61000-4-2 standard. When ESD reaches the touch electrode, it instantaneously generates a potential difference of several kV. This may cause pulse noise to occur in the CTSU measured value, reducing measurement accuracy, or may stop the measurement due to detection of overvoltage or overcurrent. Note that semiconductor devices are not designed to withstand direct application of ESD. Therefore, the ESD test should be conducted on the finished product with the board protected by the device case. Countermeasures introduced on the board itself are failsafe measures to protect the circuit in the rare case that ESD does, for some reason, enter the board.

Table 2-6 ESD Test

Test Level	Test Voltage	
	Contact Discharge	**Air Discharge**
1	2 kV	2 kV
2	4 kV	4 kV
3	6 kV	8 kV
4	8 kV	15 kV
X	Specified individually	Specified individually

2.4 EFT Noise (Electrical Fast Transients)

Electrical products generate a phenomenon called Electrical Fast Transients (EFT), such as a back electromotive force when the power is switched on due to the internal configuration of the power supply or chattering noise on relay switches. In environments where multiple electrical products are connected in some way, such as on power strips, this noise may travel through power supply lines and affect the operation of other equipment. Even power lines and signal lines of electrical products that are not plugged into a shared power strip may be affected via the air simply by being near power lines or signal lines of the noise source.

The IEC 61000-4-4 standard is used to test EFT immunity. IEC 61000-4-4 evaluates immunity by injecting periodic EFT signals into the EUT power and signal lines. EFT noise generates a periodic pulse in the CTSU measurement results, which may lower the accuracy of the results or cause false touch detection. Table 2-7 provides EFT/B (Electrical Fast Transient Burst) test details.

Table 2-7 EFT/B Test

Test Level	Open Circuit Test Voltage (peak)		Pulse repetition frequency (PRF)
	Power Supply Line/Ground Wire	**Signal/Control Line**	
1	0.5 kV	0.25 kV	5kHz or 100kHz
2	1 kV	0.5 kV	
3	2 kV	1 kV	
4	4 kV	2 kV	
X	Specified individually		Specified individually

3. CTSU Noise Countermeasure Functions

CTSUs are equipped with noise countermeasure functions, but the availability of each function differs depending on the version of the MCU and CTSU you are using. Always confirm the MCU and CTSU versions before developing a new product. This chapter explains the differences in noise countermeasure functions between each CTSU version.

3.1 Measurement Principles and Effect of Noise

The CTSU repeats charging and discharging multiple times for each measurement cycle. The measurement results for each charge or discharge current are accumulated and the final measurement result is stored in the register. In this method, the number of measurements per unit time can be increased as the frequency increases, improving the dynamic range (DR) and realizing highly sensitive CTSU measurements. On the other hand, external noise causes fluctuations in the parasitic capacitance of the sensor terminal, which changes the charge or discharge current. In an environment where periodic noise is generated, the measurement result stored in the Sensor Counter Register is offset due to an increase or decrease in the amount of current in one direction. Such noise-related effects ultimately decrease measurement accuracy.

Figure 3-1 shows an image of charge current error due to periodic noise. The frequencies that pose as periodic noise are those that match the sensor drive pulse frequency and its harmonic noise. Measurement errors are greater when the rising or falling edge of the periodic noise is synchronized with the SW1 ON period. The CTSU is equipped with hardware-level noise countermeasure functions as protection against this periodic noise.

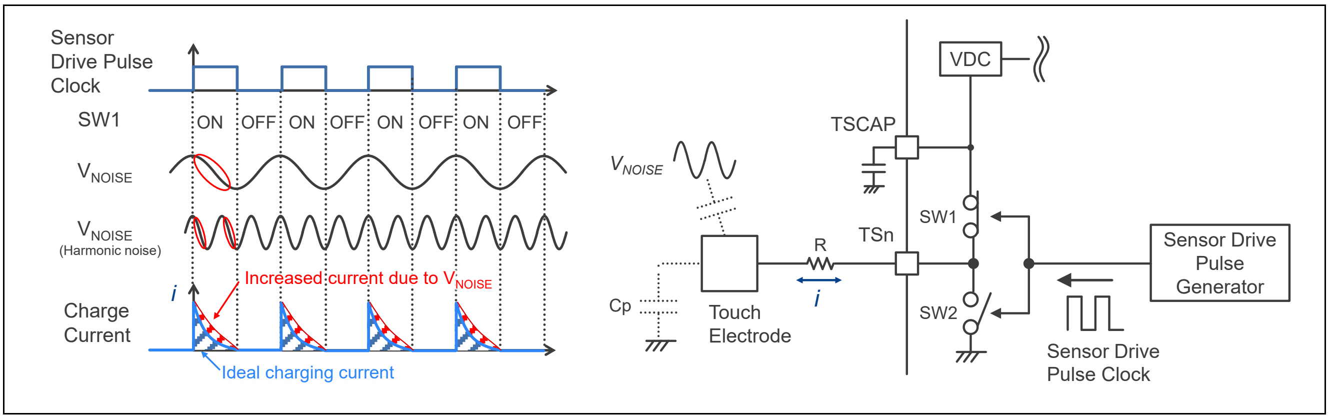


Figure 3-1 Example of Charge Current Error Due to Periodic Noise (charge current increase)

3.2 CTSU1

CTSU1 is equipped with a random phase shift function and a high-frequency noise reduction function (spread spectrum function). The effect on the measured value can be reduced when the fundamental harmonic of the sensor drive pulse frequency and the noise frequency match. The maximum sensor drive pulse frequency setting is 4.0 MHz, which improves conducted RF noise immunity.

