

RL78/G15

User's Manual: Hardware

16-Bit Single-Chip Microcontrollers

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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.

How to Use This Manual

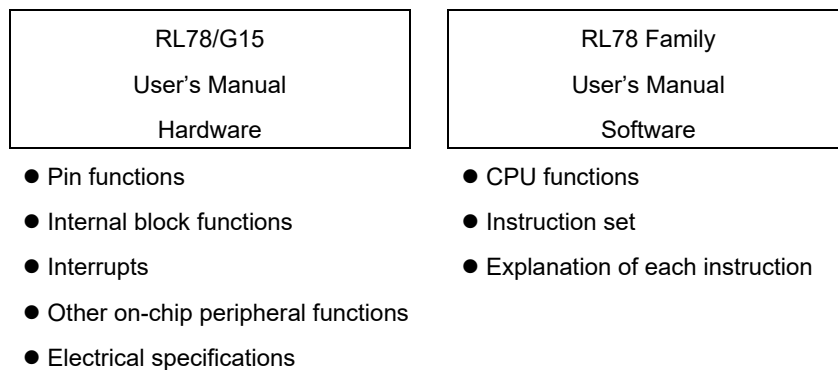
Readers This manual is intended for user engineers who wish to understand the functions of the RL78/G15 and design and develop application systems and programs for these devices.

The target products are as follows.

- 8-pin: R5F1200x (x = 7, 8)
- 10-pin: R5F1201x (x = 7, 8)
- 16-pin: R5F1204x (x = 7, 8)
- 20-pin: R5F1206x (x = 7, 8)

Purpose This manual is intended to give users an understanding of the functions described in the Organization below.

Organization The RL78/G15 manual is separated into two parts: this manual and the software edition (common to the RL78 family).



How to Read This Manual It is assumed that the readers of this manual have general knowledge of electrical engineering, logic circuits, and microcontrollers.

- To gain a general understanding of functions:
 - Read this manual in the order of the CONTENTS. The mark "<R>" shows major revised points. The revised points can be easily searched by copying an "<R>" in the PDF file and specifying it in the "Find what:" field.
- How to interpret the register format:
 - For a bit number enclosed in angle brackets, the bit name is defined as a reserved word in the assembler, and is defined as an sfr variable using the #pragma sfr directive in the compiler.
- To know details of the RL78/G15 Microcontroller instructions:
 - Refer to the separate document RL78 Family User's Manual: Software (R01US0015E).

| | | |
|--------------------|-----------------------------|--|
| Conventions | Data significance: | Higher digits on the left and lower digits on the right |
| | Active low representations: | $\overline{\text{xxx}}$ (overscore over pin and signal name) |
| | Note: | Footnote for item marked with Note in the text |
| | Caution: | Information requiring particular attention |
| | Remark: | Supplementary information |
| | Numerical representations: | Binary ... xxxx or xxxxB |
| | | Decimal ... xxxx |
| | | Hexadecimal ... xxxxH |

Related Documents The related documents indicated in this publication may include preliminary versions. However, preliminary versions are not marked as such.

Documents Related to Devices

| Document Name | Document No. |
|------------------------------------|--------------|
| RL78/G15 User's Manual Hardware | R01UH0959E |
| RL78 Family User's Manual Software | R01US0015E |

Documents Related to Flash Memory Programming and On-chip Debugging

| Document Name | Document No. |
|--|--------------|
| PG-FP5 Flash Memory Programmer User's Manual | — |
| R RL78, 78K, V850, RX100, RX200, RX600 (Except RX64x), R8C, SH | R20UT2923E |
| Common | R20UT2922E |
| Setup Manual | R20UT0930E |
| PG-FP6 Flash Memory Programmer User's Manual | Note 1 |
| E1, E20 Emulator User's Manual | R20UT0398E |
| E2 Emulator User's Manual | R20UT3538E |
| E2 Lite Emulator User's Manual | R20UT3240E |
| Renesas Flash Programmer Flash Memory Programming Software User's Manual | Note 2 |

Note 1. For the documentation of PG-FP6, see the website below.

<https://www.renesas.com/us/en/software-tool/pg-fp6>

Note 2. For the documentation of Renesas Flash Programmer, see the website below.

<https://www.renesas.com/us/en/software-tool/renesas-flash-programmer-programming-gui>

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Other Documents

| Document Name | Document No. |
|--------------------------------------|--------------|
| Renesas Microcontrollers RL78 Family | R01CP0003E |
| Semiconductor Package Mount Manual | R50ZZ0003E |
| Semiconductor Reliability Handbook | R51ZZ0001E |

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CHAPTER 1 OUTLINE

1.1 Features

Low power consumption technology

- V_{DD} = single power supply voltage of 2.4 to 5.5 V
- HALT mode
- STOP mode

RL78 CPU core

- CISC architecture with 3-stage pipeline
- Minimum instruction execution time: Can be changed from high speed (0.0625 μ s: @ 16 MHz operation with high-speed on-chip oscillator) to low speed (1.0 μ s: @ 1 MHz operation)
- Address space: 1 MB
- General-purpose registers: (8-bit register \times 8) \times 4 banks
- On-chip RAM: 1 KB

Code flash memory

- Code flash memory: 4 to 8 KB
- Block size: 1 KB
- Only write after erase is possible
- On-chip debug function
- Self-programming (with no boot swap function/flash shield window function)

Data flash memory

- Data flash memory: 1 KB
- Block size: 512 B
- Unit of rewrites: 32 bits
- Background operation (BGO) is not supported (instructions cannot be executed from the code flash memory while rewriting the data flash memory)
- Number of rewrites: 1,000,000 times (TYP.)
- Voltage of rewrites: V_{DD} = 2.4 to 5.5 V

★ High-speed on-chip oscillator

- Select from 16 MHz, 8 MHz, 4 MHz, 2 MHz, and 1 MHz
- Frequency accuracy $\pm 1.0\%$ ($V_{DD} = 2.4$ to 5.5 V, $T_A = -20$ to $+85^\circ\text{C}$)
(G: Industrial applications, M: Industrial applications)
- Frequency accuracy $\pm 1.5\%$ ($V_{DD} = 2.4$ to 5.5 V, $T_A = -40$ to -20°C)
(G: Industrial applications, M: Industrial applications)
- Frequency accuracy $\pm 1.5\%$ ($V_{DD} = 2.4$ to 5.5 V, $T_A = +85$ to $+105^\circ\text{C}$)
(G: Industrial applications)
- Frequency accuracy $\pm 1.5\%$ ($V_{DD} = 2.4$ to 5.5 V, $T_A = +85$ to $+125^\circ\text{C}$)
(M: Industrial applications)
- Frequency accuracy $\pm 2.0\%$ ($V_{DD} = 2.4$ to 5.5 V, $T_A = -40$ to $+85^\circ\text{C}$)
(A: Consumer applications)

Operating ambient temperature

- $T_A = -40$ to $+85^\circ\text{C}$ (A: Consumer applications)
- $T_A = -40$ to $+105^\circ\text{C}$ (G: Industrial applications)
- $T_A = -40$ to $+125^\circ\text{C}$ (M: Industrial applications)

Power management and reset function

- On-chip selectable power-on-reset (SPOR) circuit (Select reset from 3 levels, stop setting is available)

Serial interface

- Simplified SPI (CSI^{Note 1}): 1 to 2 channels
- UART: 1 channel
- Simplified I²C: 1 to 2 channels
- I²C: 1 channel

Note 1. Although the CSI function is generally called SPI, it is also called CSI in this product, so it is referred to as such in this manual.

Timer

- 16-bit timer: 8 channels
- 12-bit interval timer: 1 channel
- Watchdog timer: 1 channel (operable with the dedicated low-speed on-chip oscillator)

A/D converter

- 8/10-bit resolution A/D converter ($V_{DD} = 2.4$ to 5.5 V)
- Analog input: 3 to 11 channels
- Internal reference voltage (0.815 V (TYP.))

Comparator

- 1 to 2 channels
- Operation mode: High-speed mode, low-speed mode
- External reference voltage or internal reference voltage can be selected as the reference voltage.

I/O port

- I/O port: 6 to 18 (N-ch open drain output [withstand voltage of V_{DD}]: 2 to 9)
- Can be set to N-ch open drain and on-chip pull-up resistor
- External interrupt function: 8 channels
- On-chip clock output/buzzer output controller

Others

- On-chip BCD (binary-coded decimal) correction circuit

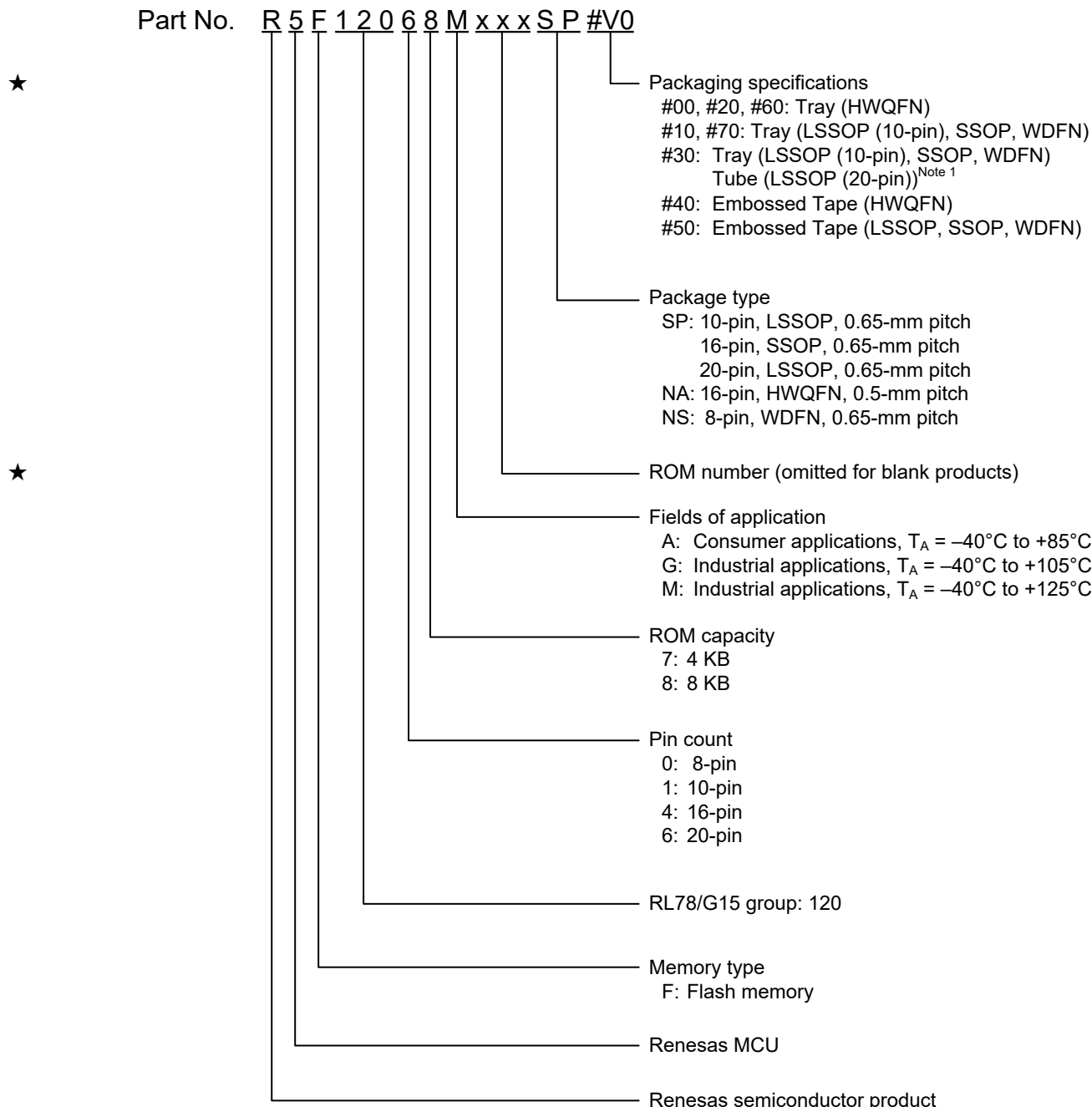
Remark The functions mounted depend on the product. See **1.6 Outline of Functions**.

ROM, RAM capacities

| Flash ROM | Data flash | RAM | RL78/G15 | | | |
|-----------|------------|------|----------|----------|----------|----------|
| | | | 8 pins | 10 pins | 16 pins | 20 pins |
| 8 KB | 1 KB | 1 KB | R5F12008 | R5F12018 | R5F12048 | R5F12068 |
| 4 KB | 1 KB | 1 KB | R5F12007 | R5F12017 | R5F12047 | R5F12067 |

1.2 List of Part Numbers

Figure 1-1. Part Number, Memory Size, and Package of RL78/G15



Note 1. For the 20-pin LSSOP products only, the packaging specification is Tube.

Table 1-1. List of Ordering Part Numbers

| Pin count | Package | Fields of Application Note 1 | Ordering Part Number | | RENESAS Code |
|-----------|---|---------------------------------|--------------------------|--------------------------|--------------|
| | | | Product Name | Packaging Specifications | |
| 8 pins | 8-pin plastic WDFN (3 × 3 mm, 0.65-mm pitch) | A | R5F12008ANS, R5F12007ANS | #10, #30, #50, #70 | PWSN0008JG-A |
| | | G | R5F12008GNS, R5F12007GNS | | |
| | | M | R5F12008MNS, R5F12007MNS | | |
| 10 pins | 10-pin plastic LSSOP (4.4 × 3.6 mm, 0.65-mm pitch) | A | R5F12018ASP, R5F12017ASP | #10, #30, #50, #70 | PLSP0010JA-A |
| | | G | R5F12018GSP, R5F12017GSP | | |
| | | M | R5F12018MSP, R5F12017MSP | | |
| 16 pins | 16-pin plastic SSOP (4.4 × 5.0 mm, 0.65-mm pitch) | A | R5F12048ASP, R5F12047ASP | #10, #30, #50, #70 | PRSP0016JC-B |
| | | G | R5F12048GSP, R5F12047GSP | | |
| | | M | R5F12048MSP, R5F12047MSP | | |
| 16 pins | 16-pin plastic HWQFN (3 × 3 mm, 0.5-mm pitch) | A | R5F12048ANA, R5F12047ANA | #00, #20, #40, #60 | PWQN0016KD-A |
| | | G | R5F12048GNA, R5F12047GNA | | |
| | | M | R5F12048MNA, R5F12047MNA | | |
| 20 pins | 20-pin plastic LSSOP (4.4 × 6.5 mm, 0.65-mm pitch) | A | R5F12068ASP, R5F12067ASP | #30, #50 | PLSP0020JB-A |
| | | G | R5F12068GSP, R5F12067GSP | | |
| | | M | R5F12068MSP, R5F12067MSP | | |

Note 1. For the fields of application, refer to **Figure 1-1 Part Number, Memory Size, and Package of RL78/G15**.

Caution The ordering part numbers represent the numbers at the time of publication. For the latest ordering part numbers, refer to the target product page of the Renesas Electronics website.

1.3 Pin Configuration (Top View)

1.3.1 8-pin products

- 8-pin plastic WDFN (3 × 3 mm, 0.65-mm pitch)

| | | | | |
|---|---|-------------------------------|---|---|
| P40/TOOL0/PCLBUZ0/VCOUT0/INTP2/(TI01/TO01) | 1 | RL78/G15 (Top View) | 8 | P137/INTP0/TI00 |
| P125/ $\overline{\text{RESET}}$ /INTP1/(VCOUT0) | 2 | | 7 | P04/ANI3/IVREF0/INTP3/TI01/TO01/SCK00/SCL00 |
| V_{SS} | 3 | | 6 | P03/TOOLTxD/ANI2/IVCMP0/INTP4/TO00/SO00/TxD0/SCLA0/(TI00) |
| V_{DD} | 4 | | 5 | P01/TOOLRxD/ANI0/INTP5/TI02/TO02/SI00/RxD0/SDA00/SDAA0 |

Table 1-2. Multiplexed Functions of 8-pin Products

| Pin No. | I/O | Power supply, system, clock, debug | Analog | | HMI | Timer | Communications Interface | |
|---------|------|------------------------------------|---------------|------------|--------------------|------------------|--------------------------|-----------------------|
| | | | A/D converter | Comparator | Interrupt function | Timer array unit | Serial array unit | Serial interface IICA |
| 1 | P40 | TOOL0 PCLBUZ0 | — | VCOUT0 | INTP2 | (TI01/TO01) | — | — |
| 2 | P125 | $\overline{\text{RESET}}$ | — | (VCOUT0) | INTP1 | — | — | — |
| 3 | — | V_{SS} | — | — | — | — | — | — |
| 4 | — | V_{DD} | — | — | — | — | — | — |
| 5 | P01 | TOOLRxD | ANI0 | — | INTP5 | TI02/TO02 | SI00/RxD0/ SDA00 | SDAA0 |
| 6 | P03 | TOOLTxD | ANI2 | IVCMP0 | INTP4 | (TI00) TO00 | SO00/TxD0 | SCLA0 |
| 7 | P04 | — | ANI3 | IVREF0 | INTP3 | TI01/TO01 | SCK00/SCL00 | — |
| 8 | P137 | — | — | — | INTP0 | TI00 | — | — |

Remark 1. For pin identification, see 1.4 Pin Identification.

Remark 2. Functions in parentheses can be assigned via settings in the peripheral I/O redirection register (PIOR). Refer to **Figure 4-6 Format of Peripheral I/O Redirection Registers 0 to 3 (PIOR0 to PIOR3)**.

1.3.2 10-pin products

- 10-pin plastic LSSOP (4.4 × 3.6 mm, 0.65-mm pitch)

| | | | | |
|---------------------------------------|---|------------------------|----|--|
| P40/TOOL0/INTP2/(TI01/TO01)/(PCLBUZ0) | 1 | RL78/G15 (Top View) | 10 | P04/ANI3/IVREF0/INTP3/TI01/TO01 |
| P125/RESET/INTP1/(VCOUT0) | 2 | | 9 | P03/ANI2/INTP4/IVCMP0/TO00/SCLA0/(TI00) |
| P137/INTP0/TI00 | 3 | | 8 | P02/PCLBUZ0/ANI1/INTP7/VCOUT0/SCK00/SCL00/(TI01/TO01) |
| V _{SS} | 4 | | 7 | P01/TOOLRxD/ANI0/INTP5/TI02/TO02/SI00/RxD0/SDA00/SDAA0 |
| V _{DD} | 5 | | 6 | P00/TOOLTxD/INTP6/SO00/TxD0 |

Table 1-3. Multiplexed Functions of 10-pin Products

| Pin No. | I/O | Power supply, system, clock, debug | Analog | | HMI | Timer | Communications Interface | |
|---------|------|------------------------------------|---------------|------------|--------------------|------------------|--------------------------|-----------------------|
| | | | A/D converter | Comparator | Interrupt function | Timer array unit | Serial array unit | Serial interface IICA |
| 1 | P40 | TOOL0 (PCLBUZ0) | — | — | INTP2 | (TI01/TO01) | — | — |
| 2 | P125 | RESET | — | (VCOUT0) | INTP1 | — | — | — |
| 3 | P137 | — | — | — | INTP0 | TI00 | — | — |
| 4 | — | V _{SS} | — | — | — | — | — | — |
| 5 | — | V _{DD} | — | — | — | — | — | — |
| 6 | P00 | TOOLTxD | — | — | INTP6 | — | SO00/TxD0 | — |
| 7 | P01 | TOOLRxD | ANI0 | — | INTP5 | TI02/TO02 | SI00/RxD0/SDA00 | SDAA0 |
| 8 | P02 | PCLBUZ0 | ANI1 | VCOUT0 | INTP7 | (TI01/TO01) | SCK00/SCL00 | — |
| 9 | P03 | — | ANI2 | IVCMP0 | INTP4 | (TI00) TO00 | — | SCLA0 |
| 10 | P04 | — | ANI3 | IVREF0 | INTP3 | TI01/TO01 | — | — |

Remark 1. For pin identification, see 1.4 Pin Identification.

Remark 2. Functions in parentheses can be assigned via settings in the peripheral I/O redirection register (PIOR). Refer to Figure 4-6 Format of Peripheral I/O Redirection Registers 0 to 3 (PIOR0 to PIOR3).

1.3.3 16-pin products

- 16-pin plastic SSOP (4.4 × 5.0 mm, 0.65-mm pitch)

| | | | | |
|---------------------------------------|---|------------------------|----|---|
| P41/TI03/TO03/(INTP4)/(TI02/TO02) | 1 | RL78/G15 (Top View) | 16 | P07/ANI6/SCK01/SCL01/SDAA0/(INTP5)/(TO03) |
| P40/TOOL0/INTP2/(PCLBUZ0)/(TI01/TO01) | 2 | | 15 | P06/ANI5/SI01/SDA01/SCLA0/(PCLBUZ0)/(INTP7)/(SCK00/SCL00) |
| P125/RESET/INTP1/(VCOU0) | 3 | | 14 | P05/ANI4/TI02/TO02/SO01/(INTP6)/(SCK00/SCL00)/(SI00/RxD0/SDA00) |
| P137/INTP0/TI00 | 4 | | 13 | P04/ANI3/IVREF0/INTP3/TI01/TO01/(SI00/RxD0/SDA00)/(SO00/TxD0) |
| P122/X2/EXCLK/TI05/TO05/(INTP2) | 5 | | 12 | P03/ANI2/IVCMP0/INTP4/TO00/(TI00)/(SO00/TxD0) |
| P121/X1/TI07/TO07/(INTP3) | 6 | | 11 | P02/PCLBUZ0/ANI1/VCOU0/INTP7/SCK00/SCL00/(TI01/TO01)/(SO01) |
| V _{SS} | 7 | | 10 | P01/TOOLRxD/ANI0/INTP5/SI00/RxD0/SDA00/(TI02/TO02)/(SI01)/(SDA01)/(SDAA0) |
| V _{DD} | 8 | | 9 | P00/TOOLTxD/INTP6/SO00/TxD0/(SCK01/SCL01)/(SCLA0) |

- 16-pin plastic HWQFN (3 × 3 mm, 0.5-mm pitch)

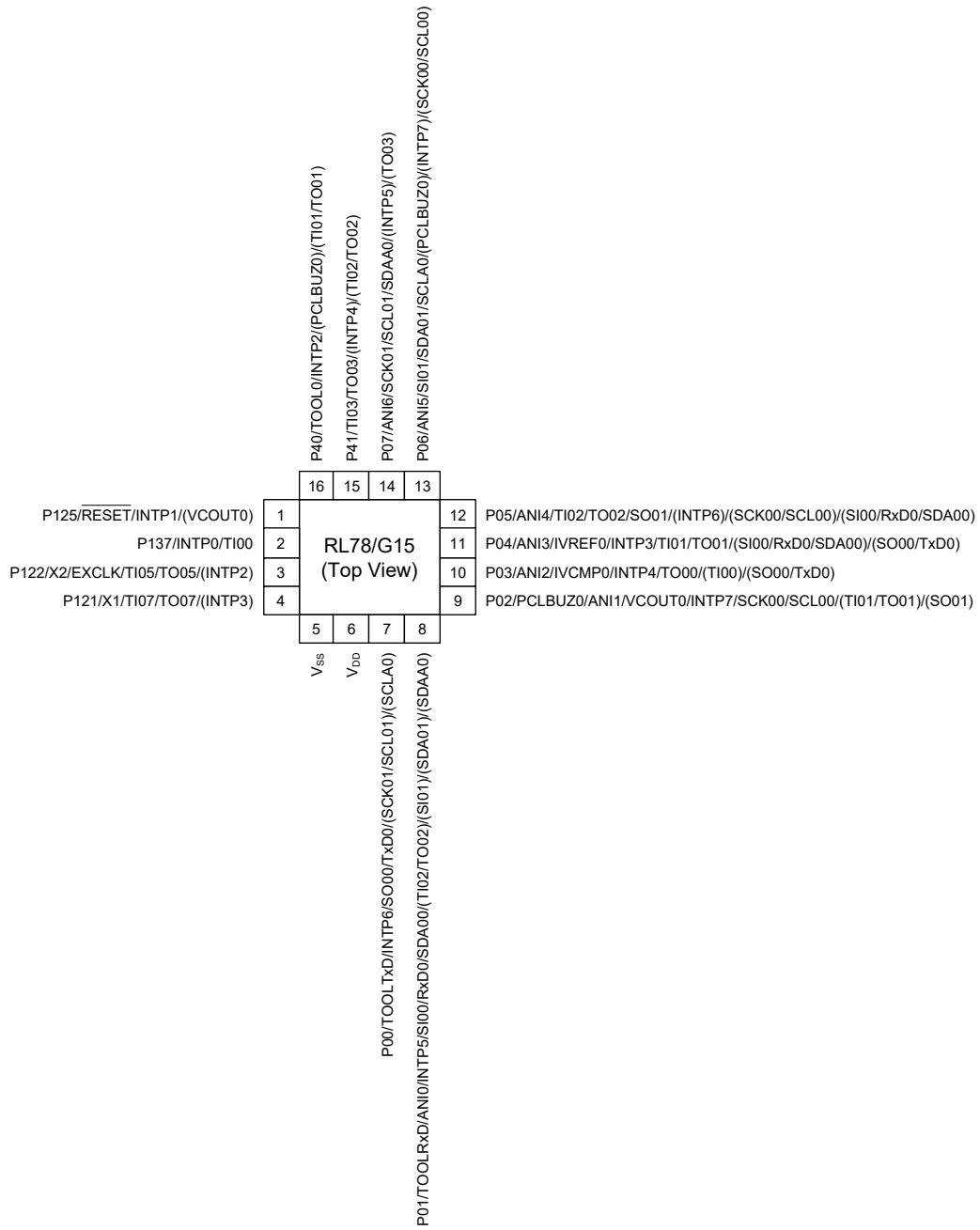


Table 1-4. Multiplexed Functions of 16-pin Products

| Pin No. | | I/O | Power supply, system, clock, debug | Analog | | HMI | Timer | Communications Interface | |
|---------|---------|--------------|--|---------------|------------|-----------------------|--------------------------|--|--------------------------|
| 16SSOP | 16HWQFN | Digital port | | A/D converter | Comparator | Interrupt function | Timer array unit | Serial array unit | Serial interface IICA |
| 1 | 15 | P41 | — | — | — | (INTP4) | TI03/TO03 (TI02/TO02) | — | — |
| 2 | 16 | P40 | TOOL0 (PCLBUZ0) | — | — | INTP2 | (TI01/TO01) | — | — |
| 3 | 1 | P125 | RESET | — | (VCOUT0) | INTP1 | — | — | — |
| 4 | 2 | P137 | — | — | — | INTP0 | TI00 | — | — |
| 5 | 3 | P122 | X2 EXCLK | — | — | (INTP2) | TI05/TO05 | — | — |
| 6 | 4 | P121 | X1 | — | — | (INTP3) | TI07/TO07 | — | — |
| 7 | 5 | — | V _{SS} | — | — | — | — | — | — |
| 8 | 6 | — | V _{DD} | — | — | — | — | — | — |
| 9 | 7 | P00 | TOOLTxD | — | — | INTP6 | — | SO00/TxD0 (SCK01/SCL01) | (SCLA0) |
| 10 | 8 | P01 | TOOLRxD | ANI0 | — | INTP5 | (TI02/TO02) | SI00/RxD0/ SDA00 (SI01)/(SDA01) | (SDAA0) |
| 11 | 9 | P02 | PCLBUZ0 | ANI1 | VCOUT0 | INTP7 | (TI01/TO01) | SCK00/SCL00 (SO01) | — |
| 12 | 10 | P03 | — | ANI2 | IVCMP0 | INTP4 | (TI00) TO00 | (SO00/TxD0) | — |
| 13 | 11 | P04 | — | ANI3 | IVREF0 | INTP3 | TI01/TO01 | (SI00/RxD0/ SDA00) (SO00/TxD0) | — |
| 14 | 12 | P05 | — | ANI4 | — | (INTP6) | TI02/TO02 | SO01 (SCK00/SCL00) (SI00/RxD0/ SDA00) | — |
| 15 | 13 | P06 | (PCLBUZ0) | ANI5 | — | (INTP7) | — | SI01/SDA01 (SCK00/SCL00) | SCLA0 |
| 16 | 14 | P07 | — | ANI6 | — | (INTP5) | (TO03) | SCK01/SCL01 | SDAA0 |

Remark 1. For pin identification, see **1.4 Pin Identification**.

Remark 2. Functions in parentheses can be assigned via settings in the peripheral I/O redirection register (PIOR). Refer to **Figure 4-6 Format of Peripheral I/O Redirection Registers 0 to 3 (PIOR0 to PIOR3)**.

★ **Remark 3.** For the product in a QFN package, solder the exposed die pad onto a plated area of the PCB that has no electrical connections.

1.3.4 20-pin products

- 20-pin plastic LSSOP (4.4 × 6.5 mm, 0.65-mm pitch)

| | | | | |
|---|----|------------------------|----|---|
| P21/ANI9/IVCMP1/(INTP7)/(TO00) | 1 | RL78/G15 (Top View) | 20 | P22/ANI8/TI06/TO06/(INTP5)/(SDA01) |
| P20/ANI10/IVREF1/(INTP1)/(TI00)/(TI03/TO03)/(SCK01/SCL01) | 2 | | 19 | P23/ANI7/TI04/TO04/(INTP6)/(SCL01) |
| P41/VCOU1/TI03/TO03/(INTP4)/(TI02/TO02)/(SO01)/(SDA01) | 3 | | 18 | P07/ANI6/SCK01/SCL01/SDAA0/(INTP5)/(TO03) |
| P40/TOOL0/INTP2/(PCLBUZ0)/(TI01/TO01) | 4 | | 17 | P06/ANI5/SI01/SDA01/SCLA0/(PCLBUZ0)/(INTP7)/(SCK00/SCL00) |
| P125/RESET/INTP1/(VCOU0)/(VCOU1)/(SI01) | 5 | | 16 | P05/ANI4/TI02/TO02/SO01/(INTP6)/(SCK00/SCL00)/(SI00/RxD0/SDA00) |
| P137/INTP0/TI00 | 6 | | 15 | P04/ANI3/IVREF0/INTP3/TI01/TO01/(SI00/RxD0/SDA00)/(SO00/TxD0) |
| P122/X2/EXCLK/TI05/TO05/(INTP2) | 7 | | 14 | P03/ANI2/IVCMP0/INTP4/TO00/(TI00)/(SO00/TxD0) |
| P121/X1/TI07/TO07/(INTP3) | 8 | | 13 | P02/PCLBUZ0/ANI1/VCOU0/INTP7/SCK00/SCL00/(TI01/TO01)/(SO01) |
| V _{SS} | 9 | | 12 | P01/TOOLRxD/ANI0/INTP5/SI00/RxD0/SDA00/(TI02/TO02)/(SI01)/(SDA01)/(SDAA0) |
| V _{DD} | 10 | | 11 | P00/TOOLTxD/INTP6/SO00/TxD0/(SCK01/SCL01)/(SCLA0) |

Table 1-5. Multiplexed Functions of 20-pin Products (1/2)

| Pin No. | I/O | Power supply, system, clock, debug | Analog | | HMI | Timer | Communications Interface | |
|---------|------|------------------------------------|---------------|--------------------|--------------------|--------------------------|--|-----------------------|
| | | | A/D converter | Comparator | Interrupt function | Timer array unit | Serial array unit | Serial interface IICA |
| 1 | P21 | — | ANI9 | IVCMP1 | (INTP7) | (TO00) | — | — |
| 2 | P20 | — | ANI10 | IVREF1 | (INTP1) | (TI00) (TI03/TO03) | (SCK01/SCL01) | — |
| 3 | P41 | — | — | VCOU1 | (INTP4) | TI03/TO03 (TI02/TO02) | (SO01)/(SDA01) | — |
| 4 | P40 | TOOL0 (PCLBUZ0) | — | — | INTP2 | (TI01/TO01) | — | — |
| 5 | P125 | RESET | — | (VCOU0) (VCOU1) | INTP1 | — | (SI01) | — |
| 6 | P137 | — | — | — | INTP0 | TI00 | — | — |
| 7 | P122 | X2 EXCLK | — | — | (INTP2) | TI05/TO05 | — | — |
| 8 | P121 | X1 | — | — | (INTP3) | TI07/TO07 | — | — |
| 9 | | V _{SS} | — | — | — | — | — | — |
| 10 | | V _{DD} | — | — | — | — | — | — |
| 11 | P00 | TOOLTxD | — | — | INTP6 | — | SO00/TxD0 (SCK01/SCL01) | (SCLA0) |
| 12 | P01 | TOOLRxD | ANI0 | — | INTP5 | (TI02/TO02) | SI00/RxD0/SDA00 (SI01)/(SDA01) | (SDAA0) |
| 13 | P02 | PCLBUZ0 | ANI1 | VCOU0 | INTP7 | (TI01/TO01) | SCK00/SCL00 (SO01) | — |
| 14 | P03 | — | ANI2 | IVCMP0 | INTP4 | (TI00) TO00 | (SO00/TxD0) | — |
| 15 | P04 | — | ANI3 | IVREF0 | INTP3 | TI01/TO01 | (SI00/RxD0/ SDA00) (SO00/TxD0) | — |
| 16 | P05 | — | ANI4 | — | (INTP6) | TI02/TO02 | SO01 (SCK00/SCL00) (SI00/RxD0/ SDA00) | — |
| 17 | P06 | (PCLBUZ0) | ANI5 | — | (INTP7) | — | SI01/SDA01 (SCK00/SCL00) | SCLA0 |
| 18 | P07 | — | ANI6 | — | (INTP5) | (TO03) | SCK01/SCL01 | SDAA0 |

Table 1-5. Multiplexed Functions of 20-pin Products (2/2)

| Pin No. | I/O | Power supply, system, clock, debug | Analog | | HMI | Timer | Communications Interface | |
|---------|-----|------------------------------------|---------------|------------|--------------------|------------------|--------------------------|-----------------------|
| | | | A/D converter | Comparator | Interrupt function | Timer array unit | Serial array unit | Serial interface IICA |
| 19 | P23 | — | ANI7 | — | (INTP6) | TI04/TO04 | (SCL01) | — |
| 20 | P22 | — | ANI8 | — | (INTP5) | TI06/TO06 | (SDA01) | — |

Remark 1. For pin identification, see **1.4 Pin Identification**.

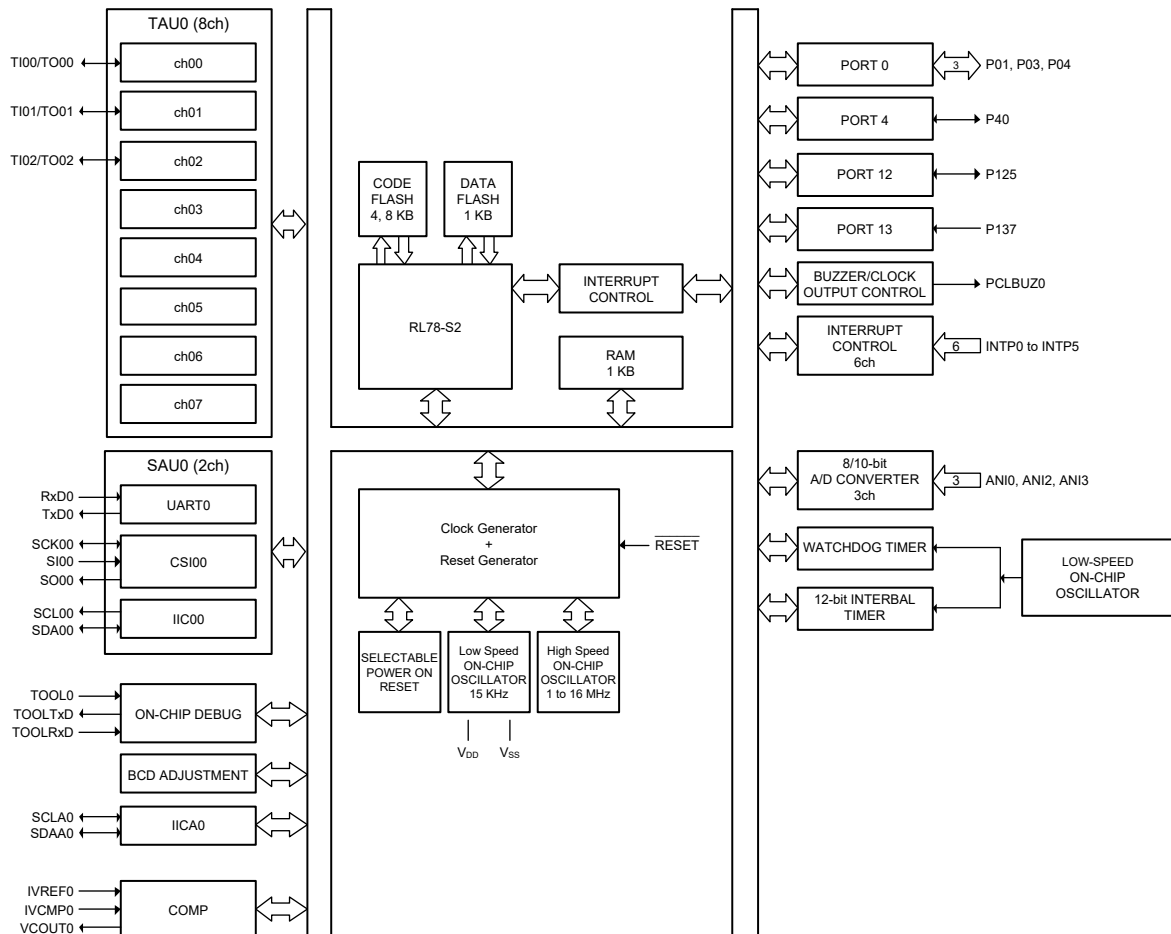
Remark 2. Functions in parentheses can be assigned via settings in the peripheral I/O redirection register (PIOR). Refer to **Figure 4-6 Format of Peripheral I/O Redirection Registers 0 to 3 (PIOR0 to PIOR3)**.

1.4 Pin Identification

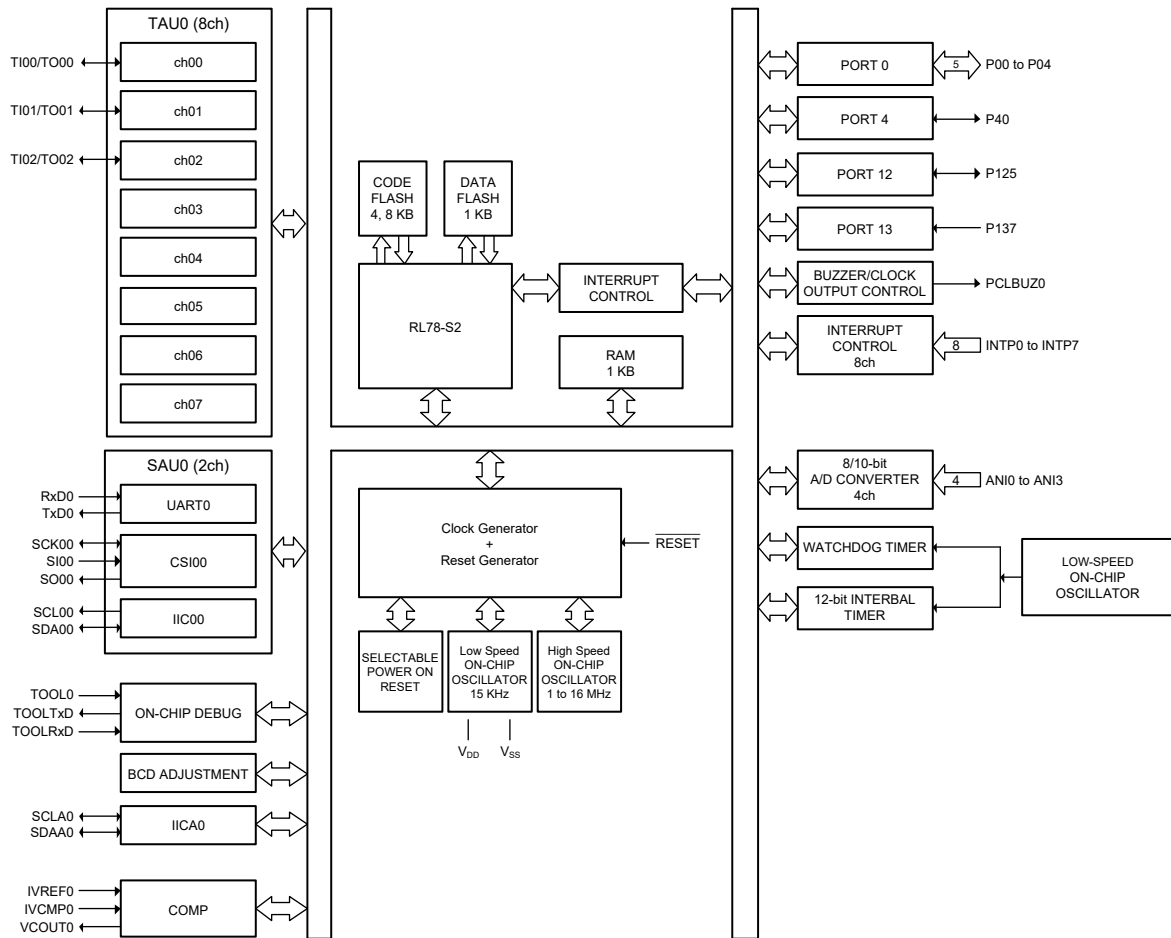
| | |
|---------------------|---|
| ANI0 to ANI10 | : Analog Input |
| INTP0 to INTP7 | : Interrupt Request From Peripherals |
| P00 to P07 | : Port 0 |
| P20 to P23 | : Port 2 |
| P40, P41 | : Port 4 |
| P121, P122, P125 | : Port 12 |
| P137 | : Port 13 |
| PCLBUZ0 | : Programmable Clock Output/Buzzer Output |
| EXCLK | : External Clock Input |
| X1, X2 | : Crystal Oscillator (Main System Clock) |
| IVCMP0, IVCMP1 | : Comparator Input |
| VCOUT0, VCOUT1 | : Comparator Output |
| IVREF0, IVREF1 | : Comparator Reference Input |
| RESET | : Reset |
| RxD0 | : Receive Data |
| SCK00, SCK01 | : Serial Clock Input/Output |
| SCL00, SCL01, SCLA0 | : Serial Clock Output |
| SDA00, SDA01, SDAA0 | : Serial Data Input/Output |
| SI00, SI01 | : Serial Data Input |
| SO00, SO01 | : Serial Data Output |
| TI00 to TI07 | : Timer Input |
| TO00 to TO07 | : Timer Output |
| TOOL0 | : Data Input/Output for Tool |
| TOOLRxD, TOOLTxD | : Data Input/Output for External Device |
| TxD0 | : Transmit Data |
| V _{DD} | : Power Supply |
| V _{SS} | : Ground |

1.5 Block Diagram

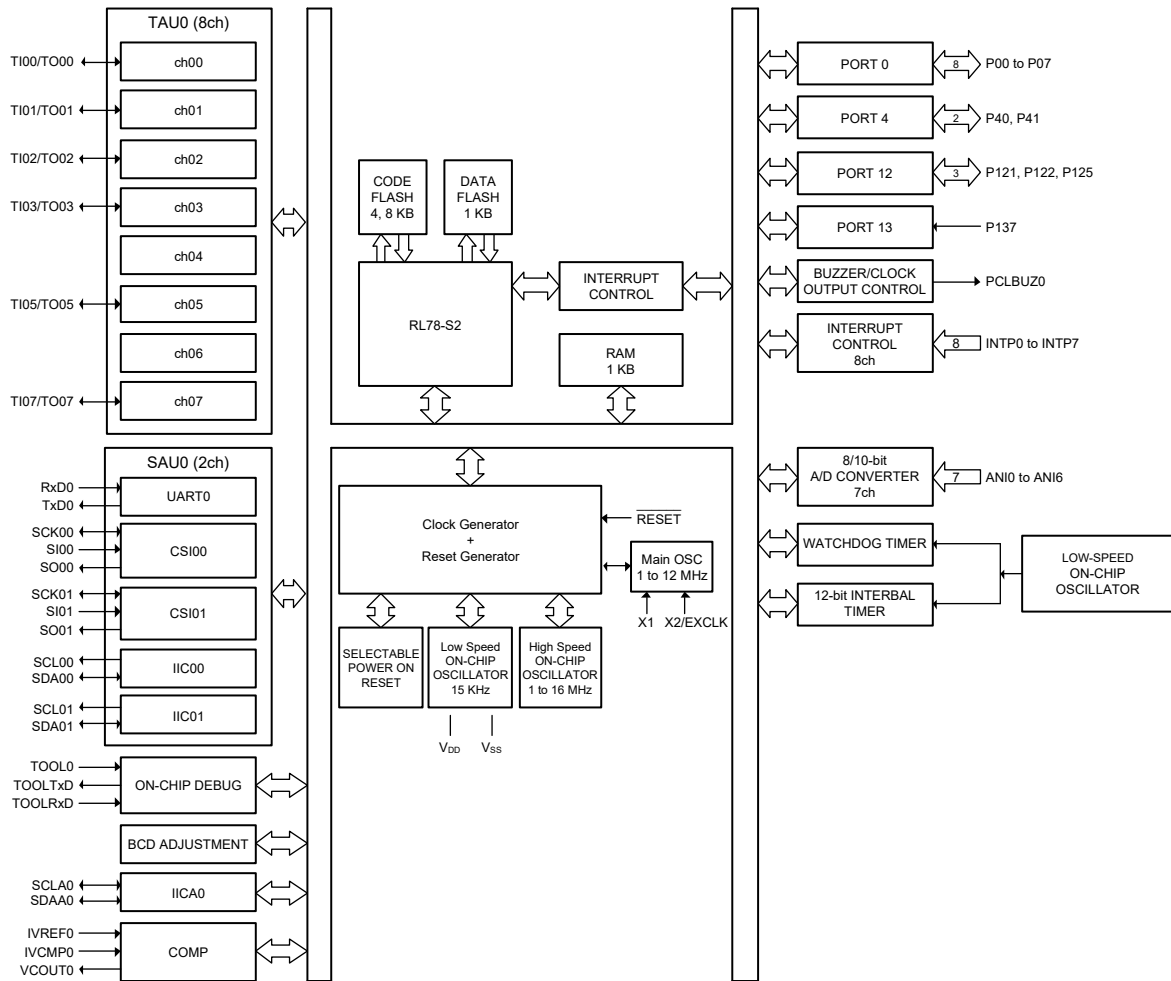
1.5.1 8-pin products



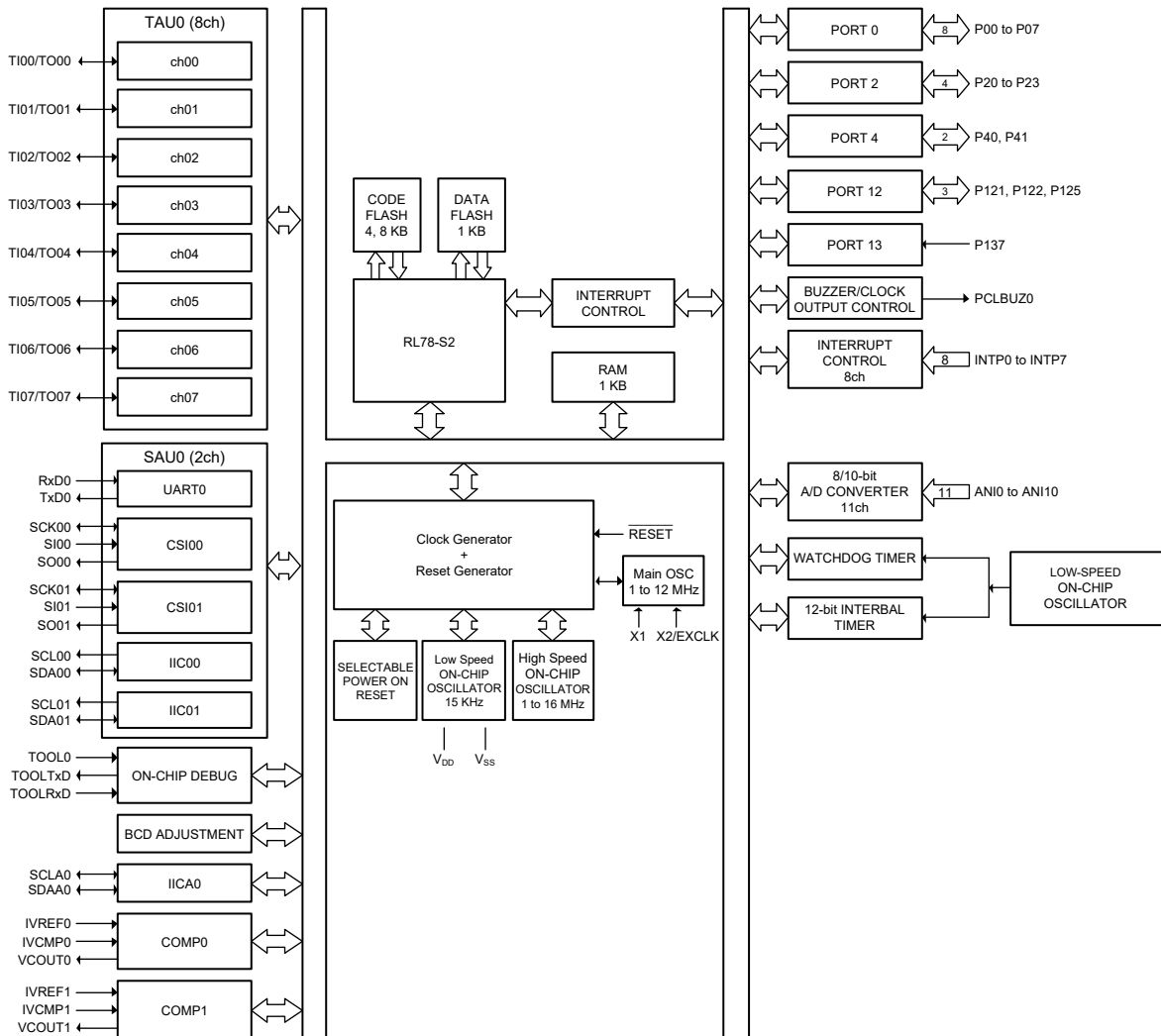
1.5.2 10-pin products



1.5.3 16-pin products



1.5.4 20-pin products



1.6 Outline of Functions

This outline describes the functions at the time when Peripheral I/O redirection register (PIOR) is set to 00H.

(1/2)

| Item | | 8-pin | | 10-pin | | 16-pin | | 20-pin | |
|--------------------------------------|-------------------------------|---|--|--|--|--|----------|----------|----------|
| | | R5F12007 | R5F12008 | R5F12017 | R5F12018 | R5F12047 | R5F12048 | R5F12067 | R5F12068 |
| Code flash memory | | 4 KB | 8 KB | 4 KB | 8 KB | 4 KB | 8 KB | 4 KB | 8 KB |
| Data flash memory | | 1 KB | | | | | | | |
| RAM | | 1 KB | | | | | | | |
| Main system clock | High-speed system clock | — | | — | | X1, X2 (crystal/ceramic) oscillation: 1 to 12 MHz: VDD = 2.4 to 5.5 V External main system clock input (EXCLK): 1 to 16 MHz: VDD = 2.4 to 5.5 V | | | |
| | High-speed on-chip oscillator | 1 to 16 MHz (VDD = 2.4 to 5.5 V) | | | | | | | |
| Low-speed on-chip oscillator clock | | 15 kHz (TYP.) | | | | | | | |
| General-purpose registers | | (8-bit register × 8) × 4 banks | | | | | | | |
| Minimum instruction execution time | | 0.0625 μs (16 MHz operation) | | | | | | | |
| Instruction set | | <ul style="list-style-type: none"> • Data transfer (8/16 bits) • Adder and subtractor/logical operation (8/16 bits) • Multiplication (8 bits × 8 bits) • Rotate, barrel shift, and bit manipulation (Set, reset, test, and Boolean operation), etc. | | | | | | | |
| I/O port | Total | 6 | 8 | 14 | 18 | | | | |
| | CMOS I/O | 5 | 7 | 13 | 17 | | | | |
| | CMOS input | 1 | | | | | | | |
| Timer | 16-bit timer | 8 channels | | | | | | | |
| | Watchdog timer | 1 channel | | | | | | | |
| | 12-bit interval timer | 1 channel | | | | | | | |
| | Timer output | 3 channels (PWM outputs: 2) ^{Note 1} | 3 channels (PWM outputs: 2) ^{Note 1} | 6 channels (PWM outputs: 4) ^{Note 1} | 8 channels (PWM outputs: 7) ^{Note 1} | | | | |
| Clock output/buzzer output | | 1 | | | | | | | |
| | | Up to 10 MHz (peripheral hardware clock: f _{MAIN} = 10 MHz operation) | | | | | | | |
| Comparator | | 1 channel | 1 channel | 1 channel | 2 channels | | | | |
| 8/10-bit resolution A/D converter | | 3 channels | 4 channels | 7 channels | 11 channels | | | | |
| Serial interface | | Simplified SPI (CSI): 1 channel/simplified I ² C: 1 channel/UART: 1 channel | | | | Simplified SPI (CSI ^{Note 2}): 2 channels/simplified I ² C: 2 channels/UART: 1 channel | | | |
| I ² C bus | | 1 channel | | | | | | | |
| Number of Vectored interrupt sources | Internal | 8 | 10 | 16 | 19 | | | | |
| | External | 6 | 8 | 8 | 8 | | | | |
| Reset | | <ul style="list-style-type: none"> • Reset by $\overline{\text{RESET}}$ pin • Internal reset by watchdog timer • Internal reset by selectable power-on-reset • Internal reset by illegal instruction execution^{Note 3} • Internal reset by data retention lower limit voltage • Internal reset by illegal-memory access | | | | | | | |
| Selectable power-on-reset circuit | | <ul style="list-style-type: none"> • Detection voltage • Rising edge (V_{SPOR}): 2.25 V/2.68 V/3.02 V/4.45 V (MAX.) • Falling edge (V_{SPDR}): 2.20 V/2.62 V/2.96 V/4.37 V (MAX.) | | | | | | | |

(2/2)

| Item | 8-pin | | 10-pin | | 16-pin | | 20-pin | |
|-------------------------------|---|----------|----------|----------|----------|----------|----------|----------|
| | R5F12007 | R5F12008 | R5F12017 | R5F12018 | R5F12047 | R5F12048 | R5F12067 | R5F12068 |
| On-chip debug function | Provided | | | | | | | |
| Power supply voltage | $V_{DD} = 2.4$ to 5.5 V | | | | | | | |
| Operating ambient temperature | $T_A = -40$ to $+85^\circ\text{C}$ (A: Consumer applications), $T_A = -40$ to $+105^\circ\text{C}$ (G: Industrial applications), $T_A = -40$ to $+125^\circ\text{C}$ (M: Industrial applications) | | | | | | | |

- Note 1. The number of outputs varies, depending on the setting of channels in use and the number of the master (see **6.9.3 Operation as multiple PWM output function**).
- Note 2. Although the CSI function is generally called SPI, it is also called CSI in this product, so it is referred to as such in this manual.
- Note 3. The illegal instruction is generated when instruction code FFH is executed. Reset by the illegal instruction execution not issued by emulation with the on-chip debug emulator.

CHAPTER 2 PIN FUNCTIONS

2.1 Port Function

The input or output, buffer, and pull-up resistor settings on each port are also valid for the alternate functions.

2.1.1 8-pin products

| Function Name | Pin Type | I/O | After Reset Release | Alternate Function | Function |
|---------------|----------|-------|---------------------|---|--|
| P01 | 7-3-2 | I/O | Analog input | TOOLRxD/ANI0/INTP5/TI02/ TO02/SI00/RxD0/SDA00/ SDAA0 | Port 0. 3-bit I/O port. Input/output can be specified in 1-bit units. Use of an on-chip pull-up resistor can be specified by a software setting at input port. Output of P01 and P03 can be set to N-ch open-drain output (V_{DD} tolerance). P01, P03, and P04 can be set to analog input ^{Note 1} . |
| P03 | 7-9-2 | | | TOOLTxD/ANI2/IVCMP0/ INTP4/TO00/SO00/TxD0/ SCLA0/(TI00) | |
| P04 | | | | ANI3/IVREF0/INTP3/TI01/ TO01/SCK00/SCL00 | |
| P40 | 7-1-1 | I/O | Input port | TOOL0/PCLBUZ0/VCOU0/ INTP2/(TI01/TO01) | Port 4. 1-bit I/O port. Input/output can be specified in 1-bit units. Use of an on-chip pull-up resistor can be specified by a software setting at input port. |
| P125 | 3-2-1 | I/O | Input port | $\overline{\text{RESET}}/\text{INTP1}/(\text{VCOU0})$ | Port 12. 1-bit I/O port. Use of an on-chip pull-up resistor can be specified by a software setting. P125 is also used for the input pin for external reset (RESET). To use the pin for external reset, set the PORTSELB bit in the option byte (000C1H) to 1. |
| P137 | 2-1-2 | Input | Input port | INTP0/TI00 | Port 13. 1-bit input only port. |

Note 1. Setting digital or analog to each pin can be done in the port mode control register 0 (PMC0) (can be set in 1-bit units).

Remark Functions in parentheses can be assigned via settings in the peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3). Refer to **Figure 4-6 Format of Peripheral I/O Redirection Registers 0 to 3 (PIOR0 to PIOR3)**.

2.1.2 10-pin products

| Function Name | Pin Type | I/O | After Reset Release | Alternate Function | Function |
|---------------|----------|-------|-------------------------------------|--|---|
| P00 | 7-1-2 | I/O | Input port | TOOLTxD/INTP6/SO00/TxD0 | Port 0. 5-bit I/O port. Input/output can be specified in 1-bit units. Use of an on-chip pull-up resistor can be specified by a software setting at input port. Output of P00, P01, and P03 can be set to N-ch open-drain output (V_{DD} tolerance). P01 to P04 can be set to analog input ^{Note 1} . |
| P01 | 7-3-2 | | Analog input | TOOLRxD/ANI0/INTP5/TI02/TO02/SI00/RxD0/SDA00/SDAA0 | |
| P02 | | | | PCLBUZ0/ANI1/INTP7/VCOUT0/SCK00/SCL00/(TI01/TO01) | |
| P03 | 7-9-2 | | ANI2/INTP4/IVCMP0/TO00/SCLA0/(TI00) | | |
| P04 | | | ANI3/IVREF0/INTP3/TI01/TO01 | | |
| P40 | 7-1-1 | I/O | Input port | TOOL0/INTP2/(TI01/TO01)/(PCLBUZ0) | Port 4. 1-bit I/O port. Input/output can be specified in 1-bit units. Use of an on-chip pull-up resistor can be specified by a software setting at input port. |
| P125 | 3-2-1 | I/O | Input port | $\overline{\text{RESET}}$ /INTP1/(VCOUT0) | Port 12. 1-bit I/O port. Use of an on-chip pull-up resistor can be specified by a software setting. P125 is also used for the input pin for external reset ($\overline{\text{RESET}}$). To use the pin for external reset, set the PORTSELB bit in the option byte (000C1H) to 1. |
| P137 | 2-1-2 | Input | Input port | INTP0/TI00 | Port 13. 1-bit input only port. |

Note 1. Setting digital or analog to each pin can be done in the port mode control register 0 (PMC0) (can be set in 1-bit units).

Remark Functions in parentheses can be assigned via settings in the peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3). Refer to **Figure 4-6 Format of Peripheral I/O Redirection Registers 0 to 3 (PIOR0 to PIOR3)**.

2.1.3 16-pin products

| Function Name | Pin Type | I/O | After Reset Release | Alternate Function | Function |
|---------------|----------|-------|---------------------|---|--|
| P00 | 7-1-2 | I/O | Input port | TOOLTxD/INTP6/SO00/ TxD0/(SCK01/SCL01)/ (SCLA0) | Port 0. 8-bit I/O port. Input/output can be specified in 1-bit units. Use of an on-chip pull-up resistor can be specified by a software setting at input port. Output of P00, P01, and P03 to P07 can be set to N-ch open-drain output (V_{DD} tolerance). P01 to P07 can be set to analog input ^{Note 1} . |
| P01 | 7-3-2 | | Analog input | TOOLRxD/ANI0/INTP5/SI00/ RxD0/SDA00/(TI02/TO02)/ (SI01)/(SDA01)/(SDAA0) | |
| P02 | | | | PCLBUZ0/ANI1/VCOU0/ INTP7/SCK00/SCL00/ (TI01/TO01)/(SO01) | |
| P03 | 7-9-2 | | | ANI2/IVCMP0/INTP4/TO00/ (TI00)/(SO00/TxD0) | |
| P04 | | | | ANI3/IVREF0/INTP3/TI01/ TO01/(SI00/RxD0/SDA00)/ (SO00/TxD0) | |
| P05 | 7-3-2 | | | ANI4/TI02/TO02/SO01/ (INTP6)/(SCK00/SCL00)/ (SI00/RxD0/SDA00) | |
| P06 | | | | ANI5/SI01/SDA01/SCLA0/ (PCLBUZ0)/(INTP7)/ (SCK00/SCL00) | |
| P07 | | | | ANI6/SCK01/SCL01/SDAA0/ (INTP5)/(TO03) | |
| P40 | 7-1-1 | I/O | Input port | TOOL0/INTP2/(PCLBUZ0)/ (TI01/TO01) | Port 4. 2-bit I/O port. Input/output can be specified in 1-bit units. Use of an on-chip pull-up resistor can be specified by a software setting at input port. |
| P41 | | | | TI03/TO03/(INTP4)/ (TI02/TO02) | |
| P121 | 7-2-2 | I/O | Input port | X1/TI07/TO07/(INTP3) | Port 12. 3-bit I/O port. Use of an on-chip pull-up resistor can be specified by a software setting at P121, P122, and P125. P125 is also used for the input pin for external reset (RESET). To use the pin for external reset, set the PORTSELB bit in the option byte (000C1H) to 1. |
| P122 | | | | X2/EXCLK/TI05/TO05/ (INTP2) | |
| P125 | 3-2-1 | | | RESET/INTP1/(VCOU0) | |
| P137 | 2-1-2 | Input | Input port | INTP0/TI00 | Port 13. 1-bit input only port. |

Note 1. Setting digital or analog to each pin can be done in the port mode control register 0 (PMC0) (can be set in 1-bit units).

Remark Functions in parentheses can be assigned via settings in the peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3). Refer to **Figure 4-6 Format of Peripheral I/O Redirection Registers 0 to 3 (PIOR0 to PIOR3)**.

2.1.4 20-pin products

(1/2)

| Function Name | Pin Type | I/O | After Reset Release | Alternate Function | Function |
|---------------|----------|-----|---------------------|---|--|
| P00 | 7-1-2 | I/O | Input port | TOOLTxD/INTP6/SO00/ TxD0/(SCK01/SCL01)/ (SCLA0) | Port 0. 8-bit I/O port. Input/output can be specified in 1-bit units. Use of an on-chip pull-up resistor can be specified by a software setting at input port. Output of P00, P01, and P03 to P07 can be set to N-ch open-drain output (V_{DD} tolerance). P01 to P07 can be set to analog input ^{Note 1} . |
| P01 | 7-3-2 | | Analog input | TOOLRxD/ANI0/INTP5/SI00/ RxD0/SDA00/(TI02/TO02)/ (SI01)/(SDA01)/(SDAA0) | |
| P02 | | | | PCLBUZ0/ANI1/VCOU0/ INTP7/SCK00/SCL00/ (TI01/TO01)/(SO01) | |
| P03 | 7-9-2 | | | ANI2/IVCMP0/INTP4/TO00/ (TI00)/(SO00/TxD0) | |
| P04 | | | | ANI3/IVREF0/INTP3/TI01/ TO01/(SI00/RxD0/SDA00)/ (SO00/TxD0) | |
| P05 | 7-3-2 | | | ANI4/TI02/TO02/SO01/ (INTP6)/(SCK00/SCL00)/ (SI00/RxD0/SDA00) | |
| P06 | | | | ANI5/SI01/SDA01/SCLA0/ (PCLBUZ0)/(INTP7)/ (SCK00/SCL00) | |
| P07 | | | | ANI6/SCK01/SCL01/SDAA0/ (INTP5)/(TO03) | |
| P20 | 7-9-1 | I/O | Analog input | ANI10/IVREF1/(INTP1)/(TI00)/ (TI03/TO03)/(SCK01/SCL01) | Port 2. 4-bit I/O port. Input/output can be specified in 1-bit units. Use of an on-chip pull-up resistor can be specified by a software setting at input port. Output of P22 can be set to N-ch open-drain output (V_{DD} tolerance). P20 to P23 can be set to analog input ^{Note 1} . |
| P21 | | | | ANI9/IVCMP1/(INTP7)/ (TO00) | |
| P22 | 7-3-2 | | | ANI8/TI06/TO06/(INTP5)/ (SDA01) | |
| P23 | 7-3-1 | | | ANI7/TI04/TO04/(INTP6)/ (SCL01) | |
| P40 | 7-1-1 | I/O | Input port | TOOL0/INTP2/(PCLBUZ0)/ (TI01/TO01) | Port 4. 2-bit I/O port. Input/output can be specified in 1-bit units. Use of an on-chip pull-up resistor can be specified by a software setting at input port. Output of P41 can be set to N-ch open-drain output (V_{DD} tolerance). |
| P41 | 7-1-2 | | | VCOU1/TI03/TO03/(INTP4)/ (TI02/TO02)/(SO01)/(SDA01) | |

(2/2)

| Function Name | Pin Type | I/O | After Reset Release | Alternate Function | Function |
|---------------|----------|--------------------------------------|---------------------|----------------------------|---|
| P121 | 7-2-2 | I/O | Input port | X1/TI07/TO07/(INTP3) | Port 12. 3-bit I/O port. Use of an on-chip pull-up resistor can be specified by a software setting at P121, P122, and P125. P125 is also used for the input pin for external reset (RESET). To use the pin for external reset, set the PORTSELB bit in the option byte (000C1H) to 1. |
| P122 | | | | X2/EXCLK/TI05/TO05/(INTP2) | |
| P125 | 3-2-1 | RESET/INTP1/(VCOUT0)/(VCOUT1)/(SI01) | | | |
| P137 | 2-1-2 | Input | Input port | INTP0/TI00 | Port 13. 1-bit input only port. |

Note 1. Setting digital or analog to each pin can be done in the port mode control registers 0, 2 (PMC0, PMC2) (can be set in 1-bit units).

Remark Functions in parentheses can be assigned via settings in the peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3). Refer to **Figure 4-6 Format of Peripheral I/O Redirection Registers 0 to 3 (PIOR0 to PIOR3)**.

2.2 Functions other than port pins

2.2.1 Functions for each product

| Function Name | 20-pin products | 16-pin products | 10-pin products | 8-pin products |
|-----------------|-----------------|-----------------|-----------------|----------------|
| ANI0 | ✓ | ✓ | ✓ | ✓ |
| ANI1 | ✓ | ✓ | ✓ | — |
| ANI2 | ✓ | ✓ | ✓ | ✓ |
| ANI3 | ✓ | ✓ | ✓ | ✓ |
| ANI4 | ✓ | ✓ | — | — |
| ANI5 | ✓ | ✓ | — | — |
| ANI6 | ✓ | ✓ | — | — |
| ANI7 | ✓ | — | — | — |
| ANI8 | ✓ | — | — | — |
| ANI9 | ✓ | — | — | — |
| ANI10 | ✓ | — | — | — |
| IVCMP0 | ✓ | ✓ | ✓ | ✓ |
| IVREF0 | ✓ | ✓ | ✓ | ✓ |
| VCOUT0 | ✓ | ✓ | ✓ | ✓ |
| IVCMP1 | ✓ | — | — | — |
| IVREF1 | ✓ | — | — | — |
| VCOUT1 | ✓ | — | — | — |
| INTP0 | ✓ | ✓ | ✓ | ✓ |
| INTP1 | ✓ | ✓ | ✓ | ✓ |
| INTP2 | ✓ | ✓ | ✓ | ✓ |
| INTP3 | ✓ | ✓ | ✓ | ✓ |
| INTP4 | ✓ | ✓ | ✓ | ✓ |
| INTP5 | ✓ | ✓ | ✓ | ✓ |
| INTP6 | ✓ | ✓ | ✓ | — |
| INTP7 | ✓ | ✓ | ✓ | — |
| PCLBUZ0 | ✓ | ✓ | ✓ | ✓ |
| RESET | ✓ | ✓ | ✓ | ✓ |
| X1 | ✓ | ✓ | — | — |
| X2 | ✓ | ✓ | — | — |
| EXCLK | ✓ | ✓ | — | — |
| TOOLTxD | ✓ | ✓ | ✓ | ✓ |
| TOOLRxD | ✓ | ✓ | ✓ | ✓ |
| TOOL0 | ✓ | ✓ | ✓ | ✓ |
| V _{DD} | ✓ | ✓ | ✓ | ✓ |
| V _{SS} | ✓ | ✓ | ✓ | ✓ |

| Function Name | 20-pin products | 16-pin products | 10-pin products | 8-pin products |
|---------------|-----------------|-----------------|-----------------|----------------|
| RxD0 | ✓ | ✓ | ✓ | ✓ |
| TxD0 | ✓ | ✓ | ✓ | ✓ |
| SCL00 | ✓ | ✓ | ✓ | ✓ |
| SDA00 | ✓ | ✓ | ✓ | ✓ |
| SCL01 | ✓ | ✓ | — | — |
| SDA01 | ✓ | ✓ | — | — |
| SCK00 | ✓ | ✓ | ✓ | ✓ |
| SI00 | ✓ | ✓ | ✓ | ✓ |
| SO00 | ✓ | ✓ | ✓ | ✓ |
| SCK01 | ✓ | ✓ | — | — |
| SI01 | ✓ | ✓ | — | — |
| SO01 | ✓ | ✓ | — | — |
| SCLA0 | ✓ | ✓ | ✓ | ✓ |
| SDAA0 | ✓ | ✓ | ✓ | ✓ |
| TI00 | ✓ | ✓ | ✓ | ✓ |
| TO00 | ✓ | ✓ | ✓ | ✓ |
| TI01 | ✓ | ✓ | ✓ | ✓ |
| TO01 | ✓ | ✓ | ✓ | ✓ |
| TI02 | ✓ | ✓ | ✓ | ✓ |
| TO02 | ✓ | ✓ | ✓ | ✓ |
| TI03 | ✓ | ✓ | — | — |
| TO03 | ✓ | ✓ | — | — |
| TI04 | ✓ | — | — | — |
| TO04 | ✓ | — | — | — |
| TI05 | ✓ | ✓ | — | — |
| TO05 | ✓ | ✓ | — | — |
| TI06 | ✓ | — | — | — |
| TO06 | ✓ | — | — | — |
| TI07 | ✓ | ✓ | — | — |
| TO07 | ✓ | ✓ | — | — |

2.2.2 Pins for each product (pins other than port pins)

| Function Name | I/O | Function |
|----------------|--------|--|
| ANI0 to ANI10 | Input | A/D converter analog input (see Figure 10-23 Internal Equivalent Circuit of ANIn Pin). |
| VCOUT0, VCOUT1 | Output | Comparator output |
| IVCMP0, IVCMP1 | Input | Analog input for the comparator |
| IVREF0, IVREF1 | Input | Reference voltage input for the comparator |
| INTP0 to INTP7 | Input | External interrupt request input pin for which the valid edge (rising edge, falling edge, or both rising and falling edges) can be specified. |
| PCLBUZ0 | Output | Clock output/buzzer output |
| RESET | Input | This is the active-low system reset input pin. When the external reset pin is not used, connect this pin directly or via a resistor to V_{DD} . |
| RxD0 | Input | Serial data input pin of serial interface UART0 |
| TxD0 | Output | Serial data output pin of serial interface UART0 |
| SCK00, SCK01 | I/O | Serial clock I/O pins of serial interfaces CSI00 and CSI01 |
| SI00, SI01 | Input | Serial data input pins of serial interfaces CSI00 and CSI01 |
| SO00, SO01 | Output | Serial data output pins of serial interfaces CSI00 and CSI01 |
| SCL00, SCL01 | Output | Serial clock output pins of serial interface simple I ² C (IIC00 and IIC01) |
| SDA00, SDA01 | I/O | Serial data I/O pins of serial interface simple I ² C (IIC00 and IIC01) |
| SCLA0 | I/O | Clock I/O pin of serial interface IICA0 |
| SDAA0 | I/O | Serial data I/O pin of serial interface IICA0 |
| TI00 to TI07 | Input | The pins for inputting an external count clock/capture trigger to 16-bit timers 00 to 07 |
| TO00 to TO07 | Output | Timer output pins of 16-bit timers 00 to 07 |
| X1, X2 | — | Resonator connection for main system clock |
| EXCLK | Input | External clock input for main system clock |
| V_{DD} | — | Positive power supply |
| V_{SS} | — | Ground potential |
| TOOL0 | I/O | Data I/O for flash memory programmer/debugger |
| TOOLRxD | Input | UART reception pin for the external device connection used during flash memory programmer |
| TOOLTxD | Output | UART transmission pin for the external device connection used during flash memory programmer |

Caution After reset release, the relationships between P40/TOOL0 and the operating mode are as follows.

Table 2-1. Relationships Between P40/TOOL0 and Operation Mode After Reset Release

| P40/TOOL0 | Operating mode |
|-----------|-------------------------------|
| V_{DD} | Normal operation mode |
| 0V | Flash memory programming mode |

For details, see **19.4.2 Flash memory programming mode**.

Remark Use bypass capacitors (about 0.1 μ F) as noise and latch up countermeasures with relatively thick wires at the shortest distance to V_{DD} to V_{SS} line.

2.3 Connection of Unused Pins

Table 2-2 shows the connections of unused pins.

Remark The pins mounted depend on the product. Refer to **1.3 Pin Configuration (Top View)** and **2.1 Port Function**.

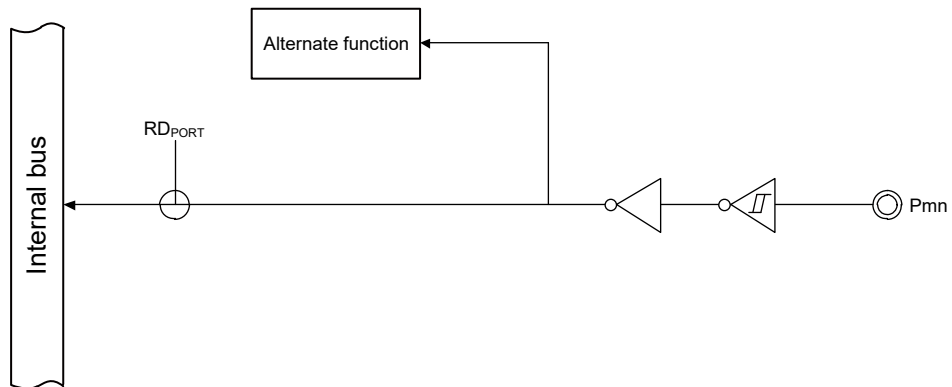
Table 2-2. Connections of Unused Pins

| Pin Name | I/O | Recommended Connection of Unused Pins |
|---------------------------------|-------|---|
| P00 to P07 | I/O | Input: Independently connect to V_{DD} or V_{SS} via a resistor. Output: Leave open. |
| P20 to P23 | | Input: Independently connect to V_{DD} or V_{SS} via a resistor. Output: Leave open. |
| P40/TOOL0 | | Input: Independently connect to V_{DD} via a resistor. Output: Leave open. |
| P41 | | Input: Independently connect to V_{DD} or V_{SS} via a resistor. Output: Leave open. |
| P121, P122 | I/O | Input: Independently connect to V_{DD} or V_{SS} via a resistor. Output: Leave open. |
| P125/ $\overline{\text{RESET}}$ | I/O | PORTSELB = 0: Input: Independently connect to V_{DD} via a resistor. Output: Leave open. PORTSELB = 1: Leave open, or connect to V_{DD} . |
| P137 | Input | Independently connect to V_{DD} or V_{SS} via a resistor. |

2.4 Block Diagrams of Pins

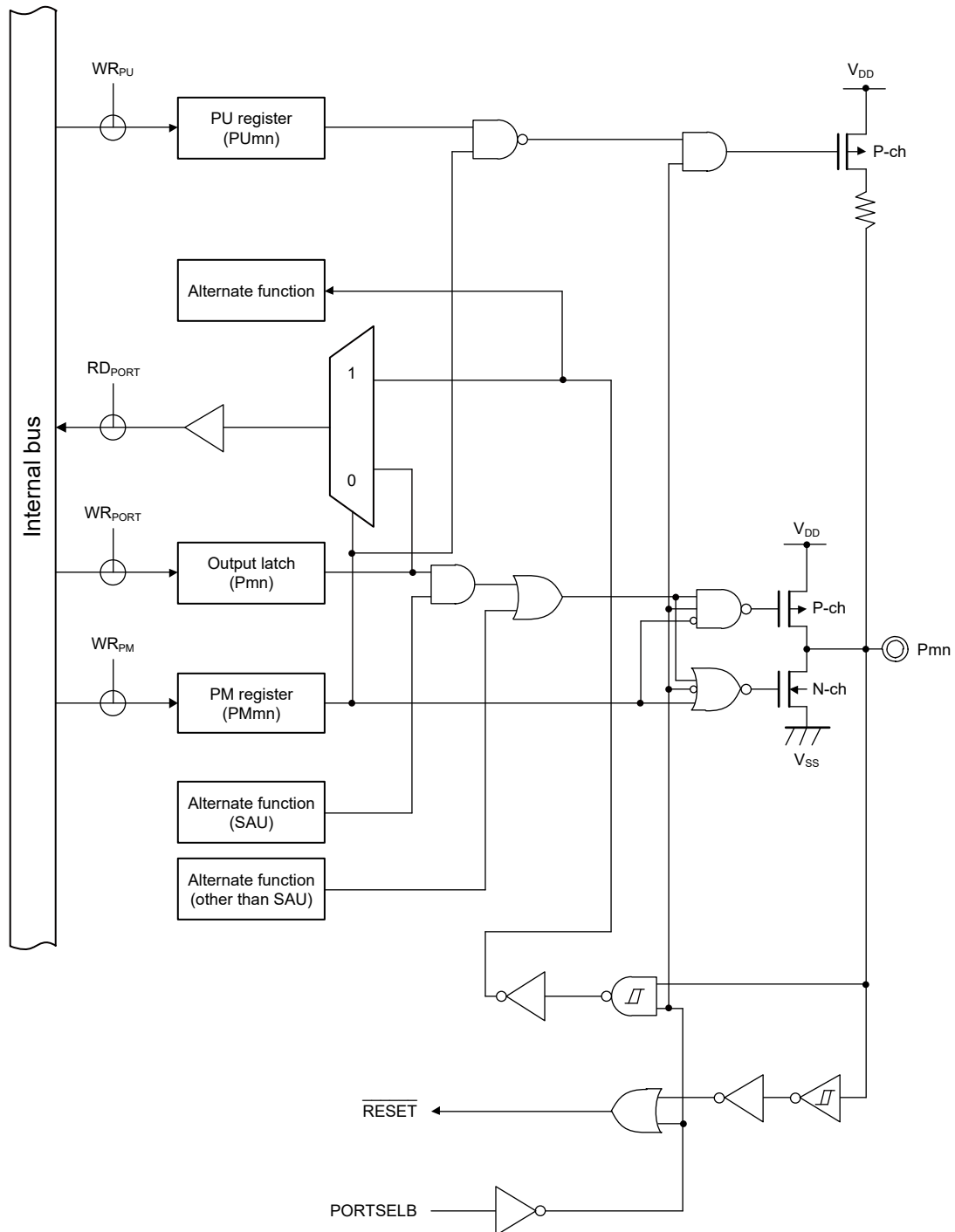
Figure 2-1 to Figure 2-9 show the block diagrams of the pins described in 2.1.1 8-pin products to 2.1.4 20-pin products.

Figure 2-1. Pin Block Diagram for Pin Type 2-1-2



Remark For alternate functions, see 2.1 Port Function.

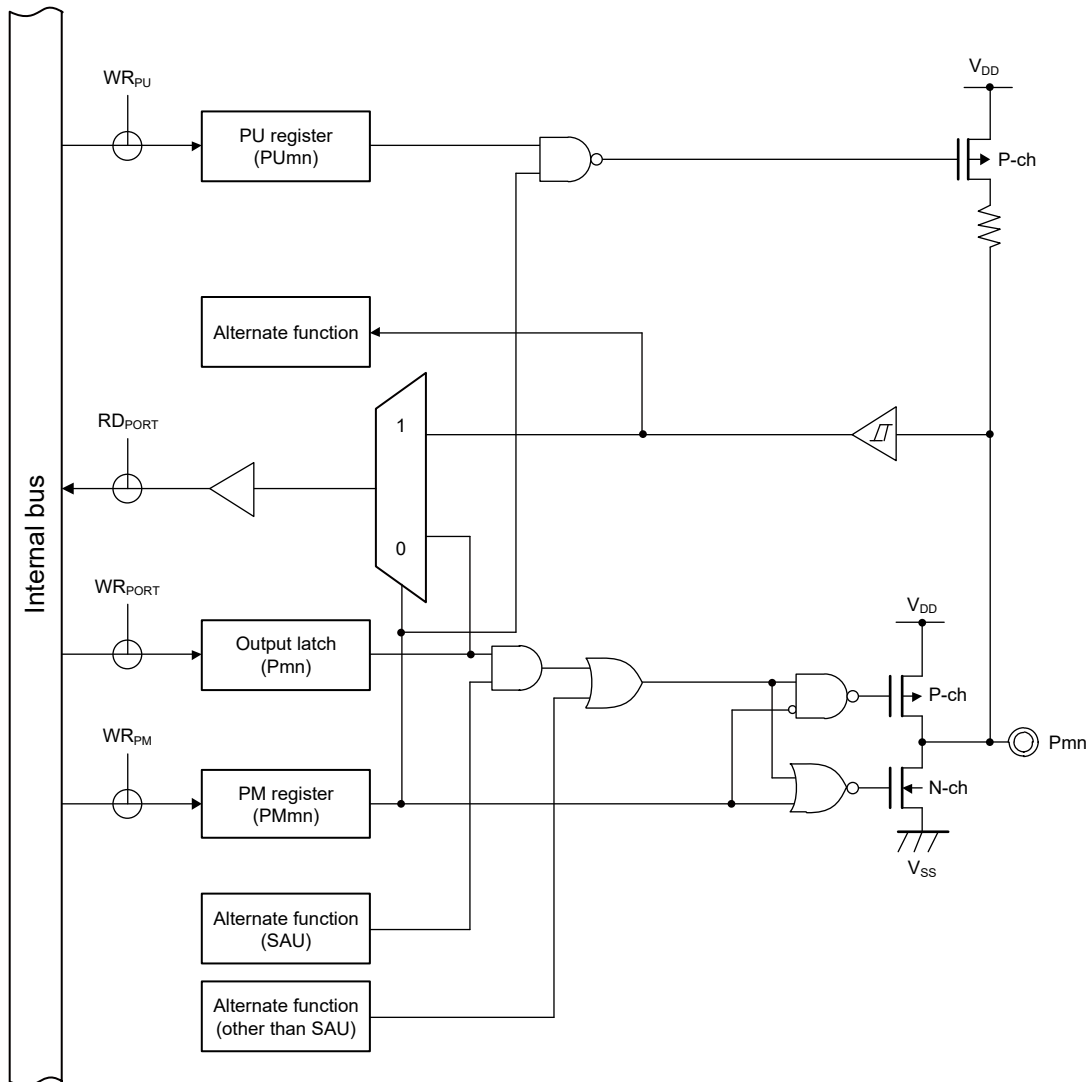
Figure 2-2. Pin Block Diagram for Pin Type 3-2-1



Remark 1. For alternate functions, see 2.1 Port Function.

Remark 2. SAU: Serial array unit

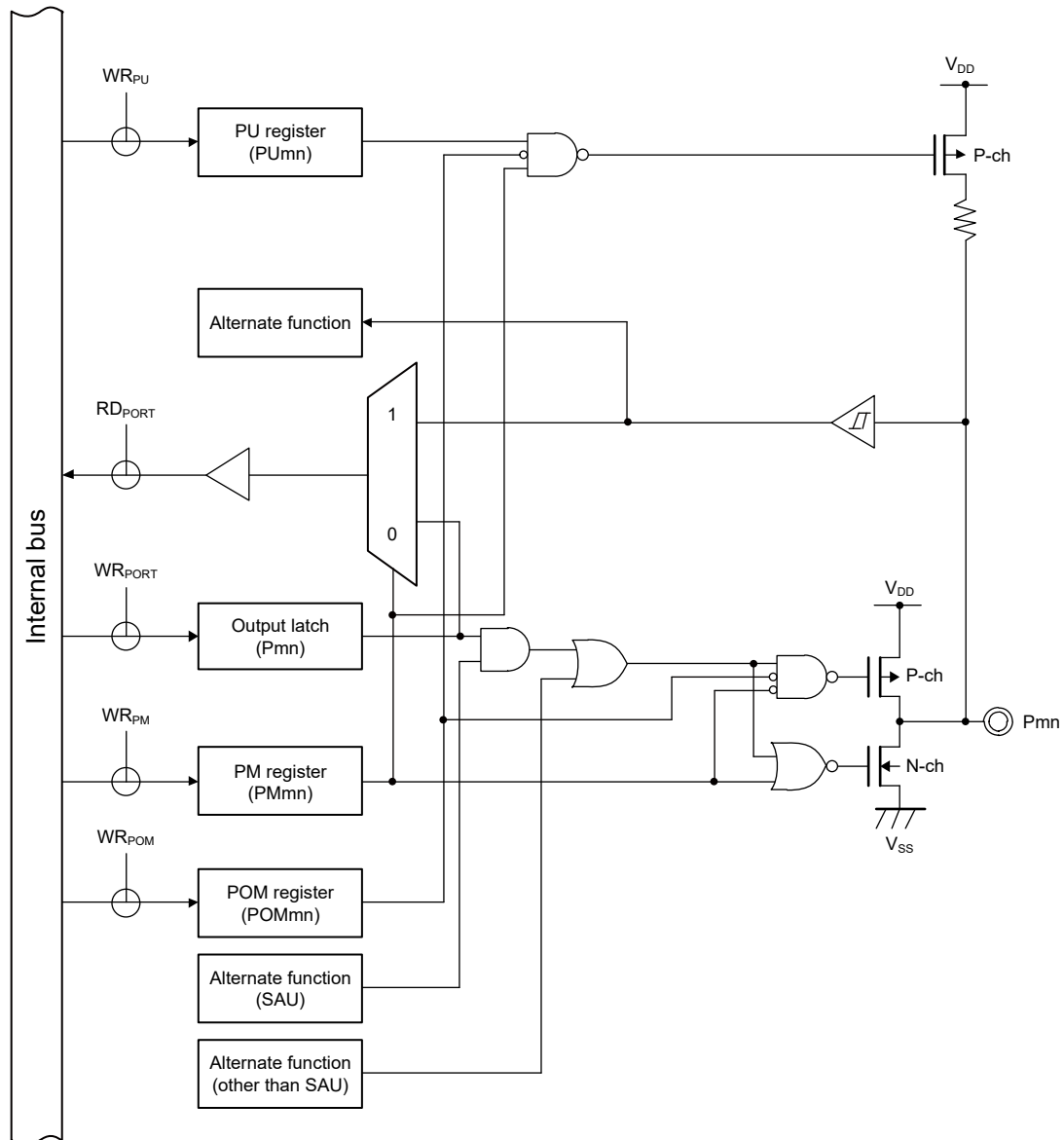
Figure 2-3. Pin Block Diagram for Pin Type 7-1-1



Remark 1. For alternate functions, see **2.1 Port Function**.

Remark 2. SAU: Serial array unit

Figure 2-4. Pin Block Diagram for Pin Type 7-1-2

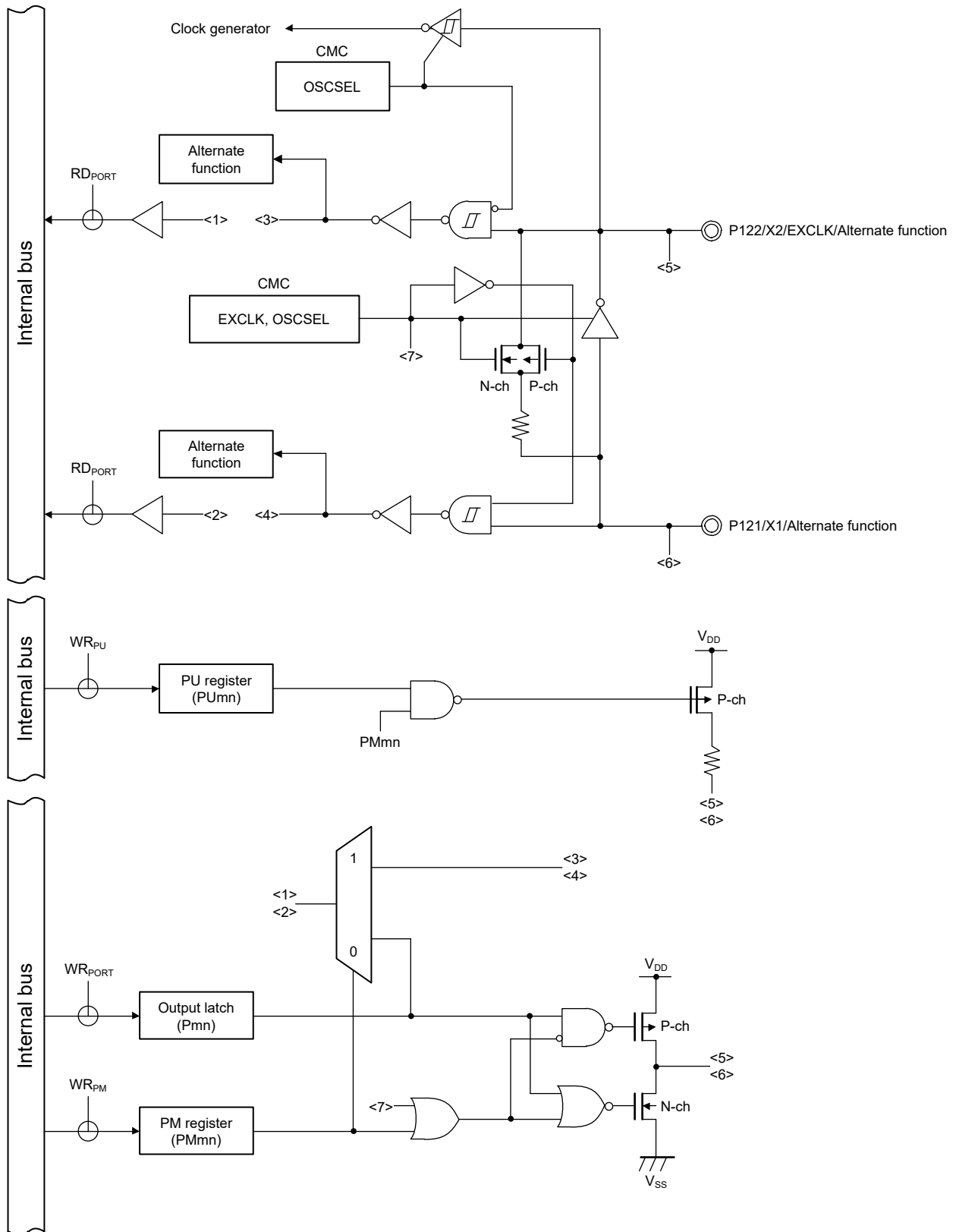


Caution The input buffer is enabled even if the type 7-1-2 pin is operating as an output when the N-ch open drain output mode is selected by the corresponding bit in the port output mode register (POMxx). This may lead to a through current flowing through the type 7-1-2 pin when the voltage level on this pin is intermediate.

Remark 1. For alternate functions, see 2.1 Port Function.

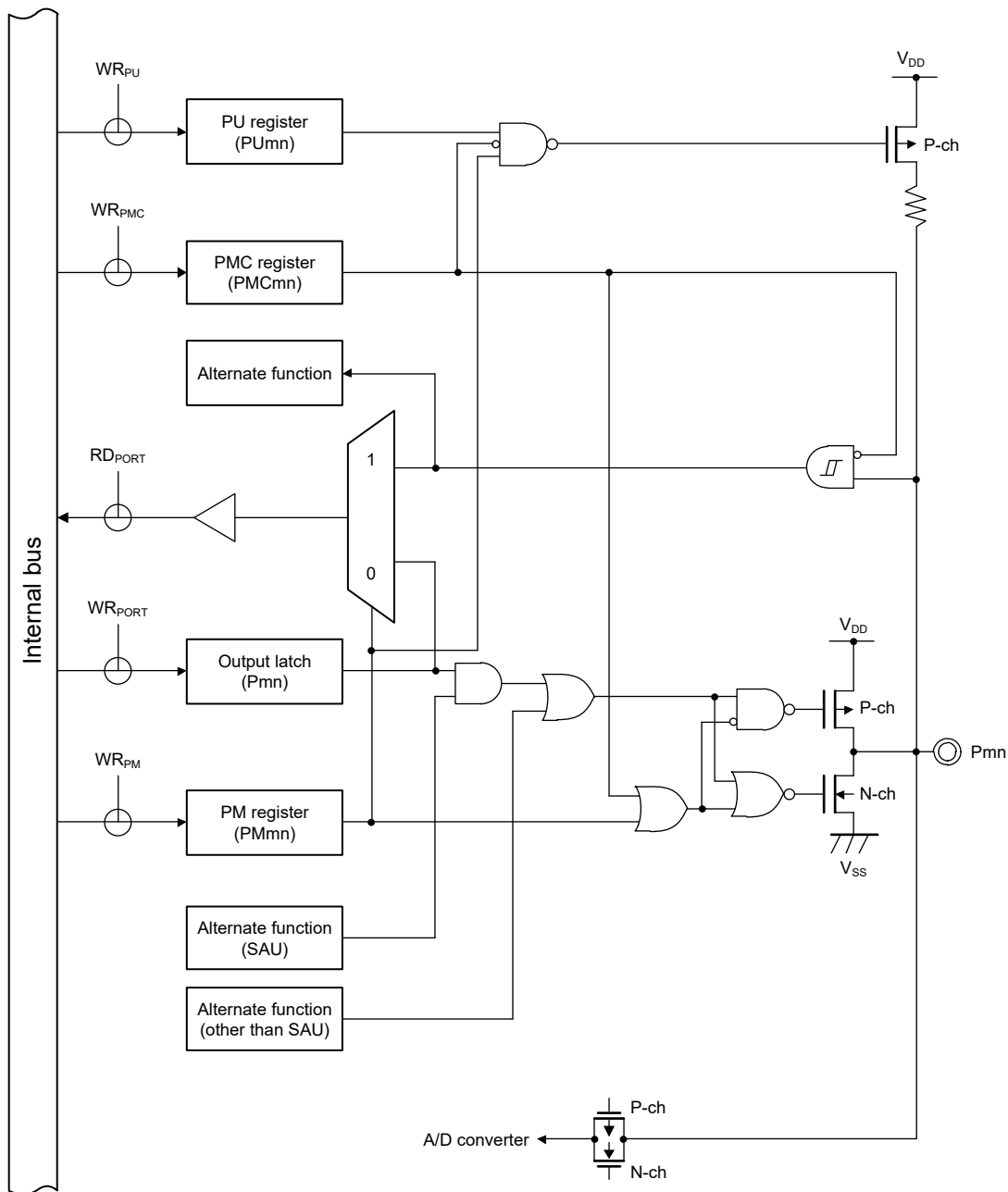
Remark 2. SAU: Serial array unit

Figure 2-5. Pin Block Diagram for Pin Type 7-2-2



Remark 1. For alternate functions, see 2.1 Port Function.

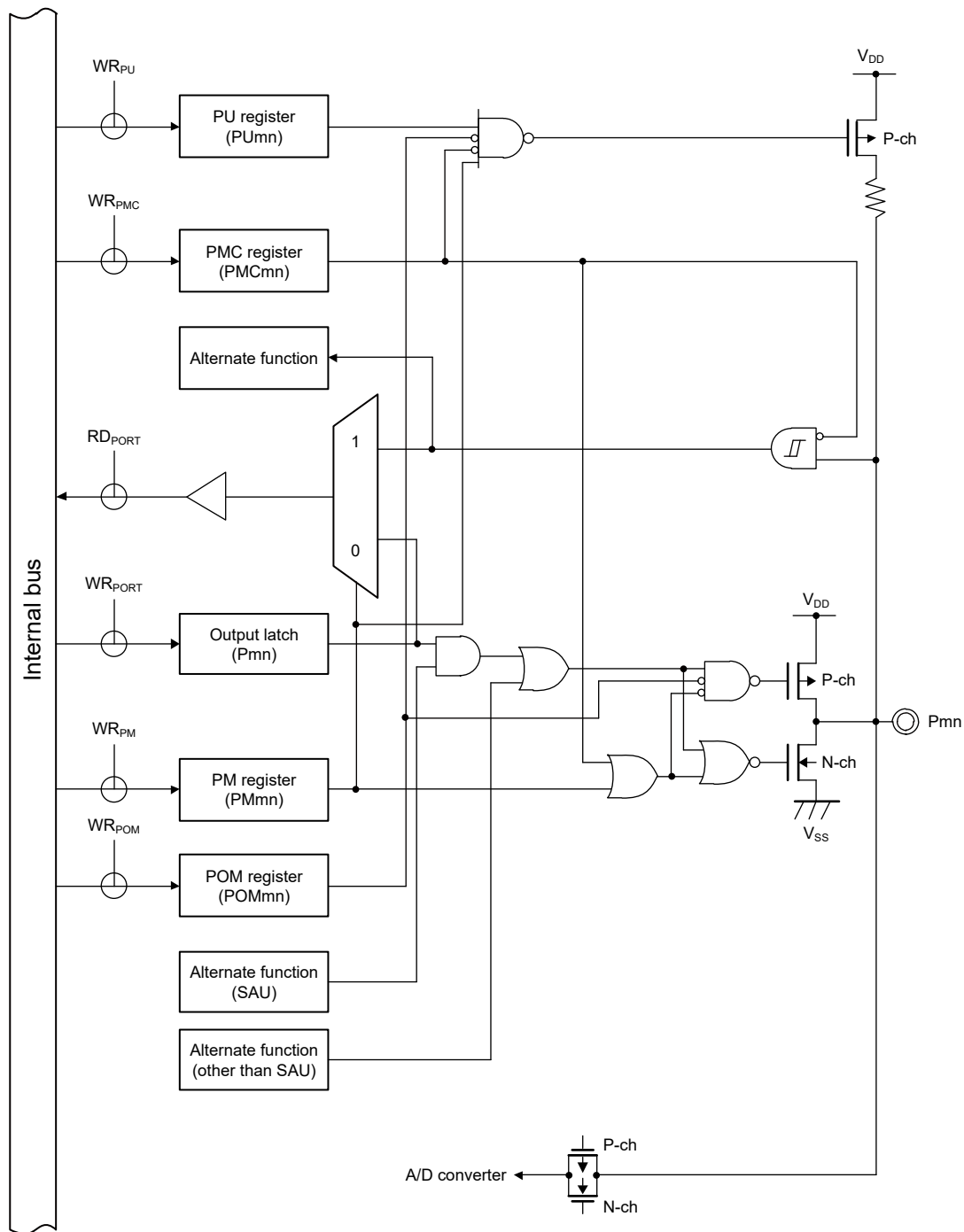
Figure 2-6. Pin Block Diagram for Pin Type 7-3-1



Remark 1. For alternate functions, see 2.1 Port Function.

