Capacitive Sensor Microcontrollers

CTSU Capacitive Touch Electrode Design Guide

Introduction

This application note describes how to design electrode patterns, with sample patterns for reference, for MCUs embedding the Capacitive Touch Sensing Unit (CTSU)

Target Device

RX Family, RA Family, and RL78 Family MCUs and Renesas Synergy™ embedding the CTSU
(CTSU indicates CTSU2, CTSU2L, CTSU2SL, etc.)

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1. Outline

Capacitive touch button sensitivity and anti-noise performance are both influenced by the shape and size of the touch electrode pad (herein referred to as “electrode”), wire routing, patterns surrounding the electrode, overlay panel thickness, inclusion of air gap, internal configuration of product casing, and other factors. All of these factors need to be taken into consideration when designing the electrode as well as the surrounding area.

This application note describes how to design electrode pads and wiring as well as how to deal with related issues and potential problems when using the Renesas Touch Capacitance Sensor Unit (CTSU). It also provides recommended applications.

2. Self-capacitance Method Buttons: Electrode Layout Patterns

2.1 Outline of Design Recommendations

The following provides reference information for designing self-capacitance method buttons on a two-sided printed board. We recommend using a 2- or more layer board and placing a shield guard of a cross-hatched GND pattern around the electrodes to suppress parasitic capacitance fluctuations due to the surrounding environment and noise factors. We also recommend using an ESD countermeasure by shielding the outer circumference of the board with a GND plane pattern. The numbers listed here correspond to the numbers in each figure, excluding numbers 8 and 9. Each item is described in detail later.

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 2-1. Example of Anti-noise Layout Pattern for Self-capacitance Method Buttons](image)
2.2 Self-capacitance Method Overview

Figure 2-2 shows the self-capacitance generated in the electrode. A single electrode connected to the capacitive sensor in the self-capacitance method button measures capacitance C. The value of C is a composite of parasitic capacitance Cp formed by the electrode and surrounding conductors and parasitic capacitance Cf formed by the electrode and the finger. The size of the capacitance can be considered in the capacitor equation \( C = \varepsilon \frac{S}{d} \) (see note). Cp is constant as the surrounding devices are static, but Cf increases as the finger gets closer. By setting a threshold for the amount of increase in Cf, you can determine whether the touch button is ON or OFF. Note that if the finger actually touches the electrode, it will short and no longer be able to measure capacitance. Normally, there is an overlay panel of a few mm between the electrode and the finger.

Note) C: capacitance, \( \varepsilon \): Relative permittivity, S: electrode facing area, d: inter-electrode distance

![Figure 2-2. Image of Self-capacitance Generated in the Electrode](image-url)
2.3 Principle of CTSU Self-capacitance Method Detection

Figure 2-3 shows an overview of the CTSU internal configuration for the self-capacitance method. The CTSU outputs a digital count value proportional to capacitance C of the connected electrode, and determines whether the touch button is ON or OFF by software. When the electrode is connected to the CTSU, it performs as a switched capacitor controlled by the sensor drive pulse and estimates capacitance from the charge/discharge current to C. The CTSU measurement block has a current-frequency conversion function which inputs a current equivalent to the charge/discharge current and outputs a frequency proportional to the amount of current. For details on the detection principle, refer to the application note “RX113 Group CTSU Basis of Cap Touch Detection.”

Figure 2-3. Internal Configuration Overview of Self-capacitance CTSU

Figure 2-4 shows an image of CTSU measurement. When one cycle of the sensor drive pulse frequency is shorter than the C charge/discharge time and the charge/discharge is insufficient, not enough current flows to C and the count value is smaller than the ideal value. When parasitic capacitance is large, it may be possible to take a measurement by lowering the sensor drive pulse frequency. When the sensor drive pulse frequency is lowered, the CTSU can measure a maximum of 50pF. Note that when the sensor drive pulse frequency is decreased, the number of measurements per unit time by the current-frequency conversion function also declines. The sensitivity of the electrode is likely to decrease as well. The unit time can be increased by adjusting the register setting value in the CTSU, but the amount of time required to complete the measurement will also increase. When designing a capacitive electrode circuit, conditions for button sensitivity, measurement time and noise immunity must be met.