3.2.1 Random Phase Shift Function

Figure 3-2 shows an image of noise desynchronization using the random phase shift function. By changing the phase of the sensor drive pulse by 180 degrees at random timing, the unidirectional increase/decrease in current due to periodic noise can be randomized and smoothed to improve measurement accuracy.

This function is always enabled in the CTSU module and TOUCH module.

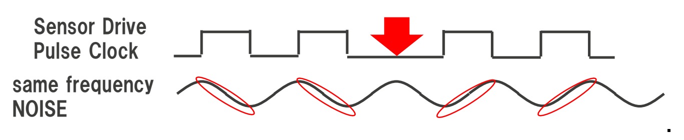


Figure 3-2 Periodic Noise Desynchronization by Random Phase Shift Function (image)

3.2.2 High-frequency Noise Reduction Function (spread spectrum function)

The high-frequency noise reduction function measures at the sensor drive pulse frequency with intentionally added chattering. It then randomizes the synchronization point with the synchronous noise to disperse the peak of the measurement error and improve measurement accuracy.

This function is always enabled in the CTSU module output and TOUCH module output by code generation.

3.3 CTSU2

3.3.1 Multi-frequency Measurement

Multi-frequency measurement uses multiple sensor drive pulse frequencies with differing frequencies. This function improves immunity against conducted and radiated RF noise because it is effective against synchronous noise on the sensor drive pulse frequency, as well as noise introduced through the touch electrode pattern.

Figure 3-3 shows an image of how measured values are selected in multi-frequency measurement, and Figure 3-4 shows an image of separating noise frequencies in the same measurement method. Multi-frequency measurement discards the measurement results affected by noise from the group of measurements taken at multiple frequencies to improve measurement accuracy.

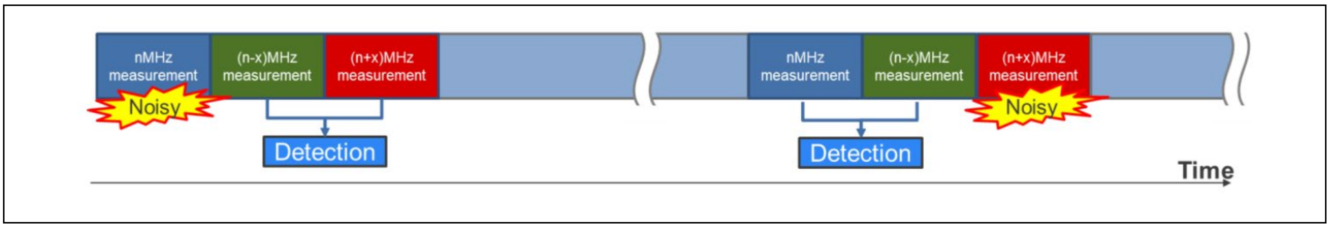


Figure 3-3 Measured Value Selection in Multi-Frequency Measurement (image)

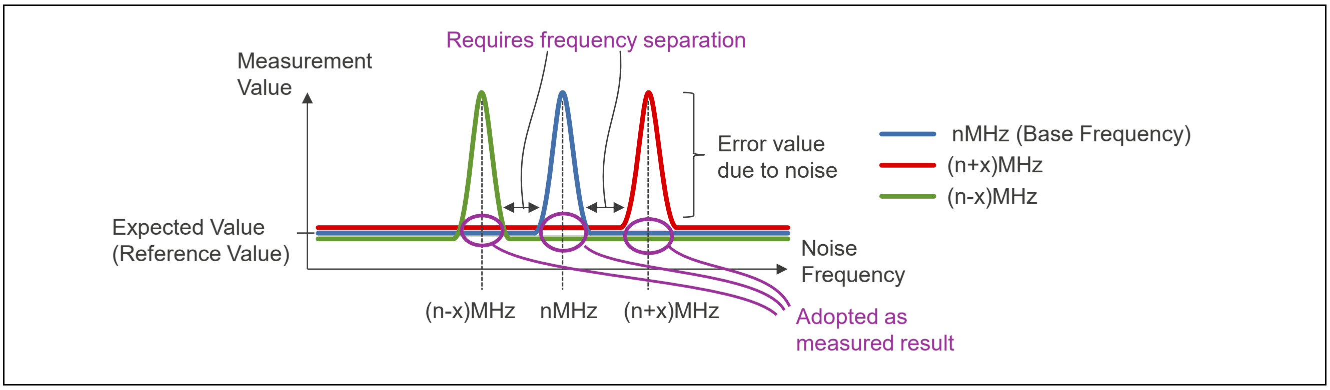


Figure 3-4 Noise Frequency Separation in Multi-Frequency Measurement (image)

In application projects that incorporate CTSU driver and TOUCH middleware modules (refer to the FSP, FIT or SIS documentation), when “QE for Capacitive Touch” tuning phase is executed the parameters of multi-frequency measurement are automatically generated and multi-frequency measurement can be used.