Remark 2. SAU: Serial array unit

Figure 2-7. Pin Block Diagram for Pin Type 7-3-2

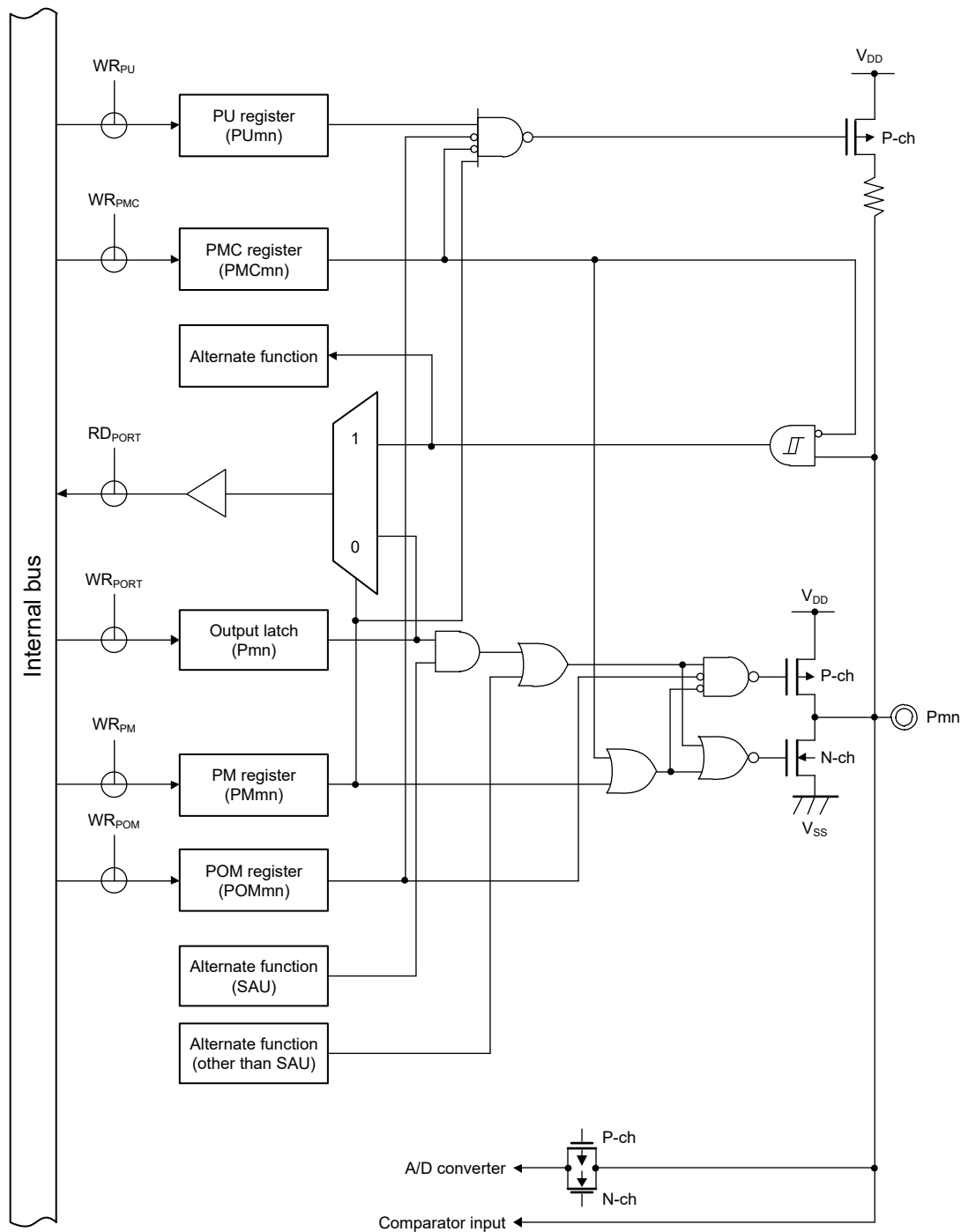


Caution The input buffer is enabled even if the type 7-3-2 pin is operating as an output when the N-ch open drain output mode is selected by the corresponding bit in the port output mode register (POMxx). This may lead to a through current flowing through the type 7-3-2 pin when the voltage level on this pin is intermediate.

Remark 1. For alternate functions, see 2.1 Port Function.

Remark 2. SAU: Serial array unit

Figure 2-9. Pin Block Diagram for Pin Type 7-9-2



Caution The input buffer is enabled even if the type 7-9-2 pin is operating as an output when the N-ch open drain output mode is selected by the corresponding bit in the port output mode register (POMxx). This may lead to a through current flowing through the type 7-9-2 pin when the voltage level on this pin is intermediate.

Remark 1. For alternate functions, see 2.1 Port Function.

Remark 2. SAU: Serial array unit

CHAPTER 3 CPU ARCHITECTURE

3.1 Overview

The CPU core of the RL78 microcontroller is based on the Harvard architecture where instruction fetch buses, address buses, and data buses are kept separate. In addition, through the adoption of three-stage pipeline control of fetch, decode, and memory access, the operation efficiency is improved drastically over the conventional CPU core. The CPU core features high performance and highly functional instruction processing, and can be suited for use in various applications that require high speed and highly functional processing.

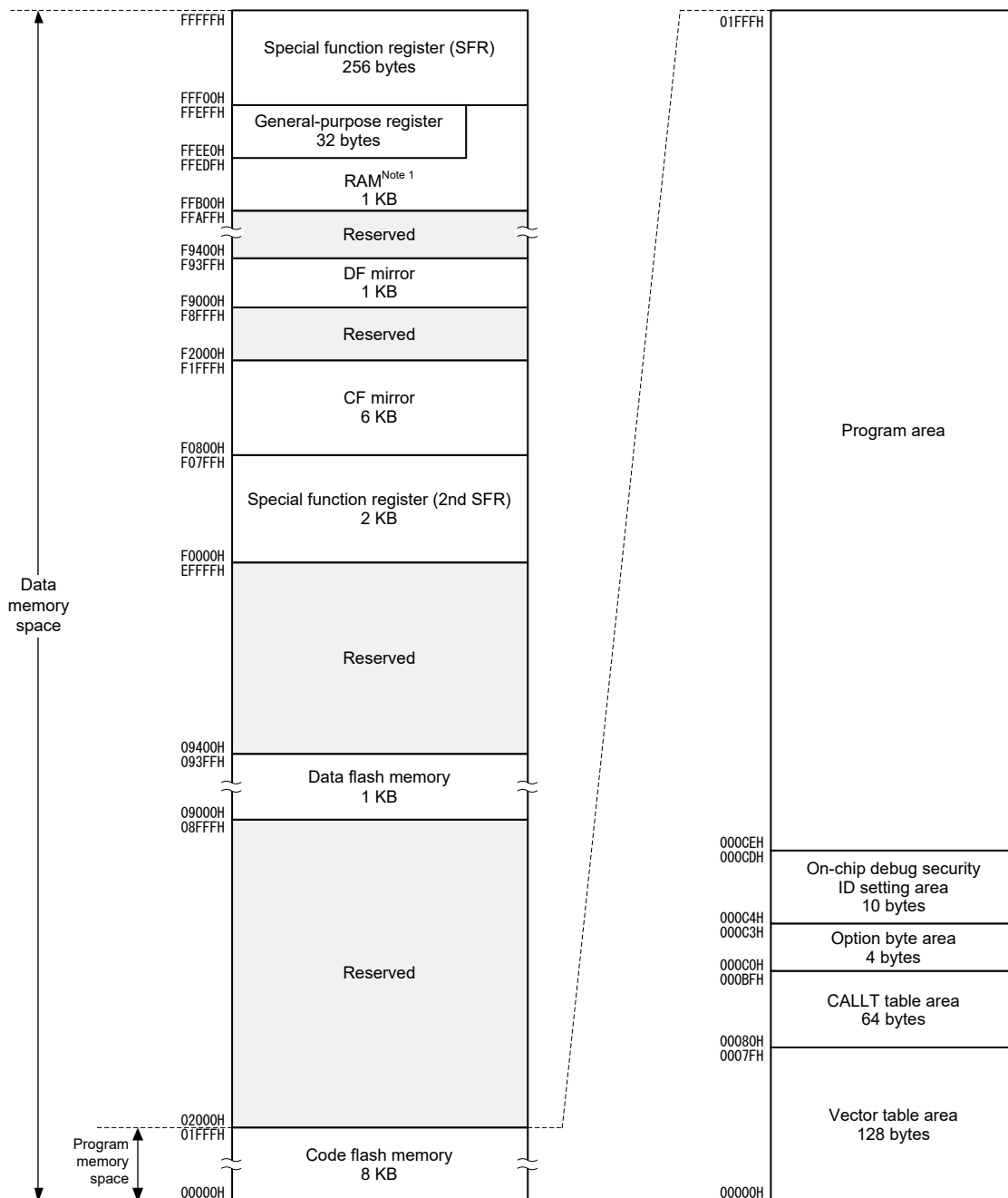
The RL78/G15 has the RL78-S2 CPU core. Its main features are as follows.

- 3-stage pipeline CISC architecture
- Address space: 1 Mbyte
- Minimum instruction execution time: One clock cycle for one instruction
- General-purpose register: 8-bit registers × 8 × 4 banks
- Types of instruction: 75
- Data allocation: Little endian

3.2 Memory Space

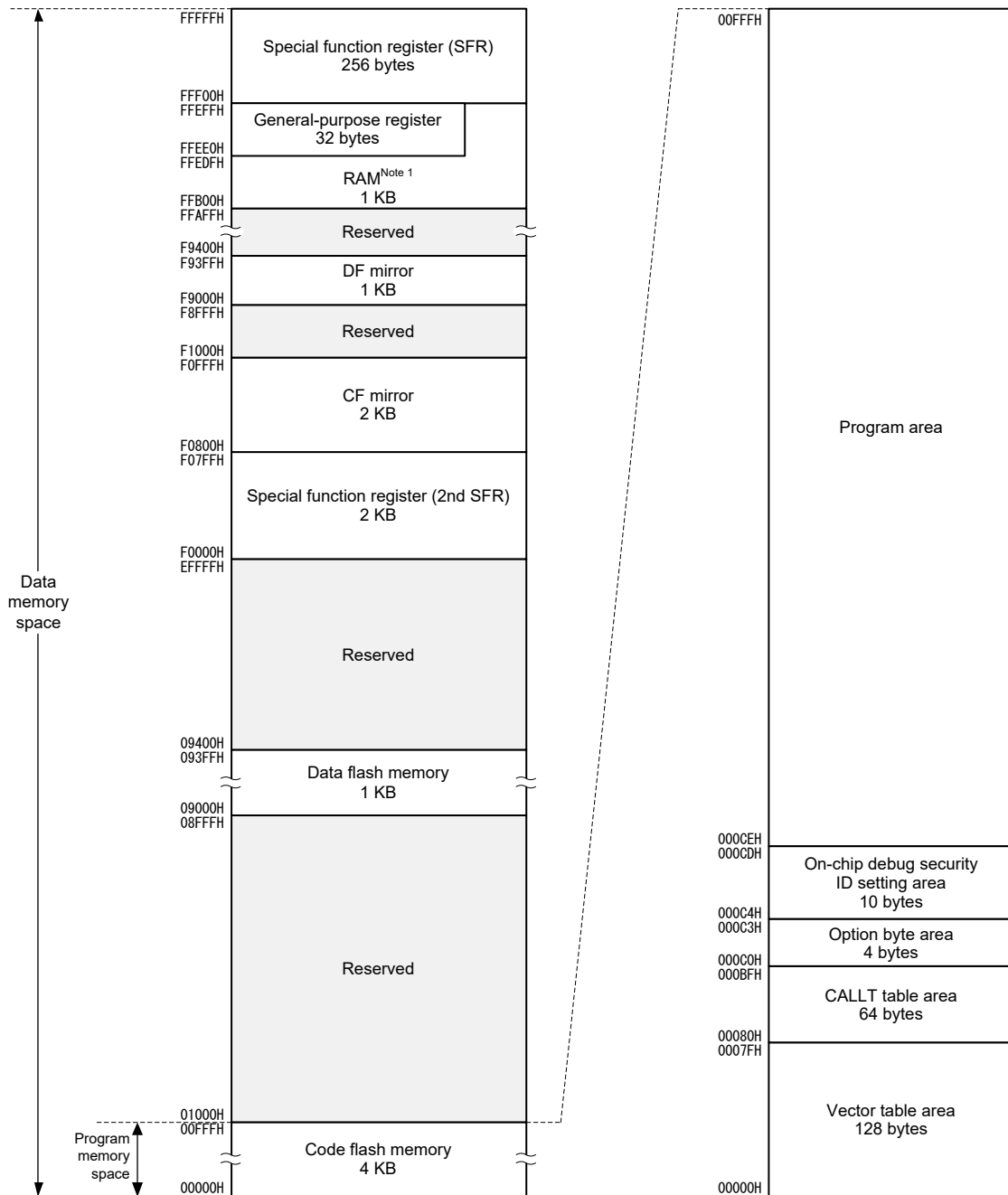
Products in the RL78/G15 can access a 1-MB address space. **Figure 3-1** and **Figure 3-2** show the memory maps.

Figure 3-1. Memory Map (R5F120x8 (x = 0, 1, 4, 6))



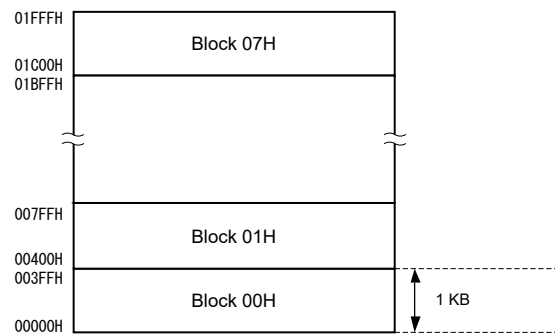
Note 1. Instructions can be executed from the RAM area excluding the general-purpose register area.

Figure 3-2. Memory Map (R5F120x7 (x = 0, 1, 4, 6))



Note 1. Instructions can be executed from the RAM area excluding the general-purpose register area.

Remark The flash memory is divided into blocks (one block = 1 KB). For the address values and block numbers, see **Table 3-1. Correspondence Between Address Values and Block Numbers in Flash Memory.**



(R5F120x8 (x = 0, 1, 4, 6))

Table 3-1. Correspondence Between Address Values and Block Numbers in Flash Memory

| Address Value | Block Number |
|------------------|--------------|
| 00000H to 003FFH | 00H |
| 00400H to 007FFH | 01H |
| 00800H to 00BFFH | 02H |
| 00C00H to 00FFFH | 03H |
| 01000H to 013FFH | 04H |
| 01400H to 017FFH | 05H |
| 01800H to 01BFFH | 06H |
| 01C00H to 01FFFH | 07H |

3.2.1 Internal program memory space

The internal program memory space stores the program and table data. The RL78/G15 products incorporate internal ROM (flash memory), as shown below.

Table 3-2. Internal ROM Capacity

| Part Number | Internal ROM | |
|---------------------------|--------------|----------------------------------|
| | Structure | Capacity |
| R5F120x8 (x = 0, 1, 4, 6) | Flash memory | 8192 × 8 bits (00000H to 01FFFH) |
| R5F120x7 (x = 0, 1, 4, 6) | | 4096 × 8 bits (00000H to 00FFFH) |

The internal program memory space is divided into the following areas.

(1) Vector table area

The 128-byte area 00000H to 0007FH is reserved as a vector table area. The program start addresses for branch upon reset or generation of each interrupt request are stored in the vector table area. Furthermore, the interrupt jump address is a 64 K address of 00000H to 0FFFFH, because the vector code is assumed to be 2 bytes.

Of the 16-bit address, the lower 8 bits are stored at even addresses and the higher 8 bits are stored at odd addresses.

Table 3-3. Vector Table

| Vector Table Address | Interrupt Source | 20-pin | 16-pin | 10-pin | 8-pin |
|----------------------|-----------------------------|--------|--------|--------|-------|
| 00000H | RESET, SPOR, WDT, TRAP, IAW | ✓ | ✓ | ✓ | ✓ |
| 00004H | INTWDTI | ✓ | ✓ | ✓ | ✓ |
| 00006H | INTP0 | ✓ | ✓ | ✓ | ✓ |
| 00008H | INTP1 | ✓ | ✓ | ✓ | ✓ |
| 0000AH | INTP2 | ✓ | ✓ | ✓ | ✓ |
| 0000CH | INTP3 | ✓ | ✓ | ✓ | ✓ |
| 0000EH | INTP4 | ✓ | ✓ | ✓ | ✓ |
| 00010H | INTP5 | ✓ | ✓ | ✓ | ✓ |
| 00012H | INTST0, INTCSI00, INTIIC00 | ✓ | ✓ | ✓ | ✓ |
| 00014H | INTSR0, INTCSI01, INTIIC01 | ✓ | ✓ | ✓ | ✓ |
| 00016H | INTSRE0 | ✓ | ✓ | ✓ | ✓ |
| 00018H | INTTM01H | ✓ | ✓ | ✓ | ✓ |
| 0001AH | INTTM00 | ✓ | ✓ | ✓ | ✓ |
| 0001CH | INTTM01 | ✓ | ✓ | ✓ | ✓ |
| 0001EH | INTAD | ✓ | ✓ | ✓ | ✓ |
| 00020H | INTP6 | ✓ | ✓ | ✓ | — |
| 00022H | INTP7 | ✓ | ✓ | ✓ | — |
| 00024H | INTTM03H | ✓ | ✓ | ✓ | ✓ |
| 00026H | INTICA0 | ✓ | ✓ | ✓ | ✓ |
| 00028H | INTTM02 | ✓ | ✓ | ✓ | ✓ |
| 0002AH | INTTM03 | ✓ | ✓ | ✓ | ✓ |
| 0002CH | INTIT | ✓ | ✓ | ✓ | ✓ |
| 0002EH | INTTM04 | ✓ | ✓ | ✓ | ✓ |
| 00030H | INTTM05 | ✓ | ✓ | ✓ | ✓ |
| 00032H | INTTM06 | ✓ | ✓ | ✓ | ✓ |
| 00034H | INTTM07 | ✓ | ✓ | ✓ | ✓ |
| 00036H | INTCMP0 | ✓ | ✓ | ✓ | ✓ |
| 00038H | INTCMP1 | ✓ | — | — | — |
| 0007EH | BRK | ✓ | ✓ | ✓ | ✓ |

(2) CALLT instruction table area

The 64-byte area 00080H to 000BFH can store the subroutine entry address of a 2-byte call instruction (CALLT). Set the subroutine entry address to a value in a range of 00000H to 0FFFFH (because an address code is of 2 bytes).

(3) Option byte area

A 4-byte area of 000C0H to 000C3H can be used as an option byte area. For details, see **CHAPTER 18 OPTION BYTE**.

(4) On-chip debug security ID setting area

A 10-byte area of 000C4H to 000CDH can be used as an on-chip debug security ID setting area. For details, see **CHAPTER 20 ON-CHIP DEBUG FUNCTION**.

3.2.2 Mirror area

The RL78/G15 mirrors the code flash area of 00800H to 01FFFFH, to F0800H to F1FFFFH. It also mirrors the data flash area of 09000H to 093FFFH, to F9000H to F93FFFH.

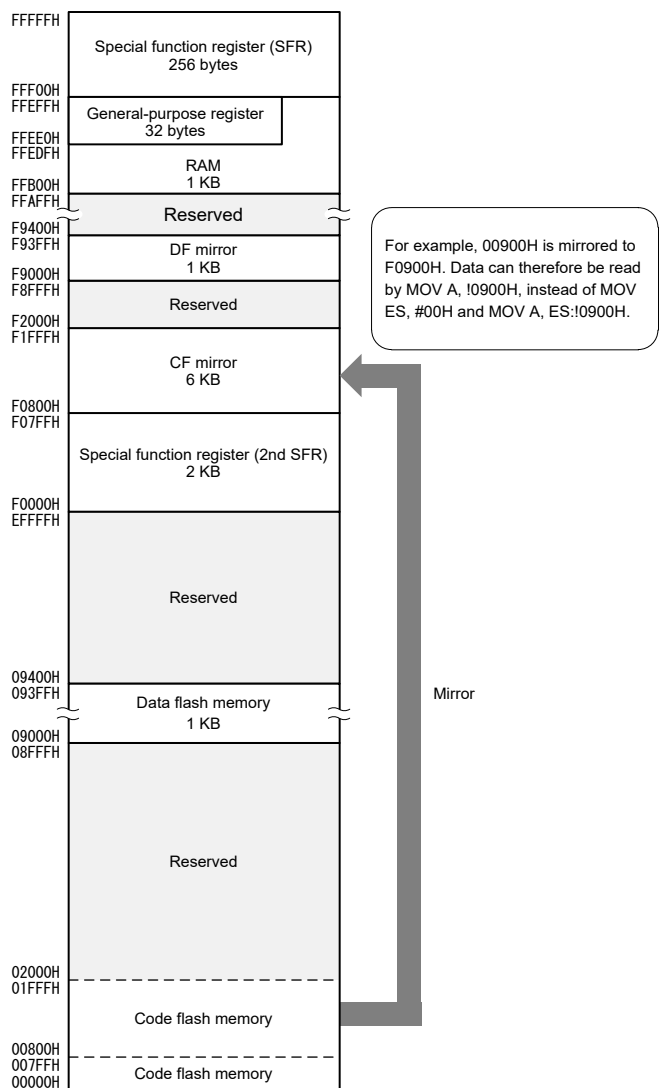
By reading data from F0800H to F1FFFFH and F9000H to F93FFFH, an instruction that does not have the ES register as an operand can be used, and thus the contents of the code flash can be read with the shorter code. However, the code flash area is not mirrored to the SFR, extended SFR, RAM, and use prohibited areas.

See **3.2 Memory Space** for the mirror area of each product.

The mirror area can only be read and no instruction can be fetched from this area.

The following shows examples.

Example) R5F120x8 (x = 0, 1, 4, 6) (Flash memory: 8 KB, RAM: 1 KB)



3.2.3 Internal data memory space

The RL78/G15 products incorporate the following RAMs.

Table 3-4. Internal RAM Capacity

| Part Number | Internal RAM |
|---------------------------|----------------------------------|
| R5F120x8 (x = 0, 1, 4, 6) | 1024 × 8 bits (FFB00H to FFEFFH) |
| R5F120x7 (x = 0, 1, 4, 6) | |

The internal RAM can be used as a data area and a program area where instructions are fetched (it is prohibited to use the general-purpose register area for fetching instructions). Four general-purpose register banks consisting of eight 8-bit registers per bank are assigned to the 32-byte area of FFEE0H to FFEFFH of the internal RAM area.

The internal RAM is used as stack memory.

Caution It is prohibited to use the general-purpose register (FFEE0H to FFEFFH) space for fetching instructions or as a stack area.

3.2.4 Special function register (SFR) area

On-chip peripheral hardware special function registers (SFRs) are allocated in the area FFF00H to FFFFFH (see Table 3-5 in 3.3.4 Special function registers (SFRs)).

Caution Do not access addresses to which SFRs are not assigned.

3.2.5 Extended special function register (2nd SFR: 2nd Special Function Register) area

On-chip peripheral hardware special function registers (2nd SFRs) are allocated in the area F0000H to F07FFH (see Table 3-6 in 3.3.5 Extended special function registers (2nd SFRs: 2nd Special Function Registers)).

SFRs other than those in the SFR area (FFF00H to FFFFFH) are allocated to this area. An instruction that accesses the extended SFR area, however, is 1 byte longer than an instruction that accesses the SFR area.

Caution Do not access addresses to which extended SFRs are not assigned.

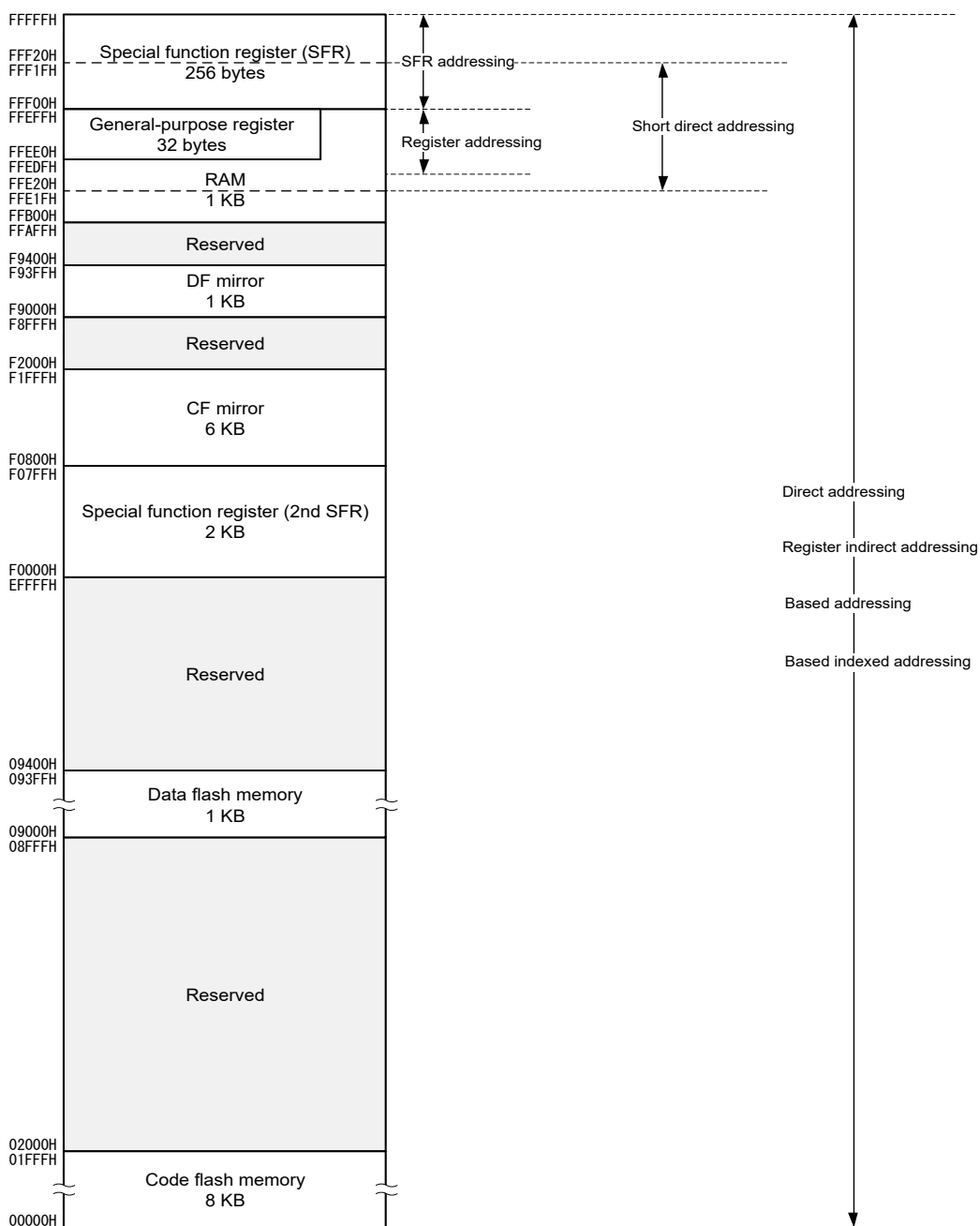
3.2.6 Data memory addressing

Addressing refers to the method of specifying the address of the instruction to be executed next or the address of the register or memory relevant to the execution of instructions.

Several addressing modes are provided for addressing the memory relevant to the execution of instructions for the RL78/G15, based on operability and other considerations. In particular, special addressing methods designed for the functions of the special function registers (SFR) and general-purpose registers are available for use. **Figure 3-3** shows correspondence between data memory and addressing.

For details of each addressing, see **3.5 Addressing for Processing Data Addresses**.

Figure 3-3. Correspondence Between Data Memory and Addressing



3.3 Processor Registers

The RL78/G15 products incorporate the following processor registers.

3.3.1 Control registers

The control registers control the program sequence, status, and stack memory. The control registers consist of a program counter (PC), a program status word (PSW) and a stack pointer (SP).

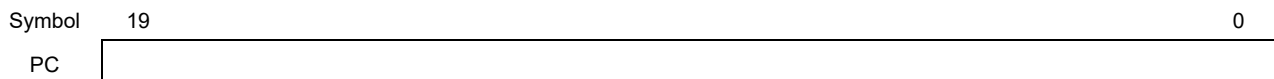
(1) Program counter (PC)

The program counter is a 20-bit register that holds the address information of the next program to be executed.

In normal operation, PC is automatically incremented according to the number of bytes of the instruction to be fetched. When a branch instruction is executed, immediate data and register contents are set.

Reset signal generation sets the reset vector table values at addresses 00000H and 00001H to the 16 lower-order bits of the program counter. The four higher-order bits of the program counter are cleared to 0000.

Figure 3-4. Format of Program Counter



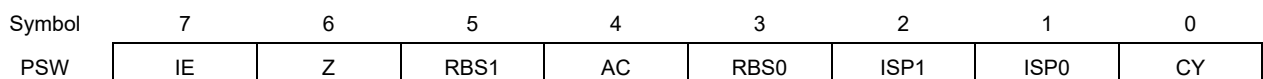
(2) Program status word (PSW)

The program status word is an 8-bit register consisting of various flags set/reset by instruction execution.

Program status word contents are stored in the stack area upon vectored interrupt request is acknowledged or PUSH PSW instruction execution and are restored upon execution of the RETB, RETI and POP PSW instructions.

Reset signal generation sets the PSW register to 06H.

Figure 3-5. Format of Program Status Word



(a) Interrupt enable flag (IE)

This flag controls the interrupt request acknowledge operations of the CPU.

When 0, the IE flag is set to the interrupt disabled (DI) state, and all maskable interrupt requests are disabled.

When 1, the IE flag is set to the interrupt enabled (EI) state and maskable interrupt request acknowledgment is controlled with an in-service priority flag (ISP1, ISP0), an interrupt mask flag for various interrupt sources, and a priority specification flag.

The IE flag is reset (0) upon DI instruction execution or interrupt acknowledgment and is set (1) upon EI instruction execution.

(b) Zero flag (Z)

When the operation or comparison result is zero or equal, this flag is set (1). It is reset (0) in all other cases.

(c) Register bank select flags (RBS0, RBS1)

These are 2-bit flags to select one of the four register banks.

In these flags, the 2-bit information that indicates the register bank selected by SEL RBn instruction execution is stored.

(d) Auxiliary carry flag (AC)

If the operation result has a carry from bit 3 or a borrow at bit 3, this flag is set (1). It is reset (0) in all other cases.

(e) In-service priority flags (ISP1, ISP0)

These flags manage the priority of acknowledgeable maskable vectored interrupts. Vectored interrupt requests specified lower than the value of ISP0 and ISP1 flags by the priority specification flag registers (PRn0L, PRn0H, PRn1L, PRn1H) (see **14.3.3**) cannot be acknowledged. Actual vectored interrupt request acknowledgment is controlled by the interrupt enable flag (IE).

Remark n = 0, 1

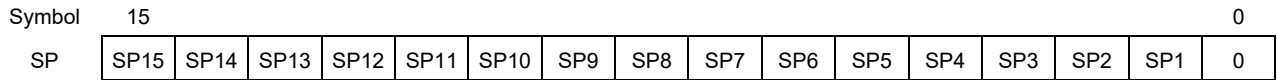
(f) Carry flag (CY)

This flag stores overflow and underflow upon add/subtract instruction execution. It stores the shift-out value upon rotate instruction execution and functions as a bit accumulator during bit operation instruction execution.

(3) Stack pointer (SP)

This is a 16-bit register to hold the start address of the memory stack area. Only the internal RAM area can be set as the stack area.

Figure 3-6. Format of Stack Pointer



In stack addressing through a stack pointer, the SP is decremented ahead of write (save) to the stack memory and is incremented after read (restore) from the stack memory.

Caution 1. Since reset signal generation makes the SP contents undefined, be sure to initialize the SP before using the stack.

Caution 2. It is prohibited to use the general-purpose register (FFEE0H to FFEFFH) space for fetching instructions or a stack area.

3.3.2 General-purpose registers

General-purpose registers are mapped at particular addresses (FFEE0H to FFEFFH) of the data memory. The general-purpose registers consists of 4 banks, each bank consisting of eight 8-bit registers (X, A, C, B, E, D, L, and H).

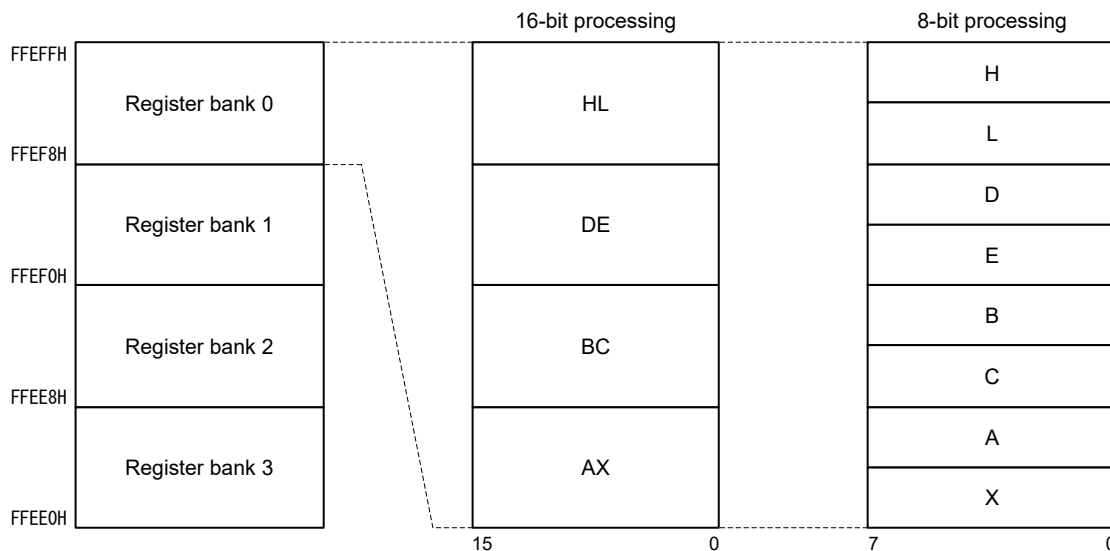
Each register can be used as an 8-bit register, and two 8-bit registers can also be used in a pair as a 16-bit register (AX, BC, DE, and HL).

Register banks to be used for instruction execution are set by the CPU control instruction (SEL RBn). Because of the 4-register bank configuration, an efficient program can be created by switching between a register for normal processing and a register for interrupt processing for each bank.

Caution It is prohibited to use the general-purpose register (FFEE0H to FFEFFH) space for fetching instructions or as a stack area.

Figure 3-7. Configuration of General-Purpose Registers

(a) Function name



3.3.3 ES and CS registers

The ES register and CS register are used to specify the higher address for data access and when a branch instruction is executed (register indirect addressing), respectively.

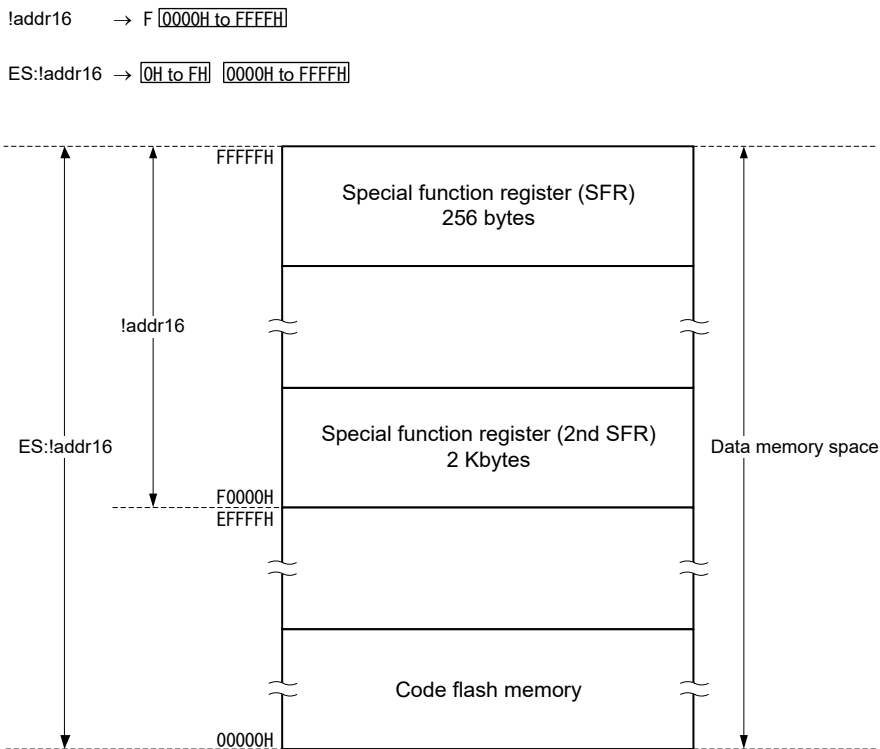
The default value of the ES register after reset is 0FH, and that of the CS register is 00H.

Figure 3-8. Configuration of ES and CS Registers

| | | | | | | | | |
|--------|---|---|---|---|-----|-----|-----|-----|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| ES | 0 | 0 | 0 | 0 | ES3 | ES2 | ES1 | ES0 |
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| CS | 0 | 0 | 0 | 0 | CS3 | CS2 | CS1 | CS0 |

Though the data area which can be accessed with 16-bit addresses is the 64 Kbytes from F0000H to FFFFFH, using the ES register as well extends this to the 1 Mbyte from 00000H to FFFFFH.

Figure 3-9. Extension of Data Area Which Can Be Accessed



3.3.4 Special function registers (SFRs)

Unlike a general-purpose register, each SFR has a special function.

SFRs are allocated to the FFF00H to FFFFFH area.

SFRs can be manipulated like general-purpose registers, using operation, transfer, and bit manipulation instructions. The manipulable bit units, 1, 8, and 16, depend on the SFR type.

Each manipulation bit unit can be specified as follows.

[1-bit manipulation]

Describe as follows for the 1-bit manipulation instruction operand (sfr.bit).

When the bit name is defined: <Bit name>

When the bit name is not defined: <Register name>.<Bit number> or <Address>.<Bit number>

[8-bit manipulation]

Describe the symbol defined by the assembler for the 8-bit manipulation instruction operand (sfr). This manipulation can also be specified with an address.

[16-bit manipulation]

Describe the symbol defined by the assembler for the 16-bit manipulation instruction operand (sfrp). When specifying an address, describe an even address.

Table 3-5 gives a list of the SFRs. The meanings of items in the table are as follows.

[Symbol]

Symbol indicating the address of a special function register. It is a reserved word in the assembler, and is defined as an sfr variable using the #pragma sfr directive in the compiler. When using the assembler, debugger, and simulator, symbols can be written as an instruction operand.

[R/W]

Indicates whether the corresponding SFR can be read or written.

R/W: Read/write enable

R: Read only

W: Write only

[Manipulable bit units]

“✓” indicates the manipulable bit unit (1, 8, or 16). “—” indicates a bit unit for which manipulation is not possible.

[After reset]

Indicates each register status upon reset signal generation.

Caution Do not access addresses to which extended SFRs are not assigned.

Remark For extended SFRs (2nd SFRs), see 3.3.5 Extended special function registers (2nd SFRs: 2nd Special Function Registers).

Table 3-5. SFR List (1/2)

| Address | Special Function Register (SFR) Name | Symbol | | R/W | Manipulable Bit Range | | | After Reset |
|---------|---|------------|-------|-----|-----------------------|-------|--------|-------------|
| | | | | | 1-bit | 8-bit | 16-bit | |
| FFF00H | Port register 0 | P0 | | R/W | ✓ | ✓ | — | 00H |
| FFF02H | Port register 2 | P2 | | R/W | ✓ | ✓ | — | 00H |
| FFF04H | Port register 4 | P4 | | R/W | ✓ | ✓ | — | 00H |
| FFF0CH | Port register 12 | P12 | | R/W | ✓ | ✓ | — | Undefined |
| FFF0DH | Port register 13 | P13 | | R/W | ✓ | ✓ | — | Undefined |
| FFF10H | Serial data register 00 | TXD0/SIO00 | SDR00 | R/W | — | ✓ | ✓ | 0000H |
| FFF11H | | — | | | — | — | | |
| FFF12H | Serial data register 01 | RXD0/SIO01 | SDR01 | R/W | — | ✓ | ✓ | 0000H |
| FFF13H | | — | | | — | — | | |
| FFF18H | Timer data register 00 | TDR00 | | R/W | — | — | ✓ | 0000H |
| FFF19H | | | | | | | | |
| FFF1AH | Timer data register 01 | TDR01L | TDR01 | R/W | — | ✓ | ✓ | 00H |
| FFF1BH | | TDR01H | | | — | ✓ | 00H | |
| FFF1EH | 10-bit A/D conversion result register | ADCR | | R | — | — | ✓ | 0000H |
| FFF1FH | 8-bit A/D conversion result register | ADCRH | | R | — | ✓ | — | 00H |
| FFF20H | Port mode register 0 | PM0 | | R/W | ✓ | ✓ | — | FFH |
| FFF22H | Port mode register 2 | PM2 | | R/W | ✓ | ✓ | — | FFH |
| FFF24H | Port mode register 4 | PM4 | | R/W | ✓ | ✓ | — | FFH |
| FFF2CH | Port mode register 12 | PM12 | | R/W | ✓ | ✓ | — | FFH |
| FFF30H | A/D converter mode register 0 | ADM0 | | R/W | ✓ | ✓ | — | 00H |
| FFF31H | Analog input channel specification register | ADS | | R/W | ✓ | ✓ | — | 00H |
| FFF38H | External interrupt rising edge enable register 0 | EGP0 | | R/W | ✓ | ✓ | — | 00H |
| FFF39H | External interrupt falling edge enable register 0 | EGN0 | | R/W | ✓ | ✓ | — | 00H |
| FFF50H | IICA shift register 0 | IICA0 | | R/W | — | ✓ | — | 00H |
| FFF51H | IICA status register 0 | IICS0 | | R | ✓ | ✓ | — | 00H |
| FFF52H | IICA flag register 0 | IICF0 | | R/W | ✓ | ✓ | — | 00H |
| FFF60H | Comparator mode setting register | COMPMDR | | R/W | ✓ | ✓ | — | 00H |
| FFF61H | Comparator filter control register | COMPFIR | | R/W | ✓ | ✓ | — | 00H |
| FFF62H | Comparator output control register | COMPOCR | | R/W | ✓ | ✓ | — | 00H |
| FFF64H | Timer data register 02 | TDR02 | | R/W | — | — | ✓ | 0000H |
| FFF65H | | | | | | | | |
| FFF66H | Timer data register 03 | TDR03L | TDR03 | R/W | — | ✓ | ✓ | 00H |
| FFF67H | | TDR03H | | | — | ✓ | 00H | |
| FFF68H | Timer data register 04 | TDR04 | | R/W | — | — | ✓ | 0000H |
| FFF69H | | | | | | | | |
| FFF6AH | Timer data register 05 | TDR05 | | R/W | — | — | ✓ | 0000H |
| FFF6BH | | | | | | | | |
| FFF6CH | Timer data register 06 | TDR06 | | R/W | — | — | ✓ | 0000H |
| FFF6DH | | | | | | | | |

Table 3-5. SFR List (2/2)

| Address | Special Function Register (SFR) Name | Symbol | | R/W | Manipulable Bit Range | | | After Reset |
|---------|--|--------|------|-----|-----------------------|-------|--------|---------------------|
| | | | | | 1-bit | 8-bit | 16-bit | |
| FFF6EH | Timer data register 07 | TDR07 | | R/W | — | — | ✓ | 0000H |
| FFF6FH | | | | | | | | |
| FFF90H | Interval timer control register | ITMC | | R/W | — | — | ✓ | 0FFFH |
| FFF91H | | | | | | | | |
| FFFA0H | Clock operation mode control register | CMC | | R/W | — | ✓ | — | 00H |
| FFFA1H | Clock operation status control register | CSC | | R/W | ✓ | ✓ | — | 80H |
| FFFA2H | Oscillation stabilization time counter status register | OSTC | | R | ✓ | ✓ | — | 00H |
| FFFA3H | Oscillation stabilization time select register | OSTS | | R/W | — | ✓ | — | 07H |
| FFFA4H | System clock control register | CKC | | R/W | ✓ | ✓ | — | 00H |
| FFFA5H | Clock output select register 0 | CKS0 | | R/W | ✓ | ✓ | — | 00H |
| FFFA8H | Reset control flag register | RESF | | R | — | ✓ | — | Undefined Note 1 |
| FFFABH | Watchdog timer enable register | WDTE | | R/W | — | ✓ | — | 1AH/9AH Note 2 |
| FFFE0H | Interrupt request flag register 0 | IF0L | IF0 | R/W | ✓ | ✓ | ✓ | 00H |
| FFFE1H | | IF0H | | R/W | ✓ | ✓ | | 00H |
| FFFE2H | Interrupt request flag register 1 | IF1L | IF1 | R/W | ✓ | ✓ | ✓ | 00H |
| FFFE3H | | IF1H | | R/W | ✓ | ✓ | | 00H |
| FFFE4H | Interrupt mask flag register 0 | MK0L | MK0 | R/W | ✓ | ✓ | ✓ | FFH |
| FFFE5H | | MK0H | | R/W | ✓ | ✓ | | FFH |
| FFFE6H | Interrupt mask flag register 1 | MK1L | MK1 | R/W | ✓ | ✓ | ✓ | FFH |
| FFFE7H | | MK1H | | R/W | ✓ | ✓ | | FFH |
| FFFE8H | Priority specification flag register 00 | PR00L | PR00 | R/W | ✓ | ✓ | ✓ | FFH |
| FFFE9H | | PR00H | | R/W | ✓ | ✓ | | FFH |
| FFFEAH | Priority specification flag register 01 | PR01L | PR01 | R/W | ✓ | ✓ | ✓ | FFH |
| FFFEBH | | PR01H | | R/W | ✓ | ✓ | | FFH |
| FFFECH | Priority specification flag register 10 | PR10L | PR10 | R/W | ✓ | ✓ | ✓ | FFH |
| FFFE DH | | PR10H | | R/W | ✓ | ✓ | | FFH |
| FFFE EH | Priority specification flag register 11 | PR11L | PR11 | R/W | ✓ | ✓ | ✓ | FFH |
| FFFE FH | | PR11H | | R/W | ✓ | ✓ | | FFH |

Note 1. The reset values of the registers vary depending on the reset source as shown below.

| Reset Source | | RESET Input | Reset by Execution of Illegal Instruction | Reset by WDT | Reset by Illegal-Memory Access | Reset by SPOR | Reset by data retention lower limit voltage |
|--------------|-------|-------------|---|--------------|--------------------------------|---------------|---|
| Register | RESF | Cleared (0) | TRAP | Set (1) | Held | | Cleared (0) |
| | WDTRF | | Held | Set (1) | Held | | |
| | IAWRF | | Held | | Set (1) | | |
| | SPORF | | Held | | | Set (1) | |

Note 2. The reset value of the WDTE register is determined by the setting of the option byte.

Remark For extended SFRs (2nd SFRs), see Table 3-6. **Extended SFR (2nd SFR) List (1/4).**

3.3.5 Extended special function registers (2nd SFRs: 2nd Special Function Registers)

Unlike a general-purpose register, each extended SFR (2nd SFR) has a special function.

Extended SFRs are allocated to the F0000H to F07FFH area. SFRs other than those in the SFR area (FFF00H to FFFFFH) are allocated to this area. An instruction that accesses the extended SFR area, however, is 1 byte longer than an instruction that accesses the SFR area.

Extended SFRs can be manipulated like general-purpose registers, using operation, transfer, and bit manipulation instructions. The manipulable bit units, 1, 8, and 16, depend on the extended SFR type.

Each manipulation bit unit can be specified as follows.

[1-bit manipulation]

Describe as follows for the 1-bit manipulation instruction operand (!addr16.bit).

When the bit name is defined: <Bit name>

When the bit name is not defined: <Register name>.<Bit number> or <Address>.<Bit number>

[8-bit manipulation]

Describe the symbol defined by the assembler for the 8-bit manipulation instruction operand (!addr16). This manipulation can also be specified with an address.

[16-bit manipulation]

Describe the symbol defined by the assembler for the 16-bit manipulation instruction operand (!addr16). When specifying an address, describe an even address.

Table 3-6 gives a list of the extended SFRs. The meanings of items in the table are as follows.

[Symbol]

Symbol indicating the address of an extended SFR. It is a reserved word in the assembler, and is defined as an sfr variable using the #pragma sfr directive in the compiler. When using the assembler, debugger, and simulator, symbols can be written as an instruction operand.

[R/W]

Indicates whether the corresponding extended SFR can be read or written.

R/W: Read/write enable

R: Read only

W: Write only

[Manipulable bit units]

“✓” indicates the manipulable bit unit (1, 8, or 16). “—” indicates a bit unit for which manipulation is not possible.

[After reset]

Indicates each register status upon reset signal generation.

Caution Do not access addresses to which extended SFRs (2nd SFRs) are not assigned.

Remark For SFRs in the SFR area, see 3.2.4 Special function register (SFR) area.

Table 3-6. Extended SFR (2nd SFR) List (1/4)

| Address | Special Function Register (SFR) Name | Symbol | R/W | Manipulable Bit Range | | | After Reset |
|---------|---|---------|-----|-----------------------|-------|--------|---------------------|
| | | | | 1-bit | 8-bit | 16-bit | |
| F0010H | A/D converter mode register 2 | ADM2 | R/W | ✓ | ✓ | — | 00H |
| F0013H | A/D test register | ADTES | R/W | — | ✓ | — | 00H |
| F0030H | Pull-up resistor option register 0 | PU0 | R/W | ✓ | ✓ | — | 00H |
| F0032H | Pull-up resistor option register 2 | PU2 | R/W | ✓ | ✓ | — | 00H |
| F0034H | Pull-up resistor option register 4 | PU4 | R/W | ✓ | ✓ | — | 01H |
| F003CH | Pull-up resistor option register 12 | PU12 | R/W | ✓ | ✓ | — | 00H |
| F004EH | Port input mode register 14 | PIM14 | R/W | ✓ | ✓ | — | 00H |
| F0050H | Port output mode register 0 | POM0 | R/W | ✓ | ✓ | — | 00H |
| F0052H | Port output mode register 2 | POM2 | R/W | ✓ | ✓ | — | 00H |
| F0054H | Port output mode register 4 | POM4 | R/W | ✓ | ✓ | — | 00H |
| F0060H | Port mode control register 0 | PMC0 | R/W | ✓ | ✓ | — | FFH |
| F0062H | Port mode control register 2 | PMC2 | R/W | ✓ | ✓ | — | FFH |
| F0070H | Noise filter enable register 0 | NFEN0 | R/W | ✓ | ✓ | — | 00H |
| F0071H | Noise filter enable register 1 | NFEN1 | R/W | ✓ | ✓ | — | 00H |
| F0073H | Input switch control register | ISC | R/W | ✓ | ✓ | — | 00H |
| F0075H | Peripheral I/O redirection register 2 | PIOR2 | R/W | — | ✓ | — | 00H |
| F0077H | Peripheral I/O redirection register 0 | PIOR0 | R/W | — | ✓ | — | 00H |
| F0079H | Peripheral I/O redirection register 1 | PIOR1 | R/W | — | ✓ | — | 00H |
| F007CH | Peripheral I/O redirection register 3 | PIOR3 | R/W | — | ✓ | — | 00H |
| F00A0H | High-speed on-chip oscillator trimming register | HIOTRM | R/W | — | ✓ | — | Undefined Note 1 |
| F00A8H | High-speed on-chip oscillator frequency select register | HOCODIV | R/W | — | ✓ | — | Undefined Note 2 |
| F00BEH | Flash sequencer frequency setting register | FSSET | R/W | — | ✓ | — | 00H |
| F00C0H | Flash programming mode control register | FLPMC | R/W | — | ✓ | — | 08H |
| F00C1H | Flash sequencer control register | FSSQ | R/W | — | ✓ | — | 00H |
| F00C2H | Flash address pointer L | FLAPL | R/W | — | ✓ | — | 00H |
| F00C3H | Flash address pointer H | FLAPH | R/W | — | ✓ | — | 00H |
| F00C4H | Flash end address pointer L | FLSEDL | R/W | — | ✓ | — | 00H |
| F00C5H | Flash end address pointer H | FLSEDH | R/W | — | ✓ | — | 00H |
| F00C6H | Flash sequencer status register L | FSASTL | R | — | ✓ | — | 00H |
| F00C7H | Flash sequence status register H | FSASTH | R | — | ✓ | — | 00H |
| F00C8H | Flash write buffer register LL | FLWLL | R/W | — | ✓ | — | 00H |
| F00C9H | Flash write buffer register LH | FLWLH | R/W | — | ✓ | — | 00H |
| F00CAH | Flash write buffer register HL | FLWHL | R/W | — | ✓ | — | 00H |
| F00CBH | Flash write buffer register HH | FLWHH | R/W | — | ✓ | — | 00H |
| F00F0H | Peripheral enable register 0 | PER0 | R/W | ✓ | ✓ | — | 00H |
| F00F3H | Operation speed mode control register | OSMC | R/W | — | ✓ | — | 00H |
| F00FEH | BCD adjust result register | BCDADJ | R | — | ✓ | — | Undefined |

Table 3-6. Extended SFR (2nd SFR) List (2/4)

| Address | Special Function Register (SFR) Name | Symbol | | R/W | Manipulable Bit Range | | | After Reset |
|---------|--|--------|-------|-----|-----------------------|-------|--------|-------------|
| | | | | | 1-bit | 8-bit | 16-bit | |
| F0100H | Serial status register 00 | SSR00L | SSR00 | R | — | ✓ | ✓ | 0000H |
| F0101H | | — | | | — | | | |
| F0102H | Serial status register 01 | SSR01L | SSR01 | R | — | ✓ | ✓ | 0000H |
| F0103H | | — | | | — | | | |
| F0108H | Serial flag clear trigger register 00 | SIR00L | SIR00 | R/W | — | ✓ | ✓ | 0000H |
| F0109H | | — | | | — | | | |
| F010AH | Serial flag clear trigger register 01 | SIR01L | SIR01 | R/W | — | ✓ | ✓ | 0000H |
| F010BH | | — | | | — | | | |
| F0110H | Serial mode register 00 | SMR00 | | R/W | — | — | ✓ | 0020H |
| F0111H | | | | | | | | |
| F0112H | Serial mode register 01 | SMR01 | | R/W | — | — | ✓ | 0020H |
| F0113H | | | | | | | | |
| F0118H | Serial communication operation setting register 00 | SCR00 | | R/W | — | — | ✓ | 0087H |
| F0119H | | | | | | | | |
| F011AH | Serial communication operation setting register 01 | SCR01 | | R/W | — | — | ✓ | 0087H |
| F011BH | | | | | | | | |
| F0120H | Serial channel enable status register 0 | SE0L | SE0 | R | ✓ | ✓ | ✓ | 0000H |
| F0121H | | — | | | — | | | |
| F0122H | Serial channel start register 0 | SS0L | SS0 | R/W | ✓ | ✓ | ✓ | 0000H |
| F0123H | | — | | | — | | | |
| F0124H | Serial channel stop register 0 | ST0L | ST0 | R/W | ✓ | ✓ | ✓ | 0000H |
| F0125H | | — | | | — | | | |
| F0126H | Serial clock select register 0 | SPS0L | SPS0 | R/W | — | ✓ | ✓ | 0000H |
| F0127H | | — | | | — | | | |
| F0128H | Serial output register 0 | SO0 | | R/W | — | — | ✓ | 0303H |
| F0129H | | | | | | | | |
| F012AH | Serial output enable register 0 | SOE0L | SOE0 | R/W | ✓ | ✓ | ✓ | 0000H |
| F012BH | | — | | | — | | | |
| F0134H | Serial output level register 0 | SOL0L | SOL0 | R/W | — | ✓ | ✓ | 0000H |
| F0135H | | — | | | — | | | |
| F0180H | Timer counter register 00 | TCR00 | | R | — | — | ✓ | FFFFH |
| F0181H | | | | | | | | |
| F0182H | Timer counter register 01 | TCR01 | | R | — | — | ✓ | FFFFH |
| F0183H | | | | | | | | |
| F0184H | Timer counter register 02 | TCR02 | | R | — | — | ✓ | FFFFH |
| F0185H | | | | | | | | |
| F0186H | Timer counter register 03 | TCR03 | | R | — | — | ✓ | FFFFH |
| F0187H | | | | | | | | |
| F0188H | Timer counter register 04 | TCR04 | | R | — | — | ✓ | FFFFH |
| F0189H | | | | | | | | |
| F018AH | Timer counter register 05 | TCR05 | | R | — | — | ✓ | FFFFH |
| F018BH | | | | | | | | |
| F018CH | Timer counter register 06 | TCR06 | | R | — | — | ✓ | FFFFH |
| F018DH | | | | | | | | |

Table 3-6. Extended SFR (2nd SFR) List (3/4)

| Address | Special Function Register (SFR) Name | Symbol | | R/W | Manipulable Bit Range | | | After Reset |
|---------|--|--------|-------|-----|-----------------------|-------|--------|-------------|
| | | | | | 1-bit | 8-bit | 16-bit | |
| F018EH | Timer counter register 07 | TCR07 | | R | — | — | ✓ | FFFFH |
| F018FH | | | | | | | | |
| F0190H | Timer mode register 00 | TMR00 | | R/W | — | — | ✓ | 0000H |
| F0191H | | | | | | | | |
| F0192H | Timer mode register 01 | TMR01 | | R/W | — | — | ✓ | 0000H |
| F0193H | | | | | | | | |
| F0194H | Timer mode register 02 | TMR02 | | R/W | — | — | ✓ | 0000H |
| F0195H | | | | | | | | |
| F0196H | Timer mode register 03 | TMR03 | | R/W | — | — | ✓ | 0000H |
| F0197H | | | | | | | | |
| F0198H | Timer mode register 04 | TMR04 | | R/W | — | — | ✓ | 0000H |
| F0199H | | | | | | | | |
| F019AH | Timer mode register 05 | TMR05 | | R/W | — | — | ✓ | 0000H |
| F019BH | | | | | | | | |
| F019CH | Timer mode register 06 | TMR06 | | R/W | — | — | ✓ | 0000H |
| F019DH | | | | | | | | |
| F019EH | Timer mode register 07 | TMR07 | | R/W | — | — | ✓ | 0000H |
| F019FH | | | | | | | | |
| F01A0H | Timer status register 00 | TSR00L | TSR00 | R | — | ✓ | ✓ | 0000H |
| F01A1H | | — | | | — | | | |
| F01A2H | Timer status register 01 | TSR01L | TSR01 | R | — | ✓ | ✓ | 0000H |
| F01A3H | | — | | | — | | | |
| F01A4H | Timer status register 02 | TSR02L | TSR02 | R | — | ✓ | ✓ | 0000H |
| F01A5H | | — | | | — | | | |
| F01A6H | Timer status register 03 | TSR03L | TSR03 | R | — | ✓ | ✓ | 0000H |
| F01A7H | | — | | | — | | | |
| F01A8H | Timer status register 04 | TSR04L | TSR04 | R | — | ✓ | ✓ | 0000H |
| F01A9H | | — | | | — | | | |
| F01AAH | Timer status register 05 | TSR05L | TSR05 | R | — | ✓ | ✓ | 0000H |
| F01ABH | | — | | | — | | | |
| F01ACH | Timer status register 06 | TSR06L | TSR06 | R | — | ✓ | ✓ | 0000H |
| F01ADH | | — | | | — | | | |
| F01AEH | Timer status register 07 | TSR07L | TSR07 | R | — | ✓ | ✓ | 0000H |
| F01AFH | | — | | | — | | | |
| F01B0H | Timer channel enable status register 0 | TE0L | TE0 | R | ✓ | ✓ | ✓ | 0000H |
| F01B1H | | — | | | — | | | |
| F01B2H | Timer channel start register 0 | TS0L | TS0 | R/W | ✓ | ✓ | ✓ | 0000H |
| F01B3H | | — | | | — | | | |
| F01B4H | Timer channel stop register 0 | TT0L | TT0 | R/W | ✓ | ✓ | ✓ | 0000H |
| F01B5H | | — | | | — | | | |
| F01B6H | Timer clock select register 0 | TPS0 | | R/W | — | — | ✓ | 0000H |
| F01B7H | | | | | | | | |
| F01B8H | Timer output register 0 | TO0L | TO0 | R/W | — | ✓ | ✓ | 0000H |
| F01B9H | | — | | | — | | | |

Table 3-6. Extended SFR (2nd SFR) List (4/4)

| Address | Special Function Register (SFR) Name | Symbol | | R/W | Manipulable Bit Range | | | After Reset |
|---------|--|----------|------|-----|-----------------------|-------|--------|-------------|
| | | | | | 1-bit | 8-bit | 16-bit | |
| F01BAH | Timer output enable register 0 | TOE0L | TOE0 | R/W | ✓ | ✓ | ✓ | 0000H |
| F01BBH | | — | | | — | | | |
| F01BCH | Timer output level register 0 | TOL0L | TOL0 | R/W | — | ✓ | ✓ | 0000H |
| F01BDH | | — | | | — | | | |
| F01BEH | Timer output mode register 0 | TOM0L | TOM0 | R/W | — | ✓ | ✓ | 0000H |
| F01BFH | | — | | | — | | | |
| F0230H | IICA control register 00 | IICCTL00 | | R/W | ✓ | ✓ | — | 00H |
| F0231H | IICA control register 01 | IICCTL01 | | R/W | ✓ | ✓ | — | 00H |
| F0232H | IICA low-level width setting register 0 | IICWL0 | | R/W | — | ✓ | — | FFH |
| F0233H | IICA high-level width setting register 0 | IICWH0 | | R/W | — | ✓ | — | FFH |
| F0234H | Slave address register 0 | SVA0 | | R/W | — | ✓ | — | 00H |

Note 1. The value after a reset is adjusted at the time of shipment.

Note 2. The value is determined by the FRQSEL2 to FRQSEL0 settings in option byte 000C2H.

Remark For SFRs in the SFR area, see **Table 3-5. SFR List (1/2)**.

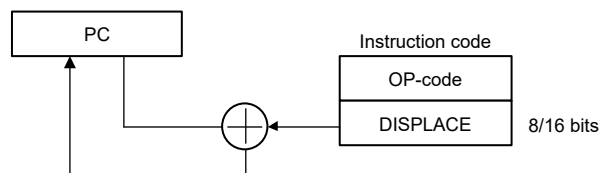
3.4 Instruction Address Addressing

3.4.1 Relative addressing

[Function]

Relative addressing stores in the program counter (PC) the result of adding a displacement value included in the instruction word (signed complement data: -128 to $+127$ or -32768 to $+32767$) to the program counter (PC)'s value (the start address of the next instruction), and specifies the program address to be used as the branch destination. Relative addressing is applied only to branch instructions.

Figure 3-10. Outline of Relative Addressing



3.4.2 Immediate addressing

[Function]

Immediate addressing stores immediate data of the instruction word in the program counter, and specifies the program address to be used as the branch destination.

For immediate addressing, CALL !!addr20 or BR !!addr20 is used to specify 20-bit addresses and CALL !addr16 or BR !addr16 is used to specify 16-bit addresses. 0000 is set to the higher 4 bits when specifying 16-bit addresses.

Figure 3-11. Example of CALL !!addr20/BR !!addr20

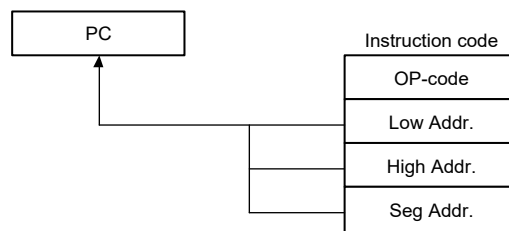
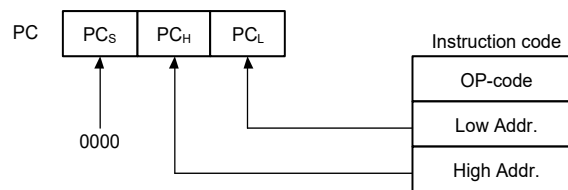


Figure 3-12. Example of CALL !addr16/BR !addr16



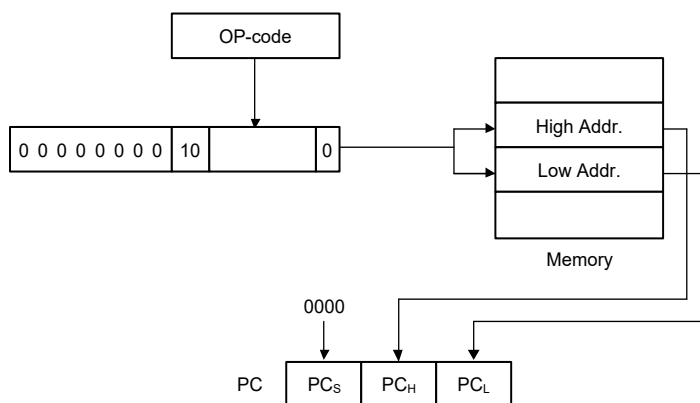
3.4.3 Table indirect addressing

[Function]

Table indirect addressing specifies a table address in the CALLT table area (0080H to 00BFH) with the 5-bit immediate data in the instruction word, stores the contents at that table address and the next address in the program counter (PC) as 16-bit data, and specifies the program address. Table indirect addressing is applied only for CALLT instructions.

In the RL78 microcontrollers, branching is enabled only to the 64 KB space from 00000H to 0FFFFH.

Figure 3-13. Outline of Table Indirect Addressing

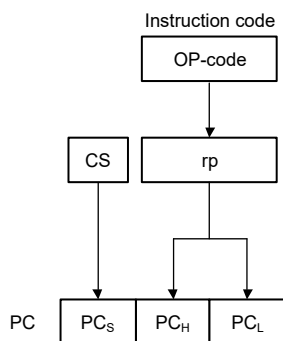


3.4.4 Register indirect addressing

[Function]

Register indirect addressing stores in the program counter (PC) the contents of a general-purpose register pair (AX/BC/DE/HL) and CS register of the current register bank specified with the instruction word as 20-bit data, and specifies the program address. Register indirect addressing can be applied only to the CALL AX, BC, DE, HL, and BR AX instructions.

Figure 3-14. Outline of Register Indirect Addressing



3.5 Addressing for Processing Data Addresses

3.5.1 Implied addressing

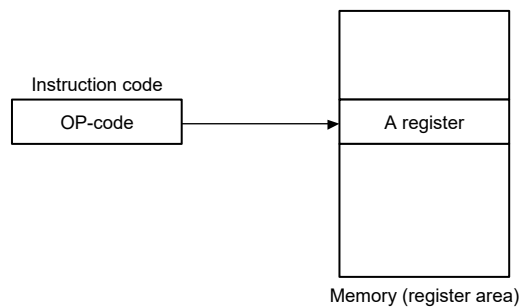
[Function]

Instructions for accessing registers (such as accumulators) that have special functions are directly specified with the instruction word, without using any register specification field in the instruction word.

[Operand format]

Implied addressing can be applied only to MULU X.

Figure 3-15. Outline of Implied Addressing



3.5.2 Register addressing

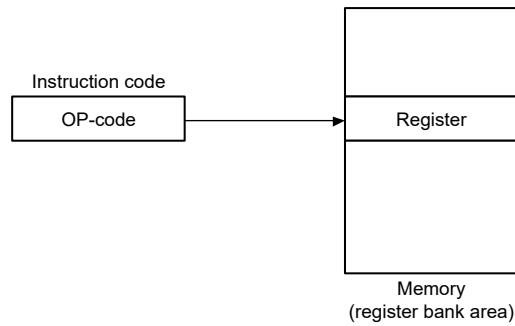
[Function]

Register addressing accesses a general-purpose register as an operand. The instruction word of 3-bit long is used to select an 8-bit register and the instruction word of 2-bit long is used to select a 16-bit register.

[Operand format]

| Identifier | Description |
|------------|------------------------|
| r | X, A, C, B, E, D, L, H |
| rp | AX, BC, DE, HL |

Figure 3-16. Outline of Register Addressing



3.5.3 Direct addressing

[Function]

Direct addressing uses immediate data in the instruction word as an operand address to directly specify the target address.

[Operand format]

| Identifier | Description |
|------------|---|
| !addr16 | Label or 16-bit immediate data (only the space from F0000H to FFFFFH is specifiable) |
| ES:!addr16 | Label or 16-bit immediate data (higher 4-bit addresses are specified by the ES register) |

Figure 3-17. Example of !addr16

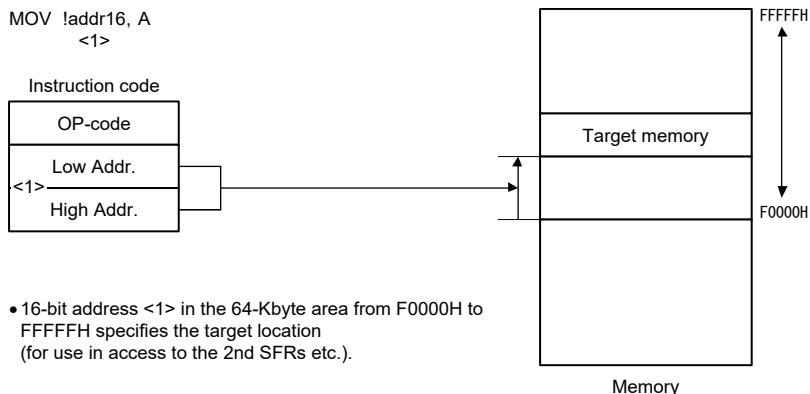
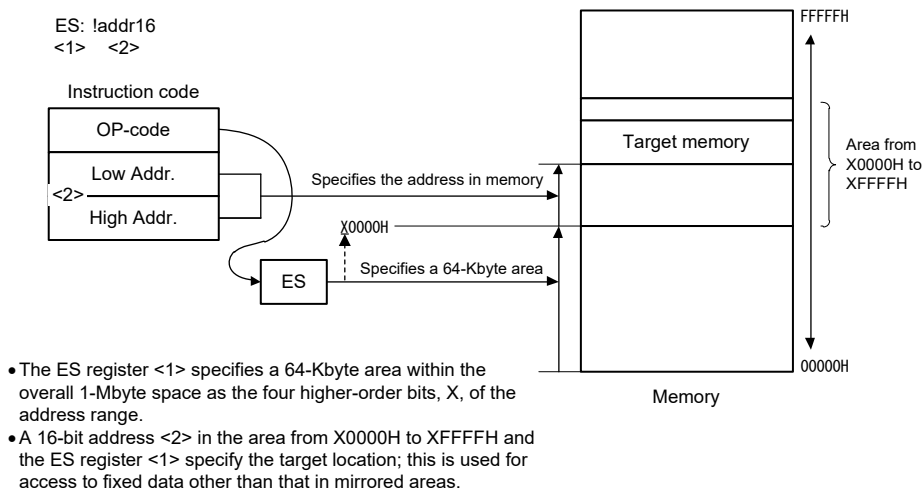


Figure 3-18. Example of ES:!addr16



3.5.4 Short direct addressing

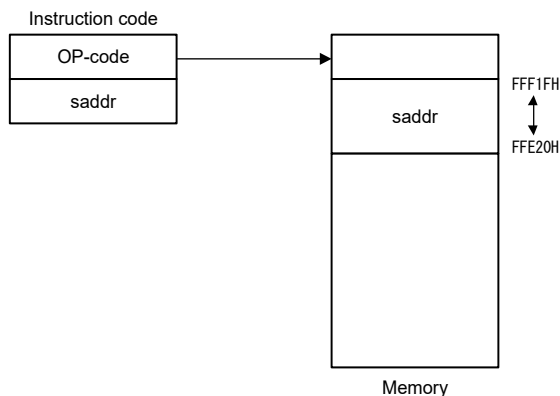
[Function]

Short direct addressing directly specifies the target addresses using 8-bit data in the instruction word. This type of addressing is applied only to the space from FFE20H to FFF1FH.

[Operand format]

| Identifier | Description |
|------------|---|
| SADDR | Label, FFE20H to FFF1FH immediate data, or 0FE20H to 0FF1FH immediate data (only the space from FFE20H to FFF1FH is specifiable) |
| SADDRP | Label, FFE20H to FFF1FH immediate data, or 0FE20H to 0FF1FH immediate data (even address only) (only the space from FFE20H to FFF1FH is specifiable) |

Figure 3-19. Outline of Short Direct Addressing



Remark SADDR and SADDRP are used to describe the values of addresses FE20H to FF1FH with 16-bit immediate data (higher 4 bits of actual address are omitted), and the values of addresses FFE20H to FFF1FH with 20-bit immediate data.

Regardless of whether SADDR or SADDRP is used, addresses within the space from FFE20H to FFF1FH are specified for the memory.

3.5.5 SFR addressing

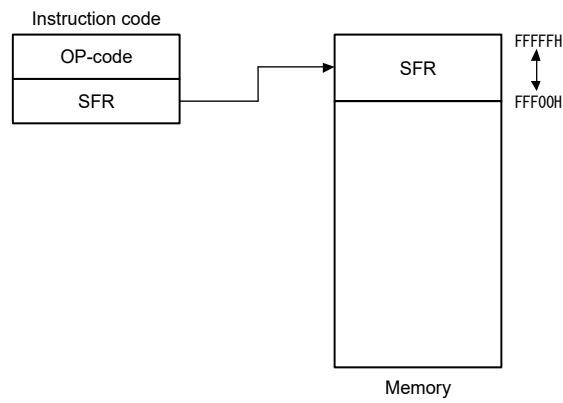
[Function]

SFR addressing directly specifies the target SFR addresses using 8-bit data in the instruction word. This type of addressing is applied only to the space from FFF00H to FFFFFH.

[Operand format]

| Identifier | Description |
|------------|--|
| SFR | SFR name |
| SFRP | 16-bit-manipulatable SFR name (even address) |

Figure 3-20. Outline of SFR Addressing



3.5.6 Register indirect addressing

[Function]

Register indirect addressing specifies the target addresses using the contents of the register pair specified with the instruction word as an operand address.

[Operand format]

| Identifier | Description |
|------------|---|
| — | [DE], [HL] (only the space from F0000H to FFFFFH is specifiable) |
| — | ES:[DE], ES:[HL] (higher 4-bit addresses are specified by the ES register) |

Figure 3-21. Example of [DE], [HL]

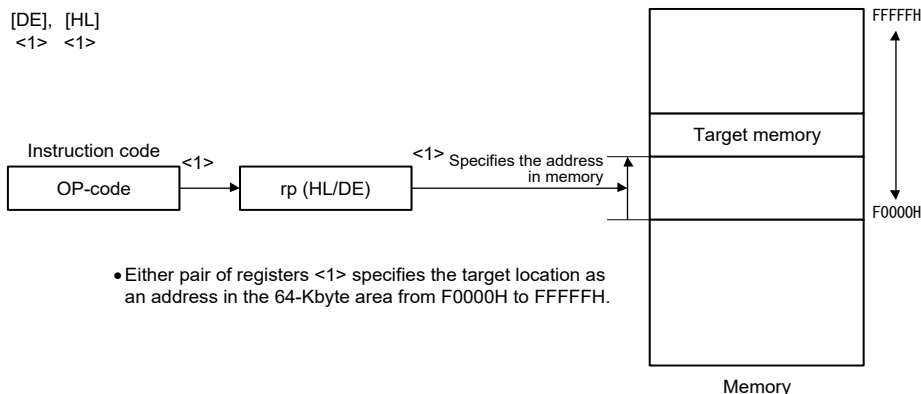
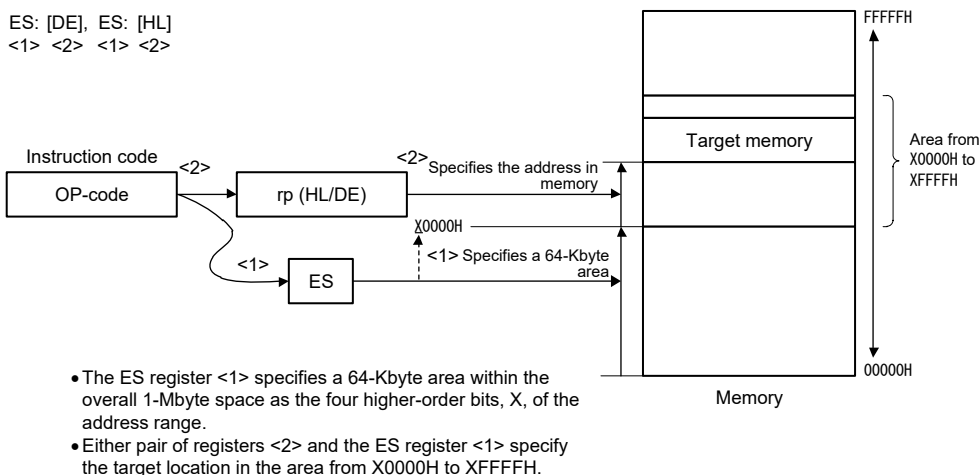


Figure 3-22. Example of ES:[DE], ES:[HL]



3.5.7 Based addressing

[Function]

Based addressing uses the contents of a register pair specified with the instruction word or 16-bit immediate data as the base address and specifies the target addresses using the result of adding the 8-bit immediate data or 16-bit immediate data as the offset data to the base address.

[Operand format]

| Identifier | Description |
|------------|--|
| — | [HL + byte], [DE + byte], [SP + byte] (only the space from F0000H to FFFFFH is specifiable) |
| — | word[B], word[C] (only the space from F0000H to FFFFFH is specifiable) |
| — | word[BC] (only the space from F0000H to FFFFFH is specifiable) |
| — | ES:[HL + byte], ES:[DE + byte] (higher 4-bit addresses are specified by the ES register) |
| — | ES:word[B], ES:word[C] (higher 4-bit addresses are specified by the ES register) |
| — | ES:word[BC] (higher 4-bit addresses are specified by the ES register) |

Figure 3-23. Example of [SP + byte]

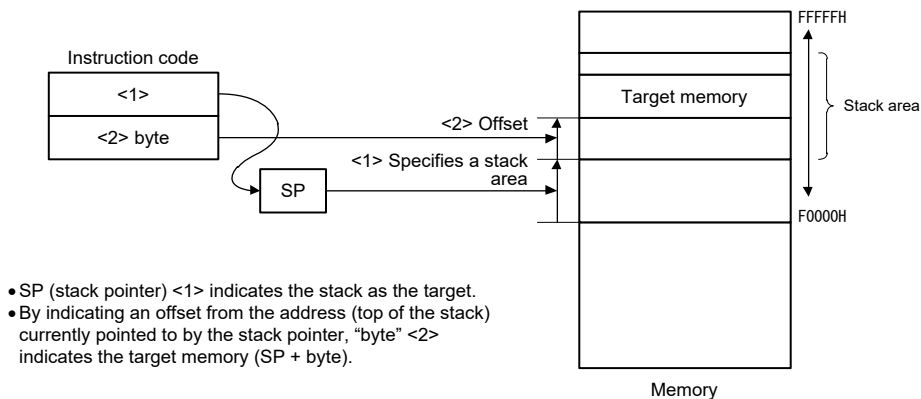


Figure 3-24. Example of [HL + byte], [DE + byte]

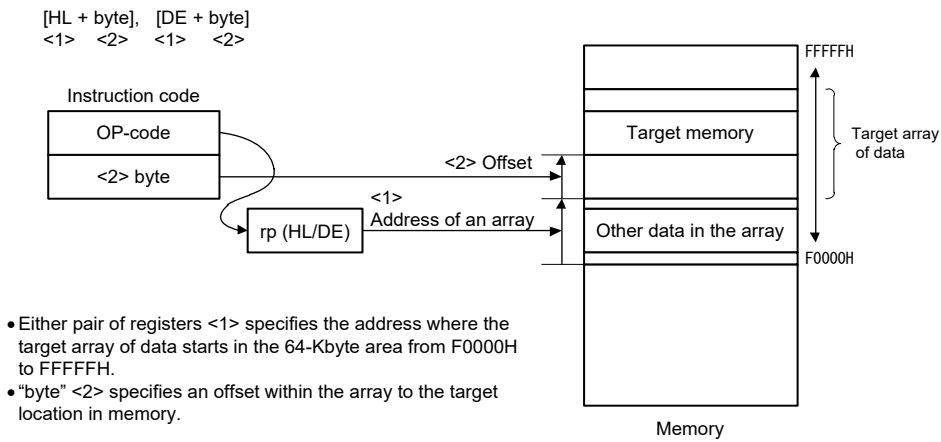


Figure 3-25. Example of word[B], word[C]

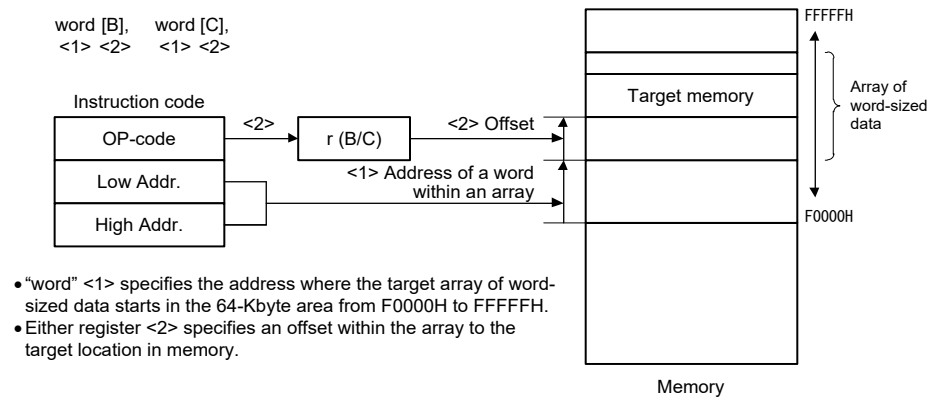


Figure 3-26. Example of word[BC]

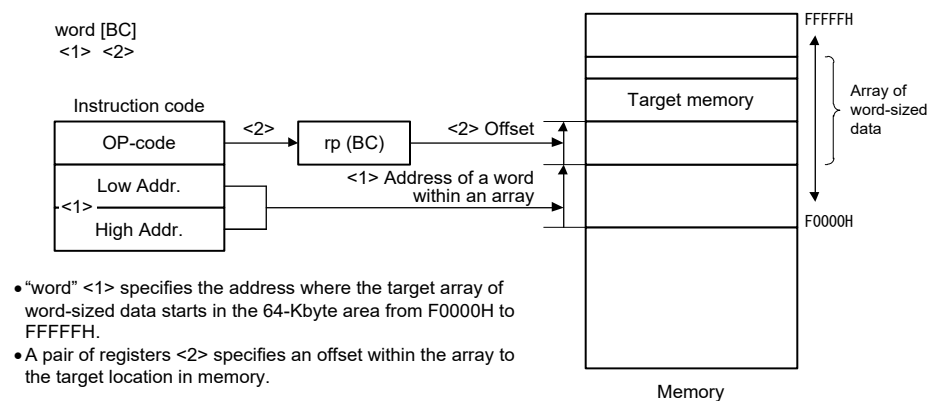


Figure 3-27. Example of ES:[HL + byte], ES:[DE + byte]

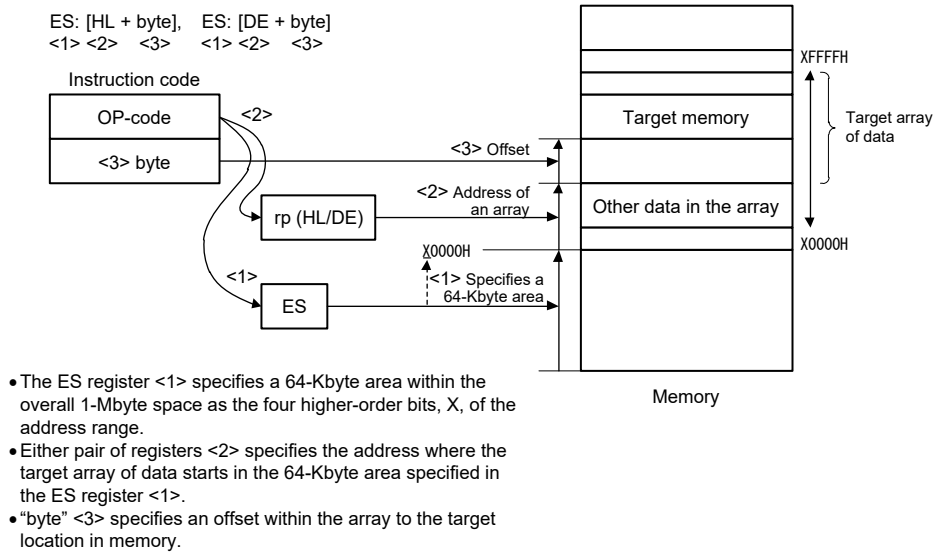


Figure 3-28. Example of ES:word[B], ES:word[C]

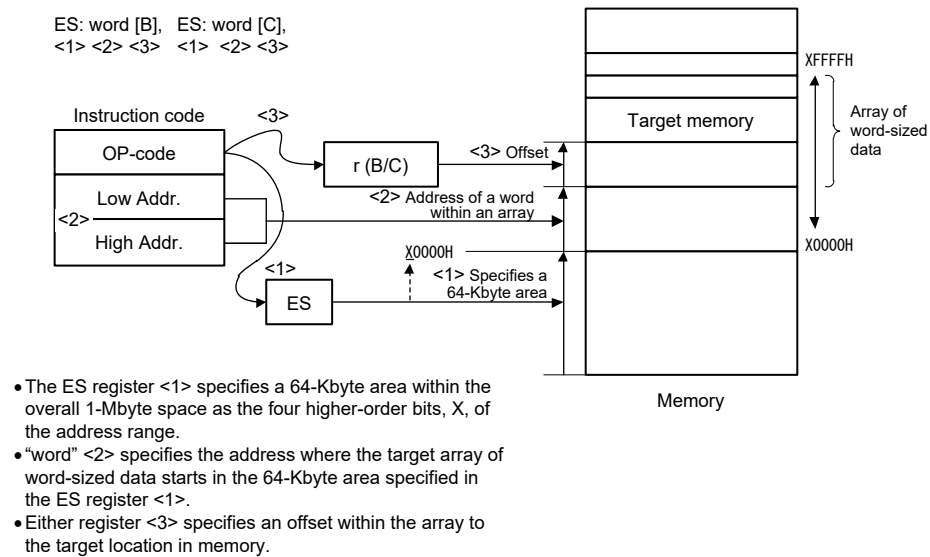
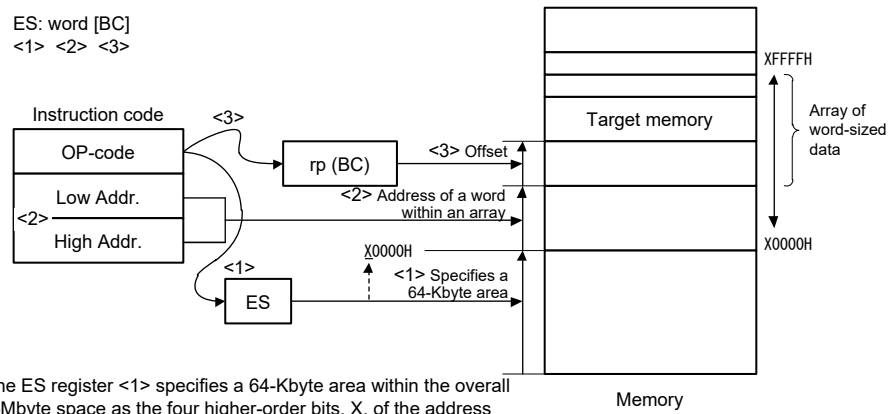


Figure 3-29. Example of ES:word[BC]



- The ES register <1> specifies a 64-Kbyte area within the overall 1-Mbyte space as the four higher-order bits, X, of the address range.
- “word” <2> specifies the address where the target array of word-sized data starts in the 64-Kbyte area specified in the ES register <1>.
- A pair of registers <3> specifies an offset within the array to the target location in memory.

3.5.8 Based indexed addressing

[Function]

Based indexed addressing uses the contents of a register pair specified with the instruction word as the base address and specifies the target addresses using the result of adding the contents of the B register or C register similarly specified with the instruction word as the offset address to the base address.

[Operand format]

| Identifier | Description |
|------------|---|
| — | [HL + B], [HL + C] (only the space from F0000H to FFFFFH is specifiable) |
| — | ES:[HL + B], ES:[HL + C] (higher 4-bit addresses are specified by the ES register) |

Figure 3-30. Example of [HL + B], [HL + C]

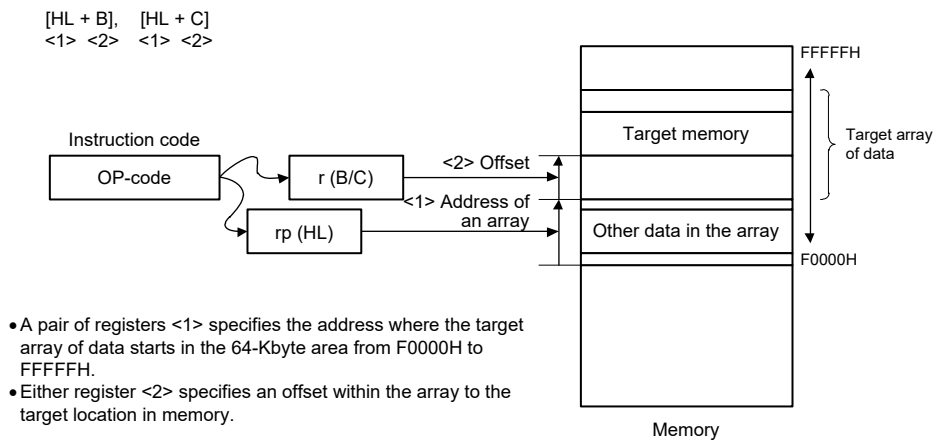
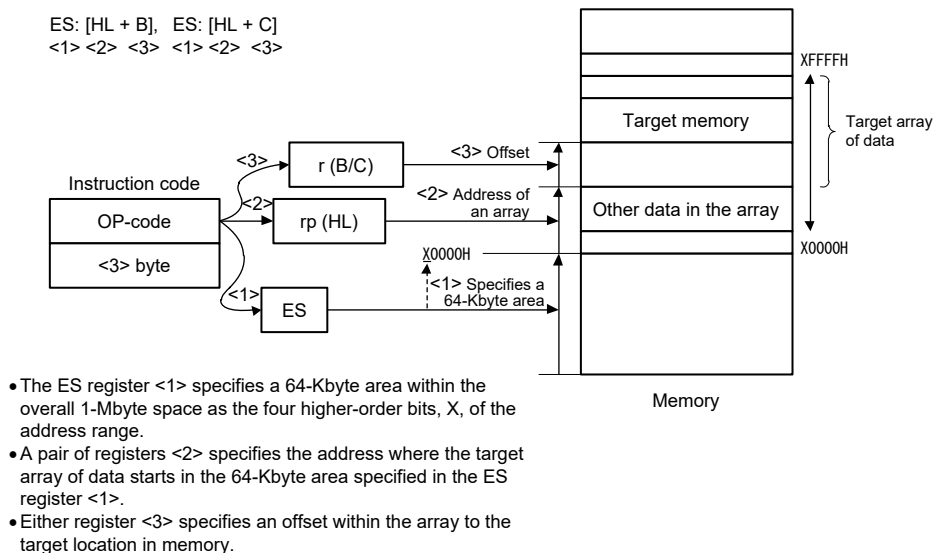


Figure 3-31. Example of ES:[HL + B], ES:[HL + C]



3.5.9 Stack addressing

[Function]

The stack area is indirectly addressed with the stack pointer (SP) values. This addressing is automatically employed when the PUSH, POP, subroutine call, and return instructions are executed or the register is saved/restored upon generation of an interrupt request.

Only the internal RAM area can be set as the stack area.

[Description format]

| Identifier | Description |
|------------|--|
| — | PUSH PSW AX/BC/DE/HL POP PSW AX/BC/DE/HL CALL/CALLT RET BRK RETB (Interrupt request generated) RETI |

Each stack operation saves or restores data as shown in **Figure 3-32** to **Figure 3-37**.

Figure 3-32. Example of PUSH rp

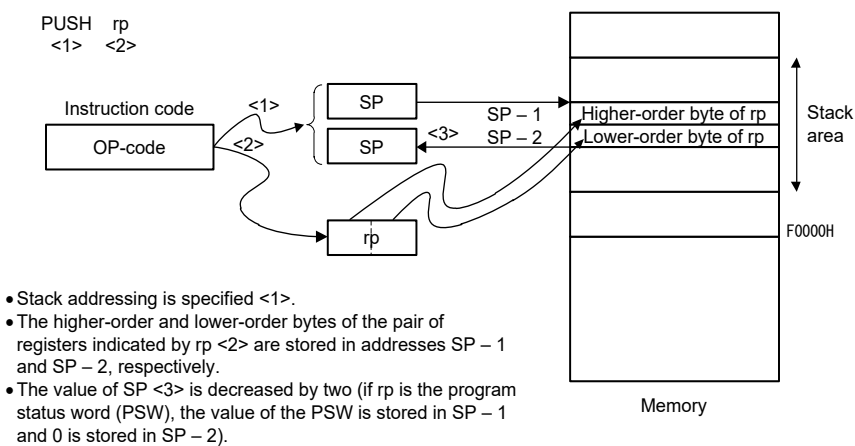


Figure 3-33. Example of POP

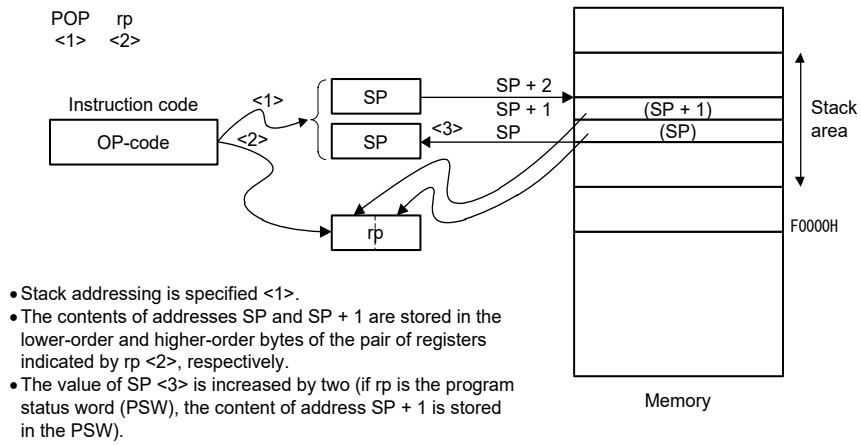


Figure 3-34. Example of CALL, CALLT

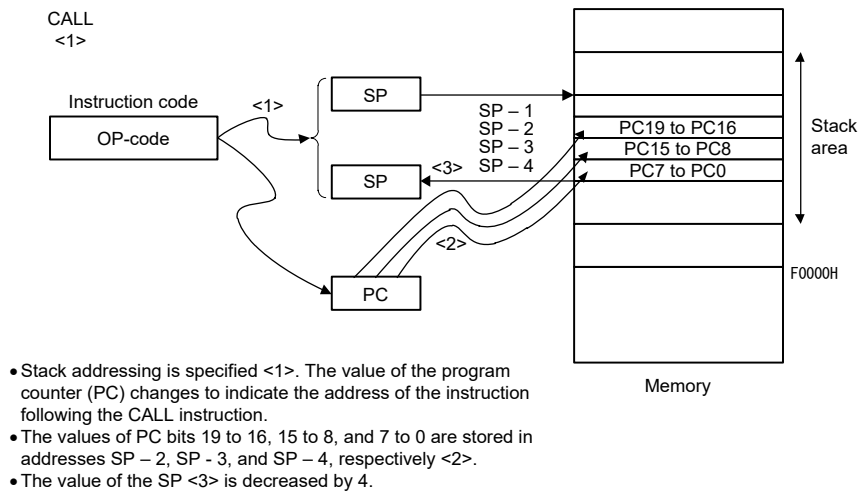


Figure 3-35. Example of RET

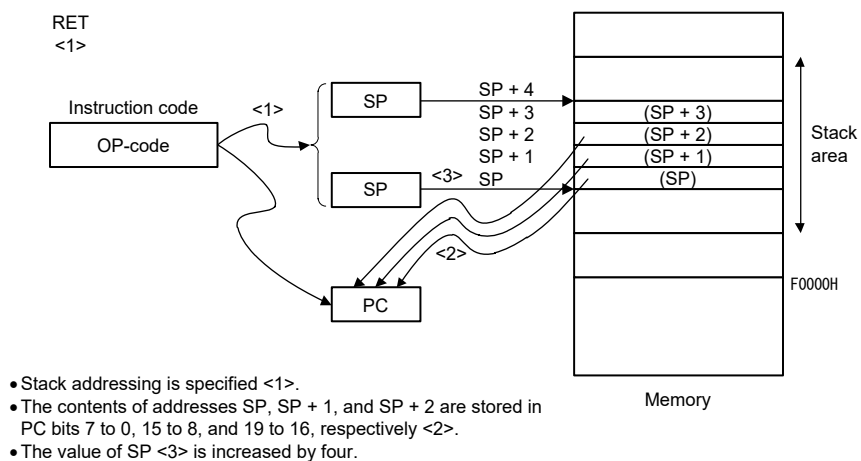


Figure 3-36. Example of Interrupt, BRK

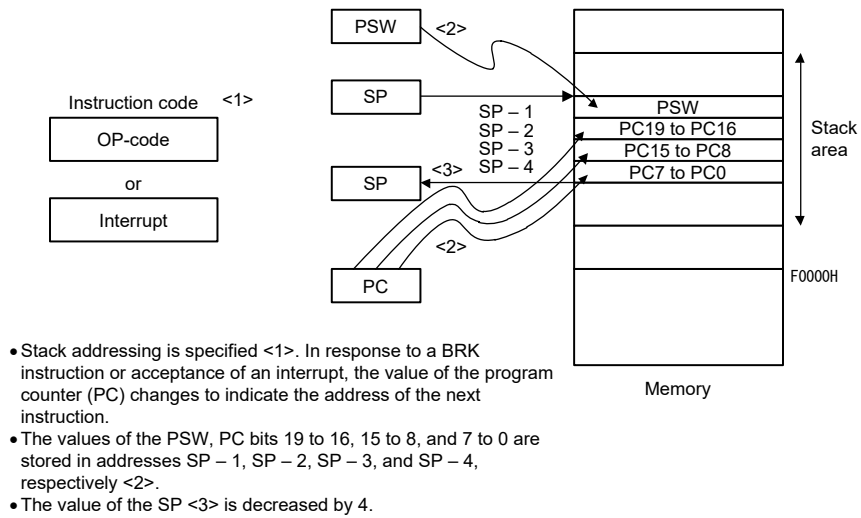
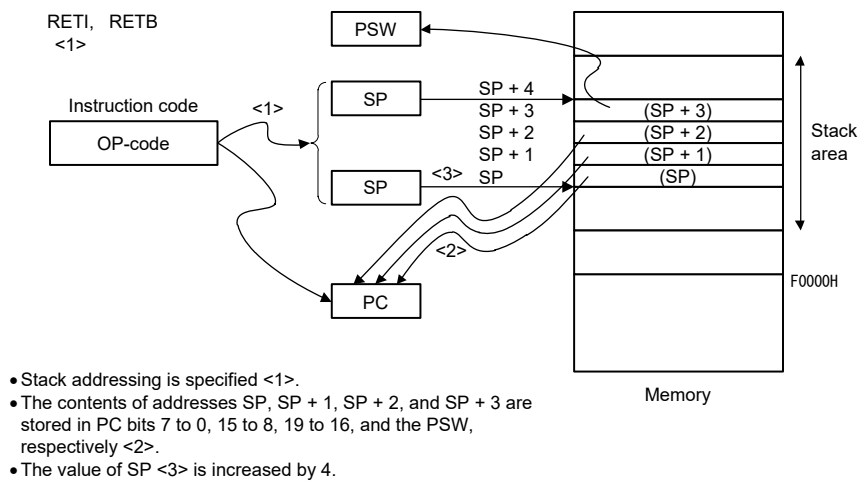


Figure 3-37. Example of RETI, RETB



3.6 Illegal Memory Access Detection Function

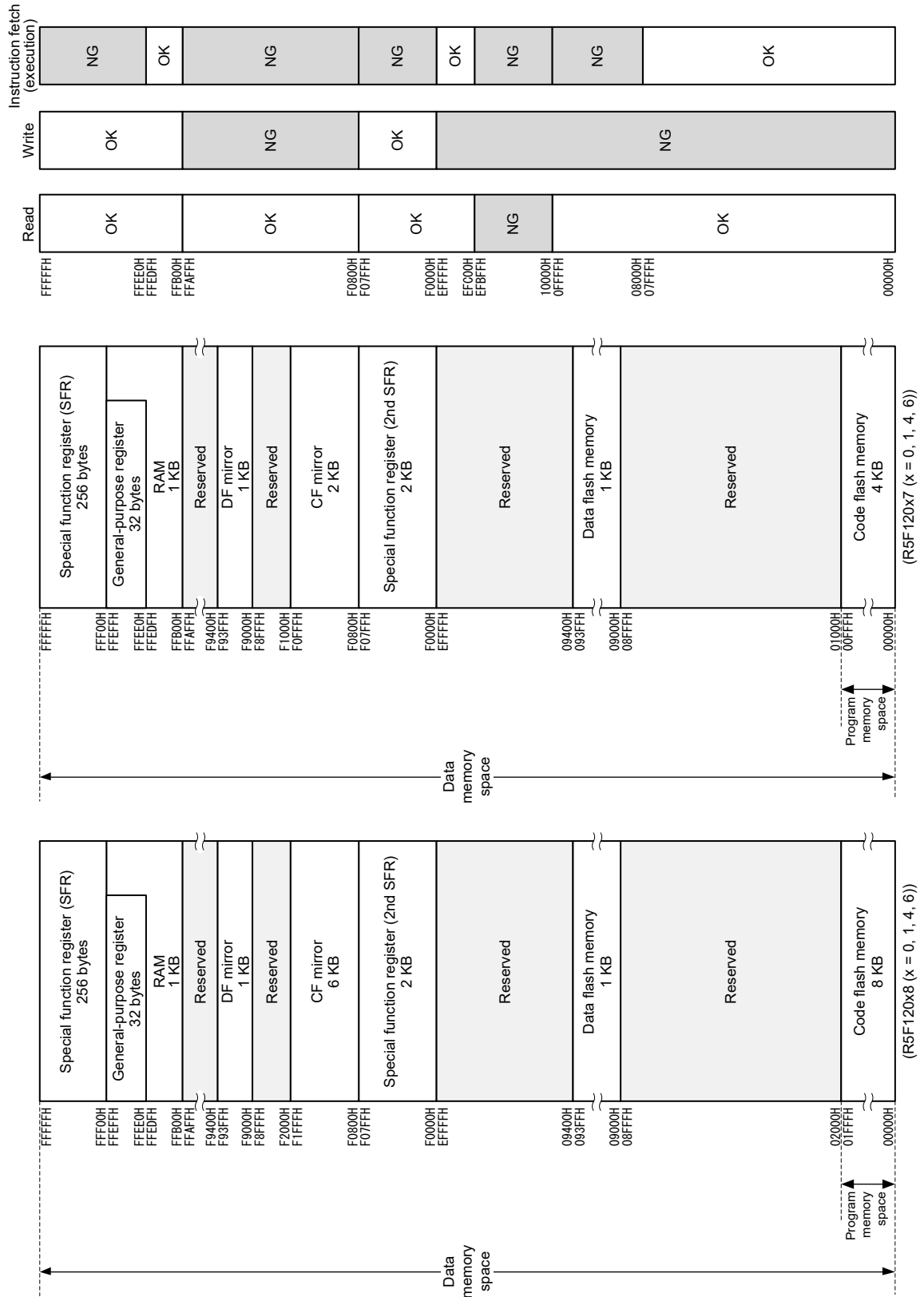
The IEC60730 checks for the correct operation of the CPU and interrupts.