Figure 2-4. Image of CTSU Measurement
Figure 2-5 shows an image of GND patterns and parasitic capacitance. When using a printed board, place a GND plane pattern directly under the wiring pattern as a general anti-noise countermeasure. In the self-capacitance button, the parasitic capacitance $C_{P,GND}$ generated by the electrode and GND plane pattern is much larger than $C_f$ and exceeds the measurement range of the CTSU. So, when designing the self-capacitance button, do not place a GND plane pattern directly under the electrode. If an anti-noise countermeasure is needed, use a cross-hatched GND pattern to reduce the increase in parasitic capacitance.

2.4 Electrode Pattern Design

When designing a self-capacitive touch button circuit, design the pattern and select the material so that the following conditions are met.

- Electrostatic capacity $C$: 50pF or less
- Resistance value $R$: 2kΩ or less (including damping resistor)

Figure 2-6 shows a self-capacitance electrode circuit. The touch button circuit configuration comprises the touch electrode, electrode wiring, and damping resistor. The reference value of the CTSU damping resistor is 560Ω. Note that touch button circuit $C$ is also affected by parasitic capacitance with objects around the board such as the GND pattern, overlay panel, and body chassis. Normal measurement values may not be obtained when using values other than the above design values. The total capacity value for each electrode can be confirmed using QE for Capacitive Touch.
2.4.1 Electrode pads and wiring
The following offers recommended shapes for button electrodes and wiring conditions.

- **Shape:** square or circular plane patterns
- **Size:** 10 x 10 to 15 x 15mm
- **Electrode interval:** To avoid crosstalk, use an interval wide enough to prevent simultaneous response by adjacent electrodes based on finger or other touch interface
  - Target interval size: electrode button size x 0.8 or more
- **Interval between electrode and GND pattern:** 5mm or more
- **Do not place wiring or a pattern for another function, or a GND plane pattern directly under an electrode.**
  - When a GND pattern is necessary as an anti-noise countermeasure, place a cross-hatched GND pattern.

Crosstalk refers to capacitive coupling between adjacent electrodes or capacitive coupling between a finger and adjacent electrodes when the target electrode is touched. For more details, see section “2.6 Effect of Panel Thickness.”

Fig. 2-7 shows the recommended electrode shapes and size. Size and shape are fairly flexible and can be determined based on the button design of the panel on the final product. Make sure that the size is not extremely large or extremely small with respect to the part of the human body (finger, etc.) that will be operating the product. If the pad is square, round the corners of the electrode with a radius of 0.5 to 1.0 mm to reduce the effects of noise.

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**Figure 2-7. Recommended Electrode Shapes and Size**

Figure 2-8 shows shapes that are not recommended for electrodes—triangles with angles of 90 degrees or less and E-shapes with narrow line width and long total length. These shapes are not recommended as they tend to perform as antennas and degrade the RF noise immunity.

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**Figure 2-8. Unsuitable Electrode Shapes**
2.4.2 Wiring
The wiring part of the electrode has a small parasitic capacitance and is easily affected by external noise. Noise immunity can be improved by suitably arranging the wiring spacing and GND pattern. In addition, the CTSU also functions as a shield because, other than during measurements, the TS terminals and wiring are fixed at the GND level. Since the coupling capacitance changes depending on the wiring width and length, adjust the wiring spacing and the spacing between wiring and the GND pattern so that the conditions for total parasitic capacitance are satisfied.

Recommended layout and dimensions of wiring are listed below.

- Wiring width: 0.15mm (the thinnest wire capable through mass production)
- Wiring spacing: 1.27mm pitch
  However, leave at least 5mm, more if possible, between the electrode pad circumference (about twice the length of the electrode pad)
- Wiring and cross-hatched GND pattern spacing: 1.27mm (1.27mm pitch)
- Wiring and GND pattern spacing: 3mm or more

Make sure the design satisfies the following wiring requirements as well.

- Keep the wiring as short as possible.
- Try to have as few corners in the wiring as possible; make corners 45 degrees or rounded.
- Drill vias at the edge of the electrode pad and layout wiring on the back side. This helps reduce malfunctions when wires are touched. However, keep the number of vias at a minimum as they tend to increase parasitic capacitance.
- As an anti-noise countermeasure, place a cross-hatched GND pattern directly under the electrode and wiring.
- The wire routing extending from the electrode is vulnerable to noise as there is no cross-hatched GND pattern directly under the wiring. Bring the cross-hatched GND as close as 0.5mm to this part.
- Do not place wiring other than that used for the touch function directly under the electrode wiring. If you must do so, make the wiring orthogonal and minimize the facing area.

