Introduction

The RX113 group has incorporated hardware (Capacitive Touch Sensor Unit; CTSU) that detects human body contact by measuring capacitance existed between touch electrode and human body.

The CTSU is capable of detection by self-capacitance or mutual capacitance. This application note introduces the matrix button design for the mutual capacitance method.

Target Device

RX113 Group

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1. Basis of Mutual capacitance method

1.1 Outline

Capacitive touch detection by the mutual method utilizes the phenomenon that a part of capacitive coupling the mutual electrodes generating the electric field to the conductive material such as a human body as shown in Figure 1-1. One electrode is impressed the pulse as the transmitting electrode and the other is connected to the capacity detector as the receiving electrode. The capacity detector measures the coupling of electric charge from one electrode to the other. If the conductive material comes closer the mutual electrode, a part of capacitive coupling is diverted into that object and the coupling to the receiving electrode is decreased. By periodically measuring the coupled field it is possible to detect a “touch”. For more information on the differences between mutual and self-capacitance detection refer to application note R01ANxxxxxx, Capacitive Touch Detection.

1.2 Renesas mutual capacitance method

The basis of Renesas mutual capacitance method is shown in Figure 1-2. The CTSU(Capacitive Touch Sensing Unit) is constructed using a capacitance-current convertor with SCF (Switched Capacitor Filter) and a current detector. The CTSU can represent any parasitic capacitance connected the external port of the MCU as a digital value. In addition, it includes a pulse generator synchronized with the SCF switching cycle and it is possible to measure the mutual capacitance of electrodes that are placed between SCF port and the pulse output port.
In order to measure the capacitance \( C_m \) existing on the mutual electrodes, the CTSU measures the mutual electrode’s capacitance twice. The primary measurement measures the capacitance when SCF and the driving pulse are driven to the same level, and secondly measurement occurs when the pulse is driven to the opposite level of the SCF. The \( C_m \) value is determined by subtracting the first measurement value from the secondly one. The formulas below show the relationship of the currents for the two measurements. These are based on the fundamental formula relating current, frequency and capacitance in a switched network with a constant voltage.

Basic Formula:

\[
I_c = VFC \\
\text{Where} \\
I_c = \text{Capacitor Current} \\
F = \text{Switching Frequency} \\
C = \text{capacitance} \\
V = \text{Switching Voltage}
\]

Mutual Capacitance Formulas:

\[
\begin{align*}
I_{pri} &= FCpVd + FCm(Vt - Vd) \\
I_{sec} &= FCpVd + FCm(Vt + Vd) \\
I_{sec} &= FCpVd + FCm(Vt + Vd) \\
&= I_{sec} - I_{pri} \\
&= FCpVd + FCm(Vt + Vd) - [FCpVd + FCm(Vt - Vd)] \\
&= 2FCmVd
\end{align*}
\]

\( I_{pri} \) = Primary current measurement value
\( I_{sec} \) = Secondly current measurement value
\( F \) = Frequency of SCF and Driving pulse
\( Vd \) = Voltage of the pulse generator circuit
\( Vt \) = Voltage of SCF driving
\( Cm \) = Capacitance existing between the electrodes
\( Cp \) = Parasitic capacitance of each electrode and its wiring

\( I_{pri} = FCpVd + FCm(Vt - Vd) \) \hspace{1cm} \text{ Formula 1-1} \hspace{1cm} \text{ and } \hspace{1cm} I_{sec} = FCpVd + FCm(Vt + Vd) \hspace{1cm} \text{ Formula 1-2} \)

Formula 1-1 and Formula 1-2 show the current values resulting from the primary and secondary measurements. Formula 1-4 shows the subtraction the primary measurement from the second one. In the CTSU circuit \( F \) and \( Vd \) are constant values so \( C_m \) value can be calculated from Formula 1-5. Notice another benefit is the parasitic capacitance is cancelled in the result.
2. Button design of the mutual capacitance method

2.1 Outline

The mutual capacitance method has the following advantage:

A. The mutual configuration allows a matrix configuration of the buttons to increase the number of buttons with a given set of sensors.

B. Water and moisture false touch rejection– in mutual method water or moisture on the surface increases coupling of the sensors which is opposite of a touch interaction. In self-capacitance water increases the parasitic capacitance which is identical to a touch interaction.

C. Possibility of the noise countermeasure by the structure of the electrodes

2.2 Construction of the button

Figure 2-1 shows the recommended pattern for a mutual button. The outside pattern is the transmitting electrode (Tx) and inside is the receiving electrode (Rx).

![Transmitting electrode](image1)

**Figure 2-1 the sample of the button pattern by the mutual capacitance method**

In order to increase the capacitance, the opposing areas of the transmit and receive surface should be kept large. The opposing surfaces form the plates of the coupling capacitance. The recommended area of the button is from 10x10 to 16x16 mm. It is possible to construct a button larger than 16 x16mm button but there will be little increase in the sensitivity of the mutual field influence and you have to consider the effect of the parasitic capacitance.