The illegal memory access detection function generates a reset when the specified illegal access detection space is accessed.

The illegal access detection space is the range indicated as "NG" in **Figure 3-38**.

For details on the reset function, refer to **CHAPTER 16 RESET FUNCTION**.

Figure 3-38. Illegal Memory Access Detection Space



CHAPTER 4 PORT FUNCTIONS

4.1 Port Functions

The RL78 microcontrollers are provided with digital I/O ports, which enable variety of control operations.

In addition to the function as digital I/O ports, these ports have several alternate functions. For details of the alternate functions, see **CHAPTER 2 PIN FUNCTIONS**.

4.2 Port Configuration

Ports include the following hardware.

Table 4-1. Port Configuration

| Item | Configuration |
|--------------------------|---|
| Control registers | Port mode registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12) Port registers 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13) Pull-up resistor option registers 0, 2, 4, 12 (PU0, PU2, PU4, PU12) Port output mode registers 0, 2, 4 (POM0, POM2, POM4) Port mode control registers 0, 2 (PMC0, PMC2) Peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3) |
| Port | <ul style="list-style-type: none"> • 8-pin products Total: 6 (CMOS I/O: 5 (N-ch open drain output (V_{DD} tolerance): 2), CMOS input: 1) • 10-pin products Total: 8 (CMOS I/O: 7 (N-ch open drain output (V_{DD} tolerance): 3), CMOS input: 1) • 16-pin products Total: 14 (CMOS I/O: 13 (N-ch open drain output (V_{DD} tolerance): 7), CMOS input: 1) • 20-pin products Total: 18 (CMOS I/O: 17 (N-ch open drain output (V_{DD} tolerance): 9), CMOS input: 1) |
| On-chip pull-up resistor | <ul style="list-style-type: none"> • 8-pin products Total: 5 • 10-pin products Total: 7 • 16-pin products Total: 13 • 20-pin products Total: 17 |

4.2.1 Port 0

Port 0 is an I/O port with an output latch. Port 0 can be set to the input mode or output mode in 1-bit units using port mode register 0 (PM0). When the P00 to P07^{Note 1} pins are used as an input port, use of an on-chip pull-up resistor can be specified in 1-bit units by pull-up resistor option register 0 (PU0).

Output from the P00, P01, and P03 to P07 pins can be specified as N-ch open-drain output (V_{DD} tolerance) in 1-bit units using port output mode register 0 (POM0).

This port can also be used for serial interface data I/O and clock I/O, UART transmission and reception for the external device connection used during flash memory programming, analog input, comparator output, clock/buzzer output, timer I/O, and external interrupt request input.

Reset signal generation sets P00 to input mode, and sets P01 to P07 to analog input mode.

Note 1. P01, P03, and P04 for 8-pin products; P00 to P04 for 10-pin products; P00 to P07 for 16-pin and 20-pin products.

4.2.2 Port 2

Port 2 is an I/O port with an output latch. Port 2 can be set to the input mode or output mode in 1-bit units using port mode register 2 (PM2). When the P20 to P23^{Note 1} pins are used as an input port, use of an on-chip pull-up resistor can be specified in 1-bit units by pull-up resistor option register 2 (PU2).

Output from the P22 pin can be specified as N-ch open-drain output (V_{DD} tolerance) in 1-bit units using port output mode register 2 (POM2).

This port can also be used for serial interface data I/O and clock I/O, analog input, timer I/O, and external interrupt request input.

Reset signal generation sets P20 to P23 to analog input mode.

Note 1. For 20-pin products.

4.2.3 Port 4

Port 4 is an I/O port with an output latch. Port 4 can be set to the input mode or output mode in 1-bit units using port mode register 4 (PM4). When the P40 and P41^{Note 1} pins are used as an input port, use of an on-chip pull-up resistor can be specified in 1-bit units by pull-up resistor option register 4 (PU4).

Output from the P41 pin can be specified as N-ch open-drain output (V_{DD} tolerance) in 1-bit units using port output mode register 4 (POM4).

This port can also be used for data I/O for a flash memory programmer/debugger, serial interface data I/O and clock I/O, comparator output, clock/buzzer output, timer I/O, and external interrupt request input. Reset signal generation sets port 4 to input mode.

Note 1. P40 for 8-pin and 10-pin products; P40 and P41 for 16-pin and 20-pin products

4.2.4 Port 12

Port 12 is an I/O port with an output latch. Port 12 can be set to the input mode or output mode in 1-bit units using port mode register 12 (PM12). When the P121^{Note 1}, P122^{Note 1}, and P125 pins are used as an input port, use of an on-chip pull-up resistor can be specified in 1-bit units by pull-up resistor option register 12 (PU12) (the on-chip pull-up resistor is always valid for P125 when $\overline{\text{RESET}}$ input is selected (PORTSELB = 1)).

This port can also be used for external interrupt request input, connecting resonator for main system clock, external clock input for main system clock, reset input, serial interface data input, comparator output, and timer I/O. Reset signal generation sets port 12 to input mode.

Note 1. For 16-pin and 20-pin products.

Caution Once the power is turned on, P125 functions as the $\overline{\text{RESET}}$ input. The PORTSELB bit of the option byte (000C1H) defines whether this port operates as P125/INTP1/(VCOUT0)/(VCOUT1)/(SI01) or $\overline{\text{RESET}}$. When this pin is set to P125/INTP1/(VCOUT0)/(VCOUT1)/(SI01), do not input the low level to this pin during a reset by the selectable power-on-reset (SPOR) circuit and during the period from release from the reset by the SPOR circuit to the start of normal operation. If input of the low level continues during this period, the chip will remain in the reset state in response to the external reset. Accordingly, the on-chip pull-up resistor is enabled after power is turned on.

4.2.5 Port 13

P137 is an input-only port. This port can also be used for timer input and external interrupt request input.

4.3 Registers Controlling Port Function

Port functions are controlled by the following registers.

- Port mode registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12)
- Port registers 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13)
- Pull-up resistor option registers 0, 2, 4, 12 (PU0, PU2, PU4, PU12)
- Port output mode registers 0, 2, 4 (POM0, POM2, POM4)
- Port mode control registers 0, 2 (PMC0, PMC2)
- Peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3)

Caution Which registers and bits are included depends on the product. For registers and bits mounted on each product, see Table 4-2 to Table 4-5. Be sure to set bits that are not mounted to their initial values.

Table 4-2. Pm, PMn, PUp, POMq, PMCr Registers and the Bits (8-pin Products)

| Port | | Bit name | | | | |
|--------|---|-------------|--------------|--------------|---------------|---------------|
| | | Pm register | PMn register | PUp register | POMq register | PMCr register |
| PORT0 | 1 | P01 | PM01 | PU01 | POM01 | PMC01 |
| | 3 | P03 | PM03 | PU03 | POM03 | PMC03 |
| | 4 | P04 | PM04 | PU04 | — | PMC04 |
| PORT4 | 0 | P40 | PM40 | PU40 | — | — |
| PORT12 | 5 | P125 | PM125 | PU125 | — | — |
| PORT13 | 7 | P137 | — | — | — | — |

Table 4-3. Pm, PMn, PUp, POMq, PMCr Registers and the Bits (10-pin Products)

| Port | | Bit name | | | | |
|--------|---|-------------|--------------|--------------|---------------|---------------|
| | | Pm register | PMn register | PUp register | POMq register | PMCr register |
| PORT0 | 0 | P00 | PM00 | PU00 | POM00 | — |
| | 1 | P01 | PM01 | PU01 | POM01 | PMC01 |
| | 2 | P02 | PM02 | PU02 | — | PMC02 |
| | 3 | P03 | PM03 | PU03 | POM03 | PMC03 |
| | 4 | P04 | PM04 | PU04 | — | PMC04 |
| PORT4 | 0 | P40 | PM40 | PU40 | — | — |
| PORT12 | 5 | P125 | PM125 | PU125 | — | — |
| PORT13 | 7 | P137 | — | — | — | — |

Table 4-4. Pm, PMn, PUp, POMq, PMCr Registers and the Bits (16-pin Products)

| Port | | Bit name | | | | |
|--------|---|-------------|--------------|--------------|---------------|---------------|
| | | Pm register | PMn register | PUp register | POMq register | PMCr register |
| PORT0 | 0 | P00 | PM00 | PU00 | POM00 | — |
| | 1 | P01 | PM01 | PU01 | POM01 | PMC01 |
| | 2 | P02 | PM02 | PU02 | — | PMC02 |
| | 3 | P03 | PM03 | PU03 | POM03 | PMC03 |
| | 4 | P04 | PM04 | PU04 | POM04 | PMC04 |
| | 5 | P05 | PM05 | PU05 | POM05 | PMC05 |
| | 6 | P06 | PM06 | PU06 | POM06 | PMC06 |
| | 7 | P07 | PM07 | PU07 | POM07 | PMC07 |
| PORT4 | 0 | P40 | PM40 | PU40 | — | — |
| | 1 | P41 | PM41 | PU41 | — | — |
| PORT12 | 1 | P121 | PM121 | PU121 | — | — |
| | 2 | P122 | PM122 | PU122 | — | — |
| | 5 | P125 | PM125 | PU125 | — | — |
| PORT13 | 7 | P137 | — | — | — | — |

Table 4-5. Pm, PMn, PUp, POMq, PMCr Registers and the Bits (20-pin Products)

| Port | | Bit name | | | | |
|--------|---|-------------|--------------|--------------|---------------|---------------|
| | | Pm register | PMn register | PUp register | POMq register | PMCr register |
| PORT0 | 0 | P00 | PM00 | PU00 | POM00 | — |
| | 1 | P01 | PM01 | PU01 | POM01 | PMC01 |
| | 2 | P02 | PM02 | PU02 | — | PMC02 |
| | 3 | P03 | PM03 | PU03 | POM03 | PMC03 |
| | 4 | P04 | PM04 | PU04 | POM04 | PMC04 |
| | 5 | P05 | PM05 | PU05 | POM05 | PMC05 |
| | 6 | P06 | PM06 | PU06 | POM06 | PMC06 |
| | 7 | P07 | PM07 | PU07 | POM07 | PMC07 |
| PORT2 | 0 | P20 | PM20 | PU20 | — | PMC20 |
| | 1 | P21 | PM21 | PU21 | — | PMC21 |
| | 2 | P22 | PM22 | PU22 | POM22 | PMC22 |
| | 3 | P23 | PM23 | PU23 | — | PMC23 |
| PORT4 | 0 | P40 | PM40 | PU40 | — | — |
| | 1 | P41 | PM41 | PU41 | POM41 | — |
| PORT12 | 1 | P121 | PM121 | PU121 | — | — |
| | 2 | P122 | PM122 | PU122 | — | — |
| | 5 | P125 | PM125 | PU125 | — | — |
| PORT13 | 7 | P137 | — | — | — | — |

Remark m = 0, 2, 4, 12, 13
n = 0, 2, 4, 12
p = 0, 2, 4, 12
q = 0, 2, 4
r = 0, 2

The format of each register is described below.

4.3.1 Port mode registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12)

These registers specify input or output mode for the port in 1-bit units.

These registers can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation sets these registers to FFH.

When port pins are used as alternate-function pins, set the port mode register by referencing **4.5 Register Settings When Using Alternate Function**.

Figure 4-1. Format of Port Mode Registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12)

8-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|-------|------|------|---|------|------|---------|-------------|-----|
| PM0 | 1 | 1 | 1 | PM04 | PM03 | 1 | PM01 | 1 | FFF20H | FFH | R/W |
| PM4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | PM40 | FFF24H | FFH | R/W |
| PM12 | 1 | 1 | PM125 | 1 | 1 | 1 | 1 | 1 | FFF2CH | FFH | R/W |

10-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|-------|------|------|------|------|------|---------|-------------|-----|
| PM0 | 1 | 1 | 1 | PM04 | PM03 | PM02 | PM01 | PM00 | FFF20H | FFH | R/W |
| PM4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | PM40 | FFF24H | FFH | R/W |
| PM12 | 1 | 1 | PM125 | 1 | 1 | 1 | 1 | 1 | FFF2CH | FFH | R/W |

16-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|------|------|-------|------|------|-------|-------|------|---------|-------------|-----|
| PM0 | PM07 | PM06 | PM05 | PM04 | PM03 | PM02 | PM01 | PM00 | FFF20H | FFH | R/W |
| PM4 | 1 | 1 | 1 | 1 | 1 | 1 | PM41 | PM40 | FFF24H | FFH | R/W |
| PM12 | 1 | 1 | PM125 | 1 | 1 | PM122 | PM121 | 1 | FFF2CH | FFH | R/W |

20-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|------|------|-------|------|------|-------|-------|------|---------|-------------|-----|
| PM0 | PM07 | PM06 | PM05 | PM04 | PM03 | PM02 | PM01 | PM00 | FFF20H | FFH | R/W |
| PM2 | 1 | 1 | 1 | 1 | PM23 | PM22 | PM21 | PM20 | FFF22H | FFH | R/W |
| PM4 | 1 | 1 | 1 | 1 | 1 | 1 | PM41 | PM40 | FFF24H | FFH | R/W |
| PM12 | 1 | 1 | PM125 | 1 | 1 | PM122 | PM121 | 1 | FFF2CH | FFH | R/W |

| PMmn | Pmn pin I/O mode selection |
|------|--------------------------------|
| 0 | Output mode (output buffer on) |
| 1 | Input mode (output buffer off) |

Remark m = 0, 2, 4, 12
n = 0 to 7

Caution Be sure to set bits that are not mounted to their initial values.

4.3.2 Port registers 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13)

These registers set the output latch value of a port.

If the data is read in the input mode, the pin level is read. If it is read in the output mode, the output latch value is read^{Note 1}.

These registers can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation sets the P13 register to the undefined value, and clears the other registers to 00H.

Note 1. When a pin that is set as an analog input pin (PMCxx = 1, PMxx = 1) is read, the value read is always 0 regardless of the input signal level on the pin.
When the data bit is read while the setting for the P125/ $\overline{\text{RESET}}$ /INTP1/(VCOU0)/(VCOU1)/(SI01) pin is $\overline{\text{RESET}}$ input (PORTSELB = 1), the value read is always 1.

Figure 4-2. Format of Port Registers 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13)

8-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|------|---|------|-----|-----|---|-----|-----|---------|--------------------|-----|
| P0 | 0 | 0 | 0 | P04 | P03 | 0 | P01 | 0 | FFF00H | 00H (output latch) | R/W |
| P4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | P40 | FFF04H | 00H (output latch) | R/W |
| P12 | 0 | 0 | P125 | 0 | 0 | 0 | 0 | 0 | FFF0CH | 00H (output latch) | R/W |
| P13 | P137 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | FFF0DH | Undefined | R |

10-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|------|---|------|-----|-----|-----|-----|-----|---------|--------------------|-----|
| P0 | 0 | 0 | 0 | P04 | P03 | P02 | P01 | P00 | FFF00H | 00H (output latch) | R/W |
| P4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | P40 | FFF04H | 00H (output latch) | R/W |
| P12 | 0 | 0 | P125 | 0 | 0 | 0 | 0 | 0 | FFF0CH | 00H (output latch) | R/W |
| P13 | P137 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | FFF0DH | Undefined | R |

16-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|------|-----|------|-----|-----|------|------|-----|---------|--------------------|-----|
| P0 | P07 | P06 | P05 | P04 | P03 | P02 | P01 | P00 | FFF00H | 00H (output latch) | R/W |
| P4 | 0 | 0 | 0 | 0 | 0 | 0 | P41 | P40 | FFF04H | 00H (output latch) | R/W |
| P12 | 0 | 0 | P125 | 0 | 0 | P122 | P121 | 0 | FFF0CH | 00H (output latch) | R/W |
| P13 | P137 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | FFF0DH | Undefined | R |

20-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|------|-----|------|-----|-----|------|------|-----|---------|--------------------|-----|
| P0 | P07 | P06 | P05 | P04 | P03 | P02 | P01 | P00 | FFF00H | 00H (output latch) | R/W |
| P2 | 0 | 0 | 0 | 0 | P23 | P22 | P21 | P20 | FFF02H | 00H (output latch) | R/W |
| P4 | 0 | 0 | 0 | 0 | 0 | 0 | P41 | P40 | FFF04H | 00H (output latch) | R/W |
| P12 | 0 | 0 | P125 | 0 | 0 | P122 | P121 | 0 | FFF0CH | 00H (output latch) | R/W |
| P13 | P137 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | FFF0DH | Undefined | R |

| Pmn | Output data control (in output mode) | Input data read (in input mode) |
|-----|--------------------------------------|---------------------------------|
| 0 | Output 0 | Input low level |
| 1 | Output 1 | Input high level |

Remark m = 0, 2, 4, 12, 13
n = 0 to 7

Caution Be sure to set bits that are not mounted to their initial values.

4.3.3 Pull-up resistor option registers 0, 2, 4, 12 (PU0, PU2, PU4, PU12)

These registers specify whether the on-chip pull-up resistors are to be used or not. On-chip pull-up resistors can be used in 1-bit units only for the bits that satisfy the following usage conditions for the pins to which the use of an on-chip pull-up resistor has been specified in these registers.

Usage conditions of the on-chip pull-up resistor:

- PMmn = 1 (Input mode)
- PMCmn = 0 (Digital I/O)
- POMmn = 0 (Normal output mode)

On-chip pull-up resistors cannot be connected to bits set to output mode and bits used as alternate-function output pins and analog setting (PMC = 1), regardless of the settings of these registers.

These registers can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation sets PU4 to 01H, PU12 to 20H, and clears PU0 and PU2 to 00H.

Figure 4-3. Format of Pull-up Resistor Option Registers 0, 2, 4, 12 (PU0, PU2, PU4, PU12)

8-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|-----------------|------|------|---|------|------|---------|-------------|-----|
| PU0 | 0 | 0 | 0 | PU04 | PU03 | 0 | PU01 | 0 | F0030H | 00H | R/W |
| PU4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | PU40 | F0034H | 01H | R/W |
| PU12 | 0 | 0 | PU125 Note 1 | 0 | 0 | 0 | 0 | 0 | F003CH | 20H | R/W |

10-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|-----------------|------|------|------|------|------|---------|-------------|-----|
| PU0 | 0 | 0 | 0 | PU04 | PU03 | PU02 | PU01 | PU00 | F0030H | 00H | R/W |
| PU4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | PU40 | F0034H | 01H | R/W |
| PU12 | 0 | 0 | PU125 Note 1 | 0 | 0 | 0 | 0 | 0 | F003CH | 20H | R/W |

16-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|------|------|-----------------|------|------|-------|-------|------|---------|-------------|-----|
| PU0 | PU07 | PU06 | PU05 | PU04 | PU03 | PU02 | PU01 | PU00 | F0030H | 00H | R/W |
| PU4 | 0 | 0 | 0 | 0 | 0 | 0 | PU41 | PU40 | F0034H | 01H | R/W |
| PU12 | 0 | 0 | PU125 Note 1 | 0 | 0 | PU122 | PU121 | 0 | F003CH | 20H | R/W |

20-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|------|------|--------------------------------|------|------|-------|-------|------|---------|-------------|-----|
| PU0 | PU07 | PU06 | PU05 | PU04 | PU03 | PU02 | PU01 | PU00 | F0030H | 00H | R/W |
| PU2 | 0 | 0 | 0 | 0 | PU23 | PU22 | PU21 | PU20 | F0032H | 00H | R/W |
| PU4 | 0 | 0 | 0 | 0 | 0 | 0 | PU41 | PU40 | F0034H | 01H | R/W |
| PU12 | 0 | 0 | PU125 <small>Note 1</small> | 0 | 0 | PU122 | PU121 | 0 | F003CH | 20H | R/W |

| PU _m n | P _m n pin on-chip pull-up resistor selection |
|-------------------|---|
| 0 | On-chip pull-up resistor not connected |
| 1 | On-chip pull-up resistor connected |

Note 1. This bit can be only manipulated when the P125/INTP1/(VCOOUT0)/(VCOOUT1)/(SI01) pin is selected (PORTSELB = 0) (the on-chip pull-up resistor is always valid (PU125 = 1) when the RESET input (PORTSELB = 1) is selected).

Remark m = 0, 2, 4, 12
n = 0 to 7

Caution Be sure to set bits that are not mounted to their initial values.

4.3.4 Port input mode registers 0, 2, 4 (POM0, POM2, POM4)

These registers set CMOS output or N-ch open drain output in 1-bit units.

N-ch open drain output (V_{DD} tolerance) mode can be selected for the SDA00 and SDA01 pins during simplified I²C communication with an external device.

These registers can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears these registers to 00H.

Caution An on-chip pull-up resistor is not connected to a bit for which N-ch open drain output (V_{DD} tolerance) mode (POMmn = 1) is set.

Figure 4-4. Format of Port Output Mode Registers 0, 2, 4 (POM0, POM2, POM4)

8-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|---|---|-------|---|-------|---|---------|-------------|-----|
| POM0 | 0 | 0 | 0 | 0 | POM03 | 0 | POM01 | 0 | F0050H | 00H | R/W |

10-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|---|---|-------|---|-------|-------|---------|-------------|-----|
| POM0 | 0 | 0 | 0 | 0 | POM03 | 0 | POM01 | POM00 | F0050H | 00H | R/W |

16-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|-------|-------|-------|-------|-------|---|-------|-------|---------|-------------|-----|
| POM0 | POM07 | POM06 | POM05 | POM04 | POM03 | 0 | POM01 | POM00 | F0050H | 00H | R/W |

20-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|---------|-------------|-----|
| POM0 | POM07 | POM06 | POM05 | POM04 | POM03 | 0 | POM01 | POM00 | F0050H | 00H | R/W |
| POM2 | 0 | 0 | 0 | 0 | 0 | POM22 | 0 | 0 | F0052H | 00H | R/W |
| POM4 | 0 | 0 | 0 | 0 | 0 | 0 | POM41 | 0 | F0054H | 00H | R/W |

| POMmn | P0n pin output mode selection |
|-------|---|
| 0 | Normal output mode |
| 1 | N-ch open-drain output (V_{DD} tolerance) mode |

Remark m = 0, 2, 4
n = 0 to 7

Caution Be sure to set bits that are not mounted to their initial values.

4.3.5 Port mode control registers 0, 2 (PMC0, PMC2)

These registers set the digital I/O/analog input in 1-bit units.

These registers can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears these registers to FFH.

Figure 4-5. Format of Port Mode Control Registers 0, 2 (PMC0, PMC2)

8-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|---|-------|-------|---|-------|---|---------|-------------|-----|
| PMC0 | 1 | 1 | 1 | PMC04 | PMC03 | 1 | PMC01 | 1 | F0060H | FFH | R/W |

10-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|---|-------|-------|-------|-------|---|---------|-------------|-----|
| PMC0 | 1 | 1 | 1 | PMC04 | PMC03 | PMC02 | PMC01 | 1 | F0060H | FFH | R/W |

16-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|-------|-------|-------|-------|-------|-------|-------|---|---------|-------------|-----|
| PMC0 | PMC07 | PMC06 | PMC05 | PMC04 | PMC03 | PMC02 | PMC01 | 1 | F0060H | FFH | R/W |

20-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|---------|-------------|-----|
| PMC0 | PMC07 | PMC06 | PMC05 | PMC04 | PMC03 | PMC02 | PMC01 | 1 | F0060H | FFH | R/W |
| PMC2 | 1 | 1 | 1 | 1 | PMC23 | PMC22 | PMC21 | PMC20 | F0062H | FFH | R/W |

| PMCmn | P0n pin digital I/O/analog input selection |
|-------|--|
| 0 | Digital I/O (alternate function other than analog input) |
| 1 | Analog input |

Remark m = 0, 2
n = 1 to 7

Caution 1. Select input mode by using port mode registers 0, 2 (PM0, PM2) for the ports which are set by the PMC0, PMC2 registers as analog input.

Caution 2. Be sure to set bits that are not mounted to their initial values.

4.3.6 Peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3)

These registers are used to specify whether to enable or disable the peripheral I/O redirect function.

This function is used to switch ports to which alternate functions are assigned.

Use the PIOR0 to PIOR3 registers to assign a port to the function to redirect and enable the function.

In addition, the settings for redirection can be changed only until operation of the function is enabled.

The PIOR0 to PIOR3 registers can be set by an 8-bit memory manipulation instruction.

Reset signal generation clears these registers to 00H.

Figure 4-6. Format of Peripheral I/O Redirection Registers 0 to 3 (PIOR0 to PIOR3)

8-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|---|---|---|--------|---|--------|---------|-------------|-----|
| PIOR0 | 0 | 0 | 0 | 0 | 0 | PIOR02 | 0 | PIOR00 | F0077H | 00H | R/W |
| PIOR3 | 0 | 0 | 0 | 0 | 0 | PIOR32 | 0 | 0 | F007CH | 00H | R/W |

10-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|---|---|---|--------|--------|---|--------|---------|-------------|-----|
| PIOR0 | 0 | 0 | 0 | 0 | PIOR03 | PIOR02 | 0 | PIOR00 | F0077H | 00H | R/W |
| PIOR3 | 0 | 0 | 0 | 0 | 0 | PIOR32 | 0 | PIOR30 | F007CH | 00H | R/W |

16-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|---|--------|--------|--------|--------|--------|--------|--------|---------|-------------|-----|
| PIOR0 | 0 | PIOR06 | PIOR05 | PIOR04 | PIOR03 | PIOR02 | 0 | PIOR00 | F0077H | 00H | R/W |
| PIOR1 | 0 | 0 | 0 | PIOR14 | 0 | PIOR12 | PIOR11 | PIOR10 | F0079H | 00H | R/W |
| PIOR2 | 0 | PIOR26 | 0 | PIOR24 | PIOR23 | PIOR22 | PIOR21 | 0 | F0075H | 00H | R/W |
| PIOR3 | 0 | 0 | 0 | PIOR34 | 0 | PIOR32 | PIOR31 | PIOR30 | F007CH | 00H | R/W |

20-pin products

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | Address | After reset | R/W |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|---------|-------------|-----|
| PIOR0 | PIOR07 | PIOR06 | PIOR05 | PIOR04 | PIOR03 | PIOR02 | PIOR01 | PIOR00 | F0077H | 00H | R/W |
| PIOR1 | 0 | 0 | 0 | PIOR14 | PIOR13 | PIOR12 | PIOR11 | PIOR10 | F0079H | 00H | R/W |
| PIOR2 | PIOR27 | PIOR26 | PIOR25 | PIOR24 | PIOR23 | PIOR22 | PIOR21 | PIOR20 | F0075H | 00H | R/W |
| PIOR3 | 0 | 0 | PIOR35 | PIOR34 | PIOR33 | PIOR32 | PIOR31 | PIOR30 | F007CH | 00H | R/W |

8-pin products

| Bit | Function | Setting value | |
|--------|-----------|---------------|------|
| | | 0 | 1 |
| PIOR02 | TI01/TO01 | P04 | P40 |
| PIOR00 | TI00 | P137 | P03 |
| PIOR32 | VCOUT0 | P40 | P125 |

10-pin products

| Bit | Function | Setting value | |
|--------|----------|---------------|------|
| | | 0 | 1 |
| PIOR00 | TI00 | P137 | P03 |
| PIOR32 | VCOUT0 | P02 | P125 |
| PIOR30 | PCLBUZ0 | P02 | P40 |

| Bit | | Function | Setting value | | | |
|--------|--------|-----------|---------------|-----|-----|--------------------|
| | | | 00 | 01 | 10 | 11 |
| PIOR03 | PIOR02 | TI01/TO01 | P04 | P40 | P02 | Setting prohibited |

16-pin products

| Bit | | Function | Setting value | |
|--------|--|-------------|---------------|------|
| | | | 0 | 1 |
| PIOR06 | | TO03 | P41 | P07 |
| PIOR00 | | TI00 | P137 | P03 |
| PIOR14 | | SCLA0 | P06 | P00 |
| | | SDAA0 | P07 | P01 |
| PIOR12 | | SCK01/SCL01 | P07 | P00 |
| | | SI01/SDA01 | P06 | P01 |
| | | SO01 | P05 | P02 |
| PIOR26 | | INTP6 | P00 | P05 |
| PIOR24 | | INTP5 | P01 | P07 |
| PIOR23 | | INTP4 | P03 | P41 |
| PIOR22 | | INTP3 | P04 | P121 |
| PIOR21 | | INTP2 | P40 | P122 |
| PIOR34 | | INTP7 | P02 | P06 |
| PIOR32 | | VCOUT0 | P02 | P125 |

| Bit | | Function | Setting value | | | |
|--------|--------|-----------------|---------------|-----|-----|--------------------|
| | | | 00 | 01 | 10 | 11 |
| PIOR05 | PIOR04 | TI02/TO02 | P05 | P01 | P41 | Setting prohibited |
| PIOR03 | PIOR02 | TI01/TO01 | P04 | P40 | P02 | Setting prohibited |
| PIOR11 | PIOR10 | SCK00/SCL00 | P02 | P06 | P05 | Setting prohibited |
| | | SI00/RxD0/SDA00 | P01 | P05 | P04 | Setting prohibited |
| | | SO00/TxD0 | P00 | P04 | P03 | Setting prohibited |
| PIOR31 | PIOR30 | PCLBUZ0 | P02 | P40 | P06 | Setting prohibited |

20-pin products

| Bit | Function | Setting value | |
|--------|----------|---------------|------|
| | | 0 | 1 |
| PIOR14 | SCLA0 | P06 | P00 |
| | SDAA0 | P07 | P01 |
| PIOR23 | INTP4 | P03 | P41 |
| PIOR22 | INTP3 | P04 | P121 |
| PIOR21 | INTP2 | P40 | P122 |
| PIOR20 | INTP1 | P125 | P20 |
| PIOR33 | VCOUT1 | P41 | P125 |
| PIOR32 | VCOUT0 | P02 | P125 |

| Bit | | Function | Setting value | | | |
|--------|--------|-----------------|---------------|-----|------|--------------------|
| | | | 00 | 01 | 10 | 11 |
| PIOR07 | PIOR06 | TI03 | P41 | P41 | P20 | Setting prohibited |
| | | TO03 | P41 | P07 | P20 | |
| PIOR05 | PIOR04 | TI02/TO02 | P05 | P01 | P41 | Setting prohibited |
| PIOR03 | PIOR02 | TI01/TO01 | P04 | P40 | P02 | Setting prohibited |
| PIOR01 | PIOR00 | TI00 | P137 | P03 | P20 | Setting prohibited |
| | | TO00 | P03 | P03 | P21 | |
| PIOR13 | PIOR12 | SCK01 | P07 | P00 | P20 | P07 |
| | | SCL01 | P07 | P00 | P20 | P23 |
| | | SI01 | P06 | P01 | P125 | P06 |
| | | SDA01 | P06 | P01 | P41 | P22 |
| | | SO01 | P05 | P02 | P41 | P05 |
| PIOR11 | PIOR10 | SCK00/SCL00 | P02 | P06 | P05 | Setting prohibited |
| | | SI00/RxD0/SDA00 | P01 | P05 | P04 | Setting prohibited |
| | | SO00/TxD0 | P00 | P04 | P03 | Setting prohibited |
| PIOR27 | PIOR26 | INTP6 | P00 | P05 | P23 | Setting prohibited |
| PIOR25 | PIOR24 | INTP5 | P01 | P07 | P22 | Setting prohibited |
| PIOR35 | PIOR34 | INTP7 | P02 | P06 | P21 | Setting prohibited |
| PIOR31 | PIOR30 | PCLBUZ0 | P02 | P40 | P06 | Setting prohibited |

Caution Be sure to set bits that are not mounted to their initial values.

4.4 Port Function Operations

Port operations differ depending on whether the input or output mode is set, as shown below.

4.4.1 Writing to I/O port

1) Output mode

A value is written to the output latch by a transfer instruction, and the output latch contents are output from the pin.

Once data is written to the output latch, it is retained until data is written to the output latch again.

The data of the output latch is cleared when a reset signal is generated.

2) Input mode

A value is written to the output latch by a transfer instruction, but since the output buffer is off, the pin status does not change. Therefore, byte data can be written to the ports used for both input and output.

Once data is written to the output latch, it is retained until data is written to the output latch again.

The data of the output latch is cleared when a reset signal is generated.

4.4.2 Reading from I/O port

1) Output mode

The output latch contents are read by a transfer instruction. The output latch contents do not change.

2) Input mode

The pin status is read by a transfer instruction. The output latch contents do not change.

4.4.3 Operations on I/O port

1) Output mode

An operation is performed on the output latch contents, and the result is written to the output latch. The output latch contents are output from the pins.

Once data is written to the output latch, it is retained until data is written to the output latch again.

The data of the output latch is cleared when a reset signal is generated.

2) Input mode

The pin level is read and an operation is performed on its contents. The result of the operation is written to the output latch, but since the output buffer is off, the pin status does not change. Therefore, byte data can be written to the ports used for both input and output.

The data of the output latch is cleared when a reset signal is generated.

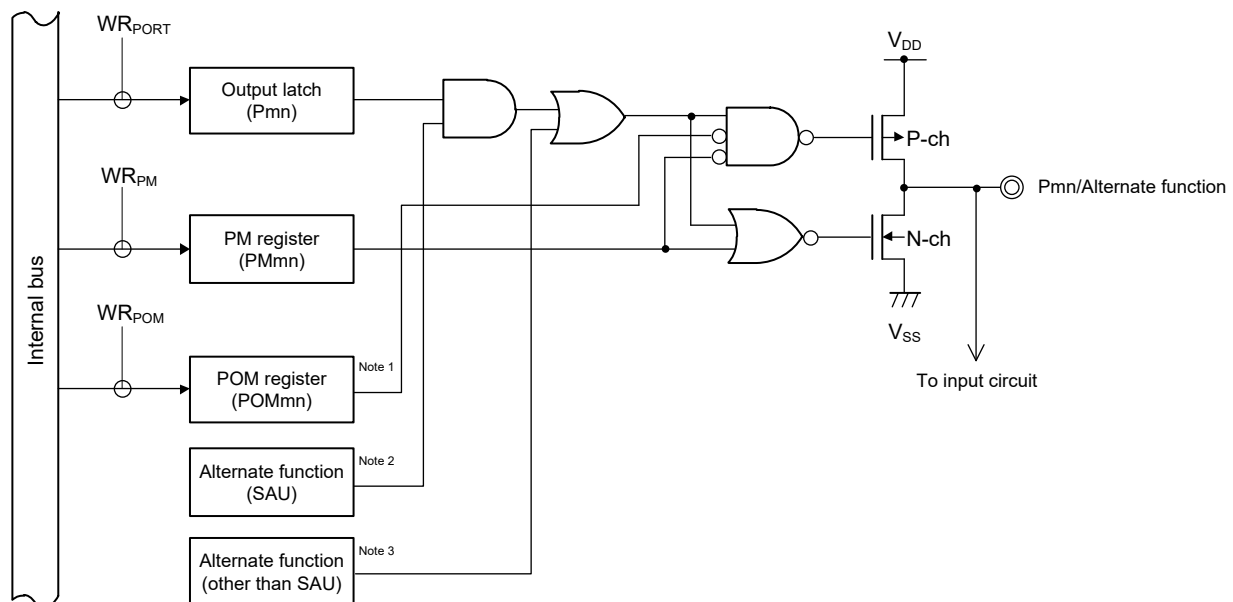
4.5 Register Settings When Using Alternate Function

4.5.1 Basic concept when using alternate function

In the beginning, for a pin also assigned to be used for analog input, use the port mode control registers 0, 2 (PMC0, PMC2) to specify whether to use the pin for analog input or digital input/output.

Figure 4-7 shows the basic configuration of an output circuit for pins used for digital input/output. The output of the output latch for the port and the output of the alternate SAU function are input to an AND gate. The output of the AND gate is input to an OR gate. The output of an alternate function other than SAU (TAU, clock/buzzer output, IICA, etc.) is connected to the other input pin of the OR gate. When such kind of pins are used as the port function or an alternate function, the unused alternate function must not hinder the output of the function to be used. An idea of basic settings for this kind of case is shown in **Table 4-6**.

Figure 4-7. Basic Configuration of Output Circuit for Pins



Note 1. When there is no POM register, this signal should be considered to be low level (0).

Note 2. When there is no alternate function, this signal should be considered to be high level (1).

Note 3. When there is no alternate function, this signal should be considered to be low level (0).

Remark m: Port number (m = 0, 2, 4, 12, 13); n: Bit number (n = 0 to 7)

Table 4-6. Concept of Basic Settings

| Output Function of Used Pin | Output Settings of Unused Alternate Function | | |
|------------------------------------|--|-------------------------|------------------------------------|
| | Output Function for Port | Output Function for SAU | Output Function for other than SAU |
| Output function for port | — | Output: High (1) | Output: Low (0) |
| Output function for SAU | High (1) | — | Output: Low (0) |
| Output function for other than SAU | Low (0) | don't care | Output:Low (0) ^{Note 1} |

Note 1. Since more than one output function other than SAU may be assigned to a single pin, the output of an unused alternate function must be set to low level (0). For details on the setting method, see **4.5.2 Register settings for alternate function whose output function is not used**.

4.5.2 Register settings for alternate function whose output function is not used

When the output of an alternate function of the pin is not used, the following settings should be made. Note that when the peripheral I/O redirection function is the target, the output can be switched to another pin by setting the peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3). This allows usage of the port function or other alternate function assigned to the target pin.

(1) SOp = 1, TxDq = 1 (settings when the serial output (SOp/TxDq) of SAU is not used)

When the serial output (SOp/TxDq) is not used, such as, a case in which only the serial input of SAU is used, set the bit in serial output enable register 0 (SOE0) which corresponds to the unused output to 0 (output disabled) and set the SO0n bit in serial output register 0 (SO0) to 1 (high). These are the same settings as the initial state.

(2) SCKp = 1, SDAr = 1, SCLr = 1 (settings when channel n in SAU is not used)

When SAU is not used, set bit n (SE0n) in serial channel enable status register 0 (SE0) to 0 (operation stopped state), set the bit in serial output enable register 0 (SOE0) which corresponds to the unused output to 0 (output disabled), and set the SO0n and CKO0n bits in serial output register 0 (SO0) to 1 (high). These are the same settings as the initial state.

(3) TO0n = 0 (settings when the output of channel n in TAU is not used)

When the TO0n output of TAU is not used, set the bit in timer output enable register 0 (TOE0) which corresponds to the unused output to 0 (output disabled) and set the bit in timer output register 0 (TO0) to 0 (low). These are the same settings as the initial state.

(4) SDAA0 = 0, SCLA0 = 0 (settings when IICA is not used)

When IICA is not used, set the IICE0 bit in IICA control register 00 (IICCTL00) to 0 (operation stopped). This is the same setting as the initial state.

(5) PCLBUZ0 = 0 (setting when clock/buzzer output is not used)

When the clock/buzzer output is not used, set the PCLOE0 bit in clock output select register 0 (CKS0) to 0 (output disabled). This is the same setting as the initial state.

4.5.3 Register setting examples for used port and alternate functions

Register setting examples for used port and alternate functions are shown in **Table 4-7**. The registers used to control the port functions should be set as shown in **Table 4-7**. See the following remark for legends used in **Table 4-7**.

Remark —: Not supported
 x: don't care
 PIORr: Peripheral I/O redirection register r (r = 0 to 3)
 POMp: Port output mode register p (p = 0, 2, 4)
 PMCq: Port mode control register q (q = 0, 2)
 PMn: Port mode register n (n = 0, 2, 4, 12)
 Pm: Port output latch (m = 0, 2, 4, 12, 13)
 Functions in parentheses can be assigned via settings in the peripheral I/O redirection register 0 to 3 (PIOR0 to PIOR3).

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (1/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | Alternate Function Output | | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|------------------------|--|------|------|-----|-----|--|-------------------------------|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | SAU Output Function | Other than SAU | | | | |
| P00 | P00 | Input | — | x | — | 1 | x | x | x | ✓ | ✓ | ✓ | — |
| | | Output | — | 0 | — | 0 | 0/1 | TxD0/SO00 = 1 (SCK01/SCL01) = 1 ^{Note 1} | (SCLA0) = 0 ^{Note 1} | | | | |
| | | N-ch open drain output | — | 1 | — | 0 | 0/1 | | | | | | |
| | SO00 | Output | PIOR11 = 0 ^{Note 1} PIOR10 = 0 ^{Note 1} | 0 | — | 0 | 1 | (SCK01/SCL01) = 1 ^{Note 1} | (SCLA0) = 0 ^{Note 1} | ✓ | ✓ | ✓ | — |
| | TxD0 | Output | PIOR11 = 0 ^{Note 1} PIOR10 = 0 ^{Note 1} | 0/1 | — | 0 | 1 | (SCK01/SCL01) = 1 ^{Note 1} | (SCLA0) = 0 ^{Note 1} | ✓ | ✓ | ✓ | — |
| | INTP6 | Input | PIOR27 = 0 ^{Note 2} PIOR26 = 0 ^{Note 1} | x | — | 1 | x | x | x | ✓ | ✓ | ✓ | — |
| | (SCK01) | Input | PIOR13 = 0 ^{Note 2} PIOR12 = 1 ^{Note 1} | x | — | 1 | x | x | x | ✓ | ✓ | — | — |
| | | Output | PIOR13 = 0 ^{Note 2} PIOR12 = 1 ^{Note 1} | 0 | — | 0 | 1 | TxD0/SO00 = 1 | (SCLA0) = 0 | | | | |
| | (SCL01) | Output | PIOR13 = 0 ^{Note 2} PIOR12 = 1 ^{Note 1} | 0 | — | 0 | 1 | TxD0/SO00 = 1 | (SCLA0) = 0 | ✓ | ✓ | — | — |
| | (SCLA0) | I/O | PIOR14 = 1 | 1 | — | 0 | 0 | x | x | ✓ | ✓ | — | — |

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (2/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | Alternate Function Output | | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|------------------------|--|------|------|-----|-----|--|--|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | SAU Output Function | Other than SAU | | | | |
| P01 | P01 | Input | — | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | | Output | — | 0 | 0 | 0 | 0/1 | SDA00 = 1 (SDA01) = 1 ^{Note 1} | (TO02) = 0 (SDAA0) = 0 ^{Note 1} SDAA0 = 0 ^{Note 3} | ✓ | ✓ | ✓ | ✓ |
| | | N-ch open drain output | — | 1 | 0 | 0 | 0/1 | | | | | | |
| | ANI0 | Analog input | — | x | 1 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | SI00 | Input | PIOR11 = 0 ^{Note 1} PIOR10 = 0 ^{Note 1} | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | RxD0 | Input | PIOR11 = 0 ^{Note 1} PIOR10 = 0 ^{Note 1} | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | SDA00 | I/O | PIOR11 = 0 ^{Note 1} PIOR10 = 0 ^{Note 1} | 1 | 0 | 0 | 1 | (SDA01) = 1 ^{Note 1} | (TO02) = 0 (SDAA0) = 0 ^{Note 1} SDAA0 = 0 ^{Note 3} | ✓ | ✓ | ✓ | ✓ |
| | INTP5 | Input | PIOR25 = 0 ^{Note 2} PIOR24 = 0 ^{Note 1} | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | (TI02) | Input | PIOR05 = 0 PIOR04 = 1 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | (TO02) | Output | PIOR05 = 0 PIOR04 = 1 | 0 | 0 | 0 | 0 | x | (SDAA0) = 0 | ✓ | ✓ | — | — |
| | (SI01) | Input | PIOR13 = 0 ^{Note 2} PIOR12 = 1 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | (SDA01) | I/O | PIOR13 = 0 ^{Note 2} PIOR12 = 1 | 1 | 0 | 0 | 1 | SDA00 = 1 | (TO02) = 0 (SDAA0) = 0 | ✓ | ✓ | — | — |
| | (SDAA0) | I/O | PIOR14 = 1 | 1 | 0 | 0 | 0 | x | (TO02) = 0 | ✓ | ✓ | — | — |
| | TI02 | Input | — | x | 0 | 1 | x | x | x | — | — | ✓ | ✓ |
| | TO02 | Output | — | 0 | 0 | 0 | 0 | x | SDAA0 = 0 | — | — | ✓ | ✓ |
| SDAA0 | I/O | — | 1 | 0 | 0 | 0 | x | (TO02) = 0 | — | — | ✓ | ✓ | |

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (3/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | Alternate Function Output | | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|--|--|------|------|-----|-----------------|--|---|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | SAU Output Function | Other than SAU | | | | |
| P02 | P02 | Input | — | — | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | — |
| | | Output | — | — | 0 | 0 | 0/1 | SCK00/SCL00 = 1 (SO01) = 1 ^{Note 1} | PCLBUZ0 = 0 VCOUT0 = 0 (TO01) = 0 | | | | |
| | ANI1 | Analog input | — | — | 1 | 1 | x | x | x | ✓ | ✓ | ✓ | — |
| | SCK00 | Input | PIOR11 = 0 ^{Note 1} PIOR10 = 0 ^{Note 1} | — | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | — |
| | | Output | PIOR11 = 0 ^{Note 1} PIOR10 = 0 ^{Note 1} | — | 0 | 0 | 1 | (SO01) = 1 ^{Note 1} | PCLBUZ0 = 0 VCOUT0 = 0 (TO01) = 0 | | | | |
| | SCL00 | Output | PIOR11 = 0 ^{Note 1} PIOR10 = 0 ^{Note 1} | — | 0 | 0 | 1 | (SO01) = 1 ^{Note 1} | PCLBUZ0 = 0 VCOUT0 = 0 (TO01) = 0 | ✓ | ✓ | ✓ | — |
| | PCLBUZ0 | Output | PIOR31 = 0 ^{Note 1} PIOR30 = 0 | — | 0 | 0 | 0 | x | VCOUT0 = 0 (TO01) = 0 | ✓ | ✓ | ✓ | — |
| | VCOUT0 | Output | PIOR32 = 0 | — | 0 | 0 | 0 | x | PCLBUZ0 = 0 (TO01) = 0 | ✓ | ✓ | ✓ | — |
| | INTP7 | Input | PIOR35 = 0 ^{Note 2} PIOR34 = 0 ^{Note 1} | — | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | — |
| | (TI01) | Input | PIOR03 = 1 PIOR02 = 0 | — | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | — |
| | (TO01) | Output | PIOR03 = 1 PIOR02 = 0 | — | 0 | 0 | 0 | x | PCLBUZ0 = 0 VCOUT0 = 0 | ✓ | ✓ | ✓ | — |
| (SO01) | Output | PIOR13 = 0 ^{Note 2} PIOR12 = 1 | — | 0 | 0 | 1 | SCK00/SCL00 = 1 | PCLBUZ0 = 0 VCOUT0 = 0 (TO01) = 0 | ✓ | ✓ | — | — | |
| P03 | P03 | Input | — | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | | Output | — | 0 | 0 | 0 | 0/1 | SO00/TxD0 = 1 ^{Note 4} (SO00/TxD0) = 1 ^{Note 1} | TO00 = 0 SCLA0 = 0 ^{Note 3} | | | | |
| | | N-ch open drain output | — | 1 | 0 | 0 | 0/1 | | | | | | |
| | ANI2 | Analog input | — | x | 1 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | TO00 | Output | PIOR01 = 0 ^{Note 2} PIOR00 = 0 ^{Note 2} | 0 | 0 | 0 | 0 | x | SCLA0 = 0 ^{Note 3} | ✓ | ✓ | ✓ | ✓ |
| | INTP4 | Input | PIOR23 = 0 ^{Note 1} | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | IVCMP0 | Input | — | x | 1 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | (TI00) | Input | PIOR01 = 0 ^{Note 2} PIOR00 = 1 | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | (SO00) | Output | PIOR11 = 1 PIOR10 = 0 | 0 | 0 | 0 | 1 | x | TO00 = 0 | ✓ | ✓ | — | — |
| | (TxD0) | Output | PIOR11 = 1 PIOR10 = 0 | 0/1 | 0 | 0 | 1 | x | TO00 = 0 | ✓ | ✓ | — | — |
| | SCLA0 | I/O | — | 1 | 0 | 0 | 0 | x | TO00 = 0 | — | — | ✓ | ✓ |
| SO00 | Output | — | 0 | 0 | 0 | 1 | x | TO00 = 0 SCLA0 = 0 | — | — | — | ✓ | |
| TxD0 | Output | — | 0/1 | 0 | 0 | 1 | x | TO00 = 0 SCLA0 = 0 | — | — | — | ✓ | |

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (4/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | Alternate Function Output | | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|------------------------|--|------|------|-----|-----|---|----------------|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | SAU Output Function | Other than SAU | | | | |
| P04 | P04 | Input | — | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | | Output | — | 0 | 0 | 0 | 0/1 | (SO00/TxD0) = 1 ^{Note 1} (SDA00) = 1 ^{Note 1} SCL00/SCL00 = 1 ^{Note 4} | TO01 = 0 | ✓ | ✓ | ✓ | ✓ |
| | | N-ch open drain output | — | 1 | 0 | 0 | 0/1 | | | | | | |
| | ANI3 | Analog input | — | x | 1 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | TI01 | Input | PIOR03 = 0 ^{Note 5} PIOR02 = 0 | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | TO01 | Output | PIOR03 = 0 ^{Note 5} PIOR02 = 0 | 0 | 0 | 0 | 0 | x | x | ✓ | ✓ | ✓ | ✓ |
| | IVREF0 | Input | — | x | 1 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | INTP3 | Input | PIOR22 = 0 ^{Note 1} | x | 0 | 1 | x | x | x | ✓ | ✓ | ✓ | ✓ |
| | (SI00) | Input | PIOR11 = 1 PIOR10 = 0 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | (RxD0) | Input | PIOR11 = 1 PIOR10 = 0 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | (SDA00) | I/O | PIOR11 = 1 PIOR10 = 0 | 1 | 0 | 0 | 1 | (SO00/TxD0) = 1 | TO01 = 0 | ✓ | ✓ | — | — |
| | (SO00) | Output | PIOR11 = 0 PIOR10 = 1 | 0 | 0 | 0 | 1 | (SDA00) = 1 | TO01 = 0 | ✓ | ✓ | — | — |
| | (TxD0) | Output | PIOR11 = 0 PIOR10 = 1 | 0/1 | 0 | 0 | 1 | (SDA00) = 1 | TO01 = 0 | ✓ | ✓ | — | — |
| | SCK00 | Input | — | x | 0 | 1 | x | x | x | — | — | — | ✓ |
| Output | | — | 0 | 0 | 0 | 1 | x | TO01 = 0 | — | — | — | — | |
| SCL00 | Output | — | 0 | 0 | 0 | 1 | x | TO01 = 0 | — | — | — | ✓ | |

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (5/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | Alternate Function Output | | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|--------------------------|--|------|------|-----|-------------------------------|--|----------------------------|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | SAU Output Function | Other than SAU | | | | |
| P05 | P05 | Input | — | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | | Output | — | 0 | 0 | 0 | 0/1 | SO01 = 1 (SCK00/SCL00) = 1 (SDA00) = 1 | TO02 = 0 | ✓ | ✓ | — | — |
| | | N-ch open drain output | — | 1 | 0 | 0 | 0/1 | | | | | | |
| | ANI4 | Analog input | — | x | 1 | 1 | x | x | x | ✓ | ✓ | — | — |
| | TI02 | Input | PIOR05 = 0 PIOR04 = 0 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | TO02 | Output | PIOR05 = 0 PIOR04 = 0 | 0 | 0 | 0 | 0 | x | x | ✓ | ✓ | — | — |
| | SO01 | Output | PIOR13 = 0 ^{Note 2} PIOR12 = 0 | 0 | 0 | 0 | 1 | (SCK00/SCL00) = 1 (SDA00) = 1 | TO02 = 0 | ✓ | ✓ | — | — |
| | (INTP6) | Input | PIOR27 = 0 ^{Note 2} PIOR26 = 1 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | (SCK00) | Input | PIOR11 = 1 PIOR10 = 0 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | | Output | PIOR11 = 1 PIOR10 = 0 | 0 | 0 | 0 | 1 | SO01 = 1 (SDA00) = 1 | TO02 = 0 | | | | |
| | (SCL00) | Output | PIOR11 = 1 PIOR10 = 0 | 0 | 0 | 0 | 1 | SO01 = 1 (SDA00) = 1 | TO02 = 0 | ✓ | ✓ | — | — |
| | (SI00) | Input | PIOR11 = 0 PIOR10 = 1 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | (RxD0) | Input | PIOR11 = 0 PIOR10 = 1 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| (SDA00) | I/O | PIOR11 = 0 PIOR10 = 1 | 1 | 0 | 0 | 1 | SO01 = 1 (SCK00/SCL00) = 1 | TO02 = 0 | ✓ | ✓ | — | — | |
| P06 | P06 | Input | — | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | | Output | — | 0 | 0 | 0 | 0/1 | SDA01 = 1 (SCK00/SCL00) = 1 | SCLA0 = 0 (PCLBUZ0) = 0 | | | | |
| | | N-ch open drain output | — | 1 | 0 | 0 | 0/1 | | | | | | |
| | ANI5 | Analog input | — | x | 1 | 1 | x | x | x | ✓ | ✓ | — | — |
| | SI01 | Input | PIOR13 = 0 ^{Note 2} PIOR12 = 0 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | SDA01 | I/O | PIOR13 = 0 ^{Note 2} PIOR12 = 0 | 1 | 0 | 0 | 1 | (SCK00/SCL00) = 1 | SCLA0 = 0 (PCLBUZ0) = 0 | ✓ | ✓ | — | — |
| | SCLA0 | I/O | PIOR14 = 0 | 1 | 0 | 0 | 0 | x | (PCLBUZ0) = 0 | ✓ | ✓ | — | — |
| | (INTP7) | Input | PIOR35 = 0 ^{Note 2} PIOR34 = 1 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | (PCLBUZ0) | Output | PIOR31 = 1 PIOR30 = 0 | 0 | 0 | 0 | 0 | x | SCLA0 = 0 | ✓ | ✓ | — | — |
| | (SCK00) | Input | PIOR11 = 0 PIOR10 = 1 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | | Output | PIOR11 = 0 PIOR10 = 1 | 0 | 0 | 0 | 1 | SDA01 = 1 | SCLA0 = 0 (PCLBUZ0) = 0 | | | | |
| (SCL00) | Output | PIOR11 = 0 PIOR10 = 1 | 0 | 0 | 0 | 1 | SDA01 = 1 | SCLA0 = 0 (PCLBUZ0) = 0 | ✓ | ✓ | — | — | |

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (6/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | Alternate Function Output | | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|--|--|------|------|-----|-----|---------------------------|-------------------------|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | SAU Output Function | Other than SAU | | | | |
| P07 | P07 | Input | — | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | | Output | — | 0 | 0 | 0 | 0/1 | SCK01/SCL01 = 1 | (TO03) = 0 SDAA0 = 0 | ✓ | ✓ | — | — |
| | | N-ch open drain output | — | 1 | 0 | 0 | 0/1 | | | | | | |
| | ANI6 | Analog input | — | x | 1 | 1 | x | x | x | ✓ | ✓ | — | — |
| | (TO03) | Output | PIOR07 = 0 ^{Note 2} PIOR06 = 1 | 0/1 | 0 | 0 | 0 | x | SDAA0 = 0 | ✓ | ✓ | — | — |
| | SCK01 | Input | PIOR13 = 0 ^{Note 2} PIOR12 = 0 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — |
| | | Output | PIOR13 = 0 ^{Note 2} PIOR12 = 0 | 0 | 0 | 0 | 1 | x | (TO03) = 0 SDAA0 = 0 | ✓ | ✓ | — | — |
| | SCL01 | Output | PIOR13 = 0 ^{Note 2} PIOR12 = 0 | 0 | 0 | 0 | 1 | x | (TO03) = 0 SDAA0 = 0 | | | | |
| | SDAA0 | I/O | PIOR14 = 0 | 1 | 0 | 0 | 0 | x | (TO03) = 0 | ✓ | ✓ | — | — |
| (INTP5) | Input | PIOR25 = 0 ^{Note 2} PIOR24 = 1 | x | 0 | 1 | x | x | x | ✓ | ✓ | — | — | |

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (7/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | Alternate Function Output | | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|--------------------------|--------------------------|------|------|-----|-----|---------------------------|----------------|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | SAU Output Function | Other than SAU | | | | |
| P20 | P20 | Input | — | — | 0 | 1 | x | x | x | ✓ | — | — | — |
| | | Output | — | — | 0 | 0 | 0/1 | (SCK01/SCL01) = 1 | (TO03) = 0 | ✓ | — | — | — |
| | ANI10 | Analog input | — | — | 1 | 1 | x | x | x | ✓ | — | — | — |
| | IVREF1 | Input | — | — | 1 | 1 | x | x | x | ✓ | — | — | — |
| | (INTP1) | Input | PIOR20 = 1 | — | 0 | 1 | x | x | x | ✓ | — | — | — |
| | (TI00) | Input | PIOR01 = 1 PIOR00 = 0 | — | 0 | 1 | x | x | x | ✓ | — | — | — |
| | (TI03) | Input | PIOR07 = 1 PIOR06 = 0 | — | 0 | 1 | x | x | x | ✓ | — | — | — |
| | (TO03) | Output | PIOR07 = 1 PIOR06 = 0 | — | 0 | 0 | 0 | x | x | ✓ | — | — | — |
| | (SCK01) | Input | PIOR13 = 1 PIOR12 = 0 | — | 0 | 1 | x | x | x | ✓ | — | — | — |
| | | Output | PIOR13 = 1 PIOR12 = 0 | — | 0 | 0 | 1 | x | (TO03) = 0 | ✓ | — | — | — |
| (SCL01) | Output | PIOR13 = 1 PIOR12 = 0 | — | 0 | 0 | 1 | — | (TO03) = 0 | ✓ | — | — | — | |
| P21 | P21 | Input | — | — | 0 | 1 | x | — | x | ✓ | — | — | — |
| | | Output | — | — | 0 | 0 | 0/1 | — | (TO00) = 0 | ✓ | — | — | — |
| | ANI9 | Analog input | — | — | 1 | 1 | x | — | x | ✓ | — | — | — |
| | IVCMP1 | Input | — | — | 1 | 1 | x | — | x | ✓ | — | — | — |
| | (INTP7) | Input | PIOR35 = 1 PIOR34 = 0 | — | 0 | 1 | x | — | x | ✓ | — | — | — |
| (TO00) | Output | PIOR01 = 1 PIOR00 = 0 | — | 0 | 0 | 0 | — | x | ✓ | — | — | — | |
| P22 | P22 | Input | — | x | 0 | 1 | x | x | x | ✓ | — | — | — |
| | | Output | — | 0 | 0 | 0 | 0/1 | (SDA01) = 1 | TO06 = 0 | ✓ | — | — | — |
| | | N-ch open drain output | — | 1 | 0 | 0 | 0/1 | | | | | | |
| | ANI8 | Analog input | — | x | 1 | 1 | x | x | x | | | | |
| | (SDA01) | I/O | PIOR13 = 1 PIOR12 = 1 | 1 | 0 | 0 | 1 | x | TO06 = 0 | ✓ | — | — | — |
| | TI06 | Input | — | x | 0 | 1 | x | x | x | ✓ | — | — | — |
| | TO06 | Output | — | 0 | 0 | 0 | 0 | x | x | ✓ | — | — | — |
| | (INTP5) | Input | PIOR25 = 1 PIOR24 = 0 | x | 0 | 1 | x | x | x | ✓ | — | — | — |
| P23 | P23 | Input | — | — | 0 | 1 | x | x | x | ✓ | — | — | — |
| | | Output | — | — | 0 | 0 | 0/1 | (SCL01) = 1 | TO04 = 0 | ✓ | — | — | — |
| | ANI7 | Analog input | — | — | 1 | 1 | x | x | x | ✓ | — | — | — |
| | (SCL01) | Output | PIOR13 = 1 PIOR12 = 1 | — | 0 | 0 | 1 | x | TO04 = 0 | ✓ | — | — | — |
| | (INTP6) | Input | PIOR27 = 1 PIOR26 = 0 | — | 0 | 1 | x | x | x | ✓ | — | — | — |
| | TI04 | Input | — | — | 0 | 1 | x | x | x | ✓ | — | — | — |
| TO04 | Output | — | — | 0 | 0 | 0 | x | x | ✓ | — | — | — | |

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (8/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | Alternate Function Output | | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|--------------------------|--|------|------|-----|-----|--------------------------------------|---|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | SAU Output Function | Other than SAU | | | | |
| P40 | P40 | Input | — | — | — | 1 | x | — | x | ✓ | ✓ | ✓ | ✓ |
| | | Output | — | — | — | 0 | 0/1 | — | (PCLBUZ0) = 0 Note 5 (TO01) = 0 PCLBUZ0 = 0 ^{Note 4} VCOUT = 0 ^{Note 4} | ✓ | ✓ | ✓ | ✓ |
| | (PCLBUZ0) | Output | PIOR31 = 0 ^{Note 1} PIOR30 = 1 | — | — | 0 | 0 | — | (TO01) = 0 | ✓ | ✓ | ✓ | — |
| | (TI01) | Input | PIOR03 = 0 ^{Note 5} PIOR02 = 1 | — | — | 1 | x | — | x | ✓ | ✓ | ✓ | ✓ |
| | (TO01) | Output | PIOR03 = 0 ^{Note 5} PIOR02 = 1 | — | — | 0 | 0 | — | (PCLBUZ0) = 0 Note 5 PCLBUZ0 = 0 ^{Note 4} VCOUT = 0 ^{Note 4} | ✓ | ✓ | ✓ | ✓ |
| | INTP2 | Input | PIOR21 = 0 ^{Note 1} | x | — | 1 | x | — | x | ✓ | ✓ | ✓ | ✓ |
| | PCLBUZ0 | Output | — | — | — | 0 | 0 | — | (TO01) = 0 VCOUT = 0 | — | — | — | ✓ |
| | VCOUT0 | Output | PIOR32 = 0 | — | — | 0 | 0 | — | (TO01) = 0 PCLBUZ0 = 0 | — | — | — | ✓ |
| P41 | P41 | Input | — | x | — | 1 | x | x | x | ✓ | ✓ | — | — |
| | | Output | — | 0 | — | 0 | 0/1 | (SDA01/SO01) = 1 ^{Note 2} | TO03 = 0 (TO02) = 0 VCOUT1 = 0 ^{Note 2} | ✓ | ✓ | — | — |
| | | N-ch open drain output | — | 1 | — | 0 | 0/1 | | | | | | |
| | TI03 | Input | PIOR07 = 0 ^{Note 2} | x | — | 1 | x | x | x | | | | |
| | TO03 | Output | PIOR07 = 0 ^{Note 2} PIOR06 = 0 | 0 | — | 0 | 0 | x | (TO02) = 0 VCOUT1 = 0 ^{Note 2} | ✓ | ✓ | — | — |
| | (INTP4) | Input | PIOR23 = 1 | x | — | 1 | x | x | x | ✓ | ✓ | — | — |
| | (TI02) | Input | PIOR05 = 1 PIOR04 = 0 | x | — | 1 | x | x | x | ✓ | ✓ | — | — |
| | (TO02) | Output | PIOR05 = 1 PIOR04 = 0 | 0 | — | 0 | 0 | x | TO03 = 0 VCOUT1 = 0 ^{Note 2} | ✓ | ✓ | — | — |
| | VCOUT1 | Output | PIOR33 = 0 | 0 | — | 0 | 0 | x | TO03 = 0 (TO02) = 0 | ✓ | — | — | — |
| | (SDA01) | I/O | PIOR13 = 1 PIOR12 = 0 | 1 | — | 0 | 1 | x | TO03 = 0 (TO02) = 0 VCOUT1 = 0 | ✓ | — | — | — |
| (SO01) | Output | PIOR13 = 1 PIOR12 = 0 | 0 | — | 0 | 1 | x | TO03 = 0 (TO02) = 0 VCOUT1 = 0 | ✓ | — | — | — | |

Note 1. 16-pin and 20-pin products only

Note 2. 20-pin products only

Note 3. 8-pin and 10-pin products only

Note 4. 8-pin products only

Note 5. 10- to 20-pin products only

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (9/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | CMC (EXCLK,OSCSEL) | Alternate Function Output | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|--------|------------|------|------|-----|-----|--------------------|---------------------------|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | | | | | | |
| P121 | P121 | Input | — | — | — | 1 | x | 00/10/11 | x | ✓ | ✓ | — | — |
| | | Output | — | — | — | 0 | 0/1 | 00/10/11 | TO07 = 0 | | | | |
| | X1 | Input | — | — | — | x | x | 01 | x | ✓ | ✓ | — | — |
| | (INTP3) | Input | PIOR22 = 1 | — | — | 1 | x | 00/10/11 | x | ✓ | ✓ | — | — |
| | TI07 | Input | — | — | — | 1 | x | 00/10/11 | x | ✓ | ✓ | — | — |
| | TO07 | Output | — | — | — | 0 | 0 | 00/10/11 | x | ✓ | ✓ | — | — |
| P122 | P122 | Input | — | — | — | 1 | x | 00/10 | x | ✓ | ✓ | — | — |
| | | Output | — | — | — | 0 | 0/1 | 00/10 | TO05 = 0 | | | | |
| | X2 | Input | — | — | — | x | x | 01 | x | ✓ | ✓ | — | — |
| | EXCLK | Input | — | — | — | x | x | 11 | x | ✓ | ✓ | — | — |
| | (INTP2) | Input | PIOR21 = 1 | — | — | 1 | x | 00/10 | x | ✓ | ✓ | — | — |
| | TI05 | Input | — | — | — | 1 | x | 00/10 | x | ✓ | ✓ | — | — |
| | TO05 | Output | — | — | — | 0 | 0 | 00/10 | x | ✓ | ✓ | — | — |

Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (10/10)

| Pin Name | Used Function | | PIORr | POMp | PMCq | PMn | Pm | Notes | Alternate Function Output | 20-pin | 16-pin | 10-pin | 8-pin |
|----------|---------------|--------|--|------|------|-----|-----|---------------------------------------|--|--------|--------|--------|-------|
| | Function Name | I/O | | | | | | | | | | | |
| P125 | P125 | Input | — | — | — | 1 | x | Optional bytes 000C1H PORTSELB = 0 | x | ✓ | ✓ | ✓ | ✓ |
| | | Output | — | — | — | 0 | 0/1 | | (VCOUT0) = 0 (VCOUT1) = 0 ^{Note 1} | | | | |
| | INTP1 | Input | PIOR20 = 0 ^{Note 1} | — | — | 1 | x | | x | ✓ | ✓ | ✓ | ✓ |
| | (VCOUT0) | Output | PIOR32 = 1 | — | — | 0 | 0 | | (VCOUT1) = 0 ^{Note 1} | ✓ | ✓ | ✓ | ✓ |
| | (VCOUT1) | Output | PIOR33 = 1 | — | — | 0 | 0 | | (VCOUT0) = 0 | ✓ | — | — | — |
| | (SI01) | Input | PIOR13 = 1 PIOR12 = 0 | — | — | 1 | x | | x | ✓ | — | — | — |
| | RESET | Input | — | — | — | x | x | | Optional bytes 000C1H PORTSELB = 1 | x | ✓ | ✓ | ✓ |
| P137 | P137 | Input | — | — | — | — | x | — | — | ✓ | ✓ | ✓ | ✓ |
| | TI00 | Input | PIOR01 = 0 ^{Note 1} PIOR00 = 0 | — | — | — | x | — | — | ✓ | ✓ | ✓ | ✓ |
| | INTP0 | Input | — | — | — | — | x | — | — | ✓ | ✓ | ✓ | ✓ |

Note 1. 20-pin products only

4.6 Cautions When Using Port Function

4.6.1 Cautions on 1-bit manipulation instruction for port register n (Pn)

When a 1-bit manipulation instruction is executed on a port that provides both input and output functions, the output latch value of an input port that is not subject to manipulation may be written in addition to the targeted bit.

Therefore, it is recommended to rewrite the output latch when switching a port from input mode to output mode.

[Example]

When P00 is an output port, P01 to P07 are input ports (the status of all pins is high level), and the output latch value of port 0 is 00H, if the output of output port P00 is changed from low level to high level via a 1-bit manipulation instruction, the output latch value of port 0 is FFH.

[Explanation]

The targets of writing to and reading from the Pn register of a port whose PMnm bit is 1 are the output latch and pin status, respectively.

A 1-bit manipulation instruction is executed in the following order in the RL78 microcontroller.

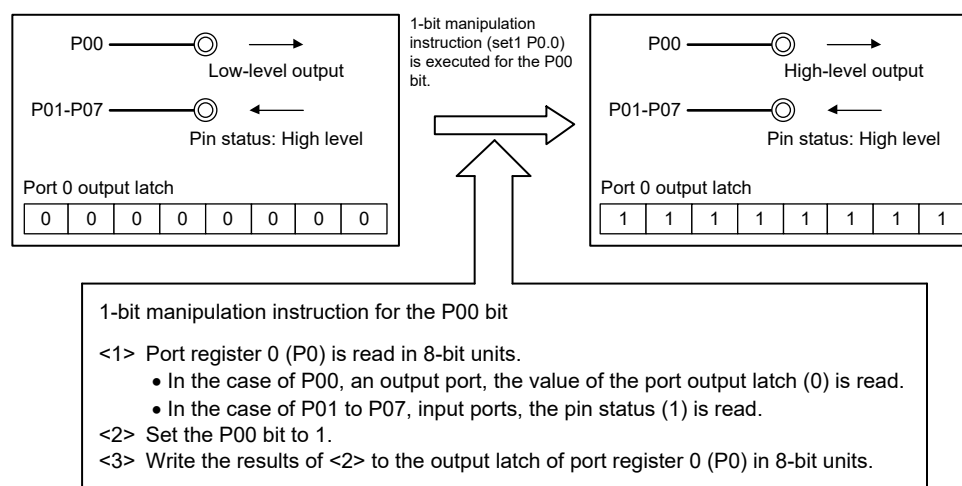
- <1> The Pn register is read in 8-bit units.
- <2> The targeted one bit is manipulated.
- <3> The Pn register is written in 8-bit units.

In step <1>, the output latch value (0) of P00, which is an output port, is read, while the pin status of P01 to P07, which are input ports, is read. If the pin status of P01 to P07 is high level at this time, the read value is FEH.

The value is changed to FFH by the manipulation in <2>.

FFH is written to the output latch by the manipulation in <3>.

Figure 4-8. Bit Manipulation Instruction (P00)



4.6.2 Notes on specifying the pin settings

For an output pin to which multiple alternate functions are assigned, the output of the unused alternate functions must be set to its initial state so as to prevent conflicting outputs. This also applies to the functions assigned by using the peripheral I/O redirection register 0 to 3 (PIOR0 to PIOR3). For details about the alternate output function, see **4.5 Register Settings When Using Alternate Function**.

No specific setting is required for input pins because the output of their alternate functions is disabled (the buffer output is Hi-Z).

Disabling the unused functions, including blocks that are only used for input or do not have I/O, is recommended for lower power consumption.

CHAPTER 5 CLOCK GENERATOR

5.1 Functions of Clock Generator

The clock generator generates the clock to be supplied to the CPU and peripheral hardware.

The following three kinds of system clocks and clock oscillators are selectable.

1) Main system clock

<1> X1 oscillator (16-pin and 20-pin products only)

This circuit oscillates a clock of $f_x = 1$ to 12 MHz by connecting a resonator to X1 and X2 pins.

The external main system clock ($f_{EX} = 1$ to 16 MHz) can also be supplied from EXCLK/X2/P122 pin.

Oscillation can be stopped by executing the STOP instruction or setting of the MSTOP bit (bit 7 of the clock operation status control register (CSC)).

<2> High-speed on-chip oscillator

The frequency at which to oscillate can be selected from among $f_{IH} = 16/8/4/2/1$ MHz (typ.) by using the option byte (000C2H). After a reset release, the CPU always starts operating with this high-speed on-chip oscillator clock.

Oscillation can be stopped by executing the STOP instruction or setting the HIOSTOP bit (bit 0 of the CSC register).

The frequency specified by using an option byte can be changed by using the high-speed on-chip oscillator frequency select register (HOCODIV). For details about the frequency, see **Figure 5-9 Format of High-speed On-chip Oscillator Frequency Select Register (HOCODIV)**.

The frequencies that can be specified for the high-speed on-chip oscillator by using the option byte and the high-speed on-chip oscillator frequency select register (HOCODIV) are shown below.

| Power Supply Voltage | Oscillation Frequency (MHz) | | | | |
|--|-----------------------------|---|---|---|----|
| | 1 | 2 | 4 | 8 | 16 |
| $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | ✓ | ✓ | ✓ | ✓ | ✓ |

Remark ✓: Can operate, — : Cannot operate

As the main system clock, a high-speed system clock (X1 clock) or high-speed on-chip oscillator clock can be selected by setting of the MCM0 bit (bit 4 of the system clock control register (CKC)).

The external main system clock ($f_{EX} = 1$ to 16 MHz) can also be supplied from EXCLK/X2/P122 pin. An external main system clock input can be disabled by executing the STOP instruction or setting of the MSTOP bit.

2) Low-speed on-chip oscillator clock

This circuit oscillates a clock of $f_{IL} = 15$ kHz (typ.).

The low-speed on-chip oscillator clock cannot be used as the CPU clock.

Only the following peripheral hardware runs on the low-speed on-chip oscillator clock.

- Watchdog timer
- 12-bit Interval timer

This clock operates when bit 4 (WDTON) of the option byte (000C0H), bit 4 (WUTMMCK0) of the operation speed mode control register (OSMC), or both are set to 1.

However, when WDTON = 1, WUTMMCK0 = 0, and bit 0 (WDSTBYON) of the option byte (000C0H) is 0, oscillation of the low-speed on-chip oscillator stops if the HALT or STOP instruction is executed.

Remark f_X : X1 clock oscillation frequency
 f_{EX} : External main system clock frequency
 f_{IH} : High-speed on-chip oscillator clock frequency
 f_{IL} : Low-speed on-chip oscillator clock frequency

5.2 Configuration of Clock Generator

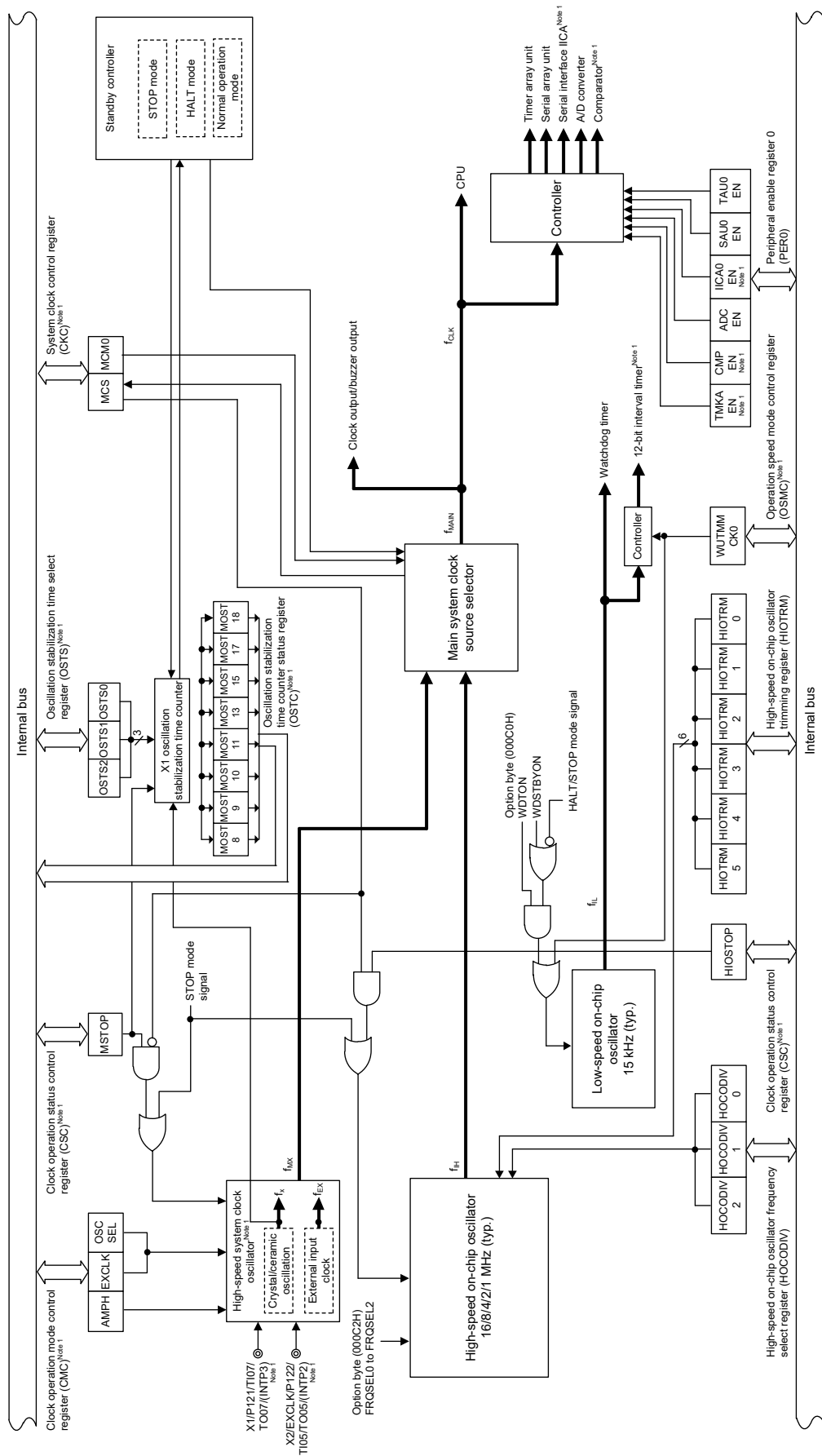
The clock generator includes the following hardware.

Table 5-1. Configuration of Clock Generator

| Item | Configuration | 8-pin products | 10-pin products | 16-pin products | 20-pin products |
|-------------------|---|----------------|-----------------|-----------------|-----------------|
| Control registers | Clock operation mode control register (CMC) | — | — | ✓ | ✓ |
| | System clock control register (CKC) | — | — | ✓ | ✓ |
| | Clock operation status control register (CSC) | — | — | ✓ | ✓ |
| | Oscillation stabilization time counter status register (OSTC) | — | — | ✓ | ✓ |
| | Oscillation stabilization time select register (OSTS) | — | — | ✓ | ✓ |
| | Peripheral enable register 0 (PER0) | ✓ | ✓ | ✓ | ✓ |
| | Operation speed mode control register (OSMC) | ✓ | ✓ | ✓ | ✓ |
| | High-speed on-chip oscillator frequency select register (HOCODIV) | ✓ | ✓ | ✓ | ✓ |
| | High-speed on-chip oscillator trimming register (HIOTRM) | ✓ | ✓ | ✓ | ✓ |
| Oscillators | X1 oscillator | — | — | ✓ | ✓ |
| | High-speed on-chip oscillator | ✓ | ✓ | ✓ | ✓ |
| | Low-speed on-chip oscillator | ✓ | ✓ | ✓ | ✓ |

Remark ✓: Provided, —: Not provided

Figure 5-1. Block Diagram of Clock Generator



Note 1. 16-pin and 20-pin products only.

Remark f_X : X1 clock oscillation frequency
 f_{IH} : High-speed on-chip oscillator clock frequency
 f_{EX} : External main system clock frequency
 f_{MX} : High-speed system clock frequency
 f_{MAIN} : Main system clock frequency
 f_{CLK} : CPU/peripheral hardware clock frequency
 f_{IL} : Low-speed on-chip oscillator clock frequency

5.3 Registers Controlling Clock Generator

The clock generator is controlled by the following registers depending on the products.

1) 8-pin and 10-pin products

- Peripheral enable register 0 (PER0)
- High-speed on-chip oscillator frequency select register (HOCODIV)
- Operation speed mode control register (OSMC)
- High-speed on-chip oscillator trimming register (HIOTRM)

2) 16-pin and 20-pin products

- Clock operation mode control register (CMC)
- System clock control register (CKC)
- Clock operation status control register (CSC)
- Oscillation stabilization time counter status register (OSTC)
- Oscillation stabilization time select register (OSTS)
- Peripheral enable register 0 (PER0)
- Operation speed mode control register (OSMC)
- High-speed on-chip oscillator frequency select register (HOCODIV)
- High-speed on-chip oscillator trimming register (HIOTRM)

Caution Which registers and bits are included depends on the product. Be sure to set registers and bits that are not mounted in a product to their initial values.

5.3.1 Clock operation mode control register (CMC)

This register is used to set the operation mode of the X1/P121/TI07/TO07/(INTP3) and X2/EXCLK/P122/TI05/TO05/(INTP2) pins, and to select a gain of the oscillator.

The CMC register can be written only once by an 8-bit memory manipulation instruction after reset release. This register can be read by an 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 5-2. Format of Clock Operation Mode Control Register (CMC)

Address: FFFA0H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|-------|---|--|---|--------------------------------------|---|-------------------------------------|------|
| CMC | EXCLK | OSCSEL | 0 | 0 | 0 | 0 | 0 | AMPH |
| | EXCLK | OSCSEL | High-speed system clock pin operation mode | | X1/P121/TI07/TO07/(INTP3) pin | | X2/EXCLK/P122/TI05/TO05/(INTP2) pin | |
| | 0 | 0 | I/O port mode | | I/O port | | | |
| | 0 | 1 | X1 oscillation mode | | Crystal/ceramic resonator connection | | | |
| | 1 | 0 | I/O port mode | | I/O port | | | |
| | 1 | 1 | External clock input mode | | I/O port | | External clock input | |
| | AMPH | Control of X1 clock oscillation frequency | | | | | | |
| | 0 | $1 \text{ MHz} \leq f_x \leq 10 \text{ MHz}$ | | | | | | |
| | 1 | $10 \text{ MHz} \leq f_x \leq 12 \text{ MHz}$ | | | | | | |

- Caution 1.** The CMC register can be written only once after reset release, by an 8-bit memory manipulation instruction. When using the CMC register with its initial value (00H), be sure to set the register to 00H after a reset ends in order to prevent malfunction due to a program loop. Such a malfunction becomes unrecoverable when a value other than 00H is mistakenly written.
- Caution 2.** After reset release, set the CMC register before X1 oscillation is started as set by the clock operation status control register (CSC).
- Caution 3.** Be sure to set the AMPH bit to 1 if the X1 clock oscillation frequency exceeds 10 MHz. Specify the settings for the AMPH bits while f_{IH} is selected as f_{CLK} after a reset ends (before f_{CLK} is switched to f_{MX}).
- Caution 4.** Switch the operation mode of the X1 pin and X2 pin only when $MSTOP = 1$.

Remark f_x : X1 clock frequency

5.3.2 System clock control register (CKC)

This register is used to select a main system clock.

The CKC register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation sets this register to 00H.

Figure 5-3. Format of System Clock Control Register (CKC)

Address: FFFA4H After reset: 00H R/W^{Note 1}

| | | | | | | | | |
|--------|---|---|-----|------|---|---|---|---|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| CKC | 0 | 0 | MCS | MCM0 | 0 | 0 | 0 | 0 |

| | |
|-----|--|
| MCS | Status of Main system clock (f_{MAIN}) |
| 0 | High-speed on-chip oscillator clock (f_{IH}) |
| 1 | High-speed system clock (f_{MX}) |

| | |
|------|--|
| MCM0 | Main system clock (f_{MAIN}) operation control |
| 0 | Selects the high-speed on-chip oscillator clock (f_{IH}) as the main system clock (f_{MAIN}) |
| 1 | Selects the high-speed system clock (f_{MX}) as the main system clock (f_{MAIN}) |

Note 1. Bit 5 is read-only.

Caution 1. Be sure to set bit 0 to 3, 6, and 7 to 0.

Caution 2. Do not select the high-speed system clock (f_{MX}) as the main system clock (f_{MAIN}) before the oscillation stabilization time has elapsed after oscillation of f_{MX} is started.

Caution 3. When the main system clock (f_{MAIN}) is changed, the peripheral hardware clock also changes at the same time. Only change f_{MAIN} after stopping all peripheral functions and setting the MCM0 bit.

5.3.3 Clock operation status control register (CSC)

This register is used to control the operations of the high-speed system clock and high-speed on-chip oscillator clock (except the low-speed on-chip oscillator clock).

The CSC register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation sets this register to 80H.

Figure 5-4. Format of Clock Operation Status Control Register (CSC)

Address: FFFA1H After reset: 80H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---------|---|---|--|---|---|-----------------|---|---------|
| CSC | MSTOP | 0 | 0 | 0 | 0 | 0 | 0 | HIOSTOP |
| MSTOP | High-speed system clock operation control | | | | | | | |
| | X1 oscillation mode | | External clock input mode | | | Input port mode | | |
| 0 | X1 oscillator operating | | External clock from EXCLK pin is valid | | | Input port | | |
| 1 | X1 oscillator stopped | | External clock from EXCLK pin is invalid | | | | | |
| HIOSTOP | High-speed on-chip oscillator clock operation control | | | | | | | |
| 0 | High-speed on-chip oscillator clock operating | | | | | | | |
| 1 | High-speed on-chip oscillator clock stopped | | | | | | | |

- Caution 1.** After reset release, set the clock operation mode control register (CMC) before setting the CSC register.
- Caution 2.** Switch the operation mode of the X1 pin and X2 pin only when MSTOP = 1.
- Caution 3.** When setting MSTOP bit to 0, switch the X1 pin and X2 pin to the fx operation mode beforehand. Setting the MSTOP flag is disabled in the input port mode.
- Caution 4.** Set the oscillation stabilization time select register (OSTS) before setting the MSTOP bit to 0 after releasing reset. Note that if the OSTs register is being used with its default settings, the OSTs register is not required to be set here.
- Caution 5.** To start X1 oscillation as set by the MSTOP bit, check the oscillation stabilization time of the X1 clock by using the oscillation stabilization time counter status register (OSTC).
- Caution 6.** When setting MSTOP bit to 1 in the fx operation mode, make sure that MCS in the CKC register is 0 beforehand.
- Caution 7.** In the fx operation mode, writing to the MSTOP flag is enabled but the stop control is not performed.
- Caution 8.** Do not stop the clock selected for the CPU peripheral hardware clock (f_{CLK}) with the OSC register.
- Caution 9.** The setting of the flags of the register to stop clock oscillation (invalidate the external clock input) and the condition before clock oscillation is to be stopped are as Table 5-2. Before stopping the clock oscillation, check the conditions before the clock oscillation is stopped.

Table 5-2. Conditions Before Clock Oscillation Is Stopped and Flag Settings

| Clock | Conditions Before Clock Oscillation Is Stopped | Flag Settings of CSC Register |
|-------------------------------------|--|-------------------------------|
| X1 clock | CPU/peripheral hardware clock operates with the high-speed on-chip oscillator clock (MCS = 0). | MSTOP = 1 |
| External main system clock | | |
| High-speed on-chip oscillator clock | CPU/peripheral hardware clock operates with the high-speed system clock (MCS = 1). | HIOSTOP = 1 |

5.3.4 Oscillation stabilization time counter status register (OSTC)

This register is used to indicate the count status of the X1 clock oscillation stabilization time counter.

The X1 clock oscillation stabilization time can be checked in the following case.

- If the X1 clock starts oscillation while the high-speed on-chip oscillator clock is being used as the CPU clock.
- If the STOP mode is entered and then released while the high-speed on-chip oscillator clock is being used as the CPU clock with the X1 clock oscillating.

The OSTC register can be read by a 1-bit or 8-bit memory manipulation instruction.

When reset signal is generated, the STOP instruction and MSTOP (bit 7 of clock operation status control register (CSC)) = 1 clear the OSTC register to 00H.

Remark The oscillation stabilization time counter starts counting in the following cases.

- When oscillation of the X1 clock starts (EXCLK, OSCSEL = 0, 1 → MSTOP = 0)
- When the STOP mode is released

Figure 5-5. Format of Oscillation Stabilization Time Counter Status Register (OSTC)

Address: FFFA2H After reset: 00H R

| | | | | | | | | |
|--------|-------|-------|--------|--------|--------|--------|--------|--------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| OSTC | MOST8 | MOST9 | MOST10 | MOST11 | MOST13 | MOST15 | MOST17 | MOST18 |

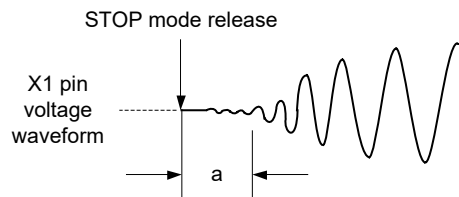
| MOST8 | MOST9 | MOST10 | MOST11 | MOST13 | MOST15 | MOST17 | MOST18 | Oscillation stabilization time status | | |
|-------|-------|--------|--------|--------|--------|--------|--------|--|-------------------------|--------------|
| | | | | | | | | f _x = 10 MHz | f _x = 16 MHz | |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | (2 ⁸ + 16)/f _x max. | 27.2 μs max. | 17.0 μs max. |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | (2 ⁸ + 16)/f _x min. | 27.2 μs min. | 17.0 μs min. |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | (2 ⁹ + 16)/f _x min. | 52.8 μs min. | 33.0 μs min. |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | (2 ¹⁰ + 16)/f _x min. | 104 μs min. | 65.0 μs min. |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | (2 ¹¹ + 16)/f _x min. | 206 μs min. | 129 μs min. |
| 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | (2 ¹³ + 16)/f _x min. | 820 μs min. | 513 μs min. |
| 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | (2 ¹⁵ + 16)/f _x min. | 3.27 ms min. | 2.05 ms min. |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | (2 ¹⁷ + 16)/f _x min. | 13.1 ms min. | 8.19 ms min. |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | (2 ¹⁸ + 16)/f _x min. | 26.2 ms min. | 16.4 ms min. |

Caution 1. After the above time has elapsed, the bits are set to 1 in order from the MOST8 bit and remain 1.

Caution 2. The oscillation stabilization time counter counts up to the oscillation stabilization time set by the oscillation stabilization time select register (OSTS).
In the following cases, set the oscillation stabilization time of the OSTS register to the value greater than the count value which is to be checked by the OSTC register.

- If the X1 clock starts oscillation while the high-speed on-chip oscillator clock is being used as the CPU clock.
- If the STOP mode is entered and then released while the high-speed on-chip oscillator clock is being used as the CPU clock with the X1 clock oscillating.

Caution 3. The X1 clock oscillation stabilization time does not include the time until clock oscillation starts (“a” below).



Remark f_x : X1 clock oscillation frequency

5.3.5 Oscillation stabilization time select register (OSTS)

This register is used to select the X1 clock oscillation stabilization time at releasing of the STOP mode.

When the X1 clock is selected as the CPU clock, the operation automatically waits for the time set using the OSTS register after the STOP mode is released. When switching the CPU clock from the high-speed on-chip oscillator clock to the X1 clock, and when the STOP mode is entered and then released while the high-speed on-chip oscillator clock is being used as the CPU clock with the X1 clock oscillating, use the oscillation stabilization time counter status register (OSTC) to confirm that the oscillation stabilization time has elapsed.

Use the OSTC register to check that the oscillation stabilization time corresponding to its setting has been reached.

The OSTS register can be set by an 8-bit memory manipulation instruction.

Reset signal generation sets the OSTS register to 07H.

Figure 5-6. Format of Oscillation Stabilization Time Select Register (OSTS)

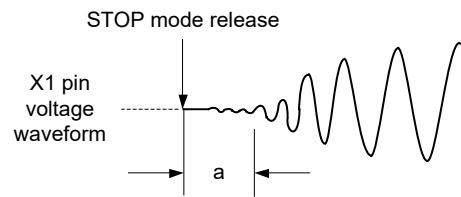
Address: FFFA3H After reset: 07H R/W

| | | | | | | | | |
|--------|---|---|---|---|---|-------|-------|-------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| OSTS | 0 | 0 | 0 | 0 | 0 | OSTS2 | OSTS1 | OSTS0 |

| OSTS2 | OSTS1 | OSTS0 | Oscillation stabilization time selection | | |
|-------|-------|-------|--|------------------------|--------------------|
| | | | $f_x = 10 \text{ MHz}$ | $f_x = 16 \text{ MHz}$ | |
| 0 | 0 | 0 | $(2^8 + 16)/f_x$ | 27.2 μs | 17.0 μs |
| 0 | 0 | 1 | $(2^9 + 16)/f_x$ | 52.8 μs | 33.0 μs |
| 0 | 1 | 0 | $(2^{10} + 16)/f_x$ | 104 μs | 65.0 μs |
| 0 | 1 | 1 | $(2^{11} + 16)/f_x$ | 206 μs | 129 μs |
| 1 | 0 | 0 | $(2^{13} + 16)/f_x$ | 820 μs | 513 μs |
| 1 | 0 | 1 | $(2^{15} + 16)/f_x$ | 3.27 ms | 2.05 ms |
| 1 | 1 | 0 | $(2^{17} + 16)/f_x$ | 13.1 ms | 8.19 ms |
| 1 | 1 | 1 | $(2^{18} + 16)/f_x$ | 26.2 ms | 16.4 ms |

- Caution 1.** To set the STOP mode when the X1 clock is used as the CPU clock, set the OSTS register before executing the STOP instruction.
- Caution 2.** Change the setting of the OSTS register before setting the MSTOP bit of the clock operation status control register (CSC) to 0.
- Caution 3.** Do not change the value of the OSTS register during the X1 clock oscillation stabilization time.
- Caution 4.** The oscillation stabilization time counter counts up to the oscillation stabilization time set by the OSTS register.
In the following cases, set the oscillation stabilization time of the OSTS register to the value greater than the count value which is to be checked by the OSTC register after the oscillation starts.
- If the X1 clock starts oscillation while the high-speed on-chip oscillator clock is being used as the CPU clock.
 - If the STOP mode is entered and then released while the high-speed on-chip oscillator clock is being used as the CPU clock with the X1 clock oscillating (note, therefore, that only the status up to the oscillation stabilization time set by the OSTS register is set to the OSTC register after the STOP mode is released).

Caution 5. The X1 clock oscillation stabilization time does not include the time until clock oscillation starts (“a” below).



Remark f_x : X1 clock oscillation frequency

5.3.6 Peripheral enable register 0 (PER0)

This register is used to enable or disable supplying the clock to the peripheral hardware. Clock supply to the hardware that is not used is also stopped so as to decrease the power consumption and noise.

To use the peripheral functions below, which are controlled by this register, set (1) the bit corresponding to each function before specifying the initial settings of the peripheral functions.

- 12-bit Interval timer
- A/D converter
- Comparator
- IICA Serial interface IICA
- Serial array unit
- Timer array unit

The PER0 register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears these registers to 00H.