In the tuning phase using QE for Capacitive Touch, the auto-tuning process automatically selects and sets the 1st frequency from 0.5, 1.0, 2.0, and 4.0MHz, based on the system. The 2nd frequency is set to the 1st frequency -12.5%, and the 3rd frequency is set to the 1st frequency +12.5%, setting a total of three frequencies.

By enabling advanced settings in the tuning phase, the parameters can then be set manually. The measurement frequency can be selected from 3 or 1, and the 2nd and 3rd frequencies can be set within the range of -50% to +125% of the 1st frequency. Care must be taken when setting a frequency higher than the 1st frequency, as this may cause unstable measurements and adversely affect touch detection.

Figure 3-5 shows the recommended auto-tuning process when using advanced settings. Before enabling the advanced settings, we recommend executing the normal auto-tuning process. An auto-tuning process with advanced settings references the previous auto-tuning results. By performing normal auto-tuning in advance to generate the original parameters, the system can be run safely with minimal manual settings. In addition, when using advanced tuning, we recommend fine tuning the parameters based on the normal auto-tuning.

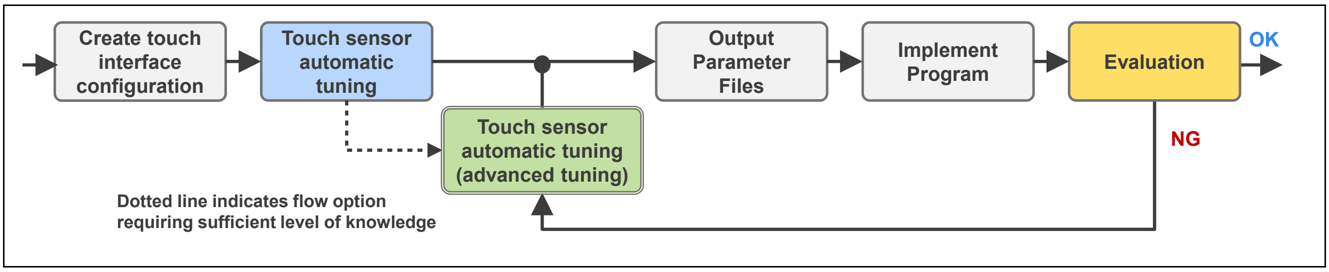


Figure 3-5 Recommended Auto-tuning Procedure When Using Advanced Settings

Figure 3-6 shows how to switch to advanced settings for the tuning phase of QE for Capacitive Touch. To enable the advanced settings, check the box for “Enable advanced settings” in the flow shown in 2. Tuning Touch Sensors of the CapTouch workflow window. After enabling advanced settings, click the “Start tuning” button. This will display the system clock settings and usage notes dialog box. After agreeing to the usage notes, the parameter setting window will be displayed and you can fine-tune the CTSU measurement settings.

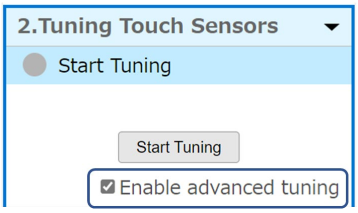
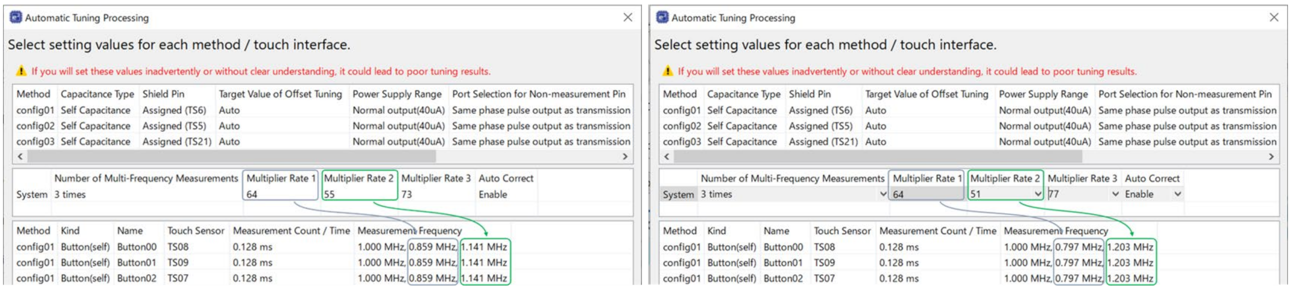


Figure 3-6 Switch to Advanced Settings for QE for Capacitive Touch Tuning Phase

Figure 3-7 shows an example of changing the frequency settings for multi-frequency measurement. To change the 2nd frequency, select “Multiply ratio 2” from the dropdown list, and to change the 3rd frequency, select “Multiply ratio 3.” “Multiply ratio 1” cannot be changed. The results of changes “Multiply ratio 2” and “Multiply ratio 3” are immediately reflected in the measurement frequency shown at the bottom of the window, allowing you to confirm the actual frequency. Always carry out sufficient evaluations after changing the settings.



(a) Setting value after auto-tuning (b) Setting value after changes

Figure 3-7 Changing Frequency Settings for Multi-Frequency Measurement (example)

3.3.2 Active Shield

In the CTSU2 self-capacitance method, an active shield can be used to drive the shield pattern in the same pulse phase as the sensor drive pulse. To enable the active shield, in the QE for Capacitive Touch interface configuration, set the pin that connects to the active shield pattern to “shield pin.” Active shield can be set to one pin per Touch interface configuration (method).

