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S5U1C17656T
Touch Key
Reference Material

SEIKO EPSON CORPORATION

Rev.1.0

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Summary

This is reference material for the S5U1C17656T with an S1C17656 mounted to sample the counter values (capacitance equivalent values) that vary according to the touch key capacitance using the I/O ports (PPORT) and 16-bit PWM timer (T16A2), to send the results via the UART, and to display the operation results depending on the touched key to the LCD.

Operating Environment

- S5U1C17656T (SVT17656: Software Evaluation Tool for S1C17656)
  Two dedicated cables (4 pins to 4 pins) are required to connect with ICDmini.
- ICDmini (S5U1C17001H)
  A USB cable is required to connect with a PC.
- PC
  - With GNU17 (S5U1C17001C) development tool installed *
  - With ICDmini USB driver installed
- Latest version FLS17656 (file name: fls17656.elf)
  This file is mandatory for programming the embedded flash memory.
- S1C17656 Touch Key Programming Package (this package)
  - Touch Key Capacitance Variation Visualization Programming Package (s1c17656_touch_oscillo), Excel file with VBA macro included (MeasTouch.xlsm), and Active-X control file (NonComSck.ocx)
  - Touch Key Scan and Key Operation Result LCD Display Programming Package (s1c17656_touch_demo)

* GNU17 V2.3.0 is used for operation checking of this package.

Table of Contents

1. Specifications

The S5U1C17656T (SVT17656) with an S1C17656 mounted samples the counter values (capacitance equivalent values) that vary according to the touch key capacitance using the I/O ports (PPORT) and 16-bit PWM timer (T16A2).

The sample program s1c17656_touch_oscillo samples the counter values equivalent to the touch key capacitance variations at a fixed interval and sends them to the PC via the UART to write to an Excel sheet in conjunction with a VBA macro. The values in the array written to the Excel sheet are graphed, this makes it possible to visualize the changes of the capacitance equivalent values on the time series.

The sample program s1c17656_touch_demo scans the touch key status periodically at a fixed interval using the clock timer (CT) and displays the operation results depending on the touched key to the LCD.

2. Descriptions of the Functions Used

PPORT	P0[5:2], P1[7:4], and P2[3:0]: These 12 ports are assigned for the touch keys and configured to L level output, H level output, or Hi-Z.
T16A2	Used as the counter to determine the touch key capacitance equivalent values.
CT	Used as an interval timer and the clock timer interrupt function is used to scan the touch key status periodically.

The peripheral circuit shown below is used in the s1c17656_touch_oscillo program.

UART	USIN0 and USOUT0 are assigned to P00 and P01 of PPORT, respectively. They are used to communicate with the Excel VBA macro executed on the PC.

The two peripheral circuits shown below are used in the s1c17656_touch_demo program.

LCD	Used to display touch key status on the LCD panel.
SND	Used to output the touch key click sound.

Operating mode — T16A2: Used as the counter to determine the touch key pin capacitance equivalent values.

System clock — OSC3B (4 MHz internal oscillator) is used as the system clock.
OSC1A (32.768 kHz) is also used in s1c17656_touch_demo.

Interrupts — The following description is applied to s1c17656_touch_oscillo.

The following shows the T8 vector number and vector address:
T8 Vector number: 14 (0x0e)
Vector address: 0x8038
The sample program uses the following interrupt:
Timer underflow interrupt

The following shows the UART vector number and vector address:
UART Vector number: 16 (0x10)
Vector address: 0x8040
The sample program uses the following interrupt:
Receive buffer full interrupt

The following description is applied to s1c17656_touch_demo.
The following shows the CT vector number and vector address:
CT Vector number: 7 (0x07)
Vector address: 0x801c
The sample program uses the following interrupts:
32 Hz, 2 Hz, and 1 Hz timer signal interrupts

The following shows the RTC vector number and vector address:
RTC Vector number: 8 (0x08)
Vector address: 0x8020
The sample program uses the following interrupts:
One day and half-day interrupts

3. Principle of Operation

3.1 Principle of Detection

A capacitor with a certain capacitance is formed between two conductors isolated from each other with an insulator (dielectric) such as air or plastic. When an electrode for a sensor pad and ground patterns are placed on a printed circuit board, for example, as the structure shown in Figure 3-1, two capacitors C1 and C2 are formed. In this case, capacitance (C1 + C2) when both capacitors are connected in parallel is obtained between the sensor pad and the ground patterns.

Furthermore, the human body is a good conductor and a large capacitance is generated between the body and ground even if it is isolated from the ground with a high insulative material such as shoes as shown by the fact that static electricity is charged on the body. Therefore, a proximity effect occurs when the body comes near the sensor pad. In other words, touching the dielectric surface of the sensor pad with a finger forms the capacitor C3 on the sensor pad anew and the sensor pad capacitance is increased to (C1 + C2 + C3).

By detecting this capacitance variation, a touch sensor can be configured.

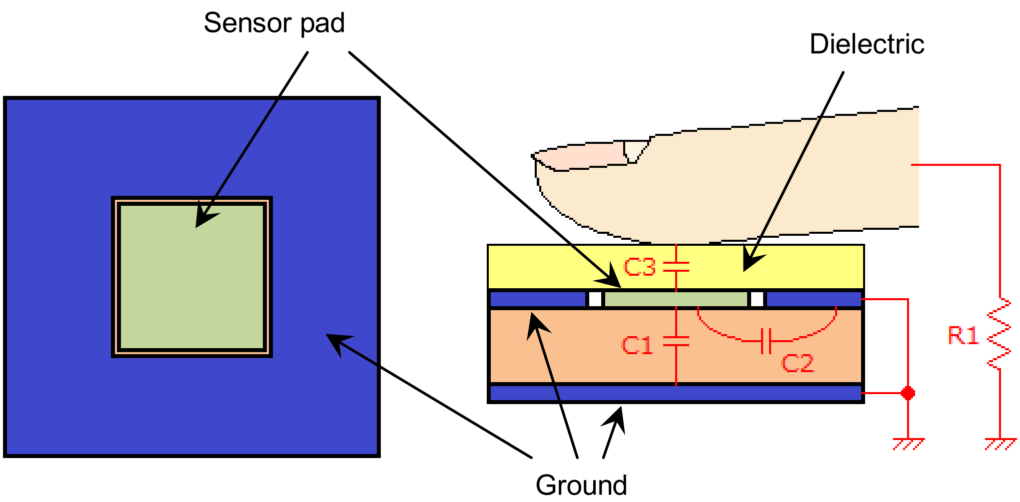

Figure 3-1 Sensor Pad Capacitances (Top View and Section View)

3.2 Method of Detection

This section explains the method of detection using Figure 3-2, Capacitance Detection Circuit Conceptual Diagram, and Figure 3-3, Temporal Change of Detection Waveform.