Figure 2-9 shows an example of the wiring section of a double-layer board layout example.
Figure 2-10 shows an example of the electrode section of a double-layer board layout.

Figure 2-10. Double-Layer Board Layout Example (electrode section)

Figure 2-11 and Figure 2-12 show layout examples for each layer.

Figure 2-11. Top Layer Layout Example

Figure 2-12. Bottom Layer Layout Example
Figure 2-13 shows an example of high-density wiring. When you have limited board size and need to increase the wiring density, shift the wiring by a half pitch and lay out the wiring on both sides of the board. For 4-layer boards, make sure to place a cross-hatched GND on the inner layers.
2.5 Anti-Noise Layout Pattern Designs

The electrode circuit configuration allows the circuit to act as an antenna (the MCU pin is open only for capacitive coupling) and makes it vulnerable to electromagnetic field noise. Renesas Touch MCUs employ several anti-noise countermeasures to ensure high noise immunity. However, an MCU alone cannot prevent influence from all noise. Hardware countermeasures are indispensable when using the MCU in a severe noise environment. The following are a few examples of how to protect the system from external noise.

In general, the longer the wiring, the more chances for noise to synchronize and mix with the many noise frequencies. Make sure the wiring between button electrodes and the touch MCU is kept as short as possible.

The best way to prevent malfunctions due to external noise is to shield guard the touch button circumference. CTSU2 supports active shields.

2.5.1 Shield guard countermeasures

2.5.1.1 Pattern design

Figure 2-14 shows the cross-hatched pattern dimensions. Shielding the electrode and electrode wiring serves as an effective EMS noise countermeasure. A shield guard can be placed directly under the electrode or electrode wiring on a multi-layer board but the GND plane pattern has a large coupling capacity which will prevent the electrode from detecting capacitance fluctuation when touched. Therefore, a cross-hatched pattern shield guard should be used. The Renesas Capacitive Touch Evaluation System employs a cross-hatched pattern in the dimensions listed below. In addition, the cross-hatched pattern is tilted 45 degrees depending on the wiring direction in order to reduce the capacitive coupling with the electrode wiring.

- Pitch: 1.5mm
- Line width: 0.15mm
- Line space: 1.35mm

![Figure 2-14. Cross-hatched Pattern Dimensions](image-url)
2.5.1.2 GND shield

Placing a GND pattern around the electrodes and electrode wiring generates capacitive coupling which suppresses potential fluctuation due to influence from external noise. Note that if the GND shield is placed too close to the electrode it will cause parasitic capacitance to increase too much, which may block touch detection. When close shielding is necessary due to a severe noise environment, we recommend using a hatched shape that will reduce capacitive coupling. In addition, the longer the wiring must run in parallel, the more the parasitic capacitance increases. Therefore, you may need to adjust the distance between the wiring and the shield.

The following are recommended shape and wiring conditions for the top layer. These recommendations assume the electrode pads are placed on the top layer.

- Distance between electrode and cross-hatched GND shield: 5mm
- Width of cross-hatched GND shield: 5mm or less
- Make sure to connect the cross-hatched GND pattern and GND plane.
- Cover the area directly under the electrode and wiring with the cross-hatched GND pattern.

Figure 2-15 and Figure 2-16 show an example of a GND shield pattern for a multi-layer board.

![Figure 2-15. GND Shield Pattern Example for Multi-layer Board (top layer)](image)

![Figure 2-16. GND Shield Pattern Example for Multi-layer Board (bottom layer)](image)
2.5.1.3 Active shield (CTSU2 function)

This function is provided for MCUs embedded with CTSU2.

The active shield function drives the shield guard with signals of the same potential and phase as the electrodes. Using the active shield will reduce capacitance coupling between the electrode and shield guard as well reduce noise interference. The active shield is driven by a switched capacitor in the same manner as a normal electrode. Note that the active shield can’t be driven when parasitic capacitance is large, which causes a phase shift with the electrode, making it impossible to gain sufficient results.