3.3.3 Non-measurement Channel Output Selection

In the CTSU2 self-capacitance method, pulse output in the same phase as the sensor drive pulse can be set as the non-measurement channel output. In the QE for Capacitive Touch interface configuration (method), non-measurement channels (touch electrodes) are automatically set to the same pulse phase output for methods assigned with active shielding.

4. Hardware Noise Countermeasures

4.1 Typical Noise Countermeasures

4.1.1 Touch Electrode Pattern Designs

The touch electrode circuit is very susceptible to noise, requiring noise immunity to be considered at the hardware design stage. For detailed board design rules that tackle noise immunity, please refer to the latest version of the CTSU Capacitive Touch Electrode Design Guide (R30AN0389). Figure 4-1 provides an excerpt from the Guide showing an overview of self-capacitance method pattern design, and Figure 4-2 shows the same for mutual-capacitance method pattern design.

① Electrode shape: square or circle
② Electrode size: 10mm to 15mm
③ Electrode proximity: Electrodes should be placed with ample distance so that they do not react simultaneously to the target human interface, (referred to as “finger” in this document); suggested interval: button size x 0.8 or more
④ Wire width: approx. 0.15mm to 0.20mm for printed board
⑤ Wiring length: Make the wiring as short as possible. On corners, form a 45-degree angle, not a right angle.
⑥ Wiring spacing:
 (A) Make spacing as wide as possible to prevent false detection by neighboring electrodes.
 (B) 1.27mm pitch
⑦ Cross-hatched GND pattern width: 5mm
⑧ Cross-hatched GND pattern and button/wiring spacing
 (A) area around electrodes: 5mm (B) area around wiring: 3mm or more
 Cover the electrode area as well as the wiring and opposite surface with a cross-hatched pattern. Also place a cross-hatched pattern in the empty spaces, and connect the 2 surfaces of cross-hatched patterns through vias.
 Refer to section “2.5 Anti-Noise Layout Pattern Designs” for cross-hatched pattern dimensions, active shield (CTSU2 only), and other anti-noise countermeasures.
⑨ Electrode + wiring capacitance: 50pF or less
⑩ Electrode + wiring resistance: 2kΩ or less (including damping resistor with reference value of 560Ω)

Figure 4-1 Pattern Design Recommendations for Self-capacitance Method (excerpt)

① Electrode shape: square (combined transmitter electrode TX and receiver electrode RX)
② Electrode size: 10mm or larger
③ Electrode proximity: Electrodes should be placed with ample distance so that they do not react simultaneously to the touch object (finger, etc.), (suggested interval: button size x 0.8 or more)
④ Wire width: The thinnest wire capable through mass production; approx. 0.15mm to 0.20mm for a printed board
⑤ Wiring length: Make the wiring as short as possible. On corners, form a 45-degree angle, not a right angle.
⑥ Wiring spacing:
 (A) Make spacing as wide as possible to prevent false detection by neighboring electrodes.
 (B) When electrodes are separated: 1.27mm pitch
 (C) 20mm or more to prevent coupling capacitance generation between Tx and Rx.
⑦ Cross-hatched GND pattern (shield guard) proximity
 Because the pin parasitic capacitance in the recommended button pattern is comparatively small, parasitic capacitance increases the closer the pins are to GND.
 A: 4mm or more around electrodes
 We also recommend approx. 2-mm wide cross-hatched GND plane pattern between electrodes.
 B: 1.27mm or more around wiring
⑧ Tx, Rx parasitic capacitance: 20pF or less
⑨ Electrode + wiring resistance: 2kΩ or less (including damping resistor with reference value of 560Ω)
⑩ Do not place GND pattern directly under the electrodes or wiring.
The active shield function cannot be used for the mutual-capacitance method.

Figure 4-2 Pattern Design Recommendations for Mutual Capacitance Method (excerpt)

4.1.2 Power Supply Design

The CTSU is an analog peripheral module that handles minute electrical signals. When noise infiltrates the voltage supplied to the MCU or GND pattern, it causes potential fluctuation on the sensor drive pulse and decreases measurement accuracy. We strongly suggest adding a noise countermeasure device to the power supply line or onboard power supply circuit to safely supply power to the MCU.

4.1.2.1 Voltage Supply Design

Action should be taken when designing the power supply for the system or onboard device to prevent noise infiltration via the MCU power supply pin. The following design-related recommendations can help prevent noise infiltration.

- Keep the power supply cable to the system and internal wiring as short as possible to minimize impedance.
- Place and insert a noise filter (ferrite core, ferrite bead, etc.) to block high frequency noise.
- Minimize the ripple on the MCU power supply. We recommend using a linear regulator on the MCU's voltage supply. Select a linear regulator with low-noise output and high PSRR characteristics.
- When there are several devices with high current loads on the board, we recommend inserting a separate power supply for the MCU. If this is not possible, separate the pattern at the root of the power supply.
- When running a device with high current consumption on the MCU pin, use a transistor or FET.