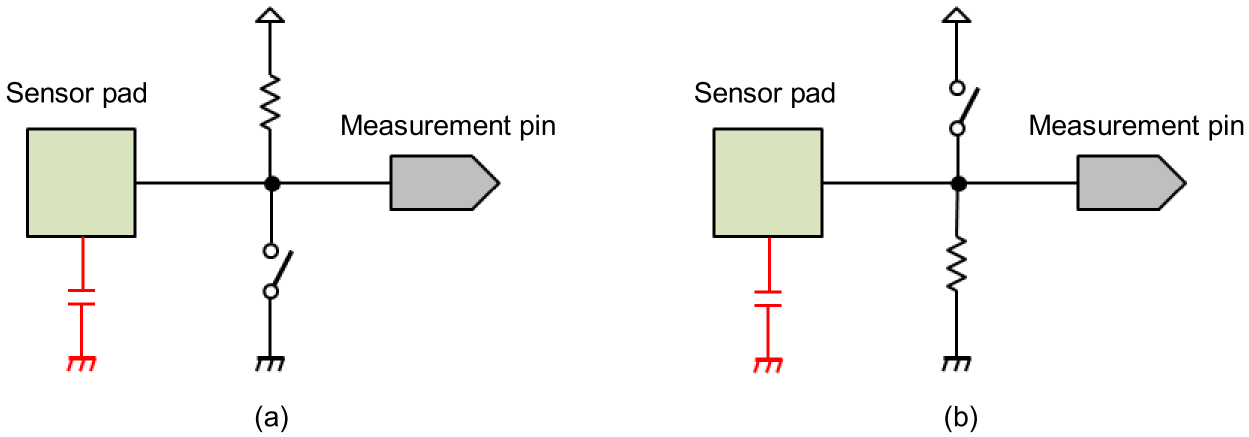

Figure 3-2 Capacitance Detection Circuit Conceptual Diagram

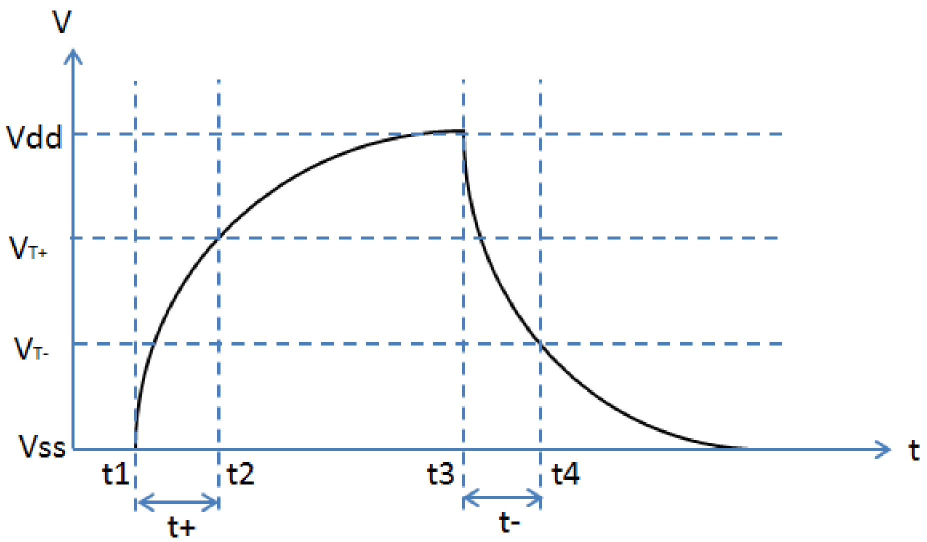

Figure 3-3 Temporal Change of Detection Waveform

There is a capacitive component between the sensor pad and ground shown in Figure 3-2. First, the switch (a) in Figure 3-2 is turned on for a fixed time to discharge the capacitive component completely, and then the switch is turned off. Time t1 in Figure 3-3 indicates that the switch is turned off. After that, the capacitive component is charged through the resistor and the potential at the measurement pin is increased with the time constant τ = CR. A CMOS Schmitt input circuit, in which a voltage equal to or lower than V_{T-} is assumed as L level and a voltage equal to or higher than V_{T+} as H level, is used as the measurement input port in this example. Therefore, the CMOS Schmitt input circuit determines that the input signal is L level until t2 at which the voltage reaches V_{T+}. After that, it determines that the input signal is H level. By measuring the time t+ between t1 and t2, the sensor pad capacitance value can be obtained.

The capacitance can also be measured by making a change to reverse potential.

The switch (b) in Figure 3-2 is turned on for a fixed time to charge the sensor pad capacitive component until the potential reaches Vdd, and then the switch is turned off. Time t3 in Figure 3-3 indicates that the switch is turned off. After that, the capacitive component is discharged through the resistor and the potential at the measurement pin is decreased with the time constant τ = CR. The CMOS Schmitt input circuit determines that the input signal is H level until t4 at which the voltage reaches V_{T-}. After that, it determines that the input signal is L level. By measuring the time t- between t3 and t4, the sensor pad capacitance value can also be obtained.