Figure 5-7. Format of Peripheral Enable Register 0 (PER0) (1/2)

Address: F00F0H After reset: 00H R/W

| | | | | | | | | |
|--------|--------------------------|--------------------------|----------|---------------------------|---|----------|---|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PER0 | TMKAEN ^{Note 1} | CM PEN ^{Note 1} | ADCEN | IICA0EN ^{Note 1} | 0 | SAU0EN | 0 | TAU0EN |

| TMKAEN | Control of 12-bit interval timer input clock supply |
|--------|---|
| 0 | Stops input clock supply. <ul style="list-style-type: none"> • SFR used by the 12-bit interval timer cannot be written. • The 12-bit interval timer is in the reset status. |
| 1 | Enables input clock supply. <ul style="list-style-type: none"> • SFR used by the 12-bit interval timer can be read and written. |

| CM PEN | Control of comparator input clock supply |
|--------|---|
| 0 | Stops input clock supply. <ul style="list-style-type: none"> • SFR used by the comparator cannot be written. • The comparator is in the reset status. |
| 1 | Enables input clock supply. <ul style="list-style-type: none"> • SFR used by the comparator can be read and written. |

| ADCEN | Control of A/D converter input clock supply |
|-------|---|
| 0 | Stops input clock supply. <ul style="list-style-type: none"> • SFR used by the A/D converter cannot be written. • The A/D converter is in the reset status. |
| 1 | Enables input clock supply. <ul style="list-style-type: none"> • SFR used by the A/D converter can be read and written. |

Figure 5-7. Format of Peripheral Enable Register 0 (PER0) (2/2)

Address: F00F0H After reset: 00H R/W

| | | | | | | | | |
|--------|--------------------------|-------------------------|-------|---------------------------|---|--------|---|--------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PER0 | TMKAEN ^{Note 1} | CMPEN ^{Note 1} | ADCEN | IICA0EN ^{Note 1} | 0 | SAU0EN | 0 | TAU0EN |

| IICA0EN | Control of serial interface IICA input clock supply |
|---------|---|
| 0 | Stops input clock supply. <ul style="list-style-type: none"> • SFR used by the serial interface IICA cannot be written. • The serial interface IICA is in the reset status. |
| 1 | Enables input clock supply. <ul style="list-style-type: none"> • SFR used by the serial interface IICA can be read and written. |

| SAU0EN | Control of serial array unit input clock supply |
|--------|---|
| 0 | Stops input clock supply. <ul style="list-style-type: none"> • SFR used by the serial array unit cannot be written. • The serial array unit is in the reset status. |
| 1 | Enables input clock supply. <ul style="list-style-type: none"> • SFR used by the serial array unit can be read and written. |

| TAU0EN | Control of timer array unit input clock supply |
|--------|---|
| 0 | Stops input clock supply. <ul style="list-style-type: none"> • SFR used by the timer array unit cannot be written. • The timer array unit is in the reset status. |
| 1 | Enables input clock supply. <ul style="list-style-type: none"> • SFR used by the timer array unit can be read and written. |

Note 1. 16-pin and 20-pin products only.

Caution 1. Be sure to clear bits 1 and 3 to 0.

Caution 2. Be sure to clear the following bits to 0.
8-pin and 10-pin products: bits 1, 3, 4, 6, 7
16-pin and 20-pin products: bits 1, 3

5.3.7 Operation speed mode control register (OSMC)

This register is used to control supply of the operation clock for the 12-bit interval timer. When operating the 12-bit interval timer, set WUTMMCK0 = 1 beforehand and do not set WUTMMCK0 = 0 until the timer is stopped.

The OSMC register can be set by an 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 5-8. Format of Operation Speed Mode Control Register (OSMC)

Address: F00F3H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|----------|---|---|---|---|
| OSMC | 0 | 0 | 0 | WUTMMCK0 | 0 | 0 | 0 | 0 |

| WUTMMCK0 | Supply of the operation clock for 12-bit interval timer |
|----------|---|
| 0 | Stops Clock supply |
| 1 | Low-speed on-chip oscillator clock (f_{IL}) supply |

5.3.8 High-speed on-chip oscillator frequency select register (HOCODIV)

This register is used to change the frequency of the high-speed on-chip oscillator which is set by an option byte (000C2H).

The HOCODIV register can be set by an 8-bit memory manipulation instruction.

Reset signal generation clears this register to the value set by FRQSEL2 to FRQSEL0 of the option byte (000C2H).

Figure 5-9. Format of High-speed On-chip Oscillator Frequency Select Register (HOCODIV)

Address: F00A8H After reset: the value set by FRQSEL2 to FRQSEL0 of the option byte (000C2H) R/W

| | | | | | | | | |
|---------|---|---|---|---|---|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| HOCODIV | 0 | 0 | 0 | 0 | 0 | HOCODIV2 | HOCODIV1 | HOCODIV0 |

| HOCODIV2 | HOCODIV1 | HOCODIV0 | High-speed on-chip oscillator clock frequency selection |
|------------------|----------|----------|---|
| 0 | 0 | 1 | 16 MHz |
| 0 | 1 | 0 | 8 MHz |
| 0 | 1 | 1 | 4 MHz |
| 1 | 0 | 0 | 2 MHz |
| 1 | 0 | 1 | 1 MHz |
| Other than above | | | Setting prohibited |

Caution 1. Set the HOCODIV register with the high-speed on-chip oscillator clock (f_{IH}) selected as the CPU/peripheral hardware clock (f_{CLK}).

Caution 2. After the frequency is changed with the HOCODIV register, the frequency is switched after the following transition time has elapsed.

- Operation for up to three clocks at the pre-change frequency
- CPU/peripheral hardware clock wait at the post-change frequency for up to three clocks

5.3.9 High-speed on-chip oscillator trimming register (HIOTRM)

This register is used to adjust the accuracy of the high-speed on-chip oscillator.

With self-measurement of the high-speed on-chip oscillator frequency via a timer using high-accuracy external clock input (timer array unit), and so on, the accuracy can be adjusted.

The HIOTRM register can be set by an 8-bit memory manipulation instruction.

Caution The frequency will vary if the temperature and V_{DD} pin voltage change after accuracy adjustment. When the temperature and V_{DD} voltage change, accuracy adjustment must be executed regularly or before the frequency accuracy is required.

Figure 5-10. Format of High-Speed On-Chip Oscillator Trimming Register (HIOTRM)

Address: F00A0H After reset: undefined^{Note 1} R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---------|---------|---------|---------|---------|---------|
| HIOTRM | 0 | 0 | HIOTRM5 | HIOTRM4 | HIOTRM3 | HIOTRM2 | HIOTRM1 | HIOTRM0 |

| HIOTRM5 | HIOTRM4 | HIOTRM3 | HIOTRM2 | HIOTRM1 | HIOTRM0 | High-speed on-chip oscillator Minimum speed ↑ ↓ Maximum speed |
|-------------|---------|---------|---------|---------|---------|---|
| 0 | 0 | 0 | 0 | 0 | 0 | |
| 0 | 0 | 0 | 0 | 0 | 1 | |
| 0 | 0 | 0 | 0 | 1 | 0 | |
| 0 | 0 | 0 | 0 | 1 | 1 | |
| 0 | 0 | 0 | 1 | 0 | 0 | |
| • • • | | | | | | |
| 1 | 1 | 1 | 1 | 1 | 0 | |
| 1 | 1 | 1 | 1 | 1 | 1 | |

Note 1. The value after reset is the value adjusted at shipment.

Remark The HIOTRM register holds a six-bit value used to adjust the high-speed on-chip oscillator with an increment of 1 corresponding to an increase of frequency by about 0.05%.

5.4 System Clock Oscillator

5.4.1 X1 oscillator (16-pin and 20-pin products only)

The X1 oscillator oscillates with a crystal resonator or ceramic resonator (1 to 12 MHz) connected to the X1 pin and X2 pin. An external clock can also be input. In this case, input the clock signal to the EXCLK pin.

To use the X1 oscillator, set bits 7 and 6 (EXCLK, OSCSEL) of the clock operation mode control register (CMC) as follows.

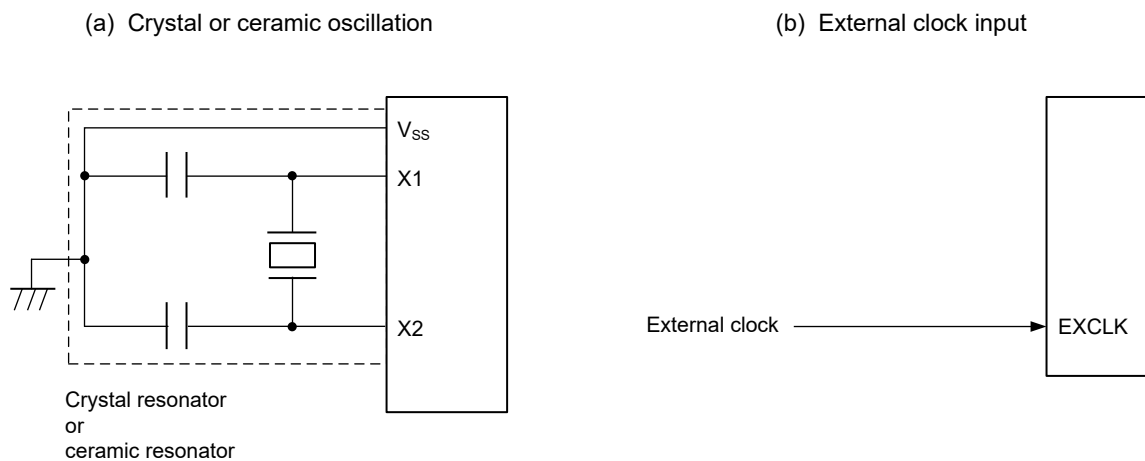
- Crystal or ceramic oscillation: EXCLK, OSCSEL = 0, 1
- External clock input: EXCLK, OSCSEL = 1, 1

When the X1 oscillator is not used, set the input port mode (EXCLK, OSCSEL = 0, 0).

When the pins are not used as input port pins, either, see **Table 2-2 Connections of Unused Pins**.

Figure 5-11 shows an example of the external circuit of the X1 oscillator.

Figure 5-11. Example of External Circuit of X1 Oscillator



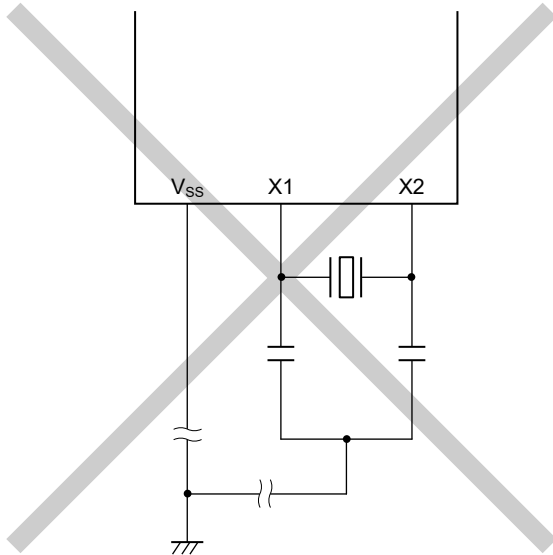
Caution When using the X1 oscillator, wire as follows in the area enclosed by the broken lines in Figure 5-11 to avoid an adverse effect from wiring capacitance.

- Keep the wiring length as short as possible.
- Do not cross the wiring with the other signal lines. Do not route the wiring near a signal line through which a high fluctuating current flows.
- Always make the ground point of the oscillator capacitor the same potential as V_{SS} . Do not ground the capacitor to a ground pattern through which a high current flows.
- Do not fetch signals from the oscillator.

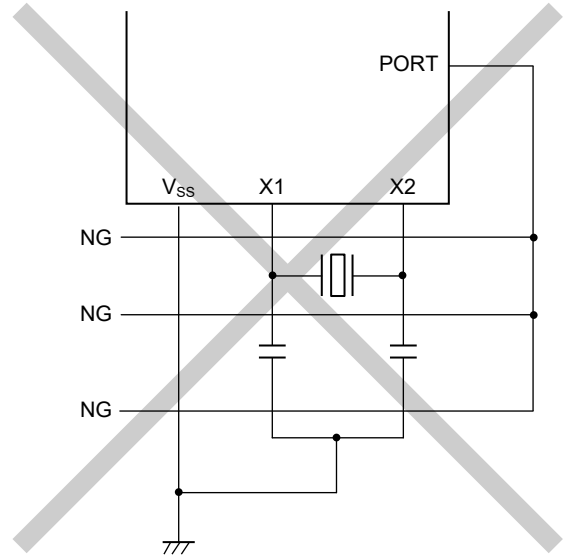
Figure 5-12 shows examples of incorrect resonator connection.

Figure 5-12. Examples of Incorrect Resonator Connection (1/2)

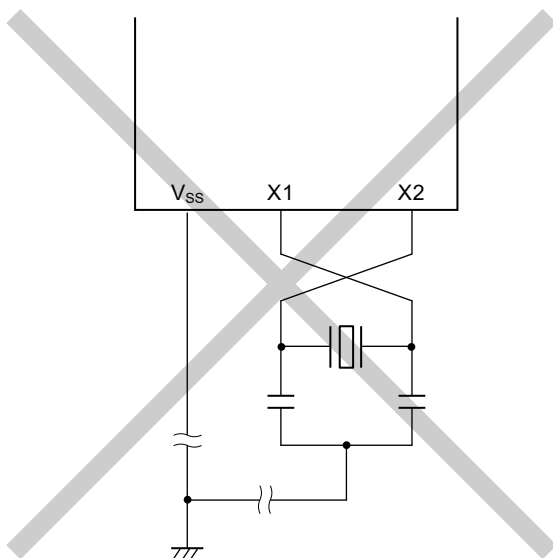
(a) Too long wiring



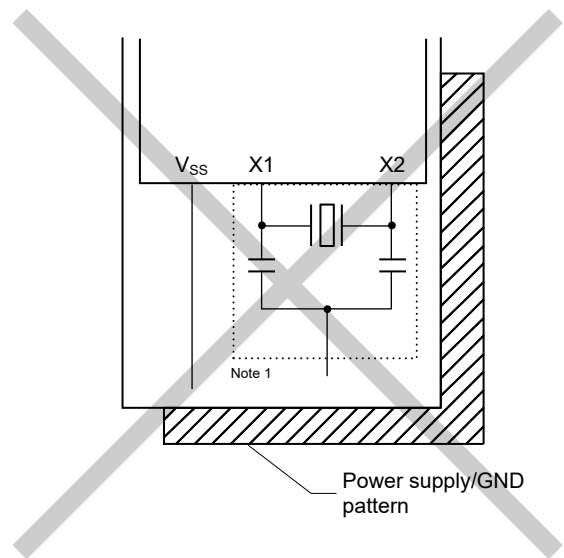
(b) Crossed signal line



(c) The X1 and X2 signal line wires cross.



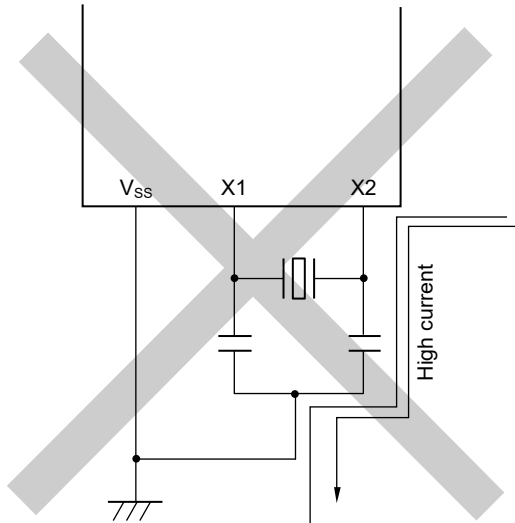
(d) A power supply/GND pattern exists under the X1 and X2 wires.



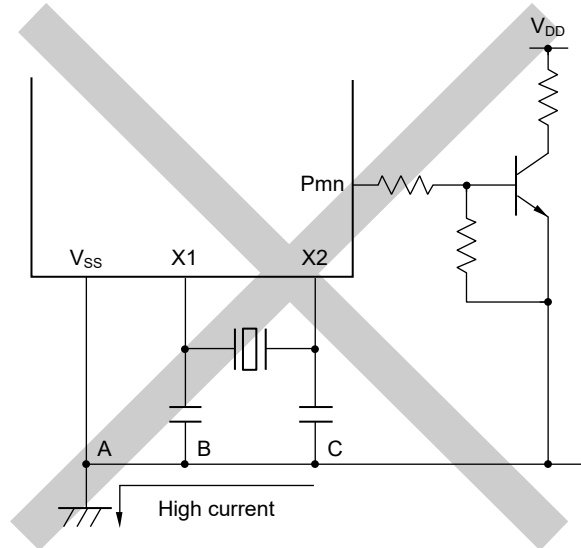
Note 1. Do not place a power supply/GND pattern under the wiring section (section indicated by a broken line in the figure) of the X1 pin and X2 pin and the resonators in a multi-layer board or double-sided board. Do not configure a layout that will cause capacitance elements and affect the oscillation characteristics.

Figure 5-12. Examples of Incorrect Resonator Connection (2/2)

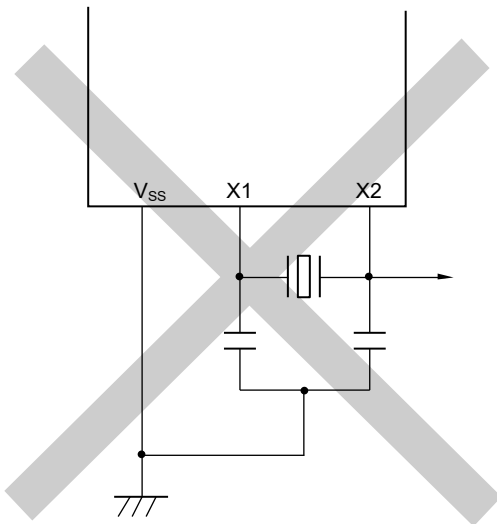
(e) Wiring near high alternating current



(f) Current flowing through ground line of oscillator
(potential at points A, B, and C fluctuates)



(g) Signals are fetched



5.4.2 High-speed on-chip oscillator

The high-speed on-chip oscillator is incorporated. The frequency can be selected from among 16, 8, 4, 2, or 1 MHz by using the option byte (000C2H). Oscillation can be controlled by bit 0 (HIOSTOP) of the clock operation status control register (CSC).

The high-speed on-chip oscillator automatically starts oscillating after reset release.

5.4.3 Low-speed on-chip oscillator

The low-speed on-chip oscillator is incorporated.

The low-speed on-chip oscillator clock is used only as the watchdog timer and 12-bit interval timer clock. The low-speed on-chip oscillator clock cannot be used as the CPU clock.

The low-speed on-chip oscillator runs while the watchdog timer is operating or when bit 4 (WUTMMCK0) in the operation speed mode control register (OSMC) is set to 1.

The low-speed on-chip oscillator is stopped when the watchdog timer is stopped and WUTMMCK0 is set to 0.

5.5 Clock Generator Operation

The clock generator generates the following clocks and controls the operation modes of the CPU, such as standby mode (see **Figure 5-1**).

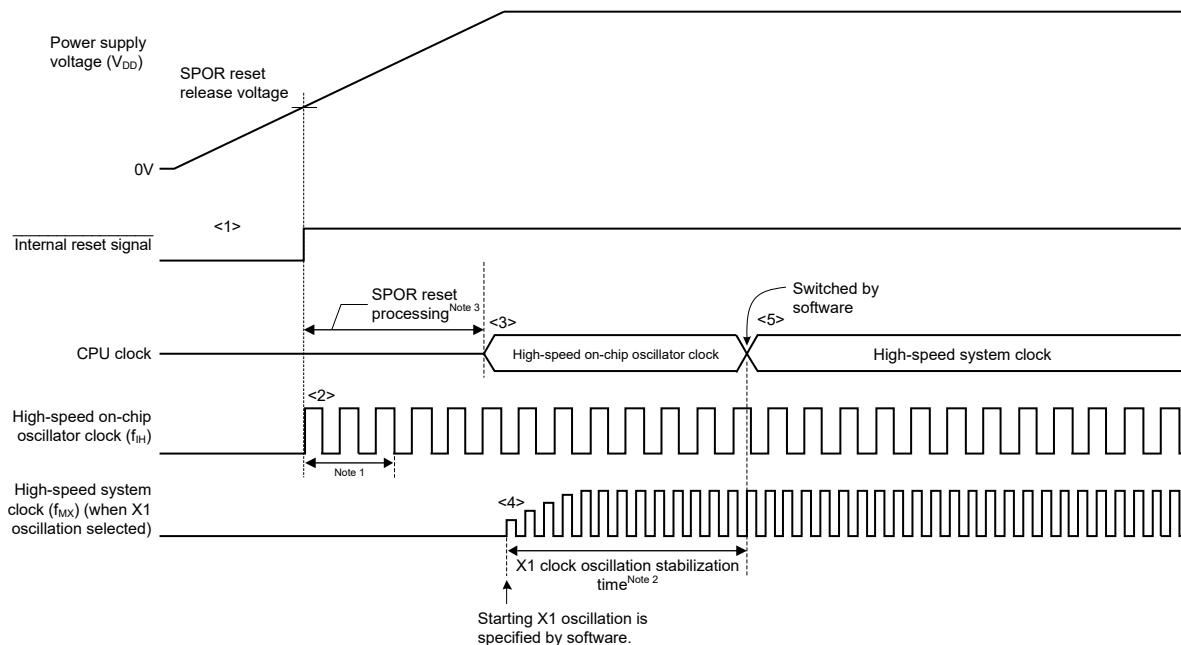
- Main system clock (f_{MAIN})
 - High-speed system clock^{Note 1} (f_{MX})
 - X1 clock^{Note 1} (f_{X})
 - External main system clock^{Note 1} (f_{EX})
 - High-speed on-chip oscillator clock (f_{IH})
- Low-speed on-chip oscillator clock (f_{IL})
- CPU/peripheral hardware clock (f_{CLK})

The CPU starts operation when the high-speed on-chip oscillator starts outputting after a reset release.

When the power supply voltage is turned on, the clock generator operation is shown in **Figure 5-13**.

Note 1. 16-pin and 20-pin products only.

Figure 5-13. Clock Generator Operation When Power Supply Voltage Is Turned On



- <1> When the power is turned on, an internal reset signal is generated by the selectable power-on-reset (SPOR) circuit.
- <2> When the power supply voltage exceeds detection voltage of the SPOR circuit, the reset is released and the high-speed on-chip oscillator automatically starts oscillation.
- <3> The CPU starts operation on the high-speed on-chip oscillator clock after waiting for the voltage to stabilize and an SPOR reset processing have been performed after reset release.
- <4> Set the start of oscillation of the X1 clock via software (see **5.6.2 Example of setting X1 oscillation clock**).
- <5> When switching the CPU clock to the X1 clock, wait for the clock oscillation to stabilize, and then switch the clock via software.

Note 1. The reset processing time includes the oscillation accuracy stabilization time of the high-speed on-chip oscillator clock.

Note 2. When releasing a reset, confirm the oscillation stabilization time for the X1 clock using the oscillation stabilization time counter status register (OSTC).

Note 3. For SPOR reset processing time, see **CHAPTER 17 SELECTABLE POWER-ON-RESET CIRCUIT**.

Caution When an external clock input from the EXCLK pin is in use, oscillation stabilization time is unnecessary.

5.6 Controlling Clock

5.6.1 Example of setting high-speed on-chip oscillator

After a reset release, the CPU/peripheral hardware clock (f_{CLK}) always starts operating with the high-speed on-chip oscillator clock. The frequency of the high-speed on-chip oscillator can be selected by using FRQSEL0 to FRQSEL2 of the option byte (000C2H). This frequency can be changed with the high-speed on-chip oscillator frequency select register (HOCODIV).

[Option byte setting]

Address: 000C2H

| | | | | | | | | |
|-------------------------|---|---|---|---|---|---------|---------|---------|
| Option byte (000C2H) | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| | 1 | 1 | 1 | 1 | 1 | FRQSEL2 | FRQSEL1 | FRQSEL0 |

| FRQSEL2 | FRQSEL1 | FRQSEL0 | Frequency of the high-speed on-chip oscillator |
|------------------|---------|---------|--|
| 0 | 0 | 1 | 16 MHz |
| 0 | 1 | 0 | 8 MHz |
| 0 | 1 | 1 | 4 MHz |
| 1 | 0 | 0 | 2 MHz |
| 1 | 0 | 1 | 1 MHz |
| Other than above | | | Setting prohibited |

[High-speed on-chip oscillator frequency select register (HOCODIV) setting]

Address: F00A8H

| | | | | | | | | |
|--|---|---|---|---|---|-----------|-----------|-----------|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | HOCODIV 2 | HOCODIV 1 | HOCODIV 0 |

| HOCODIV 2 | HOCODIV 1 | HOCODIV 0 | Selected frequency |
|------------------|-----------|-----------|--------------------|
| 0 | 0 | 1 | 16 MHz |
| 0 | 1 | 0 | 8 MHz |
| 0 | 1 | 1 | 4 MHz |
| 1 | 0 | 0 | 2 MHz |
| 1 | 0 | 1 | 1 MHz |
| Other than above | | | Setting prohibited |

- Caution 1.** Set the HOCODIV register within the operable voltage range before and after the frequency change.
- Caution 2.** Set the HOCODIV register with the high-speed on-chip oscillator clock (f_{IH}) selected as the CPU/peripheral hardware clock (f_{CLK}).
- Caution 3.** After the frequency is changed with the HOCODIV register, the frequency is switched after the following transition time has elapsed.
- Operation for up to three clocks at the pre-change frequency
 - CPU/peripheral hardware clock wait at the post-change frequency for up to three clocks

5.6.2 Example of setting X1 oscillation clock

After a reset release, the CPU/peripheral hardware clock (f_{CLK}) always starts operating with the high-speed on-chip oscillator clock. To subsequently change the clock to the X1 clock, set the oscillator and start oscillation by using the oscillation stabilization time select register (OSTS), clock operation mode control register (CMC), and clock operation status control register (CSC) and wait for oscillation to stabilize by using the oscillation stabilization time counter status register (OSTC). After the oscillation stabilizes, set the X1 clock to f_{CLK} by using the system clock control register (CKC).

[Register settings] Set the register in the order of <1> to <5> below.

- <1> Set (1) the OSCSEL bit of the CMC register, except for the cases where $f_x > 10$ MHz, in such cases set (1) the AMPH bit, to operate the X1 oscillator.

| | | | | | | | | |
|-----|------------|-------------|---|---|---|---|---|-------------|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| CMC | EXCLK 0 | OSCSEL 1 | 0 | 0 | 0 | 0 | 0 | AMPH 0/1 |

AMPH bit: Set this bit to 0 if the X1 clock is 10 MHz or less.

- <2> Using the OSTS register, select the oscillation stabilization time of the X1 oscillator at releasing of the STOP mode.

Example: Setting values when a wait of at least 104 μ s is set based on a 10 MHz resonator.

| | | | | | | | | |
|------|---|---|---|---|---|------------|------------|------------|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| OSTS | 0 | 0 | 0 | 0 | 0 | OSTS2 0 | OSTS1 1 | OSTS0 0 |

- <3> Clear (0) the MSTOP bit of the CSC register to start oscillating the X1 oscillator.

| | | | | | | | | |
|-----|------------|---|---|---|---|---|---|--------------|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| CSC | MSTOP 0 | 0 | 0 | 0 | 0 | 0 | 0 | HIOSTOP 0 |

- <4> Use the OSTC register to wait for oscillation of the X1 oscillator to stabilize.

Example: Wait until the bits reach the following values when a wait of at least 104 μ s is set based on a 10 MHz resonator.

| | | | | | | | | |
|------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| OSTC | MOST8 1 | MOST9 1 | MOST10 1 | MOST11 0 | MOST13 0 | MOST15 0 | MOST17 0 | MOST18 0 |

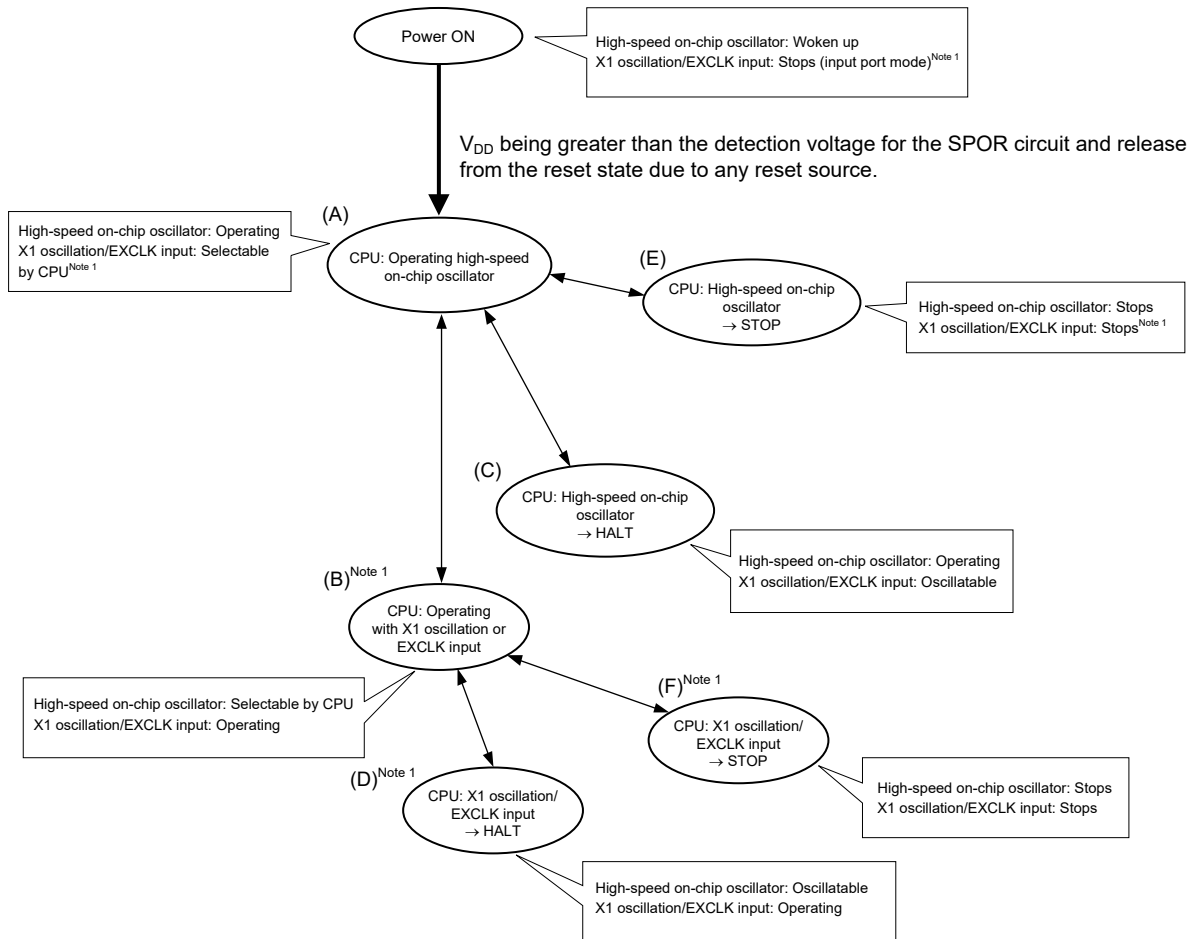
- <5> Use the MCM0 bit of the CKC register to specify the X1 clock as the CPU/peripheral hardware clock.

| | | | | | | | | |
|-----|---|---|----------|-----------|---|---|---|---|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| CKC | 0 | 0 | MCS 0 | MCM0 1 | 0 | 0 | 0 | 0 |

5.6.3 CPU clock status transition diagram

Figure 5-14 shows the CPU clock status transition diagram of this product.

Figure 5-14. CPU Clock Status Transition Diagram



Note 1. 16-pin and 20-pin products only.

Table 5-3 shows transition of the CPU clock and examples of setting the SFR registers.

Table 5-3. CPU Clock Transition and SFR Register Setting Examples for 16-Pin and 20-Pin Products (1/2)

- (1) CPU clock changing from high-speed on-chip oscillator clock (A) to high-speed system clock (B) (The CPU operates with the high-speed on-chip oscillator clock immediately after a reset release (A).)

(Setting sequence of SFR registers) →

| Setting Flag of SFR Register Status Transition | CMC Register ^{Note 1} | | | OSTS Register | CSC Register | OSTC Register | CKC Register |
|---|--------------------------------|--------|------|---------------|--------------|-----------------|--------------|
| | EXCLK | OSCSEL | AMPH | | MSTOP | | MCM0 |
| (A) → (B) (X1 clock: 1 MHz ≤ f _x ≤ 10 MHz) | 0 | 1 | 0 | Note 2 | 0 | Must be checked | 1 |
| (A) → (B) (X1 clock: 10 MHz < f _x ≤ 12 MHz) | 0 | 1 | 1 | Note 2 | 0 | Must be checked | 1 |
| (A) → (B) (External main system clock) | 1 | 1 | x | Note 2 | 0 | Must be checked | 1 |

Note 1. The clock operation mode control register (CMC) can be written only once by an 8-bit memory manipulation instruction after reset release.

Note 2. Set the oscillation stabilization time as follows.

Desired the oscillation stabilization time counter status register (OSTC) oscillation stabilization time ≤ Oscillation stabilization time set by the oscillation stabilization time select register (OSTS)

Caution Set the clock after the supply voltage has reached the operable voltage of the clock to be set (see CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C) and CHAPTER 24 ELECTRICAL SPECIFICATIONS) (T_A = -40 to +105°C, T_A = -40 to +125°C).

Remark 1. x: Don't care

Remark 2. (A) to (F) in Table 5-3 correspond to (A) to (F) in Figure 5-14.

Table 5-3. CPU Clock Transition and SFR Register Setting Examples for 16-Pin and 20-Pin Products (2/2)

(2) CPU clock changing from high-speed system clock (B) to high-speed on-chip oscillator clock (A)

(Setting sequence of SFR registers) →

| | | | |
|---|--------------|---|--------------|
| Setting Flag of SFR Register Status Transition | CSC Register | Oscillation accuracy stabilization time | CKC Register |
| | HIOSTOP | | MCM0 |
| (B) → (A) | 0 | 27 μs (typ.) | 0 |

Unnecessary if the CPU is operating with the high-speed on-chip oscillator clock

(3) HALT mode (C) set while CPU is operating with high-speed on-chip oscillator clock (A)
 HALT mode (D) set while CPU is operating with high-speed system clock (B)

| Status Transition | Setting |
|------------------------|----------------------------|
| (A) → (C) (B) → (D) | Executing HALT instruction |

(4) STOP mode (E) set while CPU is operating with high-speed on-chip oscillator clock (A)
 STOP mode (F) set while CPU is operating with high-speed system clock (B)

(Setting sequence of SFR registers) →

| Status Transition | | Setting | | |
|-------------------|-------------------|--|------------------------|----------------------------|
| (A) → (E) | | Stopping peripheral functions that cannot operate in STOP mode | — | Executing STOP instruction |
| (B) → (F) | In X1 oscillation | | Sets the OSTS register | |
| | External clock | | — | |

Remark (A) to (F) in Table 5-3 correspond to (A) to (F) in Figure 5-14.

5.6.4 Condition before changing CPU clock and processing after changing CPU clock

Condition before changing the CPU clock and processing after changing the CPU clock are shown below.

Table 5-4. Changing CPU Clock

| CPU Clock | | Condition Before Change | Processing After Change |
|-------------------------------------|-------------------------------------|--|--|
| Before Change | After Change | | |
| High-speed on-chip oscillator clock | X1 clock | Stabilization of X1 oscillation <ul style="list-style-type: none"> • OSCSEL = 1, EXCLK = 0, MSTOP = 0 • After elapse of oscillation stabilization time | The operating current can be reduced by stopping the high-speed on-chip oscillator (HIOSTOP = 1) after checking that the CPU clock is changed. |
| | External main system clock | An external clock input from the EXCLK pin must be enabled. <ul style="list-style-type: none"> • OSCSEL = 1, EXCLK = 1, MSTOP = 0 | |
| X1 clock | High-speed on-chip oscillator clock | Enabling oscillation of high-speed on-chip oscillator <ul style="list-style-type: none"> • HIOSTOP = 0 • After elapse of oscillation accuracy stabilization time | X1 oscillation can be stopped (MSTOP = 1) after checking that the CPU clock is changed. |
| | External main system clock | Change is not possible | — |
| External main system clock | High-speed on-chip oscillator clock | Enabling oscillation of high-speed on-chip oscillator <ul style="list-style-type: none"> • HIOSTOP = 0 • After elapse of oscillation accuracy stabilization time | External main system clock input can be disabled (MSTOP = 1) after checking that the CPU clock is changed. |
| | X1 clock | Change is not possible | — |

5.6.5 Time required for switchover of CPU clock and main system clock

The main system clock can be switched between the high-speed on-chip oscillator clock and the high-speed system clock by specifying bit 4 (MCM0) of the system clock control register (CKC).

The actual switchover operation is not performed immediately after rewriting to the CKC register; operation continues on the pre-switchover clock for several clocks (see **Table 5-5**).

Whether the main system clock is operating on the high-speed system clock or high-speed on-chip oscillator clock can be ascertained using bit 5 (MCS) of the CKC register.

When the CPU clock is switched, the peripheral hardware is also switched.

Table 5-5. Maximum Number of Clocks Required for Main System Clock Switchover ($f_{IH} \leftrightarrow f_{MX}$)

| Set Value Before Switchover | | Set Value After Switchover | |
|------------------------------|----------------------|------------------------------|------------------------------|
| MCM0 | | MCM0 | |
| | | 0 ($f_{MAIN} = f_{IH}$) | 1 ($f_{MAIN} = f_{MX}$) |
| 0 ($f_{MAIN} = f_{IH}$) | $f_{MX} \geq f_{IH}$ | — | $1 + f_{IH}/f_{MX}$ |
| | $f_{MX} < f_{IH}$ | — | $2f_{IH}/f_{MX}$ clock |
| 1 ($f_{MAIN} = f_{MX}$) | $f_{MX} \geq f_{IH}$ | $2f_{MX}/f_{IH}$ clock | — |
| | $f_{MX} < f_{IH}$ | $1 + f_{MX}/f_{IH}$ | — |

Remark 1. Number of CPU clocks before switchover.

Remark 2. Calculate the number of clocks by rounding to the nearest whole number.

Example) When switching the main system clock from the high-speed system clock to the high-speed on-chip oscillator clock (@ oscillation with $f_{IH} = 8$ MHz selected, $f_{MX} = 10$ MHz)

$$2f_{MX}/f_{IH} = 2 (10/8) = 2.5 \rightarrow 3 \text{ clocks}$$

5.6.6 Conditions before clock oscillation is stopped

The following lists the register flag settings for stopping the clock oscillation (disabling external clock input) and conditions before the clock oscillation is stopped. Before stopping the clock oscillation, check the conditions before the clock oscillation is stopped.

Table 5-6. Conditions Before the Clock Oscillation Is Stopped and Flag Settings

| Clock | Conditions Before Clock Oscillation Is Stopped | Flag Settings of SFR Register |
|-------------------------------------|---|-------------------------------|
| High-speed on-chip oscillator clock | MCS = 1 (The CPU is operating on the high-speed system clock.) | HIOSTOP = 1 |
| X1 clock | MCS = 0 (The CPU is operating on the high-speed on-chip oscillator clock.) | MSTOP = 1 |
| External main system clock | | |

5.7 Resonator and Oscillator Constants

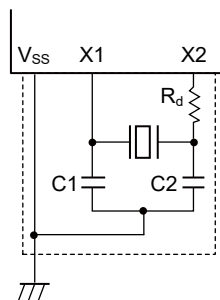
For the resonators for which the operation is verified and their oscillator constants, refer to the target product page of the Renesas Electronics website.

Caution 1. The constants for these oscillator circuits are reference values based on specific environments set up for evaluation by the manufacturers. For actual applications, request evaluation by the manufacturer of the oscillator circuit mounted on a board.

Furthermore, if you are switching from a different product to this microcontroller, and whenever you change the board, again request evaluation by the manufacturer of the oscillator circuit mounted on the new board.

Caution 2. The oscillation voltage and oscillation frequency only indicate the oscillator characteristic. Use the RL78 microcontroller so that the internal operation conditions are within the specifications of the DC and AC characteristics.

Figure 5-15. External Oscillation Circuit Example



Remark 16-pin and 20-pin products only.

CHAPTER 6 TIMER ARRAY UNIT

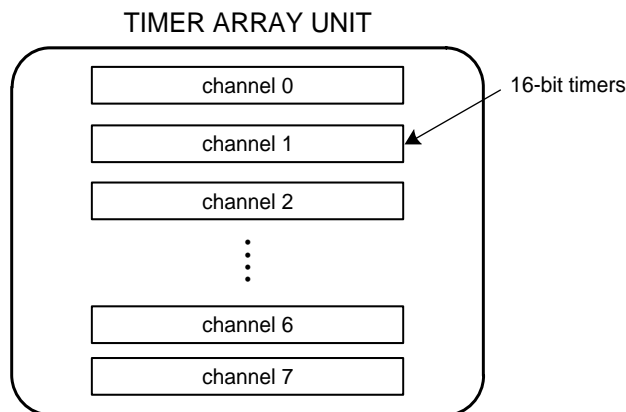
| Units | Channels | 20, 16, 10, 8-pin |
|--------|-----------|-------------------|
| Unit 0 | Channel 0 | ✓ |
| | Channel 1 | ✓ |
| | Channel 2 | ✓ |
| | Channel 3 | ✓ |
| | Channel 4 | ✓ |
| | Channel 5 | ✓ |
| | Channel 6 | ✓ |
| | Channel 7 | ✓ |

Caution 1. The presence or absence of timer I/O pins depends on the product. See Table 6-2 Timer I/O Pins provided in Each Product for details.

Caution 2. Most of the following descriptions in this chapter use the 20-pin products as an example.

The timer array unit has eight 16-bit timers.

Each 16-bit timer is called a channel and can be used as an independent timer. In addition, two or more “channels” can be used to create a high-accuracy timer.



For details about each function, see the table below.

| Independent channel operation function | Simultaneous channel operation function |
|--|--|
| <ul style="list-style-type: none"> • Interval timer (→ refer to 6.8.1 Operation as interval timer/square wave output.) • Square wave output (→ refer to 6.8.1 Operation as interval timer/square wave output.) • External event counter (→ refer to 6.8.2 Operation as external event counter.) • Divider^{Note 1} (→ refer to 6.8.3 Operation as frequency divider (channels 0 and 3 only.)) • Input pulse interval measurement (→ refer to 6.8.4 Operation as input pulse interval measurement.) • Measurement of high-/low-level width of input signal (→ refer to 6.8.5 Operation as input signal high-/low-level width measurement.) • Delay counter (→ refer to 6.8.6 Operation as delay counter.) | <ul style="list-style-type: none"> • One-shot pulse output (→ refer to 6.9.1 Operation as one-shot pulse output function.) • PWM output (→ refer to 6.9.2 Operation as PWM function.) • Multiple PWM output (→ refer to 6.9.3 Operation as multiple PWM output function.) • Two-channel input with one-shot pulse output function (→ refer to 6.9.4 Operation as two-channel input with one-shot pulse output function.) |

Note 1. Channels 0 and 3 only.

It is possible to use the 16-bit timer of channels 1 and 3 as two 8-bit timers (higher and lower). The functions that can use channels 1 and 3 as 8-bit timers are as follows:

- Interval timer (upper or lower 8-bit timer)/square wave output (lower 8-bit timer only)
- External event counter (lower 8-bit timer only)
- Delay counter (lower 8-bit timer only)

Interlinked operation of channel 1 with the serial array unit operating as UART0 can be obtained by setting the ISC register. The input pulse interval measurement mode can then be used to measure the width at the baud rate of the other party in communications and make the required adjustments in response.

6.1 Functions of Timer Array Unit

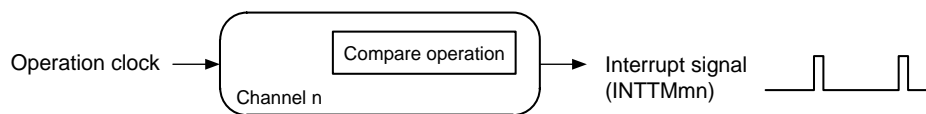
Timer array unit has the following functions.

6.1.1 Independent channel operation function

By operating a channel independently, it can be used for the following purposes without being affected by the operation mode of other channels.

1) Interval timer

Each timer of a unit can be used as a reference timer that generates an interrupt (INTTMmn) at fixed intervals.

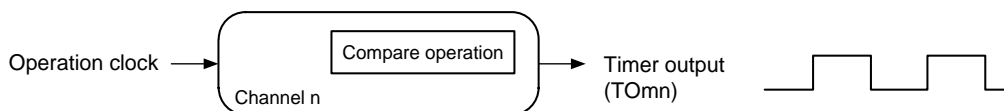


Remark 1. m: Unit number ($m = 0$), n: Channel number ($n = 0$ to 7)

Remark 2. The presence or absence of timer I/O pins of channel 0 to 7 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product** for details.

2) Square wave output

A toggle operation is performed each time an INTTMmn interrupt is generated and a square wave with a duty factor of 50% is output from a timer output pin (TOMn).

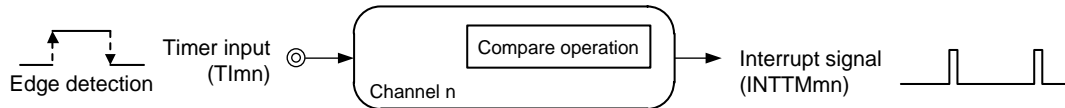


Remark 1. m: Unit number ($m = 0$), n: Channel number ($n = 0$ to 7)

Remark 2. The presence or absence of timer I/O pins of channel 0 to 7 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product** for details.

3) External event counter

Each timer of a unit can be used as an event counter that generates an interrupt when the number of the valid edges of a signal input to the timer input pin (TI_m_n) has reached a specific value.

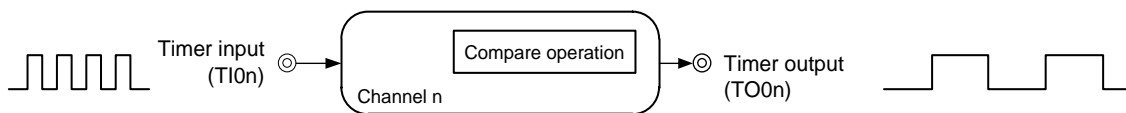


Remark 1. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Remark 2. The presence or absence of timer I/O pins of channel 0 to 7 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product** for details.

4) Divider function (channels 0 and 3 only)

A clock input from a timer input pin (TI₀_n) is divided and output from an output pin (TO₀_n).

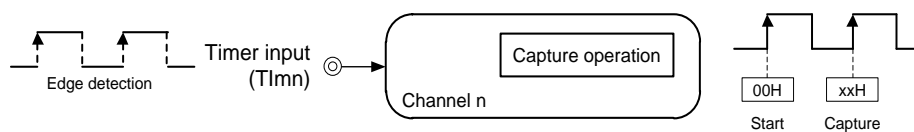


Remark 1. n: Channel number (n = 0, 3)

Remark 2. The presence or absence of timer I/O pins of channels 0 and 3 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product** for details.

5) Input pulse interval measurement

Counting is started by the valid edge of a pulse signal input to a timer input pin (TI_m_n). The count value of the timer is captured at the valid edge of the next pulse. In this way, the interval of the input pulse can be measured.

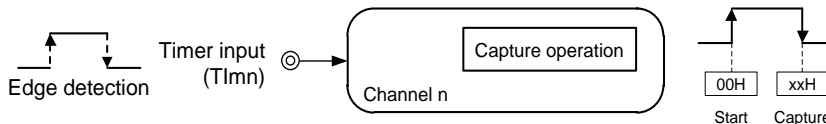


Remark 1. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Remark 2. The presence or absence of timer I/O pins of channel 0 to 7 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product** for details.

6) Measurement of high-/low-level width of input signal

Counting is started by a single edge of the signal input to the timer input pin (TImn), and the count value is captured at the other edge. In this way, the high-level or low-level width of the input signal can be measured.

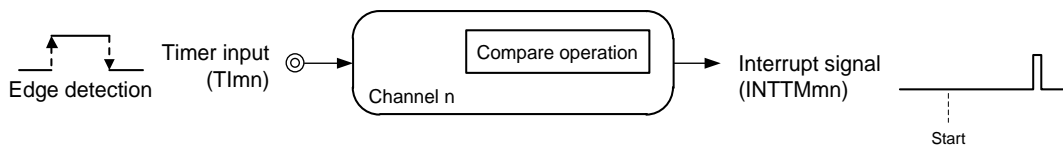


Remark 1. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Remark 2. The presence or absence of timer I/O pins of channel 0 to 7 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product** for details.

7) Delay counter

Counting is started at the valid edge of the signal input to the timer input pin (TImn), and an interrupt is generated after any delay period.



Remark 1. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

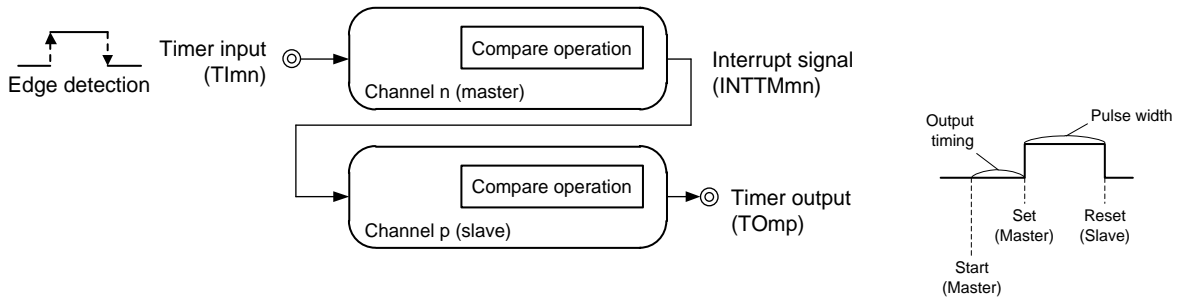
Remark 2. The presence or absence of timer I/O pins of channel 0 to 7 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product** for details.

6.1.2 Simultaneous channel operation function

By using the combination of a master channel (a reference timer mainly controlling the cycle) and slave channels (timers operating according to the master channel), channels can be used for the following purposes.

1) One-shot pulse output

Two channels are used as a set to generate a one-shot pulse with a specified output timing and a specified pulse width.

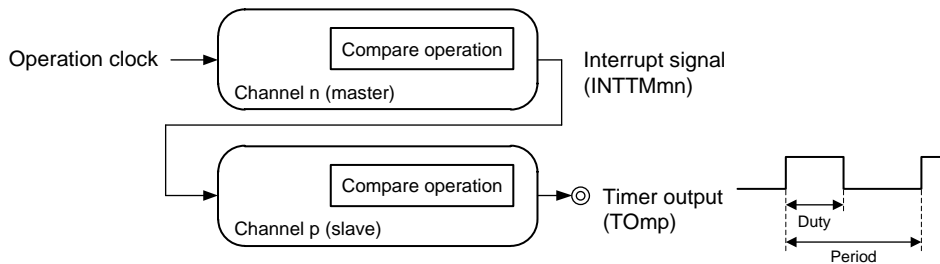


Caution For details about the rules of simultaneous channel operation function, see 6.4.1 Basic rules of simultaneous channel operation function.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)
 p: Slave channel number (n < p ≤ 7)

2) PWM (Pulse Width Modulation) output

Two channels are used as a set to generate a pulse with a specified period and a specified duty factor.

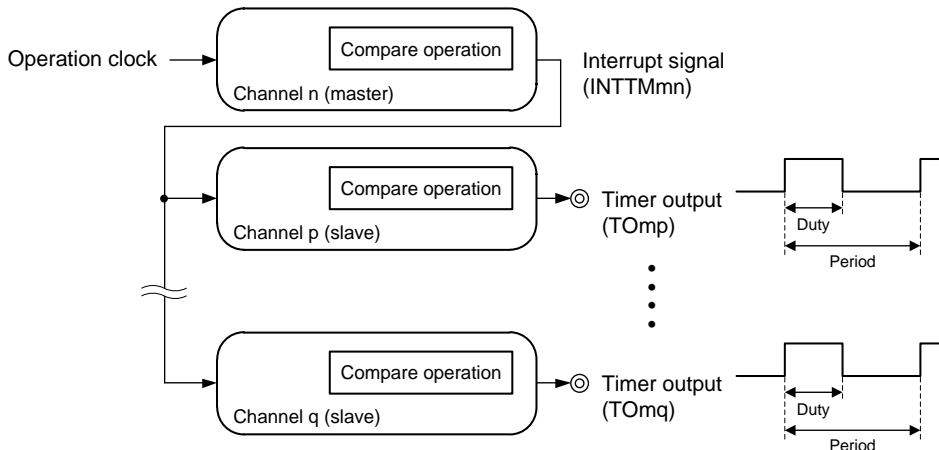


Caution For details about the rules of simultaneous channel operation function, see 6.4.1 Basic rules of simultaneous channel operation function.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)
 p: Slave channel number (n < p ≤ 7)

3) Multiple PWM (Pulse Width Modulation) output

By extending the PWM function and using one master channel and two or more slave channels, up to seven types of PWM signals that have a specific period and a specified duty factor can be generated.

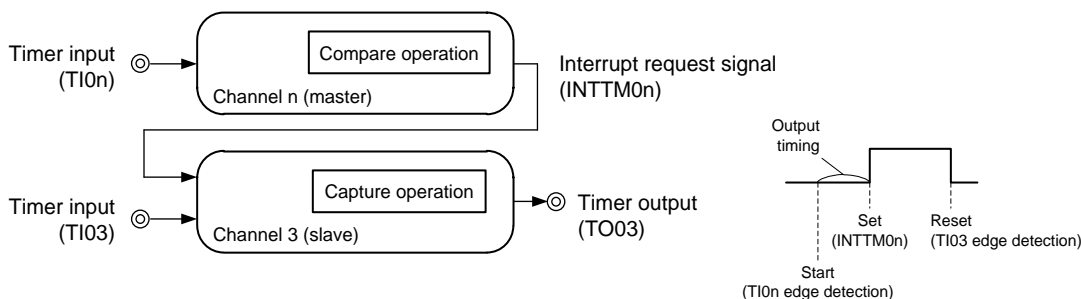


Caution For details about the rules of simultaneous channel operation function, see 6.4.1 Basic rules of simultaneous channel operation function.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)
 p, q: Slave channel number (n < p < q ≤ 7)

4) Two-channel input with one-shot pulse output function

Two channels are used as a set to generate any one-shot pulse by setting or resetting the timer output pin (TO03) at a valid edge of the timer input pin (TI0n, TI03) input.



Caution There are several rules for using the simultaneous channel operation function. For details, see 6.4.1 Basic rules of simultaneous channel operation function.

Remark n: Channel number (n = 0, 2)
 p: Slave channel number (p = 3)

6.1.3 8-bit timer operation function (channels 1 and 3 only)

The 8-bit timer operation function makes it possible to use a 16-bit timer channel in a configuration consisting of two 8-bit timer channels. This function can only be used for channels 1 and 3.

Caution There are several rules for using 8-bit timer operation function.
For details, see 6.4.2 Basic rules of 8-bit timer operation function (channels 1 and 3 only).

6.2 Configuration of Timer Array Unit

Timer array unit includes the following hardware.

Table 6-1. Configuration of Timer Array Unit

| Item | Configuration |
|-------------------|---|
| Timer/counter | Timer count register mn (TCRmn) |
| Register | Timer data register mn (TDRmn) |
| Timer input | TI00 to TI07 ^{Note 1} |
| Timer output | TO00 to TO07 ^{Note 1} , output controller |
| Control registers | <p><Registers of unit setting block></p> <ul style="list-style-type: none"> • Peripheral enable register 0 (PER0) • Timer clock select register m (TPSm) • Timer channel enable status register m (TEm) • Timer channel start register m (TSm) • Timer channel stop register m (TTm) • Timer output enable register m (TOEm) • Timer output register m (TOm) • Timer output level register m (TOLm) • Timer output mode register m (TOMm) <p><Registers of each channel></p> <ul style="list-style-type: none"> • Timer mode register mn (TMRmn) • Timer status register mn (TSRmn) • Input switch control register (ISC) • Noise filter enable registers 1 (NFEN1) • Port mode control register (PMCxx)^{Note 2} • Port mode register (PMxx)^{Note 2} • Port register (Pxx)^{Note 2} |

Note 1. The presence or absence of timer I/O pins of channel 0 to 7 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product**.

Note 2. The Port mode control register (PMCxx), port mode registers (PMxx) and port registers (Pxx) to be set differ depending on the product. For details, see **4.5.3 Register setting examples for used port and alternate functions**.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

The presence or absence of timer I/O pins in each timer array unit channel depends on the product.

Table 6-2. Timer I/O Pins provided in Each Product

| Timer array unit channels | | I/O Pins of Each Product | | | |
|---------------------------|-----------|--|------------------------------|----------------------------------|-------|
| | | 20-pin | 16-pin | 10-pin | 8-pin |
| Unit 0 | Channel 0 | P21/(TO00) P20/(TI00) P137/TI00 P03/TO00/(TI00) | P137/TI00 P03/TO00/(TI00) | | |
| | Channel 1 | P40/(TI01/TO01) P02/(TI01/TO01) P04/TI01/TO01 | | P40/(TI01/TO01) P04/TI01/TO01 | |
| | Channel 2 | P41/(TI02/TO02) P01/(TI02/TO02) P05/TI02/TO02 | | P01/TI02/TO02 | |
| | Channel 3 | P41/TI03/TO03 P07/(TO03) P20/(TI03/TO03) | P41/TI03/TO03 P07/(TO03) | — | — |
| | Channel 4 | P23/TI04/TO04 | — | — | — |
| | Channel 5 | P122/TI05/TO05 | | — | |
| | Channel 6 | P22/TI06/TO06 | — | — | |
| | Channel 7 | P121/TI07/TO07 | | — | |

- Remark 1.** When timer input and timer output are shared by the same pin, either only timer input or only timer output can be used.
- Remark 2.** —: There is no timer I/O pin, but the channel is available. (However, the channel can only be used as an interval timer.)
x: The channel is not available.
- Remark 3.** Pins in the parentheses indicate an alternate port when setting the peripheral I/O redirection register 0 to 3 (PIOR0 to PIOR3). For details, see **4.3.6 Peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3)**.

Figure 6-1 shows the block diagrams of the timer array unit.

Figure 6-1. Entire Block Diagram of Timer Array Unit

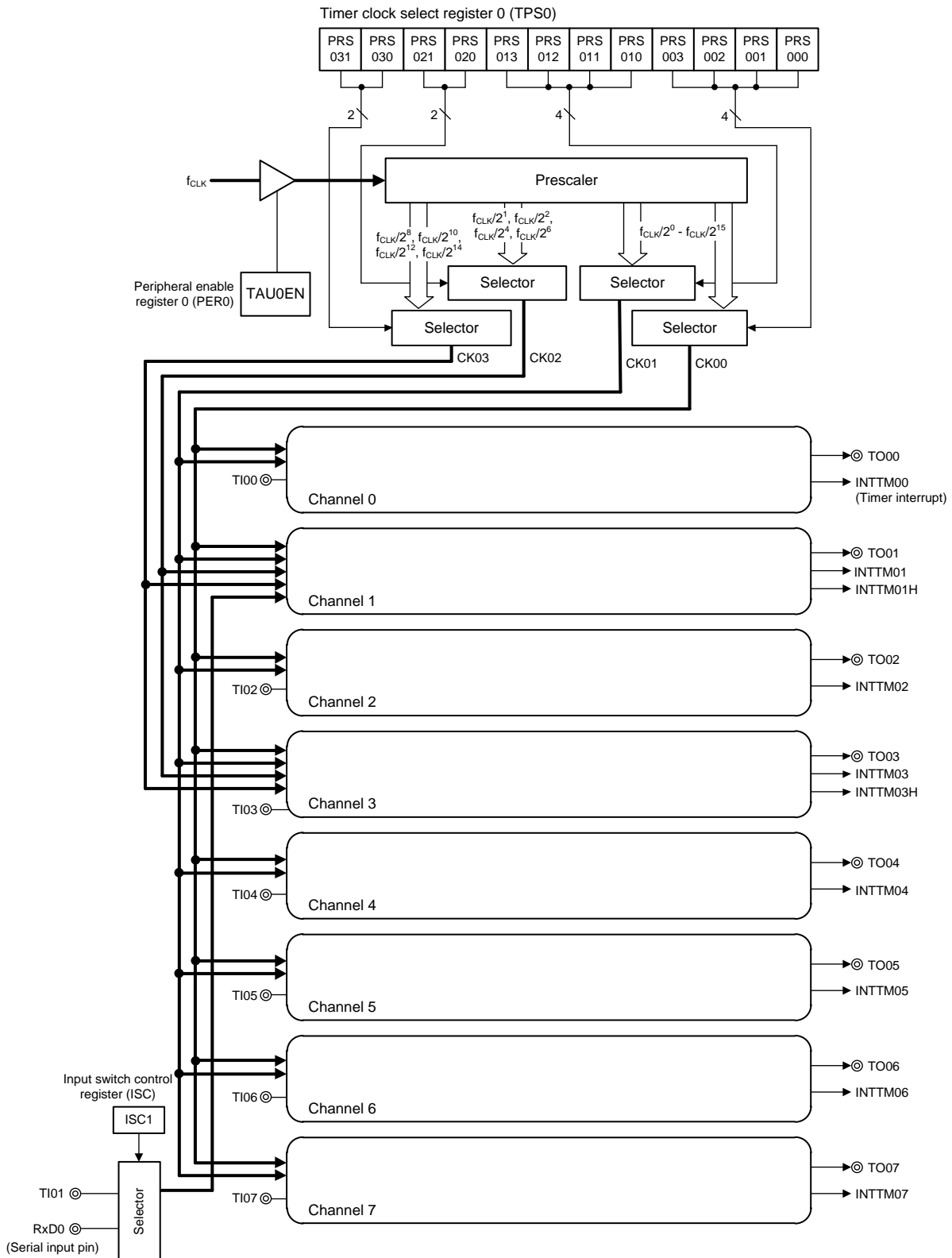
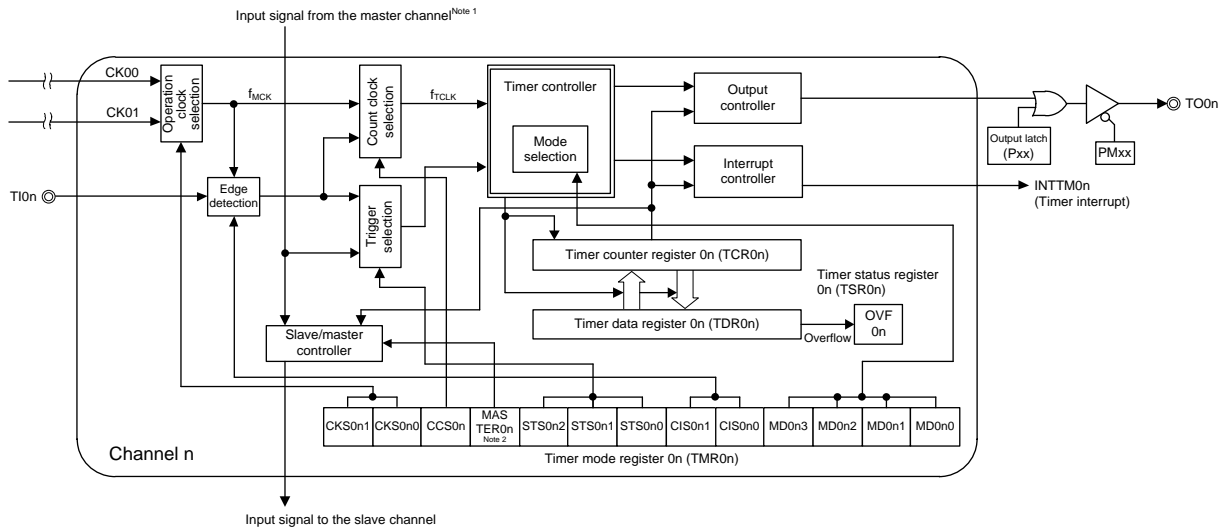


Figure 6-2. Internal Block Diagram of Channels 0, 2, 4, 6 of Timer Array Unit

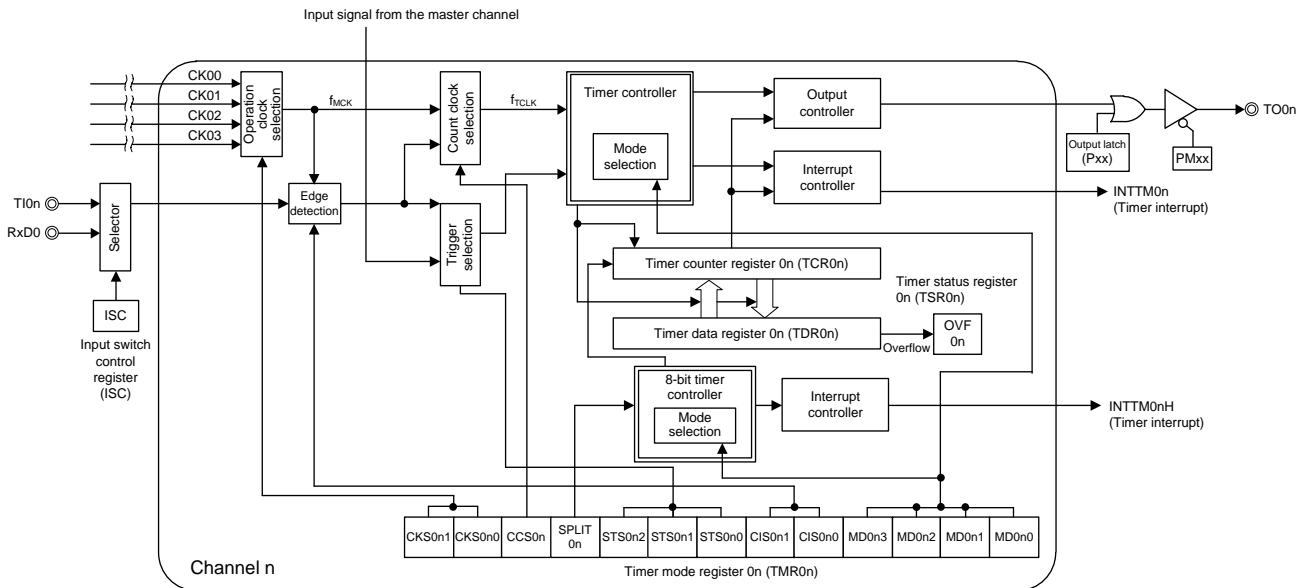


Note 1. Channels 2, 4, and 6 only

Note 2. n = 2, 4, 6 only

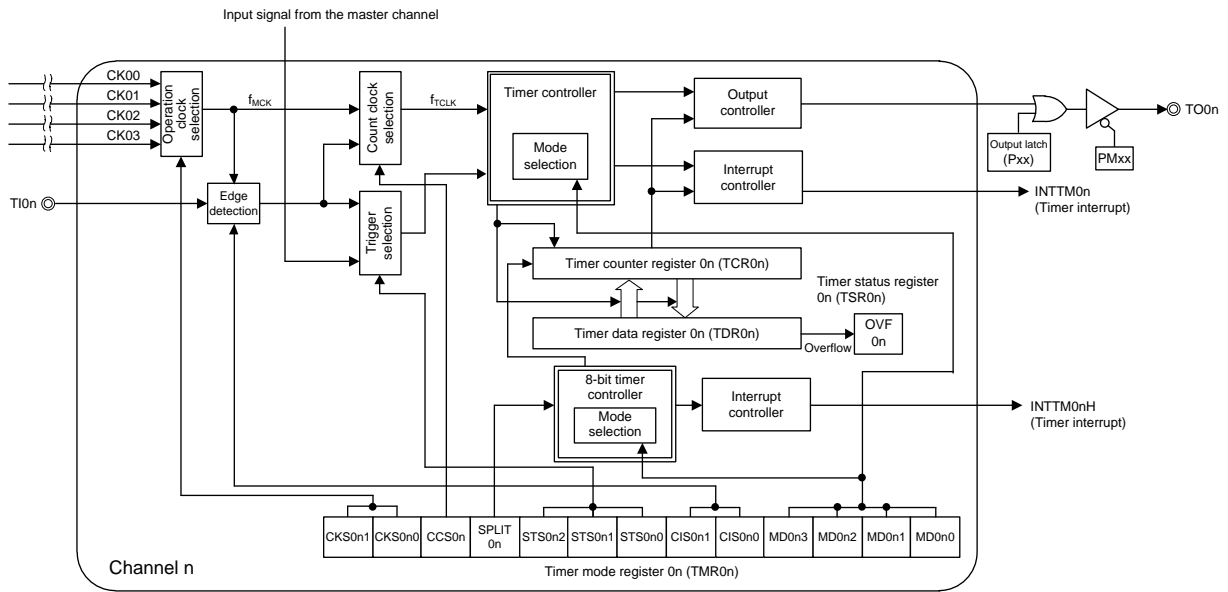
Remark n = 0, 2, 4, 6

Figure 6-3. Internal Block Diagram of Channel 1 of Timer Array Unit



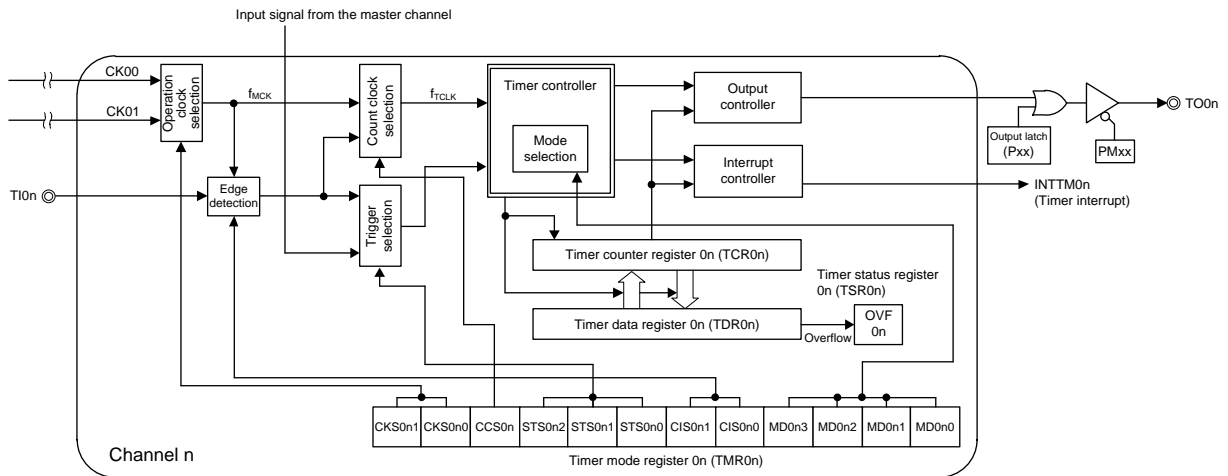
Remark n = 1

Figure 6-4. Internal Block Diagram of Channel 3 of Timer Array Unit



Remark n = 3

Figure 6-5. Internal Block Diagram of Channel n (n = 5, 7) of Timer Array Unit



Remark n = 5, 7

6.2.1 Timer count register mn (TCRmn)

The TCRmn register is a 16-bit read-only register and is used to count clocks.

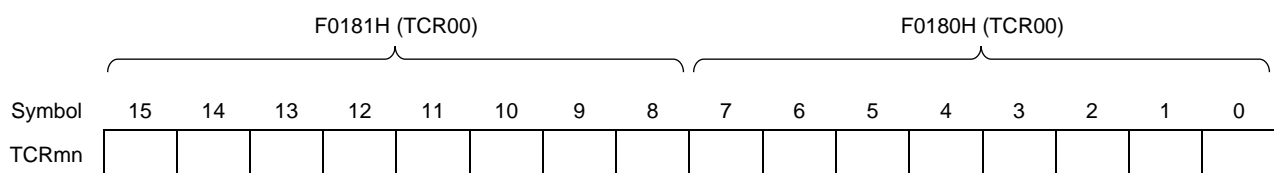
The value of this counter is incremented or decremented in synchronization with the rising edge of a count clock.

Whether the counter is incremented or decremented depends on the operation mode that is selected by the MDmn3 to MDmn0 bits of timer mode register mn (TMRmn) (refer to **6.3.3 Timer mode register mn (TMRmn)**).

Figure 6-6. Format of Timer Count Register mn (TCRmn)

Address: F0180H, F0181H (TCR00) to F018EH, F018FH (TCR07), F01C0H, F01C1H (TCR10) to F01CEH, F01CFH (TCR17)

After reset: FFFFH R



Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

The count value can be read by reading timer count register mn (TCRmn).

The count value is set to FFFFH in the following cases.

- When the reset signal is generated
- When the TAUmEN bit of peripheral enable register 0 (PER0) is cleared
- When counting of the slave channel has been completed in the PWM output mode
- When counting of the slave channel has been completed in the delay count mode
- When counting of the master/slave channel has been completed in the one-shot pulse output mode
- When counting of the slave channel has been completed in the multiple PWM output mode

The count value is cleared to 0000H in the following cases.

- When the start trigger is input in the capture mode
- When capturing has been completed in the capture mode

Caution The count value is not captured to timer data register mn (TDRmn) even when the TCRmn register is read.

The TCR_{mn} register read value differs as follows according to operation mode changes and the operating status.

Table 6-3. Timer Count Register mn (TCR_{mn}) Read Value in Various Operation Modes

| Operation Mode | Count Mode | Timer count register mn (TCR _{mn}) Read Value ^{Note 1} | | | |
|--------------------------|------------|---|--|---|--|
| | | Value if the operation mode was changed after releasing reset | Value if the Operation was restarted after count operation paused (TT _{mn} = 1) | Value if the operation mode was changed after count operation paused (TT _{mn} = 1) | Value when waiting for a start trigger after one count |
| Interval timer mode | Count down | FFFFH | Value if stop | Undefined | — |
| Capture mode | Count up | 0000H | Value if stop | Undefined | — |
| Event counter mode | Count down | FFFFH | Value if stop | Undefined | — |
| One-count mode | Count down | FFFFH | Value if stop | Undefined | FFFFH |
| Capture & one-count mode | Count up | 0000H | Value if stop | Undefined | Capture value of TDR _{mn} register + 1 |

Note 1. This indicates the value read from the TCR_{mn} register when channel n has stopped operating as a timer (TE_{mn} = 0) and has been enabled to operate as a counter (TS_{mn} = 1). The read value is held in the TCR_{mn} register until the count operation starts.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.2.2 Timer data register mn (TDRmn)

This is a 16-bit register from which a capture function and a compare function can be selected. The capture or compare function can be switched by selecting an operation mode by using the MDmn3 to MDmn0 bits of timer mode register mn (TMRmn).

The value of the TDRmn register can be changed at any time.

This register can be read or written in 16-bit units.

In addition, for the TDRm1 and TDRm3 registers, while in the 8-bit timer mode (when the SPLITm1, SPLITm3 bits of timer mode registers m1 and m3 (TMRm1, TMRm3) are 1), it is possible to read and write the data in 8-bit units, with TDRm1H and TDRm3H used as the higher 8 bits, and TDRm1L and TDRm3L used as the lower 8 bits.

Reset signal generation clears this register to 0000H.

Figure 6-7. Format of Timer Data Register mn (TDRmn) (n = 0, 2, 4 to 7)

Address: FFF18H, FFF19H (TDR00), FFF64H, FFF65H (TDR02), FFF68H, FFF69H (TDR04) to FFF6EH, FFF6FH (TDR07)
 After reset: 0000H R/W

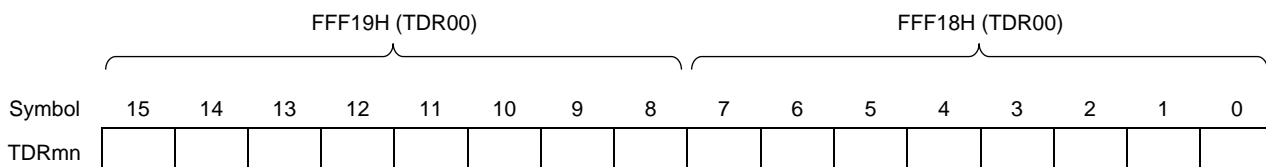
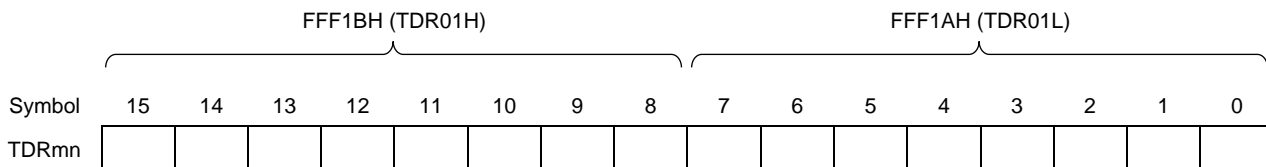


Figure 6-8. Format of Timer Data Register mn (TDRmn) (n = 1, 3)

Address: FFF1AH, FFF1BH (TDR01), FFF66H, FFF67H (TDR03) After reset: 0000H R/W



(i) When timer data register mn (TDRmn) is used as compare register

Counting down is started from the value set to the TDRmn register. When the count value reaches 0000H, an interrupt signal (INTTMmn) is generated. The TDRmn register holds its value until it is rewritten.

Caution The TDRmn register does not perform a capture operation even if a capture trigger is input, when it is set to the compare function.

(ii) When timer data register mn (TDRmn) is used as capture register

The count value of timer count register mn (TCRmn) is captured to the TDRmn register when the capture trigger is input.

A valid edge of the TImn pin can be selected as the capture trigger. This selection is made by timer mode register mn (TMRmn).

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.3 Registers Controlling Timer Array Unit

Timer array unit is controlled by the following registers.

- Peripheral enable register 0 (PER0)
- Timer clock select register m (TPSm)
- Timer mode register mn (TMRmn)
- Timer status register mn (TSRmn)
- Timer channel enable status register m (TEm)
- Timer channel start register m (TSm)
- Timer channel stop register m (TTm)
- Timer output enable register m (TOEm)
- Timer output register m (TOm)
- Timer output level register m (TOLm)
- Timer output mode register m (TOMm)
- Input switch control register (ISC)
- Noise filter enable registers 1 (NFEN1)
- Port mode control register (PMCxx)
- Port mode register (PMxx)
- Port register (Pxx)

Caution Which registers and bits are included depends on the product. Be sure to set bits that are not mounted to their initial values.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.3.1 Peripheral enable register 0 (PER0)

This register is used to enable or disable supplying the clock to the peripheral hardware. Clock supply to a hardware macro that is not used is stopped in order to reduce the power consumption and noise.

When the timer array unit 0 is used, be sure to set bit 0 (TAU0EN) of this register to 1.

The PER0 register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 6-9. Format of Peripheral Enable Register 0 (PER0)

Address: F00F0H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|----------|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PER0 | TMKAEN | CMPEN | ADCEN | IICA0EN | 0 | SAU0EN | 0 | TAU0EN |

| TAU0EN | Control of timer array unit 0 input clock |
|--------|--|
| 0 | Stops supply of input clock. <ul style="list-style-type: none"> • SFR used by the timer array unit 0 cannot be written. • The timer array unit 0 is in the reset status. |
| 1 | Supplies input clock. <ul style="list-style-type: none"> • SFR used by the timer array unit 0 can be read/written. |

Caution 1. When setting the timer array unit, be sure to set the following registers first while the TAUmEN bit is set to 1. If TAUmEN = 0, the values of the registers which control the timer array unit are cleared to their initial values and writing to them is ignored (except for input switch control register (ISC), noise filter enable register 1 (NFEN1), port mode control register 0, 2 (PMC0, PMC2), port mode register 0, 2, 4, 12 (PM0, PM2, PM4, PM12), and port register 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13)).

- Timer clock select register m (TPSm)
- Timer mode register mn (TMRmn)
- Timer status register mn (TSRmn)
- Timer channel enable status register m (TEm)
- Timer channel start register m (TSm)
- Timer channel stop register m (TTm)
- Timer output enable register m (TOEm)
- Timer output register m (TOM)
- Timer output level register m (TOLm)
- Timer output mode register m (TOMm)

Caution 2. Be sure to clear the following bits to 0.
Bits 1, 3

6.3.2 Timer clock select register m (TPSm)

The TPSm register is a 16-bit register that is used to select two types or four types of operation clocks (CKm0, CKm1, CKm2, CKm3) that are commonly supplied to each channel. CKm0 is selected by using bits 3 to 0 of the TPSm register, and CKm1 is selected by using bits 7 to 4 of the TPSm register. In addition, only for channels 1 and 3, CKm2 and CKm3 can be also selected. CKm2 is selected by using bits 9 and 8 of the TPSm register, and CKm3 is selected by using bits 13 and 12 of the TPSm register.

Rewriting of the TPSm register during timer operation is possible only in the following cases.

If the PRSm00 to PRSm03 bits can be rewritten (n = 0 to 7):

All channels for which CKm0 is selected as the operation clock (CKSmn1, CKSmn0 = 0, 0) are stopped (TEmn = 0).

If the PRSm10 to PRSm13 bits can be rewritten (n = 0 to 7):

All channels for which CKm1 is selected as the operation clock (CKSmn1, CKSmn0 = 0, 1) are stopped (TEmn = 0).

If the PRSm20 and PRSm21 bits can be rewritten (n = 1, 3):

All channels for which CKm2 is selected as the operation clock (CKSmn1, CKSmn0 = 1, 0) are stopped (TEmn = 0).

If the PRSm30 and PRSm31 bits can be rewritten (n = 1, 3):

All channels for which CKm3 is selected as the operation clock (CKSmn1, CKSmn0 = 1, 1) are stopped (TEmn = 0).

The TPSm register can be set by a 16-bit memory manipulation instruction.

Reset signal generation clears this register to 0000H.

Figure 6-10. Format of Timer Clock Select register m (TPSm) (1/2)

Address: F01B6H, F01B7H (TPS0) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|--------|----|----|------------|------------|----|----|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TPSm | 0 | 0 | PRSm 31 | PRSm 30 | 0 | 0 | PRSm 21 | PRSm 20 | PRSm 13 | PRSm 12 | PRSm 11 | PRSm 10 | PRSm 03 | PRSm 02 | PRSm 01 | PRSm 00 |

| PRSmk3 | PRSmk2 | PRSmk1 | PRSmk0 | | Selection of operation clock (CKmk) ^{Note 1} (k = 0, 1) | | | | |
|--------|--------|--------|--------|-----------------------------------|--|----------|----------|----------|----------|
| | | | | | f _{CLK} (MHz) | | | | |
| | | | | | 1 | 2 | 4 | 8 | 16 |
| 0 | 0 | 0 | 0 | f _{CLK} | 1 MHz | 2 MHz | 4 MHz | 8 MHz | 16 MHz |
| 0 | 0 | 0 | 1 | f _{CLK} /2 | 500 kHz | 1 MHz | 2 MHz | 4 MHz | 8 MHz |
| 0 | 0 | 1 | 0 | f _{CLK} /2 ² | 250 kHz | 500 kHz | 1 MHz | 2 MHz | 4 MHz |
| 0 | 0 | 1 | 1 | f _{CLK} /2 ³ | 125 kHz | 250 kHz | 500 MHz | 1 MHz | 2 MHz |
| 0 | 1 | 0 | 0 | f _{CLK} /2 ⁴ | 62.5 kHz | 125 kHz | 250kHz | 500 kHz | 1 MHz |
| 0 | 1 | 0 | 1 | f _{CLK} /2 ⁵ | 31.3 kHz | 62.5 kHz | 125kHz | 250 kHz | 500 kHz |
| 0 | 1 | 1 | 0 | f _{CLK} /2 ⁶ | 15.6 kHz | 31.3 kHz | 62.5 kHz | 125 kHz | 250 kHz |
| 0 | 1 | 1 | 1 | f _{CLK} /2 ⁷ | 7.81 kHz | 15.6 kHz | 31.3 kHz | 62.5 kHz | 125 kHz |
| 1 | 0 | 0 | 0 | f _{CLK} /2 ⁸ | 3.91 kHz | 7.81 kHz | 15.6 kHz | 31.3 kHz | 62.5 kHz |
| 1 | 0 | 0 | 1 | f _{CLK} /2 ⁹ | 1.95 kHz | 3.91 kHz | 7.81 kHz | 15.6 kHz | 31.3 kHz |
| 1 | 0 | 1 | 0 | f _{CLK} /2 ¹⁰ | 977 Hz | 1.95 kHz | 3.91 kHz | 7.81 kHz | 15.6 kHz |
| 1 | 0 | 1 | 1 | f _{CLK} /2 ¹¹ | 488 Hz | 977 Hz | 1.95 kHz | 3.91 kHz | 7.81 kHz |
| 1 | 1 | 0 | 0 | f _{CLK} /2 ¹² | 244 Hz | 488 Hz | 977 Hz | 1.95 kHz | 3.91 kHz |
| 1 | 1 | 0 | 1 | f _{CLK} /2 ¹³ | 122 Hz | 244 Hz | 488 kHz | 977 Hz | 1.95 kHz |
| 1 | 1 | 1 | 0 | f _{CLK} /2 ¹⁴ | 61 Hz | 122 Hz | 244 Hz | 488 Hz | 977 Hz |
| 1 | 1 | 1 | 1 | f _{CLK} /2 ¹⁵ | 30.5 Hz | 61 Hz | 122 Hz | 244 Hz | 488 Hz |

Note 1. When changing the clock selected for f_{CLK} (by changing the system clock control register (CKC) value), stop timer array unit (TTm = 00FFH).

Caution 1. Be sure to clear bits 15, 14, 11, 10 to “0”.

Caution 2. If f_{CLK} (undivided) is selected as the operation clock (CKmk) and TDRnm is set to 0000H (m = 0, n = 0 to 7), interrupt requests output from timer array units cannot be used.

Remark 1. f_{CLK}: CPU/peripheral hardware clock frequency

Remark 2. Waveform of the clock to be selected in the TPS0 register which becomes high level for one period of f_{CLK} from its rising edge. For details, see 6.5.1 Count clock (fTCLK).

Figure 6-10. Format of Timer Clock Select register m (TPSm) (2/2)

Address: F01B6H, F01B7H (TPS0) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|--------|----|----|------------|------------|----|----|------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TPSm | 0 | 0 | PRSm 31 | PRSm 30 | 0 | 0 | PRSm 21 | PRSm 20 | PRSm 13 | PRSm 12 | PRSm 11 | PRSm 10 | PRSm 03 | PRSm 02 | PRSm 01 | PRSm 00 |

| PRSm21 | PRSm20 | Selection of operation clock (CKm2) ^{Note 1} | | | | | |
|--------|--------|---|----------|----------|----------|---------|---------|
| | | f _{CLK} (MHz) | | | | | |
| | | 1 | 2 | 4 | 8 | 16 | |
| 0 | 0 | f _{CLK} /2 | 500 kHz | 1 MHz | 2 MHz | 4 MHz | 8 MHz |
| 0 | 1 | f _{CLK} /2 ² | 250 kHz | 500 kHz | 1 MHz | 2 MHz | 4 MHz |
| 1 | 0 | f _{CLK} /2 ⁴ | 62.5 kHz | 125 kHz | 250 kHz | 500 kHz | 1 MHz |
| 1 | 1 | f _{CLK} /2 ⁶ | 15.6 kHz | 31.3 kHz | 62.5 kHz | 125 kHz | 250 kHz |

| PRSm31 | PRSm30 | Selection of operation clock (CKm3) ^{Note 1} | | | | | |
|--------|--------|---|----------|----------|----------|----------|----------|
| | | f _{CLK} (MHz) | | | | | |
| | | 1 | 2 | 4 | 8 | 16 | |
| 0 | 0 | f _{CLK} /2 ⁸ | 3.91 kHz | 7.81 kHz | 15.6 kHz | 31.3 kHz | 62.5 kHz |
| 0 | 1 | f _{CLK} /2 ¹⁰ | 977 Hz | 1.95 kHz | 3.91 kHz | 7.81 kHz | 15.6 kHz |
| 1 | 0 | f _{CLK} /2 ¹² | 244 Hz | 488 Hz | 977 Hz | 1.95 kHz | 3.91 kHz |
| 1 | 1 | f _{CLK} /2 ¹⁴ | 61 Hz | 122 Hz | 244 Hz | 488 Hz | 977 Hz |

Note 1. When changing the clock selected for f_{CLK} (by changing the system clock control register (CKC) value), stop timer array unit (TTm = 00FFH).

The timer array unit must also be stopped if the operation clock (f_{MCK}) or the valid edge of the signal input from the TIMn pin is selected.

Caution Be sure to clear bits 15, 14, 11, 10 to “0”.

By using channels 1 and 3 in the 8-bit timer mode and specifying CKm2 or CKm3 as the operation clock, the interval times shown in **Table 6-4** can be achieved by using the interval timer function.

Table 6-4. Interval Times Available for Operation clock CKSm2 or CKSm3

| Clock | | Interval time ^{Note 1} ($f_{CLK} = 16 \text{ MHz}$) | | | |
|-------|------------------|--|-------------------|------|-------|
| | | 10 μs | 100 μs | 1 ms | 10 ms |
| CKm2 | $f_{CLK}/2$ | ✓ | — | — | — |
| | $f_{CLK}/2^2$ | ✓ | — | — | — |
| | $f_{CLK}/2^4$ | ✓ | ✓ | — | — |
| | $f_{CLK}/2^6$ | ✓ | ✓ | — | — |
| CKm3 | $f_{CLK}/2^8$ | — | ✓ | ✓ | — |
| | $f_{CLK}/2^{10}$ | — | — | ✓ | ✓ |
| | $f_{CLK}/2^{12}$ | — | — | ✓ | ✓ |
| | $f_{CLK}/2^{14}$ | — | — | — | ✓ |

Note 1. The margin is within 5%.

Remark 1. f_{CLK} : CPU/peripheral hardware clock frequency

Remark 2. For details of a signal of $f_{CLK}/2^j$ selected with the TPSm register, see **6.5.1 Count clock (fTCLK)**.

6.3.3 Timer mode register mn (TMRmn)

The TMRmn register sets an operation mode of channel n. This register is used to select the operation clock (f_{MCK}), select the count clock, select the master/slave, select the 16 or 8-bit timer (only for channels 1 and 3), specify the start trigger and capture trigger, select the valid edge of the timer input, and specify the operation mode (interval, capture, event counter, one-count, or capture and one-count).

Rewriting the TMRmn register is prohibited when the register is in operation (when $TE_{mn} = 1$). However, bits 7 and 6 (CIS_{mn1} , CIS_{mn0}) can be rewritten even while the register is operating with some functions (when $TE_{mn} = 1$) (for details, see **6.8 Independent Channel Operation Function of Timer Array Unit** and **6.9 Simultaneous Channel Operation Function of Timer Array Unit**).

The TMRmn register can be set by a 16-bit memory manipulation instruction.

Reset signal generation clears this register to 0000H.

Caution The bits mounted depend on the channels in the bit 11 of TMRmn register.

TMRm2, TMRm4, TMRm6: MASTERmn bit (n = 2, 4, 6)

TMRm1, TMRm3: SPLITmn bit (n = 1, 3)

TMRm0, TMRm5, TMRm7: Fixed to 0

Figure 6-11. Format of Timer Mode Register mn (TMRmn) (1/5)

Address: F0190H, F0191H (TMR00) to F019EH, F019FH (TMR07) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|--------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 2, 4, 6) | CKSm n1 | CKSm n0 | 0 | CCSm n | MAST ERmn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|---------------------|------------|------------|----|-----------|-------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 1, 3) | CKSm n1 | CKSm n0 | 0 | CCSm n | SPLIT mn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|---------------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 0, 5, 7) | CKSm n1 | CKSm n0 | 0 | CCSm n | 0 ^{Note 1} | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | |
|--|------------|--|
| CKSmn 1 | CKSmn 0 | Selection of operation clock (f_{MCK}) of channel |
| 0 | 0 | Operation clock CKm0 set by timer clock select register m (TPSm) |
| 0 | 1 | Operation clock CKm2 set by timer clock select register m (TPSm) |
| 1 | 0 | Operation clock CKm1 set by timer clock select register m (TPSm) |
| 1 | 1 | Operation clock CKm3 set by timer clock select register m (TPSm) |
| Operation clock (f_{MCK}) is used by the edge detector. A count clock (f_{TCLK}) and a sampling clock are generated depending on the setting of the CCSmn bit. | | |
| The operation clocks CKm2 and CKm3 can only be selected for channels 1 and 3. | | |

| | |
|--|---|
| CCSmn | Selection of count clock (f_{TCLK}) of channel n |
| 0 | Operation clock (f_{MCK}) specified by the CKSmn0 and CKSmn1 bits |
| 1 | Valid edge of input signal input from the TImn pin <ul style="list-style-type: none"> In channel 1, valid edge of input signal selected by ISC |
| Count clock (f_{TCLK}) is used for the counter, output controller, and interrupt controller. | |

Note 1. Bit 11 is a read-only bit and fixed to 0. Writing to this bit is ignored.

Caution 1. Be sure to clear bits 13, 5, and 4 to 0.

Caution 2. The timer array unit must be stopped (TTm = 00FFH) if the clock selected for f_{CLK} is changed (by changing the value of the system clock control register (CKC)), even if the operation clock (f_{MCK}) specified by using the CKSmn0 and CKSmn1 bits or the valid edge of the signal input from the TImn pin is selected as the count clock (f_{TCLK}).

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-11. Format of Timer Mode Register mn (TMRmn) (2/5)

Address: F0190H, F0191H (TMR00) to F019EH, F019FH (TMR07) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|--------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 2, 4, 6) | CKSm n1 | CKSm n0 | 0 | CCSm n | MAST ERmn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|---------------------|------------|------------|----|-----------|-------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 1, 3) | CKSm n1 | CKSm n0 | 0 | CCSm n | SPLIT mn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|---------------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 0, 5, 7) | CKSm n1 | CKSm n0 | 0 | CCSm n | 0 ^{Note 1} | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

(Bit 11 of TMRmn (n = 2, 4, 6))

| | |
|---|--|
| MASTE Rmn | Selection between using channel n independently or simultaneously with another channel (as a slave or master) |
| 0 | Operates in independent channel operation function or as slave channel in simultaneous channel operation function. |
| 1 | Operates as master channel in simultaneous channel operation function. |
| Only the channel 2, 4, 6 can be set as a master channel (MASTERmn = 1). Be sure to use channel 0, 5, 7 are fixed to 0 (Regardless of the bit setting, channel 0 operates as master, because it is the highest channel). Clear the MASTERmn bit to 0 for a channel that is used with the independent channel operation function. | |

(Bit 11 of TMRmn (n = 1, 3))

| | |
|-------------|---|
| SPLITm n | Selection of 8 or 16-bit timer operation for channels 1 and 3 |
| 0 | Operates as 16-bit timer. (Operates in independent channel operation function or as slave channel in simultaneous channel operation function.) |
| 1 | Operates as 8-bit timer. |

| | | | |
|------------------|------------|------------|--|
| STSmn 2 | STSmn 1 | STSmn 0 | Setting of start trigger or capture trigger of channel n |
| 0 | 0 | 0 | Only software trigger start is valid (other trigger sources are unselected). |
| 0 | 0 | 1 | Valid edge of the TImn pin input is used as both the start trigger and capture trigger. |
| 0 | 1 | 0 | Both the edges of the TImn pin input are used as a start trigger and a capture trigger. |
| 1 | 0 | 0 | Interrupt signal of the master channel is used (when the channel is used as a slave channel with the simultaneous channel operation function). |
| 1 | 1 | 0 | When the channel is used as a slave channel in two-channel input with one-shot pulse output function: The interrupt request signal of the master channel (INTTM0n) is used as the start trigger. A valid edge of the TI03 pin input of the slave channel is used as the end trigger. |
| Other than above | | | Setting prohibited |

Note 1. Bit 11 is a read-only bit and fixed to 0. Writing to this bit is ignored.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-11. Format of Timer Mode Register mn (TMRmn) (3/5)

Address: F0190H, F0191H (TMR00) to F019EH, F019FH (TMR07) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|--------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 2, 4, 6) | CKSm n1 | CKSm n0 | 0 | CCSm n | MAST ERmn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|---------------------|------------|------------|----|-----------|-------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 1, 3) | CKSm n1 | CKSm n0 | 0 | CCSm n | SPLIT mn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|---------------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 0, 5, 7) | CKSm n1 | CKSm n0 | 0 | CCSm n | 0 ^{Note 1} | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| CISmn1 | CISmn0 | Selection of TImn pin input valid edge |
|--------|--------|---|
| 0 | 0 | Falling edge |
| 0 | 1 | Rising edge |
| 1 | 0 | Both edges (when low-level width is measured) Start trigger: Falling edge, Capture trigger: Rising edge |
| 1 | 1 | Both edges (when high-level width is measured) Start trigger: Rising edge, Capture trigger: Falling edge |

If both the edges are specified when the value of the STSmn2 to STSmn0 bits is other than 010B, set the CISmn1 to CISmn0 bits to 10B.

Note 1. Bit 11 is a read-only bit and fixed to 0. Writing to this bit is ignored.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-11. Format of Timer Mode Register mn (TMRmn) (4/5)

Address: F0190H, F0191H (TMR00) to F019EH, F019FH (TMR07) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|--------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 2, 4, 6) | CKSm n1 | CKSm n0 | 0 | CCSm n | MAST ERmn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|---------------------|------------|------------|----|-----------|-------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 1, 3) | CKSm n1 | CKSm n0 | 0 | CCSm n | SPLIT mn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|---------------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 0, 5, 7) | CKSm n1 | CKSm n0 | 0 | CCSm n | 0 ^{Note 1} | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| MDmn3 | MDmn2 | MDmn1 | Setting of operation mode of channel n | Corresponding function | Corresponding function |
|---|-------|-------|--|---|------------------------|
| 0 | 0 | 0 | Interval timer mode | Interval timer/ Square wave output/ Divider function/ PWM output (master) | Down count |
| 0 | 1 | 0 | Capture mode | Input pulse interval measurement/ Two-channel input with one-shot pulse output function (slave) | Up count |
| 0 | 1 | 1 | Event counter mode | External event counter | Down count |
| 1 | 0 | 0 | One-count mode | Delay counter/ One-shot pulse output/ Two-channel input with one-shot pulse output function (master) PWM output (slave) | Down count |
| 1 | 1 | 0 | Capture & one-count mode | Measurement of high-/low-level width of input signal | Up count |
| Other than above | | | Setting prohibited | | |
| The operation of each mode varies depending on MDmn0 bit (see the table below). | | | | | |

Note 1. Bit 11 is a read-only bit and fixed to 0. Writing to this bit is ignored.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-11. Format of Timer Mode Register mn (TMRmn) (5/5)

Address: F0190H, F0191H (TMR00) to F019EH, F019FH (TMR07) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|--------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 2, 4, 6) | CKSm n1 | CKSm n0 | 0 | CCSm n | MAST ERmn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|---------------------|------------|------------|----|-----------|-------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 1, 3) | CKSm n1 | CKSm n0 | 0 | CCSm n | SPLIT mn | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | | | | | | | | | | | | | | | |
|------------------------|------------|------------|----|-----------|---------------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn (n = 0, 5, 7) | CKSm n1 | CKSm n0 | 0 | CCSm n | 0 ^{Note 1} | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | 0 | 0 | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |

| Operation mode (Value set by the MDmn3 to MDmn1 bits (see the table above)) | MDmn0 | Setting of starting counting and interrupt |
|---|-------|---|
| <ul style="list-style-type: none"> Interval timer mode (0, 0, 0) Capture mode (0, 1, 0) | 0 | Timer interrupt is not generated when counting is started (timer output does not change, either). |
| | 1 | Timer interrupt is generated when counting is started (timer output also changes). |
| <ul style="list-style-type: none"> Event counter mode (0, 1, 1) | 0 | Timer interrupt is not generated when counting is started (timer output does not change, either). |
| <ul style="list-style-type: none"> One-count mode^{Note 2} (1, 0, 0) | 0 | Start trigger is invalid during counting operation. At that time, interrupt is not generated. |
| | 1 | Start trigger is valid during counting operation ^{Note 3} . At that time, interrupt is not generated. |
| <ul style="list-style-type: none"> Capture & one-count mode (1, 1, 0) | 0 | Timer interrupt is not generated when counting is started (timer output does not change, either). Start trigger is invalid during counting operation. At that time interrupt is not generated. |
| Other than above | | Setting prohibited |

Note 1. Bit 11 is a read-only bit and fixed to 0. Writing to this bit is ignored.