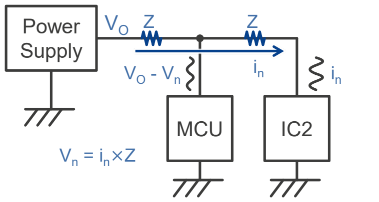
Figure 4-3 shows several layouts for the power supply line. V_o is the power supply voltage, i_n is the consumption current fluctuation resulting from IC2 operations, and Z is the power supply line impedance. V_n is the voltage generated by the power supply line and can be calculated as $V_n = i_n \times Z$. The GND pattern can be considered in the same way. For more details on the GND pattern, refer to 4.1.2.2 GND Pattern Design.

In configuration (a), the power supply line to the MCU is long and the IC2 supply lines branch near the MCU's power supply. This configuration is not recommended as the MCU's voltage supply is susceptible to V_n noise when the IC2 is in operation.

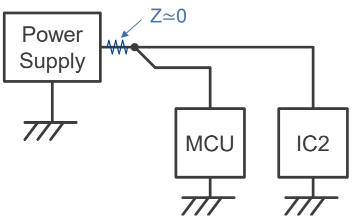
(b) and (c) circuit diagrams of (b) and (c) are the same as (a), but the pattern designs differ.

(b) branches the power supply line from the root of the power supply, and the effect of V_n noise is reduced by minimizing Z between the power supply and the MCU.

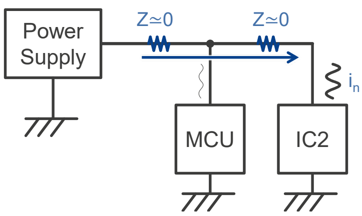
(c) also reduces the effect of V_n by increasing the surface area and line width of the power supply line to minimize Z.



(a) Undesirable power supply layout



(b) Ideal power supply layout (1)



(c) Ideal power supply layout (2)

Note: See 4.1.2.2 for details on GND pattern design.

Figure 4-3 Power Supply Line Layouts

4.1.2.2 GND Pattern Design

Depending on the pattern design, noise may cause the GND, which is the reference voltage for the MCU and on-board devices, to fluctuate in potential, decreasing CTSU measurement accuracy. The following hints for GND pattern design will help suppress potential fluctuation.

- ・Cover empty spaces with a solid GND pattern as much as possible to minimize impedance over a large surface area.
- ・Use a board layout that prevents noise from infiltrating the MCU via the GND line by increasing the distance between the MCU and devices with high current loads and separating the MCU from the GND pattern.

Figure 4-4 shows several layouts for the GND line. In this case, i_n is the consumption current fluctuation resulting from IC2 operations, and Z is the power supply line impedance. V_n is the voltage generated by the GND line and can be calculated as $V_n = i_n \times Z$.

In configuration (a), the GND line to the MCU is long and merges with the IC2 GND line near the MCU's GND pin. This configuration is not recommended as the MCU's GND potential is susceptible to V_n noise when the IC2 is in operation.

In configuration (b) the GND lines merge at the root of the power supply GND pin. Noise effects from Vn can be reduced by separating the GND lines of the MCU and the IC2 to minimize the space between the MCU and Z.

Although the circuit diagrams of (c) and (a) are the same, the pattern designs differ. Configuration (c) reduces the effect of V_n by increasing the surface area and line width of the GND line to minimize Z.

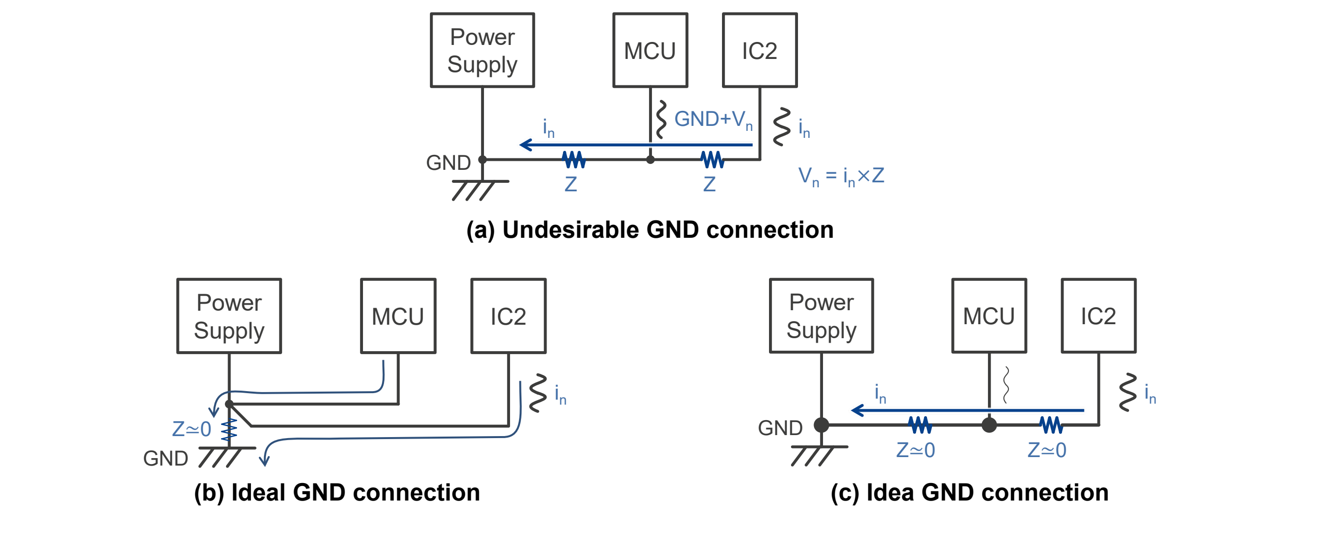


Figure 4-4 GND Line Layout

4.1.3 Processing Unused Pins

Leaving unused pins in a high impedance state makes the device susceptible to the effects of external noise. Make sure you process all unused pins after referring to the corresponding MCU Faily hardware manual of each pin. If a pulldown resistor cannot be implemented due to lack of mounting area, fix the pin output setting to low output.