In this sample program, T16A2 is used to count the times t+ and t-, and PPORT as the switches in Figure 3-2. Turning the switch (a) in Figure 3-2 on and off is realized by setting the PPORT to L level output and Hi-Z, respectively. Similarly, turning the switch (b) on and off is realized by setting the PPORT to H level output and Hi-Z, respectively. T16A2 is used to obtain the capacitance equivalent values by connecting a sensor pad to a PPORT input and counting the time until the port voltage level is changed.

Refer to Figure 3-4 in the next section that shows the PPORT, which outputs a H/L level while the sensor pad being touched with a finger is detected, by surrounding with a double-line frame. It will help you to understand these operations.

3.3 Detection Circuit

Figure 3-4 shows an example of the detection circuit that consists of the PPORT and T16A2 embedded in the S1C17656.

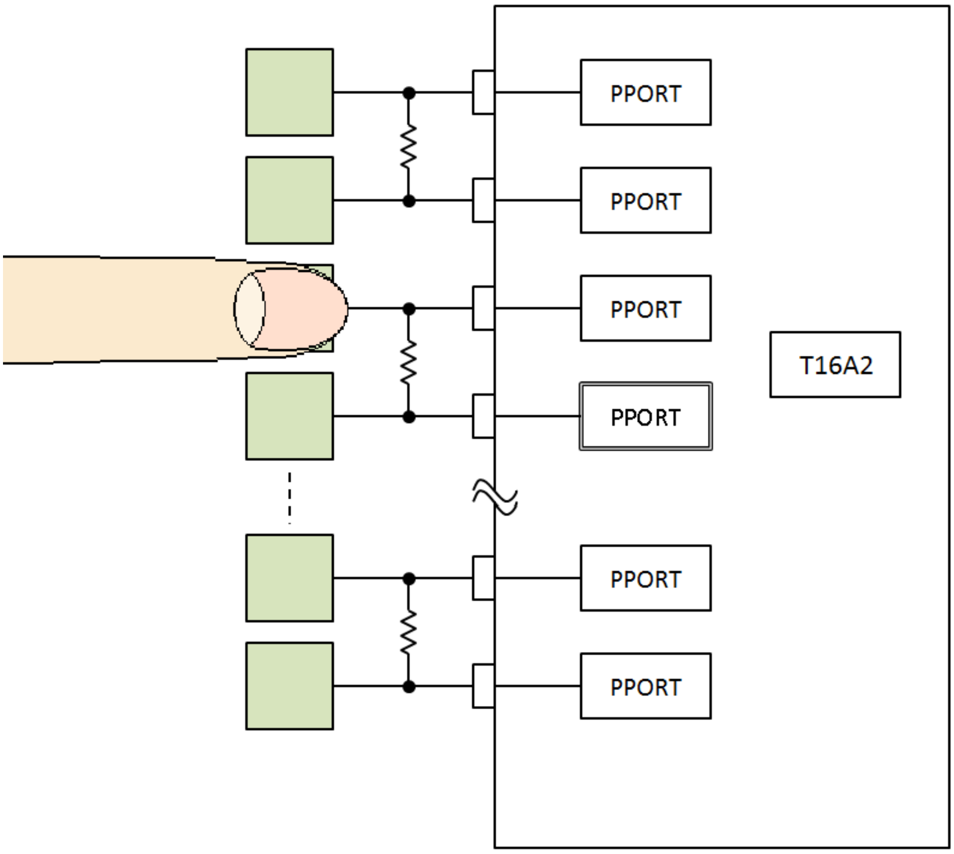

Figure 3-4 Detection Circuit Example

The touch key is formed in a pair and a resistor is attached between the keys. The resistance value can be determined as shown below by taking the PPORT leakage current range (I_{LEAK} = ±150 nA) of the S1C17 Series microcontrollers and the average Schmitt input threshold voltage (V_{T+} = 0.7Vdd, V_{T-} = 0.3Vdd) into account.

If assuming that the touch key has a 12 mm x 12 mm square shape, an FR-4 glass epoxy board having the thickness d = 1.2 mm is used as the printed circuit board, and the touch key is a simple parallel plate capacitor, the capacitance C is calculated in the equation shown below by setting the parameters as footprint S = 144 mm^2, specific inductive capacity ε_r = 4.7, dielectric constant under a vacuum ε_0 = 8.855 x 10^{-12} F/m.

$$C = \frac{\varepsilon_r \varepsilon_0 S}{d} = \frac{4.7 \times 8.855 \times 10^{-12} \times 144 \times 10^{-6}}{1.2 \times 10^{-3}} = 5.0\text{pF}$$

The following calculations are performed by focusing that the touch key voltage changes from Vss to V_{T+} within the period t+ between t1 and t2 as shown in Figure 3-3.

As the equation below shows, the voltage V of the detection waveform changes according to the elapsed time t from t1 due to the effect of the time constant CR found from the touch key capacitance C and the resistance value R.

$$V = Vdd \times \left(1 - \exp\left(-\frac{1}{CR} \cdot t\right)\right)$$

The above equation can be converted as follows:

$$R = -\frac{t}{\ln\left(1 - \frac{V}{Vdd}\right)} \cdot \frac{1}{C}$$

When time t+ has elapsed, the voltage changes to $V = V_{T+} = 0.7Vdd$.

$$R = -\frac{t+}{\ln\left(1 - \frac{0.7 \cdot Vdd}{Vdd}\right)} \cdot \frac{1}{5.0 \times 10^{-12}}$$

$$= 1.66 \times 10^{11} \cdot t+$$

If t+ is substituted with 100 cycles of the 4 MHz clock input to T16A2,

$$R = 1.66 \times 10^{11} \cdot t+$$

$$= 1.66 \times 10^{11} \cdot \frac{100}{4 \times 10^{6}}$$

$$= 4.15M\Omega$$

Leakage current of the S1C17 Series microcontrollers is within the range of $I_{LEAK} = \pm 150$ nA. If this value is converted into a resistance value at Vdd = 3.3 V,

$$R = \frac{V}{I} = \frac{3.3}{150 \times 10^{-9}}$$

$$= 22M\Omega$$

Therefore, 4.15 MΩ calculated as above is sufficiently smaller resistance than that of leakage current and you may judge that this sensing method is practical.