Note 2. In one-count mode, interrupt output (INTTMMn) when starting a count operation and TOMn output are not controlled.

Note 3. If the start trigger (TSmn = 1) is issued during operation, the counter is initialized, and recounting is started (does not occur the interrupt request).

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.3.4 Timer status register mn (TSRmn)

The TSRmn register indicates the overflow status of the counter of channel n.

The TSRmn register is valid only in the capture mode (MDmn3 to MDmn1 = 010B) and capture & one-count mode (MDmn3 to MDmn1 = 110B). See **Table 6-5** for the operation of the OVF bit in each operation mode and set/clear conditions.

The TSRmn register can be read by a 16-bit memory manipulation instruction.

The lower 8 bits of the TSRmn register can be read with an 8-bit memory manipulation instruction with TSRmnL.

Reset signal generation clears this register to 0000H.

Figure 6-12. Format of Timer Status Register mn (TSRmn)

Address: F01A0H, F01A1H (TSR00) to F01AEH, F01AFH (TSR07) After reset: 0000H R

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|-----|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TSRmn | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | OVF |

| OVF | Counter overflow status of channel n |
|--|--------------------------------------|
| 0 | Overflow does not occur. |
| 1 | Overflow occurs. |
| When OVF = 1, this flag is cleared (OVF = 0) when the next value is captured without overflow. | |

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Table 6-5. OVF Bit Operation and Set/Clear Conditions in Each Operation Mode

| Timer operation mode | OVF bit | Set/clear conditions |
|---|---------|--|
| <ul style="list-style-type: none"> • Capture mode • Capture & one-count mode | clear | When no overflow has occurred upon capturing |
| | set | When an overflow has occurred upon capturing |
| <ul style="list-style-type: none"> • Interval timer mode • Event counter mode • One-count mode | clear | — (Use prohibited) |
| | set | |

Remark The OVF bit does not change immediately after the counter has overflowed, but changes upon the subsequent capture.

6.3.5 Timer channel enable status register m (TE_m)

The TE_m register is used to display whether the timer operation of each channel is enabled or stopped.

Each bit of the TE_m register corresponds to each bit of the timer channel start register m (TS_m) and the timer channel stop register m (TT_m). When a bit of the TS_m register is set to 1, the corresponding bit of this register is set to 1. When a bit of the TT_m register is set to 1, the corresponding bit of this register is cleared to 0.

The TE_m register can be read by a 16-bit memory manipulation instruction.

The lower 8 bits of the TE_m register can be set with a 1-bit or 8-bit memory manipulation instruction with TE_mL.

Reset signal generation clears this register to 0000H.

Figure 6-13. Format of Timer Channel Enable Status register m (TE_m)

Address: F01B0H, F01B1H (TE₀) After reset: 0000H R

| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-----------------|----|----|----|----|-----------------------|----|-----------------------|---|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| TE _m | 0 | 0 | 0 | 0 | TEH _m 3 | 0 | TEH _m 1 | 0 | TE _m 7 | TE _m 6 | TE _m 5 | TE _m 4 | TE _m 3 | TE _m 2 | TE _m 1 | TE _m 0 |

| TEH _m 3 | Indication of whether operation of the higher 8-bit timer is enabled or stopped when channel 3 is in the 8-bit timer mode |
|--------------------|---|
| 0 | Operation is stopped. |
| 1 | Operation is enabled. |

| TEH _m 1 | Indication of whether operation of the higher 8-bit timer is enabled or stopped when channel 1 is in the 8-bit timer mode |
|--------------------|---|
| 0 | Operation is stopped. |
| 1 | Operation is enabled. |

| TE _m n | Indication of operation enable/stop status of channel n |
|--|---|
| 0 | Operation is stopped. |
| 1 | Operation is enabled. |
| This bit displays whether operation of the lower 8-bit timer for TE _m 1 and TE _m 3 is enabled or stopped when channel 1 or 3 is in the 8-bit timer mode. | |

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.3.6 Timer channel start register m (TSM)

The TSM register is a trigger register that is used to initialize timer count register mn (TCRmn) and start the counting operation of each channel.

When a bit of this register is set to 1, the corresponding bit of timer channel enable status register m (TEm) is set to 1. The TSMn, TSHm1, TSHm3 bits are immediately cleared when operation is enabled (TEmn, TEHm1, TEHm3 = 1), because they are trigger bits.

The TSM register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the TSM register can be set with a 1-bit or 8-bit memory manipulation instruction with TSM_L.

Reset signal generation clears this register to 0000H.

Figure 6-14. Format of Timer Channel Start register m (TSM)

Address: F01B2H, F01B3H (TS0) After reset: 0000H R/W

| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|----|----|----|----|-----------|----|-----------|---|------|------|------|------|------|------|------|------|
| TSM | 0 | 0 | 0 | 0 | TSHm 3 | 0 | TSHm 1 | 0 | TSM7 | TSM6 | TSM5 | TSM4 | TSM3 | TSM2 | TSM1 | TSM0 |

| | |
|-------|---|
| TSHm3 | Trigger to enable operation (start operation) of the higher 8-bit timer when channel 3 is in the 8-bit timer mode |
| 0 | No trigger operation |
| 1 | The TEHm3 bit is set to 1 and the count operation becomes enabled. The TCRm3 register count operation start in the interval timer mode in the count operation enabled state (see Table 6-6 in 6.5.2 Start timing of counter). |

| | |
|-------|---|
| TSHm1 | Trigger to enable operation (start operation) of the higher 8-bit timer when channel 1 is in the 8-bit timer mode |
| 0 | No trigger operation |
| 1 | The TEHm1 bit is set to 1 and the count operation becomes enabled. The TCRm1 register count operation start in the interval timer mode in the count operation enabled state (see Table 6-6 in 6.5.2 Start timing of counter). |

| | |
|------|---|
| TSMn | Operation enable (start) trigger of channel n |
| 0 | No trigger operation |
| 1 | The TEMn bit is set to 1 and the count operation becomes enabled. The TCRmn register count operation start in the count operation enabled state varies depending on each operation mode (see Table 6-6 in 6.5.2 Start timing of counter). This bit is the trigger to enable operation (start operation) of the lower 8-bit timer for TSM1 and TSM3 when channel 1 or 3 is in the 8-bit timer mode. |

(Notes and Remarks are listed on the next page.)

Caution 1. Be sure to clear bits 15 to 12, 10, and 8 to 0.

Caution 2. When switching from a function that does not use TImn pin input to one that does, the following wait period is required from when timer mode register mn (TMRmn) is set until the TSmn (TSHm1, TSHm3) bit is set to 1.

When the TImn pin noise filter is enabled (TNFENnm = 1):

Four cycles of the operation clock (f_{MCK})

When the TImn pin noise filter is disabled (TNFENnm = 0):

Two cycles of the operation clock (f_{MCK})

Remark 1. When the TSm register is read, 0 is always read.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.3.7 Timer channel stop register m (TTm)

The TTm register is a trigger register that is used to stop the counting operation of each channel.

When a bit of this register is set to 1, the corresponding bit of timer channel enable status register m (TEm) is cleared to 0. The TTm_n, TTHm₁, TTHm₃ bits are immediately cleared when operation is stopped (TEm_n, TEHm₁, TEHm₃ = 0), because they are trigger bits.

The TTm register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the TTm register can be set with a 1-bit or 8-bit memory manipulation instruction with TTmL.

Reset signal generation clears this register to 0000H.

Figure 6-15. Format of Timer Channel Stop register m (TTm)

Address: F01B4H, F01B5H (TT0) After reset: 0000H R/W

| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|----|----|----|----|-------------------|----|-------------------|---|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
| TTm | 0 | 0 | 0 | 0 | TTHm ₃ | 0 | TTHm ₁ | 0 | TTm ₇ | TTm ₆ | TTm ₅ | TTm ₄ | TTm ₃ | TTm ₂ | TTm ₁ | TTm ₀ |

| TTHm ₃ | Trigger to stop operation of the higher 8-bit timer when channel 3 is in the 8-bit timer mode |
|-------------------|---|
| 0 | No trigger operation |
| 1 | TEHm ₃ bit is cleared to 0 and the count operation is stopped. |

| TTHm ₁ | Trigger to stop operation of the higher 8-bit timer when channel 1 is in the 8-bit timer mode |
|-------------------|---|
| 0 | No trigger operation |
| 1 | TEHm ₁ bit is cleared to 0 and the count operation is stopped. |

| TTm _n | Operation stop trigger of channel n |
|------------------|--|
| 0 | No trigger operation |
| 1 | TEm _n bit is cleared to 0 and the count operation is stopped. The TTm ₁ and TTm ₃ bits respectively trigger stoppage of operation of the lower 8-bit timers in channels 1 and 3 when these channels are in the 8-bit timer mode. |

Caution Be sure to clear bits 15 to 12, 10, and 8 of the TTm register to 0.

Remark 1. When the TTm register is read, 0 is always read.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.3.8 Timer output enable register m (TOEm)

The TOEm register is used to enable or disable timer output of each channel.

Channel n for which timer output has been enabled becomes unable to rewrite the value of the TOMn bit of timer output register m (TOM) described later by software, and the value reflecting the setting of the timer output function through the count operation is output from the timer output pin (TOMn).

The TOEm register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the TOEm register can be set with a 1-bit or 8-bit memory manipulation instruction with TOEmL.

Reset signal generation clears this register to 0000H.

Figure 6-16. Format of Timer Output Enable register m (TOEm)

Address: F01BAH, F01BBH (TOE0) After reset: 0000H R/W

| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|----|----|----|----|----|----|---|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| TOEm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | TOEm 7 | TOEm 6 | TOEm 5 | TOEm 4 | TOEm 3 | TOEm 2 | TOEm 1 | TOEm 0 |

| TOEmn | Timer output enable/disable of channel n |
|-------|---|
| 0 | Disable output of timer. Without reflecting on TOMn bit timer operation, to fixed the output. Writing to the TOMn bit is enabled and the level set in the TOMn bit is output from the TOMn pin. |
| 1 | Enable output of timer. Reflected in the TOMn bit timer operation, to generate the output waveform. Writing to the TOMn bit is disabled (writing is ignored). |

Caution Be sure to clear bits 15 to 8 to 0.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.3.9 Timer output register m (TOM)

The TOM register is a buffer register of timer output of each channel.

The value of each bit in this register is output from the timer output pin (TOMn) of each channel.

The TOMn bit on this register can be rewritten by software only when timer output is disabled (TOEmn = 0). When timer output is enabled (TOEmn = 1), rewriting this register by software is ignored, and the value is changed only by the timer operation.

To use the TO0n alternate pin as a port function pin, set the corresponding TOMn bit to "0".

The TOM register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the TOM register can be set with an 8-bit memory manipulation instruction with TOML.

Reset signal generation clears this register to 0000H.

Figure 6-17. Format of Timer Output register m (TOM)

Address: F01B8H, F01B9H (TO0) After reset: 0000H R/W

| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|----|----|----|----|----|----|---|---|------|------|------|------|------|------|------|------|
| TOM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | TOM7 | TOM6 | TOM5 | TOM4 | TOM3 | TOM2 | TOM1 | TOM0 |

| TOMn | Timer output of channel n |
|------|----------------------------|
| 0 | Timer output value is "0". |
| 1 | Timer output value is "1". |

Caution Be sure to clear bits 15 to 8 to 0.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.3.10 Timer output level register m (TOLm)

The TOLm register is a register that controls the timer output level of each channel.

The setting of the inverted output of channel n by this register is reflected at the timing of set or reset of the timer output signal while the timer output is enabled (TOEmn = 1) in the simultaneous channel operation function (TOMmn = 1). In the master channel output mode (TOMmn = 0), this register setting is invalid.

The TOLm register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the TOLm register can be set with an 8-bit memory manipulation instruction with TOLmL.

Reset signal generation clears this register to 0000H.

Figure 6-18. Format of Timer Output Level register m (TOLm)

Address: F01BCH, F01BDH (TOL0) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|-------|-------|-------|-------|-------|-------|-------|---|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TOLm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | TOLm7 | TOLm6 | TOLm5 | TOLm4 | TOLm3 | TOLm2 | TOLm1 | 0 |

| | |
|-------|--|
| TOLmn | Control of timer output level of channel n |
| 0 | Positive logic output (active-high) |
| 1 | Negative logic output (active-low) |

Caution Be sure to clear bits 15 to 8, and 0 to 0.

Remark 1. If the value of this register is rewritten during timer operation, the timer output logic is inverted when the timer output signal changes next, instead of immediately after the register value is rewritten.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.3.11 Timer output mode register m (TOMm)

The TOMm register is used to control the timer output mode of each channel.

When a channel is used for the independent channel operation function, set the corresponding bit of the channel to be used to 0.

When a channel is used for the simultaneous channel operation function (PWM output, one-shot pulse output, multiple PWM output, or two-channel input with one-shot pulse output), set the corresponding bit of the master channel to 0 and the corresponding bit of the slave channel to 1.

The setting of each channel n by this register is reflected at the timing when the timer output signal is set or reset while the timer output is enabled (TOEmn = 1).

The TOMm register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the TOMm register can be set with an 8-bit memory manipulation instruction with TOMmL.

Reset signal generation clears this register to 0000H.

Figure 6-19. Format of Timer Output Mode register m (TOMm)

Address: F01BEH, F01BFH (TOM0) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|-----------|-----------|-----------|-----------|-----------|-----------|-----------|---|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TOMm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | TOMm 7 | TOMm 6 | TOMm 5 | TOMm 4 | TOMm 3 | TOMm 2 | TOMm 1 | 0 |

| | |
|-------|--|
| TOMmn | Control of timer output mode of channel n |
| 0 | Master channel output mode (to produce toggle output by timer interrupt request signal (INTTMmn)) |
| 1 | Slave channel output mode (output is set by the timer interrupt request signal (INTTMmn) of the master channel, and reset by the timer interrupt request signal (INTTMmp) of the slave channel) |

Caution Be sure to clear bits 15 to 8, and 0 to 0.

Remark m: Unit number (m = 0)
 n: Channel number
 n = 0 to 7 (n = 0, 2, 4, 6 for master channel)
 p: Slave channel number
 n < p ≤ 7

(For details of the relation between the master channel and slave channel, refer to **6.4.1 Basic rules of simultaneous channel operation function.**)

6.3.12 Input switch control register (ISC)

The ISC register is used to implement UART0 baud rate correction by using channel 1 in association with the serial array unit.

When the ISC1 bit is set to 1, the input signal of the serial data input (RxD0) pin is selected as a timer input.

The ISC register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 6-20. Format of Input Switch Control Register (ISC)

Address: F0073H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|---|---|---|------|------|
| ISC | 0 | 0 | 0 | 0 | 0 | 0 | ISC1 | ISC0 |

| ISC1 | Switching channel 1 input of timer array unit |
|------|---|
| 0 | Uses the input signal of the TI01 pin as a timer input (normal operation). |
| 1 | Uses the input signal of the RxD0 pin as a timer input (detects the wakeup signal and measures the pulse width for baud rate correction). |

| ISC0 | Switching external interrupt (INTP0) input |
|------|---|
| 0 | Uses the input signal of the INTP0 pin as an external interrupt (normal operation). |
| 1 | Uses the input signal of the RxD0 pin as an external interrupt (wakeup signal detection). |

Caution Be sure to clear bits 7 to 2 to 0.

6.3.13 Noise filter enable registers 1 (NFEN1)

The NFEN1 register is used to set whether the noise filter can be used for the timer input signal to each channel.

Enable the noise filter by setting the corresponding bits to 1 on the pins in need of noise removal.

When the noise filter is enabled, after synchronization with the operation clock (f_{MCK}) for the target channel, whether the signal keeps the same value for two clock cycles is detected. When the noise filter is disabled, the input signal is only synchronized with the operation clock (f_{MCK}) for the target channel^{Note 1}.

The NFEN1 register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Note 1. For details, see **6.5.1(2) When valid edge of input signal via the TImn pin is selected (CCSmn = 1)**, **6.5.2 Start timing of counter**, and **6.7 Timer Input (TImn) Control**.

Figure 6-21. Format of Noise Filter Enable Registers 1 (NFEN1) (1/2)

Address: F0071H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---------|------------------|---|---------|---------|---------|---------|---------|
| NFEN1 | TNFEN07 | TNFEN06 | TNFEN05 | TNFEN04 | TNFEN03 | TNFEN02 | TNFEN01 | TNFEN00 |
| | TNFEN07 | | Enable/disable using noise filter of TI07 pin | | | | | |
| | 0 | Noise filter OFF | | | | | | |
| | 1 | Noise filter ON | | | | | | |
| | TNFEN06 | | Enable/disable using noise filter of TI06 pin | | | | | |
| | 0 | Noise filter OFF | | | | | | |
| | 1 | Noise filter ON | | | | | | |
| | TNFEN05 | | Enable/disable using noise filter of TI05 pin | | | | | |
| | 0 | Noise filter OFF | | | | | | |
| | 1 | Noise filter ON | | | | | | |
| | TNFEN04 | | Enable/disable using noise filter of TI04 pin | | | | | |
| | 0 | Noise filter OFF | | | | | | |
| | 1 | Noise filter ON | | | | | | |
| | TNFEN03 | | Enable/disable using noise filter of TI03 pin | | | | | |
| | 0 | Noise filter OFF | | | | | | |
| | 1 | Noise filter ON | | | | | | |

Remark The presence or absence of timer I/O pins of channel 0 to 7 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product**.

Figure 6-21. Format of Noise Filter Enable Registers 1 (NFEN1) (2/2)

Address: F0071H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---------|------------------|---|---------|---------|---------|---------|---------|
| NFEN1 | TNFEN07 | TNFEN06 | TNFEN05 | TNFEN04 | TNFEN03 | TNFEN02 | TNFEN01 | TNFEN00 |
| | TNFEN02 | | Enable/disable using noise filter of TI02 pin | | | | | |
| | 0 | Noise filter OFF | | | | | | |
| | 1 | Noise filter ON | | | | | | |
| | TNFEN01 | | Enable/disable using noise filter of TI01 pin ^{Note 1} | | | | | |
| | 0 | Noise filter OFF | | | | | | |
| | 1 | Noise filter ON | | | | | | |
| | TNFEN00 | | Enable/disable using noise filter of TI00 pin | | | | | |
| | 0 | Noise filter OFF | | | | | | |
| | 1 | Noise filter ON | | | | | | |

- Note 1. The applicable pin can be switched by setting the ISC1 bit of the ISC register.
 ISC1 = 0: Whether or not to use the noise filter of the TI01 pin can be selected.
 ISC1 = 1: Whether or not to use the noise filter of the RxD0 pin can be selected.

Remark The presence or absence of timer I/O pins of channel 0 to 7 depends on the product. See **Table 6-2 Timer I/O Pins provided in Each Product**.

6.3.14 Registers controlling port functions of pins to be used for timer I/O

Using port pins for the timer array unit functions requires setting of the registers that control the port functions multiplexed on the target pins (port mode register (PMxx), port register (Pxx), and port mode control register (PMCxx)). For details, see **4.3.1 Port mode registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12)**, **4.3.2 Port registers 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13)**, and **4.3.5 Port mode control registers 0, 2 (PMC0, PMC2)**.

The port mode register (PMxx), port register (Pxx), and port mode control register (PMCxx) to be set depend on the product. For details, see **4.5.3 Register setting examples for used port and alternate functions**.

When using the ports (such as P03/TO00) to be shared with the timer output pin for timer output, set the port mode control register (PMCxx) bit, port mode register (PMxx) bit and port register (Pxx) bit corresponding to each port to 0.

Example) When using P03/TO00 for timer output

Set the PMC03 bit of port mode control register 0 to 0.

Set the PM03 bit of port mode register 0 to 0.

Set the P03 bit of port register 0 to 0.

When using the ports (such as P04/TI01) to be shared with the timer input pin for timer input, set the port mode register (PMxx) bit corresponding to each port to 1. And set the port mode control register (PMCxx) bit corresponding to each port to 0. At this time, the port register (Pxx) bit may be 0 or 1.

Example) When using P04/TI01 for timer input

Set the PMC04 bit of port mode control register 0 to 0.

Set the PM04 bit of port mode register 0 to 1.

Set the P04 bit of port register 0 to 0 or 1.

6.4 Basic Rules of Timer Array Unit

6.4.1 Basic rules of simultaneous channel operation function

When simultaneously using multiple channels, namely, a combination of a master channel (a reference timer mainly counting the cycle) and slave channels (timers operating according to the master channel), the following rules apply.

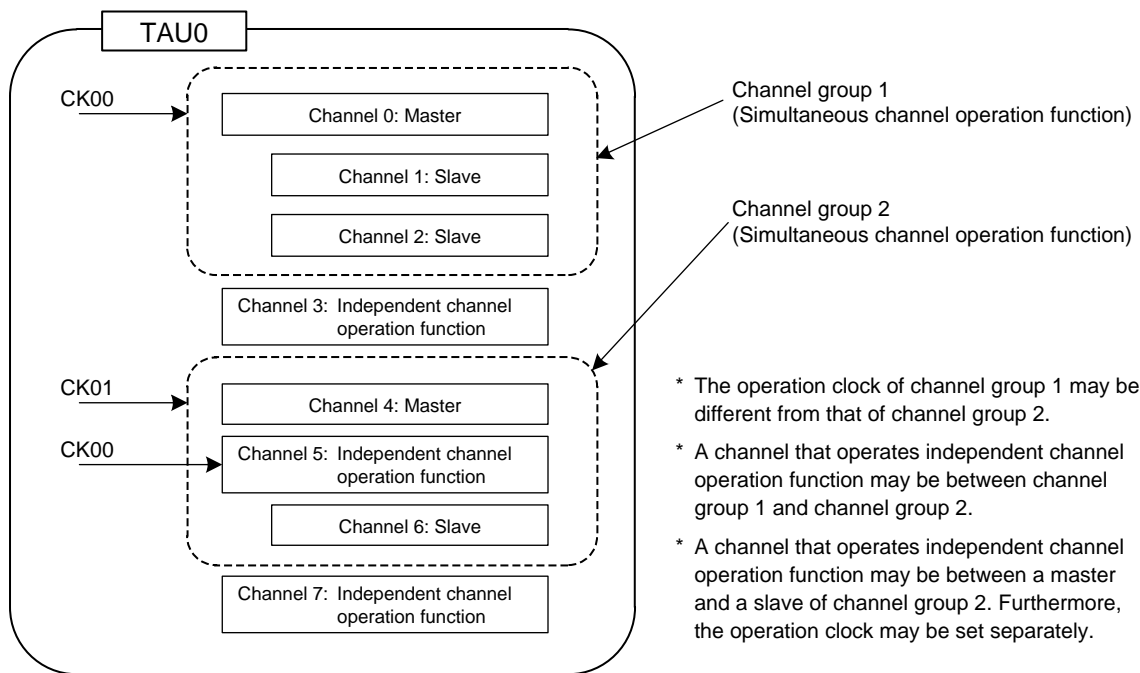
- (1) Only an even channel (channel 0, 2, 4, etc.) can be set as a master channel.
- (2) Any channel, except channel 0, can be set as a slave channel.
- (3) The slave channel must be lower than the master channel.
Example) If channel 2 is set as a master channel,
channel 3 or those that follow (channels 3, 4, 5, etc.) can be set as a slave channel.
- (4) Two or more slave channels can be set for one master channel.
- (5) When two or more master channels are to be used, slave channels with a master channel between them may not be set.
Example) If channels 0 and 4 are set as master channels,
channels 1 to 3 can be set as the slave channels of master channel 0.
channels 5 to 7 cannot be set as the slave channels of master channel 0.
- (6) The operation clock for a slave channel in combination with a master channel must be the same as that of the master channel. The CKSmn0, CKSmn1 bits (bit 15, 14 of timer mode register mn (TMRmn)) of the slave channel that operates in combination with the master channel must be the same value as that of the master channel.
- (7) A master channel can transmit INTTMmn (interrupt), start software trigger, and count clock to the lower channels.
- (8) A slave channel can use INTTMmn (interrupt), a start software trigger, or the count clock of the master channel as a source clock, but cannot transmit its own INTTMmn (interrupt), start software trigger, or count clock to channels to the lower channels.
- (9) A master channel cannot use INTTMmn (interrupt), a start software trigger, or the count clock from the other higher master channel as a source clock.
- (10) To simultaneously start channels that operate in combination, the channel start trigger bit (TSmn) of the channels in combination must be set at the same time.
- (11) During the counting operation, a TSmn bit of a master channel or TSmn bits of all channels which are operating simultaneously can be set. It cannot be applied to TSmn bits of slave channels alone.
- (12) To stop the channels in combination simultaneously, the channel stop trigger bit (TTmn) of the channels in combination must be set at the same time.
- (13) CKm2/CKm3 cannot be selected while channels are operating simultaneously, because the operation clocks of master channels and slave channels have to be synchronized.
- (14) Timer mode register m0 (TMRm0) has no master bit (it is fixed as "0"). However, as channel 0 is the highest channel, it can be used as a master channel during simultaneous operation.

The rules of the simultaneous channel operation function are applied in a channel group (a master channel and slave channels forming one simultaneous channel operation function).

If two or more channel groups that do not operate in combination are specified, the basic rules of the simultaneous channel operation function in 6.4.1 Basic rules of simultaneous channel operation function do not apply to the channel groups.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Example)



- * The operation clock of channel group 1 may be different from that of channel group 2.
- * A channel that operates independent channel operation function may be between channel group 1 and channel group 2.
- * A channel that operates independent channel operation function may be between a master and a slave of channel group 2. Furthermore, the operation clock may be set separately.

6.4.2 Basic rules of 8-bit timer operation function (channels 1 and 3 only)

The 8-bit timer operation function makes it possible to use a 16-bit timer channel in a configuration consisting of two 8-bit timer channels.

This function can only be used for channels 1 and 3, and there are several rules for using it.

The basic rules for this function are as follows:

- (1) The 8-bit timer operation function applies only to channels 1 and 3.
- (2) When using 8-bit timers, set the SPLIT_{mn} bit of timer mode register *mn* (TMR_{mn}) to 1.
- (3) The higher 8 bits can be operated as the interval timer function.
- (4) At the start of operation, the higher 8 bits output INTT_{m1H}/INTT_{m3H} (an interrupt) (which is the same operation performed when MD_{mn0} is set to 1).
- (5) The operation clock of the higher 8 bits is selected according to the CKS_{mn1} and CKS_{mn0} bits of the lower-bit TMR_{mn} register.
- (6) For the higher 8 bits, the TSH_{m1}/TSH_{m3} bit is manipulated to start channel operation and the TTH_{m1}/TTH_{m3} bit is manipulated to stop channel operation. The channel status can be checked using the TEH_{m1}/TEH_{m3} bit.
- (7) The lower 8 bits operate according to the TMR_{mn} register settings. The following three functions support operation of the lower 8 bits:
 - Interval timer function/Square Wave Output Function
 - External event counter function
 - Delay count function
- (8) For the lower 8 bits, the TSm₁/TSm₃ bit is manipulated to start channel operation and the TTm₁/TTm₃ bit is manipulated to stop channel operation. The channel status can be checked using the TEm₁/TEm₃ bit.
- (9) During 16-bit operation, manipulating the TSH_{m1}, TSH_{m3}, TTH_{m1}, and TTH_{m3} bits is invalid. The TSm₁/TSm₃ and TTm₁/TTm₃ bits are manipulated to operate channels 1 and 3. The TEH_{m3} and TEH_{m1} bits are not changed.
- (10) For the 8-bit timer function, the simultaneous operation functions (one-shot pulse, PWM, and multiple PWM) cannot be used.

Remark m: Unit number (m = 0), n: Channel number (n = 1, 3)

6.5 Operation of Counter

6.5.1 Count clock (f_{TCLK})

The count clock (f_{TCLK}) of the timer array unit can be selected between the following by CCSmn bit of timer mode register mn (TMRmn).

- Operation clock (f_{MCK}) specified by the CKSmn0 and CKSmn1 bits
- Valid edge of input signal input from the TImn pin

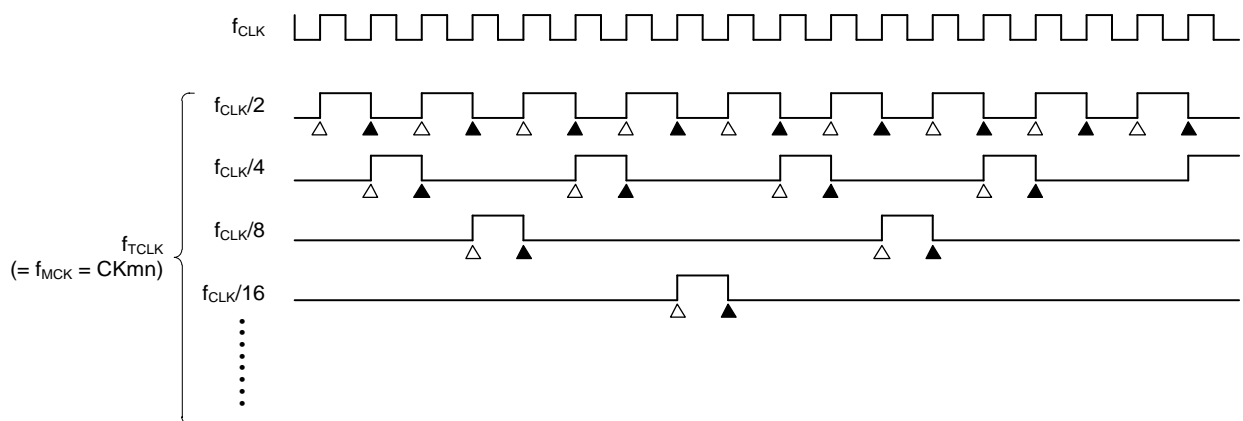
Because the timer array unit is designed to operate in synchronization with f_{CLK} , the timings of the count clock (f_{TCLK}) are shown below.

(1) When operation clock (f_{MCK}) specified by the CKSmn0 and CKSmn1 bits is selected (CCSmn = 0)

The count clock (f_{TCLK}) is between f_{CLK} to $f_{CLK}/2^{15}$ by setting of timer clock select register m (TPSm). When a divided f_{CLK} is selected, however, the clock selected in TPSmn register, but a signal which becomes high level for one period of f_{CLK} from its rising edge. When a f_{CLK} is selected, fixed to high level.

Counting of timer count register mn (TCRmn) delayed by one period of f_{CLK} from rising edge of the count clock, because of synchronization with f_{CLK} . But, this is described as “counting at rising edge of the count clock”, as a matter of convenience.

Figure 6-22. Timing of f_{CLK} and count clock (f_{TCLK}) (When CcSmn = 0)



- Remark 1.** \triangle : Rising edge of the count clock
 \blacktriangle : Synchronization, increment/decrement of counter

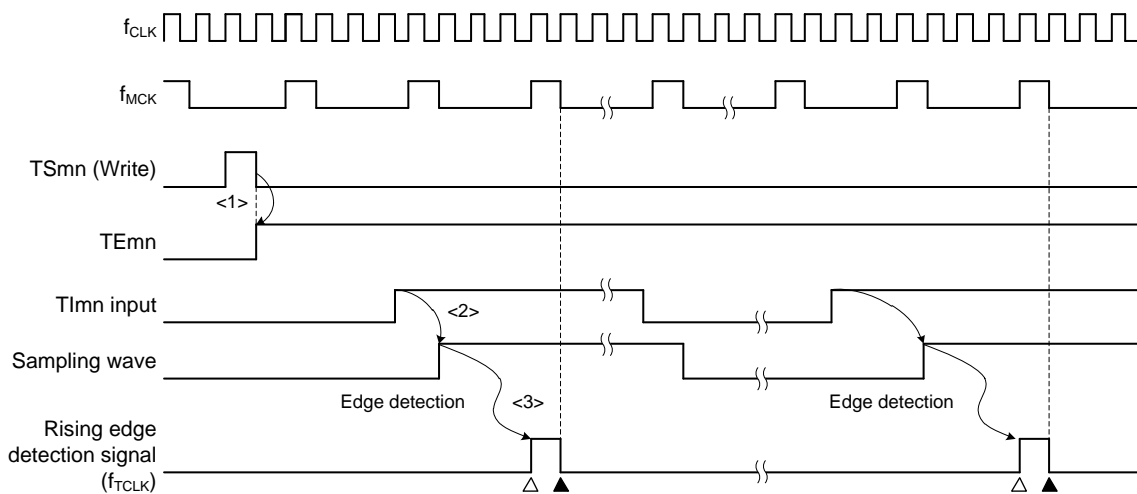
Remark 2. f_{CLK} : CPU/peripheral hardware clock

(2) When valid edge of input signal via the TImn pin is selected (CCSmn = 1)

The count clock (f_{TCLK}) becomes the signal that detects valid edge of input signal via the TImn pin and synchronizes next rising f_{MCK} . The count clock (f_{TCLK}) is delayed for 1 to 2 period of f_{MCK} from the input signal via the TImn pin (when a noise filter is used, the delay becomes 3 to 4 clock).

Counting of timer count register mn (TCRmn) delayed by one period of f_{CLK} from rising edge of the count clock, because of synchronization with f_{CLK} . But, this is described as “counting at valid edge of input signal via the TImn pin”, as a matter of convenience.

Figure 6-23. Timing of f_{CLK} and count clock (f_{TCLK}) (When CCSmn = 1, noise filter unused)



- <1> Setting TSmn bit to 1 enables the timer to be started and to become wait state for valid edge of input signal via the TImn pin.
- <2> The rise of input signal via the TImn pin is sampled by f_{MCK} .
- <3> The edge is detected by the rising of the sampled signal and the detection signal (count clock) is output.

Remark 1. △: Rising edge of the count clock
 ▲: Synchronization, increment/decrement of counter

Remark 2. f_{CLK} : CPU/peripheral hardware clock
 f_{MCK} : Operation clock of channel n

Remark 3. The waveform of the input signal via TImn pin of the input pulse interval measurement, the measurement of high/low width of input signal, the delay counter, and the one-shot pulse output are the same.

6.5.2 Start timing of counter

Timer count register mn (TCRmn) becomes enabled to operation by setting of TSmn bit of timer channel start register m (TSM).

Operations from count operation enabled state to timer count register mn (TCRmn) count start is shown in **Table 6-6**.

Table 6-6. Operations from Count Operation Enabled State to Timer count Register mn (TCRmn) Count Start

| Timer operation mode | Operation when TSmn = 1 is set |
|--------------------------|--|
| Interval timer mode | No operation is carried out from start trigger detection (TSmn=1) until count clock generation. The first count clock loads the value of the TDRmn register to the TCRmn register and the subsequent count clock performs count down operation (see 6.5.3(1) Operation of interval timer mode). |
| Event counter mode | Writing 1 to the TSmn bit loads the value of the TDRmn register to the TCRmn register. If detect edge of TImn input. The subsequent count clock performs count down operation (see 6.5.3(2) Operation of event counter mode). |
| Capture mode | No operation is carried out from start trigger detection (TSmn=1) until count clock generation. The first count clock loads 0000H to the TCRmn register and the subsequent count clock performs count up operation (see 6.5.3(3) Operation of capture mode (input pulse interval measurement)). |
| One-count mode | The waiting-for-start-trigger state is entered by writing 1 to the TSmn bit while the timer is stopped (TEmn = 0). No operation is carried out from start trigger detection until count clock generation. The first count clock loads the value of the TDRmn register to the TCRmn register and the subsequent count clock performs count down operation (see 6.5.3(4) One-count mode operation). |
| Capture & one-count mode | The waiting-for-start-trigger state is entered by writing 1 to the TSmn bit while the timer is stopped (TEmn = 0). No operation is carried out from start trigger detection until count clock generation. The first count clock loads 0000H to the TCRmn register and the subsequent count clock performs count up operation (see 6.5.3(5) Operation of capture & one-count mode (high-level width measurement)). |

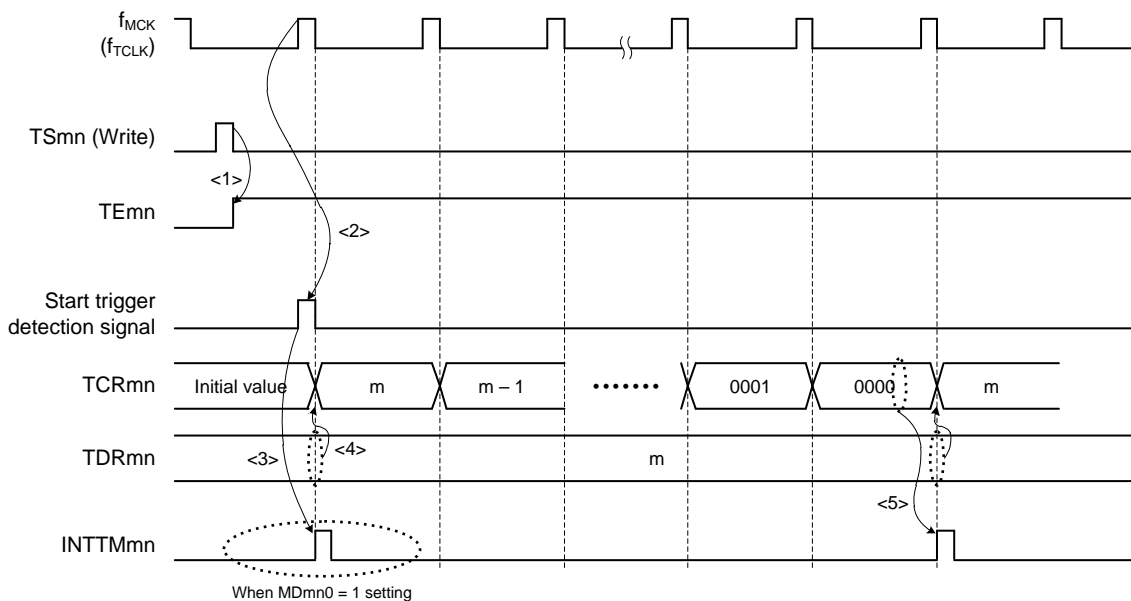
6.5.3 Operation of counter

Here, the counter operation in each mode is explained.

(1) Operation of interval timer mode

- <1> Operation is enabled ($TE_{mn} = 1$) by writing 1 to the TS_{mn} bit. Timer count register mn (TCR_{mn}) holds the initial value until count clock generation.
- <2> A start trigger is generated at the first count clock (f_{MCK}) after operation is enabled.
- <3> When the MD_{mn0} bit is set to 1, $INTTM_{mn}$ is generated by the start trigger.
- <4> By the first count clock after the operation enable, the value of timer data register mn (TDR_{mn}) is loaded to the TCR_{mn} register and counting starts in the interval timer mode.
- <5> When the TCR_{mn} register counts down and its count value is 0000H, $INTTM_{mn}$ is generated at the next count clock (f_{MCK}) and the value of timer data register mn (TDR_{mn}) is loaded to the TCR_{mn} register and counting keeps on.

Figure 6-24. Operation Timing (In Interval Timer Mode)



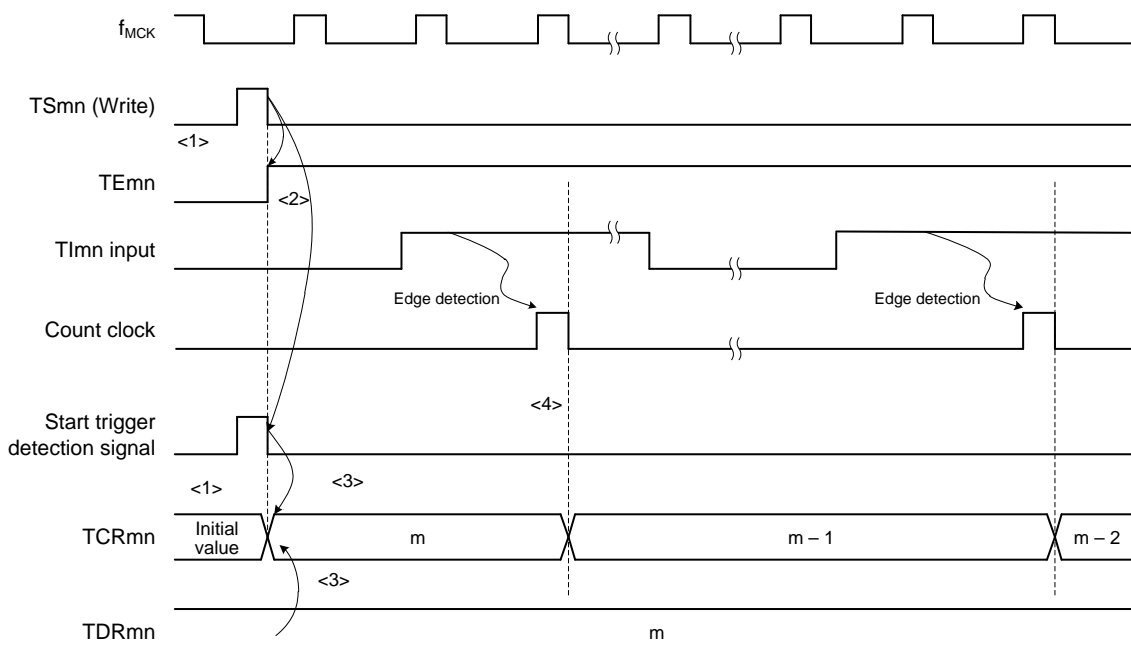
Caution In the first cycle operation of count clock after writing the TS_{mn} bit, an error at a maximum of one clock is generated since count start delays until count clock has been generated. When the information on count start timing is necessary, an interrupt can be generated at count start by setting $MD_{mn0} = 1$.

Remark f_{MCK} , the start trigger detection signal, and $INTTM_{mn}$ become active between one clock in synchronization with f_{CLK} .

(2) Operation of event counter mode

- <1> Timer count register mn (TCRmn) holds its initial value while operation is stopped (TEmn = 0).
- <2> Operation is enabled (TEmn = 1) by writing 1 to the TSmn bit.
- <3> As soon as 1 has been written to the TSmn bit and 1 has been set to the TEMn bit, the value of timer data register mn (TDRmn) is loaded to the TCRmn register to start counting.
- <4> After that, the TCRmn register value is counted down according to the count clock of the valid edge of the TImn input.

Figure 6-25. Operation Timing (In Event Counter Mode)

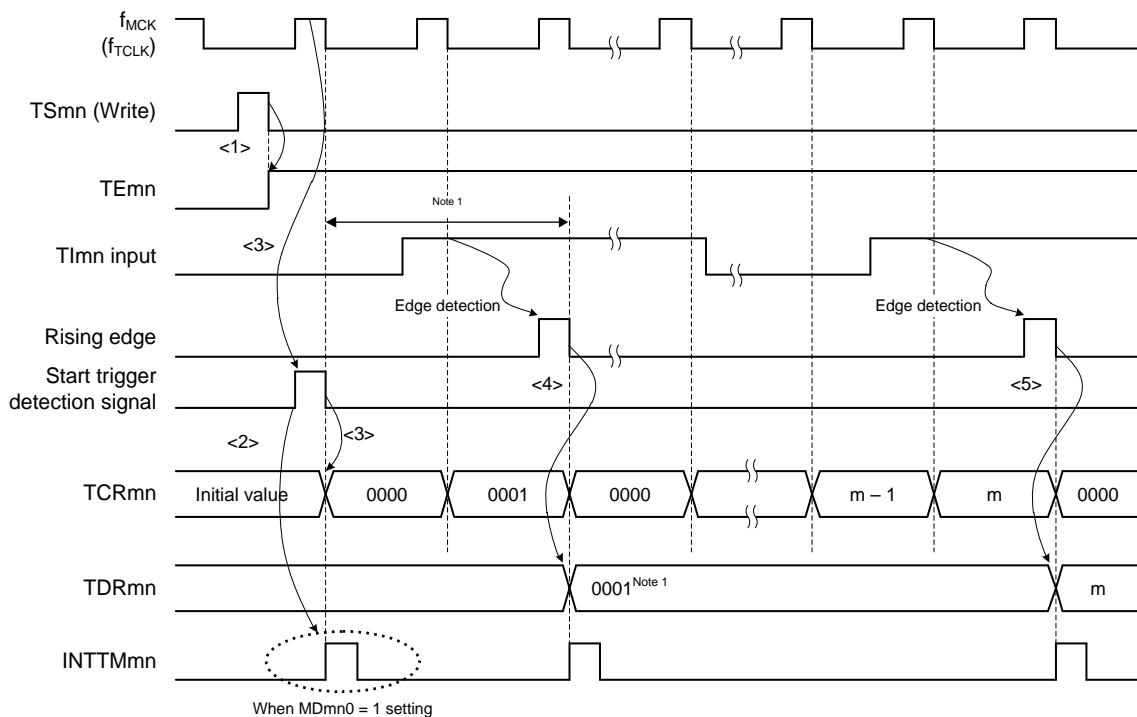


Remark Figure 6-25 shows the timing when the noise filter is not used. By making the noise filter on-state, the edge detection becomes 2 f_{MCK} cycles (it sums up to 3 to 4 cycles) later than the normal cycle of TImn input. The error per one period occurs because of the asynchronous relationship between the period of the TImn input and that of the count clock (f_{MCK}).

(3) Operation of capture mode (input pulse interval measurement)

- <1> Operation is enabled (TE_{mn} = 1) by writing 1 to the TS_{mn} bit.
- <2> Timer count register mn (TCR_{mn}) holds the initial value until count clock generation.
- <3> A start trigger is generated at the first count clock (f_{MCK}) after operation is enabled. And the value of 0000H is loaded to the TCR_{mn} register and counting starts in the capture mode (When the MD_{mn0} bit is set to 1, INTTM_{mn} is generated by the start trigger).
- <4> On detection of the valid edge of the TI_{mn} input, the value of the TCR_{mn} register is captured to timer data register mn (TDR_{mn}) and an INTTM_{mn} interrupt is generated. However, this capture value is nomenaing. The TCR_{mn} register keeps on counting from 0000H.
- <5> On next detection of the valid edge of the TI_{mn} input, the value of the TCR_{mn} register is captured to the TDR_{mn} register and an INTTM_{mn} interrupt is generated.

Figure 6-26. Operation Timing (In Capture Mode: Input Pulse Interval Measurement)



Note 1. If a clock has been input to TI_{mn} (the trigger exists) when capturing starts, counting starts when a trigger is detected, even if no edge is detected. Therefore, the first captured value (<4>) does not determine a pulse interval (in the above figure, 0001 just indicates two clock cycles but does not determine the pulse interval) and so the user can ignore it.

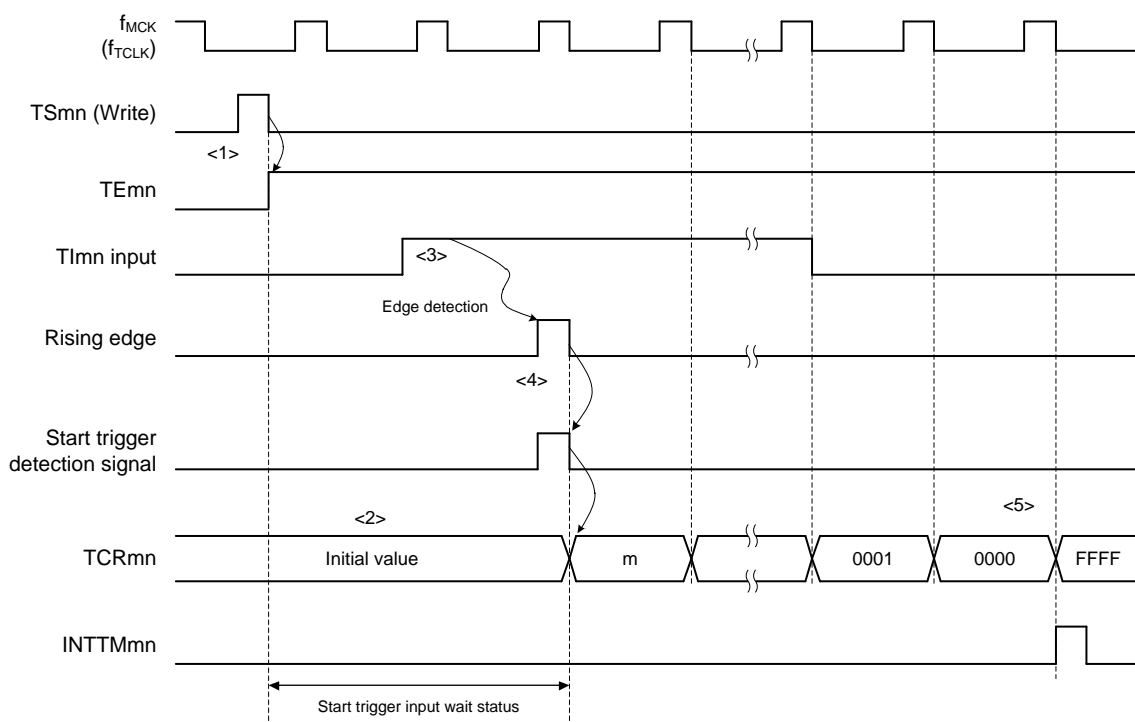
Caution In the first cycle operation of count clock after writing the TS_{mn} bit, an error at a maximum of one clock is generated since count start delays until count clock has been generated. When the information on count start timing is necessary, an interrupt can be generated at count start by setting MD_{mn0} = 1.

Remark Figure 6-26 shows the timing when the noise filter is not used. By making the noise filter on-state, the edge detection becomes $2 f_{MCK}$ cycles (it sums up to 3 to 4 cycles) later than the normal cycle of Tl_{mn} input. The error per one period occurs because of the asynchronous between the period of the Tl_{mn} input and that of the count clock (f_{MCK}).

(4) One-count mode operation

- <1> Operation is enabled ($TE_{mn} = 1$) by writing 1 to the TS_{mn} bit.
- <2> Timer count register mn (TCR_{mn}) holds the initial value until start trigger generation.
- <3> Rising edge of the Tl_{mn} input is detected.
- <4> On start trigger detection, the value of timer data register m (TDR_{mn}) is loaded to the TCR_{mn} register and count starts.
- <5> When the TCR_{mn} register counts down and its count value is 0000H, the interrupt request signal ($INTTM_{mn}$) is generated and the value of the TCR_{mn} register becomes FFFFH and counting stops.

Figure 6-27. Operation Timing (In One-count Mode)

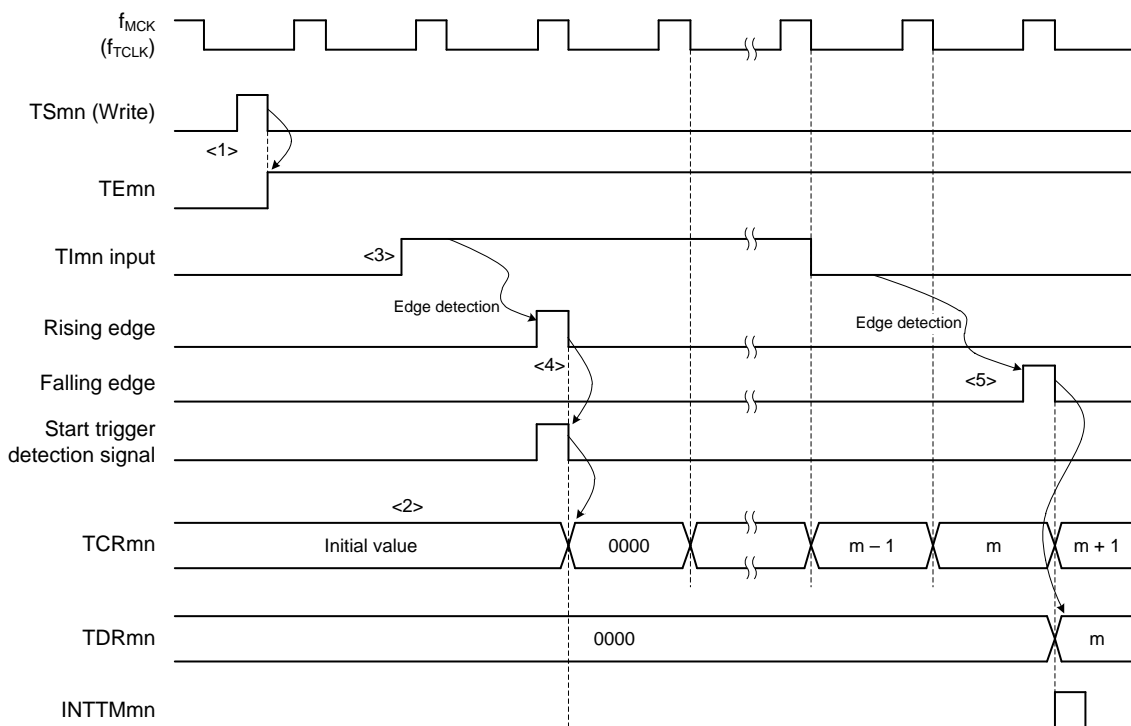


Remark Figure 6-27 shows the timing when the noise filter is not used. By making the noise filter on-state, the edge detection becomes $2 f_{MCK}$ cycles (it sums up to 3 to 4 cycles) later than the normal cycle of Tl_{mn} input. The error per one period occurs because of the asynchronous between the period of the Tl_{mn} input and that of the count clock (f_{MCK}).

(5) Operation of capture & one-count mode (high-level width measurement)

- <1> Operation is enabled ($TE_{mn} = 1$) by writing 1 to the TS_{mn} bit of timer channel start register m (TS_{mn}).
- <2> Timer count register mn (TCR_{mn}) holds the initial value until start trigger generation.
- <3> Rising edge of the TI_{mn} input is detected.
- <4> On start trigger detection, the value of 0000H is loaded to the TCR_{mn} register and count starts.
- <5> On detection of the falling edge of the TI_{mn} input, the value of the TCR_{mn} register is captured to timer data register mn (TDR_{mn}) and an $INTT_{mn}$ interrupt is generated.

Figure 6-28. Operation Timing (In Capture & One-count Mode: High-level Width Measurement)

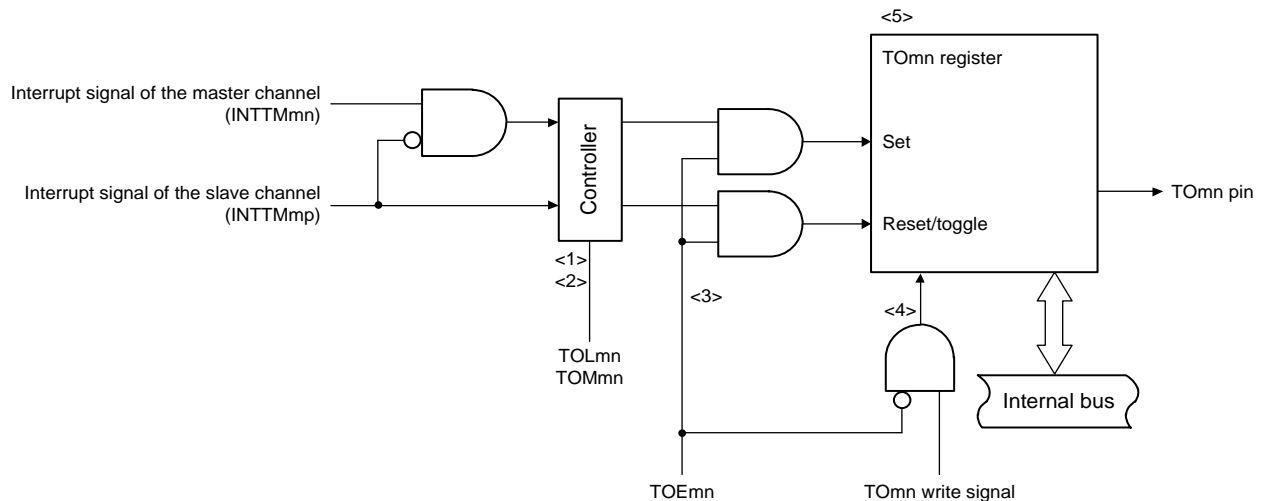


Remark Figure 6-28 shows the timing when the noise filter is not used. By making the noise filter on-state, the edge detection becomes $2 f_{MCK}$ cycles (it sums up to 3 to 4 cycles) later than the normal cycle of TI_{mn} input. The error per one period occurs because of the asynchronous relationship between the period of the TI_{mn} input and that of the count clock (f_{MCK}).

6.6 Channel Output (TOMn pin) Control

6.6.1 TOMn pin output circuit configuration

Figure 6-29. Output Circuit Configuration



The following describes the TOMn pin output circuit.

- <1> When TOMmn = 0 (master channel output mode), the set value of timer output level register m (TOLm) is ignored and only INTTMmp (slave channel timer interrupt) is transmitted to timer output register m (TOM).
- <2> When TOMmn = 1 (slave channel output mode), both INTTMmn (master channel timer interrupt) and INTTMmp (slave channel timer interrupt) are transmitted to the TOM register.
At this time, the TOLm register becomes valid and the signals are controlled as follows:
When TOLmn = 0: Positive logic output (INTTMmn → set, INTTMmp → reset)
When TOLmn = 1: Negative logic output (INTTMmn → reset, INTTMmp → set)

When INTTMmn and INTTMmp are simultaneously generated, (0% output of PWM), INTTMmp (reset signal) takes priority, and INTTMmn (set signal) is masked.

- <3> While timer output is enabled (TOEmn = 1), INTTMmn (master channel timer interrupt) and INTTMmp (slave channel timer interrupt) are transmitted to the TOM register. Writing to the TOM register (TOMn write signal) becomes invalid.
When TOEmn = 1, the TOMn pin output never changes with signals other than interrupt signals.
To initialize the TOMn pin output level, it is necessary to set timer operation is stopped (TOEmn = 0) and to write a value to the TOM register.
- <4> While timer output is disabled (TOEmn = 0), writing to the TOMn bit to the target channel (TOMn write signal) becomes valid. When timer output is disabled (TOEmn = 0), neither INTTMmn (master channel timer interrupt) nor INTTMmp (slave channel timer interrupt) is transmitted to the TOM register.

- <5> The TOM register can always be read, and the TOMn pin output level can be checked.

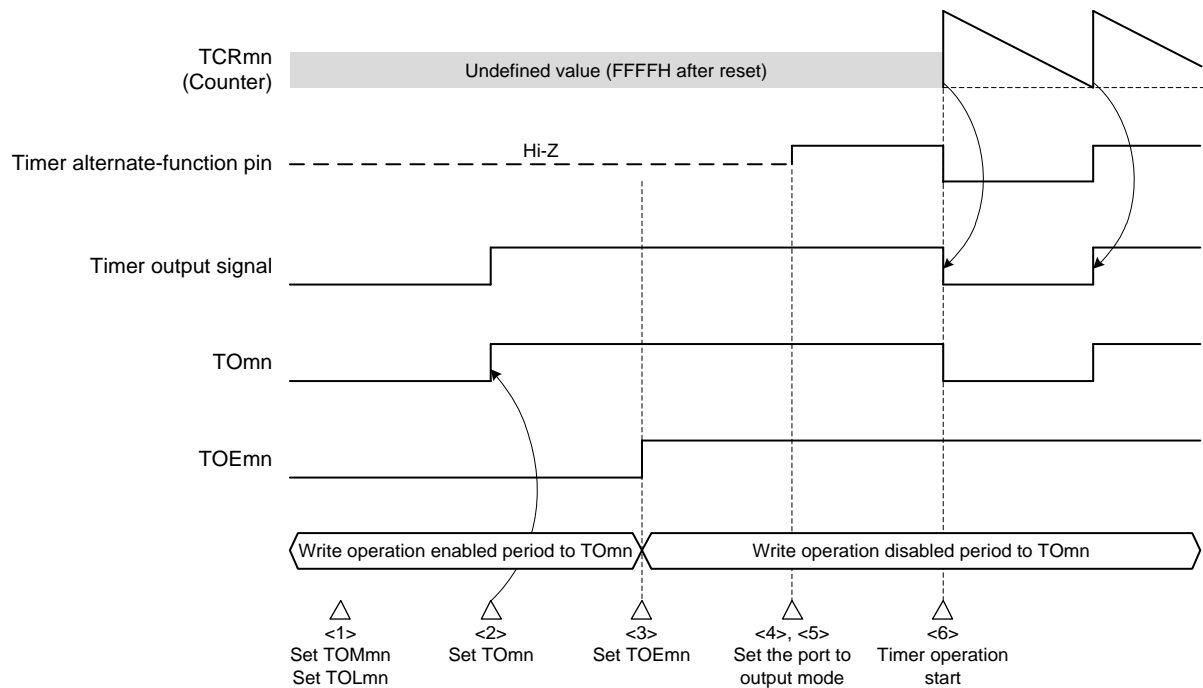
(Remark is listed on the next page.)

Remark m: Unit number ($m = 0$)
n: Channel number
n = 0 to 7 (n = 0, 2, 4, 6 for master channel)
p: Slave channel number
n < p ≤ 7

6.6.2 TOMn pin output setting

The following figure shows the procedure and status transition of the TOMn output pin from initial setting to timer operation start.

Figure 6-30. Status Transition from Timer Output Setting to Operation Start



- <1> The operation mode of timer output is set.
- TOMmn bit (0: Master channel output mode, 1: Slave channel output mode)
 - TOLmn bit (0: Positive logic output, 1: Negative logic output)
- <2> The timer output signal is set to the initial status by setting timer output register m (TOM).
- <3> The timer output operation is enabled by writing 1 to the TOEmn bit (writing to the TOM register is disabled).
- <4> The port is set to digital I/O by port mode control register (PMCxx) (see **6.3.14 Registers controlling port functions of pins to be used for timer I/O**).
- <5> The port I/O setting is set to output (see **6.3.14 Registers controlling port functions of pins to be used for timer I/O**).
- <6> The timer operation is enabled (TSmn = 1).

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.6.3 Cautions on channel output operation

(1) Changing values set in the registers T_{Om}, T_{OEm}, and T_{OLm} during timer operation

Since the timer operations (operations of timer count register mn (TCR mn) and timer data register mn (TDR mn)) are independent of the T_{Om} output circuit and changing the values set in timer output register m (T_{Om}), timer output enable register m (T_{OEm}), and timer output level register m (T_{OLm}) does not affect the timer operation, the values can be changed during timer operation. To output an expected waveform from the T_{Om} pin by timer operation, however, set the T_{Om}, T_{OEm}, T_{OLm}, and T_{OMm} registers to the values stated in the register setting example of each operation shown in **6.7 Timer Input (T_{Imn}) Control** and **6.8 Independent Channel Operation Function of Timer Array Unit**.

When the values set to the T_{OEm}, and T_{OLm} registers (but not the T_{Om} register) are changed close to the occurrence of the timer interrupt (INTT Mmn) of each channel, the waveform output to the T_{Om} pin might differ depending on whether the values are changed immediately before or immediately after the timer interrupt (INTT Mmn) occurs.

Remark m : Unit number ($m = 0$), n : Channel number ($n = 0$ to 7)

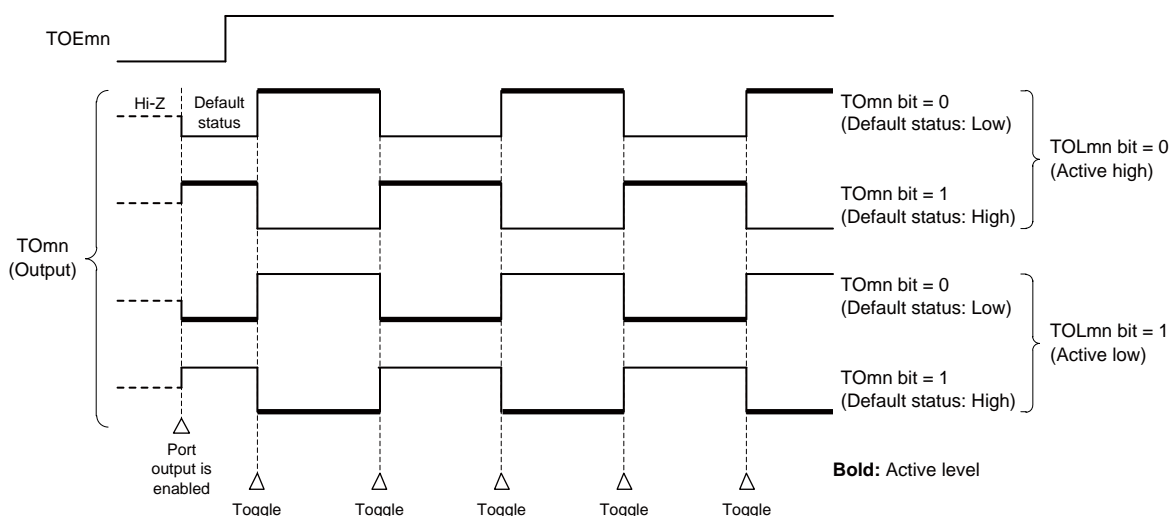
(2) Default level of TOmn pin and output level after timer operation start

The change in the output level of the TOmn pin when timer output register m (TOM) is written while timer output is disabled (TOEmn = 0), the initial level is changed, and then timer output is enabled (TOEmn = 1) before port output is enabled, is shown below.

(a) When operation starts with master channel output mode (TOMmn = 0) setting

The setting of timer output level register m (TOLm) is invalid when master channel output mode (TOMmn = 0). When the timer operation starts after setting the default level, the toggle signal is generated and the output level of the TOmn pin is reversed.

Figure 6-31. TOmn Pin Output Status at Toggle Output (TOMmn = 0)



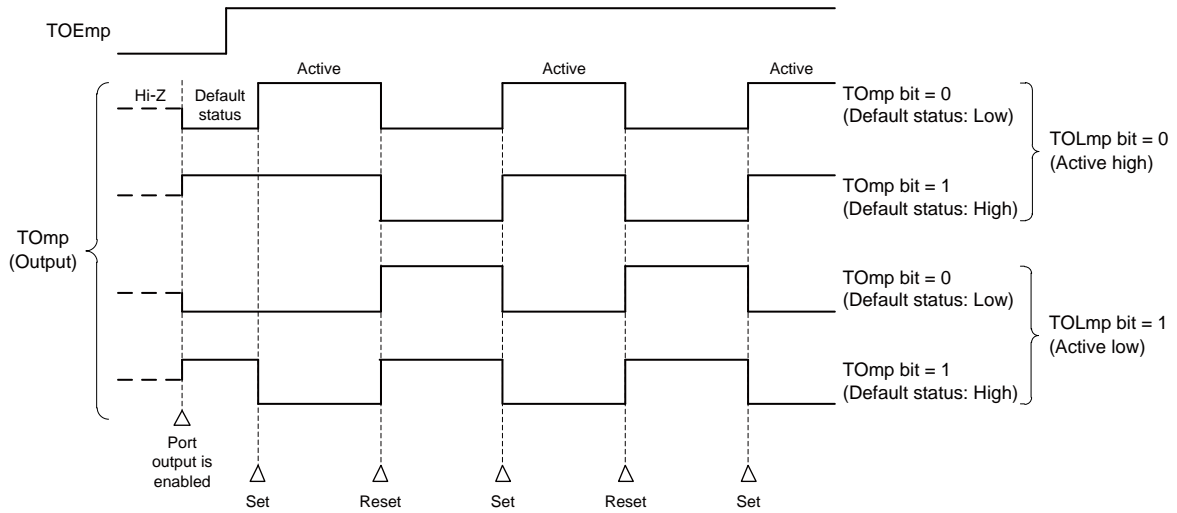
Remark 1. Toggle: Reverse TOmn pin output status

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

(b) When operation starts with slave channel output mode (TOMmp = 1) setting (PWM output)

When slave channel output mode (TOMmp = 1), the active level is determined by timer output level register m (TOLm) setting.

Figure 6-32. TOmp Pin Output Status at PWM Output (TOMmp = 1)



Remark 1. Set: The output signal of the TOmp pin changes from inactive level to active level.
 Reset: The output signal of the TOmp pin changes from active level to inactive level.

Remark 2. m: Unit number (m = 0), p: Channel number (p = 1 to 7)

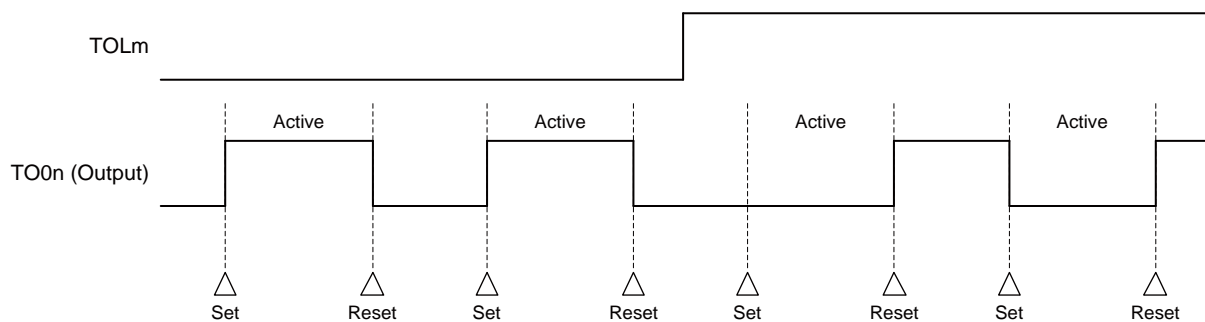
(3) Operation of TOMn pin in slave channel output mode (TOMmn = 1)

(a) When timer output level register m (TOLm) setting has been changed during timer operation

When the TOLm register setting has been changed during timer operation, the setting becomes valid at the generation timing of the TOMn pin change condition. Rewriting the TOLm register does not change the output level of the TOMn pin.

The operation when TOMmn is set to 1 and the value of the TOLm register is changed while the timer is operating (TEmn = 1) is shown below.

Figure 6-33. Operation when TOLm Register Has Been Changed Contents during Timer Operation



Remark 1. Set: The output signal of the TOMn pin changes from inactive level to active level.
 Reset: The output signal of the TOMn pin changes from active level to inactive level.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

(b) Set/reset timing

To realize 0%/100% output at PWM output, the TOMn pin/TOMn bit set timing at master channel timer interrupt (INTTMmn) generation is delayed by 1 count clock by the slave channel.

If the set condition and reset condition are generated at the same time, a higher priority is given to the latter.

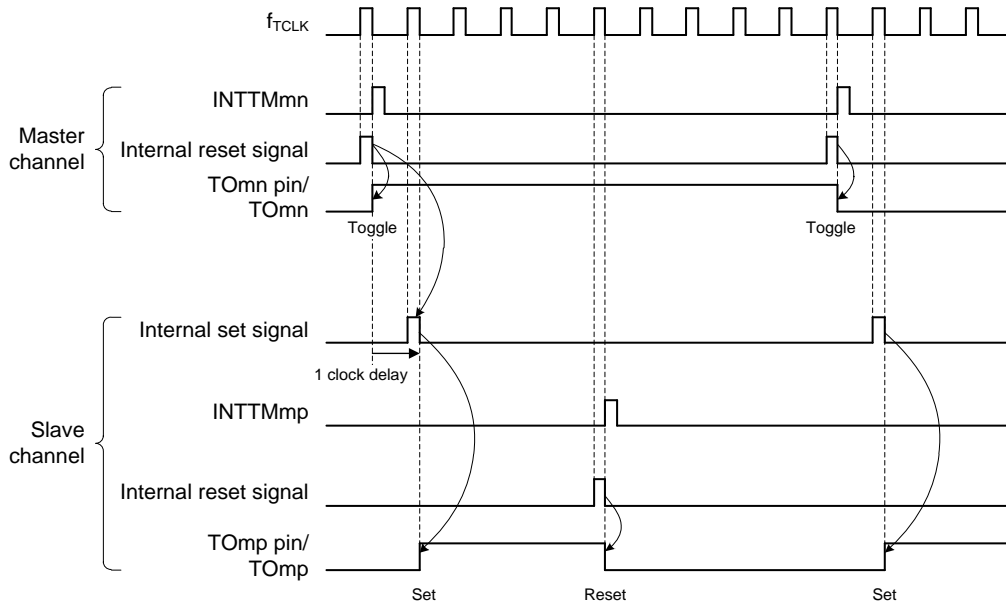
Figure 6-34 shows the set/reset operating status where the master/slave channels are set as follows.

Master channel: TOEmn = 1, TOMmn = 0, TOLmn = 0

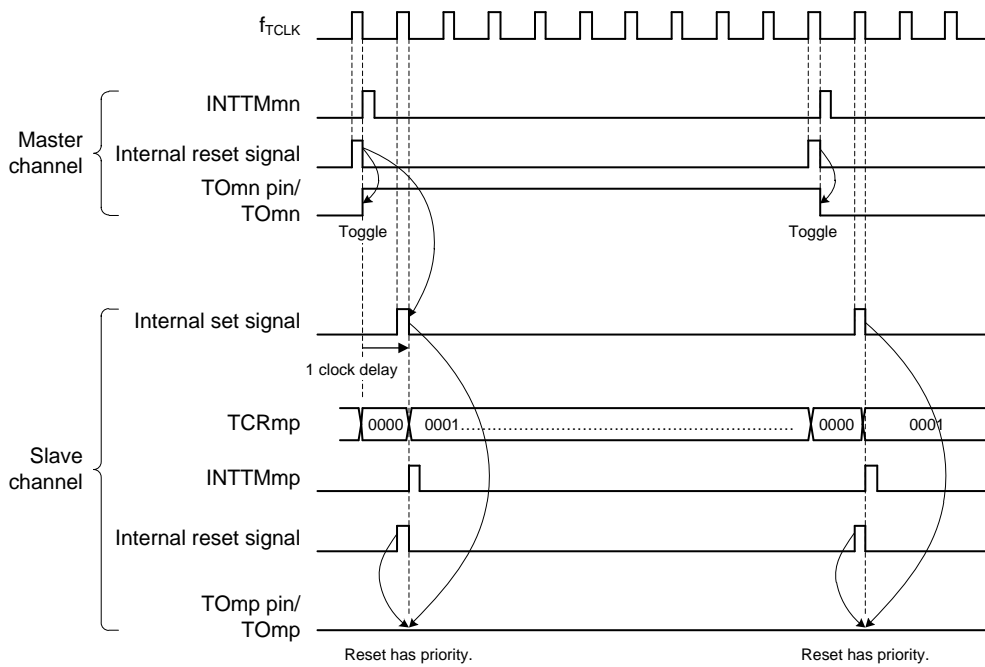
Slave channel: TOEmp = 1, TOMmp = 1, TOLmp = 0

Figure 6-34. Set/Reset Timing Operating Status

(1) Basic operation timing



(2) Operation timing when 0% duty



(Remarks are listed on the next page.)

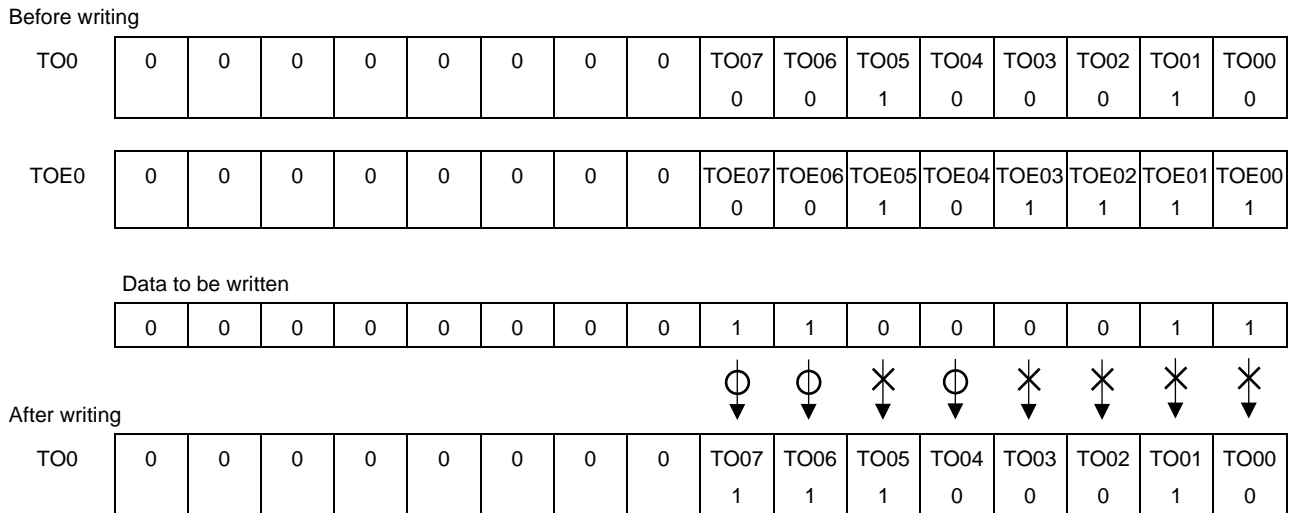
Remark 1. Internal reset signal: TOMn pin reset/toggle signal
Internal set signal: TOMn pin set signal

Remark 2. m: Unit number (m = 0)
n: Channel number
n = 0 to 7 (n = 0, 2, 4, 6 for master channel)
p: Slave channel number
n < p ≤ 7

6.6.4 Collective manipulation of TOMn bit

In timer output register m (TOM), the setting bits (TOMn) for all the channels are located in one register in the same way as timer channel start register m (TSM). Therefore, the TOMn bit of all the channels can be manipulated collectively. Only the desired bits can also be manipulated by enabling writing only to the TOMn bits (TOEmn = 0) that correspond to the relevant bits of the channel used to perform output (TOMn).

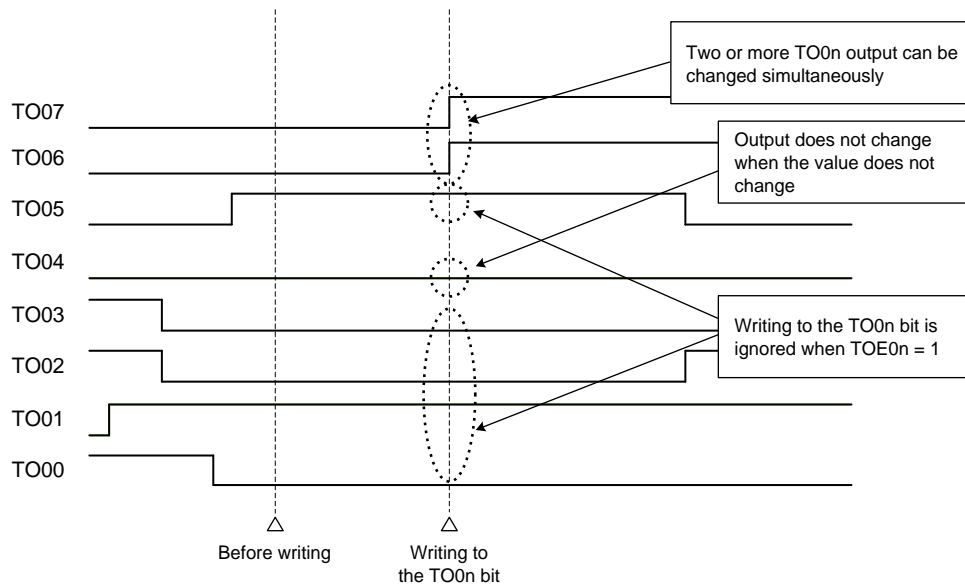
Figure 6-35. Example of TO0n Bit Collective Manipulation



Writing is done only to the TOMn bit with TOEmn = 0, and writing to the TOMn bit with TOEmn = 1 is ignored.

TOMn (channel output) to which TOEmn = 1 is set is not affected by the write operation. Even if the write operation is done to the TOMn bit, it is ignored and the output change by timer operation is normally done.

Figure 6-36. TO0n Pin Status by Collective Manipulation of TO0n Bit



Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.6.5 Timer interrupt and TOMn pin output at count operation start

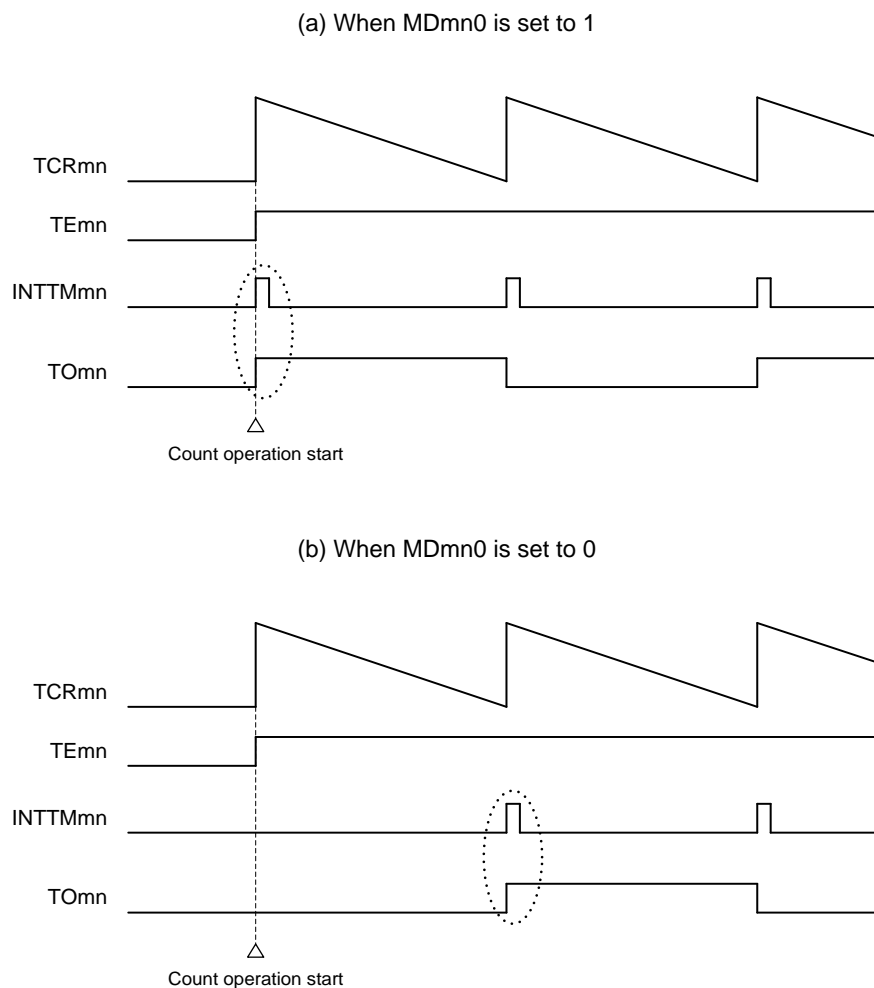
In the interval timer mode or capture mode, the MDmn0 bit in timer mode register mn (TMRmn) sets whether or not to generate a timer interrupt at count start.

When MDmn0 is set to 1, the count operation start timing can be known by the timer interrupt (INTTMmn) generation.

In the other operation modes, neither timer interrupt at count operation start nor TOMn output is controlled.

Figure 6-37 shows operation examples when the interval timer mode (TOEmn = 1, TOMmn = 0) is set.

Figure 6-37. Operation examples of timer interrupt at count operation start and TOMn output



When MDmn0 is set to 1, a timer interrupt (INTTMmn) is output at count operation start, and TOMn performs a toggle operation.

When MDmn0 is set to 0, a timer interrupt (INTTMmn) is not output at count operation start, and TOMn does not change either. After counting one cycle, INTTMmn is output and TOMn performs a toggle operation.

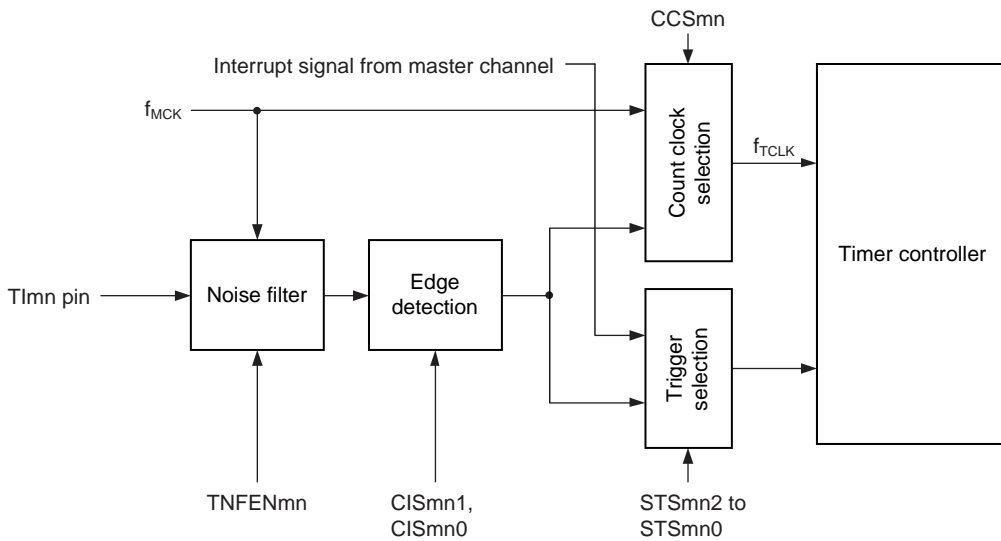
Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.7 Timer Input (TImn) Control

6.7.1 TImn input circuit configuration

A signal is input from a timer input pin, goes through a noise filter and an edge detector, and is sent to a timer controller. Enable the noise filter for the pin in need of noise removal. The following shows the configuration of the input circuit.

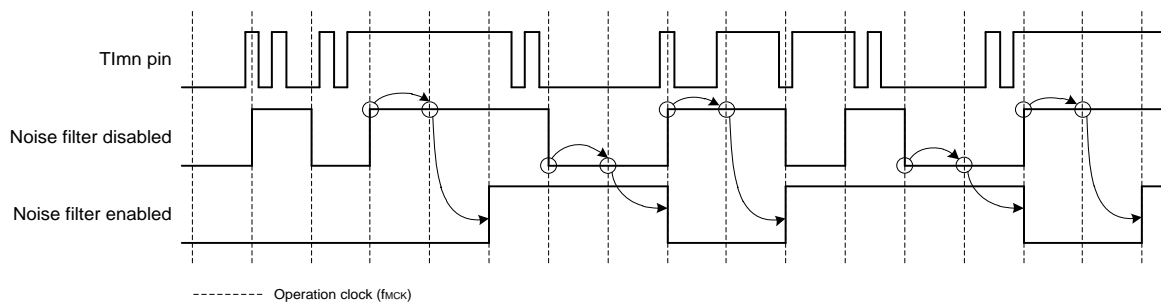
Figure 6-38. Input Circuit Configuration



6.7.2 Noise filter

When the noise filter is disabled, the input signal is only synchronized with the operation clock (f_{MCK}) for channel n. When the noise filter is enabled, after synchronization with the operation clock (f_{MCK}) for channel n, whether the signal keeps the same value for two clock cycles is detected. The following shows differences in waveforms output from the noise filter between when the noise filter is enabled and disabled.

Figure 6-39. Sampling Waveforms through TImn Input Pin with Noise Filter Enabled and Disabled



6.7.3 Cautions on channel input operation

When a timer input pin is set as unused, the operation clock is not supplied to the noise filter. Therefore, after settings are made to use the timer input pin, the following wait time is necessary before a trigger is specified to enable operation of the channel corresponding to the timer input pin.

1) Noise filter is disabled

When bits 12 (CCSmn), 9 (STSmn1), and 8 (STSmn0) in the timer mode register mn (TMRmn) are 0 and then one of them is set to 1, wait for at least two cycles of the operation clock (f_{MCK}), and then set the operation enable trigger bit in the timer channel start register (TSm).

2) Noise filter is enabled

When bits 12 (CCSmn), 9 (STSmn1), and 8 (STSmn0) in the timer mode register mn (TMRmn) are all 0 and then one of them is set to 1, wait for at least four cycles of the operation clock (f_{MCK}), and then set the operation enable trigger bit in the timer channel start register (TSm).

6.8 Independent Channel Operation Function of Timer Array Unit

6.8.1 Operation as interval timer/square wave output

(1) Interval timer

The timer array unit can be used as a reference timer that generates INTTMmn (timer interrupt) at fixed intervals.

The interrupt generation period can be calculated by the following expression.

$$\text{Generation period of INTTMmn (timer interrupt)} = \text{Period of count clock} \times (\text{Set value of TDRmn} + 1)$$

(2) Operation as square wave output

TOmn performs a toggle operation as soon as INTTMmn has been generated, and outputs a square wave with a duty factor of 50%.

The period and frequency for outputting a square wave from TOmn can be calculated by the following expressions.

$$\text{Period of square wave output from TOmn} = \text{Period of count clock} \times (\text{Set value of TDRmn} + 1) \times 2$$

$$\text{Frequency of square wave output from TOmn} = \text{Frequency of count clock} / \{(\text{Set value of TDRmn} + 1) \times 2\}$$

Timer count register mn (TCRmn) operates as a down counter in the interval timer mode.

The TCRmn register loads the value of timer data register mn (TDRmn) at the first count clock after the channel start trigger bit (TSmn, TSHm1, TSHm3) of timer channel start register m (TSm) is set to 1. If the MDmn0 bit of timer mode register mn (TMRmn) is 0 at this time, INTTMmn is not output and TOmn is not toggled. If the MDmn0 bit of the TMRmn register is 1, INTTMmn is output and TOmn is toggled.

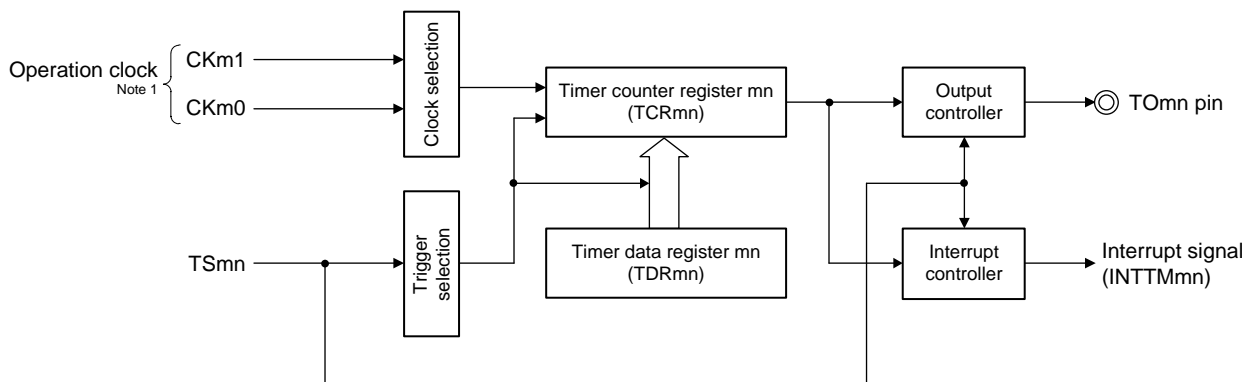
After that, the TCRmn register count down in synchronization with the count clock.

When TCRmn = 0000H, INTTMmn is output and TOmn is toggled at the next count clock. At the same time, the TCRmn register loads the value of the TDRmn register again. After that, the same operation is repeated.

The TDRmn register can be rewritten at any time. The new value of the TDRmn register becomes valid from the next period.

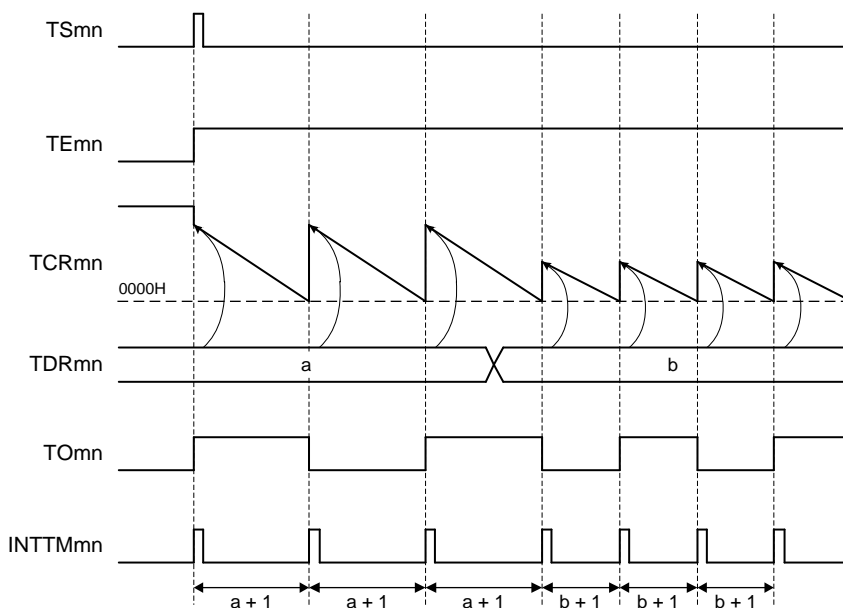
Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-40. Block Diagram of Operation as Interval Timer/Square Wave Output



Note 1. When channels 1 and 3, the clock can be selected from CKm0, CKm1, CKm2 and CKm3.

Figure 6-41. Example of Basic Timing of Operation as Interval Timer/Square Wave Output (MDmn0 = 1)



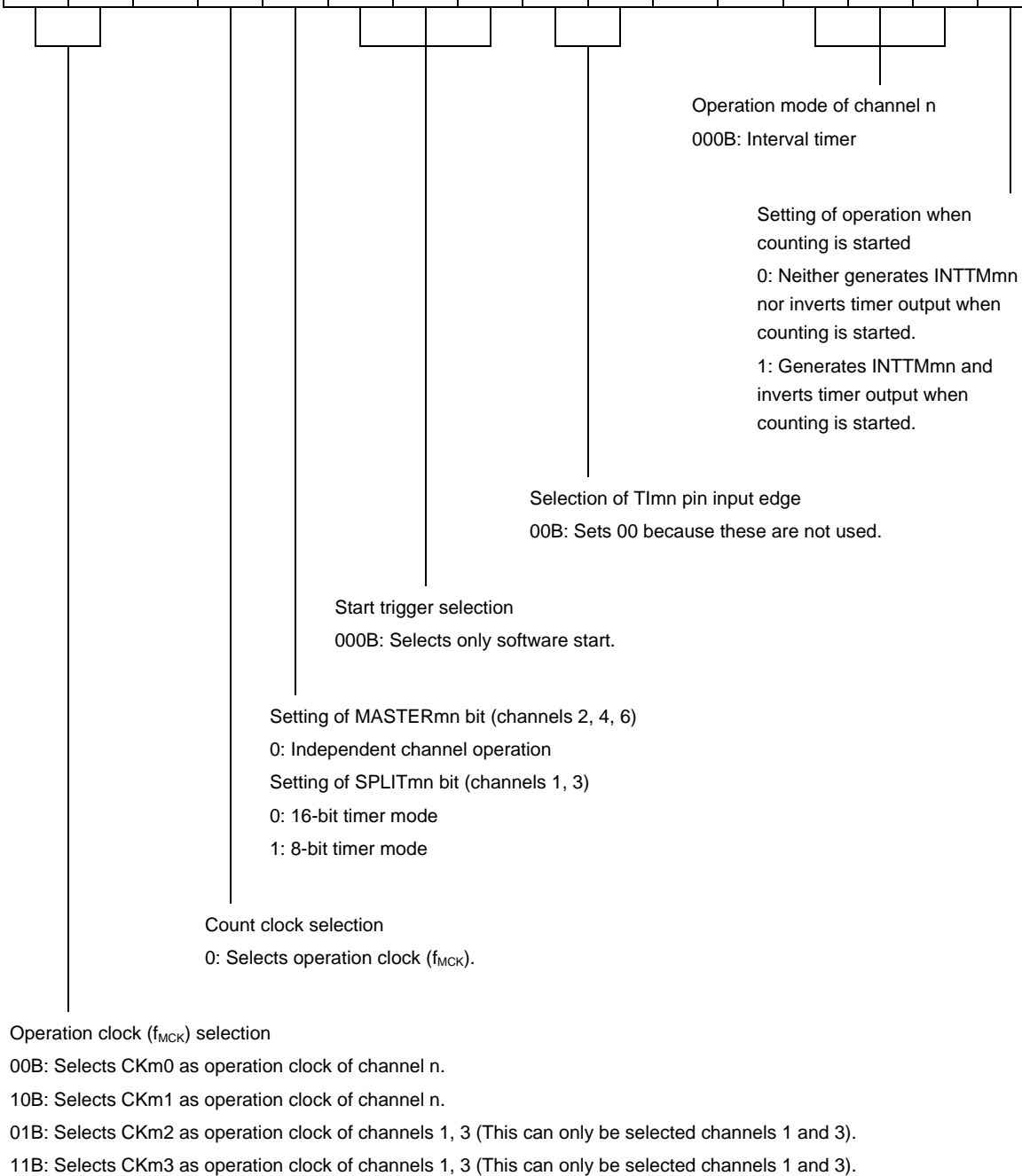
Remark 1. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Remark 2. TSmn: Bit n of timer channel start register m (TSm)
 TEMn: Bit n of timer channel enable status register m (TEm)
 TCRmn: Timer count register mn (TCRmn)
 TDRmn: Timer data register mn (TDRmn)
 TOMn: TOMn pin output signal

Figure 6-42. Example of Set Contents of Registers During Operation as Interval Timer/Square Wave Output (1/2)

(a) Timer mode register mn (TMRmn)

| | | | | | | | | | | | | | | | | |
|-------|------------|------------|----|-----------|---------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn | CKSm n1 | CKSm n0 | | CCSm n | M/S Note 1 | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | | | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |
| | 1/0 | 1/0 | 0 | 0 | 0/1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1/0 |



Note 1. TMRm2, TMRm4, TMRm6: MASTERmn bit
 TMRm1, TMRm3: SPLITmn bit
 TMRm0, TMRm5, TMRm7: Fixed to 0

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-42. Example of Set Contents of Registers During Operation as Interval Timer/Square Wave Output (2/2)

(b) Timer output register m (TOM)

| | | |
|-----|-------------|--|
| | Bit n | |
| TOM | TOMn 1/0 | 0: Outputs 0 from TOMn. 1: Outputs 1 from TOMn. |

(c) Timer output enable register m (TOEm)

| | | |
|------|------------------|--|
| | Bit n | |
| TOEm | TOEm n 1/0 | 0: Stops the TOMn output operation by counting operation. 1: Enables the TOMn output operation by counting operation. |

(d) Timer output level register m (TOLm)

| | | |
|------|------------|--|
| | Bit n | |
| TOLm | TOLmn 0 | 0: Cleared to 0 when TOMmn = 0 (master channel output mode). |

(e) Timer output mode register m (TOMm)

| | | |
|------|----------------|-------------------------------------|
| | Bit n | |
| TOMm | TOMm n 0 | 0: Sets master channel output mode. |

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-43. Operation Procedure of Interval Timer/Square Wave Output Function (1/2)

| | Software Operation | Hardware Status |
|-------------------------|--|---|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to each register is disabled.) |
| | Sets the TAUmEN bit of peripheral enable register 0 (PER0) to 1. | Power-on status. Each channel stops operating. (Clock supply is started and writing to each register is enabled.) |
| | Sets timer clock select register m (TPSm). Determines clock frequencies of CKm0 to CKm3. | |
| Channel default setting | Sets timer mode register mn (TMRmn) (determines operation mode of channel). Sets interval (period) value to timer data register mn (TDRmn). | Channel stops operating. (Clock is supplied and some power is consumed.) |
| | To use the TOMn output Clears the TOMmn bit of timer output mode register m (TOMm) to 0 (master channel output mode). Clears the TOLmn bit to 0. Sets the TOMn bit and determines default level of the TOMn output. | The TOMn pin goes into Hi-Z output state. The TOMn default setting level is output when the port mode register is in the output mode and the port register is 0. |
| | Sets the TOEmn bit to 1 and enables operation of TOMn. Clears the port register and port mode register to 0. | TOMn does not change because channel stops operating. |
| | | The TOMn pin outputs the TOMn set level. |
| Operation start | (Sets the TOEmn bit to 1 only if using TOMn output and resuming operation.) Sets the TSmn (TSHm1, TSHm3) bit to 1. The TSmn (TSHm1, TSHm3) bit automatically returns to 0 because it is a trigger bit. | TEmn (TEHm1, TEHm3) = 1, and count operation starts. Value of the TDRmn register is loaded to timer count register mn (TCRmn). INTTMmn is generated and TOMn performs toggle operation if the MDmn0 bit of the TMRmn register is 1. |
| | | |
| During operation | Set values of the TMRmn register, TOMmn, and TOLmn bits cannot be changed. Set value of the TDRmn register can be changed. The TCRmn register can always be read. The TSRmn register is not used. Set values of the TOM and TOEm registers can be changed. | Counter (TCRmn) counts down. When count value reaches 0000H, the value of the TDRmn register is loaded to the TCRmn register again and the count operation is continued. By detecting TCRmn = 0000H, INTTMmn is generated and TOMn performs toggle operation. After that, the above operation is repeated. |
| Operation stop | The TTmn (TTHm1, TTHm3) bit is set to 1. The TTmn (TTHm1, TTHm3) bit automatically returns to 0 because it is a trigger bit. | TEmn (TEHm1, TEHm3), and count operation stops. The TCRmn register holds count value and stops. The TOMn output is not initialized but holds current status. |
| | The TOEmn bit is cleared to 0 and value is set to the TOMn bit. | The TOMn pin outputs the TOMn bit set level. |

Operation is resumed.