4.2 Radiated RF Noise Countermeasures

4.2.1 TS Pin Damping Resistance

The damping resistor connected to the TS pin and the electrode's parasitic capacitance component function as a low pass filter. Increasing the damping resistor lowers the cut off frequency, thus lowering the level of radiated noise infiltrating the TS pin. However, when the capacitive measurement charge or discharge current period is lengthened, the sensor drive pulse frequency must be lowered, which also lowers the touch detection accuracy. For information regarding sensitivity when changing the damping resistor in the self-capacitance method, refer to "5. Self-capacitance Method Button Patterns and Characteristics Data" in the CTSU Capacitive Touch Electrode Design Guide (R30AN0389)

4.2.2 Digital Signal Noise

Digital signal wiring that handles communication, such as SPI and I2C, and PWM signals for LED and audio output is a source of radiated noise that affects the touch electrode circuit. When using digital signals, take the following suggestions into consideration during the design stage.

- When the digital signal level changes, the overshoot or undershoot is radiated as high-frequency noise. As a countermeasure, insert a damping resistor on the digital signal line to suppress the overshoot or undershoot. Another method is to insert a ferrite bead along the line.
- Layout the lines for digital signals and the touch electrode circuit so that they do not touch. If the configuration requires the lines to run in parallel, keep as much distance between them as possible and insert a GND shield along the digital line.
- When running a device with high current consumption on the MCU pin, use a transistor or FET.

4.2.3 Multi-frequency Measurement

When using an MCU embedded with CTSU2, make sure to use multi-frequency measurement. For details, see "3.3.1 Multi-frequency Measurement".

5. Software Filters

CTSUs touch detection is judged to be ON or OFF by software using the capacitive measurement results. The CTSU module performs noise reduction processing via signal processing according to the measurement results. It then passes the data to the TOUCH module for touch judgement. The CTSU module has a built-in IIR moving average filter as the standard filter which, in most cases, provides sufficient SNR and responsiveness. However, user systems may require an even stronger software filter. We offer an API that enables you to replace the CTSU module's filter with your own filter or to use multiple filters with the built-in filter. Refer to the CTSU module document specific to each MCU family for information on how to use the API. This section introduces effective filters according to the EMC standard. We encourage you to use the most suitable filter or a combination of filters to suit your design requirements.

Table 5-1 EMC Standards and Corresponding Software Filters

EMC Standard	Expected Noise	Corresponding Software Filter
IEC61000-4-3 Radiation immunity	Random noise	IIR moving average filter
	Periodic noise	FIR moving average filter

Figure 5-1 shows the data flow through touch detection. Multiple user filters can be used and are placed between the CTSU module and the TOUCH module. When using one or more user filter, disable the moving average filter as necessary. Figure 5-2 indicates where to make changes to qe_touch_config.c. To disable the moving average filter, change the setting of ".num_moving_average" to 1. ".num_moving_average" is a member of the ctsu_cfg_t structure described in the qe_touch_config.c output by QE for Capacitive Touch. When more than one touch interface structure (method) is used, the setting must be changed for each structure.

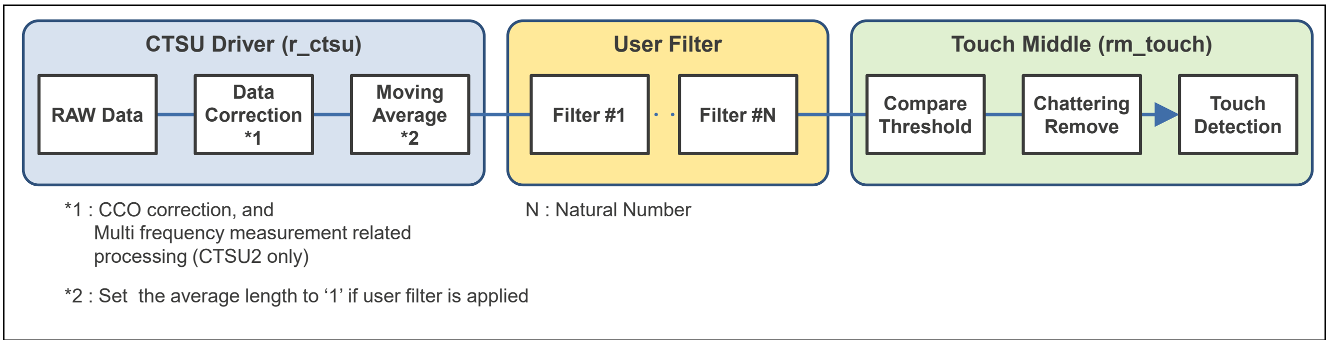


Figure 5-1 Data Flow Through Touch Detection

```
const ctsu_cfg_t g_qe_ctsu_cfg_config01 =
{
    (omitted)

    .num_moving_average = 1,
    .tunning_enable     = true,
    .p_callback    = &qe_touch_callback,

    (omitted)
};
```

Change this value here.