Figure 2-17 shows an example of a shield electrode circuit. An active shield can be thought of as the button electrode that connects to the TS terminal. The shield electrode circuit can be designed in the same manner as a normal electrode, but extra attention must be paid to size and pattern design. Since this shield is placed to cover the electrodes, the more electrodes there are, the higher the parasitic capacitance of the shield electrodes, which results in insufficient charging and discharging of the switched capacitor. Reducing the damping resistance value may help improve this problem. If the capacitance of the electrode and active shield differ significantly, also consider subdividing the button and active shield grouping. QE for Capacitive Touch supports up to 8 groupings (configurations). For details concerning the configurations, refer to QE for Capacitive Touch Help File.

![Figure 2-17. Shield Electrode Circuit](image-url)
The following are recommended shape and wiring conditions for the active shield. The recommendations assume the electrode pads are placed on the top layer.

- Distance between touch electrode and active shield electrode: 3mm
- Width of active shield electrode: 3mm
- Distance between active shield electrode and GND plane pattern: 3mm or more
- Cover all of the areas directly under the electrodes and wiring with an active shield electrode.

Figure 2-18 and Figure 2-19 show an example of the active shield pattern for multiple-layer boards.

![Figure 2-18. Example of Active Shield Pattern for Multiple-Layer Board (top layer)](image)

![Figure 2-19. Example of Active Shield Pattern for Multiple-Layer Board (bottom layer)](image)
2.6 Effect of Panel Thickness

The self-capacitance method detects the capacitance generated when there is contact between the human body and a button electrode. Accordingly, in this kind of touch detection, the larger the touch surface of the button electrode and the longer the distance between the finger or other body part and the electrode, the higher the sensitivity. As the maximum touch surface size of the button electrode is limited (10mm to 15mm), the distance, or panel thickness, is the key factor in adjusting sensitivity.

2.6.1 Relationship of panel thickness and touch sensitivity

Figure 2-20 shows the relationship of the amount of capacitance change and sensitivity distance in the self-capacitance method. In this method, the capacitance increases or decreases depending on the distance between the finger and the electrode, allowing touch detection over a broad range (distance). However, this also means that if the threshold has a large margin in comparison to the capacitance, touch detection may occur before the finger actually has contact with the panel. Capacitance may increase and decrease when touched depending on the relative permittivity of the panel material. Keep in mind that materials with a high relative permittivity may exceed the CTSU measurement range even at the same touch distance.

![Figure 2-20. Relationship of Capacitance Change and Sensitivity Distance](image)

Table 2-1. Relative Permittivity of Each Material

<table>
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<tr>
<td>Glass</td>
<td>4.5-7.5</td>
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<tr>
<td>Nylon Plastic</td>
<td>3.0-5.0</td>
</tr>
<tr>
<td>Flexible Vinyl Film</td>
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<td>Air</td>
<td>1.0</td>
</tr>
<tr>
<td>Water</td>
<td>80</td>
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2.6.2 Relationship of panel thickness and crosstalk

Figure 2-21 shows the relationship of the inter-electrode distance and panel thickness in the self-capacitance method. If the button electrodes are placed too close together, they may cause neighboring button electrodes to turn ON erroneously (left side of figure). To prevent false detections (crosstalk), among neighboring button electrodes, the recommended distance between button electrodes is 0.8 times wider than the button size.

![Figure 2-21. Relationship of Inter-electrode Distance and Overlay Thickness for Self-capacitance Method](image-url)
2.7 Electrode Application Examples

2.7.1 Example of slider electrode layout pattern design

Figure 2-22 shows the recommended pattern for a slider electrode in the self-capacitance method. This pattern is designed for finger touch and ensures that 3 electrodes respond when the slider is touched anywhere other than the two ends. To change the size of the slider, adjustments must be made by adding or removing electrodes rather than expanding or shrinking the pattern.

![Figure 2-22. Recommended Pattern for Slider Electrode for Self-Capacitance Method](image)

2.7.2 Example of wheel layout pattern design

Figure 2-23 shows the recommended wheel electrode pattern for the self-capacitance method. This pattern is designed for finger touch and ensures that 3 electrodes respond no matter where the wheel is touched. To change the size of the wheel, adjustments must be made by adding or removing electrodes rather than expanding or shrinking the pattern.

