RL78/G14
Measuring Distance to an Object with Ultrasonic Sensor

Introduction
This application note describes an example to measure distance to an object with ultrasonic sensor. The timer array unit and the serial interface IICA are used to control ultrasonic sensor and LCD character display module.

Target Device
RL78/G14

When applying the sample program covered in this application note to another microcomputer, modify the program according to the specifications for the target microcomputer and conduct an extensive evaluation of the modified program.
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1. Specifications

In this application note, measure distance to an object with ultrasonic sensor in each interval time. The Timer Array Unit (TAU) is used to control ultrasonic sensor. Time-of-Flight (TOF) value output by ultrasonic sensor is converted to distance. The distance is displayed on the LCD character display with Serial Interface IICA. Table 1.1 shows the required peripheral functions and their uses.

<table>
<thead>
<tr>
<th>Peripheral Functions</th>
<th>Purposes</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAU00</td>
<td>To generate pulse wave that activates ultrasonic sensor.</td>
</tr>
<tr>
<td>TAU01</td>
<td>To capture sensor output</td>
</tr>
<tr>
<td>IICA0</td>
<td>To communicate with the LCD character display</td>
</tr>
</tbody>
</table>

Table 1.1 Used Peripheral Functions and Purposes

![Figure 1.1 Outline of Distance Measuring System](image-url)
1.1 Method of Controlling an Ultrasonic Sensor.

An ultrasonic sensor used in this application note consists of a transmitting speaker and a receiving microphone. The sensor outputs the time sound travels between the sensor and an object.

For example, when a trigger signal is input to the sensor as shown in Figure 1.2, the sensor outputs an output signal which width has proportional to the distance to the object.

To generate the trigger signal, the "square wave output" function of the timer array unit is used. And to measure the high-level width output by the sensor, the "input signal high-/low-level width measurement" function is used. Also, to reduce noise, calculate moving average of the measurement result.

![Figure 1.2 Trigger Signal and Output Echo Signal](image)

1.2 Converting Time to Distance

The Euclidean distance between the ultrasonic sensor and the target surface \( d \ [\text{m}] \) can be obtained by converting \( t_{\text{echo}} \ [\text{s}] \) using following expressions (1.1) and (1.2). The sound velocity \( c \) is assumed to be constant at 340.29 \([\text{m/s}]\).

\[
\begin{align*}
    d \ [\text{m}] &= \frac{t_{\text{echo}} \ [\text{s}]}{2} c, \\
    c &= 340.29 \ [\text{m/s}] \\
    t_{\text{echo}} \ [\text{s}] &= \frac{\text{TD R01}}{f_{\text{CLK}} \ [\text{Hz}]} 
\end{align*}
\]  

(1.1)  

(1.2)

1.3 Format of LCD Character Display

For the LCD character display, I2C connection and 16 × 2 display HD44780 compatible products are used.

The distance measured by the sensor is displayed in the format shown in Figure 1.3. (display range is 0 to 999.9 cm)

![Figure 1.3 Display Pattern of the LCD Character Display](image)
2. Conditions of Operation Confirmation Test

The sample code with this application note runs properly under the conditions below.

**Table 2.1 Operation Confirmation Conditions**

<table>
<thead>
<tr>
<th>Items</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCU</td>
<td>RL78/G14 (R5F104PJA)</td>
</tr>
<tr>
<td>Operating frequencies</td>
<td>High-speed on-chip oscillator (HOCO) clock: 32 MHz</td>
</tr>
<tr>
<td></td>
<td>CPU/peripheral hardware clock: 32 MHz</td>
</tr>
<tr>
<td>Operating voltage</td>
<td>5.0V</td>
</tr>
<tr>
<td></td>
<td>LVD operations (VLVD): reset mode TYP. 2.75 [V]</td>
</tr>
<tr>
<td></td>
<td>Rising edge 2.76 to 2.87 [V]</td>
</tr>
<tr>
<td></td>
<td>Falling edge 2.70 to 2.81 [V]</td>
</tr>
<tr>
<td>Integrated development environment (CS+)</td>
<td>CS+ for CC V7.00.00 from Renesas Electronics Corp.</td>
</tr>
<tr>
<td>C compiler (CS+)</td>
<td>CC-RL V1.07.00 from Renesas Electronics Corp.</td>
</tr>
</tbody>
</table>
3. Hardware

3.1 Example of Hardware Configuration

Figure 3.1 shows an example of the hardware configuration used in this application note.