(Remark is listed on the next page.)

Figure 6-43. Operation Procedure of Interval Timer/Square Wave Output Function (2/2)

| | Software Operation | Hardware Status |
|----------|--|---|
| TAU stop | To hold the TOMn pin output level Clears the TOMn bit to 0 after the value to be held is set to the port register. —————> | The TOMn pin output level is held by port function. |
| | When holding the TOMn pin output level is not necessary Setting not required. | |
| | The TAUmEN bit of the PER0 register is cleared to 0. —————> | Power-off status All circuits are initialized and SFR of each channel is also initialized. (The TOMn bit is cleared to 0 and the TOMn pin is set to port mode.) |

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.8.2 Operation as external event counter

The timer array unit can be used as an external event counter that counts the number of times the valid input edge (external event) is detected in the TImn pin. When a specified count value is reached, the event counter generates an interrupt. The specified number of counts can be calculated by the following expression.

$$\text{Specified number of counts} = \text{Set value of TDRmn} + 1$$

Timer count register mn (TCRmn) operates as a down counter in the event counter mode.

The TCRmn register loads the value of timer data register mn (TDRmn) by setting any channel start trigger bit (TSmn) of timer channel start register m (TSM) to 1.

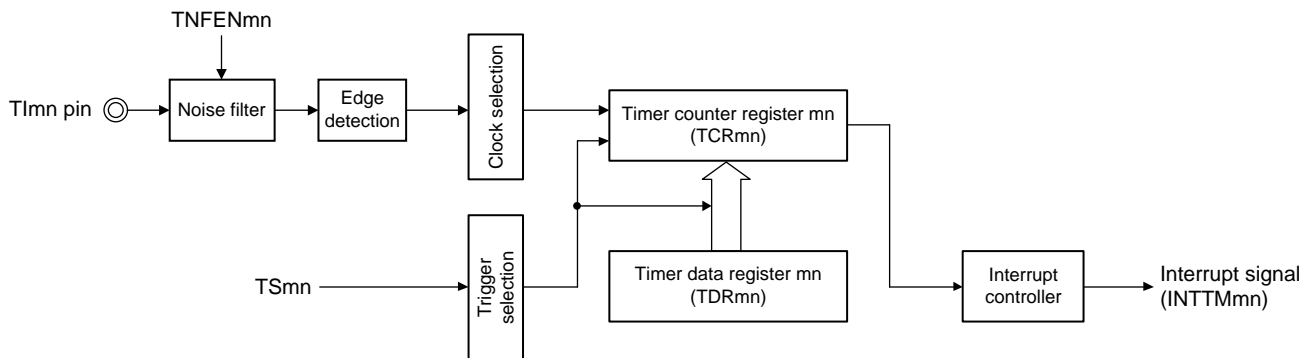
The TCRmn register counts down each time the valid input edge of the TImn pin has been detected. When TCRmn = 0000H, the TCRmn register loads the value of the TDRmn register again, and outputs INTTMmn.

After that, the above operation is repeated.

An irregular waveform that depends on external events is output from the TOmn pin. Stop the output by setting the TOEmn bit of timer output enable register m (TOEm) to 0.

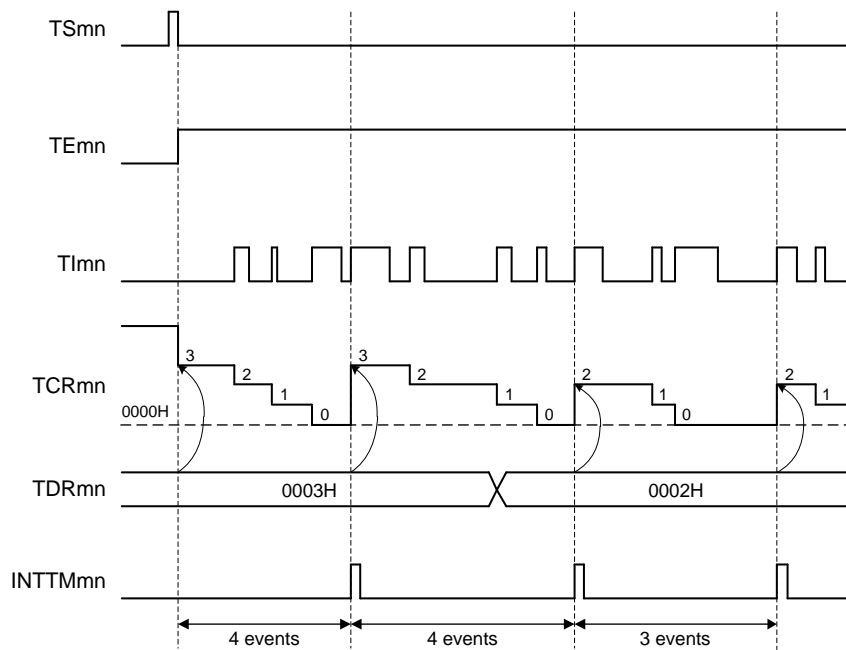
The TDRmn register can be rewritten at any time. The new value of the TDRmn register becomes valid during the next count period.

Figure 6-44. Block Diagram of Operation as External Event Counter



Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-45. Example of Basic Timing of Operation as External Event Counter



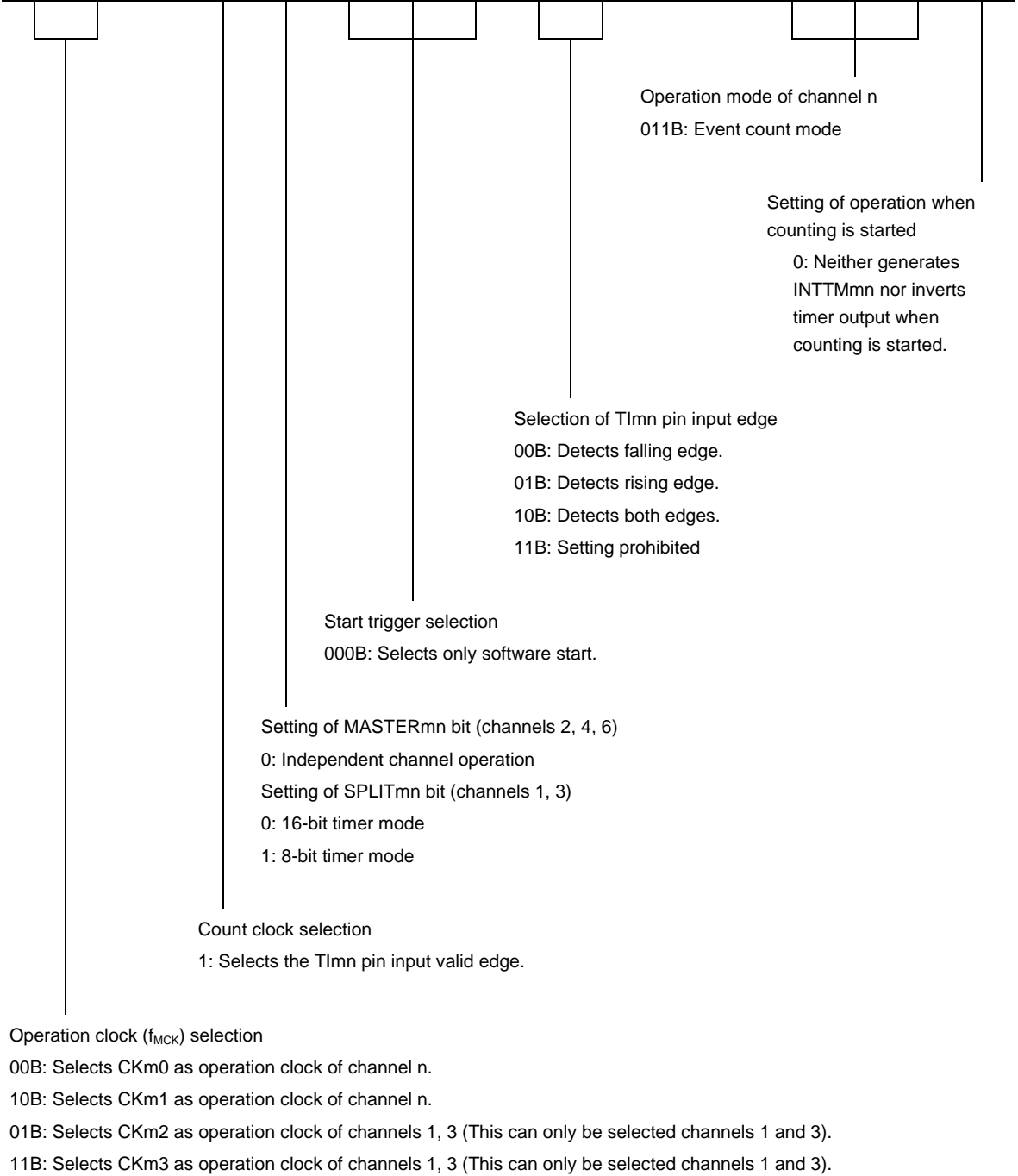
Remark 1. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Remark 2. TSmn: Bit n of timer channel start register m (TSM)
 TE mn: Bit n of timer channel enable status register m (TEM)
 TImn: TImn pin input signal
 TCRmn: Timer count register mn (TCRmn)
 TDRmn: Timer data register mn (TDRmn)

Figure 6-46. Example of Set Contents of Registers in External Event Counter Mode (1/2)

(a) Timer mode register mn (TMRmn)

| | | | | | | | | | | | | | | | | |
|-------|------------|------------|----|-----------|---------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn | CKSm n1 | CKSm n0 | | CCSm n | M/S Note 1 | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | | | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |
| | 1/0 | 1/0 | 0 | 1 | 0/1 | 0 | 0 | 0 | 1/0 | 1/0 | 0 | 0 | 0 | 1 | 1 | 0 |

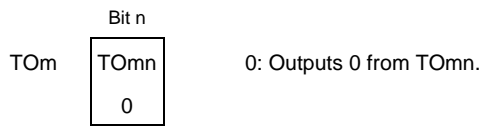


Note 1. TMRm2, TMRm4, TMRm6: MASTERmn bit
TMRm1, TMRm3: SPLITmn bit
TMRm0, TMRm5, TMRm7: Fixed to 0

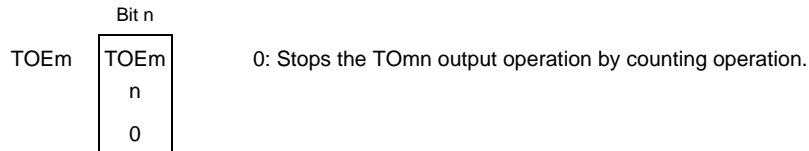
Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-46. Example of Set Contents of Registers in External Event Counter Mode (2/2)

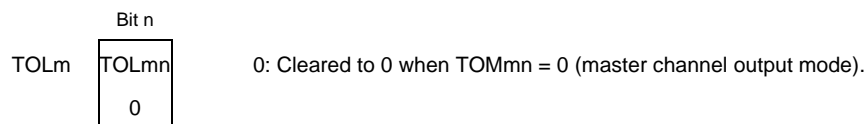
(b) Timer output register m (TOM)



(c) Timer output enable register m (TOEm)



(d) Timer output level register m (TOLm)



(e) Timer output mode register m (TOMm)

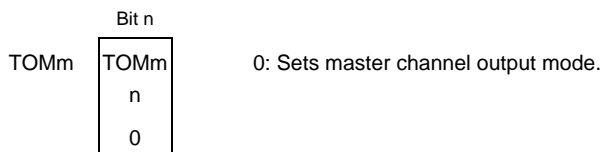
**Remark** m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-47. Operation Procedure When External Event Counter Function Is Used

| | Software Operation | Hardware Status |
|-------------------------|---|--|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to each register is disabled.) |
| | Sets the TAU _m EN bit of peripheral enable register 0 (PER0) to 1. → | Power-on status. Each channel stops operating. (Clock supply is started and writing to each register is enabled.) |
| | Sets timer clock select register m (TPS _m). Determines clock frequencies of CK _m 0 to CK _m 3. | |
| Channel default setting | Sets the corresponding bit of the noise filter enable register 1 (NFEN1) to 0 (off) or 1 (on). Sets timer mode register mn (TMR _{mn}) (determines operation mode of channel). Sets number of counts to timer data register mn (TDR _{mn}). Clears the TOE _{mn} bit of timer output enable register m (TOE _m) to 0. | Channel stops operating. (Clock is supplied and some power is consumed.) |
| Operation start | Sets the TSm _n bit to 1. → The TSm _n bit automatically returns to 0 because it is a trigger bit. | TE _m n = 1, and count operation starts. Value of the TDR _{mn} register is loaded to timer count register mn (TCR _{mn}) and detection of the TIm _n pin input edge is awaited. |
| During operation | Set value of the TDR _{mn} register can be changed. The TCR _{mn} register can always be read. The TSR _{mn} register is not used. Set values of the TMR _{mn} register, TOM _{mn} , TOL _{mn} , TOM _n , and TOE _{mn} bits cannot be changed. | Counter (TCR _{mn}) counts down each time input edge of the TIm _n pin has been detected. When count value reaches 0000H, the value of the TDR _{mn} register is loaded to the TCR _{mn} register again, and the count operation is continued. By detecting TCR _{mn} = 0000H, the INTT _m n output is generated. After that, the above operation is repeated. |
| Operation stop | The TT _m n bit is set to 1. → The TT _m n bit automatically returns to 0 because it is a trigger bit. | TE _m n = 0, and count operation stops. The TCR _{mn} register holds count value and stops. |
| TAU stop | The TAU _m EN bit of the PER0 register is cleared to 0. → | Power-off status All circuits are initialized and SFR of each channel is also initialized. |

Operation is resumed.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.8.3 Operation as frequency divider (channels 0 and 3 only)

The timer array unit can be used as a frequency divider that divides a clock input to the TI0n pin and outputs the result from the TO0n pin.

The divided clock frequency output from TO0n can be calculated by the following expression.

- When rising edge/falling edge is selected:

$$\text{Divided clock frequency} = \text{Input clock frequency} / \{(\text{Set value of TDR0n} + 1) \times 2\}$$

- When both edges are selected:

$$\text{Divided clock frequency} \approx \text{Input clock frequency} / (\text{Set value of TDR0n} + 1)$$

Timer count register 0n (TCR0n) operates as a down counter in the interval timer mode.

After the channel start trigger bit (TS0n) of timer channel start register 0 (TS0) is set to 1, the TCR0n register loads the value of timer data register 0n (TDR0n) when the TI0n valid edge is detected. If the MD0n0 bit of timer mode register 0n (TMR0n) is 0 at this time, INTTM0n is not output and TO0n is not toggled. If the MD0n0 bit of timer mode register 0n (TMR0n) is 1, INTTM0n is output and TO0n is toggled.

After that, the TCR0n register counts down at the valid edge of the TI0n pin. When TCR0n = 0000H, it toggles TO0n. At the same time, the TCR0n register loads the value of the TDR0n register again, and continues counting.

If detection of both the edges of the TI0n pin is selected, the duty factor error of the input clock affects the divided clock period of the TO0n output.

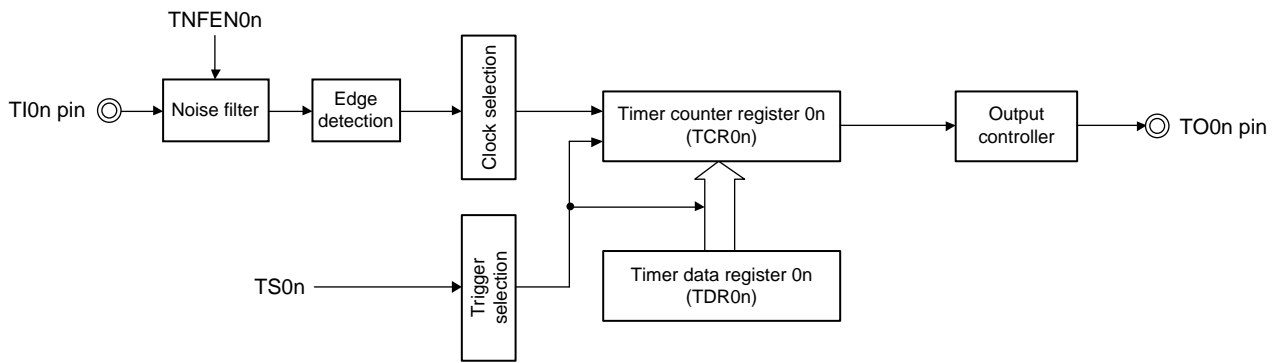
The period of the TO0n output clock includes a sampling error of one period of the operation clock.

$$\text{Clock period of TO0n output} = \text{Ideal TO0n output clock period} \pm \text{Operation clock period (error)}$$

The TDR0n register can be rewritten at any time. The new value of the TDR0n register becomes valid during the next count period.

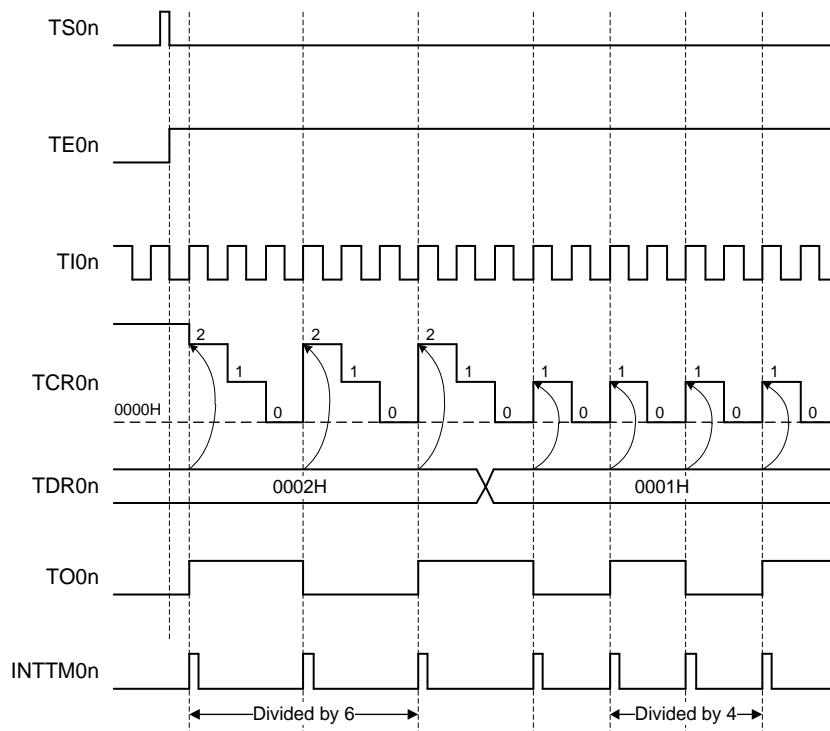
Remark n: Channel number (n = 0, 3)

Figure 6-48. Block Diagram of Operation as Frequency Divider



Remark n: Channel number (n = 0, 3)

Figure 6-49. Example of Basic Timing of Operation as Frequency Divider (MD0n0 = 1)

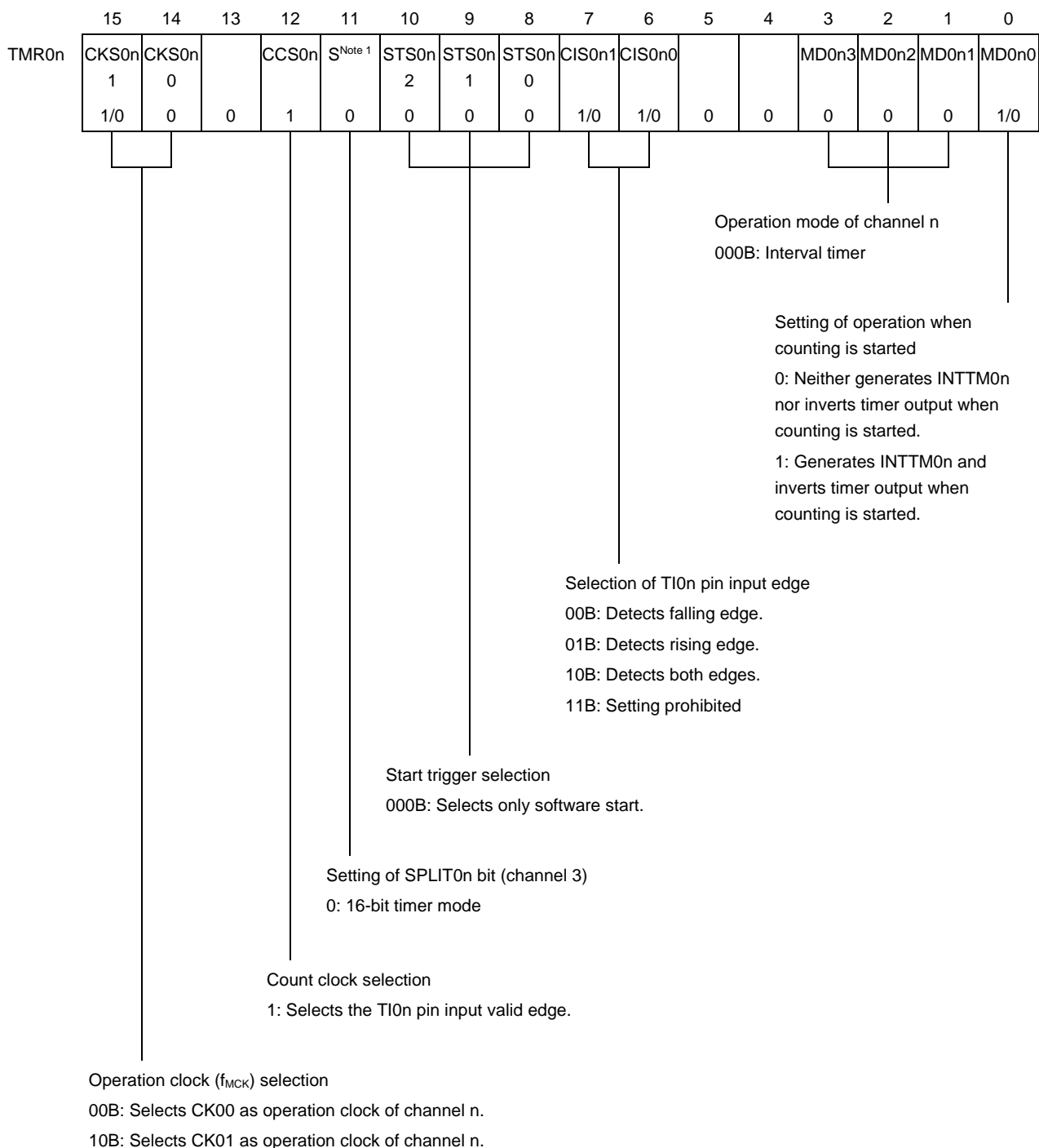


Remark 1. n: Channel number (n = 0, 3)

Remark 2. TS0n: Bit n of timer channel start register 0 (TS0)
 TE0n: Bit n of timer channel enable status register 0 (TE0)
 TI0n: TI0n pin input signal
 TCR0n: Timer count register 0n (TCR0n)
 TDR0n: Timer data register 0n (TDR0n)
 TO0n: TO0n pin output signal

Figure 6-50. Example of Set Contents of Registers During Operation as Frequency Divider (1/2)

(a) Timer mode register 0n (TMR0n)

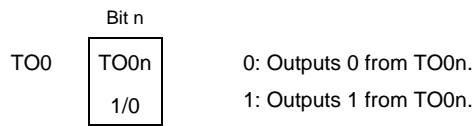


Note 1. Channel 3 only

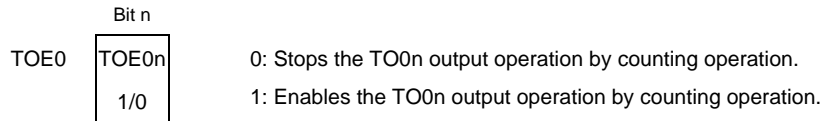
Remark n: Channel number (n = 0, 3)

Figure 6-50. Example of Set Contents of Registers During Operation as Frequency Divider (2/2)

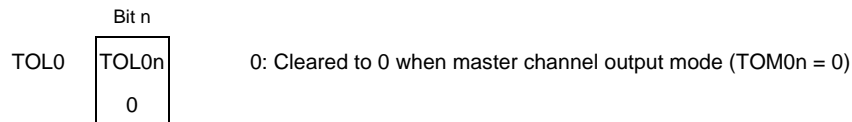
(b) Timer output register 0 (TO0)



(c) Timer output enable register 0 (TOE0)



(d) Timer output level register 0 (TOL0)



(e) Timer output mode register 0 (TOM0)

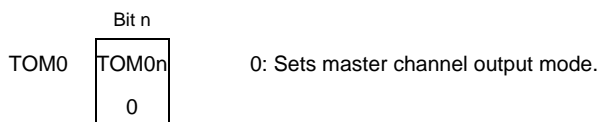
**Remark** n: Channel number (n = 0, 3)

Figure 6-51. Operation Procedure When Frequency Divider Function Is Used (1/2)

| | Software Operation | Hardware Status |
|-------------------------|---|---|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to each register is disabled.) |
| | Sets the TAU0EN bit of peripheral enable register 0 (PER0) to 1. → | Power-on status. Each channel stops operating. (Clock supply is started and writing to each register is enabled.) |
| | Sets timer clock select register 0 (TPS0). Determines clock frequencies of CK00 to CK03. | |
| Channel default setting | Sets the corresponding bit of the noise filter enable register 1 (NFEN1) to 0 (off) or 1 (on). Sets timer mode register 0n (TMR0n) (determines operation mode of channel and selects the detection edge). Sets interval (period) value to timer data register 0n (TDR0n). | Channel stops operating. (Clock is supplied and some power is consumed.) |
| | Clears the TOM0n bit of timer output mode register 0 (TOM0) to 0 (master channel output mode). Clears the TOL0n bit to 0. Sets the TO0n bit and determines default level of the TO0n output. → | The TO0n pin goes into Hi-Z output state. The TO0n default setting level is output when the port mode register is in output mode and the port register is 0. |
| | Sets the TOE0n bit to 1 and enables operation of TO0n. → Clears the port register and port mode register to 0. → | TO0n does not change because channel stops operating. The TO0n pin outputs the TO0n set level. |

Remark n: Channel number (n = 0, 3)

Figure 6-51. Operation Procedure When Frequency Divider Function Is Used (2/2)

| | Software Operation | Hardware Status |
|-----------------------|---|--|
| Operation is resumed. | Operation start Sets the TOE0n bit to 1 (only when operation is resumed). Sets the TS0n bit to 1. —————→ The TS0n bit automatically returns to 0 because it is a trigger bit. | TE0n = 1, and count operation starts. Value of the TDR0n register is loaded to timer count register 0n (TCR0n). INTTM0n is generated and TO0n performs toggle operation if the MD0n0 bit of the TMR0n register is 1. |
| | During operation Set value of the TDR0n register can be changed. The TCR0n register can always be read. The TSR0n register is not used. Set values of the TO0 and TOE0 registers can be changed. Set values of the TMR0n register, TOM0n, and TOL0n bits cannot be changed. | Counter (TCR0n) counts down. When count value reaches 0000H, the value of the TDR0n register is loaded to the TCR0n register again, and the count operation is continued. By detecting TCR0n = 0000H, INTTM0n is generated and TO0n performs toggle operation. After that, the above operation is repeated. |
| | Operation stop The TT0n bit is set to 1. —————→ The TT0n bit automatically returns to 0 because it is a trigger bit. | TE0n = 0, and count operation stops. The TCR0n register holds count value and stops. The TO0n output is not initialized but holds current status. |
| | The TOE0n bit is cleared to 0 and value is set to the TO0n bit. —————→ | The TO0n pin outputs the TO0n set level. |
| | TAU stop To hold the TO0n pin output level Clears the TO0n bit to 0 after the value to be held is set to the port register. —————→ When holding the TO0n pin output level is not necessary Setting not required. | The TO0n pin output level is held by port function. |
| | The TAU0EN bit of the PER0 register is cleared to 0. | Power-off status All circuits are initialized and SFR of each channel is also initialized. (The TO0n bit is cleared to 0 and the TO0n pin is set to port mode) |

Remark n: Channel number (n = 0, 3)

6.8.4 Operation as input pulse interval measurement

The count value can be captured on detection of a valid edge of TImn pin input and the interval of the pulse input to TImn pin can be measured. In addition, the count value can be captured by setting TSmn to 1 by software during the period of TEMn = 1.

For the UART0 baud rate correction, set bit 1 (ISC1) of the input switch control register (ISC) to 1.

In the following descriptions, read TI0n as RXD0. When the ISC1 bit is set to 1, the input signal of the serial data input (RXD0) pin is selected as a timer input (TI01). The width at the baud rate (transfer rate) of the other party in communications can be measured by using the input pulse interval measurement mode with the input edge signal of the start bit as a trigger.

The input pulse interval can be calculated by the following expression.

$$\text{TImn input pulse interval} = \text{Period of count clock} \times ((10000\text{H} \times \text{TSRmn: OVF}) + (\text{Capture value of TDRmn} + 1))$$

Caution The TImn pin input is sampled using the operation clock selected with the CKSmn bit of timer mode register mn (TMRmn), so an error of one cycle of the operation clock occurs.

Timer count register mn (TCRmn) operates as an up counter in the capture mode.

When the channel start trigger bit (TSmn) of timer channel start register m (TSM) is set to 1, the TCRmn register counts up from 0000H in synchronization with the count clock.

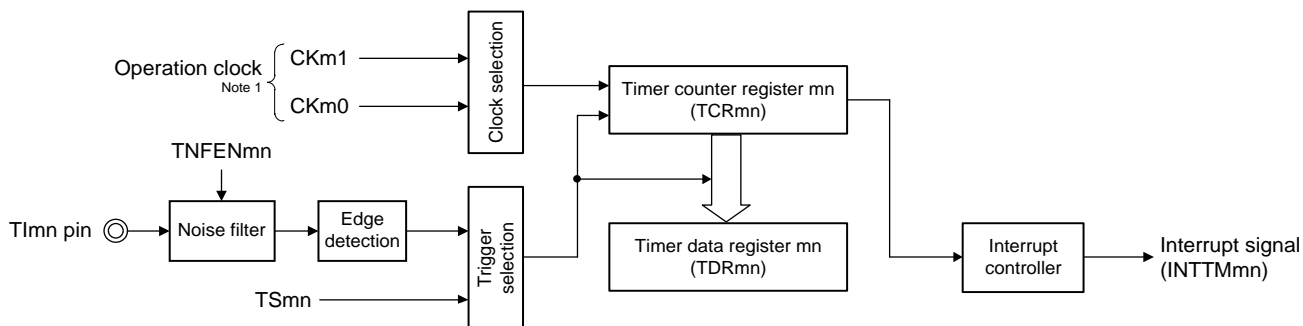
When the TImn pin input valid edge is detected, the count value of the TCRmn register is transferred (captured) to timer data register mn (TDRmn) and, at the same time, the TCRmn register is cleared to 0000H, and the INTTMmn is output. If the counter overflows at this time, the OVF bit of timer status register mn (TSRmn) is set to 1. If the counter does not overflow, the OVF bit is cleared. After that, the above operation is repeated.

As soon as the count value has been captured to the TDRmn register, the OVF bit of the TSRmn register is updated depending on whether the counter overflows during the measurement period. Therefore, the overflow status of the captured value can be checked.

If the counter reaches a full count for two or more periods, it is judged to be an overflow occurrence, and the OVF bit of the TSRmn register is set to 1. However, a normal interval value cannot be measured for the OVF bit, if two or more overflows occur.

Set the STSmn2 to STSmn0 bits of the TMRmn register to 001B to use the valid edges of TImn as a start trigger and a capture trigger.

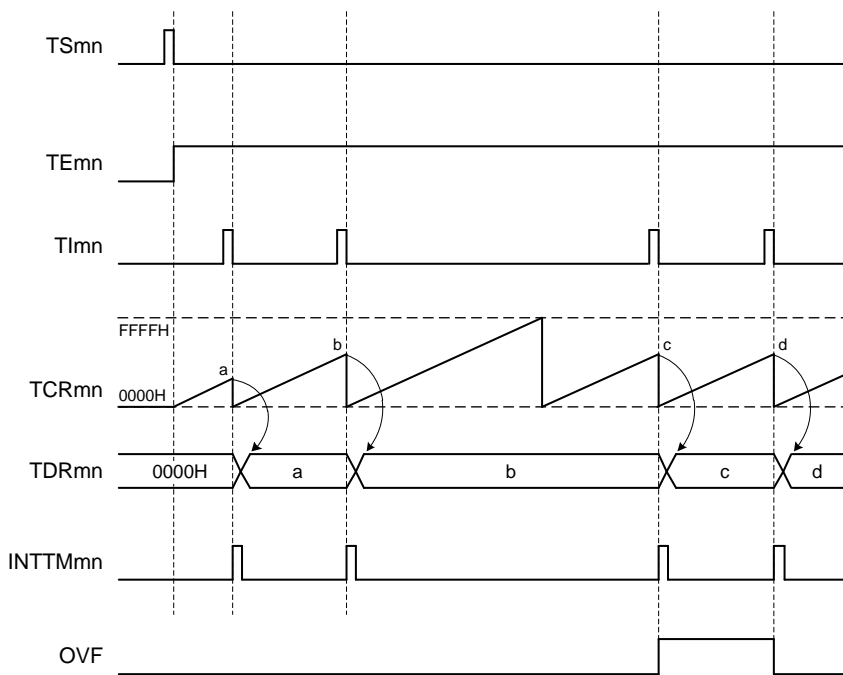
Figure 6-52. Block Diagram of Operation as Input Pulse Interval Measurement



Note 1. When channels 1 and 3, the clock can be selected from CKm0, CKm1, CKm2 and CKm3.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-53. Example of Basic Timing of Operation as Input Pulse Interval Measurement (MDmn0 = 0)



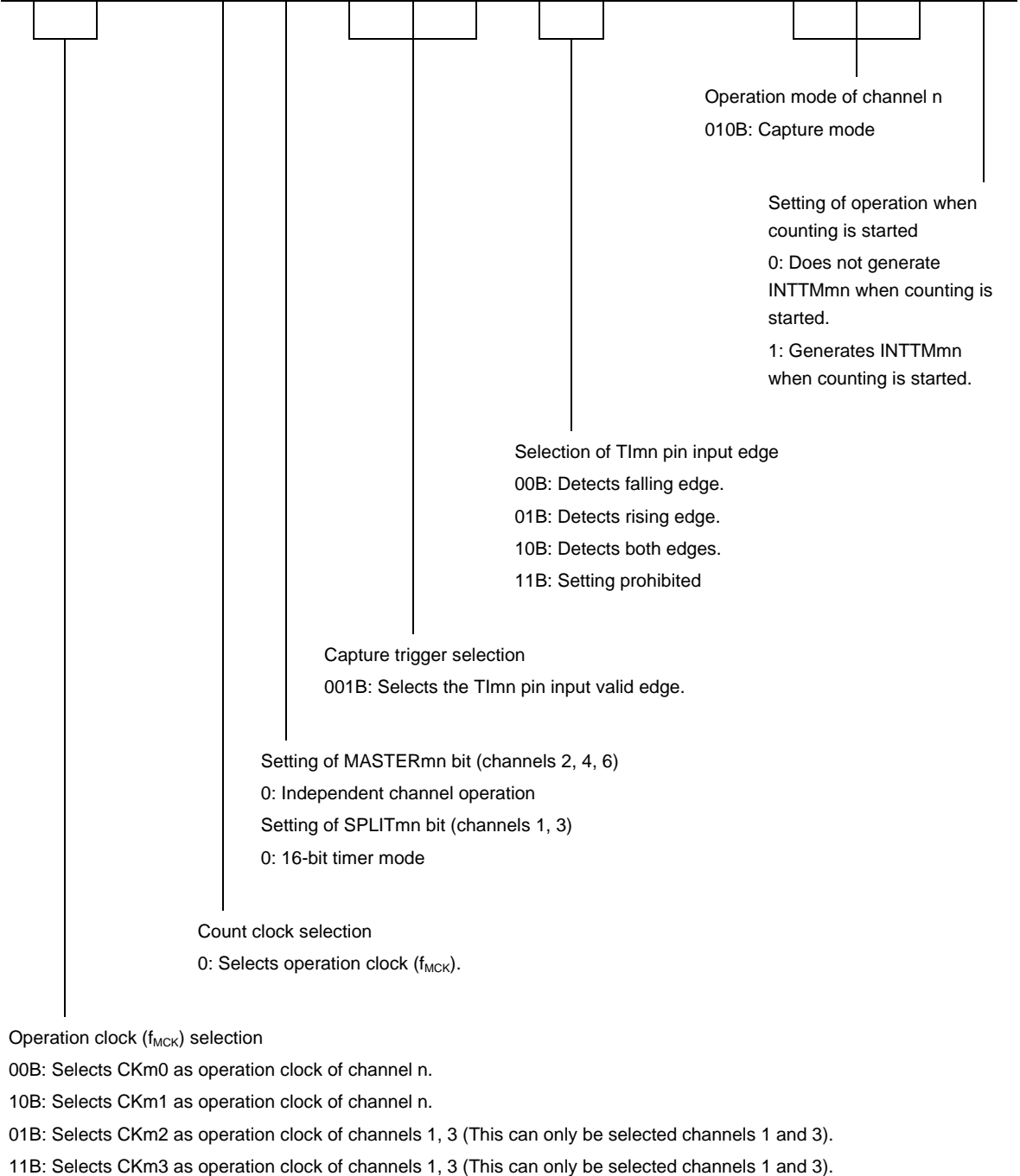
Remark 1. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Remark 2. TSmn: Bit n of timer channel start register m (TSM)
 TEMn: Bit n of timer channel enable status register m (TEM)
 TImn: TImn pin input signal
 TCRmn: Timer count register mn (TCRmn)
 TDRmn: Timer data register mn (TDRmn)
 OVF: Bit 0 of timer status register mn (TSRmn)

Figure 6-54. Example of Set Contents of Registers to Measure Input Pulse Interval (1/2)

(a) Timer mode register mn (TMRmn)

| | | | | | | | | | | | | | | | | |
|-------|------------|------------|----|-----------|---------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn | CKSm n1 | CKSm n0 | | CCSm n | M/S Note 1 | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | | | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |
| | 1/0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1/0 | 1/0 | 0 | 0 | 0 | 1 | 0 | 1/0 |

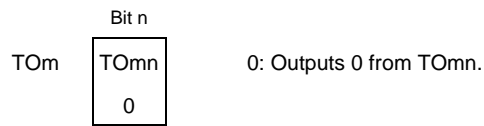


Note 1. TMRm2, TMRm4, TMRm6: MASTERmn bit
TMRm1, TMRm3: SPLITmn bit
TMRm0, TMRm5, TMRm7: Fixed to 0

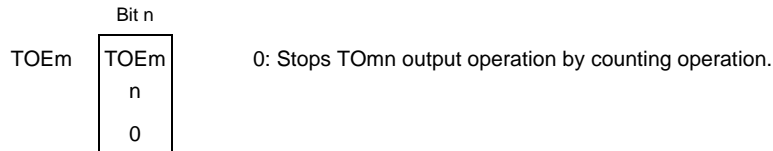
Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-54. Example of Set Contents of Registers to Measure Input Pulse Interval (2/2)

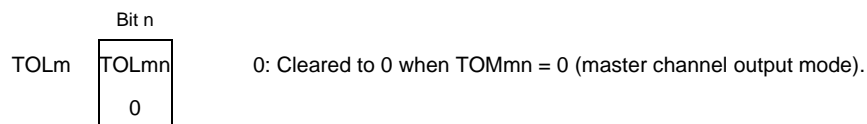
(b) Timer output register m (TOM)



(c) Timer output enable register m (TOEm)



(d) Timer output level register m (TOLm)



(e) Timer output mode register m (TOMm)

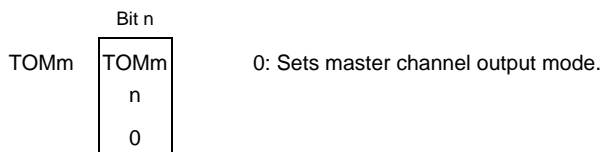
**Remark** m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-55. Operation Procedure When Input Pulse Interval Measurement Function Is Used

| | Software Operation | Hardware Status |
|-------------------------|--|--|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to each register is disabled.) |
| | Sets the TAUmEN bit of peripheral enable register m to 1. | Power-on status. Each channel stops operating. (Clock supply is started and writing to each register is enabled.) |
| | Sets timer clock select register m (TPSm). Determines clock frequencies of CKm0 to CKm3. | |
| Channel default setting | Sets the corresponding bit of the noise filter enable register 1 (NFEN1) to 0 (off) or 1 (on). Sets timer mode register mn (TMRmn) (determines operation mode of channel). | Channel stops operating. (Clock is supplied and some power is consumed.) |
| Operation start | Sets the TSmn bit to 1. The TSmn bit automatically returns to 0 because it is a trigger bit. | TEmn = 1, and count operation starts. Timer count register mn (TCRmn) is cleared to 0000H. When the MDmn0 bit of the TMRmn register is 1, INTTMmn is generated. |
| During operation | Set values of only the CISmn1 and CISmn0 bits of the TMRmn register can be changed. The TDRmn register can always be read. The TCRmn register can always be read. The TSRmn register can always be read. Set values of the TOMmn, TOLmn, TOMn, and TOEmn bits cannot be changed. | Counter (TCRmn) counts up from 0000H. When the valid edge of the Timn pin input is detected or the TSmn bit is set to 1, the count value is transferred (captured) to timer data register mn (TDRmn). At the same time, the TCRmn register is cleared to 0000H, and the INTTMmn signal is generated. If an overflow occurs at this time, the OVF bit of timer status register mn (TSRmn) is set; if an overflow does not occur, the OVF bit is cleared. After that, the above operation is repeated. |
| Operation stop | The TTmn bit is set to 1. The TTmn bit automatically returns to 0 because it is a trigger bit. | TEmn = 0, and count operation stops. The TCRmn register holds count value and stops. The OVF bit of the TSRmn register is also held. |
| TAU stop | The TAUmEN bit of the PER0 register is cleared to 0. | Power-off status All circuits are initialized and SFR of each channel is also initialized. |

Operation is resumed.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.8.5 Operation as input signal high-/low-level width measurement

By starting counting at one edge of the TImn pin input and capturing the number of counts at another edge, the signal width (high-level width/low-level width) of TImn can be measured. The signal width of TImn can be calculated by the following expression.

$$\text{Signal width of TImn input} = \text{Period of count clock} \times ((10000\text{H} \times \text{TSRmn:OVF}) + (\text{Capture value of TDRmn} + 1))$$

Caution The TImn pin input is sampled using the operation clock selected with the CKSmn bit of timer mode register mn (TMRmn), so an error of one cycle of the operation clock occurs.

Timer count register mn (TCRmn) operates as an up counter in the capture & one-count mode.

When the channel start trigger bit (TSmn) of timer channel start register m (TSM) is set to 1, the TEMn bit is set to 1 and the TImn pin start edge detection wait status is set.

When the TImn pin input start edge (rising edge of the TImn pin input when the high-level width is to be measured) is detected, the counter counts up from 0000H in synchronization with the count clock. When the valid capture edge (falling edge of the TImn pin input when the high-level width is to be measured) is detected later, the count value is transferred to timer data register mn (TDRmn) and, at the same time, INTTMmn is output. If the counter overflows at this time, the OVF bit of timer status register mn (TSRmn) is set to 1. If the counter does not overflow, the OVF bit is cleared. The TCRmn register stops at the value "value transferred to the TDRmn register + 1", and the TImn pin start edge detection wait status is set. After that, the above operation is repeated.

As soon as the count value has been captured to the TDRmn register, the OVF bit of the TSRmn register is updated depending on whether the counter overflows during the measurement period. Therefore, the overflow status of the captured value can be checked.

If the counter reaches a full count for two or more periods, it is judged to be an overflow occurrence, and the OVF bit of the TSRmn register is set to 1. However, a normal interval value cannot be measured for the OVF bit, if two or more overflows occur.

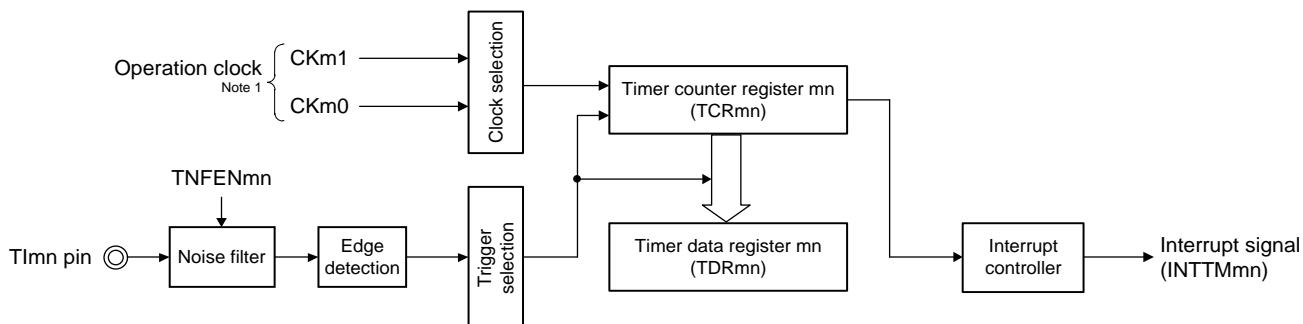
Whether the high-level width or low-level width of the TImn pin is to be measured can be selected by using the CISmn1 and CISmn0 bits of the TMRmn register.

Because this function is used to measure the signal width of the TImn pin input, the TSmn bit cannot be set to 1 while the TEMn bit is 1.

CISmn1, CISmn0 of TMRmn register = 10B: Low-level width is measured.

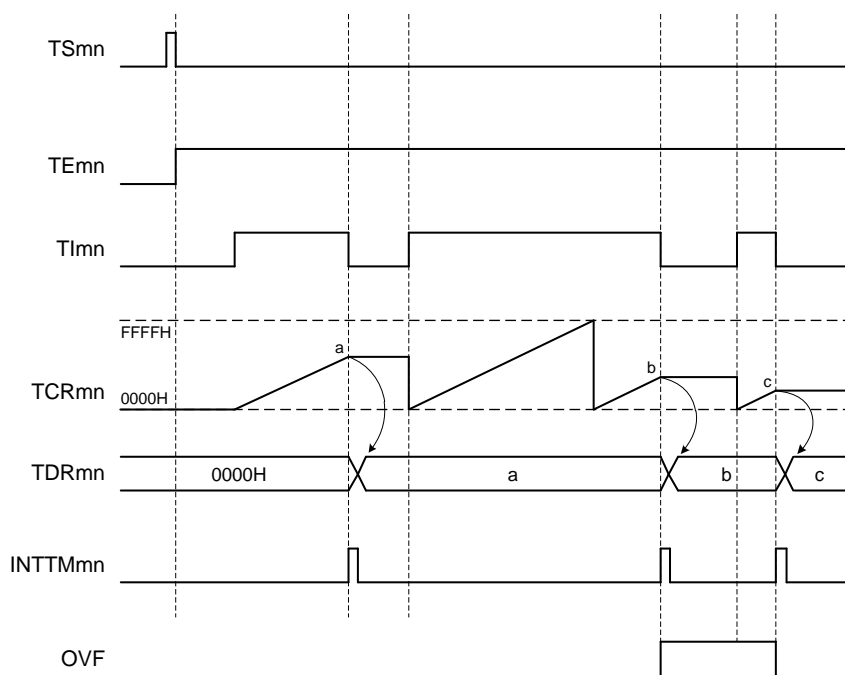
CISmn1, CISmn0 of TMRmn register = 11B: High-level width is measured.

Figure 6-56. Block Diagram of Operation as Input Signal High-/Low-Level Width Measurement



Note 1. For channels 1 and 3, the clock can be selected from CKm0, CKm1, CKm2 and CKm3.

Figure 6-57. Example of Basic Timing of Operation as Input Signal High-/Low-Level Width Measurement



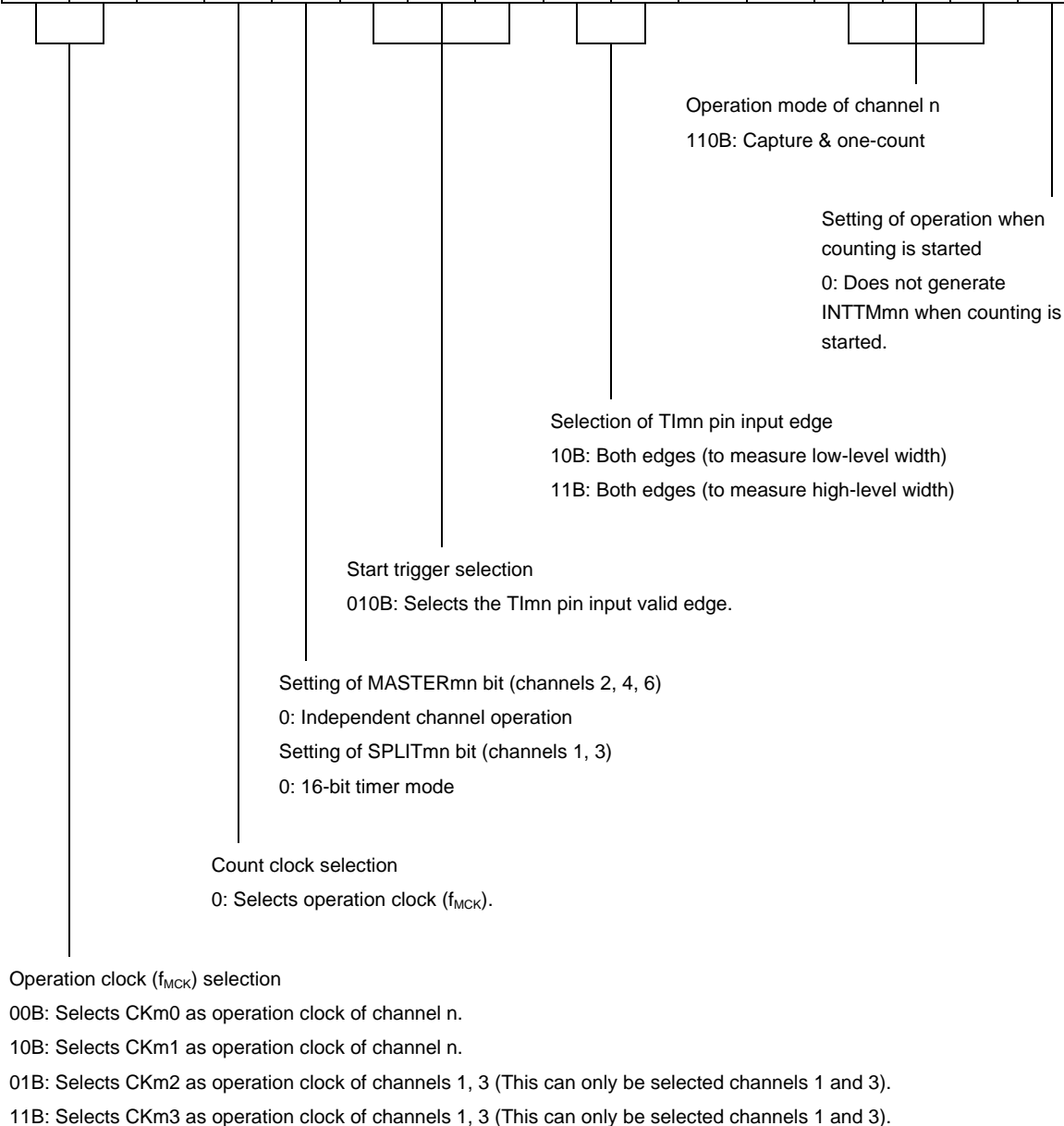
Remark 1. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Remark 2. TSmn: Bit n of timer channel start register m (TSm)
 TEMn: Bit n of timer channel enable status register m (TEm)
 TImn: TImn pin input signal
 TCRmn: Timer count register mn (TCRmn)
 TDRmn: Timer data register mn (TDRmn)
 OVF: Bit 0 of timer status register mn (TSRmn)

Figure 6-58. Example of Set Contents of Registers to Measure Input Signal High-/Low-Level Width (1/2)

(a) Timer mode register mn (TMRmn)

| | | | | | | | | | | | | | | | | |
|-------|------------|------------|----|-------|---------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn | CKSm n1 | CKSm n0 | | CCSn0 | M/S Note 1 | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | | | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |
| | 1/0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1/0 | 0 | 0 | 1 | 1 | 0 | 0 |

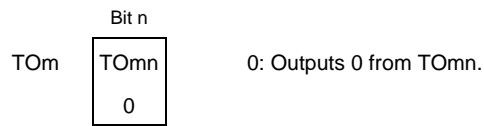


Note 1. TMRm2, TMRm4, TMRm6: MASTERmn bit
TMRm1, TMRm3: SPLITmn bit
TMRm0, TMRm5, TMRm7: Fixed to 0

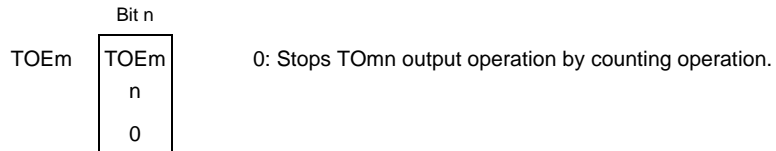
Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-58. Example of Set Contents of Registers to Measure Input Signal High-/Low-Level Width (2/2)

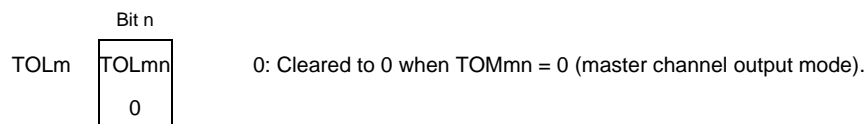
(b) Timer output register m (TOM)



(c) Timer output enable register m (TOEm)



(d) Timer output level register m (TOLm)



(e) Timer output mode register m (TOMm)

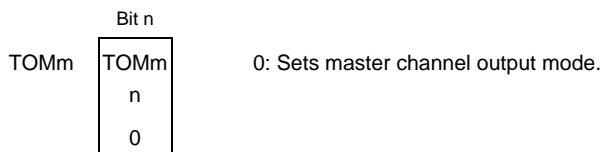
**Remark** m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-59. Operation Procedure When Input Signal High-/Low-Level Width Measurement Function Is Used

| | Software Operation | Hardware Status |
|-------------------------|---|--|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to each register is disabled.) |
| | Sets the TAUmEN bit of peripheral enable register 0 (PER0) to 1. → | Power-on status. Each channel stops operating. (Clock supply is started and writing to each register is enabled.) |
| | Sets timer clock select register m (TPSm). Determines clock frequencies of CKm0 to CKm3. | |
| Channel default setting | Sets the corresponding bit of the noise filter enable register 1 (NFEN1) to 0 (off) or 1 (on). Sets timer mode register mn (TMRmn) (determines operation mode of channel). Clears the TOEmn bit to 0 and stops operation of TOmn. | Channel stops operating. (Clock is supplied and some power is consumed.) |
| Operation start | Sets the TSmn bit to 1. → The TSmn bit automatically returns to 0 because it is a trigger bit. | TEmn = 1, and the TImn pin start edge detection wait status is set. |
| | Detects the TImn pin input count start valid edge. | Clears timer count register mn (TCRmn) to 0000H and starts counting up. |
| During operation | The TDRmn register can always be read. The TCRmn register can always be read. The TSRmn register can always be read. Set values of the TMRmn register, TOMmn, TOLmn, TOmn, and TOEmn bits cannot be changed. | When the TImn pin start edge is detected, the counter (TCRmn) counts up from 0000H. If a capture edge of the TImn pin is detected, the count value is transferred to timer data register mn (TDRmn) and INTTMmn is generated. If an overflow occurs at this time, the OVF bit of timer status register mn (TSRmn) is set; if an overflow does not occur, the OVF bit is cleared. The TCRmn register stops the count operation until the next TImn pin start edge is detected. After that, the above operation is repeated. |
| Operation stop | The TTmn bit is set to 1. → The TTmn bit automatically returns to 0 because it is a trigger bit. | TEmn = 0, and count operation stops. The TCRmn register holds count value and stops. The OVF bit of the TSRmn register is also held. |
| TAU stop | The TAUmEN bit of the PER0 register is cleared to 0. → | Power-off status All circuits are initialized and SFR of each channel is also initialized. |

Operation is resumed.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.8.6 Operation as delay counter

It is possible to start counting down when the valid edge of the TImn pin input is detected (an external event), and then generate INTTMmn (a timer interrupt) after any specified interval.

It is also possible to start counting down and generate INTTMmn (a timer interrupt) at any interval by setting TSmn to 1 by software while TEMn = 1.

The interrupt generation period can be calculated by the following expression.

$$\text{Generation period of INTTMmn (timer interrupt)} = \text{Period of count clock} \times (\text{Set value of TDRmn} + 1)$$

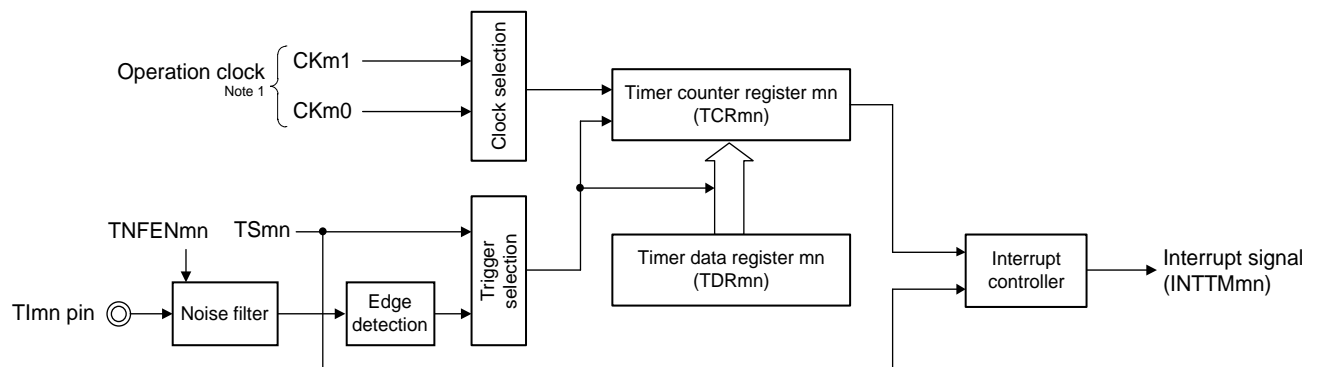
Timer count register mn (TCRmn) operates as a down counter in the one-count mode.

When the channel start trigger bit (TSmn, TSHm1, TSHm3) of timer channel start register m (TSm) is set to 1, the TEMn, TEHm1, TEHm3 bits are set to 1 and the TImn pin input valid edge detection wait status is set.

Timer count register mn (TCRmn) starts operating upon TImn pin input valid edge detection and loads the value of timer data register mn (TDRmn). The TCRmn register counts down from the value of the TDRmn register it has loaded, in synchronization with the count clock. When TCRmn = 0000H, it outputs INTTMmn and stops counting until the next TImn pin input valid edge is detected.

The TDRmn register can be rewritten at any time. The new value of the TDRmn register becomes valid from the next period.

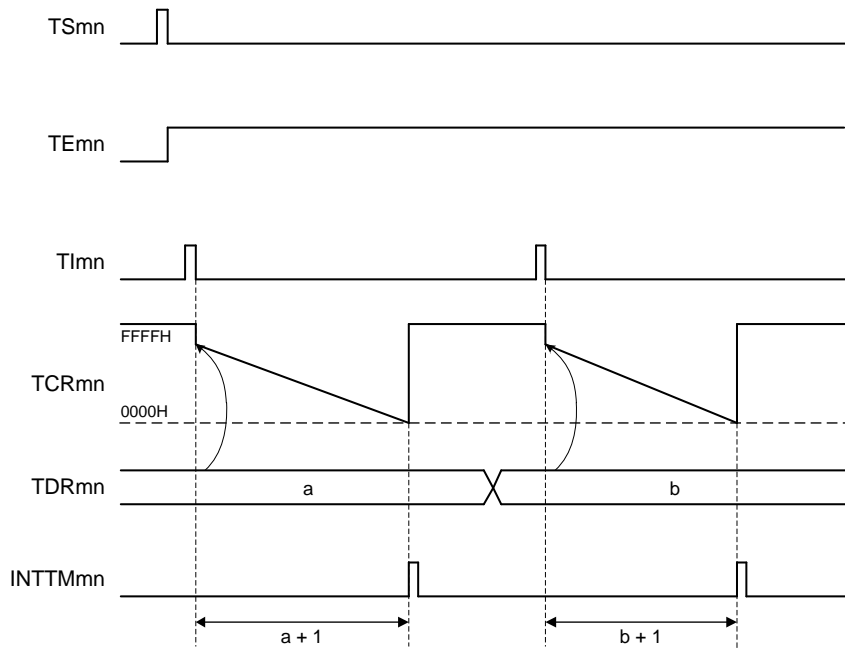
Figure 6-60. Block Diagram of Operation as Delay Counter



Note 1. For channels 1 and 3, the clock can be selected from CKm0, CKm1, CKm2 and CKm3.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-61. Example of Basic Timing of Operation as Delay Counter

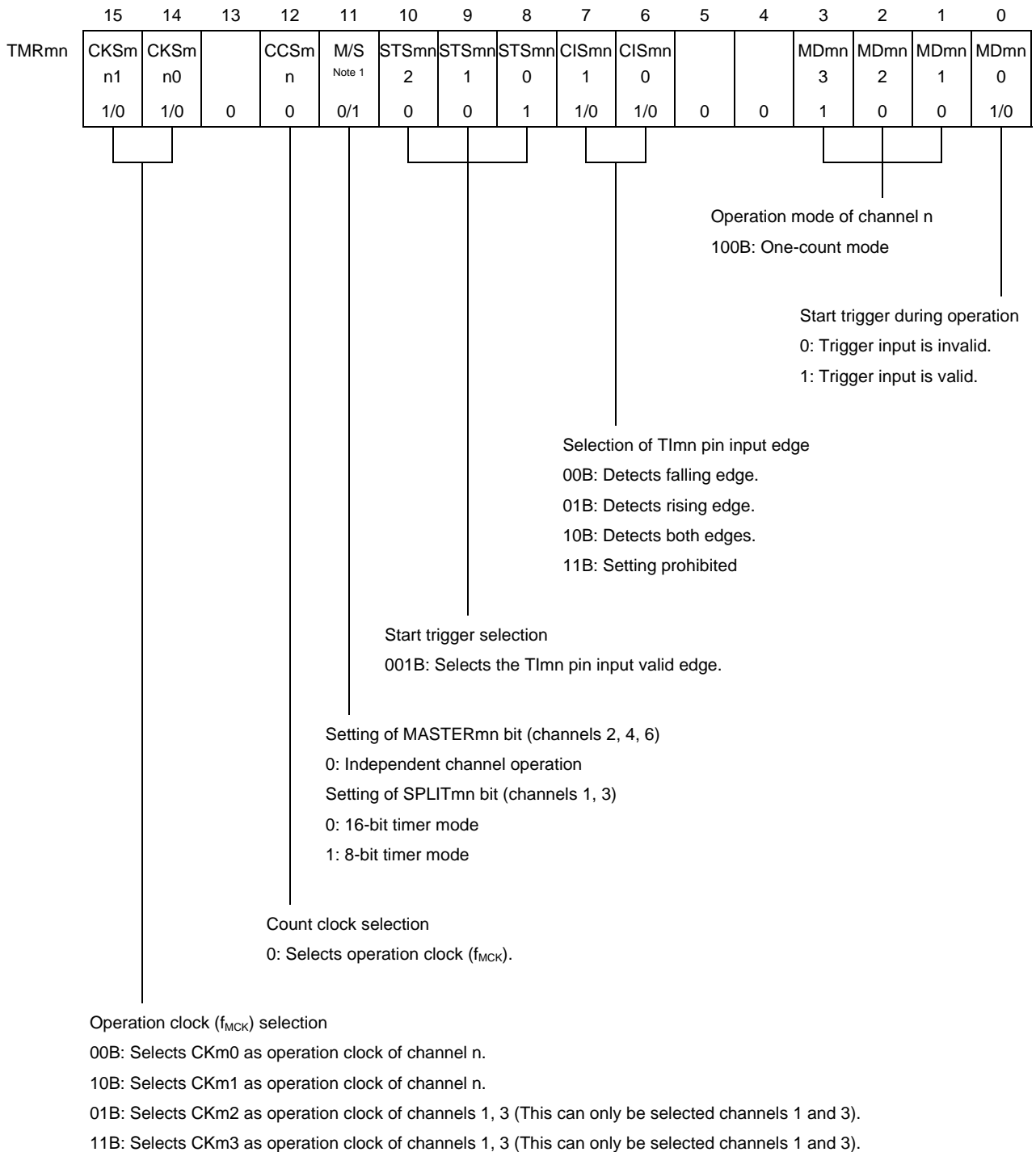


Remark 1. m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Remark 2. TSmn: Bit n of timer channel start register m (TSm)
 TE mn: Bit n of timer channel enable status register m (TE m)
 TImn: TImn pin input signal
 TCRmn: Timer count register mn (TCRmn)
 TDRmn: Timer data register mn (TDRmn)

Figure 6-62. Example of Set Contents of Registers to Delay Counter (1/2)

(a) Timer mode register mn (TMRmn)

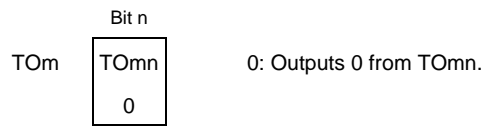


Note 1. TMRm2, TMRm4, TMRm6: MASTERmn bit
 TMRm1, TMRm3: SPLITmn bit
 TMRm0, TMRm5, TMRm7: Fixed to 0

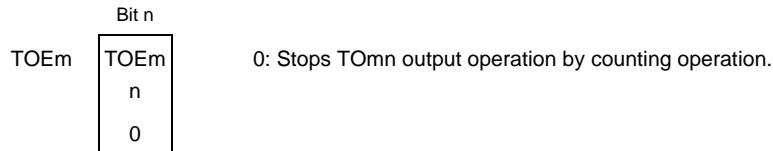
Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-62. Example of Set Contents of Registers to Delay Counter (2/2)

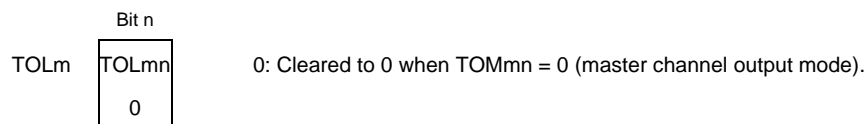
(b) Timer output register m (TOM)



(c) Timer output enable register m (TOEm)



(d) Timer output level register m (TOLm)



(e) Timer output mode register m (TOMm)

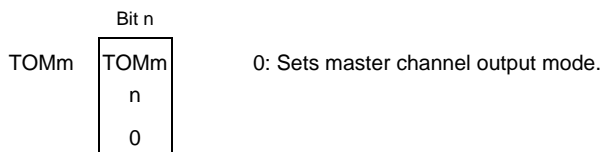
**Remark** m: Unit number (m = 0), n: Channel number (n = 0 to 7)

Figure 6-63. Operation Procedure When Delay Counter Function Is Used

| | Software Operation | Hardware Status |
|-------------------------|--|--|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to each register is disabled.) |
| | Sets the TAU _m EN bit of peripheral enable register 0 (PER0) to 1. | Power-on status. Each channel stops operating. (Clock supply is started and writing to each register is enabled.) |
| | Sets timer clock select register m (TPS _m). Determines clock frequencies of CK _m 0 to CK _m 3. | |
| Channel default setting | Sets the corresponding bit of the noise filter enable register 1 (NFEN1) to 0 (off) or 1 (on). Sets timer mode register mn (TMR _{mn}) (determines operation mode of channel). INTTM _{mn} output delay is set to timer data register mn (TDR _{mn}). Clears the TOE _{mn} bit to 0 and stops operation of TO _{mn} . | Channel stops operating. (Clock is supplied and some power is consumed.) |
| Operation start | Sets the TS _{mn} bit to 1. The TS _{mn} bit automatically returns to 0 because it is a trigger bit. | TE _{mn} = 1, and the start trigger detection (the valid edge of the TI _{mn} pin input is detected or the TS _{mn} bit is set to 1) wait status is set. |
| | The counter starts counting down by the next start trigger detection. <ul style="list-style-type: none"> • Detects the TI_{mn} pin input valid edge. • Sets the TS_{mn} bit to 1 by the software. | Value of the TDR _{mn} register is loaded to the timer count register mn (TCR _{mn}). |
| During operation | Set value of the TDR _{mn} register can be changed. The TCR _{mn} register can always be read. The TSR _{mn} register is not used. | The counter (TCR _{mn}) counts down. When the count value of TCR _{mn} reaches 0000H, the INTTM _{mn} output is generated, and the count operation stops until the next start trigger detection (the valid edge of the TI _{mn} pin input is detected or the TS _{mn} bit is set to 1). |
| Operation stop | The TT _{mn} bit is set to 1. The TT _{mn} bit automatically returns to 0 because it is a trigger bit. | TE _{mn} = 0, and count operation stops. The TCR _{mn} register holds count value and stops. |
| TAU stop | The TAU _m EN bit of the PER0 register is cleared to 0. | Power-off status All circuits are initialized and SFR of each channel is also initialized. |

Operation is resumed.

Remark m: Unit number (m = 0), n: Channel number (n = 0 to 7)

6.9 Simultaneous Channel Operation Function of Timer Array Unit

6.9.1 Operation as one-shot pulse output function

By using two channels as a set, a one-shot pulse having any delay pulse width can be generated from the signal input to the TI_{mn} pin.

The delay time and pulse width can be calculated by the following expressions.

$$\text{Delay time} = \{\text{Set value of TDR}_{mn} \text{ (master)} + 2\} \times \text{Count clock period}$$

$$\text{Pulse width} = \{\text{Set value of TDR}_{mp} \text{ (slave)}\} \times \text{Count clock period}$$

The master channel operates in the one-count mode and counts the delays. Timer count register *mn* (TCR_{mn}) of the master channel starts operating upon start trigger detection and loads the value of timer data register *mn* (TDR_{mn}). The TCR_{mn} register counts down from the value of the TDR_{mn} register it has loaded, in synchronization with the count clock. When TCR_{mn} = 0000H, it outputs INTTM_{mn} and stops counting until the next start trigger is detected.

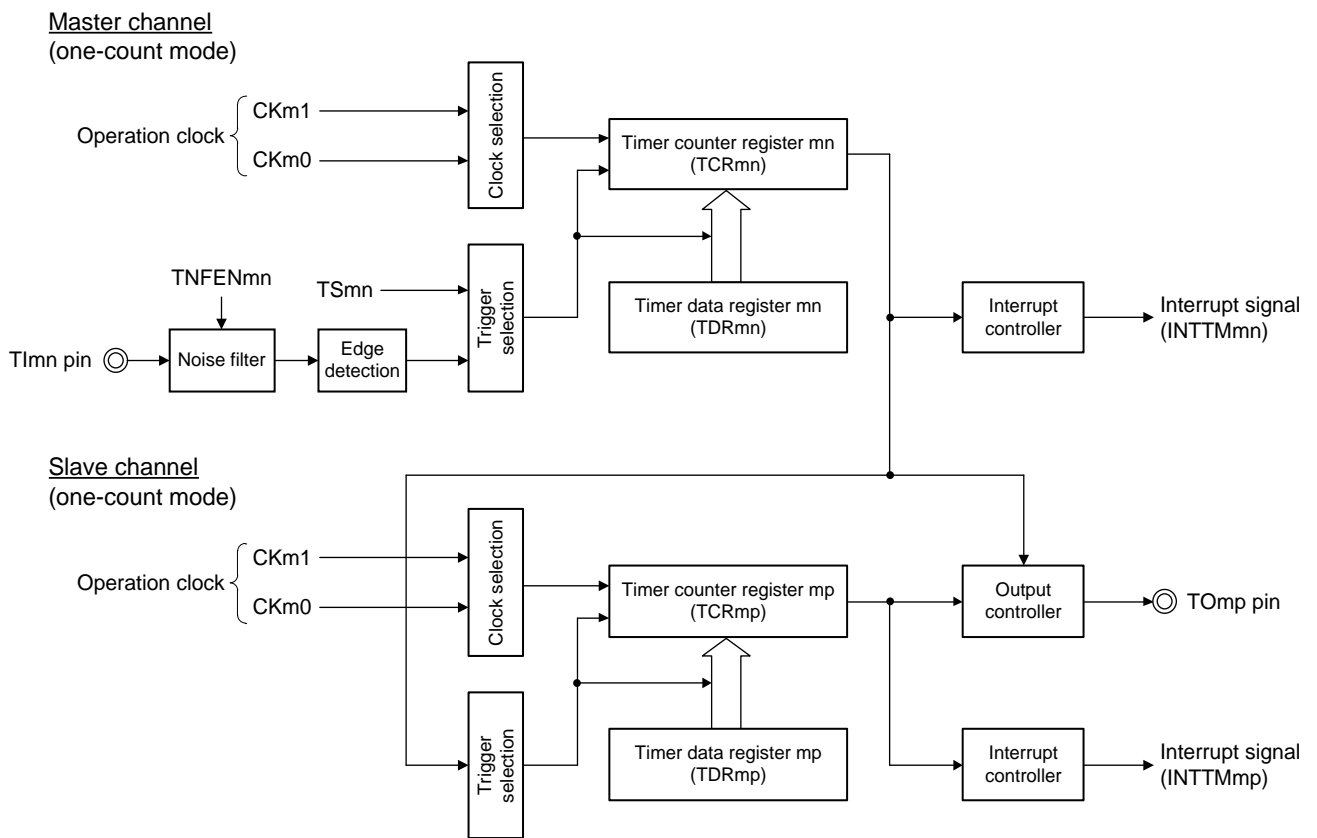
The slave channel operates in the one-count mode and counts the pulse width. The TCR_{mp} register of the slave channel starts operation using INTTM_{mn} of the master channel as a start trigger, and loads the value of the TDR_{mp} register. The TCR_{mp} register counts down from the value of The TDR_{mp} register it has loaded, in synchronization with the count clock. When count value = 0000H, it outputs INTTM_{mp} and stops counting until the next start trigger (INTTM_{mn} of the master channel) is detected. The output level of TO_{mp} becomes active one count clock after generation of INTTM_{mn} from the master channel, and inactive when TCR_{mp} = 0000H.

Instead of using the TI_{mn} pin input, a one-shot pulse can also be output using the software operation (TS_{mn} = 1) as a start trigger.

Caution The timing of loading of timer data register *mn* (TDR_{mn}) of the master channel is different from that of the TDR_{mp} register of the slave channel. If the TDR_{mn} and TDR_{mp} registers are rewritten during operation, therefore, an illegal waveform is output. Rewrite the TDR_{mn} register after INTTM_{mn} is generated and the TDR_{mp} register after INTTM_{mp} is generated.

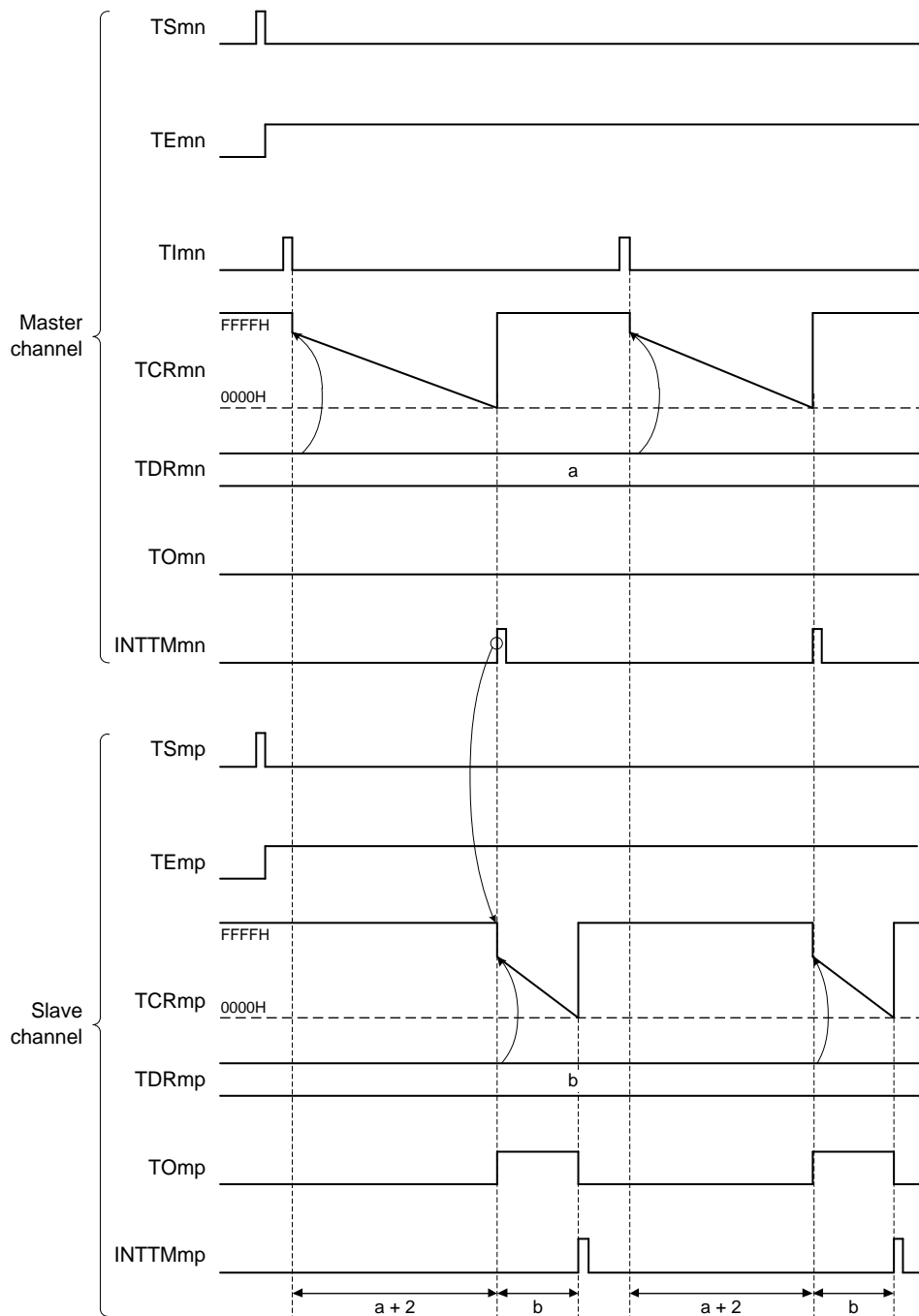
Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
p: Slave channel number (n < p ≤ 7)

Figure 6-64. Block Diagram of Operation as One-Shot Pulse Output Function



Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
 p: Slave channel number (n < p ≤ 7)

Figure 6-65. Example of Basic Timing of Operation as One-Shot Pulse Output Function



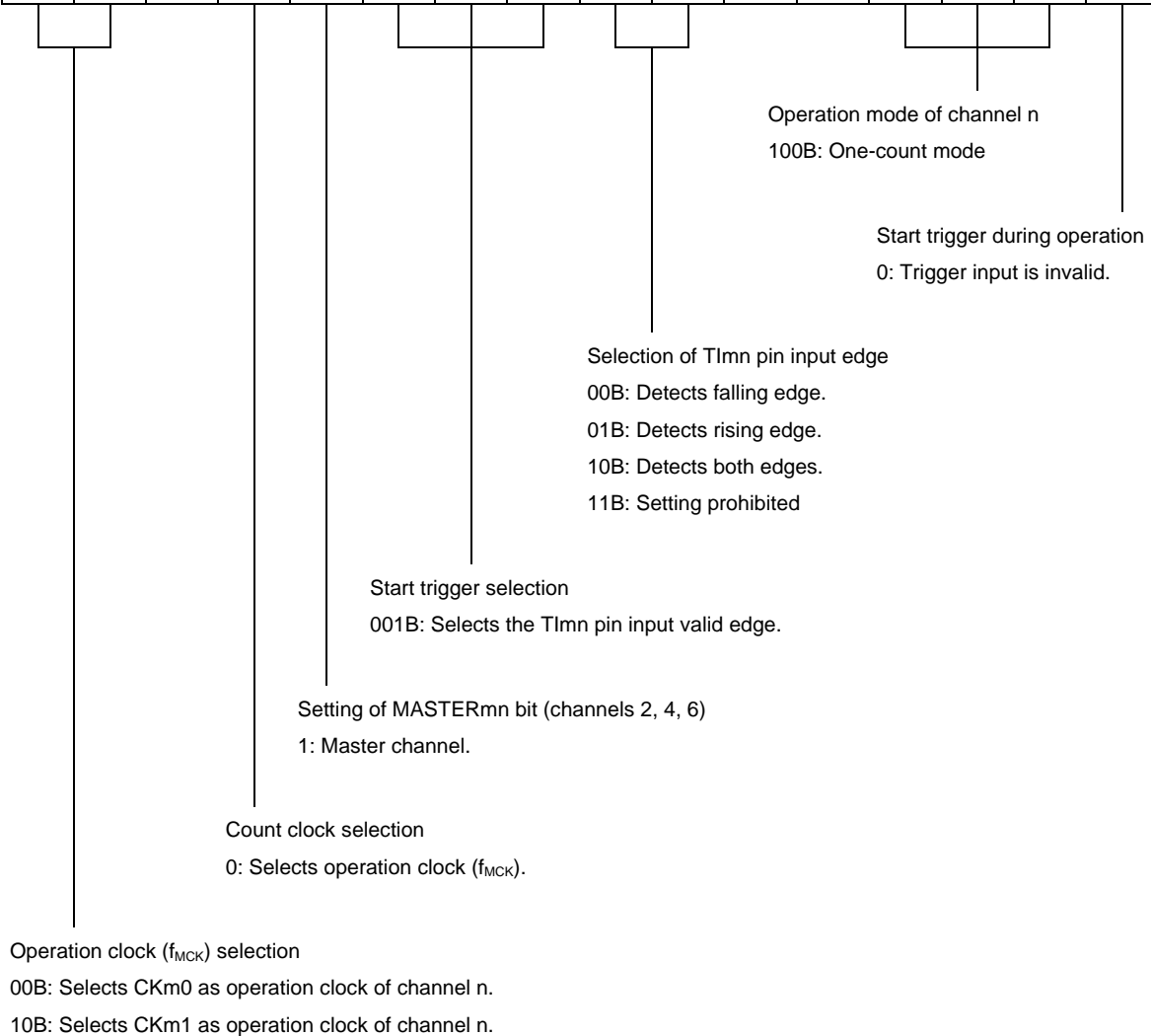
Remark 1. m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
 p: Slave channel number (n < p ≤ 7)

Remark 2. TSmn, TSmp: Bit n, p of timer channel start register m (TSm)
 TEmn, TEmp: Bit n, p of timer channel enable status register m (TEm)
 TImn, TImp: TImn and TImp pins input signal
 TCRmn, TCRmp: Timer count registers mn, mp (TCRmn, TCRmp)
 TDRmn, TDRmp: Timer data registers mn, mp (TDRmn, TDRmp)
 TOmn, TOmp: TOmn and TOmp pins output signal

Figure 6-66. Example of Set Contents of Registers When One-Shot Pulse Output Function Is Used
(Master Channel) (1/2)

(a) Timer mode register mn (TMRmn)

| | | | | | | | | | | | | | | | | |
|-------|------------|------------|----|-----------|------------------------|------------|------------|------------|------------|------------|---|---|-----------|-----------|-----------|-----------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| TMRmn | CKSm n1 | CKSm n0 | | CCSm n | MAST ERmn Note 1 | STSmn 2 | STSmn 1 | STSmn 0 | CISmn 1 | CISmn 0 | | | MDmn 3 | MDmn 2 | MDmn 1 | MDmn 0 |
| | 1/0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1/0 | 1/0 | 0 | 0 | 1 | 0 | 0 | 0 |

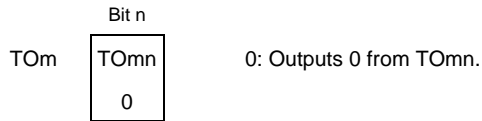


Note 1. TMRm2, TMRm4, TMRm6: MASTERmn = 1
TMRm0: Fixed to 0

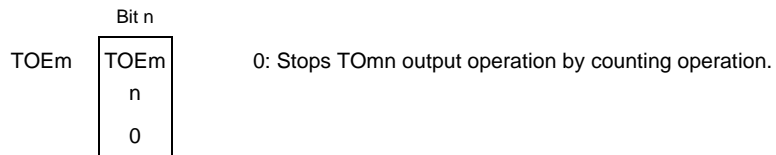
Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)

Figure 6-66. Example of Set Contents of Registers When One-Shot Pulse Output Function Is Used
(Master Channel) (2/2)

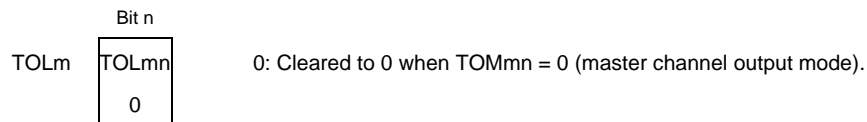
(b) Timer output register m (TOM)



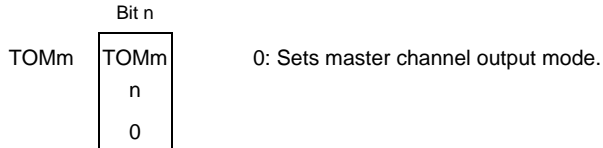
(c) Timer output enable register m (TOEm)



(d) Timer output level register m (TOLm)



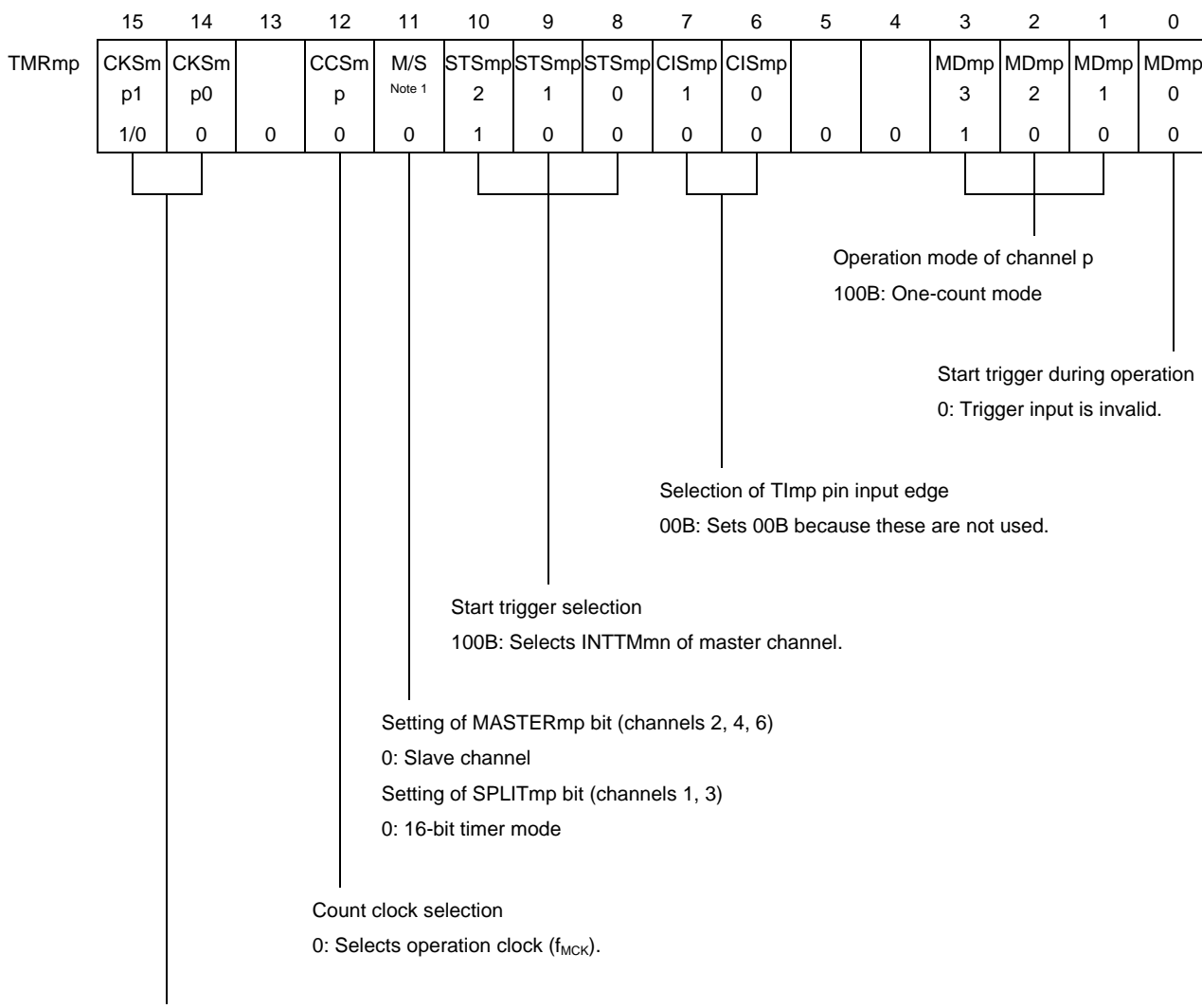
(e) Timer output mode register m (TOMm)



Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)

Figure 6-67. Example of Set Contents of Registers When One-Shot Pulse Output Function Is Used (Slave Channel) (1/2)

(a) Timer mode register mp (TMRmp)



Operation clock (f_{MCK}) selection
00B: Selects CKm0 as operation clock of channel p.
10B: Selects CKm1 as operation clock of channel p.
* Make the same setting as master channel.

Note 1. TMRm2, TMRm4, TMRm6: MASTERmn bit
TMRm1, TMRm3: SPLITmp bit
TMRm5, TMRm7: Fixed to 0

Remark m: Unit number ($m = 0$), n: Master channel number ($n = 0, 2, 4, 6$)
p: Slave channel number ($n < p \leq 7$)

Figure 6-67. Example of Set Contents of Registers When One-Shot Pulse Output Function Is Used
(Slave Channel) (2/2)

(b) Timer output register m (TOM)

| | | |
|-----|-------------|--|
| TOM | Bit p | 0: Outputs 0 from TOmp. 1: Outputs 1 from TOmp. |
| | TOmp 1/0 | |

(c) Timer output enable register m (TOEm)

| | | |
|------|------------------|--|
| TOEm | Bit p | 0: Stops the TOmp output operation by counting operation. 1: Enables the TOmp output operation by counting operation. |
| | TOEm p 1/0 | |

(d) Timer output level register m (TOLm)

| | | |
|------|--------------|---|
| TOLm | Bit p | 0: Positive logic output (active-high) 1: Negative logic output (active-low) |
| | TOLmp 1/0 | |

(e) Timer output mode register m (TOMm)

| | | |
|------|----------------|--|
| TOMm | Bit p | 1: Sets the slave channel output mode. |
| | TOMm p 1 | |

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
p: Slave channel number (n < p ≤ 7)

Figure 6-68. Operation Procedure of One-Shot Pulse Output Function (1/3)

| | Software Operation | Hardware Status |
|-------------------------|--|--|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to each register is disabled.) |
| | Sets the TAUmEN bit of peripheral enable register 0 (PER0) to 1. → | Power-on status. Each channel stops operating. (Clock supply is started and writing to each register is enabled.) |
| | Sets timer clock select register m (TPSm). Determines clock frequencies of CKm0 and CKm1. | |
| Channel default setting | Sets the corresponding bit of the noise filter enable register 1 (NFEN1) to 1. Sets timer mode register mn, mp (TMRmn, TMRmp) of two channels to be used (determines operation mode of channels). An output delay is set to timer data register mn (TDRmn) of the master channel, and a pulse width is set to the TDRmp register of the slave channel. | Channel stops operating. (Clock is supplied and some power is consumed.) |
| | Sets slave channel. The TOMmp bit of timer output mode register m (TOMm) is set to 1 (slave channel output mode). Sets the TOLmp bit. Sets the TOmp bit and determines default level of the TOmp output. → Sets the TOEmp bit to 1 and enables operation of TOmp. → Clears the port register and port mode register to 0. → | The TOmp pin goes into Hi-Z output state. The TOmp default setting level is output when the port mode register is in output mode and the port register is 0. TOmp does not change because channel stops operating. The TOmp pin outputs the TOmp set level. |

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
p: Slave channel number (n < p ≤ 7)

Figure 6-68. Operation Procedure of One-Shot Pulse Output Function (2/3)

| | Software Operation | Hardware Status |
|--|--|---|
| Operation is resumed. | <p>Operation start</p> <p>Sets the TOEmp bit (slave) to 1 (only when operation is resumed).</p> <p>The TSmn (master) and TSmp (slave) bits of timer channel start register m (TSm) are set to 1 at the same time.</p> <p>The TSmn and TSmp bits automatically return to 0 because they are trigger bits.</p> | <p>The TEMn and TEmP bits are set to 1 and the master channel enters the start trigger detection (the valid edge of the TImn pin input is detected or the TSmn bit of the master channel is set to 1) wait status.</p> <p>Counter stops operating.</p> |
| | <p>Count operation of the master channel is started by start trigger detection of the master channel.</p> <ul style="list-style-type: none"> • Detects the TImn pin input valid edge. • Sets the TSmn bit of the master channel to 1 by software^{Note 1}. | <p>Master channel starts counting.</p> |
| | <p>During operation</p> <p>Set values of only the CISmn1 and CISmn0 bits of the TMRmn register can be changed.</p> <p>Set values of the TMRmp, TDRmn, TDRmp registers, TOMmn, TOMmp, TOLmn, and TOLmp bits cannot be changed.</p> <p>The TCRmn and TCRmp registers can always be read.</p> <p>The TSRmn and TSRmp registers are not used.</p> <p>Set values of the TOm and TOEm registers by slave channel can be changed.</p> | <p>Master channel loads the value of the TDRmn register to timer count register mn (TCRmn) by the start trigger detection (the valid edge of the TImn pin input is detected or the TSmn bit of the master channel is set to 1), and the counter starts counting down.</p> <p>When the count value reaches TCRmn = 0000H, the INTTMmn output is generated, and the count operation stops until the next start trigger detection.</p> <p>The slave channel, triggered by INTTMmn of the master channel, loads the value of the TDRmp register to the TCRmp register, and the counter starts counting down. The output level of TOmp becomes active one count clock after generation of INTTMmn output from the master channel. It becomes inactive when TCRmp = 0000H, and the counting operation is stopped.</p> <p>After that, the above operation is repeated.</p> |
| <p>Operation stop</p> <p>The TTmn (master) and TTmp (slave) bits are set to 1 at the same time.</p> <p>The TTmn and TTmp bits automatically return to 0 because they are trigger bits.</p> <p>The TOEmp bit of slave channel is cleared to 0 and value is set to the TOmp bit.</p> | <p>TEmn, TEmP = 0, and count operation stops.</p> <p>The TCRmn and TCRmp registers hold count value and stop.</p> <p>The TOmp output is not initialized but holds current status.</p> <p>The TOmp pin outputs the TOmp set level.</p> | |

Note 1. Do not set the TSmn bit of the slave channel to 1.

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
 p: Slave channel number (n < p ≤ 7)

Figure 6-68. Operation Procedure of One-Shot Pulse Output Function (3/3)

| | Software Operation | Hardware Status |
|----------|--|--|
| TAU stop | To hold the TOmp pin output level Clears the TOmp bit to 0 after the value to be held is set to the port register. —————> | The TOmp pin output level is held by port function. |
| | When holding the TOmp pin output level is not necessary Setting not required. | |
| | The TAUmEN bit of the PER0 register is cleared to 0. —————> | Power-off status All circuits are initialized and SFR of each channel is also initialized. (The TOmp bit is cleared to 0 and the TOmp pin is set to port mode) |

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
 p: Slave channel number (n < p ≤ 7)

6.9.2 Operation as PWM function

Two channels can be used as a set to generate a pulse of any period and duty factor.

The period and duty factor of the output pulse can be calculated by the following expressions.

$$\text{Pulse period} = \{\text{Set value of TDRmn (master)} + 1\} \times \text{Count clock period}$$

$$\text{Duty factor[\%]} = \{\text{Set value of TDRmp (slave)}\} / \{\text{Set value of TDRmn (master)} + 1\} \times 100$$

$$0\% \text{ output: Set value of TDRmp (slave)} = 0000\text{H}$$

$$100\% \text{ output: Set value of TDRmp (slave)} \geq \{\text{Set value of TDRmn (master)} + 1\}$$

Remark The duty factor exceeds 100% if the set value of TDRmp (slave) > (set value of TDRmn (master) + 1), it summarizes to 100% output.

The master channel operates in the interval timer mode. If the channel start trigger bit (TSmn) of timer channel start register m (TSm) is set to 1, an interrupt (INTTMmn) is output, the value set to timer data register mn (TDRmn) is loaded to timer count register mn (TCRmn), and the counter counts down in synchronization with the count clock. When the counter reaches 0000H, INTTMmn is output, the value of the TDRmn register is loaded again to the TCRmn register, and the counter counts down. This operation is repeated until the channel stop trigger bit (TTmn) of timer channel stop register m (TTm) is set to 1.