![Figure 2-23. Recommended Pattern for Wheel Electrode for Self-Capacitance Method](image)
2.7.3 Flexible printed circuit boards

Although any conductive material can be used for the electrode, note that materials with high surface resistance such as carbon may reduce touch sensitivity. Also, materials with high surface resistance may not be consistently sensitive depending on where the finger is placed. If such a material must be used, lay out the wiring as shown in Figure 2-24: (b) arrange wiring as close to the center of the electrode or (c) surround the entire electrode with a material that has low surface resistance so the resistance value is constant regardless of where the surface is touched. When using copper or other sufficiently low surface resistant material, the wiring can even be routed from any point on the button electrode itself, as shown in example (a).

On flexible printed circuit (FPC) boards, compared to printed boards, wires tend to be thicker and the space between wiring wider. Although thinner wire width helps suppress parasitic capacitance, the resistance value increases. We recommend designing based on a wire width of approximately 1.0mm with approximately 1.0mm spacing between wires.

![Figure 2-24. Button Electrode Wiring Method](image)

(a) Low resistance material  (b) High resistance material  (c) High resistance material

2.7.4 LED wiring layout

2.7.4.1 Direct lighting example

Figure 2-25 shows the electrode pad and LED wiring for the self-capacitance method. We recommend routing the LED around the outer edge of the electrode pad, as shown to the right of the figure. To reduce noise radiated from the LED circuit, cover the LED wiring with a GND shield and, for multi-layer boards, cover the opposite surface with a GND shield as well.

Note that routing the LED wiring in the electrode pad requires a hole to be made in the electrode, reducing the touch-sensitive surface area and bringing the LED wiring in close proximity to the electrode. This increases the risk of weaker sensitivity due to an increased parasitic capacitance.

![Figure 2-25. Electrode Pad and LED Routing Example for Self-capacitance Method](image)
2.7.4.2 Indirect lighting (using light guide plate)

Figure 2-26 shows an example of LED routing using an electrode pad and a light guide plate for the self-capacitance method. The LED (the light source) must be a set distance from light-emitting surface to ensure even lighting. Placing multiple LEDs (light sources) in opposing positions helps to eliminate uneven lighting.

![Figure 2-26. Example of LED Routing using Electrode Pad Light Guide Plate for Self-capacitance Method](image)

2.7.5 When panel and button electrodes are separated

Figure 2-27 shows an example configuration with space between the panel and button electrodes. Although the configuration depends on the size of the button electrode, parasitic capacitance, and other factors, if all conditions are favorable, touch can be detected even with a 2mm air gap between the panel and electrodes. However, when dealing with strict noise immunity requirements, if the air gap is larger than 2mm and touch detection is difficult due to other conditions, you may need to extend the button electrodes to the panel, as shown on the right of the figure.

![Figure 2-27. Example of Air Gap Measure for Auto-capacitance Method](image)
3. Mutual Capacitance Method: Electrode Layout Patterns

3.1 Outline

The mutual-capacitance method boasts button electrodes with superior water-resistance, support based on using matrix structure, and many other functions not available with self-capacitance. However, mutual-capacitance requires complicated button electrode configurations and wire routing, making sensitivity adjustment difficult. The merits and demerits of each method must be taken into account when designing layout patterns. Furthermore, unlike the self-capacitance method, sensitivity is lost when panel thickness falls below a specified level. The designer must carefully consider the button electrode configuration when determining panel thickness.

Always use a multi-layer board of at least two layers for the mutual-capacitance method. This chapter describes a double-layer board as an example.
3.2 Outline of Design Recommendations

This section provides reference design information for creating mutual-capacitance method buttons on a printed board. We recommend placing a cross-hatched pattern GND shield guard around the electrodes. We also recommend using an ESD countermeasure by shielding the outer circumference of the board with a GND plane pattern. The numbers listed here correspond to the numbers in each figure, excluding numbers 8 and 9. Each item is described in detail later.