Note 1: This simplified circuit diagram was created to show an overview of connections only. When actually designing your circuit, make sure the design includes sufficient pin processing and meets electrical characteristic requirements. (Connect each input-only port to \( V_{DD} \) or \( V_{SS} \) through a resistor.)

Note 2: Connect any pins whose name begins with EVSS to VSS and any pins whose name begins with EVDD to VDD, respectively.

Note 3: VDD must be held at not lower than the reset release voltage (VLVD) that is specified as LVD.

3.2 Used Pins

Table 3.1 shows list of used Pins and assigned functions.

<table>
<thead>
<tr>
<th>Pin Name</th>
<th>Input/Output</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCLA0</td>
<td>Output</td>
<td>I(^2)C serial clock</td>
</tr>
<tr>
<td>SDAA0</td>
<td>Output</td>
<td>I(^2)C serial data bus</td>
</tr>
<tr>
<td>TO00</td>
<td>Output</td>
<td>Trigger signal for ultrasonic sensor</td>
</tr>
<tr>
<td>TI01</td>
<td>Inpt</td>
<td>Output signal from ultrasonic sensor</td>
</tr>
</tbody>
</table>
4. Software Explanation

4.1 Operation Outline

In the sample program in this application note, after initializing the timer array unit Serial Interface IICA, MCU shifts to HALT mode.

MCU releases HALT mode by INTTM00 or INTTM01 interrupt. If capturing of sensor output have been completed, display the calculated distance to LCD character display, then shifts to HALT mode. In other case, just shifts to HALT mode.

1. Initialize the Timer Array Unit

<Conditions for setting channel 0>

- Timer operation mode is set to Interval Timer.
- Interval time is set to 100 us by the Timer data register (TDR).
- Timer interrupt (INTTM00) from timer channel 0 is used. (INTTM00)
- Timer interrupt is generated when counting is started (INTTM00)

<Conditions for setting channel 1>

- Timer operation mode is set to “capture & one-count” mode.
- Set the measurable pulse interval to 2 us < TI01 < 131.071 ms.
- Enable the noise filter of TI01
- Both edges (to measure high-level width)
- Select TI01 pin input edge to both edge for measuring high-level width
- Timer interrupt is generated when counting is started (INTTM01)

2. Initialize serial interface IICA

- Set the transfer mode to single master.
- Select the count clock to fCLK / 2.
- Set the local address to 10H.
- Select the normal mode as the operation mode.
- Set the transfer clock frequency to 50000 Hz.

3. Initialize LCD display pattern.

4. MCU shifts to HALT mode.

5. MCU releases HALT mode by interrupts.

6. If capturing of sensor output have been completed, display the calculated distance to LCD character display,

7. Repeat steps 4 to 6 above.
4.2 Option Byte Settings

Table 4.1 lists the option byte settings.

<table>
<thead>
<tr>
<th>Address</th>
<th>Setting Value</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>000C0H/010C0H</td>
<td>1110 1111B</td>
<td>Operation of Watchdog timer is stopped (counting is stopped after reset.)</td>
</tr>
<tr>
<td>000C1H/010C1H</td>
<td>0111 1111B</td>
<td>LVD operations (VLVD): reset mode TYP. 2.75 [V] Rising edge 2.76 to 2.87 [V] Falling edge 2.70 to 2.81 [V]</td>
</tr>
<tr>
<td>000C2H/010C2H</td>
<td>1110 1000B</td>
<td>HS mode, High-speed on-chip oscillator clock: 32 MHz</td>
</tr>
<tr>
<td>000C3H/010C3H</td>
<td>1000 0100B</td>
<td>On-chip debugging enabled</td>
</tr>
</tbody>
</table>

4.3 Constants

Table 4.2 lists the constants that are used in this sample program.