Although the calculated R value is 4.15 MΩ, an E24 series resistance value, such as 4.7 MΩ, 5.1 MΩ, or 5.6 MΩ, is suited to practical use as they can easily be obtained.

However, the actual C value is larger than 5.0 pF since a capacitance resulting from routing of wiring is added even though the board pattern is designed so that the capacitance will be smaller than the value calculated as a parallel plate capacitor (refer to the Board Design chapter for more information). Therefore, the T16A2 counter value in untouched status will normally be larger than 100.

Furthermore, the same results can be obtained if the above calculations are performed by focusing that the touch key voltage changes from Vdd to V_{T-} within the period t- between t3 and t4 as shown in Figure 3-3.

4. Examples of Capacitance Equivalent Value Measurement Results

As shown with the detection waveform in Figure 3-3, the touch key capacitance equivalent values can be obtained from one of the two measurement periods t+ and t-. Using both results measured in a very short time suppresses influence caused by noise. The touch key status can be sensed more clearly by performing moving average processing. For more information, refer to the “S1C17W22/S1C17W23 Touch Key Application Note.”

Figures 4-1 to 4-5, which were obtained under different conditions, show the plots of the differences between 1,000 data that were sampled at a 30 ms interval and the average value of the sum of the capacitance equivalent values t+ and t-. There are distinctive differences between the plots (Figures 4-1 and 4-2) when the keys were touched with a finger and the plots (Figures 4-3 to 4-5) when an other parts of the keys were touched, this shows that the program can detect touches on the keys with a finger.

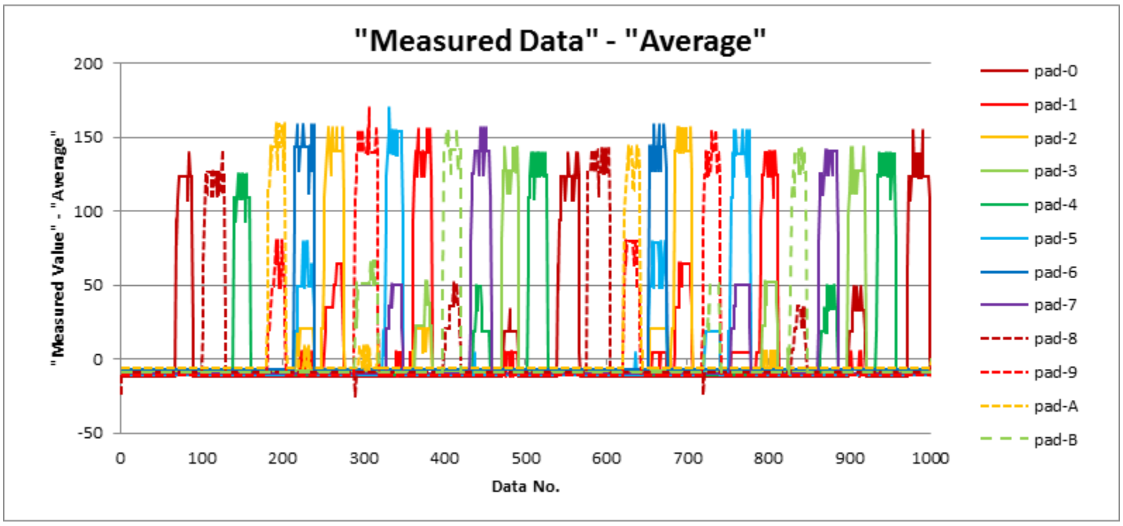

Figure 4-1 Example of Measurement Result (when keys were securely touched with a finger)

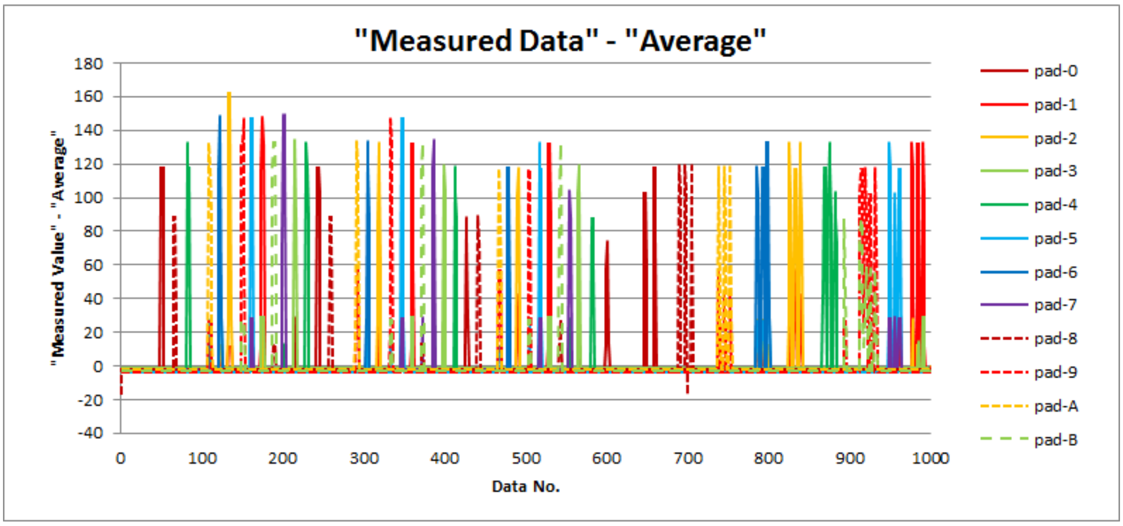

Figure 4-2 Example of Measurement Result (when keys were lightly touched with a finger)