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 3-1. Example of Button Pattern for Mutual-capacitance Method
### 3.3 Mutual-capacitance Method Overview

Figure 3-2 shows the mutual-capacitance generated in the electrode. The mutual-capacitance method is characterized by parasitic capacitance $C_m$ which is generated between two differing conductors. The mutual-capacitance method button comprises two electrodes, receiver electrode $RX$ and transmitter electrode $TX$, connected to a capacitive sensor. An electric field is generated when $TX$ is pulse-driven, and electric charge is also accumulated in $C_m$. When a finger comes close to the electrode, parasitic capacitance $C_f$ is generated between the finger and the electrode, and $C_m$ and $C_f$ are connected in parallel. Since the driving energy of $TX$ is constant, the amount of electric charge does not change. Therefore, the charge on $C_m$ and $C_f$ is dissipated and the $C_m$ electric charge decreases. By setting a threshold for the amount of increase in $C_f$, you can determine whether the touch button is ON or OFF. Note that if the finger actually touches the electrode, it will short and no longer be able to measure capacitance. Normally, there is an overlay panel of a few mm between the electrode and the finger.

![Figure 3-2. Image of Mutual-capacitance Electrodes](image)

### 3.4 Principle of CTSU Mutual-capacitance Method Detection

Figure 3-3 shows an overview of the CTSU internal configuration for the mutual-capacitance method. The CTSU outputs a digital count that is negatively proportional to the mutual capacitance of $RX$ and $TX$ connected to the electrode, and determines whether the touch button is ON or OFF by software.

In order to measure the capacitance $C_m$ existing on the two connected electrodes, the CTSU obtains $C_m$ by inverting the phase relationship between the pulse output and the switched capacitor, measuring the self capacitance twice, then calculating the difference of the two values by software. For more details on the mutual-capacitance detection principle, refer to the application note “RX113 Group CTSU Basis of Cap Touch Detection.”.

![Figure 3-3. Internal Configuration Outline for Mutual-Capacitance Method](image)
3.5 Electrode Pattern Designs

Figure 3-4 shows an electrode circuit for the mutual-capacitance method. Mutual-capacitance method button electrodes are configured as receiver electrode (Rx) and transmitter electrode (Tx). In the mutual-capacitance method, the total capacitance value for 1 electrode should be 20pF or less, and the total resistance (including protective resistor value) should be 2kΩ or less. The total capacity value for each electrode can be confirmed using QE for Capacitive Touch.

![Electrode Circuit for Mutual-capacitance Method](image)

Figure 3-4. Electrode Circuit for Mutual-capacitance Method

Figure 3-5 shows the recommended electrode pattern for the mutual-capacitance method. The receiver electrode, which is more susceptible to noise, is protected by encompassing the sides of Rx with the sides of Tx. This configuration increases the distance between Tx and Rx opposing sides (called “facing distance” herein) as well as the surface area that comes in contact with the finger. This pattern supports an overlay thickness of 2mm to 3mm.

![Mutual Capacitance Method: Recommended Electrode Patterns](image)

Figure 3-5. Mutual Capacitance Method: Recommended Electrode Patterns
Mutual-capacitance method touch measurement measures the electromagnetic field (capacitive coupling) between Tx and Rx and captures the phenomenon of the capacitive coupling decreasing as a fingertip (i.e., part of the human body) in close proximity attracts part of the electromagnetic field. Therefore, the layout pattern must be designed to (1) maximize the capacitive coupling between Rx and Tx, and (2) make the rate of capacitance coupling reduction as large as possible when a finger is in proximity.

Figure 3-6 shows an image of the Tx/Rx coupling capacitance electromagnetic field for mutual-capacitance method electrodes. A greater Tx/Rx facing distance is required when using a thick overlay panel. However, as most products limit the electrode size, it is often difficult to extend the Tx/Rx distance. As shown in Figure 3-5, you may need to use an electrode with a shorter Tx/Rx distance like the Type C electrode, but compared to the Type 2 electrode, the shorter Tx/Rx distance of the Type C electrode means the measured value may also be smaller.

Figure 3-6. Image of Electrode Tx-Rx Capacitance Coupling for Mutual Capacitance Method

Figure 3-7 shows an image of capacitance coupling based on electrode pad Tx/Rx parallel run distance and Tx/Rx facing distance in the mutual-capacitance method. The longer the parallel run distance of transmitter electrode Tx and receiver electrode Rx, the larger the Tx/Rx coupling capacitance, which results in greater change in the measured value when a touch is detected. When electrode pads are the same size, the longer the Tx/Rx parallel run distance, the more complicated the layout. In addition, a longer Tx/Rx facing distance supports thicker overlay panels and air gaps, but creates a denser electromagnetic field, leading to lower sensor counts.