<table>
<thead>
<tr>
<th>Constant Name</th>
<th>Setting Value</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOVE_AVERAGE_NUM</td>
<td>5</td>
<td>number of samples to calculate moving average</td>
</tr>
<tr>
<td>DISTANCE_SENSOR_WAIT_MSEC</td>
<td>250</td>
<td>interval time of activating the ultrasonic sensor</td>
</tr>
<tr>
<td>LCD_SLAVE_ADDR</td>
<td>A0H</td>
<td>I2C slave address for the LCD character display module</td>
</tr>
</tbody>
</table>
4.4 Global Variables

Table 4.3 lists the global variables.

<table>
<thead>
<tr>
<th>Type</th>
<th>Variable Name</th>
<th>Contents</th>
<th>Functions used in</th>
</tr>
</thead>
<tbody>
<tr>
<td>uint32_t</td>
<td>g_distance_echo_sum</td>
<td>Sum of high-level width measurement result for calculate moving average.</td>
<td>user_main(), r_tau0_channel1_interrupt()</td>
</tr>
<tr>
<td>uint8_t</td>
<td>g_f_distance_updated</td>
<td>Whether high-level width measurement is completed or not</td>
<td>user_main(), r_tau0_channel1_interrupt()</td>
</tr>
</tbody>
</table>

4.5 Functions

Table 4.4 lists the functions.

<table>
<thead>
<tr>
<th>Function Name</th>
<th>Outline</th>
</tr>
</thead>
<tbody>
<tr>
<td>main</td>
<td>Main processing</td>
</tr>
<tr>
<td>user_main</td>
<td>User main processing</td>
</tr>
<tr>
<td>R_MAIN_UserInit</td>
<td>Main initial setting</td>
</tr>
<tr>
<td>calc_distance</td>
<td>Convert the time it took a sound to travel between objects to distance.</td>
</tr>
<tr>
<td>LCD_Init</td>
<td>LCD character display initialization function</td>
</tr>
<tr>
<td>write_command</td>
<td>Send a control command to the LCD character display</td>
</tr>
<tr>
<td>write_data</td>
<td>Send a display data to the LCD character display</td>
</tr>
<tr>
<td>wait_msec</td>
<td>Wait for n [ms] set by argument</td>
</tr>
<tr>
<td>wait_1msec</td>
<td>Wait for 1 [ms]</td>
</tr>
</tbody>
</table>
4.6 Function Specifications
This part describes function specifications of the sample code.

<table>
<thead>
<tr>
<th>Function Name</th>
<th>r_main</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outline</td>
<td>Main processing</td>
</tr>
<tr>
<td>Header</td>
<td>None</td>
</tr>
<tr>
<td>Declaration</td>
<td>None</td>
</tr>
<tr>
<td>Description</td>
<td>Call R_MAIN_UserInit(), user_main()</td>
</tr>
<tr>
<td>Arguments</td>
<td>None</td>
</tr>
<tr>
<td>Return value</td>
<td>None</td>
</tr>
<tr>
<td>Remarks</td>
<td>None</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function Name</th>
<th>user_main</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outline</td>
<td>User main processing</td>
</tr>
<tr>
<td>Header</td>
<td>None</td>
</tr>
<tr>
<td>Declaration</td>
<td>static void user_main(void);</td>
</tr>
<tr>
<td>Description</td>
<td>Shift MCU to HALT mode after start timer array unit channel 0 and 1.</td>
</tr>
<tr>
<td></td>
<td>Transcend display data to LCD character display in each time the high-level width measurement completed.</td>
</tr>
<tr>
<td>Arguments</td>
<td>None</td>
</tr>
<tr>
<td>Return value</td>
<td>None</td>
</tr>
<tr>
<td>Remarks</td>
<td>None</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Function Name</th>
<th>R_MAIN_UserInit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outline</td>
<td>Main initial setting</td>
</tr>
<tr>
<td>Header</td>
<td>None</td>
</tr>
<tr>
<td>Declaration</td>
<td>static void R_MAIN_UserInit(void);</td>
</tr>
<tr>
<td>Description</td>
<td>Enable interrupt processing by the EI instruction.</td>
</tr>
<tr>
<td></td>
<td>Call LCD_Init().</td>
</tr>
<tr>
<td>Arguments</td>
<td>None</td>
</tr>
<tr>
<td>Return value</td>
<td>None</td>
</tr>
<tr>
<td>Remarks</td>
<td>None</td>
</tr>
</tbody>
</table>
Function Name: lcd_init
Outline: LCD character display initialization function
Header: lcd.h
Declaration: void LCD_Init(void);
Description: Initialize LCD character display
Arguments: None
Return value: None
Remarks: None