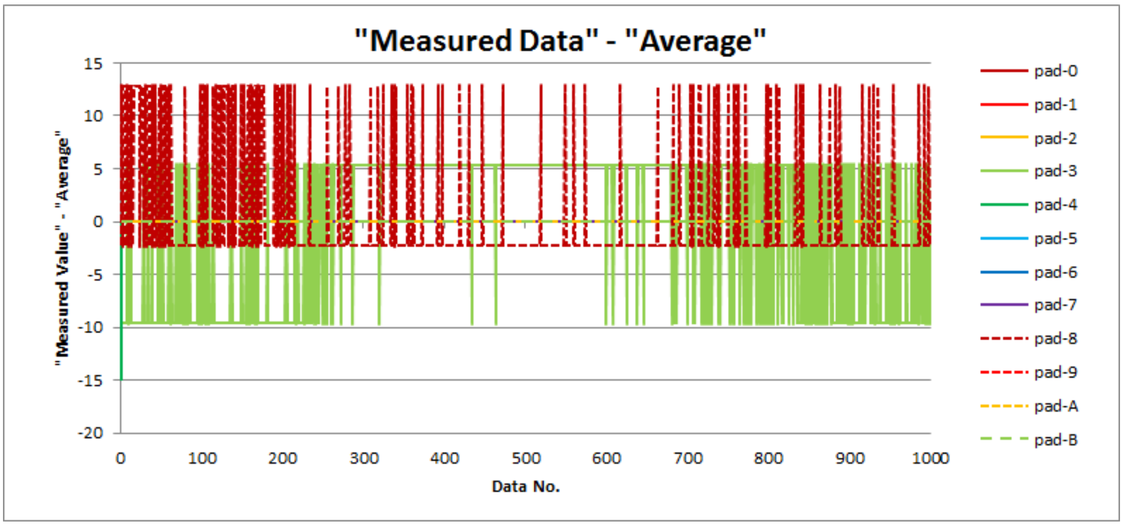

Figure 4-3 Example of Measurement Result (when both sides of the board were held with a hand)

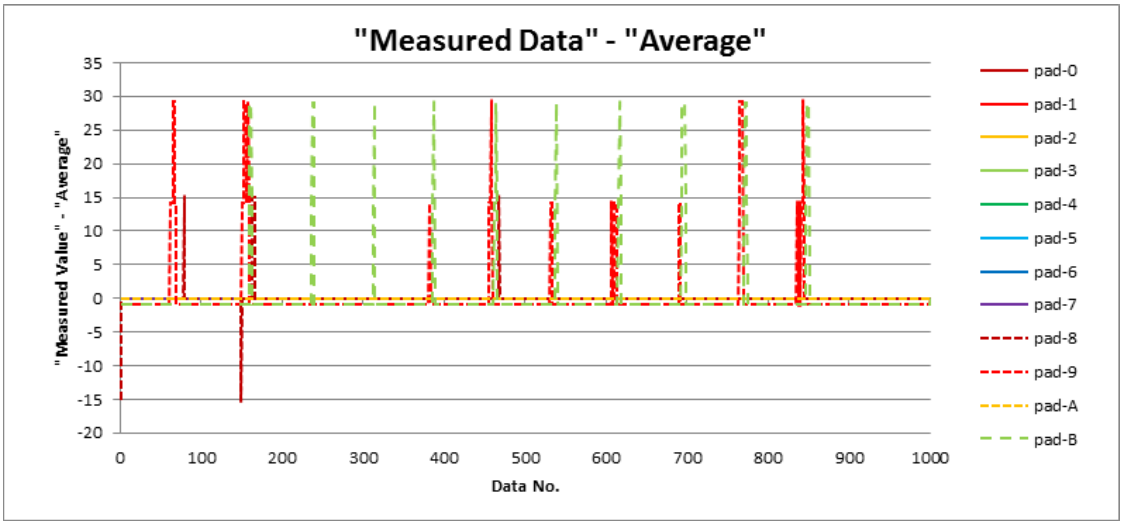

Figure 4-4 Example of Measurement Result (when GNDs at the left and right side on the front surface of the board were alternately touched with a finger)

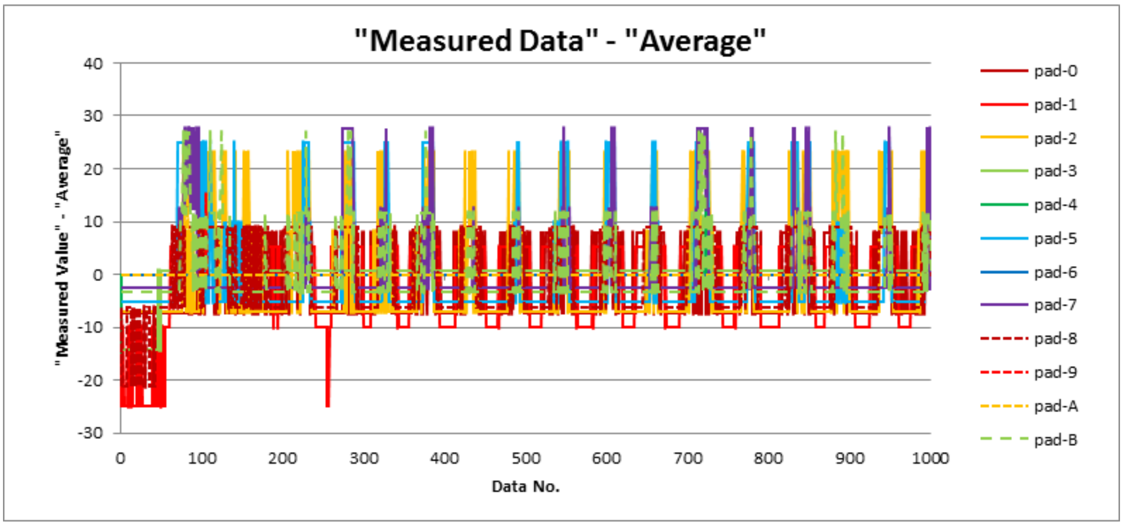

Figure 4-5 Example of Measurement Result (when the finger that touched the back surface of the board was wiggled)

5. Board Design

Figure 5-1 shows the conductor pattern of the S5U1C17656T (SVT17656) board.