![Electrode pattern width](image2)

**Figure 2-2 the electrode pattern width**

Figure 2-2 shows the electrode pattern width. To reduce the parasitic capacitance, the width of Rx pattern is recommended less than 0.5mm. The actual width used depends on the resistance of the pattern material. When the material resistance is large (ex. Carbon film), the width will have to be increased to keep the resistance small. It is recommended to keep the Tx pattern the same thickness as the cover panel. The distance of Rx and Tx should be 0.6 x thickness of cover panel. If there is a conflict between these trace thicknesses and the parallel areas of the Rx and Tx surface the opposing area is a higher priority.
3. Wiring

3.1 Construction of wiring

When sensing using the mutual method, the Rx trace layout is the most critical. Noise injection from other wirings and the parasitic capacitance with GND pattern can become problems. This section details examples of routing.

3.2 Examples of wiring

In order to prevent unanticipated capacitive coupling between Tx and Rx wiring, Tx and Rx wiring should be separated as far as they practical. At a minimum, the distance should be more than a finger touch distance as shown Figure 3-1. In addition, if Tx and Rx must cross it is recommended to wire orthogonal and to minimize any parallel traces as shown Figure 3-2.

![Figure 3-1 Tx and Rx wirings distance](image1.png)

![Figure 3-2 In case of crossing Tx and Rx wirings](image2.png)

The trace length from the Rx MCU port pin should be kept as short as possible to minimize the parasitic capacitance and series resistance. We recommend keeping the parasitic capacitance under 20pF and the resistance under 2Kohm as shown Figure 3-3.

![Figure 3-3 Parasitic capacitance and resistance of Rx wiring](image3.png)
4. Examples of the matrix buttons

4.1 4x3 10x10mm\(^2\) buttons (Tx:4,Rx:3) with the cover panel thickness 1-2mm

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**Figure 4-1 4x3 10mm\(^2\) buttons example**

Through hole

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**Figure 4-2 10x10mm electrode example**
Table 4-1: the relation of the capacitance of Touch & Non touch and the panel thickness

<table>
<thead>
<tr>
<th>Panel thickness</th>
<th>Non touch</th>
<th>touch</th>
<th>difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2mm</td>
<td>1.868</td>
<td>1.661</td>
<td>0.207</td>
</tr>
<tr>
<td>4mm</td>
<td>1.842</td>
<td>1.775</td>
<td>0.067</td>
</tr>
<tr>
<td>6mm</td>
<td>1.829</td>
<td>1.804</td>
<td>0.025</td>
</tr>
</tbody>
</table>

Cover panel: PET (Specific inductive capacity: 3.6)
Finger: Dummy finger (Iron rod 10mm in diameter)

Table 4-1 shows the relation of the capacitance of Touch & Non touch and the panel thickness. This is the simulation data and it suggests the capacitance of the dummy finger becomes worse suddenly from 4mm. It means around 2mm is the maximum thickness for this electrode.

4.2 4x3 14x16mm buttons (Tx:4, Rx:3) with the cover panel thickness 2-4mm

Figure 4-3 14x16mm buttons example
Table 4-2 the relation of the capacitance of Touch & Non touch and the panel thickness

<table>
<thead>
<tr>
<th>Panel thickness</th>
<th>Non touch</th>
<th>touch</th>
<th>difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2mm</td>
<td>2.538</td>
<td>2.248</td>
<td>0.29</td>
</tr>
<tr>
<td>4mm</td>
<td>2.493</td>
<td>2.382</td>
<td>0.111</td>
</tr>
<tr>
<td>6mm</td>
<td>2.468</td>
<td>2.423</td>
<td>0.045</td>
</tr>
</tbody>
</table>

Panel: PET (Specific inductive capacity:3.6)
Finger: Dummy finger (Iron rod 10mm in diameter)

Table 4-2 shows the relation of the capacitance of Touch & Non touch and the panel thickness. The distance between Tx & Rx electrodes is as same as 10mm electrode, but the area is bigger than it so it may achieve 4mm thickness of the panel.
Website and Support

Renesas Electronics Website
http://www.renesas.com/

Inquiries
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## Revision History

<table>
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<th>Rev.</th>
<th>Date</th>
<th>Description</th>
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<tbody>
<tr>
<td>Rev 1.0</td>
<td>2014.12.25</td>
<td>First release</td>
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General Precautions in the Handling of MPU/MCU Products

The following usage notes are applicable to all MPU/MCU 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. 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 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. Unused pins should be handled as described under Handling of Unused Pins in the manual.

2. Processing at Power-on
   The state of the product is undefined at the moment 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 moment 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 moment 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 moment when power is supplied until the power reaches the level at which resetting has been specified.

3. Prohibition of Access to Reserved Addresses
   Access to reserved addresses is prohibited.
   - The reserved addresses are provided for the possible future expansion of functions. Do not access these addresses; the correct operation of LSI is not guaranteed if they are accessed.

4. Clock Signals
   After applying a reset, only release the reset line after the operating clock signal has become stable. When switching the clock signal during program execution, wait until the target clock signal has 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. Moreover, 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.

5. Differences between Products
   Before changing from one product to another, i.e. to a product with a different part number, confirm that the change will not lead to problems.
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