If two channels are used to output a PWM waveform, the period until the master channel counts down to 0000H is the PWM output (TOmp) cycle.

The slave channel operates in one-count mode. By using INTTMmn from the master channel as a start trigger, the TCRmp register loads the value of the TDRmp register and the counter counts down to 0000H. When the counter reaches 0000H, it outputs INTTMmp and waits until the next start trigger (INTTMmn from the master channel) is generated.

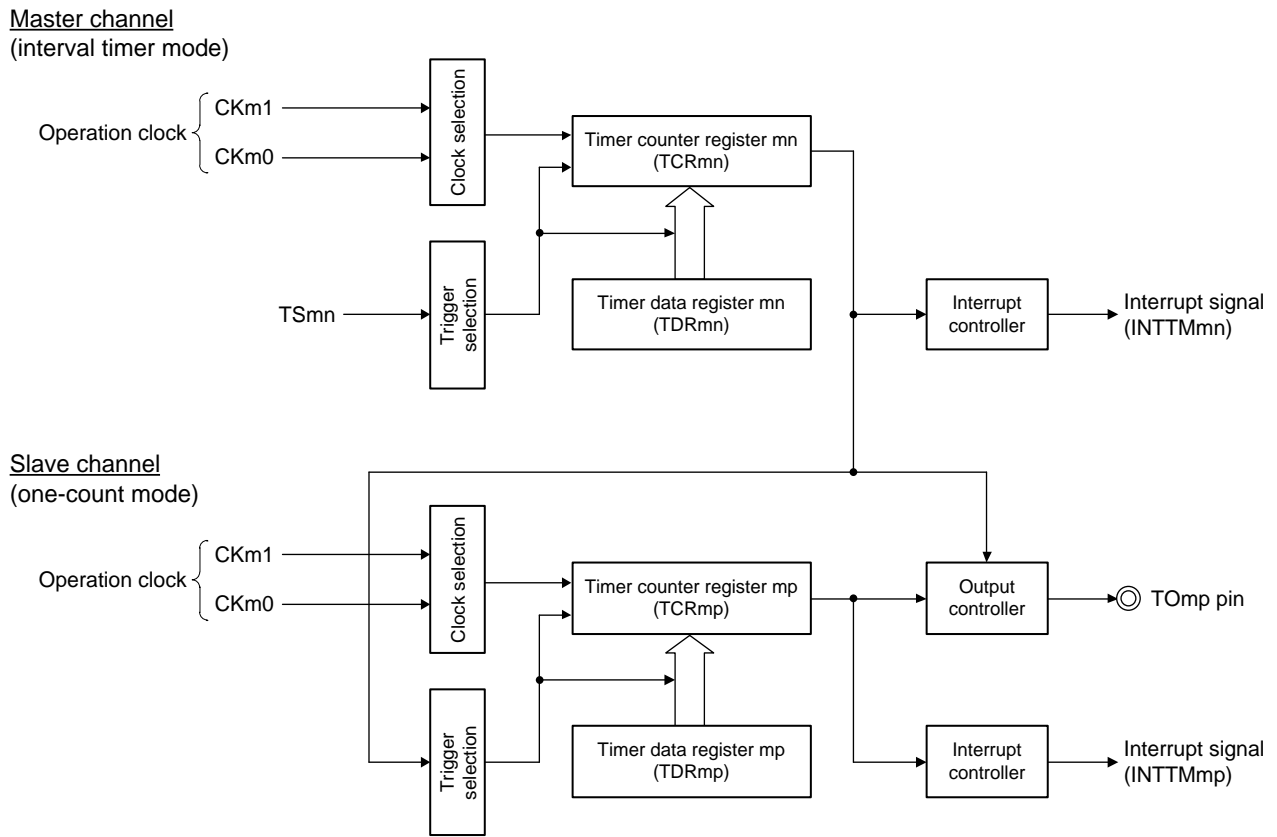
If two channels are used to output a PWM waveform, the period until the slave channel counts down to 0000H is the PWM output (TOmp) duty.

PWM output (TOmp) goes to the active level one clock after the master channel generates INTTMmn and goes to the inactive level when the TCRmp register of the slave channel becomes 0000H.

Caution To rewrite both timer data register mn (TDRmn) of the master channel and the TDRmp register of the slave channel, a write access is necessary two times. The timing at which the values of the TDRmn and TDRmp registers are loaded to the TCRmn and TCRmp registers is upon occurrence of INTTMmn of the master channel. Thus, when rewriting is performed split before and after occurrence of INTTMmn of the master channel, the TOmp pin cannot output the expected waveform. To rewrite both the TDRmn register of the master and the TDRmp register of the slave, therefore, be sure to rewrite both the registers immediately after INTTMmn is generated from the master channel.

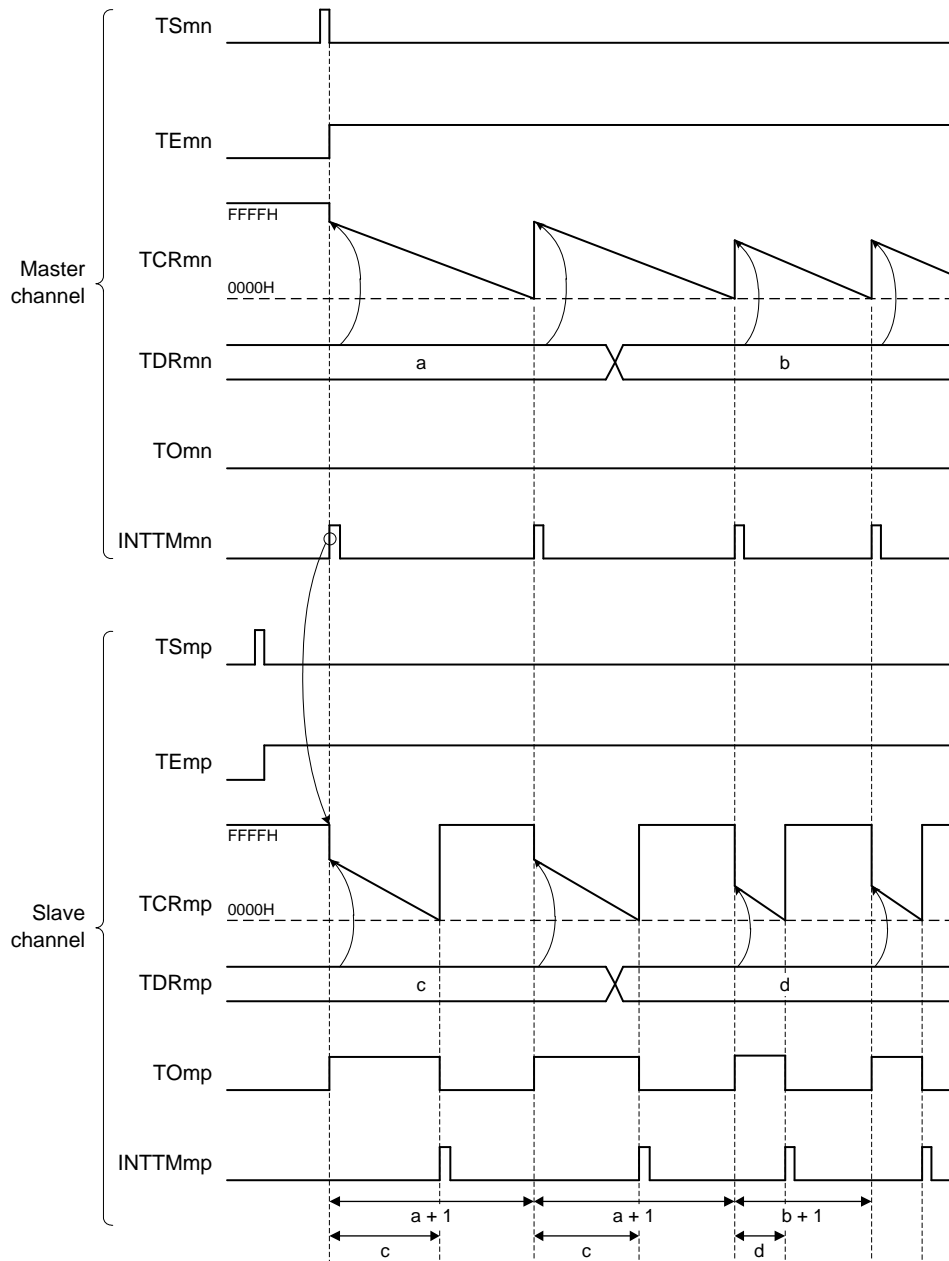
Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
p: Slave channel number (n < p ≤ 7)

Figure 6-69. Block Diagram of Operation as PWM Function



Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
 p: Slave channel number (n < p ≤ 7)

Figure 6-70. Example of Basic Timing of Operation as PWM Function

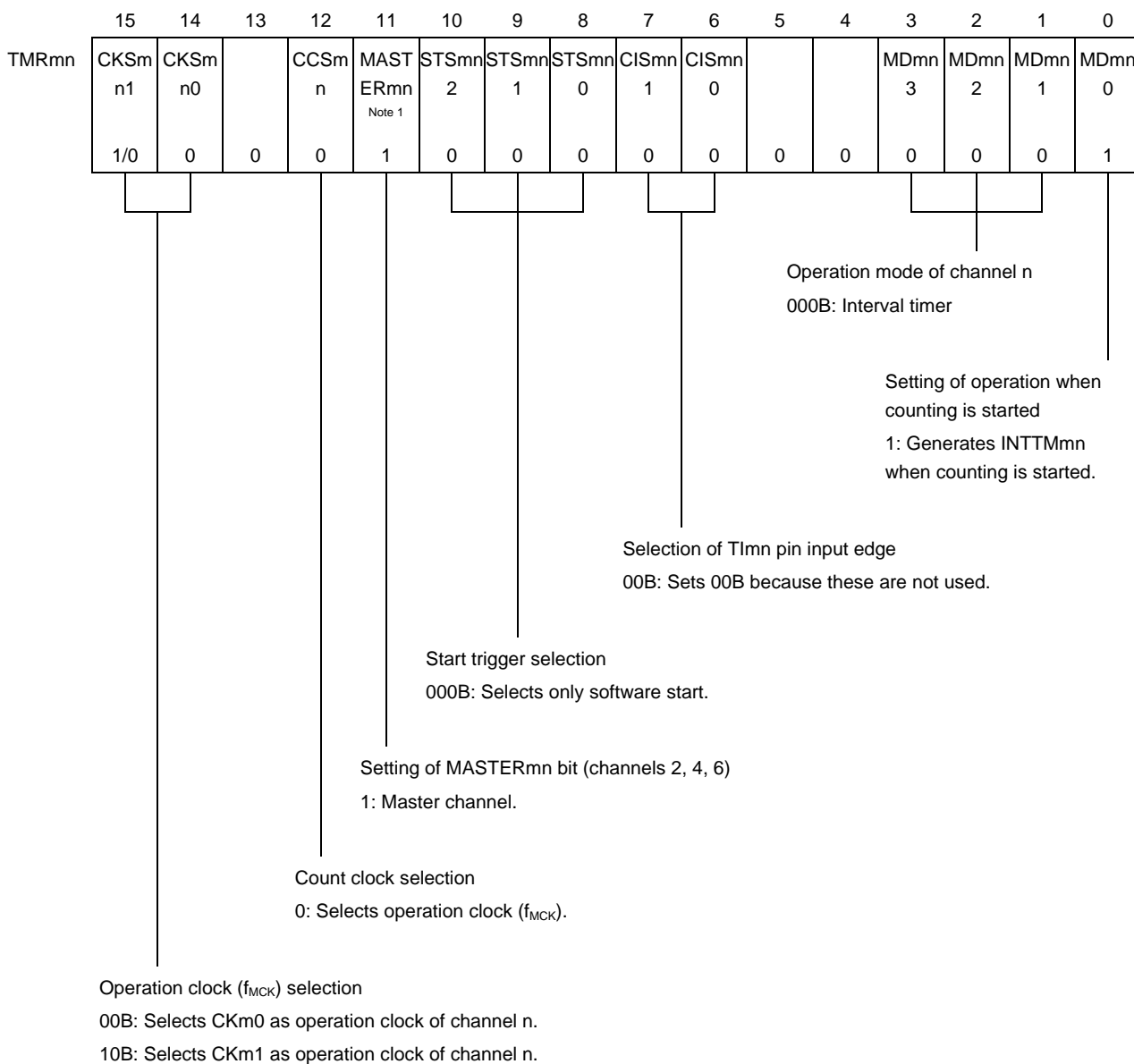


Remark 1. m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
 p: Slave channel number (n < p ≤ 7)

Remark 2. TSm_n, TSmp: Bit n, p of timer channel start register m (TSm)
 TE_{mn}, TE_{mp}: Bit n, p of timer channel enable status register m (TE_m)
 TCR_{mn}, TCR_{mp}: Timer count registers mn, mp (TCR_{mn}, TCR_{mp})
 TDR_{mn}, TDR_{mp}: Timer data registers mn, mp (TDR_{mn}, TDR_{mp})
 TO_{mn}, TO_{mp}: TO_{mn} and TO_{mp} pins output signal

Figure 6-71. Example of Set Contents of Registers When PWM Function (Master Channel) Is Used (1/2)

(a) Timer mode register mn (TMRmn)

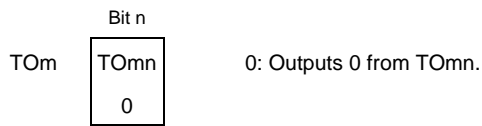


Note 1. TMRm2, TMRm4, TMRm6: MASTERmn = 1
TMRm0: Fixed to 0

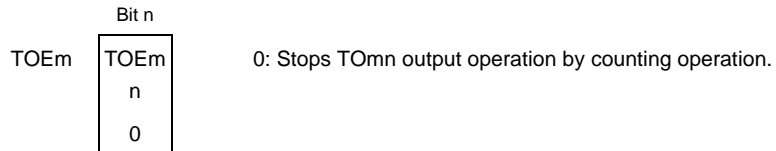
Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)

Figure 6-71. Example of Set Contents of Registers When PWM Function (Master Channel) Is Used (2/2)

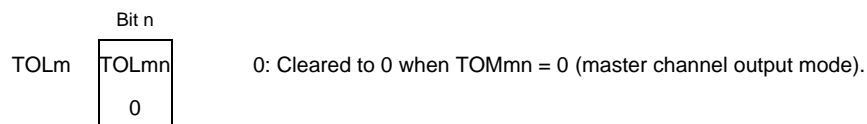
(b) Timer output register m (TOM)



(c) Timer output enable register m (TOEm)



(d) Timer output level register m (TOLm)



(e) Timer output mode register m (TOMm)

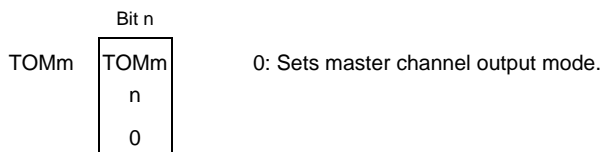
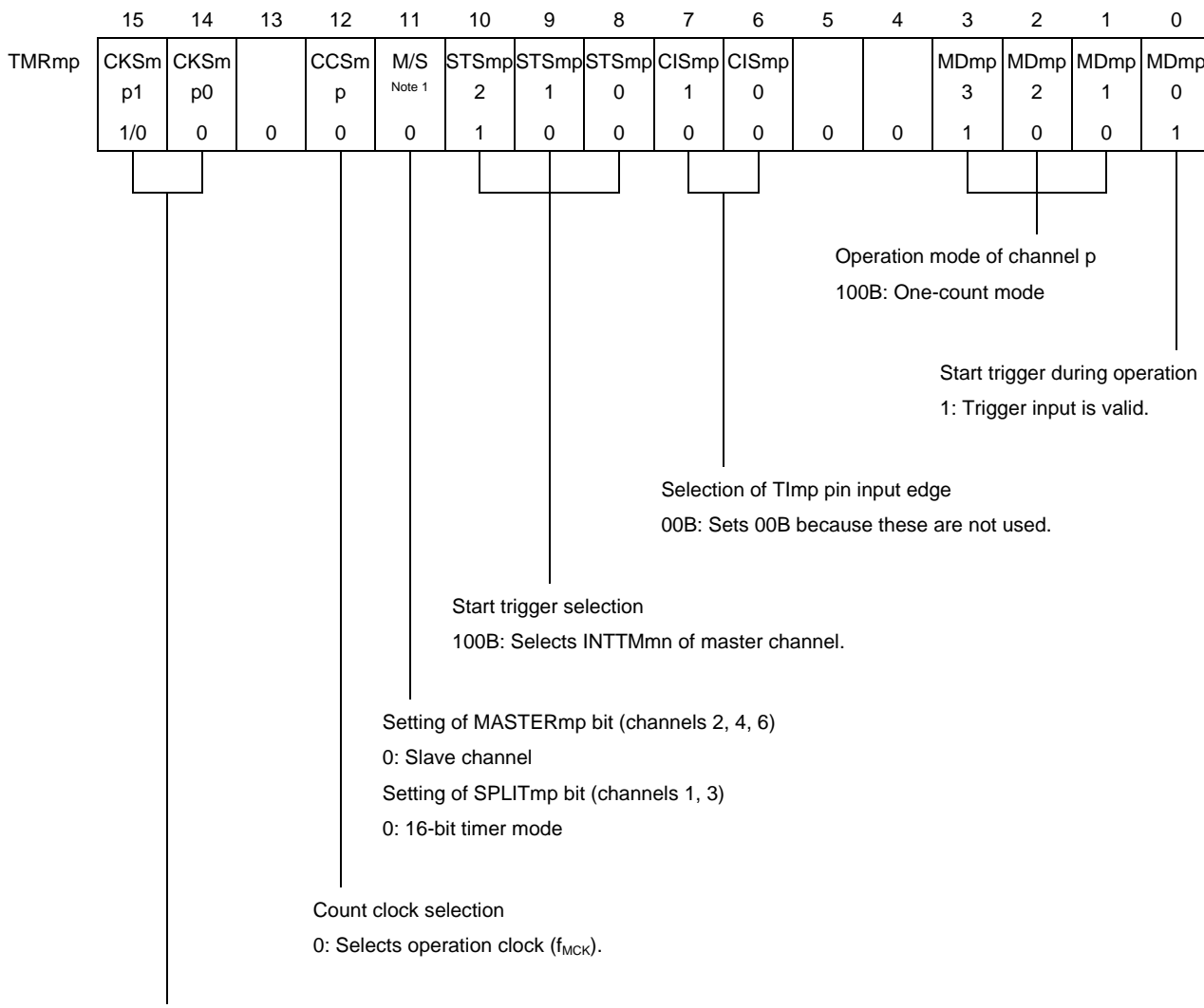
**Remark** m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)

Figure 6-72. Example of Set Contents of Registers When PWM Function (Slave Channel) Is Used (1/2)

(a) Timer mode register mp (TMRmp)



Operation clock (f_{MCK}) selection
00B: Selects CKm0 as operation clock of channel p.
10B: Selects CKm1 as operation clock of channel p.
* Make the same setting as master channel.

Note 1. TMRm2, TMRm4, TMRm6: MASTERmn bit
TMRm1, TMRm3: SPLITmp bit
TMRm5, TMRm7: Fixed to 0

Remark m: Unit number ($m = 0$), n: Master channel number ($n = 0, 2, 4, 6$)
p: Slave channel number ($n < p \leq 7$)

Figure 6-72. Example of Set Contents of Registers When PWM Function (Slave Channel) Is Used (2/2)

(b) Timer output register m (TOM)

| | | |
|-----|-------------|--|
| | Bit p | |
| TOM | TOMP 1/0 | 0: Outputs 0 from TOMP. 1: Outputs 1 from TOMP. |

(c) Timer output enable register m (TOEM)

| | | |
|------|------------------|--|
| | Bit p | |
| TOEM | TOEM P 1/0 | 0: Stops the TOMP output operation by counting operation. 1: Enables the TOMP output operation by counting operation. |

(d) Timer output level register m (TOLM)

| | | |
|------|--------------|---|
| | Bit p | |
| TOLM | TOLMP 1/0 | 0: Positive logic output (active-high) 1: Negative logic output (active-low) |

(e) Timer output mode register m (TOMM)

| | | |
|------|----------------|--|
| | Bit p | |
| TOMM | TOMM p 1 | 1: Sets the slave channel output mode. |

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
p: Slave channel number (n < p ≤ 7)

Figure 6-73. Operation Procedure When PWM Function Is Used (1/2)

| | Software Operation | Hardware Status |
|-------------------------|---|---|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to each register is disabled.) |
| | Sets the TAUmEN bit of peripheral enable register 0 (PER0) to 1. | Power-on status. Each channel stops operating. (Clock supply is started and writing to each register is enabled.) |
| | Sets timer clock select register m (TPSm). Determines clock frequencies of CKm0 and CKm1. | |
| Channel default setting | Sets timer mode register mn, mp (TMRmn, TMRmp) of two channels to be used (determines operation mode of channels). An interval (period) value is set to timer data register mn (TDRmn) of the master channel, and a duty factor is set to the TDRmp register of the slave channel. | Channel stops operating. (Clock is supplied and some power is consumed.) |
| | Sets slave channel. The TOMmp bit of timer output mode register m (TOMm) is set to 1 (slave channel output mode). Sets the TOLmp bit. Sets the TOmp bit and determines default level of the TOmp output. | The TOmp pin goes into Hi-Z output state. The TOmp default setting level is output when the port mode register is in output mode and the port register is 0. |
| | Sets the TOEmp bit to 1 and enables operation of TOmp. Clears the port register and port mode register to 0. | TOmp does not change because channel stops operating. The TOmp pin outputs the TOmp set level. |

(Remark is listed on the next page.)

Figure 6-73. Operation Procedure When PWM Function Is Used (2/2)

| | Software Operation | Hardware Status |
|-----------------------|--|--|
| Operation is resumed. | <p>Operation start</p> <p>Sets the TOEmp bit (slave) to 1 (only when operation is resumed).</p> <p>The TSmn (master) and TSmp (slave) bits of timer channel start register m (TSm) are set to 1 at the same time.</p> <p>The TSmn and TSmp bits automatically return to 0 because they are trigger bits.</p> | <p>TEmn = 1, TEmp = 1</p> <p>When the master channel starts counting, INTTMmn is generated. Triggered by this interrupt, the slave channel also starts counting.</p> |
| | <p>During operation</p> <p>Set values of the TMRmn and TMRmp registers, TOMmn, TOMmp, TOLmn, and TOLmp bits cannot be changed.</p> <p>Set values of the TDRmn and TDRmp registers can be changed after INTTMmn of the master channel is generated.</p> <p>The TCRmn and TCRmp registers can always be read.</p> <p>The TSRmn and TSRmp registers are not used.</p> | <p>Master channel loads the value of the TDRmn register to timer count register mn (TCRmn), and the counter starts counting down. When the count value reaches TCRmn = 0000H, INTTMmn output is generated. At the same time, the value of the TDRmn register is loaded to the TCRmn register, and the counter starts counting down again.</p> <p>At the slave channel, the value of the TDRmp register is loaded to the TCRmp register, triggered by INTTMmn of the master channel, and the counter starts counting down. The output level of TOmp becomes active one count clock after generation of the INTTMmn output from the master channel. It becomes inactive when TCRmp = 0000H, and the counting operation is stopped.</p> <p>After that, the above operation is repeated.</p> |
| Operation stop | <p>The TTmn (master) and TTmp (slave) bits are set to 1 at the same time.</p> <p>The TTmn and TTmp bits automatically return to 0 because they are trigger bits.</p> | <p>TEmn, TEmp = 0, and count operation stops.</p> <p>The TCRmn and TCRmp registers hold count value and stop.</p> <p>The TOmp output is not initialized but holds current status.</p> |
| | <p>The TOEmp bit of slave channel is cleared to 0 and value is set to the TOmp bit.</p> | <p>The TOmp pin outputs the TOmp set level.</p> |
| TAU stop | <p>To hold the TOmp pin output level</p> <p>Clears the TOmp bit to 0 after the value to be held is set to the port register.</p> <p>When holding the TOmp pin output level is not necessary</p> <p>Setting not required.</p> | <p>The TOmp pin output level is held by port function.</p> |
| | <p>The TAUEN bit of the PER0 register is cleared to 0.</p> | <p>Power-off status</p> <p>All circuits are initialized and SFR of each channel is also initialized.</p> <p>(The TOmp bit is cleared to 0 and the TOmp pin is set to port mode)</p> |

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4, 6)
 p: Slave channel number (n < p ≤ 7)

6.9.3 Operation as multiple PWM output function

By extending the PWM function and using multiple slave channels, many PWM waveforms with different duty values can be output.

For example, when using two slave channels, the period and duty factor of an output pulse can be calculated by the following expressions.

$$\text{Pulse period} = \{\text{Set value of TDRmn (master)} + 1\} \times \text{Count clock period}$$

$$\text{Duty factor 1[\%]} = \{\text{Set value of TDRmp (slave 1)}\} / \{\text{Set value of TDRmn (master)} + 1\} \times 100$$

$$\text{Duty factor 2[\%]} = \{\text{Set value of TDRmq (slave 2)}\} / \{\text{Set value of TDRmn (master)} + 1\} \times 100$$

Remark Although the duty factor exceeds 100% if the set value of TDRmp (slave 1) > {set value of TDRmn (master) + 1} or if the {set value of TDRmq (slave 2)} > {set value of TDRmn (master) + 1}, it is summarized into 100% output.

Timer count register mn (TCRmn) of the master channel operates in the interval timer mode and counts the periods.

The TCRmp register of the slave channel 1 operates in one-count mode, counts the duty factor, and outputs a PWM waveform from the TOmp pin. The TCRmp register loads the value of timer data register mp (TDRmp), using INTTMmn of the master channel as a start trigger, and starts counting down. When TCRmp = 0000H, TCRmp outputs INTTMmp and stops counting until the next start trigger (INTTMmn of the master channel) has been input. The output level of TOmp becomes active one count clock after generation of INTTMmn from the master channel, and inactive when TCRmp = 0000H.

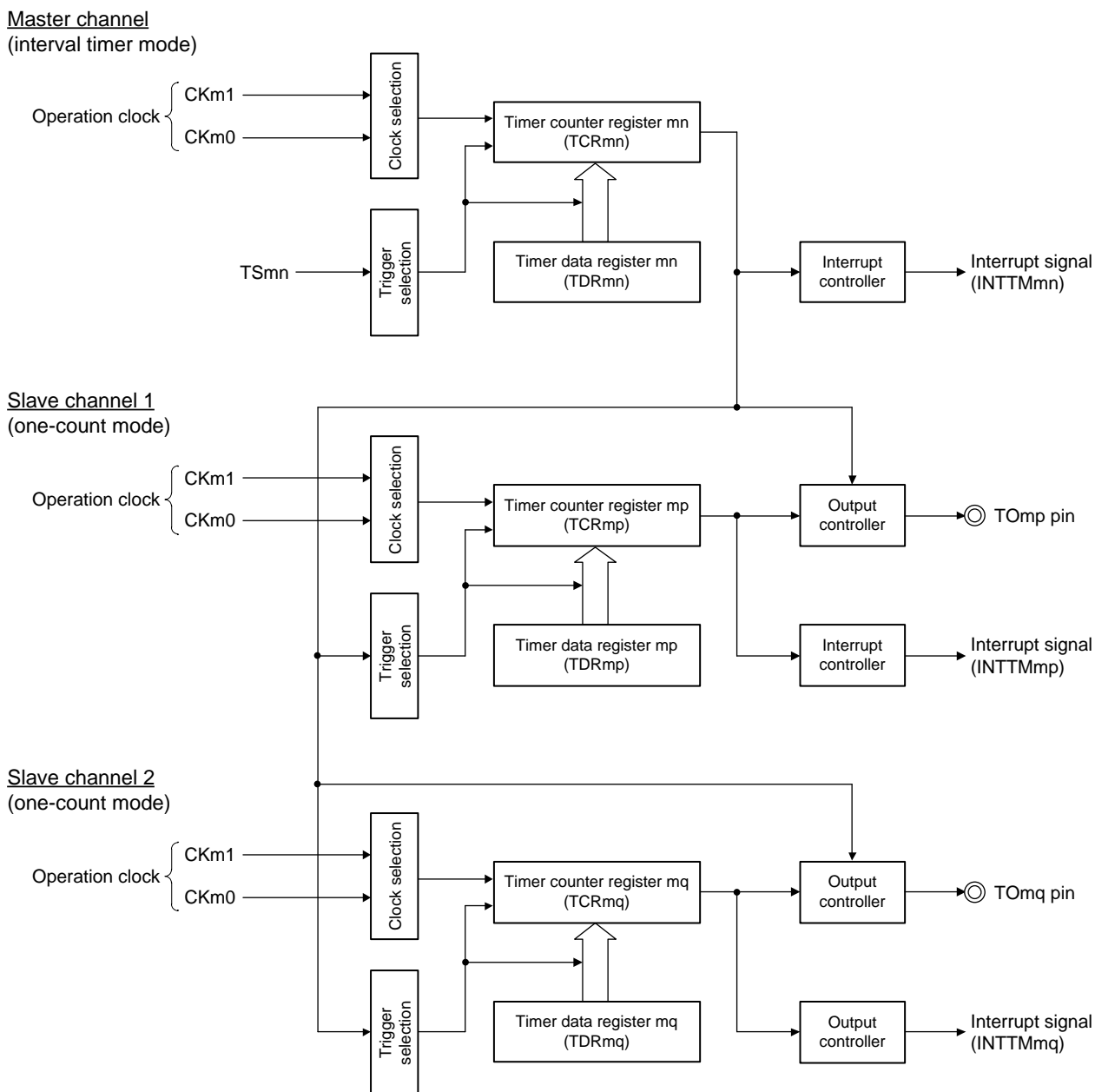
In the same way as the TCRmp register of the slave channel 1, the TCRmq register of the slave channel 2 operates in one-count mode, counts the duty factor, and outputs a PWM waveform from the TOMq pin. The TCRmq register loads the value of the TDRmq register, using INTTMmn of the master channel as a start trigger, and starts counting down. When TCRmq = 0000H, the TCRmq register outputs INTTMmq and stops counting until the next start trigger (INTTMmn of the master channel) has been input. The output level of TOMq becomes active one count clock after generation of INTTMmn from the master channel, and inactive when TCRmq = 0000H.

When channel 0 is used as the master channel as above, up to seven types of PWM signals can be output at the same time.

Caution To rewrite both timer data register mn (TDRmn) of the master channel and the TDRmp register of the slave channel 1, write access is necessary at least twice. Since the values of the TDRmn and TDRmp registers are loaded to the TCRmn and TCRmp registers after INTTMmn is generated from the master channel, if rewriting is performed separately before and after generation of INTTMmn from the master channel, the TOmp pin cannot output the expected waveform. To rewrite both the TDRmn register of the master and the TDRmp register of the slave, be sure to rewrite both the registers immediately after INTTMmn is generated from the master channel (This applies also to the TDRmq register of the slave channel 2).

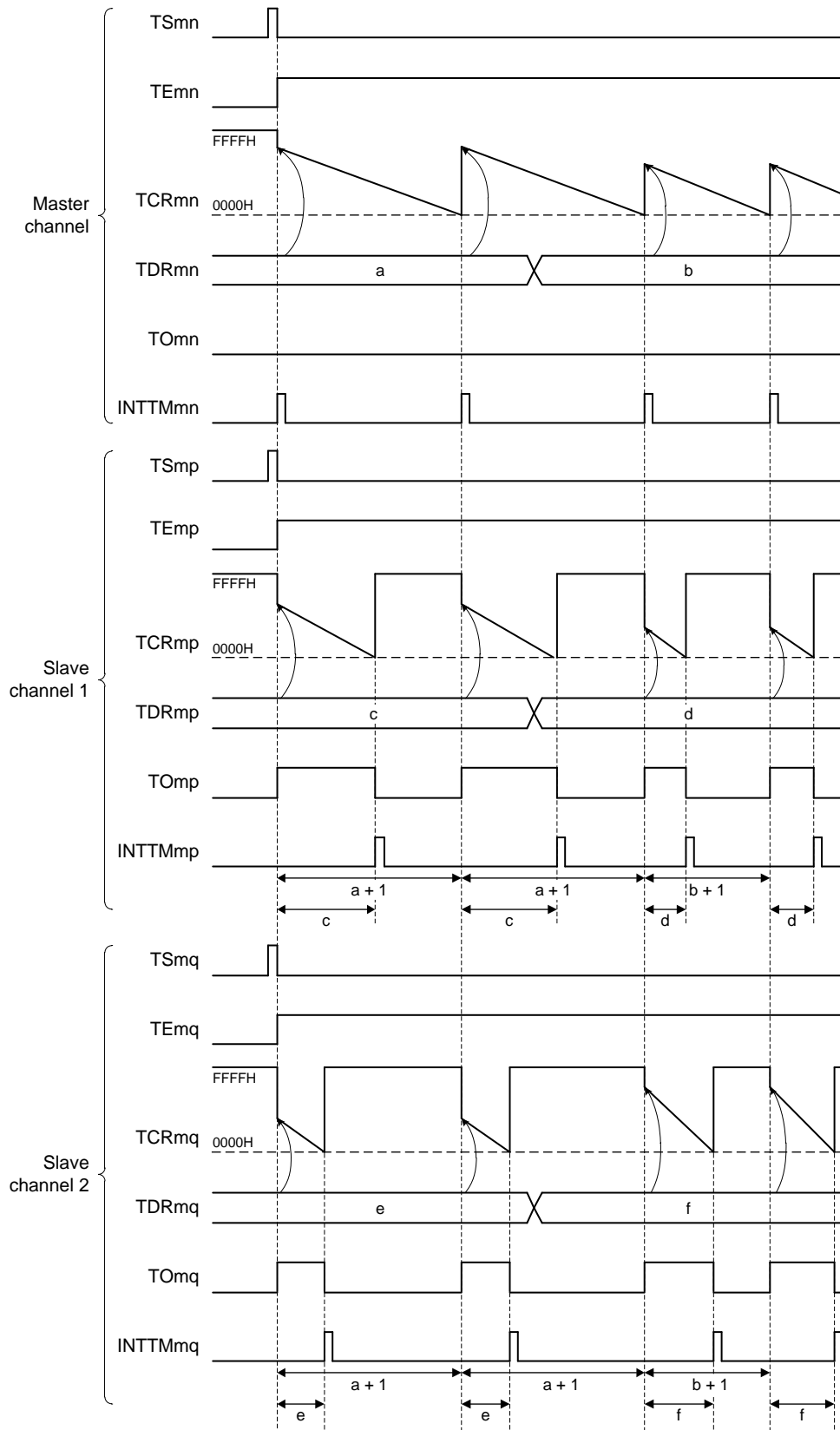
Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4)
 p: Slave channel number, q: Slave channel number
 n < p < q ≤ 7 (Where p and q are integers greater than n)

Figure 6-74. Block Diagram of Operation as Multiple PWM Output Function (Output Two Types of PWMs)



Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4)
 p: Slave channel number, q: Slave channel number
 n < p < q ≤ 7 (Where p and q are integers greater than n)

Figure 6-75. Example of Basic Timing of Operation as Multiple PWM Output Function (Output Two Types of PWMs)

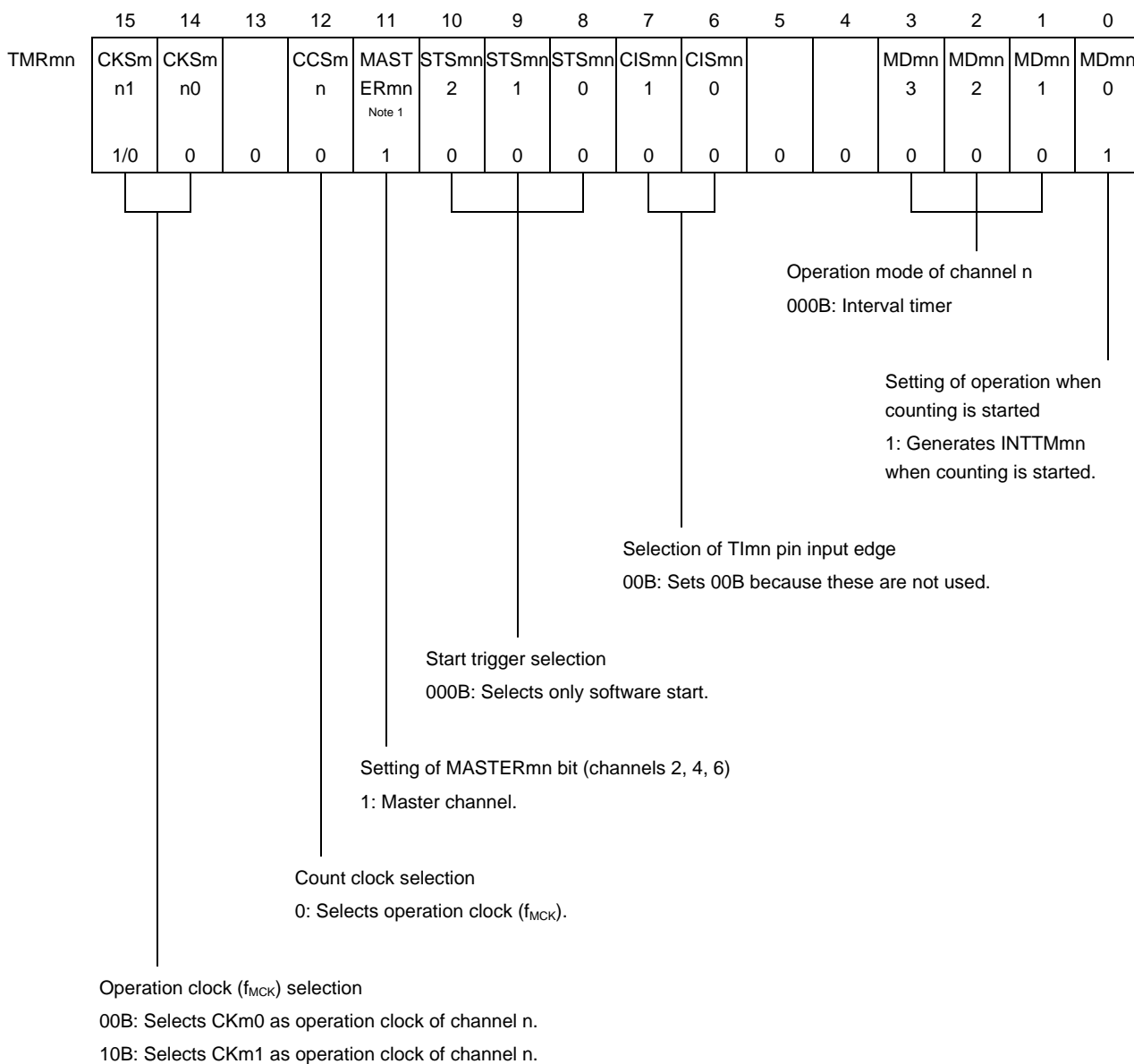


(Remarks are listed on the next page.)

- Remark 1.** m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4)
p: Slave channel number, q: Slave channel number
n < p < q ≤ 7 (Where p and q are integers greater than n)
- Remark 2.** TSmn, TSmp, TSmq: Bit n, p, q of timer channel start register m (TSm)
TEmn, TEmq, TEmq: Bit n, p, q of timer channel enable status register m (TEm)
TCRmn, TCRmp, TCRmq: Timer count registers mn, mp, mq (TCRmn, TCRmp, TCRmq)
TDRmn, TDRmp, TDRmq: Timer data registers mn, mp, mq (TDRmn, TDRmp, TDRmq)
TOmn, TOmp, TOmq: TOmn, TOmp, and TOmq pins output signal

Figure 6-76. Example of Set Contents of Registers When Multiple PWM Output Function (Master Channel) Is Used (1/2)

(a) Timer mode register mn (TMRmn)

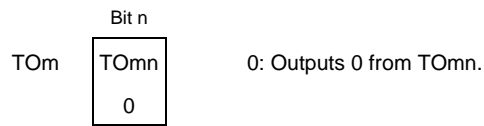


Note 1. TMRm2, TMRm4, TMRm6: MASTERmn = 1
TMRm0: Fixed to 0

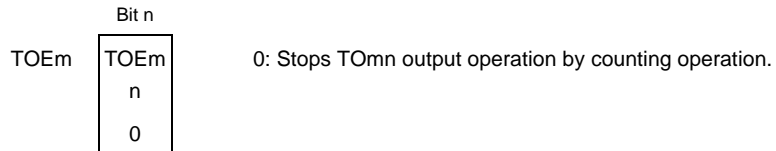
Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4)

Figure 6-76. Example of Set Contents of Registers When Multiple PWM Output Function (Master Channel) Is Used (2/2)

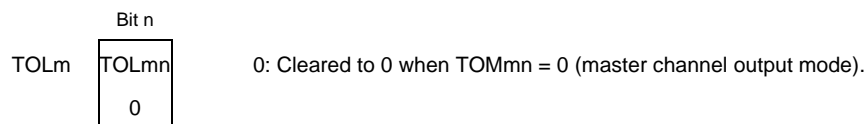
(b) Timer output register m (TOM)



(c) Timer output enable register m (TOEm)



(d) Timer output level register m (TOLm)



(e) Timer output mode register m (TOMm)

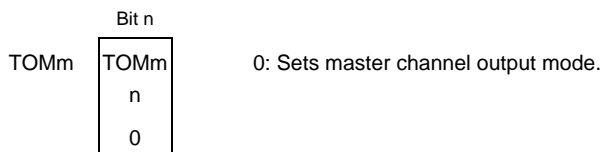
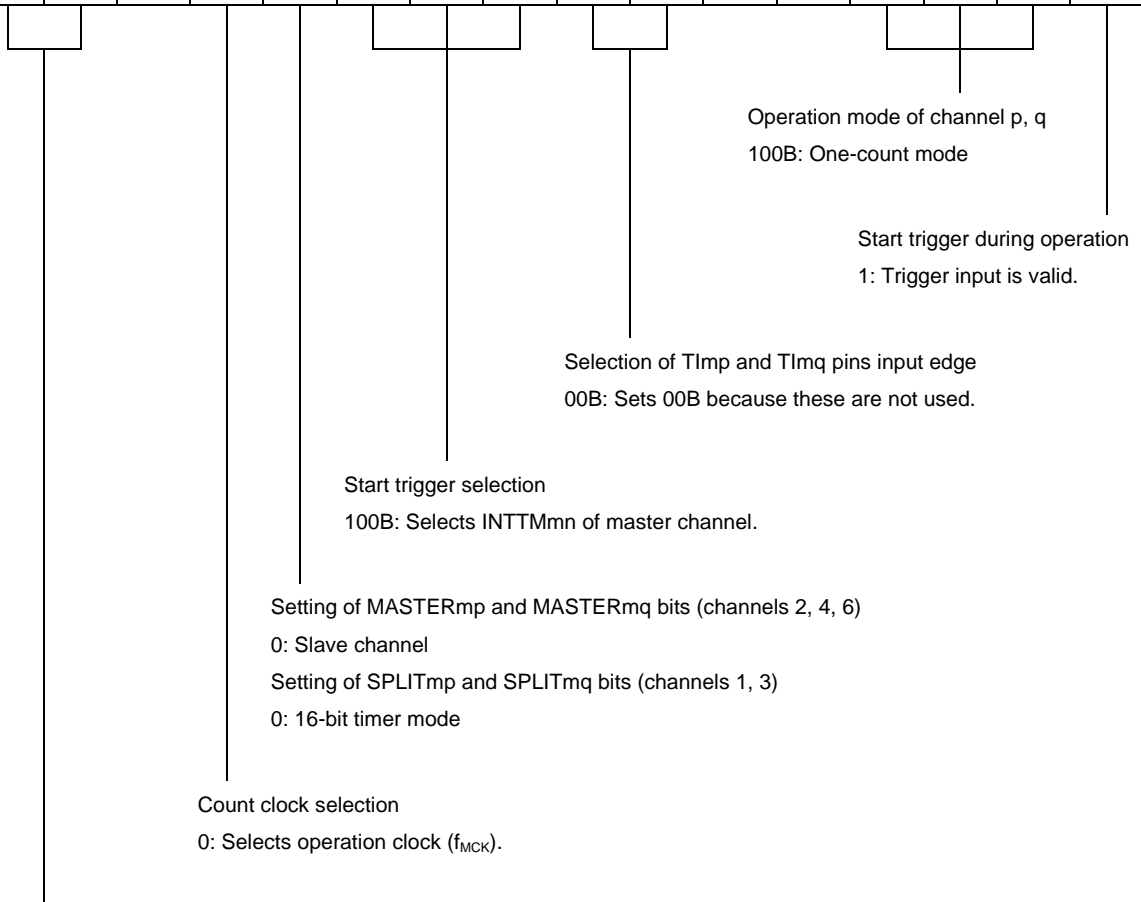
**Remark** m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4)

Figure 6-77. Example of Set Contents of Registers When Multiple PWM Output Function (Slave Channel) Is Used
(Output Two Types of PWMs) (1/2)

(a) Timer mode register mp, mq (TMRmp, TMRmq)

| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------|------|------|----|------|--------|-------------------|-------------------|-------------------|-------|-------|---|---|------|------|------|------|
| TMRmp | CKSm | CKSm | | CCSm | M/S | STSm _p | STSm _p | STSm _p | CISmp | CISmp | | | MDmp | MDmp | MDmp | MDmp |
| | p1 | p0 | | p | Note 1 | 2 | 1 | 0 | 1 | 0 | | | 3 | 2 | 1 | 0 |
| | 1/0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| TMRmq | CKSm | CKSm | | CCSm | M/S | STSm _q | STSm _q | STSm _q | CISmq | CISmq | | | MDmq | MDmq | MDmq | MDmq |
| | q1 | q0 | | q | Note 1 | 2 | 1 | 0 | 1 | 0 | | | 3 | 2 | 1 | 0 |
| | 1/0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |



Operation clock (f_{mck}) selection
 00B: Selects CKm0 as operation clock of channel p, q.
 10B: Selects CKm1 as operation clock of channel p, q.
 * Make the same setting as master channel.

Note 1. TMRm2, TMRm4, TMRm6: MASTERmp, MASTERmq bit
 TMRm1, TMRm3: SPLITmp, SPLITmq bit
 TMRm5, TMRm7: Fixed to 0

Remark m: Unit number ($m = 0$), n: Master channel number ($n = 0, 2, 4$)
 p: Slave channel number, q: Slave channel number
 $n < p < q \leq 7$ (Where p and q are integers greater than n)

Figure 6-77. Example of Set Contents of Registers When Multiple PWM Output Function (Slave Channel) Is Used
(Output Two Types of PWMs) (2/2)

(b) Timer output register m (TOM)

| | Bit q | Bit p | |
|-----|-------|-------|---------------------------------|
| TOM | TOmq | TOmp | 0: Outputs 0 from TOmp or TOmq. |
| | 1/0 | 1/0 | 1: Outputs 1 from TOmp or TOmq. |

(c) Timer output enable register m (TOEm)

| | Bit q | Bit p | |
|------|-------|-------|---|
| TOEm | TOEq | TOEp | 0: Stops the TOmp or TOmq output operation by counting operation. |
| | q | p | 1: Enables the TOmp or TOmq output operation by counting operation. |
| | 1/0 | 1/0 | |

(d) Timer output level register m (TOLm)

| | Bit q | Bit p | |
|------|-------|-------|--|
| TOLm | TOLmq | TOLmp | 0: Positive logic output (active-high) |
| | 1/0 | 1/0 | 1: Negative logic output (active-low) |

(e) Timer output mode register m (TOMm)

| | Bit q | Bit p | |
|------|-------|-------|--|
| TOMm | TOMmq | TOMmp | 1: Sets the slave channel output mode. |
| | q | p | |
| | 1 | 1 | |

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4)

p: Slave channel number, q: Slave channel number

n < p < q ≤ 7 (Where p and q are integers greater than n)

Figure 6-78. Operation Procedure When Multiple PWM Output Function Is Used (Output Two Types of PWMs) (1/3)

| | Software Operation | Hardware Status |
|-------------------------|---|---|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to each register is disabled.) |
| | Sets the TAUmEN bit of peripheral enable register 0 (PER0) to 1. → | Power-on status. Each channel stops operating. (Clock supply is started and writing to each register is enabled.) |
| | Sets timer clock select register m (TPSm). Determines clock frequencies of CKm0 and CKm1. | |
| Channel default setting | Sets timer mode registers mn, mp, mq (TMRmn, TMRmp, TMRmq) of each channel to be used (determines operation mode of channels). An interval (period) value is set to timer data register mn (TDRmn) of the master channel, and a duty factor is set to the TDRmp and TDRmq registers of the slave channels. | Channel stops operating. (Clock is supplied and some power is consumed.) |
| | Sets slave channel. The TOMmp and TOMmq bits of timer output mode register m (TOMm) are set to 1 (slave channel output mode). Sets the TOLmp and TOLmq bits. Sets the TOmp and TOmq bits and determines default level of the TOmp and TOmq outputs. → Sets the TOEmp and TOEmq bits to 1 and enables operation of TOmp and TOmq. → Clears the port register and port mode register to 0. → | The TOmp and TOmq pins go into Hi-Z output state. The TOmp and TOmq default setting levels are output when the port mode register is in output mode and the port register is 0. TOmp and TOmq do not change because channels stop operating. The TOmp and TOmq pins output the TOmp and TOmq set levels. |

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4)
 p: Slave channel number, q: Slave channel number
 n < p < q ≤ 7 (Where p and q are a consecutive integer greater than n)

Figure 6-78. Operation Procedure When Multiple PWM Output Function Is Used (Output Two Types of PWMs) (2/3)

| | Software Operation | Hardware Status |
|-----------------------|---|--|
| Operation is resumed. | <p>Operation start</p> <p>(Sets the TOEmp and TOEmq (slave) bits to 1 only when resuming operation.)</p> <p>The TSmn bit (master), and TSmp and TSmq (slave) bits of timer channel start register m (TSm) are set to 1 at the same time. →</p> <p>The TSmn, TSmp, and TSmq bits automatically return to 0 because they are trigger bits.</p> | <p>TEmn = 1, TEmq = 1</p> <p>When the master channel starts counting, INTTMmn is generated. Triggered by this interrupt, the slave channel also starts counting.</p> |
| | <p>During operation</p> <p>Set values of the TMRmn, TMRmp, TMRmq registers, TOMmn, TOMmp, TOMmq, TOLmn, TOLmp, and TOLmq bits cannot be changed.</p> <p>Set values of the TDRmn, TDRmp, and TDRmq registers can be changed after INTTMmn of the master channel is generated.</p> <p>The TCRmn, TCRmp, and TCRmq registers can always be read.</p> <p>The TSRmn, TSRmp, and TSRmq registers are not used.</p> | <p>Master channel loads the value of the TDRmn register to timer count register mn (TCRmn), and the counter starts counting down. When the count value reaches TCRmn = 0000H, INTTMmn output is generated. At the same time, the value of the TDRmn register is loaded to the TCRmn register, and the counter starts counting down again.</p> <p>At the slave channel 1, the values of the TDRmp register are transferred to the TCRmp register, triggered by INTTMmn of the master channel, and the counter starts counting down. The output levels of TOmp become active one count clock after generation of the INTTMmn output from the master channel. It becomes inactive when TCRmp = 0000H, and the counting operation is stopped.</p> <p>At the slave channel 2, the values of the TDRmq register are transferred to TCRmq register, triggered by INTTMmn of the master channel, and the counter starts counting down. The output levels of TOMq become active one count clock after generation of the INTTMmn output from the master channel. It becomes inactive when TCRmq = 0000H, and the counting operation is stopped. After that, the above operation is repeated.</p> |
| | <p>Operation stop</p> <p>The TTmn (master), TTmp, and TTmq (slave) bits are set to 1 at the same time. →</p> <p>The TTmn, TTmp, and TTmq bits automatically return to 0 because they are trigger bits.</p> | <p>TEmn, TEmq = 0, and count operation stops.</p> <p>The TCRmn, TCRmp, and TCRmq registers hold count value and stop.</p> <p>The TOmp and TOMq output are not initialized but hold current status.</p> |
| | <p>The TOEmp and TOEmq bits of slave channels are cleared to 0 and value is set to the TOmp and TOMq bits. →</p> | <p>The TOmp and TOMq pins output the TOmp and TOMq set levels.</p> |

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4)
 p: Slave channel number, q: Slave channel number
 n < p < q ≤ 7 (Where p and q are a consecutive integer greater than n)

Figure 6-78. Operation Procedure When Multiple PWM Output Function Is Used (Output Two Types of PWMs) (3/3)

| | Software Operation | Hardware Status |
|----------|---|---|
| TAU stop | To hold the TOmp and TOMq pin output levels Clears the TOmp, TOMq bits to 0 after the value to be held is set to the port register. → When holding the TOmp and TOMq pin output levels are not necessary Setting not required. | The TOmp and TOMq pin output levels are held by port function. |
| | The TAUmEN bit of the PER0 register is cleared to 0. → | Power-off status All circuits are initialized and SFR of each channel is also initialized. (The TOmp and TOMq bits are cleared to 0 and the TOmp and TOMq pins are set to port mode.) |

Remark m: Unit number (m = 0), n: Master channel number (n = 0, 2, 4)
 p: Slave channel number, q: Slave channel number
 n < p < q ≤ 7 (Where p and q are a consecutive integer greater than n)

6.9.4 Operation as two-channel input with one-shot pulse output function

By using signal input to two pins (TI0n and TI0p), a one-shot pulse having any delay pulse width can be generated.

The delay (output delay time) and one-shot pulse width can be calculated by the following expressions.

$$\text{Delay time} = \{\text{Set value of TDR0n (master)} + 2\} \times \text{count clock period}$$

$$\text{One-shot pulse active-level width} =$$

$$\text{count clock period} \times ((10000\text{H} + \text{TSR0p: OVF}) + (\text{capture value of TDR0p (slave)} + 1))$$

Caution The TI0n and TI0p pin inputs are each sampled using the operation clock (f_{MCK}) selected with the CKS0n1 bit of the timer mode register 0n (TMR0n), so an error of one cycle of the operation clock (f_{MCK}) per pin occurs.

The master channel should be operated in the one-count mode to start counting the delays (output delay time) upon detection of a valid edge of the master channel TI0n pin input used as the start trigger. Upon detection of a start trigger (valid edge of TI0n pin input), the master channel loads the value of timer data register 0n (TDR0n) to the timer count register 0n (TCR0n), and performs counting down in synchronization with the count clock (f_{CLK}). When TCR0n = 0000H, the master channel outputs INTTM0n and outputs the active level from the TO0p pin. It stops counting until the next start trigger is detected.

The slave channel should be operated in the capture mode to set the one-shot pulse to the inactive level upon detection of a valid edge of the slave channel TI0p pin input used as the end trigger.

Upon detection of an end trigger (valid edge of TI0p pin input), the slave channel transfers (captures) the count value of the TCR0p register to the TDR0p register, and clears it to 0000H. Simultaneously, the slave channel outputs INTTM0p and the inactive level from the TO0p pin. Here, if the counter overflow has occurred, the OVF bit in the timer status register 0p (TSR0p) is set; if not, the OVF bit is cleared. After this, the same steps are repeated.

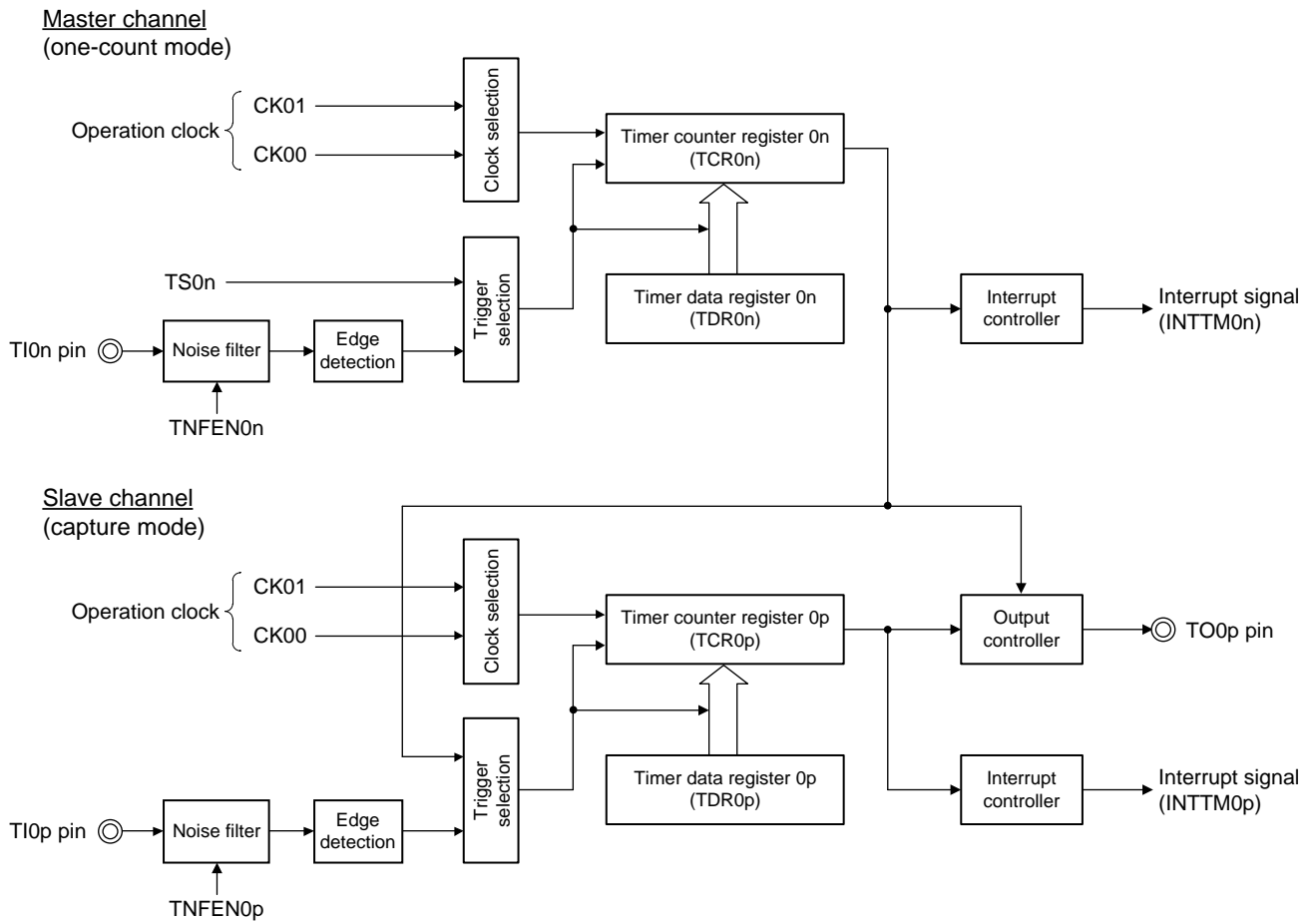
When the count value is captured to the TDR0p register, the OVF bit in the TSR0p register is updated depending on the overflow status during the active level period, which allows the overflow status of the captured value to be checked.

If the counter reaches a full count for two or more periods, it is judged to be an overflow occurrence, and the OVF bit of the TSR0p register is set to 1. However, a normal interval value cannot be measured for the OVF bit, if two or more overflows occur.

Instead of using the TI0n pin input, the software operation (TS0n = 1) can be used as a start trigger for the master channel startup detection.

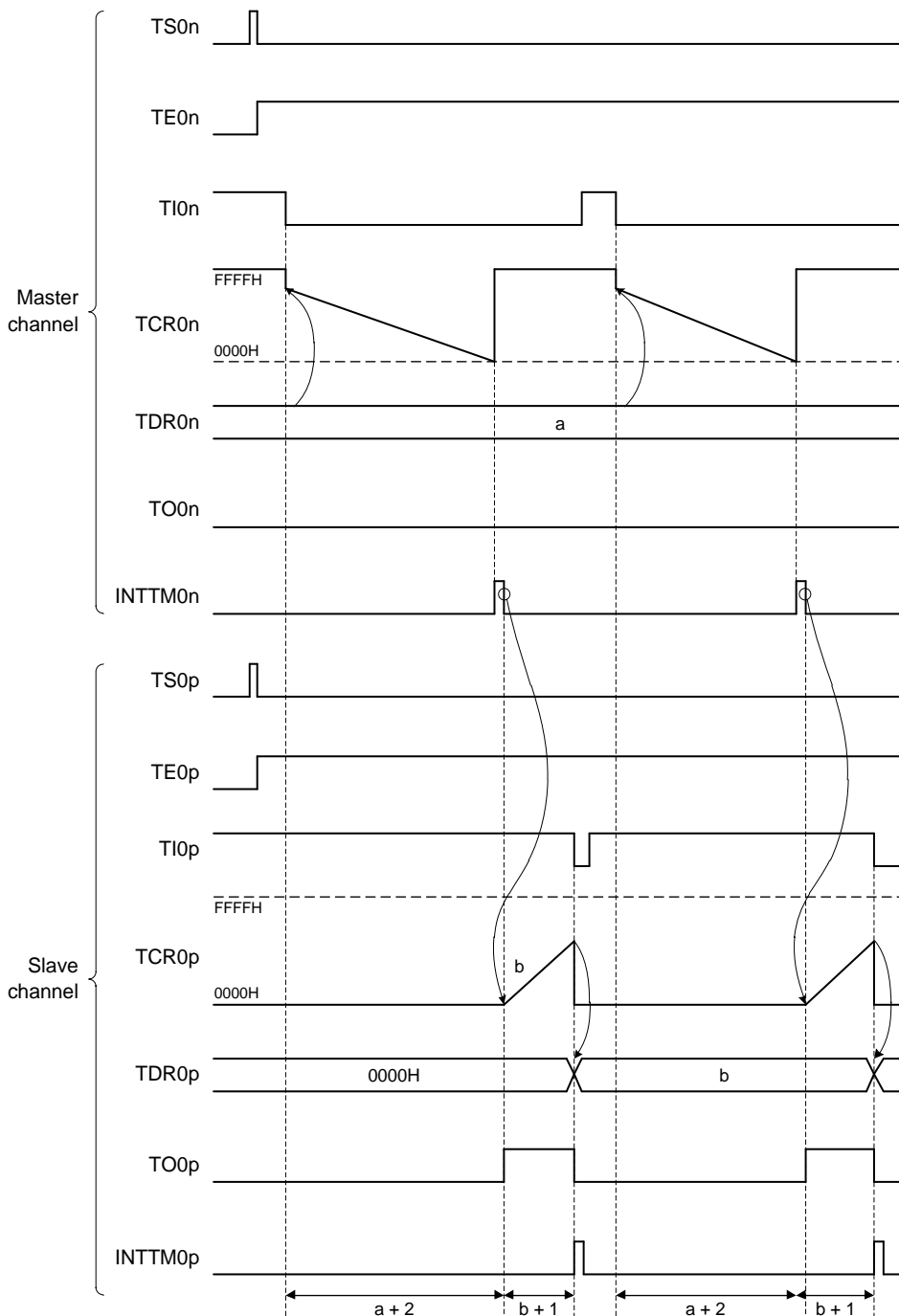
Remark n: Master channel number (n = 0, 2), p: Slave channel number (p = 3)

Figure 6-79. Block Diagram of Operation for Two-channel Input with One-shot Pulse Output Function



Remark n: Master channel number (n = 0, 2)
 p: Slave channel number (p = 3)

Figure 6-80. Example of Basic Timing of Operation for Two-channel Input with One-shot Pulse Output Function

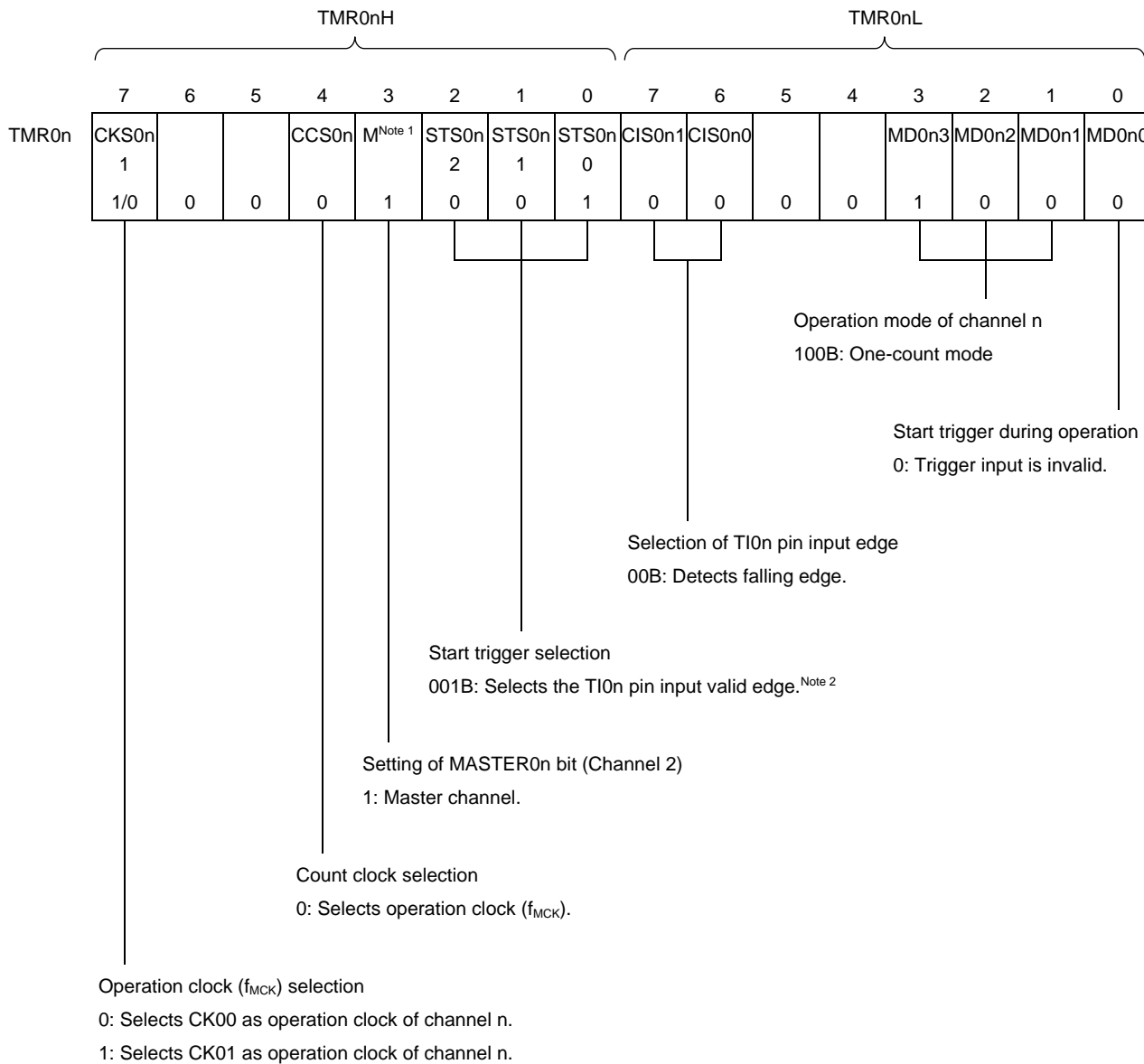


Remark 1. n: Master channel number (n = 0, 2)
 p: Slave channel number (p = 3)

Remark 2. TS0n, TS0p: Bit n, p of timer channel start register 0 (TS0)
 TE0n, TE0p: Bit n, p of timer channel enable status register 0 (TE0)
 TI0n, TI0p: TI0n and TI0p pins input signal
 TCR0n, TCR0p: Timer count registers 0n, 0p (TCR0n, TCR0p)
 TDR0n, TDR0p: Timer data registers 0n, 0p (TDR0n, TDR0p)
 TO0n, TO0p: TO0n and TO0p pins output signal

Figure 6-81. Example of Set Contents of Registers for Two-channel Input with One-shot Pulse Output Function
(Master Channel) (1/2)

(a) Timer mode register 0n (TMR0nH, TMR0nL)



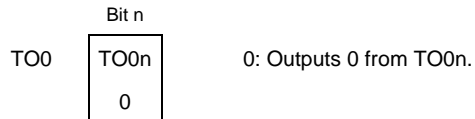
Note 1. TMR02: MASTER02 bit
TMR00: 0 fixed

Note 2. A software operation (TS0n = 1) can be used as a start trigger, instead of using the TI0n pin input.

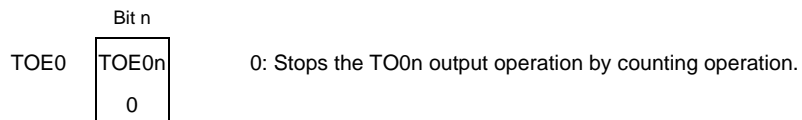
Remark n: Master channel number (n = 0, 2)

Figure 6-81. Example of Set Contents of Registers for Two-channel Input with One-shot Pulse Output Function
(Master Channel) (2/2)

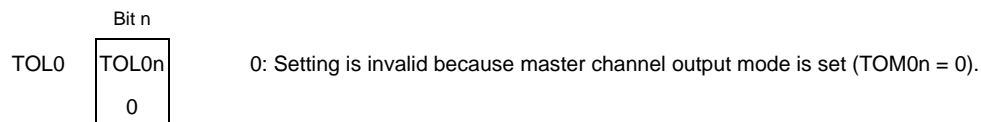
(b) Timer output register 0 (TO0)



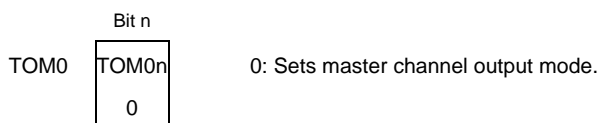
(c) Timer output enable register 0 (TOE0)



(d) Timer output level register 0 (TOL0)



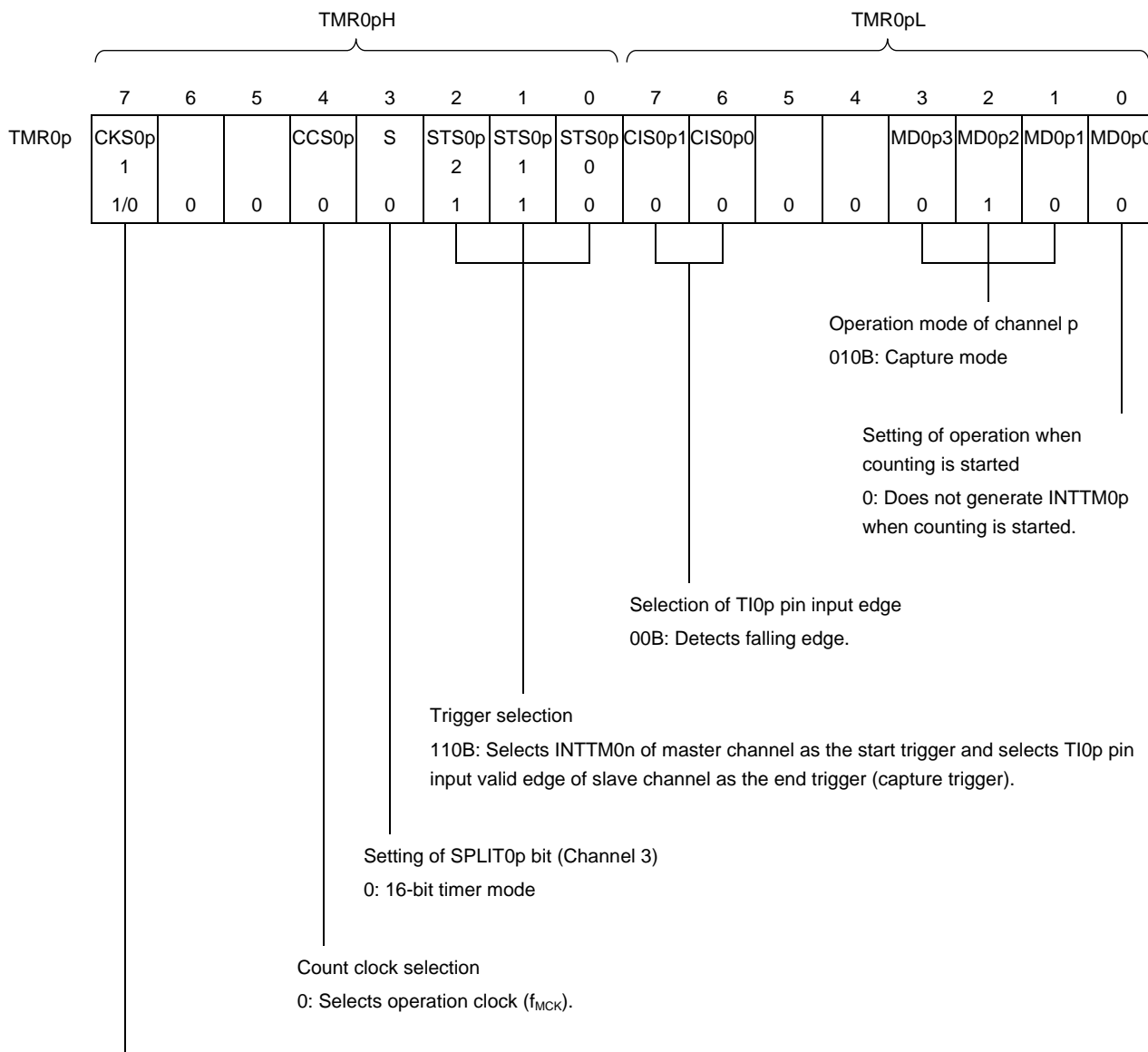
(e) Timer output mode register 0 (TOM0)



Remark n: Master channel number (n = 0, 2)

Figure 6-82. Example of Set Contents of Registers for Two-channel Input with One-shot Pulse Output Function
(Slave Channel) (1/2)

(a) Timer mode register 0p (TMR0pH, TMR0pL)



Operation clock (f_{MCK}) selection
0: Selects CK00 as operation clock of channel p.
1: Selects CK01 as operation clock of channel p.
* Make the same setting as master channel.

Remark n: Master channel number (n = 0, 2)
p: Slave channel number (p = 3)

Figure 6-82. Example of Set Contents of Registers for Two-channel Input with One-shot Pulse Output Function
(Slave Channel) (2/2)

(b) Timer output register 0 (TO0)

| | | |
|-----|-------------|---|
| | Bit p | |
| TO0 | TO0p 1/0 | <p>0: Outputs 0 from TO0p.</p> <p>1: Outputs 1 from TO0p.</p> |

(c) Timer output enable register 0 (TOE0)

| | | |
|------|--------------|---|
| | Bit p | |
| TOE0 | TOE0p 1/0 | <p>0: Stops the TO0p output operation by counting operation (the level set in the TO0p bit is output from the TO0p pin).</p> <p>1: Enables the TO0p output operation by counting operation (output from the TO0p pin is toggled).</p> |

(d) Timer output level register 0 (TOL0)

| | | |
|------|--------------|--|
| | Bit p | |
| TOL0 | TOL0p 1/0 | <p>0: Positive logic output (active-high)</p> <p>1: Negative logic output (active-low)</p> |

(e) Timer output mode register 0 (TOM0)

| | | |
|------|------------|---|
| | Bit p | |
| TOM0 | TOM0p 1 | <p>1: Sets the slave channel output mode.</p> |

Remark p: Slave channel number (p = 3)

Figure 6-83. Operation Procedure of Two-channel Input with One-shot Pulse Output Function (1/2)

| | Software Operation | Hardware Status |
|-------------------------|--|---|
| TAU default setting | | Power-off status (Clock supply is stopped and writing to SFR of the TAU is disabled.) |
| | Sets the TAU0EN bit of peripheral enable registers 0 (PER0) to 1 (when the TAU0EN bit is 0, read/write operation is disabled). | Power-on status. Each channel stops operating. (Clock supply is started and writing to SFR of the TAU is enabled.) |
| | Sets timer clock select register 0 (TPS0). Determines operation clock (CK00 and CK01) for each channel. | |
| Channel default setting | Sets noise filter enable register 1 (NFEN1). Sets timer mode register 0n, p (TMR0n, TMR0p) (determines operation mode for each channel and selects the detection edge). | Channel stops operating. |
| | <p>Sets master channel</p> <p>Sets delay (output delay time) to timer data register 0n (TDR0n) (for the access procedure to the TDR0nH and TDR0nL registers, see 6.2.2 Timer data register mn (TDRmn)). Clears the target bit of timer output mode register 0 (TOM0) to 0 (master channel output mode).</p> <p>Clears the target bit of the TOL0 register to 0.</p> <p>Clears the target bit of the timer output enable register 0 (TOE0) to 0.</p> <p>Sets slave channel.</p> <p>Sets the target bit of timer output mode register 0 (TOM0) to 1 (slave channel output mode).</p> <p>Sets the target bit of the TOL0 register.</p> <p>Sets the TO0p bit and determines default level of the TO0p output.</p> <p>Sets the TOE0p bit to 1 and enables operation of TO0p.</p> <p>Clears the port register and port mode register to 0 (output mode is set).</p> | <p>The TO0p pin goes into Hi-Z state. (The port mode register is set to input mode.)</p> <p>TO0p does not change because channel stops operating (The TO0p pin is not affected even if the TO0p bit is modified).</p> <p>The level set in the TO0p bit is output from the TO0p pin.</p> |

Remark n: Master channel number (n = 0, 2)
p: Slave channel number (p = 3)

Figure 6-83. Operation Procedure of Two-channel Input with One-shot Pulse Output Function (2/2)

| | Software Operation | Hardware Status |
|------------------|---|---|
| Operation start | Sets the TOE0p bit of the slave channel to 1 to enable TO0p operation (only when operation is resumed). Sets the target bits of the TS0 register (master and slave) to 1 at the same time. The target bits of the TS0 register automatically return to 0 because they are trigger bits. | The target bits of the TE0 register are set to 1 and the master channel enters the TIO0n pin input valid edge detection wait status. |
| | Count operation starts on detection of the next start triggers: <ul style="list-style-type: none"> The TIO0n pin input valid edge is detected. The TS0n bit is set to 1 by software. | Value of the TDR0n register is loaded to the timer count register 0n (TCR0n) of the master channel, and count down operation starts. |
| During operation | Changes master channel setting. The TCR0n register can always be read (for the access procedure to the TCR0nH and TCR0nL registers, see 6.2.1 Timer count register mn (TCRmn)). The set values of only the CIS0n1 and CIS0n0 bits of the TMR0n register can be changed. The set values in the target bits of the TDR0n, TO0, TOE0, TOM0, and TOL0 registers cannot be changed. Changes slave channel setting. The TDR0p register can always be read. The TCR0p register can always be read. The TSR0p register can always be read. The set values of only the CIS0p1 and CIS0p0 bits of the TMR0p register can be changed. The set values in the target bits of the TO0p, TOE0p, TOM0, and TOL0 registers cannot be changed. | The master channel counter (TCR0n) performs count down operation. When the count value reaches TCR0n = 0000H, INTTM0n is generated, and the counter stops at TCR0n = FFFFH until the next start trigger is detected (the TIO0n pin input valid edge is detected or TS0n bit is set to 1). The slave channel, triggered by INTTM0n of the master channel, clears the timer counter register 0p (TCR0p) to 0000H. The counter (TCR0p) starts counting up from 0000H, and when the TIO0n pin input valid edge is detected, the count value is transferred to the timer data register 0p (TDR0p) (capture) and the TCR0p register is cleared to 0000H. At this time, INTTM0p is generated, which sets the TO0p output level to inactive. After that, the above operation is repeated. |
| Operation stop | Sets the target bits of the TT0 register (master and slave) to 1 at the same time. The target bits of the TT0 register automatically return to 0 because they are trigger bits. | The target bits of the TE0 register are cleared to 0, and count operation stops. The TCR0n and TCR0p registers hold count value and stop. The TO0p output is not initialized but holds current status. |
| | Clears the TOE0p bit of slave channel to 0 and sets a value to the TO0p bit. | The level set in the TO0p bit is output from the TO0p pin. |
| TAU stop | To hold the TO0p pin output level Clears the TO0p bit to 0 after the value to be held (output latch) is set to the port register. | The TO0p pin output level is held by port function. |
| | Clears the TAU0EN bit of the PER0 register to 0. | Power-off status (Clock supply is stopped and SFR of the TAU is initialized.) |

Operation is resumed.

Remark n: Master channel number (n = 0, 2)
 p: Slave channel number (p = 3)

6.10 Cautions When Using Timer Array Unit

6.10.1 Cautions when using timer output

Depending on the product, a timer output and other alternate functions may be assigned to some pins. In such case, the outputs of the other alternate functions must be set to their initial states.

For details, see **4.5 Register Settings When Using Alternate Function**.

CHAPTER 7 12-BIT INTERVAL TIMER

7.1 Functions of 12-bit Interval Timer

An interrupt request signal (INTIT) is generated at any previously specified time interval. It can be utilized as the trigger for waking up from STOP mode and HALT mode.

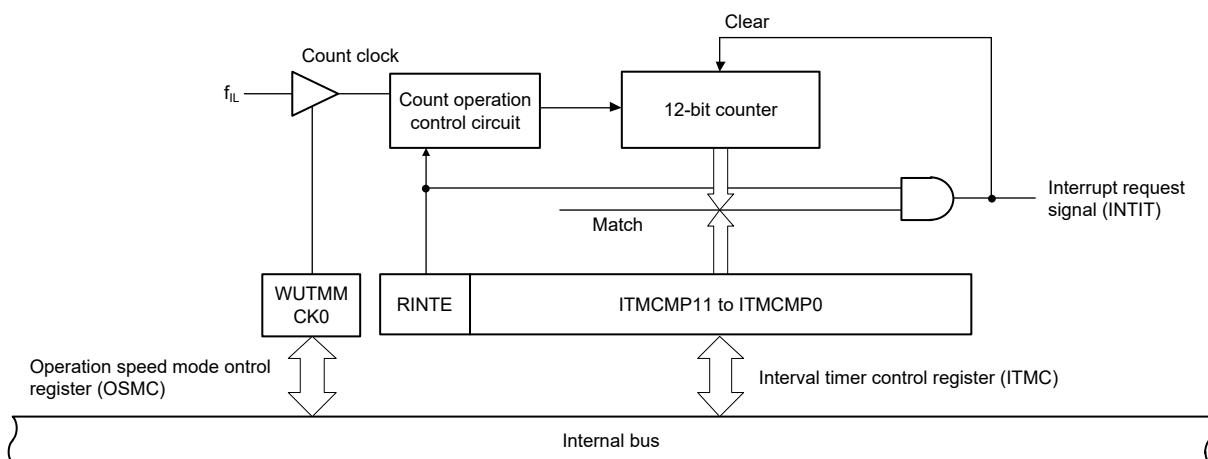
7.2 Configuration of 12-bit Interval Timer

The 12-bit interval timer includes the following hardware.

Table 7-1. Configuration of 12-bit Interval Timer

| Item | Configuration |
|-------------------|--|
| Counter | 12-bit counter |
| Control registers | Peripheral enable register 0 (PER0) |
| | Operation speed mode control register (OSMC) |
| | Interval timer control register (ITMC) |

Figure 7-1. Block Diagram of 12-bit Interval Timer



7.3 Registers Controlling 12-bit Interval Timer

The 12-bit interval timer is controlled by the following registers.

- Peripheral enable register 0 (PER0)
- Operation speed mode control register (OSMC)
- Interval timer control register (ITMC)

7.3.1 Peripheral enable register 0 (PER0)

This register is used to enable or disable supplying the clock to the peripheral hardware. Clock supply to the hardware that is not used is also stopped so as to decrease the power consumption and noise.

When using the 12-bit interval timer, be sure to set bit 7 (TMKAEN) to 1 at first.

The PER0 register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 7-2. Format of Peripheral Enable Register 0 (PER0)

Address: F00F0H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|---|----------|---|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PER0 | TMKAEN | CMPEN | ADCEN | IICA0EN | 0 | SAU0EN | 0 | TAU0EN |

| | |
|--------|---|
| TMKAEN | Control of 12-bit interval timer input clock supply |
| 0 | Stops input clock supply. <ul style="list-style-type: none"> • SFR used by the 12-bit interval timer cannot be written. • The 12-bit interval timer is in the reset status. |
| 1 | Enables input clock supply. <ul style="list-style-type: none"> • SFR used by the 12-bit interval timer can be read and written. |

Caution 1. Set the WUTMMCK0 bit of the OSMC register to 1 to determine the clock source for counting before supplying an input clock signal to the 12-bit interval timer (TMKAEN = 1).

Caution 2. When setting the 12-bit interval timer, be sure to first set the TMKAEN bit to 1 and then set the following register, while oscillation of the count clock is stable.
If TMKAEN = 0, writing to the 12-bit interval timer is ignored, and all read values are default values (except for the operation speed mode control register (OSMC)).

- Interval timer control register (ITMC)

Caution 3. Be sure to clear bits 1 and 3 to 0.

7.3.2 Operation speed mode control register (OSMC)

The WUTMMCK0 bit can be used to control supply of the 12-bit interval timer count clock.

Set the WUTMMCK0 bit to 1 before operating the 12-bit interval timer. Do not clear the WUTMMCK0 bit to 0 before counter operation has stopped.

The OSMC register can be set by an 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 7-3. Format of Operation Speed Mode Control Register (OSMC)

Address: F00F3H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|----------|---|---|---|---|
| OSMC | 0 | 0 | 0 | WUTMMCK0 | 0 | 0 | 0 | 0 |

| WUTMMCK0 | Supply of the count clock for 12-bit interval timer |
|----------|--|
| 0 | Clock supply stop. |
| 1 | Low-speed on-chip oscillator clock (f_{IL}) supply |

7.3.3 Interval timer control register (ITMC)

This register is used to set up the starting and stopping of the 12-bit interval timer operation and to specify the timer compare value.

The ITMC register can be set by a 16-bit memory manipulation instruction.

Reset signal generation sets this register to 0FFFH.

Figure 7-4. Format of Interval Timer Control Register (ITMC)

Address: FFF90H After reset: 0FFFH R/W

| | | | | | | | | | | | | | | | | |
|--------|-------|----|----|----|---------|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| ITMC | RINTE | 0 | 0 | 0 | ITCMP11 | ITCMP10 | ITCMP9 | ITCMP8 | ITCMP7 | ITCMP6 | ITCMP5 | ITCMP4 | ITCMP3 | ITCMP2 | ITCMP1 | ITCMP0 |

| RINTE | 12-bit interval timer operation control |
|-------|---|
| 0 | Count operation stopped (count clear) |
| 1 | Count operation started |

| ITCMP11 to ITCMP0 | Specification of the 12-bit interval timer compare value |
|-------------------|---|
| 001H | These bits generate an interrupt at the fixed cycle (count clock cycles x (ITCMP setting + 1)). |
| ... | |
| FFFH | |
| 000H | Setting prohibited |

Example interrupt cycles when 001H or FFFH is specified for ITCMP11 to ITCMP0

- ITCMP11 to ITCMP0 = 001H, count clock: when $f_{iL} = 15 \text{ kHz}$
 $1/15 \text{ [kHz]} \times (1 + 1) \cong 0.1333 \text{ [ms]} = 133.3 \text{ [\mu s]}$
- ITCMP11 to ITCMP0 = FFFH, count clock: when $f_{iL} = 15 \text{ kHz}$
 $1/15 \text{ [kHz]} \times (4095 + 1) \cong 273 \text{ [ms]}$

- Caution 1.** Set the TMKAMK flag to 1 to disable processing of the INTIT interrupt before stopping the counter (by clearing the RINTE bit to 0). Clear the TMKAIF flag to 0 to enable INTIT interrupt processing before restarting counter operation (by setting the RINTE bit to 1).
- Caution 2.** The value read from the RINTE bit is applied one count clock cycle after setting the RINTE bit to 1.
- Caution 3.** When setting the RINTE bit after returned from standby mode and entering standby mode again, confirm that the written value of the RINTE bit is reflected, or wait that more than one clock of the count clock has elapsed after returned from standby mode. Then enter standby mode.
- Caution 4.** Only change the setting of the ITCMP11 to ITCMP0 bits when the counting operation is stopped (RINTE = 0). However, it is possible to change the settings of the ITCMP11 to ITCMP0 bits at the same time as when changing the setting of the RINTE bit from 0 to 1 or 1 to 0.

7.4 12-bit Interval Timer Operation

7.4.1 12-bit interval timer operation timing

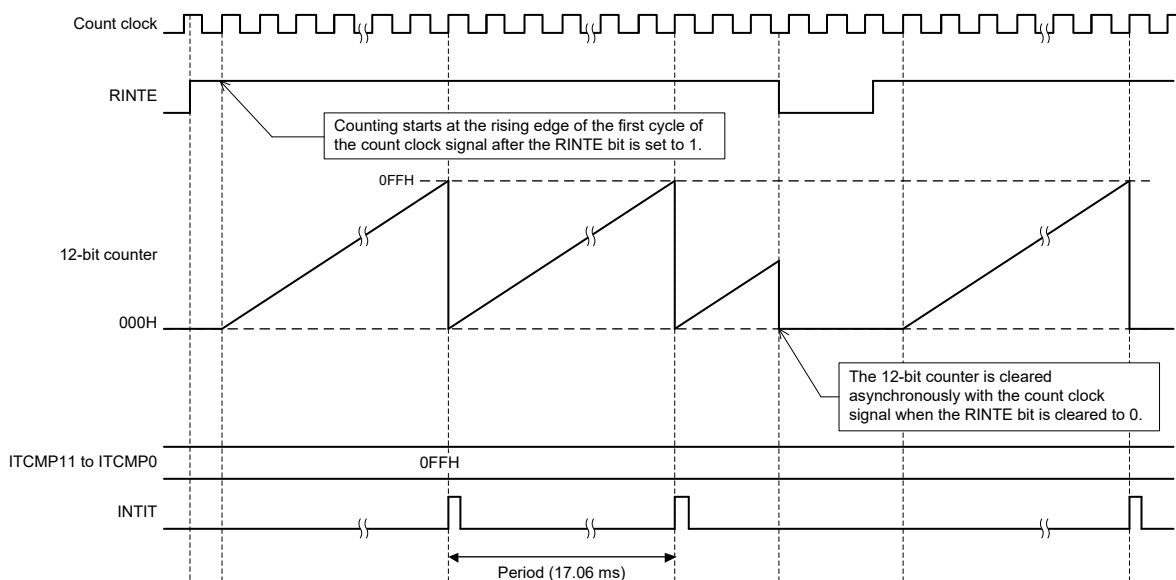
The count value specified for the ITCMP11 to ITCMP0 bits is used as an interval to operate a 12-bit interval timer that repeatedly generates interrupt requests (INTIT).

When the RINTE bit is set to 1, the 12-bit counter starts counting.

When the 12-bit counter value matches the value specified for the ITCMP11 to ITCMP0 bits, the 12-bit counter value is cleared to 0, counting continues, and an interrupt request signal (INTIT) is generated at the same time.

The basic operation of the 12-bit interval timer is shown in **Figure 7-5**.

Figure 7-5. 12-bit Interval Timer Operation Timing
(ITCMP11 to ITCMP0 = 0FFH, count clock: $f_{IL} = 15 \text{ kHz}$)

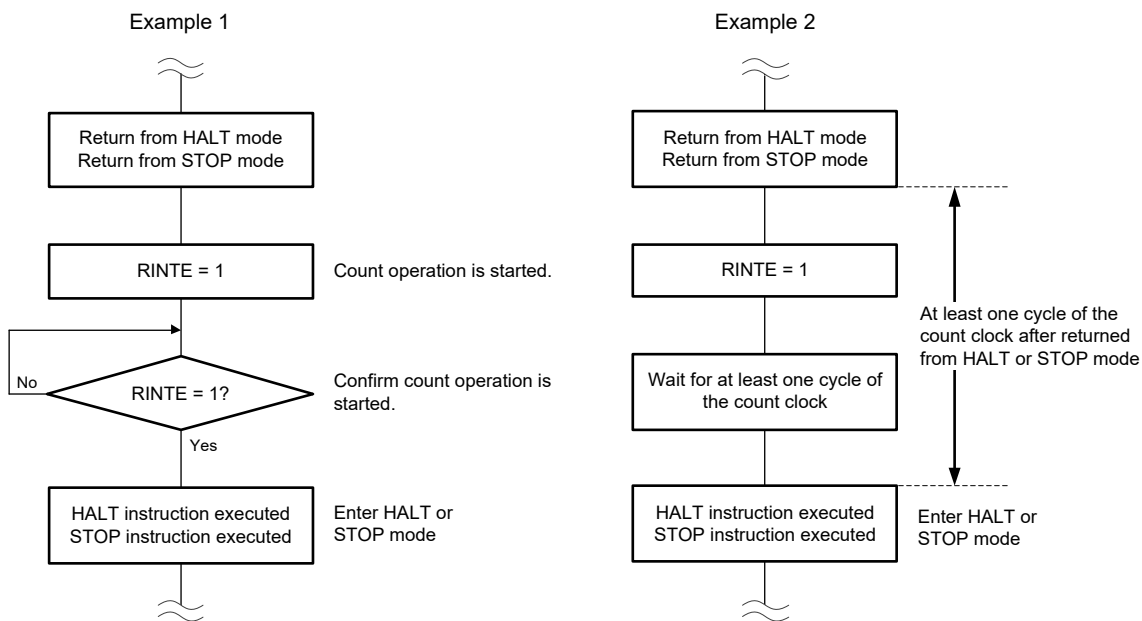


7.4.2 Start of count operation and re-enter to HALT/STOP mode after returned from HALT/STOP mode

When setting the RINTE bit after returned from HALT or STOP mode and entering HALT or STOP mode again, write 1 to the RINTE bit, and confirm the written value of the RINTE bit is reflected or wait for at least one cycle of the count clock. Then, enter HALT or STOP mode.

- After setting RINTE to 1, confirm by polling that the RINTE bit has become 1, and then enter HALT or STOP mode (see Example 1 in **Figure 7-6**).
- After setting RINTE to 1, wait for at least one cycle of the count clock and then enter HALT or STOP mode (see Example 2 in **Figure 7-6**).

Figure 7-6. Procedure of entering to HALT or STOP mode after setting RINTE to 1



CHAPTER 8 CLOCK OUTPUT/BUZZER OUTPUT CONTROLLER

8.1 Functions of Clock Output/Buzzer Output Controller

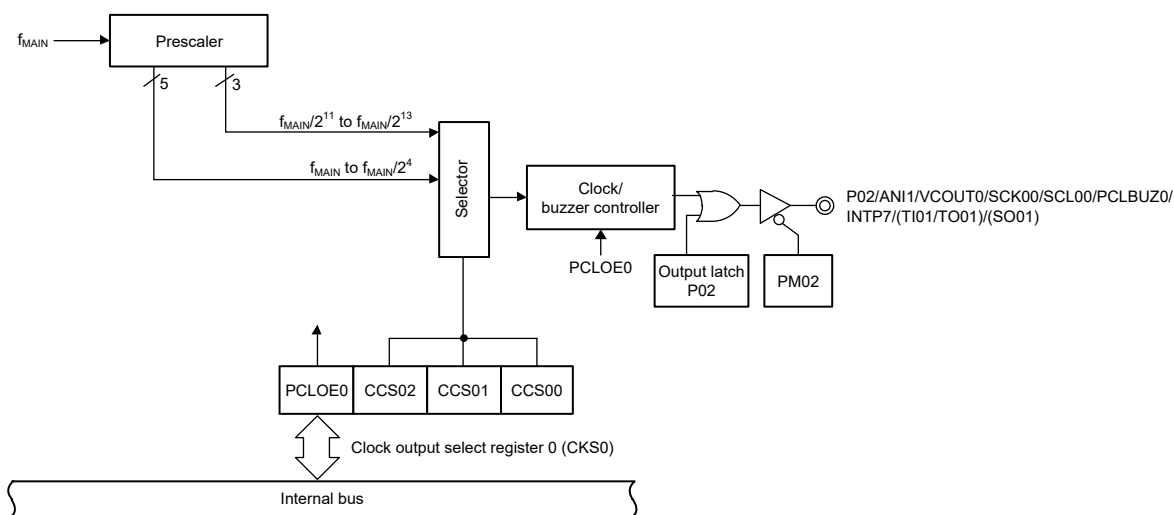
The clock output controller is intended for clock output for supply to peripheral ICs. Buzzer output is a function to output a square wave of buzzer frequency.

One pin can be used to output a clock or buzzer sound.

The PCLBUZ0 pin outputs a clock selected by clock output select register 0 (CKS0).

Figure 8-1 shows a block diagram of the clock output/buzzer output controller.

Figure 8-1. Block Diagram of Clock Output/Buzzer Output Controller



Caution 1. For output frequencies available from the PCLBUZ0 pin, refer to 23.4 AC Characteristics and 24.4 AC Characteristics.

Remark The clock output/buzzer output pins in the above diagram are those when PIOR31 = 0 and PIOR30 = 0 in 16-pin and 20-pin products and when PIOR30 = 0 in 10-pin products.

8.2 Configuration of Clock Output/Buzzer Output Controller

The clock output/buzzer output controller includes the following hardware.

Table 8-1. Configuration of Clock Output/Buzzer Output Controller

| Item | Configuration |
|-------------------|--|
| Control registers | Clock output select register 0 (CKS0) Port mode registers 0, 4 (PM0, PM4) Port registers 0, 4 (P0, P4) Port mode control register 0 (PMC0) Peripheral I/O redirection register 3 (PIOR3) |

8.3 Registers Controlling Clock Output/Buzzer Output Controller

The following registers are used to control the clock output/buzzer output controller.

- Clock output select register 0 (CKS0)
- Port mode registers 0, 4 (PM0, PM4)
- Port mode control register 0 (PMC0)
- Peripheral I/O redirection register 3 (PIOR3)

8.3.1 Clock output select register 0 (CKS0)

This register enables or disables output from the pin for clock output or buzzer frequency output (PCLBUZ0) and sets the output clock.

The CKS0 register is set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 8-2. Format of Clock Output Select Register 0 (CKS0)

Address: FFFA5H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|---|---|---|---|-------|-------|-------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| CKS0 | PCLOE0 | 0 | 0 | 0 | 0 | CCS02 | CCS01 | CCS00 |

| | |
|--------|---|
| PCLOE0 | PCLBUZ0 pin output enable/disable specification |
| 0 | Output disable (default) |
| 1 | Output enable |

| CCS02 | CCS01 | CCS00 | PCLBUZ0 pin output clock selection | | | | | |
|-------|-------|-------|------------------------------------|----------|-------------------------|-------------------------|--------------------------|--------------------------------------|
| | | | f_{MAIN} (MHz) | | | | | |
| | | | 1 | 5 | 8 | 10 | 16 | |
| 0 | 0 | 0 | f_{MAIN} | 1 MHz | 5 MHz ^{Note 1} | 8 MHz ^{Note 1} | 10 MHz ^{Note 1} | Setting prohibited ^{Note 1} |
| 0 | 0 | 1 | $f_{\text{MAIN}}/2$ | 500 kHz | 2.5 MHz | 4 MHz | 5 MHz ^{Note 1} | 8 MHz ^{Note 1} |
| 0 | 1 | 0 | $f_{\text{MAIN}}/2^2$ | 250 kHz | 1.25 MHz | 2 MHz | 2.5 MHz | 4 MHz |
| 0 | 1 | 1 | $f_{\text{MAIN}}/2^3$ | 125 kHz | 625 kHz | 1 MHz | 1.25 MHz | 2 MHz |
| 1 | 0 | 0 | $f_{\text{MAIN}}/2^4$ | 62.5 kHz | 312.5 kHz | 500 kHz | 625 kHz | 1 MHz |
| 1 | 0 | 1 | $f_{\text{MAIN}}/2^{11}$ | 488 Hz | 2.44 kHz | 3.91 kHz | 4.88 kHz | 7.81 kHz |
| 1 | 1 | 0 | $f_{\text{MAIN}}/2^{12}$ | 244 Hz | 1.22 kHz | 1.95 kHz | 2.44 kHz | 3.91 kHz |
| 1 | 1 | 1 | $f_{\text{MAIN}}/2^{13}$ | 122 Hz | 610 Hz | 977 Hz | 1.22 kHz | 1.95 kHz |

Note 1. The available output clock varies depending on the operating voltage range. For detail, refer to **23.4 AC Characteristics** and **24.4 AC Characteristics**.