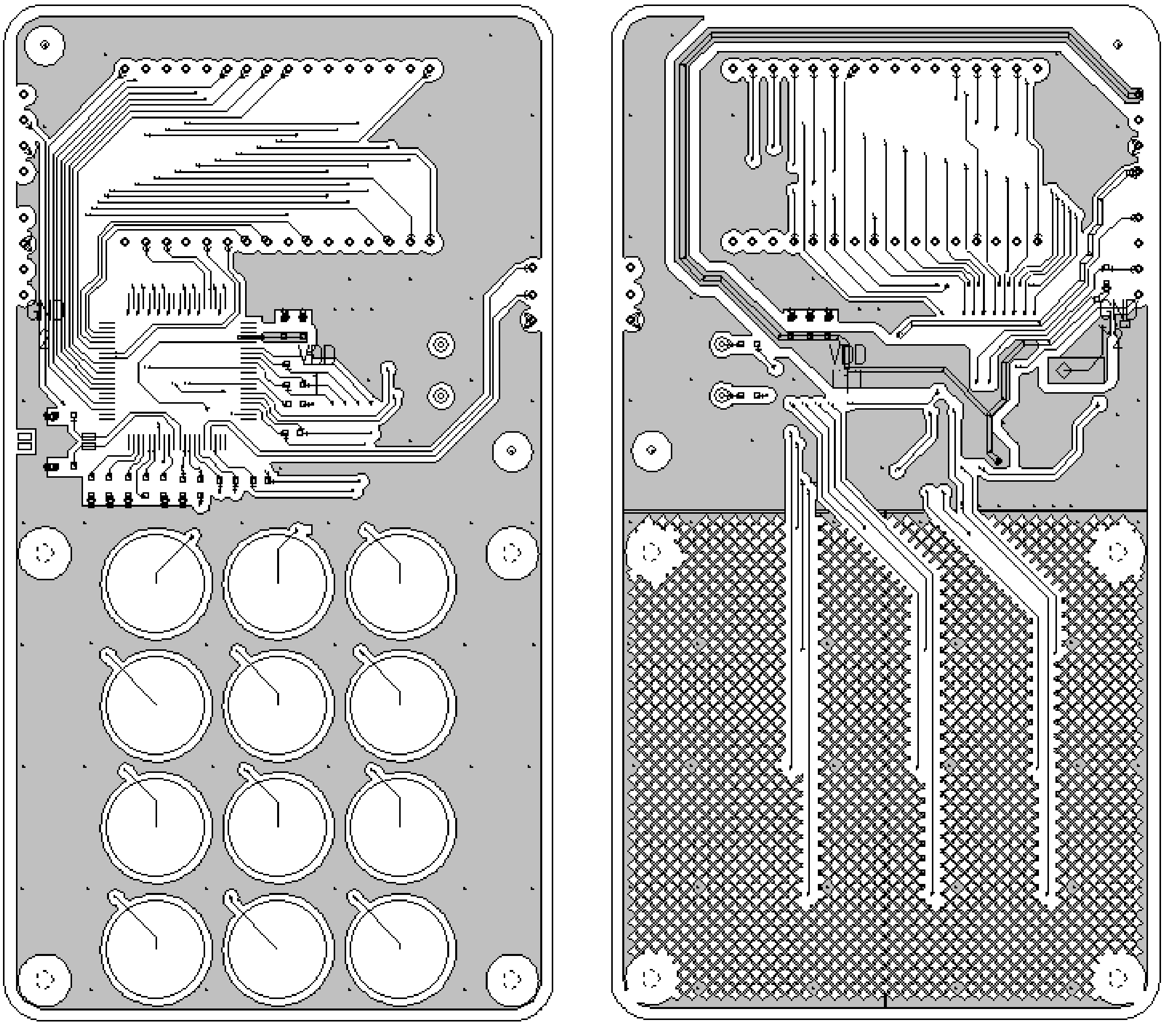

Figure 5-1 Conductor Pattern of the S5U1C17656T Board (Front and Back)

The conductor pattern layout of the S5U1C17656T (SVT17656) board was designed by following the description in the “S1C17W22/S1C17W23 Touch Key Application Note.” For more information, refer to the document.

6. Software Description

6.1 s1c17656_touch_oscillo

This s1c17656_touch_oscillo software runs in conjunction with Excel and a VBA macro. It samples the counter value (capacitance equivalent value) that varies according to the touch key capacitance in certain cycles, and sends the counter values to the PC via the UART to write it to an Excel sheet. The following describes this software.

6.1.1 Operation Procedures

Importing project

(1) Launch IDE and import the s1c17656_touch_oscillo project.

* For the import method, refer to Chapter 3, "Software Development Procedures," in the S5U1C17001C Manual.

Building

(1) Build the s1c17656_touch_oscillo project using IDE.

Preparation for using Excel VBA

(1) Copy the MeasTouch folder to the desktop. This folder contains the Excel file MeasTouch.xlsm and the Active-X control file NonComSck.ocx. Note that the Active-X control file MSCOMM32.OCX provided by Microsoft Corporation is not included in this package. Please get it from a reliable download site and copy to the MeasTouch folder.

(2) Click [Start] - [All Programs] - [Accessories]. Right-click [Command Prompt] and select [Run as administrator] to open the [Administrator: Command Prompt] window.

(3) Execute "cd C:\Desktop\MeasTouch," "regsvr32.exe MSCOMM32.OCX," and "regsvr32.exe NonComSck.ocx" to enable the Active-X control files.

(4) If something goes wrong with the operation above, copy the Active-X control files to C:\Windows\System32, and then execute "cd C:\Windows\System32," "regsvr32.exe MSCOMM32.OCX," and "regsvr32.exe NonComSck.ocx."