Function Name: calc_distance
Outline: Convert time to distance
Header: None
Declaration: uint16_t calc_distance(uint16_t tdr);
Description: Convert the time it took a sound to travel between two objects to distance.
Arguments: tdr Measurement result of high-level width (TDR register value)
Return value: distance Distance to the object [mm]
Remarks: None

Function Name: write_command
Outline: Control command send function to LCD character display
Header: lcd.h
Declaration: void write_command(uint8_t command)
Description: Send a control command to the LCD character display
Arguments: command Control command
Return value: None
Remarks: None

Function Name: write_data
Outline: Display data send function to LCD character display
Header: lcd.h
Declaration: void write_data(uint8_t* data, uint8_t data_num)
Description: Send display data to the LCD character display
Arguments: data Address of data buffer
data_num Size of data [Byte]
Return value: None
Remarks: None
Outline: None
### Function Name: `wait_1msec`

**Outline**: Wait for 1 millisecond @fCLK=32MHz

**Header**: None

**Declaration**: `void wait_1msec(void);`

**Description**: None

**Arguments**: None

**Return value**: None

**Remarks**: None

### Function Name: `wait_msec`

**Outline**: Wait for n milliseconds @fCLK=32MHz

**Header**: None

**Declaration**: `void wait_msec(uint16_t msec);`

**Description**: None

**Arguments**: `msec` Wait time [ms]

**Return value**: None

**Remarks**: None

### Function Name: `r_tau0_channel0_interrupt`

**Outline**: Interrupt handler of TAU00

**Header**: None

**Declaration**: `static void __near r_tau0_channel0_interrupt(void);`

**Description**: Interrupt handler of TAU00.

**Arguments**: None

**Return value**: None

**Remarks**: None

### Function Name: `r_tau0_channel1_interrupt`

**Outline**: Interrupt handler of TAU01

**Header**: None

**Declaration**: `static void __near r_tau0_channel1_interrupt(void);`

**Description**: Interrupt handler of TAU01.

**Arguments**: None

**Return value**: None

**Remarks**: None
4.7 Flowcharts

4.7.1 Overall Flow

Figure 4.1 shows an overall flow of the sample code.

Note: Refer to the RL78/G14 user's manual (hardware) for details on individual registers.

4.7.2 Initialization Function

Figure 4.2 shows the flowchart of the initialization function.

Note: Refer to the RL78/G14 user’s manual (hardware) for details on individual registers.
4.7.3 System Initial Setting

Figure 4.3 shows the flowchart of the system initial setting.

![Flowchart of System Initial Setting](image)

- R_Systeminit()
  - Peripheral I/O redirection function disable
    - PIOR0 register ← 00H
    - PIOR1 register ← 00H
  - CPU clock initialization
    - R_CGC_Create()
  - Port initialization
    - R_PORT_Create()
  - Serial Interface IICA initialization
    - R_IICA0_Create()
  - Timer array unit initialization
    - R_TAU0_Create()
  - Disable the invalid memory access detection
    - IAWCTL register ← 00H

**Figure 4.3 System initial setting**

Note: Refer to the RL78/G14 user’s manual (hardware) for details on individual registers.
4.7.4 CPU Initial Setting

Figure 4.4 shows the flowchart of the CPU initial setting.