Figure 3-7. Image of Capacitance Coupling Based on Electrode Tx/Rx Parallel Run Distance and Facing Distance for Mutual-capacitance Method
### 3.6 Air Gap

Figure 3-8 shows the electrode Tx/Rx coupling capacitance electromagnetic field and air gap (incl. panel thickness) for the mutual-capacitance method. In this method, when the layout design includes an air gap between the electrode and overlay panel, the Tx/Rx facing distance must be as long as possible, in the same manner as when using a thick panel. The facing distance between the transmitter electrode Tx and receiver electrode Rx depends on the panel thickness. The recommended Tx/Rx facing distance is approx. 0.6 times the panel and air gap thickness.

![Figure 3-8. Tx/Rx Coupling Capacitance Electromagnetic Field and Air Gap (incl. panel thickness) for Mutual Capacitance Method](image)

### 3.7 Distance from Touch Surface to Electrode

Figure 3-9 shows the relationship between the amount of capacitance change and the sensitive electrode. In the mutual capacitance method, no matter how close or far apart the finger (human body) and electrodes are, the decrease in Tx/Rx coupling capacitance will be reduced, so panel thickness and air gap thickness are factors to keep in mind at the design stage. As mentioned earlier, the ideal optimal panel thickness, including the air gap, is 1.7 times the distance between the Tx/Rx electrodes.

![Figure 3-9. Relationship of Capacitance Change and Sensitivity Distance for Mutual-capacitance Method](image)
Figure 3-10 shows the relationship between inter-electrode distance and panel thickness in the mutual capacitance method. To avoid false detections (crosstalk) between neighboring electrodes, the recommended inter-electrode distance is 2 times or more the panel thickness (including the air gap).

![Figure 3-10. Relationship of Inter-electrode Distance and Overlay for Mutual-capacitance Method](image)

### 3.8 Electrode Routing Design

Figure 3-11 shows an electrode routing example for the mutual capacitance method. Tx and Rx electrode wiring must be routed with ample distance from neighboring button electrodes and other areas where finger touch is anticipated. This clearance distance will reduce the risk of false detection due to a non-accurate touch, which may occur when a non-electrode pad area is touched. It is important to separate the Tx and Rx electrode wiring so that an unintentional touch does not occur across both traces at the same time. Similarly, if the touch measurement terminals (TS) set to Rx and Tx are adjacent, coupling capacitance may occur between the two terminals, reducing the relative rate of decreasing capacitance, thus causing a decrease in sensitivity. To prevent capacitive crosstalk, group the Rx and Tx lines separately and keep them as far away as possible.

![Figure 3-11. Example of Electrode Routing for Mutual-capacitance Method](image)
Figure 3-12 shows the electrode wiring restrictions that apply in the mutual-capacitance method. Tx and Rx electrode wiring should not be routed in parallel in short range within the wiring area; they must be kept as far apart as possible. If the wiring must cross due to board constraints, do so at a 90° angle as far from the electrode as possible, and then separate the wiring immediately.

3.9 Anti-noise Layout Pattern Designs
The electrode circuit configuration makes the electrode act as an antenna (the MCU pin is open only for coupling capacitance) and makes it vulnerable to electromagnetic field noise. Renesas Touch MCUs employ several anti-noise countermeasures to ensure high noise immunity. However, an MCU alone cannot prevent influence from all noise. Hardware countermeasures are indispensable when using the MCU in a severe noise environment. This section includes several design examples.

In general, the longer the wiring, the more chances for noise to synchronize and mix with the many noise frequencies. Make sure the wiring between button electrodes and the MCU is kept as short as possible.

The active shield cannot be used for the mutual capacitance method.