Connection and power up

(1) Connect the S5U1C17656T (SVT17656) to the ICDmini and then it to the PC with a USB cable.

(2) Connect between UART Ch.0 of the S5U1C17656T (SVT17656) and the serial connector on the PC in which Excel VBA is executed (in general, USB I/F is used for serial communication. See sheet "Note" in the Excel VBA file for commercial cables that can be used). When using a PC with sufficient processing ability, IDE and Excel can be run simultaneously on that PC, otherwise two PCs should be used.

(3) Reset the S5U1C17656T (SVT17656) and ICDmini.

Excel VBA execution

(1) Double-click the Excel file MeasTouch.xlsm to execute the VBA.

Execution

(1) Edit the path to fls17656.elf described in the command file s1c17656_touch_oscillo_gnu17IDE.cmd as necessary. By default, it is set as C:/EPSON/GNU17/mcu_model/17656/fls/fls17656.elf.

* For how to edit a command file, refer to the S5U1C17001C Manual.

(2) Execute the s1c17656_touch_oscillo project using IDE.

(3) Operate Excel VBA to start touch key scan.

6.1.2 How to Use MeasTouch.xlsm

Figure 6-1 shows the appearance of MeasTouch.xlsm.

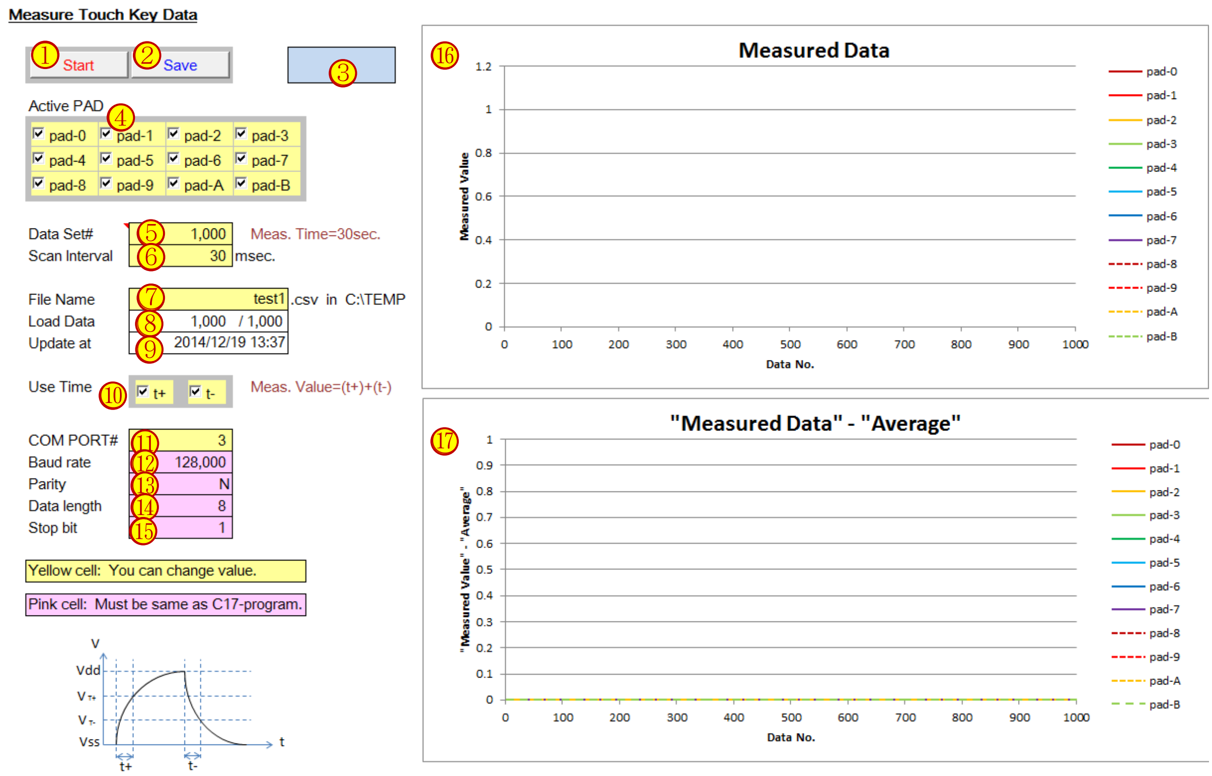

Figure 6-1 Appearance of MeasTouch.xlsm

① Measurement start button	Starts measurement of touch key capacitance equivalent values.
② Data save button	Saves the measured data in CSV format.
③ Status indicator	Indicates the measurement or data saving status.
④ Measuring touch key selector	Selects the touch keys to be measured.
⑤ Number of sampling data	Sets the number of data to be sampled.
⑥ Scan interval	Sets the interval between data samplings.
⑦ Save file name	Specifies the name of the file for storing measured data.
⑧ Number of data sampled	Displays the successively updated number of data sampled.
⑨ Data sampling date and time	Displays the date and time at which the latest data is sampled.
⑩ t+/t- selector	Selects the period to be converted into capacitance equivalent values from t+, t-, or both.
⑪ COM port number	Specifies the COM port number used for serial communication.
⑫ Baud rate	Specifies the baud rate for serial communication.
⑬ Parity	Enables serial data parity addition/check with even or odd specified, or disables it.
⑭ Data length	Specifies the serial data length.
⑮ Stop bit	Specifies the number of stop bits for serial communication.

⑯ Measured data graph	Draws a graph representing measured data on the vertical axis.
⑰ Measured data - average graph	Draws a graph representing difference between measured data and the average value on the vertical axis.

Note 1) This sample program assumes two-wire serial communication using the UART. On the other hand, the S5U1C17656T (SVT17656) is designed to send data one-sidedly. Therefore, communication data will be lost if the receive buffer on the PC cannot follow. The program detects this error by checking if the high- or low-order data is out of the range. If a such an error message is displayed, try to avoid it by changing the ④, ⑤, and ⑥ setting values.