R_CGC_Create()

- Set high-speed system clock/subsystem clock
  - CMC register ← 00000000B
  - High-speed system clock pin operation mode: input port
  - Subsystem clock pin operation mode: input port

- Set clock operation control
  - MSTOP bit ← 1: X1 oscillator stopped.

- Select main system clock (fMAIN)
  - MCM0 bit ← 0: Select high-speed on-chip oscillator clock (fIH) as main system clock (fMAIN)

- Set clock operation control
  - XTSTOP bit ← 1: XT1 oscillator stopped

- Set subsystem clock supply mode control
  - OSMC register ← 00010000B: Select low-speed on-chip oscillator clock

- Select CPU/peripheral hardware (fCLK)
  - CSS bit ← 0: Select main system clock (fMAIN) to CPU/Peripheral hardware clock (fCLK)
  - HIOSTOP bit ← 0: High-speed on-chip oscillator operating

return

Figure 4.4 CPU Initial Setting

Note: Refer to the RL78/G14 user’s manual (hardware) for details on individual registers.
4.7.5 I/O Port Setup

Figure 4.5 Shows the flowchart of I/O port setup.

Note: Refer to the RL78/G14 user's manual (hardware) for details on individual registers.

When actually designing your circuit, make sure the design includes sufficient pin processing and meets electrical characteristic requirements. (Connect each input-only port to VDD or VSS through a resistor.)
4.7.6 Serial Interface IICA Initialization Function

Figure 4.6, Figure 4.7 shows the flowchart of Serial Interface IICA Initialization Function.

Figure 4.6 Serial Interface IICA initialization function (1/2)

Note: Refer to the RL78/G14 user’s manual (hardware) for details on individual registers.
Figure 4.7 Serial Interface IICA initialization function (2/2)

Note: Refer to the RL78/G14 user’s manual (hardware) for details on individual registers.
4.7.7 Timer Array Unit Initial Setting

Figure 4.8, Figure 4.9 shows the flowchart for the timer array unit initial setting.

![Flowchart for Timer Array Unit Initial Setting](image)

- **R_TAU0_Create()**
- Supply clock to the timer array unit
- Selection of operation clock
  - $CK00 = \frac{f_{CLK}}{2}$
  - $CK01 = \frac{f_{CLK}}{2^5}$
- Deactive timer array unit 0
- Disable timer array unit interrupts
- Clear timer array unit interrupt request flag
- TAU0EN bit ← 1
- TPS0 register ← 0050H
- TT0 register ← 0AFFH
- TMMK00 bit ← 1
- TMIF00 bit ← 0
- TMMK01 bit ← 1
- TMIF01 bit ← 0
- TMMK01H bit ← 1
- TMIF01H bit ← 0
- TMMK02 bit ← 1
- TMIF02 bit ← 0
- TMMK03 bit ← 1
- TMIF03 bit ← 0
- TMMK03H bit ← 1
- TMIF03H bit ← 0
- TMPR100 bit ← 1
- TMPR000 bit ← 1
- TMPR101 bit ← 1
- TMPR001 bit ← 1

**Note:** Refer to the RL78/G14 user’s manual (hardware) for details on individual registers.
Initial setting of channel 0
Operation clock: CK00
Operation mode: Interval timer mode
Interval: 100us
Output 0 from TO00
Stop the TO00 output operation by counting operation

Initial setting of channel 1
Operation clock: CK01
Operation mode: Capture & one-count mode
High-level width is measured
Set master channel output mode
Output 0 from TO01
Stop the TO01 output operation by counting operation
Noise filter: ON
P02/TI01: input

TMR register ← 0001H
TDR00 register ← 0C7FH
TO00 bit ← 0
TOE00 bit ← 0

TIS0 register ← 00H
TMR01 register ← 82CCH

TOM01 bit ← 0
TO01 bit ← 0
TOE01 bit ← 0
TNFEN01 bit ← 1
PM02 bit ← 1

Note: Refer to the RL78/G14 user’s manual (hardware) for details on individual registers.
### 4.7.8 Main Processing

Figure 4.10, Figure 4.11, Figure 4.12 Shows the flowchart of main processing.