Initial value is '4'.

Figure 5-2 Where to Change qe_touch_config.c

Refer to the following application note for details on how to integrate filters into the project file, a software filter sample code, and the project file with usage samples.

- RA Family Capacitive Touch Software Filter Sample Program（R30AN0427）

5.1 IIR Filter

The IIR filter can reduce the number of high-frequency components with less memory and less computational load, making it ideal for low-power systems and applications with many buttons. IIR filters can affect subsequent outputs based on previous signal components, and the accumulation of calculation errors may reduce measurement accuracy. Also note that a design employing fewer high frequency components increases the amount of time required for settling, which delays the response to button touch.

5.1.1 Moving Average

The IIR moving average is the CTSU module standard software filter. The value of the moving average depth (L) is initially 4 and can be set to any value from 1 to 255. When L=1, input data is output as is, when L=2 or more, the noise in the measured value is reduced in proportion to the numerical value. The moving average filter reduces periodic and random noise, and improves self-capacitance method button sensitivity (SNR), but it presents a tradeoff with responsiveness. It is, however recommended for reducing random noise, as discussed in a comparison with the FIR method discussed later in the document.

The following is the formula for calculating the moving average.

$y_n = (x_n + y_{n-1}*(L-1)) / L$ ···Expression 1

y_n: n^{th} output value, x_n: n^{th} input value, L: moving average depth

5.1.2 First-order IIR Filter

The first-order IIR filter is a simple operation that multiplies and adds a coefficient to the input data and one previous data.

Formula:

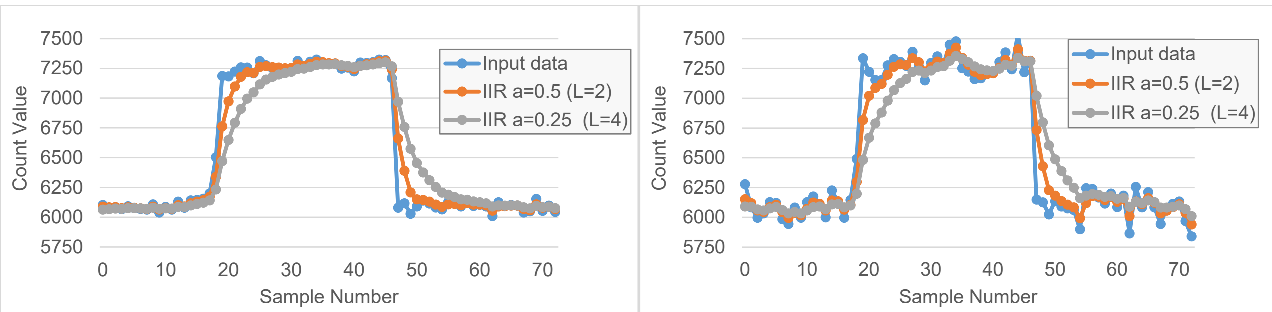
$y_n = ax+by_{n-1}$ ···Expression 2

$\quad = ax+(1-a)y_{n-1}$ ···Expression 3

y_n: n^{th} output value, x_n: n^{th} input value, a/b: filter coefficient, where $0<a<1.0$

To equalize the input and output gains, the filter coefficients must be ratioed so that a+b=1.0. Expression 3 can be used for simplicity. The lower a is, the lower the noise effect on the measured value; however, the responsiveness also decreases correspondingly. Decreasing the value of a reduces periodic and random noise and improves SNR, but it also presents a tradeoff with responsiveness. Setting the value of a = 1/n (n=1, 2, 3…), achieves the same value as the L = n filter shown in 5.1.1 Moving Average.

Figure 5-3 shows an example of implementing an IIR filter.



(a) Responsiveness (b) Random noise suppression

Figure 5-3 IIR Filter Implementation Example

5.2 FIR Filter

The FIR filter is a highly stable filter that suffers minimal accuracy degradation due to calculation errors and has a settling time equal to the number of samples of the filter order +1. The FIR filter reduces periodic and random noise and improves SNR, but it presents a tradeoff with responsiveness. As mentioned previously, compared to the IIR method, FIR is more effective for reducing periodic noise. Since samples from a previous period are retained and computed, memory usage and computation load both increase in proportion to the characteristics.