3.9.1 Pattern Designs
3.9.2 Shield guard anti-noise countermeasure
A GND pattern is placed around the electrodes and wiring to generate capacitive coupling and suppress potential fluctuations due to the effects of external noise. Placing the GND shield too close to the electrode may cause the parasitic capacitance to increase too much, blocking touch detection. If the noise environment is severe and the shield needs to be brought closer, we recommend using a cross-hatched configuration as the ground pattern to minimize capacitive coupling. The Renesas Capacitive touch Evaluation System employs a cross-hatched pattern in the dimensions listed below. In addition, the cross-hatched pattern is tilted 45 degrees depending on the wiring direction in order to reduce the capacitive coupling with the electrode wiring. Also, the longer the wiring must run in parallel, the more the parasitic capacitance increases. Therefore, you may need to adjust the distance between the wiring and the shield.
Figure 3-14 and Figure 3-15 shows an anti-noise layout pattern example for the mutual capacitance method. We recommend using a cross-hatched ground pattern to cover the area around the electrode wiring. When the entire wiring area cannot be covered due to layout limitations, place priority on covering the area around the Rx electrode wiring with the cross-hatched GND pattern. Make sure the distance between the electrode wiring and the cross-hatched GND is 4mm or more.

**Figure 3-14. Anti-noise Countermeasure Layout Pattern Example (top layer)**

**Figure 3-15. Anti-noise Countermeasure Layout Pattern Example (bottom layer)**
3.10 Design Application Examples

3.10.1 Water-resistant electrode layout pattern design

Figure 3-16 depicts cautions regarding water-resistant electrode layout patterns for the mutual capacitance method. If the device is used under flowing water and a water film forms on the electrode surface, when the fingertip touches the water film, the effect is almost as if all electrodes under the water film are touched. This state greatly increases the risk of false detection (crosstalk) between adjacent electrodes in inverse proportion to the resistance value of the flowing water. Using sensing devices in the ocean or in other water containing electrolytes will deteriorate the operating conditions for electrostatic touch. The resistance value of the water film is reduced due to an increasingly thicker water film and a high dielectric constant of the water, which is increased even further by the electrolytes.

Products that require water resistance must be designed with wide spaces between electrode pads as a countermeasure against false detections between adjacent electrodes.

Figure 3-17 shows the recommended water-resistant electrode layout for the mutual-capacitance method. Considering that water flows from top to bottom, the best water-resistant layout would be to position all electrodes in a single horizontal line.

Since the Tx wiring, which is not used by the electrode during measurement, outputs low, all Tx can be grouped into one line for water-resistant designs. This will enable the L level output by non-active Tx wiring to bridge with other electrodes via the water film, preventing false detections.
Figure 3-18 shows the relationship between electrode proximity and the panel thickness for the mutual capacitance method. To prevent false detection between adjacent electrodes (crosstalk), the recommended inter-electrode distance is 2 or more times the thickness of the panel overlay (including air gap).

Inter-electrode distance $\geq (\text{Panel thickness} + \text{Air gap}) \times 1^-2$

**Actual example**

![Diagram showing the relationship between electrode proximity and panel thickness](image)

Figure 3-18. Relationship of Water-resistant Inter-electrode Distance and Overlay for Mutual-capacitance Method
3.10.2 LED wiring layout

3.10.2.1 Direct lighting example

Figure 3-19 shows an example of the electrode pad and LED wiring for the mutual-capacitance method. The ideal routing is to position the LED around the outer edge of the electrode pad, as shown to the right of the figure. In the mutual capacitance method, the Tx/Rx facing area can be increased to improve detection sensitivity. However, this creates difficulty in positioning the LED wiring going into the electrode pad at the Tx and Rx electrodes. The Tx/Rx parallel runs are short and may cause sensitivity deterioration for electrode pads of the same size.

![Figure 3-19 Electrode Pad and LED Wire Routing for Mutual-capacitance Method](image)

3.10.2.2 Indirect lighting example

Figure 3-20 shows an LED routing example using an electrode pad and a light guide plate for the mutual capacitance method. The LED (the light source) must be a set distance from light-emitting surface to ensure even lighting. Placing multiple LEDs (light sources) in opposing positions helps to eliminate uneven lighting.

![Figure 3-20 LED Wire Routing with Electrode Pad and Light Guide Plate for Mutual-capacitance Method](image)
## Revision History

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General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)

   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.

2. Processing at power-on

   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.

3. Input of signal during power-off state

   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.

4. Handling of unused pins

   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.

5. Clock signals

   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.

6. Voltage application waveform at input pin

   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between \( V_{IL}(\text{Max.}) \) and \( V_{IH}(\text{Min.}) \) 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 \( V_{IL}(\text{Max.}) \) and \( V_{IH}(\text{Min.}) \).

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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