![Main Processing Flowchart](image)

**Figure 4.10 Main Processing (1/3)**

**Figure 4.11 Main Processing (2/3)**
user_main()

LCD display pattern initialization
write_command()
write_data()

Start timer array unit channel 0 and 1
R_TAU0_Channel1_Start()
R_TAU0_Channel0_Start()

Main loop

__HALT();

Is measurement of high-level width of input signal finished?
g_f_distance_updated == 1

no
yes

g_f_distance_updated = 0

Calculate distance to the object by the high-level width
calc_distance()

generate display data

Set LCD display pattern
write_command()
write_data()

Main loop

Figure 4.12 Main Processing (3/3)
4.7.9 LCD Character Display Initialization Function

Figure 4.13 shows the flowchart of LCD character display initialization function.

```plaintext
lcd_init()

Clear Display
WriteCommand(01H)

Display Configuration
• interface data length: 8 bit
• number of display line: 2-line
• display font type: 5x10 dots
  WriteCommand(3CH)

Set cursor moving to right
WriteCommand(06H)

Return cursor to its original position
WriteCommand(02H)

Turn Display ON
WriteCommand(0CH)

return
```

Figure 4.13 LCD Character Display Initialization Function
4.7.10 LCD Character Display Command Send Function

Figure 4.14 shows the flowchart of LCD character display command send function.

```
write_command(command)

Send byte data “command” to the LCD module after send “00H”
R_IICA0_Master_Send()

Wait for processing time on LCD module

return
```

Figure 4.14 LCD Character Display Command Send Function
4.7.11 LCD Character Display Data Send Function

Figure 4.15 show the flowchart of LCD character display data send function.

```
write_data(data, num)

Loop “num” times
   n = 0; n < num; n += 1

Send nth byte data of “data” to the LCD module after send “01H”
   R_IICA0_Master_Send()

Wait for processing time on LCD module

Loop “num” times

return
```

Figure 4.15 LCD Character Display Data Send Function
4.7.12 TAU00 Operation Start Function

Figure 4.16 shows the flowchart of TAU00 operation start function.

![Flowchart of TAU00 Operation Start Function](image)

Note: Refer to the RL78/G14 user’s manual (hardware) for details on individual registers.

4.7.13 TAU01 Operation Start Function

Figure 4.17 shows the flowchart of TAU01 operation start function.

![Flowchart of TAU01 Operation Start Function](image)

Note: Refer to the RL78/G14 user’s manual (hardware) for details on individual registers.
4.7.14 Calculate Distance Function

Figure 4.18 shows the flowchart of calculate distance function

```
calc_distance()

Calculate distance to the object by the high-level width

return
```

Figure 4.18 Calculate Distance Function
4.7.15 TAU00 Interrupt Function

Figure 4.19 shows the flowchart of TAU00 interrupt function.

```
r_tau0_channel0_interrupt()

Is value of interrupt occurrence counter 0?
  no
  yes

Output high level from P01/TO01 pin

Increment interrupt occurrence counter

Has the interval time of measuring high-level width been passed?
  no
  yes

Clear interrupt occurrence counter

return

Output low level from P01/TO01 pin
```

Figure 4.19 TAU00 Interrupt Function
4.7.16 TAU01 Interrupt Function

Figure 4.20 shows the flowchart of TAU01 interrupt function:

1. Call the function `r_tau0_channel1_interrupt()`
2. Read measurement result of high-level width
3. Calculate moving-average of high-level widths
4. Set `g_f_distance_updated = 1`
5. Return
5. Sample Code

Sample code can be downloaded from the Renesas Electronics website.

Website and Support

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

Inquiries
http://www.renesas.com/contact/

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## Revision History

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<th>Rev.</th>
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<td>First edition</td>
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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 $V_{IL}$ (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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Corporate Headquarters
TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

Contact information
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