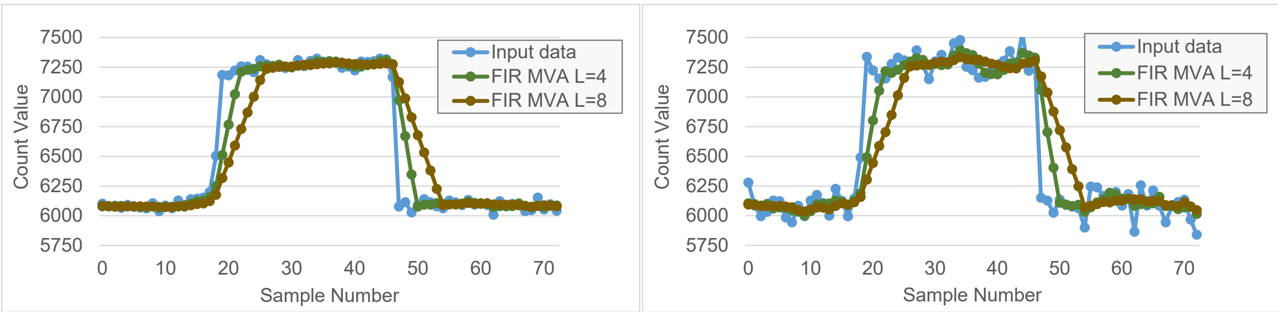
The following is the formula for calculating the FIR filter.

$$y(n) = \sum_{i=0}^{T-1} h(i) * x(n-i) \quad \text{... Expression 4}$$

n: sample data, $h(i)$: coefficient, $x(n-i)$: input data of sample, i delay, $y(n)$: output data

The FIR filter changes the frequency characteristics by multiplying the input data and delay data by coefficient $h(i)$. If all $h(i)$ are equalized, the FIR filter performance is equivalent to the simple moving average. The moving average filter provides sufficient noise suppression using capacitive touch detection.

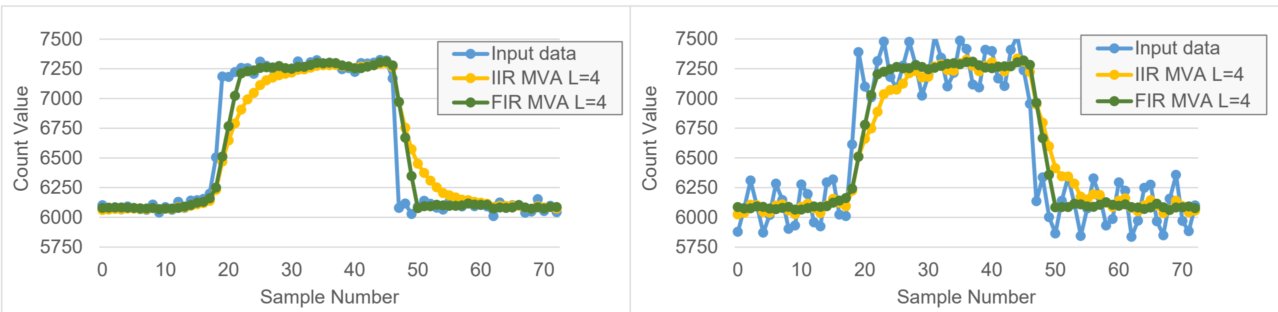
Figure 5-4 shows an example of implementing the FIR moving average filter. The L in the graph legend indicates the moving average depth.



(a) Responsiveness (b) Random noise suppression

Figure 5-4 FIR Moving Average Filter Implementation Example

Figure 5-5 shows a comparison of IFR and IIR moving average filters. The L in the graph legend indicates the moving average depth. Compared to IIR, FIR shows better results for period noise suppression.



(a) Responsiveness (b) Random noise suppression

Figure 5-5 Comparison of FIR and IIR Moving Average Filters

5.3 Usage Notes Regarding Measurement Cycle

The frequency characteristics of software filters change depending on the accuracy of the measurement cycle. In addition, you may not obtain expected filter characteristics due to deviations or variations in the measurement cycle. To focus priority on filter characteristics, use a high-speed on-chip oscillator (HOCO) or an external crystal oscillator as the main clock. We also recommend managing touch measurement execution cycles with a hardware timer.

Glossary

Term	Definition
CTSU	Capacitive Touch Sensing Unit. Also used in CTSU1 and CTSU2.
CTSU1	Second generation CTSU IP. “1” is added to differentiate from CTSU2.
CTSU2	Third generation CTSU IP.
CTSU driver	CTSU driver software bundled in Renesas Software packages.
CTSU module	A unit of CTSU driver software that can be embedded using the Smart Configurator.
TOUCH middleware	Middleware for touch detection processing when using CTSU bundled in Renesas software packages.
TOUCH module	A unit of TOUCH middleware that can be embedded using the Smart Configurator.
r_ctsu module	The CTSU driver displayed in the Smart Configurator.
rm_touch module	The TOUCH module displayed in the Smart Configurator
CCO	Current Control Oscillator. The current-controlled oscillator used in capacitive touch sensors. Also written as ICO in some documents.
ICO	Same as CCO.
TSCAP	A capacitor for stabilizing the CTSU internal voltage.
Damping resistor	A resistor used to reduce pin damage or effects due to external noise. For details, refer to Capacitive Touch Electrode Design Guide (R30AN0389).
VDC	Voltage Down Converter. Power supply circuit for capacitive sensor measurement built into the CTSU.
Multi-frequency measurement	A function that uses multiple sensor unit clocks with differing frequencies to measure touch; indicates the multi-clock measurement function.
Sensor drive pulse	Signal that drives the switched capacitor.
Synchronous noise	Noise at the frequency that matches the sensor drive pulse.
EUT	Equipment Under Test. Indicates the device to be tested.
LDO	Low Dropout Regulator
PSRR	Power Supply Rejection Ration
FSP	Flexible Software Package
FIT	Firmware Integration Technology。
SIS	Software Integration System

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	May 31, 2023	−	Initial revision

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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