Note 2) Normally, it is not necessary to change the serial communication parameters ⑪, ⑫, ⑬, ⑭, and ⑮. Note that the related part of s1c17656_touch_oscillo must be modified if these parameters are changed.

Note 3) The graphs ⑯ and ⑰ are drawn after all data has been loaded. While data are being sampled, they are not updated successively and the graphs retain the previous plot.

Note 4) The reference clock for communication via the UART is generated from the OSC3B (4 MHz) clock of the S5U1C17656T (SVT17656). The OSC3B is a CR oscillator that has clock frequency variation, therefore, communication timing deviations may occur depending on the operating environment. If a serial communication error has occurred, try to adjust the configuration parameters to avoid error.

6.2 s1c17656_touch_demo

This section describes the s1c17656_touch_demo software that displays the touch key status and capacitance equivalent values as a touch key demonstration.

6.2.1 Operation Procedures

Importing project

(1) Launch IDE and import the s1c17656_touch_demo project.

* For the import method, refer to Chapter 3, "Software Development Procedures," in the S5U1C17001C Manual.

Building

(1) Build the s1c17656_touch_demo project using IDE.

Connection and power up

(1) Connect the S5U1C17656T (SVT17656) to the ICDmini and then it to the PC with a USB cable. If the same system as s1c17656_touh_oscillo is used, disconnect the serial communication cable for interfacing with the UART.

(2) Reset the S5U1C17656T (SVT17656) and ICDmini.

Execution

(1) Edit the path to fls17656.elf described in the command file s1c17656_touch_demo_gnu17IDE.cmd as necessary. By default, it is set as C:/EPSON/GNU17/mcu_model/17656/fls/fls17656.elf.

* For how to edit a command file, refer to the S5U1C17001C Manual.

(2) Execute the s1c17656_touch_demo project using IDE.

(3) Step (2) starts a demonstration of touch key operation.

6.2.2 Outline of Sample Program Operations

1. Touch keys

The touch keys consist of 12 keys: *N* (Enter), ← (Back Space), and 0 to 9 number keys.

2. LCD panel

The LCD panel has the following display items: six digits of 7-segment numbers, a dot, a three-level battery remaining quantity indicator, an "L" for indicating lock state, six bars for indicating the remaining time of the displayed number to be valid for 1 minute in 10-second units as a security token, and two colons.

3. Switching operating mode

Note that a hand or a part of the body must be kept away from the board while the "INIT #" display is being counted down after power is turned on, as the program is correcting the touch key background level information.

Table 6-1 Switching Operating Mode

Key	Function and operation
N	This key is used to cancel lock mode. When the system is in lock mode in which "L" is displayed on the LCD panel, touch the *N* key two seconds or more to display "KEY=." Then touch the 1, 2, 3, 4, 5, and *N* keys sequentially within 30 seconds. Lock mode is canceled and the "L" display on the LCD panel goes off. If a wrong keyword is entered or the valid keyword is not entered within 30 seconds, lock mode is not canceled. If two minutes has elapsed without touching any key, the system enters lock mode.
←	This key functions as a backspace key to cancel the last entered digit while a number is being entered. If this key is touched when the cursor is located at the left end, the command being currently executed is canceled.
0	This key initiates the help display to show the command of each key.
1	This key displays a number and remaining time indicator bars similar to a security token. The displayed number is updated on a random basis in 60-second cycles if another command is not executed. (Token mode [Note 1])
2	This key displays the current time obtained from the RTC. (Current time display mode [Note 1])
3	This key displays the date for about four seconds, then transits to the current time display mode of the 2 key.
4	This key initiates the operation that imitates a challenge response authentication. In this mode, entering a number and touching the *N* key displays a number valid for 60 seconds and transits to token mode of the Key 1 function after 60 seconds has elapsed. If this key entering operation cannot be completed within 30 seconds, the operation mode automatically transits to token mode.
5	This key intentionally causes the CPU to hang. The WDT issues a reset and the system is rebooted from the initialization. At this time the RTC retains the date and time. Note, however, that a delay of about 1.5 seconds occurs, as the OSC1A oscillator stops oscillating during rebooting.
6	This key enables/disables the key click sound to be output.
7	This key sets a date and time. For example, to set it to 2015/01/09 12:34:56, enter 150109123456. If the entering operation has started but cannot be completed within 60 seconds, the system returns to the operation mode immediately before this key was touched. If nothing is entered for 120 seconds, the LCD displays "SLEEP" and then the CPU enters HALT mode. In this case, the system must be restarted from the initialization by issuing a reset or taking the battery out once and then putting it back.
8	This key changes the seed of random numbers. Enter a number and then touch the *N* key. If the entering operation cannot be completed within 30 seconds, the system returns to the operation mode immediately before this key was touched.
9	This key is used to set the system into lock state manually.

Note 1) The system can return to one of the two operation modes previously entered when a command has not been completed within the time limit. Therefore, the display of one of these modes continues in lock state.

6.2.3 Estimate of Battery Life

A battery life when touch keys are driven with a coin type battery is estimated as follows based on the actual consumed current value measured by executing the sample program s1c17656_touch_demo with the S5U1C17656T (SVT17656). The calculation conditions are shown below.

- Coin type battery: CR2023 (nominal capacity = 220 mAh) One
- Touch key read time: 30 minutes per day

During detecting a touched key in unlock state, the sample program scans all 12 keys 32 times per second. In lock state, it scans only one touch key twice per second. The average current consumption in each state was measured as shown below.

- In unlock state: 32.9 µA
- In lock state: 11.2 µA

From these results, the operation available time by the battery above is calculated as shown below.

$220 / ((32.9 \times (0.5 / 24) + 11.2 \times (23.5 / 24)) / 1000) / 24 / 365 = 2.15$ years

Revision History

Attachment-1

Rev. No.	Date	Page	Category	Contents
Rev 1.0	2015/03/13	All	new	New establishment

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