Caution 1. Change the output clock after disabling the PCLBUZ0 pin output (PCLOE0 = 0).

Caution 2. To shift to STOP mode, execute the STOP instruction after at least 1.5 clock cycles of the PCLBUZ0 pin output clock have elapsed following disabling of the PCLBUZ0 pin output (PCLOE0 = 0).

Remark f_{MAIN} : Main system clock frequency

8.3.2 Registers controlling port functions of clock output/buzzer output pin

Using the port pin for the clock output/buzzer output controller requires setting of the registers that control the port function multiplexed on the clock output/buzzer output pin (PCLBUZ0 pin): (port mode registers 0, 4 (PM0, PM4), port registers 0, 4 (P0, P4), port mode control register 0 (PMC0), peripheral I/O redirection register 3 (PIOR3)).

For details on the registers that control the port functions, see **4.3.1 Port mode registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12)**, **4.3.2 Port registers 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13)**, **4.3.5 Port mode control registers 0, 2 (PMC0, PMC2)**, and **4.3.6 Peripheral I/O redirection registers 0 to 3 (PIOR0 to PIOR3)**.

When you intend to use the PCLBUZ0 pin, set the corresponding bits in the port mode register (PM0) and port mode control register 0 (PMC0) to 0 and the corresponding bits in the port register (P0) and port output mode register (POM0) to 0.

For details, see **4.5.3 Register setting examples for used port and alternate functions**.

The table below lists the clock output/buzzer output pins set by the PIOR3 register.

● 16- and 20-Pin Products

| PIOR31 | PIOR30 | Clock Output/Buzzer Output Pin |
|--------|--------|--------------------------------|
| 0 | 0 | P02 (initial value) |
| 0 | 1 | P40 |
| 1 | 0 | P06 |

● 10-Pin Products

| PIOR30 | Clock Output/Buzzer Output Pin |
|--------|--------------------------------|
| 0 | P02 (initial value) |
| 1 | P40 |

● 8-Pin Products

| Clock Output/Buzzer Output Pin |
|--------------------------------|
| Fixed to pin P40 |

8.4 Operations of Clock Output/Buzzer Output Controller

One pin can be used to output a clock or buzzer sound.

The PCLBUZ0 pin outputs a clock/buzzer selected by clock output select register 0 (CKS0).

8.4.1 Operation as output pin

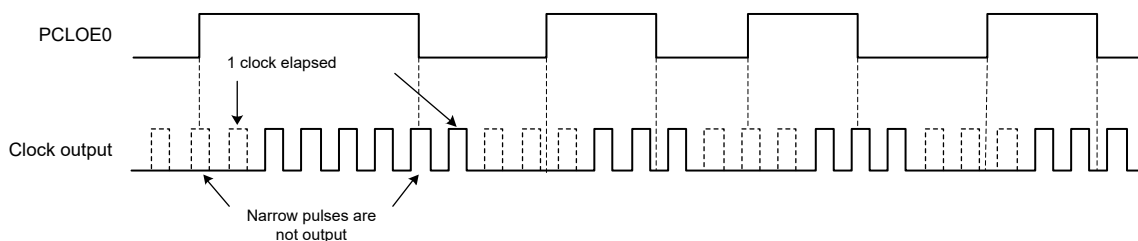
The PCLBUZ0 pin is output as the following procedure.

1. Set the corresponding bits in the port mode register (PM0/PM4), port register (P0/P4), and port mode control register 0 (PMC0) for the port pin on which the PCLBUZ0 function is multiplexed to.
2. Select the output frequency with bits 0 to 2 (CCS00 to CCS02) of the clock output select register (CKS0) for the PCLBUZ0 pin (output is disabled).
3. Set bit 7 (PCLOE0) of the CKS0 register to 1 to enable clock/buzzer output.

Remark The controller used for clock output starts or stops clock output one clock after enabling or disabling of clock output (by the PCLOE bit) is switched. At this time, pulses with a narrow width are not output.

Figure 8-3 shows enabling or stopping of output by the PCLOE0 bit and the timing of clock output.

Figure 8-3. Timing of Clock Output from PCLBUZ0 Pin



Remark If STOP mode is entered within 1.5 clock cycles of the PCLBUZ0 pin output clock after disabling the PCLBUZ0 pin output (PCLOE0 = 0), the width of the PCLBUZ0 pin output pulse becomes shorter. In such cases, only execute the STOP instruction after at least 1.5 clock cycles of the PCLBUZ0 pin output clock have elapsed following disabling of the PCLBUZ0 pin output.

CHAPTER 9 WATCHDOG TIMER

9.1 Functions of Watchdog Timer

The counting operation of the watchdog timer is set by the user option byte (000C0H).

The watchdog timer operates on the low-speed on-chip oscillator clock.

The watchdog timer is used to detect an inadvertent program loop. If a program loop is detected, an internal reset signal is generated.

Program loop is detected in the following cases.

- If the watchdog timer counter overflows
- If a 1-bit manipulation instruction is executed on the watchdog timer enable register (WDTE)
- If data other than "ACH" is written to the WDTE register

When a reset occurs due to the watchdog timer, bit 4 (WDTRF) of the reset control flag register (RESF) is set to 1. For details of the RESF register, see **CHAPTER 16 RESET FUNCTION**.

When 75% of the overflow time is reached, an interval interrupt is generated.

9.2 Configuration of Watchdog Timer

The watchdog timer includes the following hardware.

Table 9-1. Configuration of Watchdog Timer

| Item | Configuration |
|------------------|---------------------------------------|
| Control register | Watchdog timer enable register (WDTE) |

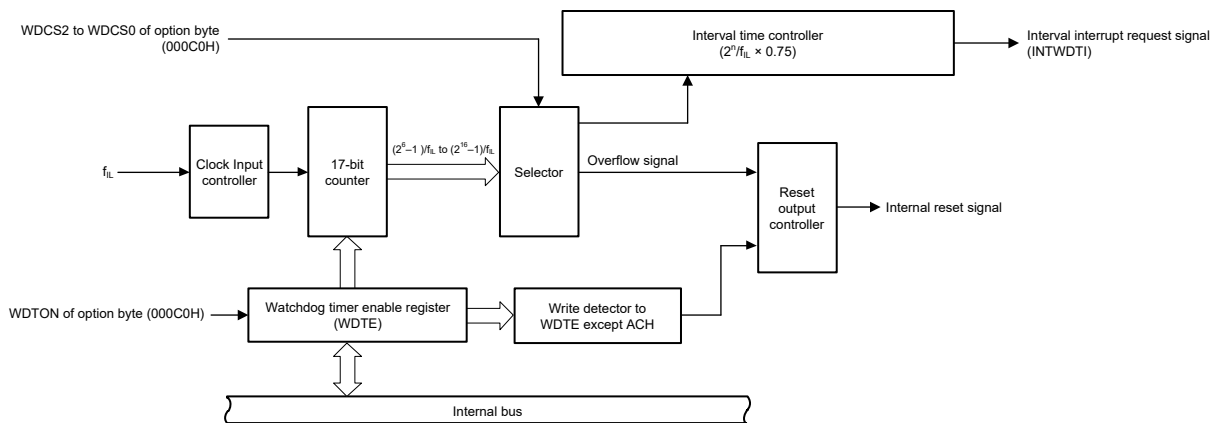
How the counter operation is controlled and the overflow time are set by the option byte.

Table 9-2. Setting of Option Bytes and Watchdog Timer

| Setting of Watchdog Timer | Option Byte (000C0H) |
|---|------------------------------|
| Controlling counter operation of watchdog timer | Bit 4 (WDTON) |
| Overflow time of watchdog timer | Bits 3 to 1 (WDCS2 to WDCS0) |
| Controlling counter operation of watchdog timer (in HALT/STOP mode) | Bit 0 (WDSTBYON) |

Remark For the option byte, see **CHAPTER 18 OPTION BYTE**.

Figure 9-1. Block Diagram of Watchdog Timer



9.3 Register Controlling Watchdog Timer

The watchdog timer is controlled by the watchdog timer enable register (WDTE).

9.3.1 Watchdog timer enable register (WDTE)

Writing “ACH” to the WDTE register clears the watchdog timer counter and starts counting again.

This register can be set by an 8-bit memory manipulation instruction.

Reset signal generation sets this register to 1AH or 9AH^{Note 1}.

Figure 9-2. Format of Watchdog Timer Enable Register (WDTE)

Address: FFFABH After reset: 1AH/9AH^{Note 1} R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---------------------------|---|---|---|---|
| WDTE | | | | | | | | |
| WDTON Bit Setting Value | | | | WDTE Register Reset Value | | | | |
| 0 (watchdog timer count operation disabled) | | | | 1AH | | | | |
| 1 (watchdog timer count operation enabled) | | | | 9AH | | | | |

Note 1. The WDTE register reset value differs depending on the WDTON bit setting value of the option byte (000C0H). To operate the watchdog timer, set the WDTON bit to 1.

- Caution 1.** If a value other than “ACH” is written to the WDTE register, an internal reset signal is generated.
- Caution 2.** If a 1-bit memory manipulation instruction is executed for the WDTE register, an internal reset signal is generated.
- Caution 3.** The value read from the WDTE register is 1AH/9AH (this differs from the written value (ACH)).

9.4 Operation of Watchdog Timer

9.4.1 Controlling operation of watchdog timer

<1> When the watchdog timer is used, its operation is specified by the option byte (000C0H).

- Enable counting operation of the watchdog timer by setting bit 4 (WDTON) of the option byte (000C0H) to 1 (the counter starts operating after a reset release) (for details, see **CHAPTER 18 OPTION BYTE**).

| WDTON | Watchdog Timer Counter |
|-------|---|
| 0 | Counter operation disabled (counting stopped after reset) |
| 1 | Counter operation enabled (counting started after reset) |

- Set an overflow time by using bits 3 to 1 (WDCS2 to WDCS0) of the option byte (000C0H) (for details, see **9.4.2 Setting time of watchdog timer** and **CHAPTER 18 OPTION BYTE**).

<2> After a reset release, the watchdog timer starts counting.

<3> By writing “ACH” to the watchdog timer enable register (WDTE) after the watchdog timer starts counting and before the overflow time set by the option byte, the watchdog timer is cleared and starts counting again.

<4> If the overflow time expires without “ACH” written to the WDTE register, an internal reset signal is generated. An internal reset signal is also generated in the following cases.

- If a 1-bit manipulation instruction is executed on the WDTE register
- If data other than “ACH” is written to the WDTE register

Caution 1. If the watchdog timer is cleared by writing “ACH” to the WDTE register, the actual overflow time may become shorter than the overflow time set by the option byte by up to one clock cycle of f_{IL} .

Caution 2. Clearing the watchdog timer is effective immediately before the counter value overflows.

Caution 3. The operation of the watchdog timer in the HALT and STOP modes differs as follows depending on the set value of bit 0 (WDSTBYON) of the option byte (000C0H).

WDSTBYON = 0: Watchdog timer operation stops.

WDSTBYON = 1: Watchdog timer operation continues.

If **WDSTBYON = 0**, the watchdog timer resumes counting after the HALT or STOP mode is released. At this time, the counter is cleared to 0 and counting starts.

When operating with the X1 clock^{Note 1} after releasing the STOP mode, the CPU starts operating after the oscillation stabilization time has elapsed. Therefore, if the period between the STOP mode release and the watchdog timer overflow is short, an overflow occurs during the oscillation stabilization time, causing a reset. Accordingly, set the overflow time in consideration of the oscillation stabilization time when operating with the X1 clock after the STOP mode release by an interval interrupt and the watchdog timer is to be cleared.

Caution 4. Setting **WDTON = 0** and **WDSTBYON = 1** is prohibited.

Note 1. 16-pin and 20-pin products only

9.4.2 Setting time of watchdog timer

Set the overflow time and interval interrupt time of the watchdog timer by using bits 3 to 1 (WDCS2 to WDCS0) of the option byte (000C0H).

If an overflow occurs, an internal reset signal is generated. The present count is cleared and the watchdog timer starts counting again by writing “ACH” to the watchdog timer enable register (WDTE) before the overflow time. When 75% of the overflow time is reached, an interval interrupt is generated.

The following overflow time and interval interrupt time can be set.

Table 9-3. Setting of Overflow Time and Interval Interrupt Time

| WDCS2 | WDCS1 | WDCS0 | Overflow Time of Watchdog Timer ($f_{iL} = 17.25 \text{ kHz (MAX.)}$) | Interval Interrupt Time of Watchdog Timer ($f_{iL} = 17.25 \text{ kHz (MAX.)}$) |
|-------|-------|-------|--|--|
| 0 | 0 | 0 | $(2^6 - 1)/f_{iL}$ (3.65 ms) | $2^6/f_{iL} \times 0.75$ (2.78 ms) |
| 0 | 0 | 1 | $(2^7 - 1)/f_{iL}$ (7.36 ms) | $2^7/f_{iL} \times 0.75$ (5.56 ms) |
| 0 | 1 | 0 | $(2^8 - 1)/f_{iL}$ (14.7 ms) | $2^8/f_{iL} \times 0.75$ (11.1 ms) |
| 0 | 1 | 1 | $(2^9 - 1)/f_{iL}$ (29.6 ms) | $2^9/f_{iL} \times 0.75$ (22.2 ms) |
| 1 | 0 | 0 | $(2^{11} - 1)/f_{iL}$ (118 ms) | $2^{11}/f_{iL} \times 0.75$ (89.0 ms) |
| 1 | 0 | 1 | $(2^{13} - 1)/f_{iL}$ (474 ms) | $2^{13}/f_{iL} \times 0.75$ (356 ms) |
| 1 | 1 | 0 | $(2^{14} - 1)/f_{iL}$ (949 ms) | $2^{14}/f_{iL} \times 0.75$ (712 ms) |
| 1 | 1 | 1 | $(2^{16} - 1)/f_{iL}$ (3799 ms) | $2^{16}/f_{iL} \times 0.75$ (2849 ms) |

Caution 1. When operating with the X1 clock^{Note 1} after releasing the STOP mode, the CPU starts operating after the oscillation stabilization time has elapsed.

Therefore, if the period between the STOP mode release and the watchdog timer overflow is short, an overflow occurs during the oscillation stabilization time, causing a reset.

Consequently, set the overflow time in consideration of the oscillation stabilization time when operating with the X1 clock^{Note 1} after the STOP mode release by an interval interrupt and the watchdog timer is to be cleared.

Caution 2. The watchdog timer continues counting even after INTWDTI is generated (until ACH is written to the watchdog timer enable register (WDTE)). If ACH is not written to the WDTE register before the overflow time, an internal reset signal is generated.

Caution 3. The watchdog timer always generates an interval interrupt when the specified time is reached unless this is specifically disabled. If the interval interrupt from the watchdog timer is not to be used, be sure to disable the interrupt by setting the WDTIMK bit to 1.

Remark f_{iL} : Low-speed on-chip oscillator clock frequency

Note 1. 16-pin and 20-pin products only

CHAPTER 10 A/D CONVERTER

The number of analog input channels of the A/D converter differs depending on the product.

- 8-pin products: 3 channels (ANI0, ANI2, ANI3), internal reference voltage^{Note 1} (0.815 V (typ.))
- 10-pin products: 4 channels (ANI0 to ANI3), internal reference voltage^{Note 1} (0.815 V (typ.))
- 16-pin products: 7 channels (ANI0 to ANI6), internal reference voltage^{Note 1} (0.815 V (typ.))
- 20-pin products: 11 channels (ANI0 to ANI10), internal reference voltage^{Note 1} (0.815 V (typ.))

Note 1. The internal reference voltage cannot be used for the A/D converter and the comparator simultaneously. When the internal reference voltage is selected as the target of conversion by the A/D converter, do not set the internal reference voltage as the reference voltage of the comparator.

10.1 Function of A/D Converter

The A/D converter is used to convert analog input signals into digital values, and is configured to control up to 11 channels of A/D converter analog inputs. 10-bit or 8-bit resolution can also be selected by using the ADTYP bit of A/D converter mode register 2 (ADM2).

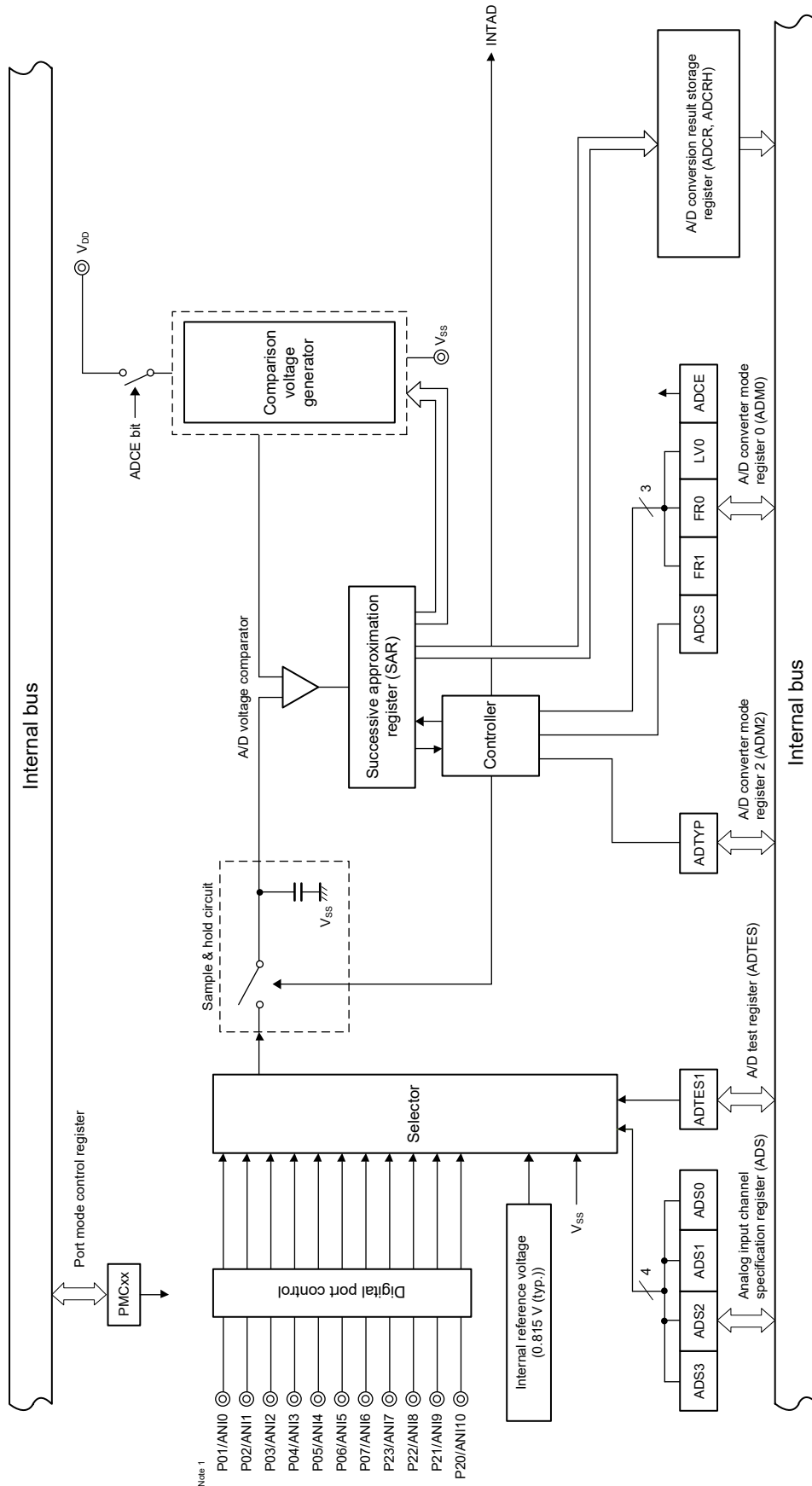
The A/D converter has the following function.

■ 10-bit/8-bit resolution A/D conversion

Following the selection of one analog input channel from among ANI0 to ANI10, software initiates A/D conversion with 10-bit or 8-bit resolution. An A/D conversion end interrupt request signal (INTAD) is generated on completion of A/D conversion.

The range of operating voltage for the A/D converter is from 2.4 V to 5.5 V.

Figure 10-1. Block Diagram of A/D Converter



Note 1

Note 1. ANI0, ANI2, ANI3 for 8-pin products; ANI0 to ANI3 for 10-pin products; ANI0 to ANI6 for 16-pin products

10.2 Configuration of A/D Converter

The A/D converter includes the following hardware.

1) ANI0 to ANI10^{Note 1}

These are the analog input pins of the 11 channels of the A/D converter. They input analog signals to be converted into digital signals. Pins other than the one selected as the analog input pin can be used as I/O port pins.

In addition to the voltages on analog input pins from ANI0 to ANI10, the internal reference voltage (0.815 (typ.)) can be selected as the target of conversion by the A/D converter.

Note 1. ANI0, ANI2, ANI3 for 8-pin products; ANI0 to ANI3 for 10-pin products; ANI0 to ANI6 for 16-pin products

2) Sample & hold circuit

The sample & hold circuit samples each of the analog input voltages sequentially sent from the input circuit, and sends them to the A/D voltage comparator. This circuit also holds the sampled analog input voltage during A/D conversion.

3) A/D voltage comparator

The A/D voltage comparator compares the voltage generated from the voltage tap of the comparison voltage generator with the analog input voltage. If the analog input voltage is found to be greater than the reference voltage ($1/2 V_{DD}$) as a result of the comparison, the most significant bit (MSB) of the successive approximation register (SAR) is set. If the analog input voltage is less than the reference voltage ($1/2 V_{DD}$), the MSB bit of the SAR is reset.

After that, bit 8 of the SAR register is automatically set, and the next comparison is made. The voltage tap of the comparison voltage generator is selected by the value of bit 9, to which the result has been already set.

Bit 9 = 0: ($1/4 V_{DD}$)

Bit 9 = 1: ($3/4 V_{DD}$)

The voltage tap of the comparison voltage generator and the analog input voltage are compared and bit 8 of the SAR register is manipulated according to the result of the comparison.

Analog input voltage \geq Voltage tap of comparison voltage generator: Bit 8 = 1

Analog input voltage \leq Voltage tap of comparison voltage generator: Bit 8 = 0

Comparison is continued like this to bit 0 of the SAR register.

When performing A/D conversion at a resolution of 8 bits, the comparison continues until bit 2 of the SAR register.

4) Comparison voltage generator

The comparison voltage generator generates the comparison voltage input from an analog input pin.

5) Successive approximation register (SAR)

The SAR register is used to set voltage tap data whose values from the comparison voltage generator match the voltage values of the analog input pins, one bit at a time starting from the most significant bit (MSB).

If data is set in the SAR register all the way to the least significant bit (LSB) (end of A/D conversion), the contents of the SAR register (conversion results) are held in the A/D conversion result register (ADCR). When all the specified A/D conversion operations have ended, an A/D conversion end interrupt request signal (INTAD) is generated.

6) 10-bit A/D conversion result register (ADCR)

Each time A/D conversion is completed, the conversion result is loaded from the successive approximation register and the ten higher-order bits of the A/D conversion result are held in this register (the six lower-order bits are fixed to 0).

7) 8-bit A/D conversion result register (ADCRH)

Each time A/D conversion is completed, the conversion result is loaded from the successive approximation register and the eight higher-order bits of the A/D conversion result are held in this register.

8) Controller

This circuit controls the conversion time of an analog input signal that is to be converted into a digital signal, as well as starting and stopping of the conversion operation. When A/D conversion has been completed, this controller generates an A/D conversion end interrupt request signal (INTAD).

10.3 Registers Controlling A/D Converter

The A/D converter is controlled by the following registers.

- Peripheral enable register 0 (PER0)
- A/D converter mode register 0 (ADM0)
- A/D converter mode register 2 (ADM2)
- 10-bit A/D conversion result register (ADCR)
- 8-bit A/D conversion result register (ADCRH)
- Analog input channel specification register (ADS)
- A/D test register (ADTES)
- Port mode registers 0, 2 (PM0, PM2)
- Port mode control registers 0, 2 (PMC0, PMC2)

10.3.1 Peripheral enable register 0 (PER0)

The PER0 register is used to enable or disable the supply of a clock signal to various on-chip peripheral modules. Clock supply to an on-chip peripheral module that is not to be used can be stopped to decrease power consumption and noise.

If the A/D converter is to be used, be sure to set bit 5 (ADCEN) of this register to 1.

The PER0 register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 10-2. Format of Peripheral Enable Register 0 (PER0)

Address: F00F0H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|---|----------|---|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PER0 | TMKAEN | CMPEN | ADCEN | IICA0EN | 0 | SAU0EN | 0 | TAU0EN |

| ADCEN | Control of A/D converter input clock supply |
|-------|---|
| 0 | Stops supply of an input clock. <ul style="list-style-type: none"> • The SFRs used by the A/D converter cannot be written. • The A/D converter is in the reset state. |
| 1 | Enables supply of an input clock. <ul style="list-style-type: none"> • The SFRs used by the A/D converter can be read/written. |

Caution 1. When setting the A/D converter, make sure that ADCEN = 1 before setting the following registers. If ADCEN = 0, the values of the A/D converter control registers are cleared to their initial values and writing to them is ignored (except for port mode registers 0 and 2 (PM0, PM2) and port mode control registers 0 and 2 (PMC0, PMC2)).

- A/D converter mode register 0 (ADM0)
- A/D converter mode register 2 (ADM2)
- 10-bit A/D conversion result register (ADCR)
- 8-bit A/D conversion result register (ADCRH)
- Analog input channel specification register (ADS)
- A/D test register (ADTES)

Caution 2. Be sure to clear bits 1 and 3 to 0.

10.3.2 A/D converter mode register 0 (ADM0)

This register sets the time for converting analog input to digital data, and starts and stops conversion operation.

The ADM0 register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 10-3. Format of A/D Converter Mode Register 0 (ADM0)

Address: FFF30H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--|---|---|---|-----------------------|-----------------------|---|-----------------------|---|
| ADM0 | ADCS | 0 | 0 | FR1 ^{Note 1} | FR0 ^{Note 1} | 0 | LV0 ^{Note 1} | ADCE |
| ADCS | A/D conversion operation control | | | | | | | |
| 0 | Stops conversion operation (conversion stopped/standby state) | | | | | | | |
| 1 | Enables conversion operation (conversion operation state) | | | | | | | |
| <Clear conditions> | | | | | | | | |
| <ul style="list-style-type: none"> • 0 is written to ADCS. • The bit is automatically cleared to 0 when A/D conversion ends. | | | | | | | | |
| <Set condition> | | | | | | | | |
| <ul style="list-style-type: none"> • 1 is written to ADCS when ADCE = 1. | | | | | | | | |
| ADCE | A/D voltage comparator operation control ^{Note 2} | | | | | | | |
| 0 | Stops A/D voltage comparator operation | | | | | | | |
| 1 | Enables A/D voltage comparator operation | | | | | | | |

Note 1. For details of the FR1, FR0, and LV0 bits and A/D conversion, see **Table 10-2 10-Bit Resolution A/D Conversion Time Selection** or **Table 10-3 8-Bit Resolution A/D Conversion Time Selection**.

Note 2. The operation of the A/D voltage comparator is controlled by the ADCS and ADCE bits, and it takes 0.125 μ s from the start of operation for the operation to stabilize. Therefore, when the ADCS bit is set to 1 after 0.125 μ s or more have elapsed from the time ADCE bit is set to 1, the conversion result at that time has priority over the first conversion result. If the ADCS bit is set to 1 to perform A/D conversion without waiting for at least 0.125 μ s, ignore data of the conversion.

Caution 1. Only rewrite the FR1, FR0, and LV0 bits while in the conversion standby state (ADCS = 0, ADCE = 1) or conversion is stopped (ADCS = 0, ADCE = 0). Rewriting the values of the FR1, FR0, and LV0 bits, and ADCS bits by an 8-bit manipulation instruction at the same time is prohibited.

Caution 2. Setting ADCS = 1 and ADCE = 0 is prohibited. When 1 is written to the ADCS bit while conversion is stopped (ADCE = 0, ADCS = 0), the ADCS bit is not set to 1.

Caution 3. Do not change the ADCS and ADCE bits from 0 to 1 at the same time by using an 8-bit manipulation instruction. Be sure to follow the procedure described in 10.7 A/D Converter Setup Flowchart.

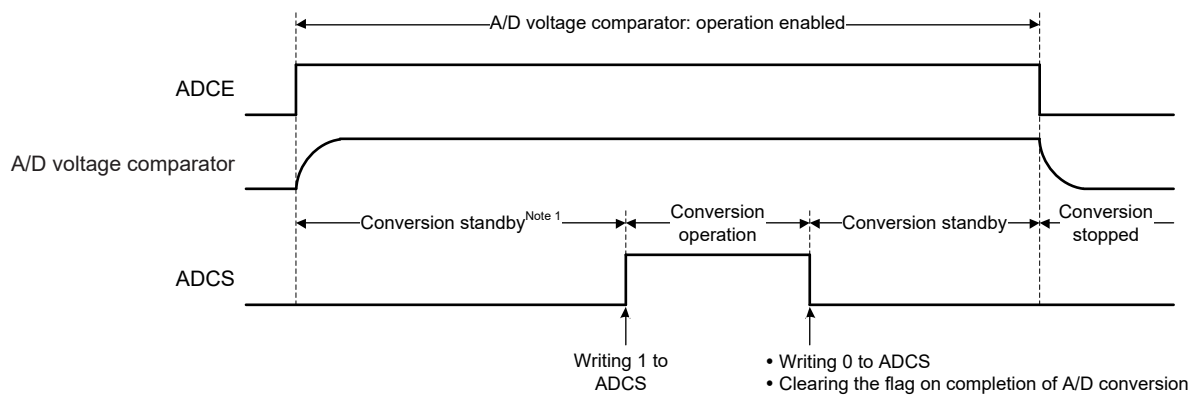
Caution 4. Be sure to clear bits 2, 5, and 6 to 0.

Caution 5. Setting the ADCS bit to 1 again during conversion (ADCS = 1) is prohibited. When re-conversion by the same channel is required, stop the conversion operation once (ADCS = 0), and then restart A/D conversion (ADCS = 1).

Table 10-1. Settings of ADCS and ADCE Bits

| ADCS | ADCE | A/D Conversion Operation |
|------|------|------------------------------|
| 0 | 0 | Conversion stopped state |
| 0 | 1 | Conversion standby state |
| 1 | 0 | Setting prohibited |
| 1 | 1 | Conversion-in-progress state |

Figure 10-4. Timing Chart when A/D Voltage Comparator Is Used



Note 1. It requires at least 0.125 μ s to stabilize the internal circuit until the A/D conversion operation is started (ADCS = 1) after the operation of the A/D voltage comparator is enabled (ADCE = 1). If the ADCS bit is set to 1 without waiting for at least 0.125 μ s, ignore data of the first conversion.

Table 10-2. 10-Bit Resolution A/D Conversion Time Selection

| A/D Converter Mode Register 0 (ADM0) | | | Conversion Clock | Number of Conversion Clocks | Conversion Time | Conversion Time Selection (μs) | | | | |
|--------------------------------------|-----|------------------------------|---------------------|---|----------------------|--------------------------------|--------------------------|--------------------------|---------------------------|---------------------------|
| FR1 | FR0 | LV0 <small>Note 2</small> | | | | f _{CLK} = 1 MHz | f _{CLK} = 4 MHz | f _{CLK} = 8 MHz | f _{CLK} = 10 MHz | f _{CLK} = 16 MHz |
| 0 | 0 | 0 | f _{CLK} /8 | 23 f _{AD} (number of sampling clocks: 9 f _{AD}) | 184/f _{CLK} | Setting prohibited | Setting prohibited | 23.0 | 18.4 | 11.5 |
| 0 | 1 | | f _{CLK} /4 | | 92/f _{CLK} | | | 23.0 | 11.5 | 9.2 |
| 1 | 0 | | f _{CLK} /2 | | 46/f _{CLK} | 23.0 | 5.75 | Setting prohibited | Setting prohibited | Setting prohibited |
| 1 | 1 | | f _{CLK} | | 23/f _{CLK} | | | | | |
| 0 | 0 | ¹ Note 1 | f _{CLK} /8 | 17 f _{AD} (number of sampling clocks: 3 f _{AD}) | 136/f _{CLK} | Setting prohibited | Setting prohibited | 17.0 | 13.6 | 8.5 |
| 0 | 1 | | f _{CLK} /4 | | 68/f _{CLK} | | | 17.0 | 8.5 | 6.8 |
| 1 | 0 | | f _{CLK} /2 | | 34/f _{CLK} | 17.0 | 4.25 | Setting prohibited | Setting prohibited | Setting prohibited |
| 1 | 1 | | f _{CLK} | | 17/f _{CLK} | | | | | |

Note 1. Setting is prohibited when 2.4 V ≤ V_{DD} < 2.7 V. Can be selected when 2.7 V ≤ V_{DD} ≤ 5.5 V.

Note 2. When the internal reference voltage is selected as the target of conversion by the A/D converter, be sure to clear the LV0 bit to 0.

Table 10-3. 8-Bit Resolution A/D Conversion Time Selection

| A/D Converter Mode Register 0 (ADM0) | | | Conversion Clock | Number of Conversion Clocks | Conversion Time | Conversion Time Selection (μs) | | | | |
|--------------------------------------|-----|------------------------------|---------------------|---|----------------------|--------------------------------|--------------------------|--------------------------|---------------------------|---------------------------|
| FR1 | FR0 | LV0 <small>Note 2</small> | | | | f _{CLK} = 1 MHz | f _{CLK} = 4 MHz | f _{CLK} = 8 MHz | f _{CLK} = 10 MHz | f _{CLK} = 16 MHz |
| 0 | 0 | 0 | f _{CLK} /8 | 21 f _{AD} (number of sampling clocks: 9 f _{AD}) | 168/f _{CLK} | Setting prohibited | Setting prohibited | 21.0 | 16.8 | 10.5 |
| 0 | 1 | | f _{CLK} /4 | | 84/f _{CLK} | | | 21.0 | 10.5 | 8.4 |
| 1 | 0 | | f _{CLK} /2 | | 42/f _{CLK} | 21.0 | 5.25 | Setting prohibited | Setting prohibited | Setting prohibited |
| 1 | 1 | | f _{CLK} | | 21/f _{CLK} | | | | | |
| 0 | 0 | ¹ Note 1 | f _{CLK} /8 | 15 f _{AD} (number of sampling clocks: 3 f _{AD}) | 120/f _{CLK} | Setting prohibited | Setting prohibited | 15.0 | 12.0 | 7.5 |
| 0 | 1 | | f _{CLK} /4 | | 60/f _{CLK} | | | 15.0 | 7.5 | 6.0 |
| 1 | 0 | | f _{CLK} /2 | | 30/f _{CLK} | 15.0 | 7.5 | 3.75 | Setting prohibited | Setting prohibited |
| 1 | 1 | | f _{CLK} | | 15/f _{CLK} | | | | | |

Note 1. Setting is prohibited when 2.4 V ≤ V_{DD} < 2.7 V. Can be selected when 2.7 V ≤ V_{DD} ≤ 5.5 V.

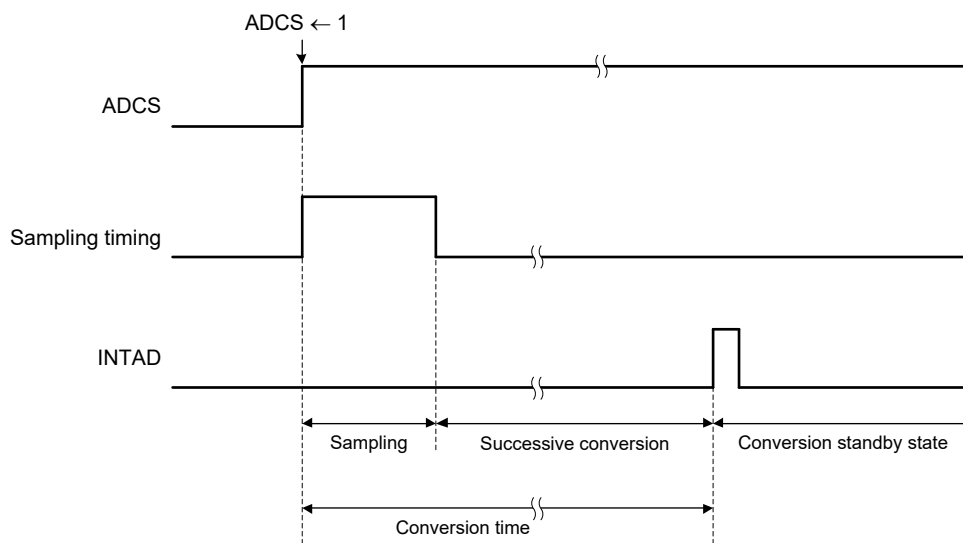
Note 2. When the internal reference voltage is selected as the target of conversion by the A/D converter, be sure to clear the LV0 bit to 0.

Caution 1. The A/D conversion time must also be within the range of the conversion time (t_{CONV}) indicated in 23.6.1 A/D converter characteristics or 24.6.1 A/D converter characteristics.

- Caution 2.** When the internal reference voltage is selected as the target of conversion by the A/D converter, the internal reference voltage cannot be used as the reference voltage of the comparator.
- Caution 3.** Only rewrite the FR1, FR0, and LV0 bits while in the conversion standby state (ADCS = 0, ADCE = 1) or conversion is stopped (ADCS = 0, ADCE = 0). Rewriting the values of the FR1, FR0, and LV0 bits, and ADCS bits by an 8-bit manipulation instruction at the same time is prohibited.
- Caution 4.** The above conversion time does not include clock frequency errors. Select the conversion time, taking clock frequency errors into consideration.

Remark f_{CLK} : CPU/peripheral hardware clock frequency

Figure 10-5. A/D Converter Sampling and A/D Conversion Timing



10.3.3 A/D converter mode register 2 (ADM2)


This register is used to set the resolution of the A/D converter.

The ADM2 register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 10-6. Format of A/D Converter Mode Register 2 (ADM2)

Address: F0010H After reset: 00H R/W

| | | | | | | | | |
|--------|---|---|---|---|---|---|---|---|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 |  |
| ADM2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ADTYP |

| | |
|-------|--|
| ADTYP | Selection of the A/D conversion resolution |
| 0 | 10-bit resolution |
| 1 | 8-bit resolution |

Caution Only rewrite the value of the ADM2 register while conversion is stopped (ADCS = 0, ADCE = 0).

10.3.4 10-bit A/D conversion result register (ADCR)

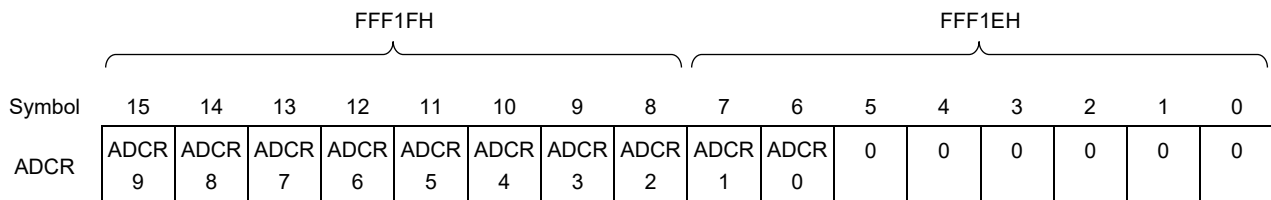
This is a 16-bit register which holds the result of A/D conversion. The six lower-order bits are fixed to 0. Each time A/D conversion ends, the conversion result is loaded from the successive approximation register (SAR). The eight higher-order bits of the conversion result are stored in FFF1FH and the two lower-order bits are stored in the two higher-order bits of FFF1EH.

The ADCR register can be read by a 16-bit memory manipulation instruction.

Reset signal generation clears this register to 0000H.

Figure 10-7. Storing of the A/D Conversion Result in the Case of 10-bit Resolution

Address: FFF1FH, FFF1EH After reset: 0000H R



- Caution 1.** When writing to A/D converter mode register 0 (ADM0) and the analog input channel specification register (ADS), the contents of the ADCR/ADCRH register may become undefined. After conversion ends, read the conversion result before writing to the ADM0 and ADS registers. Using timing other than the above may cause an incorrect conversion result to be read.
- Caution 2.** When the ADCR register is read while 8-bit resolution A/D conversion is selected (when the ADTYP bit of A/D converter mode register 2 (ADM2) is 1), 0 is read from the two lower-order bits (ADCR1, ADCR0). Note that, when the ADCR register is read before completion of A/D conversion while 8-bit resolution A/D conversion is selected, 0 may not be read from the two lower-order bits (ADCR1, ADCR0).

10.3.5 8-bit A/D conversion result register (ADCRH)

This is an 8-bit register which holds the result of A/D conversion. When A/D conversion ends, the conversion result is loaded from the successive approximation register (SAR). In the case of 10-bit resolution, the eight higher-order bits are stored.

The ADCRH register can be read by an 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 10-8. Format of 8-bit A/D Conversion Result Register (ADCRH)

Address: FFF1FH After reset: 00H R

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| ADCRH | ADCR9 | ADCR8 | ADCR7 | ADCR6 | ADCR5 | ADCR4 | ADCR3 | ADCR2 |

Caution When writing to A/D converter mode register 0 (ADM0) and the analog input channel specification register (ADS), the contents of the ADCR/ADCRH registers may become undefined. After conversion ends, read the conversion result before writing to the ADM0 and ADS registers. Using timing other than the above may cause an incorrect conversion result to be read.

10.3.6 Analog input channel specification register (ADS)

This register specifies the input channel of the analog voltage to be A/D converted.

The ADS register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 10-9. Format of Analog Input Channel Specification Register (ADS)

Address: FFF31H After reset: 00H R/W

| | | | | | | | | |
|--------|---|---|---|---|------|------|------|------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| ADS | 0 | 0 | 0 | 0 | ADS3 | ADS2 | ADS1 | ADS0 |

| ADS3 | ADS2 | ADS1 | ADS0 | Target of A/D conversion | Analog input pin |
|----------------------|------|------|------|--|------------------|
| 0 | 0 | 0 | 0 | ANI0 | P01/ANI0 pin |
| 0 | 0 | 0 | 1 | ANI1 | P02/ANI1 pin |
| 0 | 0 | 1 | 0 | ANI2 | P03/ANI2 pin |
| 0 | 0 | 1 | 1 | ANI3 | P04/ANI3 pin |
| 0 | 1 | 0 | 0 | ANI4 | P05/ANI4 pin |
| 0 | 1 | 0 | 1 | ANI5 | P06/ANI5 pin |
| 0 | 1 | 1 | 0 | ANI6 | P07/ANI6 pin |
| 0 | 1 | 1 | 1 | ANI7 | P23/ANI7 pin |
| 1 | 0 | 0 | 0 | ANI8 | P22/ANI8 pin |
| 1 | 0 | 0 | 1 | ANI9 | P21/ANI9 pin |
| 1 | 0 | 1 | 0 | ANI10 | P20/ANI10 pin |
| 1 | 1 | 0 | 1 | Internal reference voltage (0.815 V (typ.)) ^{Note 1} | — |
| Other than the above | | | | Setting prohibited | |

Note 1. When the internal reference voltage is selected as the target of conversion by the A/D converter, be sure to clear the LV0 bit in A/D converter mode register 0 (ADM0) to 0.

Caution 1. Only rewrite the ADS register while in the conversion standby state (ADCS = 0, ADCE = 1) or conversion is stopped (ADCS = 0, ADCE = 0).

Caution 2. For the ports which are used as analog input ports, select input mode with port mode registers 0 and 2 (PM0, PM2) and analog input with port mode control registers 0 and 2 (PMC0, PMC2). Do not use the ADS register to set the pins which are set as digital I/O with port mode control registers (PMC0, PMC2).

Caution 3. The internal reference voltage cannot be used for the A/D converter and the comparator simultaneously. When the internal reference voltage is selected as the target of conversion by the A/D converter (ADS3 to ADS0 = 1101B), it cannot be set as the reference voltage of the comparator.

Caution 4. Be sure to clear bits 4 to 7 to 0.

10.3.7 A/D test register (ADTES)

This register is used to select V_{SS} as the analog input to be A/D converted. When the internal reference voltage (0.815 V (typ.)) is selected as the target of A/D conversion, the sampling capacitor must be discharged before A/D conversion of this voltage proceeds. Perform A/D conversion once by setting the ADTES1 bit of the ADTES register to 1.

The ADTES register can be set by an 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 10-10. Format of A/D Test Register (ADTES)

Address: F0013H After reset: 00H R/W

| | | | | | | | | |
|--------|---|---|---|---|---|---|--------|---|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| ADTES | 0 | 0 | 0 | 0 | 0 | 0 | ADTES1 | 0 |

| ADTES1 | Selection of target of A/D conversion |
|--------|--|
| 0 | ANIX/internal reference voltage (0.815 V (typ.)) (This is specified using the analog input channel specification register (ADS).) |
| 1 | V_{SS} (discharging the sampling capacitor) |

Caution When A/D converting the internal reference voltage (0.815 V (typ.)), follow the procedure described in 10.7.2 Setting up the internal reference voltage for A/D conversion to discharge the sampling capacitor once.

Remark Be sure to clear bits 0 and 2 to 7 to 0.

10.3.8 Registers controlling port function of analog input pins

Set up the registers for controlling the functions of the ports shared with the analog input pins of the A/D converter (port mode registers 0 and 2 (PM0, PM2) and port mode control registers 0 and 2 (PMC0, PMC2)). For details, see 4.3.1 Port mode registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12) and 4.3.5 Port mode control registers 0, 2 (PMC0, PMC2).

For an example of settings when used as the analog input pins of the A/D converter, see 4.5.3 Register setting examples for used port and alternate functions.

When using the ANI0 to ANI10 pins as analog input of the A/D converter, set the corresponding bits in port mode registers 0 and 2 (PM0, PM2) and port mode control register 0 and 2 (PMC0, PMC2) to 1.

10.4 A/D Converter Conversion Operations

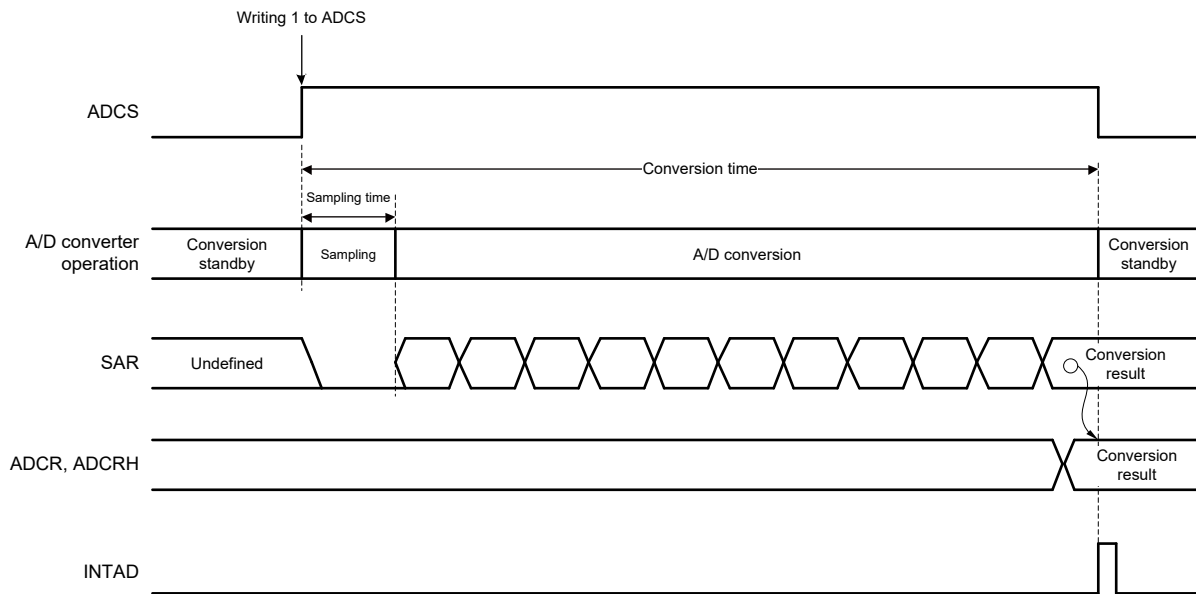
The A/D converter conversion operations are described below.

- <1> The voltage input to the selected analog input channel is sampled by the sample & hold circuit.
- <2> When sampling has been done for a certain time, the sample & hold circuit is placed in the hold state and the sampled voltage is held until the A/D conversion operation ends.
- <3> Bit 9 of the successive approximation register (SAR) is set. The series resistor string voltage tap is set to $(1/2) V_{DD}$ by the tap selector.
- <4> The voltage difference between the series resistor string voltage tap and sampled voltage is compared by the voltage comparator. If the analog input is greater than $(1/2) V_{DD}$, the MSB bit of the SAR register remains set. If the analog input is smaller than $(1/2) V_{DD}$, the MSB bit is reset.
- <5> Next, bit 8 of the SAR register is automatically set to 1, and the operation proceeds to the next comparison. The series resistor string voltage tap is selected according to the preset value of bit 9, as described below.
 - Bit 9 = 1: $(3/4) V_{DD}$
 - Bit 9 = 0: $(1/4) V_{DD}$The voltage tap and sampled voltage are compared and bit 8 of the SAR register is manipulated as follows.
 - Sampled voltage \geq Voltage tap: Bit 8 = 1
 - Sampled voltage $<$ Voltage tap: Bit 8 = 0
- <6> Comparison is continued in this way up to bit 0 of the SAR register.
- <7> Upon completion of the comparison of 10 bits, an effective digital result value remains in the SAR register, and the result value is transferred to the A/D conversion result register (ADCR, ADCRH) and then latched. At the same time, the A/D conversion end interrupt request (INTAD) is generated. After A/D conversion ends, the ADCS bit is automatically cleared to 0, and the system enters the A/D conversion standby state.

Remark Two types of the A/D conversion result registers are available.

- ADCR register (16 bits): Store 10-bit A/D conversion value
- ADCRH register (8 bits): Store 8-bit A/D conversion value

Figure 10-11. Conversion Operation of A/D Converter (Software Trigger Mode)



A/D conversion is performed once when the bit 7 (ADCS) of A/D converter mode register 0 (ADM0) is set to 1 by software. The ADCS bit is automatically cleared to 0 after A/D conversion ends.

Reset signal generation clears the A/D conversion result register (ADCR, ADCRH) to 0000H or 00H.

10.5 Input Voltage and Conversion Results

The relationship between the analog input voltage input to the analog input (ANI0 to ANI10, internal reference voltage) and the theoretical A/D conversion result (stored in the 10-bit A/D conversion result register (ADCR)) is shown by the following expression.

$$SAR = \text{INT} \left(\frac{V_{AIN}}{V_{DD}} \times 1024 + 0.5 \right)$$

$$ADCR = SAR \times 64$$

or

$$\left(\frac{ADCR}{64} - 0.5 \right) \times \frac{V_{DD}}{1024} \leq V_{AIN} < \left(\frac{ADCR}{64} + 0.5 \right) \times \frac{V_{DD}}{1024}$$

where, INT (): Function which returns integer part of value in parentheses

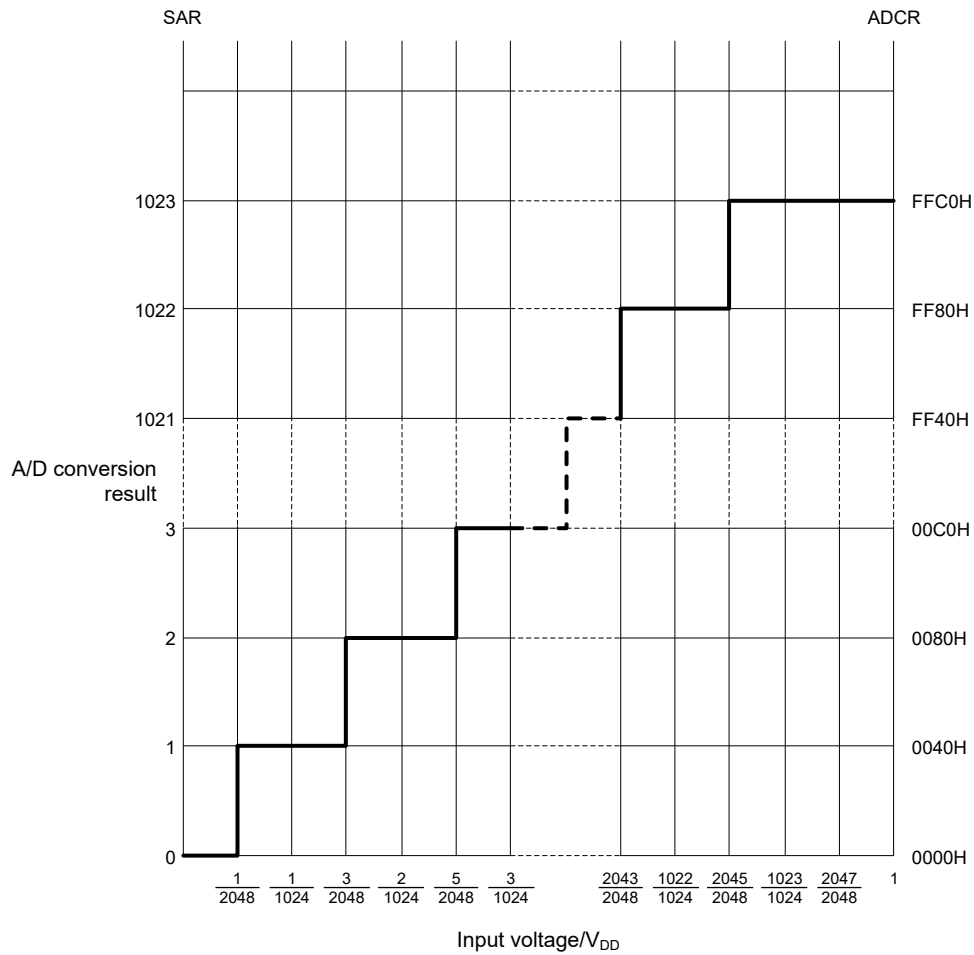
V_{AIN} : Analog input voltage

ADCR: A/D conversion result register (ADCR) value

SAR: Successive approximation register

Figure 10-12 shows the relationship between the analog input voltage and the A/D conversion result.

Figure 10-12. Relationship between Analog Input Voltage and A/D Conversion Result

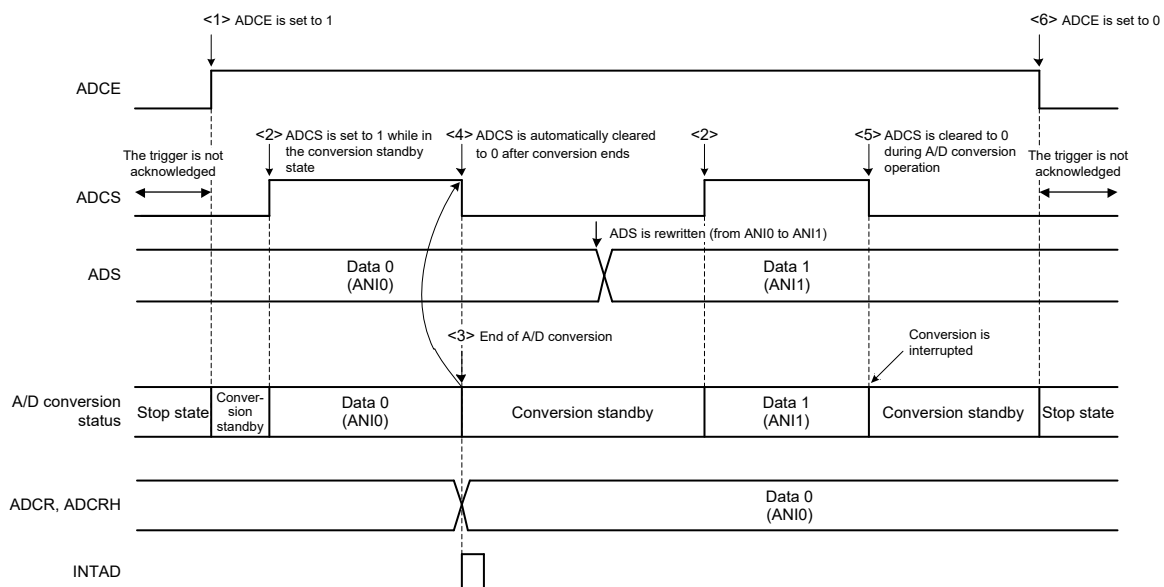


10.6 A/D Converter Operation Modes

The operation of the A/D converter is described below. In addition, the setting procedure is described in **10.7 A/D Converter Setup Flowchart**.

- <1> While conversion is stopped, the ADCE bit of A/D converter mode register 0 (ADM0) is set to 1, and the system enters the conversion standby state.
- <2> After software counts the stabilization wait time (0.125 μ s), the ADCS bit of the ADM0 register is set to 1 to perform A/D conversion of the analog input specified by the analog input channel specification register (ADS).
- <3> When A/D conversion ends, the conversion result is stored in the A/D conversion result register (ADCR, ADCRH), and the A/D conversion end interrupt request signal (INTAD) is generated.
- <4> After A/D conversion ends, the ADCS bit is automatically cleared to 0, and the system enters the conversion standby state.
- <5> When ADCS is cleared to 0 during conversion operation, the current A/D conversion is interrupted, and the system enters the conversion standby state.
- <6> When ADCE is cleared to 0 while in the conversion standby state, the A/D converter enters the stop state. Setting ADCS = 1 and ADCE = 0 is prohibited. Setting ADCS to 1 while conversion is stopped (ADCS = 0, ADCE = 0) is ignored and A/D conversion does not start.

Figure 10-13. Example of Operation Timing

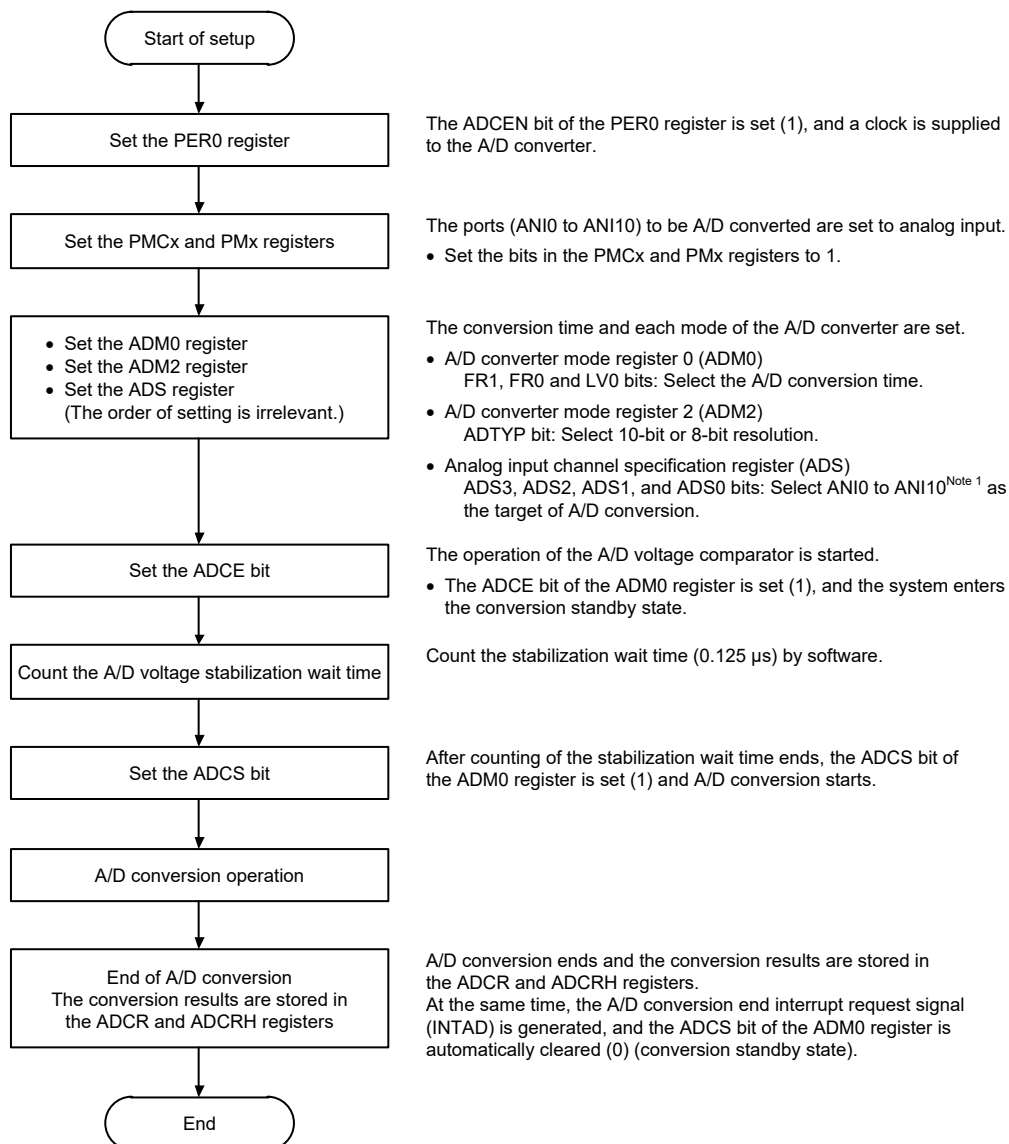


10.7 A/D Converter Setup Flowchart

The A/D converter setup flowchart is described below.

10.7.1 Setting up ANI0 to ANI10 for A/D conversion

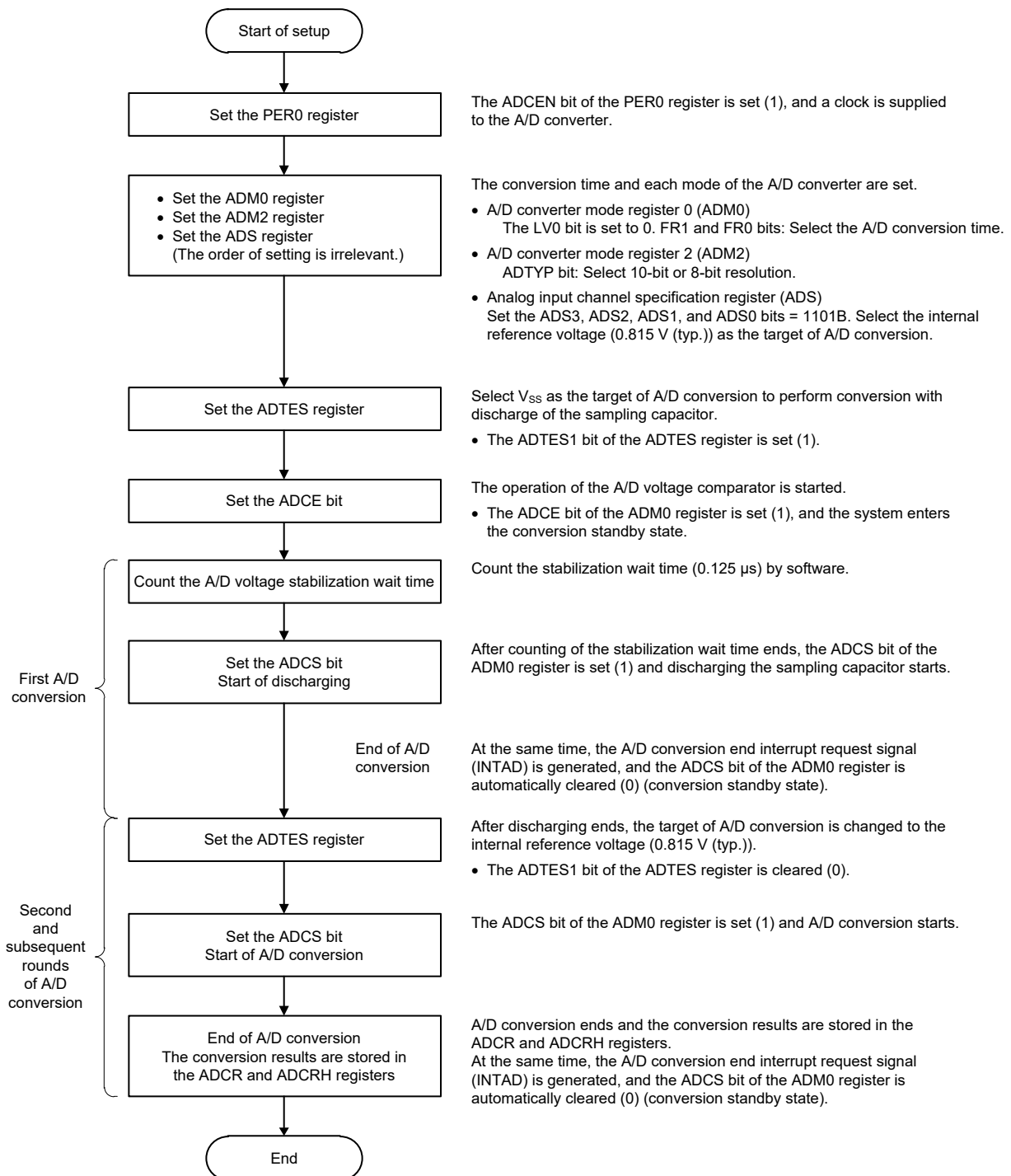
Figure 10-14. Setting up ANI0 to ANI10 for A/D Conversion



Note 1. ANI0, ANI2, ANI3 for 8-pin products,
ANI0 to ANI3 for 10-pin products,
ANI0 to ANI6 for 16-pin products

10.7.2 Setting up the internal reference voltage for A/D conversion

Figure 10-15. Setting up Internal Reference Voltage for A/D Conversion



10.8 How to Read A/D Converter Characteristics Table

Here, special terms unique to the A/D converter are explained.

10.8.1 Resolution

This is the minimum analog input voltage that can be identified. That is, the percentage of the analog input voltage per bit of digital output is called 1LSB (Least Significant Bit). The percentage of 1LSB relative to the full scale is expressed by %FSR (Full Scale Range).

1LSB is as follows when the resolution is 10 bits.

$$\begin{aligned} 1\text{LSB} &= 1/2^{10} = 1/1024 \\ &= 0.098\%\text{FSR} \end{aligned}$$

The accuracy is determined by overall error, regardless of the resolution.

10.8.2 Overall error

This shows the maximum error value between the actual measurement value and the theoretical value.

Zero-scale error, full-scale error, integral linearity error, and differential linearity errors that are combinations of these express the overall error.

Note that the quantization error is not included in the overall error in the characteristics table.

10.8.3 Quantization error

When analog values are converted to digital values, a $\pm 1/2\text{LSB}$ error naturally occurs. In an A/D converter, an analog input voltage in a range of $\pm 1/2\text{LSB}$ is converted to the same digital code, so a quantization error cannot be avoided.

Note that the quantization error is not included in the overall error, zero-scale error, full-scale error, integral linearity error, and differential linearity error in the characteristics table.

Figure 10-16. Overall Error

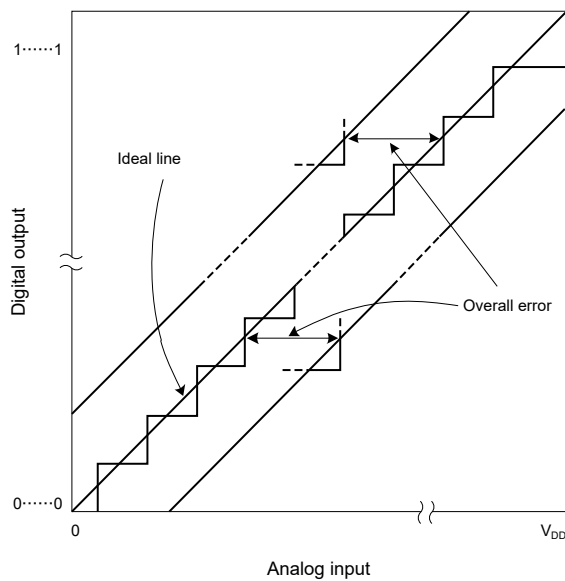
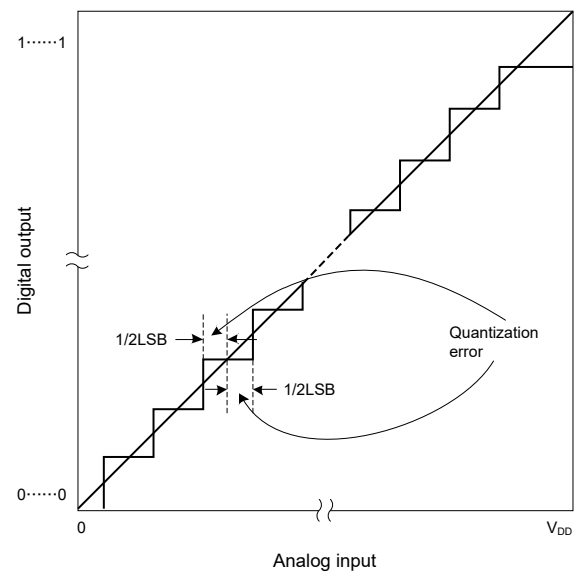


Figure 10-17. Quantization Error



10.8.4 Zero-scale error

This shows the difference between the actual measurement value of the analog input voltage and the theoretical value ($1/2\text{LSB}$) when the digital output changes from $0\dots\dots 000$ to $0\dots\dots 001$. If the actual measurement value is greater than the theoretical value, it shows the difference between the actual measurement value of the analog input voltage and the theoretical value ($3/2\text{LSB}$) when the digital output changes from $0\dots\dots 001$ to $0\dots\dots 010$.

10.8.5 Full-scale error

This shows the difference between the actual measurement value of the analog input voltage and the theoretical value (Full-scale – $3/2\text{LSB}$) when the digital output changes from $1\dots\dots 110$ to $1\dots\dots 111$.

10.8.6 Integral linearity error

This shows the degree to which the conversion characteristics deviate from the ideal linear relationship. It expresses the maximum value of the difference between the actual measurement value and the ideal straight line when the zero-scale error and full-scale error are 0.

10.8.7 Differential linearity error

While the ideal width of code output is 1LSB, this indicates the difference between the actual measurement value and the ideal value.

Figure 10-18. Zero-Scale Error

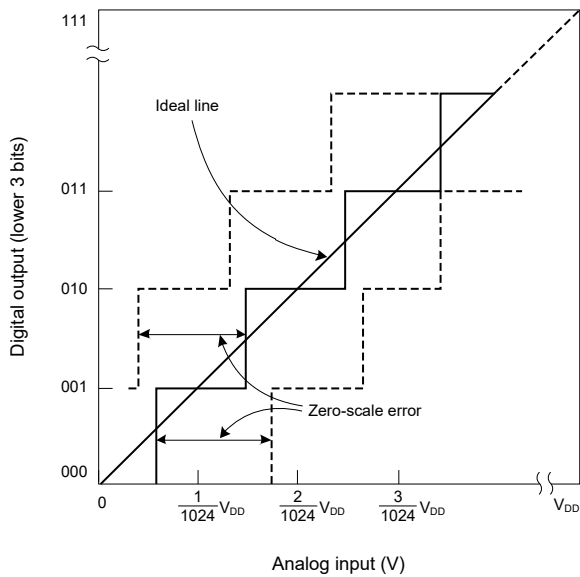


Figure 10-19. Full-Scale Error

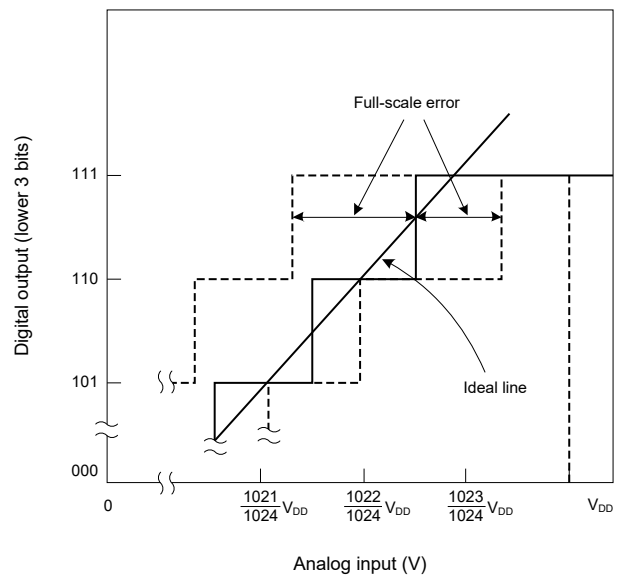


Figure 10-20. Integral Linearity Error

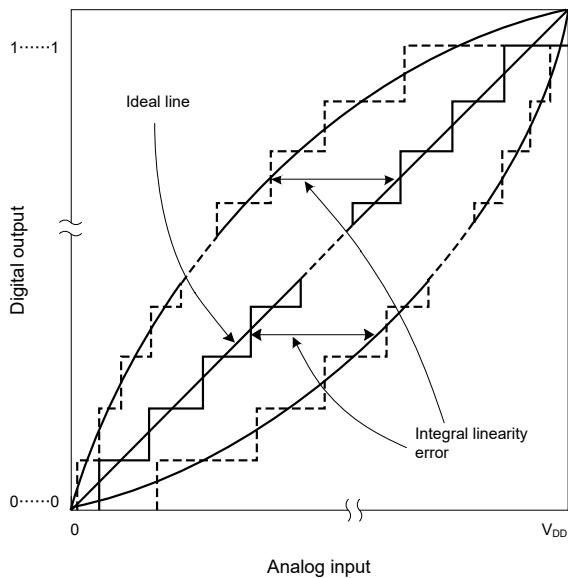
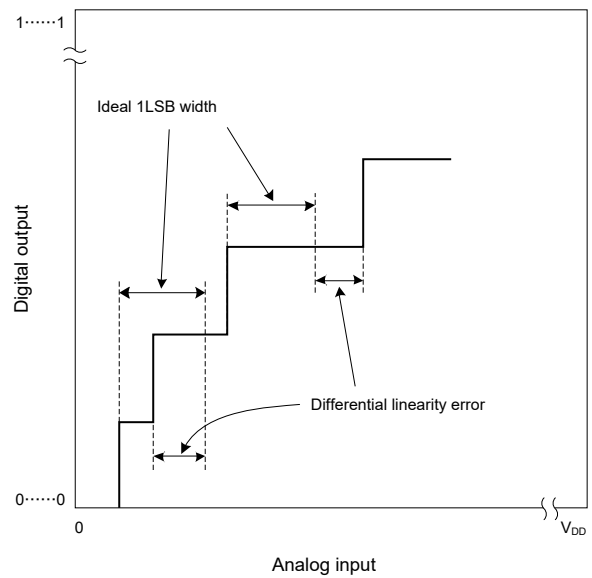


Figure 10-21. Differential Linearity Error



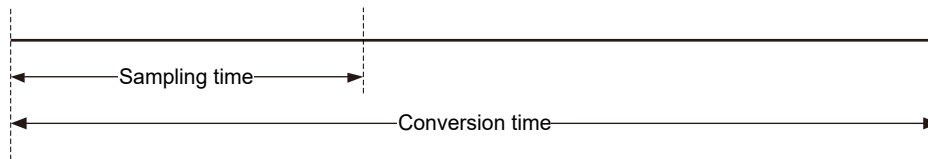
10.8.8 Conversion time

This expresses the time from the start of sampling to when the digital output is obtained.

The sampling time is included in the conversion time in the characteristics table.

10.8.9 Sampling time

This is the time the analog switch is turned on for the analog voltage to be sampled by the sample & hold circuit.



10.9 Notes on A/D Converter

10.9.1 Operating current in STOP mode

Shift to STOP mode after stopping the A/D converter (by setting bit 7 (ADCS) of A/D converter mode register 0 (ADM0) to 0). The operating current can be reduced by setting bit 0 (ADCE) of the ADM0 register to 0 at the same time.

10.9.2 Input voltage on ANI0 to ANI10 pins

Observe the rated range of the ANI0 to ANI10 pins input voltage. If a voltage exceeding V_{DD} or a voltage lower than V_{SS} (even in the range of absolute maximum ratings) is input to an analog input channel, the converted value of that channel becomes undefined. In addition, the converted values of the other channels may also be affected.

10.9.3 Conflicting operations

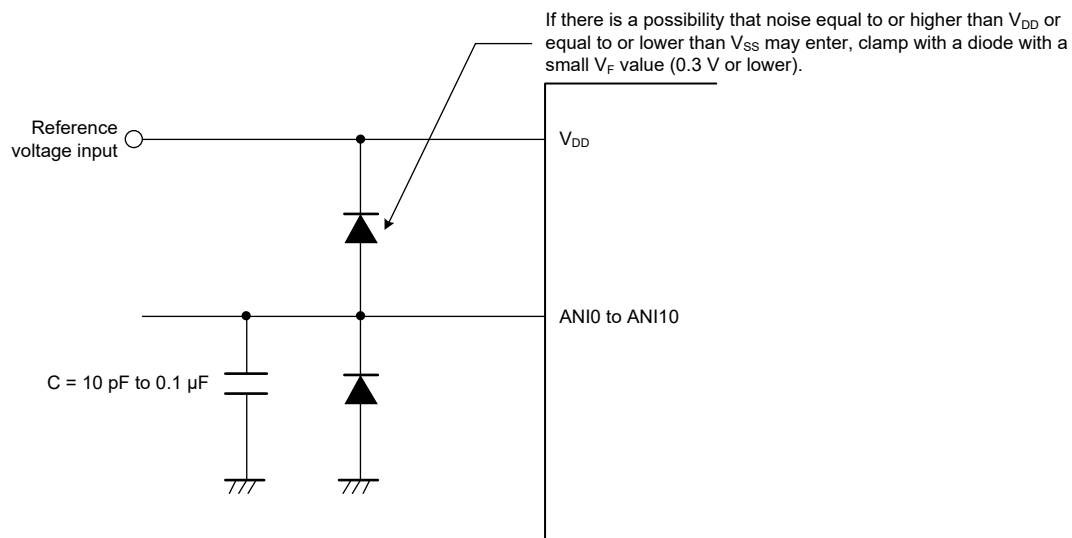
- (1) If writing to the A/D conversion result register (ADCR, ADCRH) at the end of conversion and reading of the ADCR or ADCRH register by software operation are in contention, the latter is given priority.
After the read operation, the new conversion result is written to the ADCR or ADCRH register.
- (2) If writing to the ADCR or ADCRH register at the end of conversion and writing to A/D converter mode register 0 (ADM0) are in contention, the latter is given priority. Writing to the ADCR or ADCRH register is not performed, nor is the A/D conversion end interrupt signal (INTAD) generated.

10.9.4 Noise countermeasures

To maintain the 10-bit resolution, attention must be paid to noise on V_{DD} and the ANI0 to ANI10 pins.

- (1) Connect a capacitor with a low equivalent resistance and a good frequency response to the power supply.
- (2) The higher the output impedance of the analog input source, the greater the influence. To reduce noise, we recommend connecting C externally as shown in **Figure 10-22**.
- (3) Do not switch other pins during conversion.
- (4) The accuracy is improved if the HALT mode is set immediately after the start of conversion.

Figure 10-22. Analog Input Pin Connection



10.9.5 Analog input (ANIn) pins

- (1) The analog input pins (ANI0 to ANI10^{Note 1}) are also used as input port pins (P01 to P07^{Note 2} and P20 to P23^{Note 2}). When A/D conversion is performed with any of the ANI0 to ANI10 pins selected, do not change output values to alternate port P01 to P07^{Note 2} and P20 to P23^{Note 2} while conversion is in progress; otherwise the conversion accuracy may be degraded.
- (2) If a pin adjacent to a pin that is being A/D converted is used as a digital I/O port pin, the A/D conversion result might differ from the expected value due to a coupling noise. Be sure to prevent such a pulse from being input or output.

Note 1. ANI0, ANI2, ANI3 for 8-pin products,
ANI0 to ANI3 for 10-pin products,
ANI0 to ANI6 for 16-pin products

Note 2. P01, P03, P04 for 8-pin products,
P01 to P04 for 10-pin products,
P01 to P07 for 16-pin products

10.9.6 Input impedance of analog input (ANIn) pins

This A/D converter charges a sampling capacitor for sampling during sampling time.

Therefore, only a leakage current flows when sampling is not in progress, and a current that charges the capacitor flows during sampling. Consequently, the input impedance fluctuates depending on whether sampling is in progress, and on the other states.

To make sure that sampling is effective, however, keep the output impedance of the analog input source at no greater than 1 k Ω . If the output impedance is high, we recommend connecting a capacitor of about 0.1 μ F between the ANI0 to ANI10^{Note 1} pins and the ground (see **Figure 10-22**).

Note 1. ANI0, ANI2, ANI3 for 8-pin products,
ANI0 to ANI3 for 10-pin products,
ANI0 to ANI6 for 16-pin products

10.9.7 Interrupt request flag (ADIF)

The interrupt request flag (ADIF) is not cleared even if the analog input channel specification register (ADS) is changed. When A/D conversion is to be stopped and then resumed, clear the ADIF flag before resuming the A/D conversion.

10.9.8 Conversion results just after A/D conversion start

The first A/D conversion value immediately after A/D conversion starts may not fall within the rating range if the ADCS bit is set to 1 within 0.125 μ s after the ADCE bit was set to 1. Take measures such as polling the A/D conversion end interrupt request signal (INTAD) and removing the first conversion result.

10.9.9 A/D conversion result register (ADCR, ADCRH) read operation

When a write operation is performed to A/D converter mode register 0 (ADM0), the analog input channel specification register (ADS), and port mode control register (PMCx), the contents of the ADCR and ADCRH registers may become undefined and a correct conversion result may not be read. After conversion ends, read the conversion result before writing to the ADM0, ADS, or PMCx register.

10.9.10 Internal equivalent circuit

The equivalent circuit of the analog input block is shown below.

Figure 10-23. Internal Equivalent Circuit of ANIn Pin

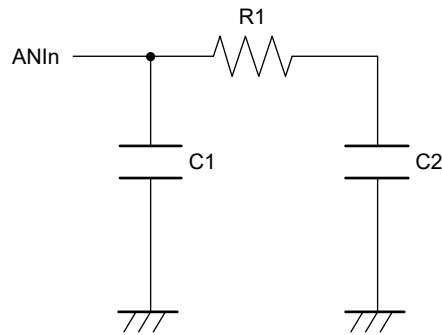


Table 10-4. Resistance and Capacitance Values of Equivalent Circuit

| V_{DD} | Pin | R1 (k Ω) | C1 (pF) | C2 (pF) |
|--|---------------------------------|------------------|---------|---------|
| $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | ANI0 to ANI10 ^{Note 1} | 40 | 8 | 1.7 |
| $2.4\text{ V} \leq V_{DD} < 2.7\text{ V}$ | ANI0 to ANI10 ^{Note 1} | 200 | | |

Note 1. ANI0, ANI2, ANI3 for 8-pin products,
ANI0 to ANI3 for 10-pin products,
ANI0 to ANI6 for 16-pin products

Remark The resistance and capacitance values are not guaranteed values.

10.9.11 Starting the A/D converter

Start the A/D converter after the V_{DD} voltage stabilizes.

CHAPTER 11 COMPARATOR

Caution 16-, 10-, and 8-pin products have only one comparator channel. 20-pin products have two comparator channels. This chapter mainly describes the comparator in the case of 20-pin products.

11.1 Comparator Functions

The comparator has the following functions.

- The comparator response speed can be selected.
High-speed mode: Decreased response delay time, with increased power consumption.
Low-speed mode: Increased response delay time, with decreased power consumption.
- The comparator reference voltage is selectable as the externally input reference voltage or the internal reference voltage^{Note 1} (0.815 V (typ.)).
- The integrated digital filter for noise elimination allows selecting the noise elimination width.
- The inverted/non-inverted comparator output can be output from the VCOUTn pin.
- An interrupt (INTCMPn) can be generated upon detection of the effective edge of the comparator output signal.

Note 1. The internal reference voltage cannot be used for the A/D converter and comparator simultaneously. When the internal reference voltage is selected as the reference voltage of the comparator, do not select the internal reference voltage as the target for conversion by the A/D converter.

Remark n = 0, 1

11.2 Comparator Configuration

The comparator consists of the following hardware:

1) IVCMPn Pin

The comparator analog input pin. An analog signal to be compared by the comparator is input to this pin.

Remark n = 0, 1

2) IVREFn Pin

An input pin to supply the reference voltage externally. The reference voltage of the comparator and analog input that is input to the IVCMPn pin are compared.

In addition to the voltage supplied to the IVREFn pin externally, the internal reference voltage (0.815 V (typ.)) can be selected for the comparator reference voltage.

For details on setting the comparator reference voltage, see **11.3.2 Comparator Mode Setting Register (COMPMDR)**.

Remark n = 0, 1

3) VCOUTn Pin

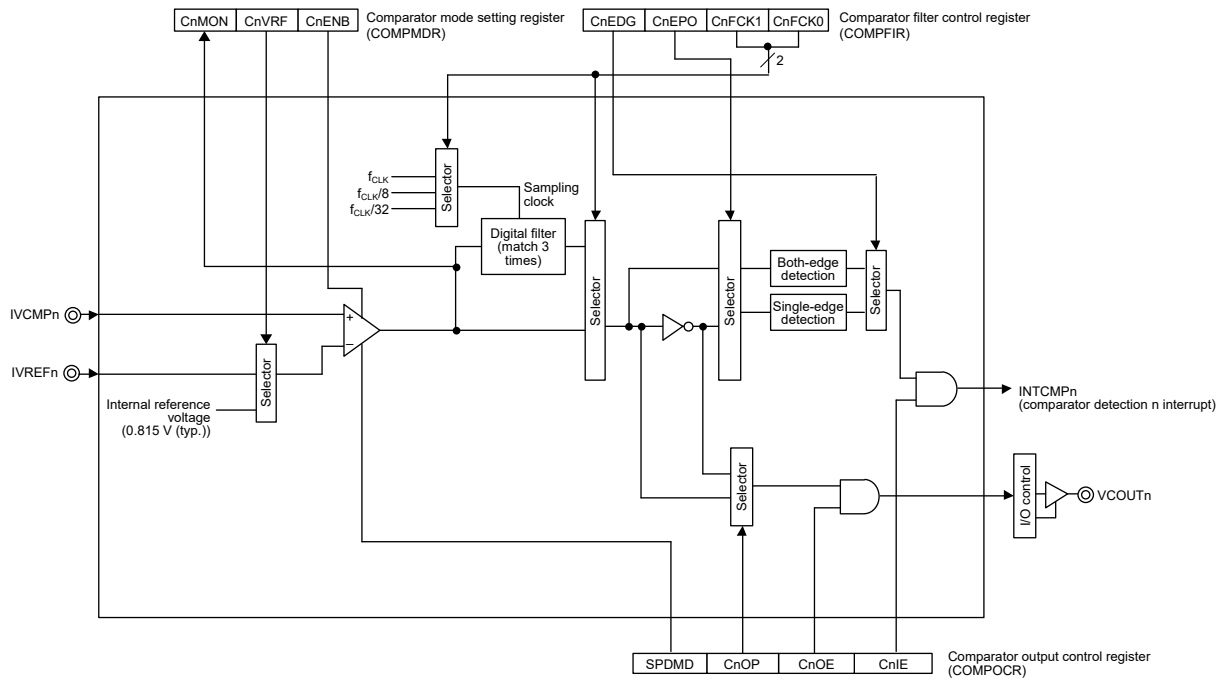
A pin to output the comparator comparison results. The inverted/non-inverted comparator output can be output from the VCOUTn pin.

For use of the VCOUTn pin as a comparator output, see **11.4.3 Comparator n Output (n = 0, 1)**.

Remark n = 0, 1

Figure 11-1 shows the block diagram of the comparator.

Figure 11-1. Block Diagram of the Comparator



Remark $n = 0, 1$

11.3 Registers Controlling the Comparator

The following lists the registers to control the comparator.

- Peripheral enable register 0 (PER0)
- Comparator mode setting register (COMPMDR)
- Comparator filter control register (COMPFIR)
- Comparator output control register (COMPOCR)
- Port mode control register 0 (PMC0)
- Port mode register 0 (PM0)
- Port register 0 (P0)
- Port mode control register 2 (PMC2)
- Port mode register 2 (PM2)
- Port register 2 (P2)

11.3.1 Peripheral Enable Register 0 (PER0)

This register enables or disables clock supply to each peripheral hardware macro. Clock supply to a hardware macro that is not used is stopped in order to reduce the power consumption and noise.

When the comparator is used, be sure to set bit 6 (CMPEN) of this register to 1.

The PER0 register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 11-2. Format of Peripheral Enable Register 0 (PER0)

Address: F00F0H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|---|----------|---|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PER0 | TMKAEN | CMPEN | ADCEN | IICA0EN | 0 | SAU0EN | 0 | TAU0EN |

| CMPEN | Control of comparator input clock |
|-------|---|
| 0 | Stops input clock supply. <ul style="list-style-type: none"> • SFR used by the comparator cannot be written. • The comparator is in the reset status. |
| 1 | Supplies input clock. <ul style="list-style-type: none"> • SFR used by the comparator can be read/written. |

Caution When setting the comparator, be sure to set the CMPEN bit to 1 first before setting the registers shown below. If CMPEN = 0, control registers of the comparator are cleared to their initial values and writing to them is ignored (except for port mode registers 0 and 2 (PM0, PM2), port registers 0 and 2 (P0, P2), and port mode control registers 0 and 2 (PMC0, PMC2)).

- Comparator mode setting register (COMPMDR)
- Comparator filter control register (COMPFIR)
- Comparator output control register (COMPOCR)

11.3.2 Comparator Mode Setting Register (COMPMDR)

This register selects the comparator reference voltage, starts/stops the comparison operation, and indicates the comparison result state.

The COMPMDR register can be set by a 1-bit or 8-bit memory manipulation instruction. Note that the CnMON bit (n = 1, 0) can only be read.

Reset signal generation clears this register to 00H.

Figure 11-3. Format of Comparator Mode Setting Register (COMPMDR)

Address: FFF60H After reset: 00H R/W^{Note 1}

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------------------------|---|-------|---|-------|-------|-------|---|-------|
| COMPMDR | C1MON | C1VRF | 0 | C1ENB | C0MON | C0VRF | 0 | C0ENB |
| C1MON ^{Note 2} | Comparator 1 monitor flag | | | | | | | |
| 0 | IVCMP1 < comparator 1 reference voltage | | | | | | | |
| 1 | IVCMP1 > comparator 1 reference voltage | | | | | | | |
| C1VRF | Comparator 1 reference voltage selection | | | | | | | |
| 0 | Supplied from the IVREF1 pin | | | | | | | |
| 1 | Supplied from the internal reference voltage (0.815 V (typ.)) ^{Note 3} | | | | | | | |
| C1ENB | Comparator 1 operation control | | | | | | | |
| 0 | Comparator 1 operation disabled | | | | | | | |
| 1 | Comparator 1 operation enabled | | | | | | | |
| C0MON ^{Note 4} | Comparator 0 monitor flag | | | | | | | |
| 0 | IVCMP0 < comparator 0 reference voltage | | | | | | | |
| 1 | IVCMP0 > comparator 0 reference voltage | | | | | | | |
| C0VRF | Comparator 0 reference voltage selection | | | | | | | |
| 0 | Supplied from the IVREF0 pin | | | | | | | |
| 1 | Supplied from the internal reference voltage (0.815 V (typ.)) ^{Note 5} | | | | | | | |
| C0ENB | Comparator 0 operation control | | | | | | | |
| 0 | Comparator 0 operation disabled | | | | | | | |
| 1 | Comparator 0 operation enabled | | | | | | | |

Note 1. Bits 3 and 7 are read-only bits.

Note 2. After the comparator 1 operation is enabled (C1ENB = 1), the IVREF1 pin state can be read from the C1MON bit setting. When the comparator 1 operation is then disabled (C1ENB = 0), the C1MON bit value is undefined.

Note 3. When the internal reference voltage (0.815 V (typ.)) is selected as the comparator 1 reference voltage, the internal reference voltage cannot be selected for the A/D converter.

- Note 4. After the comparator 0 operation is enabled (C0ENB = 1), the IVREF0 pin state can be read from the C0MON bit setting. When the comparator 0 operation is then disabled (C0ENB = 0), the C0MON bit value is undefined.
- Note 5. When the internal reference voltage (0.815 V (typ.)) is selected as the comparator 0 reference voltage, the internal reference voltage cannot be selected for the A/D converter.

11.3.3 Comparator Filter Control Register (COMPFIR)

This register selects the effective edge for the comparator interrupt signal, and enables or disables the digital filter.

If noise elimination is required, set the CnFCK1 and CnFCK0 bits (n = 1, 0) so that the digital filter is enabled. When the digital filter is enabled, the comparator output is checked if its level remains the same for three consecutive digital filter sampling clock cycles.

The COMPFIR register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 11-4. Format of Comparator Filter Control Register (COMPFIR)

Address: FFF61H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---------|--------|--------|--|--------|-------|-------|--------|--------|
| COMPFIR | C1EDG | C1EPO | C1FCK1 | C1FCK0 | C0EDG | C0EPO | C0FCK1 | C0FCK0 |
| | C1EDG | C1EPO | Effective edge selection for comparator 1 interrupt signal ^{Note 1} | | | | | |
| | 0 | 0 | Rising edge | | | | | |
| | 0 | 1 | Falling edge | | | | | |
| | 1 | × | Both rising and falling edges | | | | | |
| | C1FCK1 | C1FCK0 | Comparator 1 digital filter enable/disable ^{Note 1, Note 2, Note 3} | | | | | |
| | 0 | 0 | Digital filter disabled | | | | | |
| | 0 | 1 | Digital filter enabled, sampling clock: f_{CLK} | | | | | |
| | 1 | 0 | Digital filter enabled, sampling clock: $f_{CLK}/8$ | | | | | |
| | 1 | 1 | Digital filter enabled, sampling clock: $f_{CLK}/32$ | | | | | |
| | C0EDG | C0EPO | Effective edge selection for comparator 0 interrupt signal ^{Note 4} | | | | | |
| | 0 | 0 | Rising edge | | | | | |
| | 0 | 1 | Falling edge | | | | | |
| | 1 | × | Both rising and falling edges | | | | | |
| | C0FCK1 | C0FCK0 | Comparator 0 digital filter enable/disable ^{Note 4, Note 5, Note 6} | | | | | |
| | 0 | 0 | Digital filter disabled | | | | | |
| | 0 | 1 | Digital filter enabled, sampling clock: f_{CLK} | | | | | |
| | 1 | 0 | Digital filter enabled, sampling clock: $f_{CLK}/8$ | | | | | |
| | 1 | 1 | Digital filter enabled, sampling clock: $f_{CLK}/32$ | | | | | |

Note 1. If the C1EDG, C1EPO, and C1FCK1 or C1FCK0 bits are changed while operation of the comparator 1 is enabled, a comparator detection 1 interrupt (INTCMP1) may be generated. Change these bits only after clearing the C1IE bit in the COMPOCR register to 0 to disable an interrupt request. Also, be sure to clear bit 2 (CMPIF1) in the interrupt request flag register 1H (IF1H) to 0 after changing these bits.

Note 2. If the value of the C1FCK1 or C1FCK0 bit is changed, a wait period of four cycles of the sampling clock is required to update the digital filter. To use the comparator detection 1 interrupt (INTCMP1), set the C1IE bit in the COMPOCR register to 1 after this wait period.

- Note 3. To use the comparator in STOP mode, disable the digital filter (C1FCK1 and C1FCK0 = 00B).
- Note 4. If the C0EDG, C0EPO, and C0FCK1 or C0FCK0 bits are changed while operation of the comparator 0 is enabled, a comparator detection 0 interrupt (INTCMP0) may be generated. Change these bits only after clearing the C0IE bit in the COMPOCR register to 0 to disable an interrupt request. Also, be sure to clear bit 1 (CMPIF0) in the interrupt request flag register 1H (IF1H) to 0 after changing these bits.
- Note 5. If the value of the C0FCK1 or C0FCK0 bit is changed, a wait period of four cycles of the sampling clock is required to update the digital filter. To use the comparator detection 0 interrupt (INTCMP0), set the C0IE bit in the COMPOCR register to 1 after this wait period.
- Note 6. To use the comparator in STOP mode, disable the digital filter (C0FCK1 and C0FCK0 = 00B).
- Remark** ×: Don't care

11.3.4 Comparator Output Control Register (COMPOCR)

This register selects the comparator response speed, controls the VCOUTn output, and enables or disables the interrupt request signal.

Remark n = 0, 1

The COMPOCR register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 11-5. Format of Comparator Output Control Register (COMPOCR)

Address: FFF62H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|-------------------------|---|------|------|------|---|------|------|------|
| COMPOCR | SPDMD | C1OP | C1OE | C1IE | 0 | C0OP | C0OE | C0IE |
| SPDMD ^{Note 1} | Comparator speed selection | | | | | | | |
| 0 | Low-speed mode | | | | | | | |
| 1 | High-speed mode | | | | | | | |
| C1OP | VCOUT1 output polarity selection | | | | | | | |
| 0 | Non-inverted comparator 1 output is output from the VCOUT1 pin. | | | | | | | |
| 1 | Inverted comparator 1 output is output from the VCOUT1 pin. | | | | | | | |
| C1OE | VCOUT1 pin output enable/disable | | | | | | | |
| 0 | Comparator 1 VCOUT1 pin output disabled | | | | | | | |
| 1 | Comparator 1 VCOUT1 pin output enabled | | | | | | | |
| C1IE | Comparator 1 interrupt request enable/disable | | | | | | | |
| 0 | Comparator 1 interrupt request disabled | | | | | | | |
| 1 | Comparator 1 interrupt request enabled | | | | | | | |
| C0OP | VCOUT0 output polarity selection | | | | | | | |
| 0 | Non-inverted comparator 0 output is output from the VCOUT0 pin. | | | | | | | |
| 1 | Inverted comparator 0 output is output from the VCOUT0 pin. | | | | | | | |
| C0OE | VCOUT0 pin output enable/disable | | | | | | | |
| 0 | Comparator 0 VCOUT0 pin output disabled | | | | | | | |
| 1 | Comparator 0 VCOUT0 pin output enabled | | | | | | | |
| C0IE | Comparator 0 interrupt request enable/disable | | | | | | | |
| 0 | Comparator 0 interrupt request disabled | | | | | | | |
| 1 | Comparator 0 interrupt request enabled | | | | | | | |

Note 1. When rewriting the SPDMD bit, be sure to clear the CnENB bit (n = 0, 1) in the COMPMDR register to 0 in advance.

11.3.5 Registers Controlling Port Functions of Comparator I/O Pins

The port mode register 0 (PM0), port mode register 2 (PM2), port register 0 (P0), port register 2 (P2), port mode control register 0 (PMC0), and port mode control register 2 (PMC2) should be appropriately set to control the functions of the port pins that are also used for input and output of the comparator. For details, see **4.3.1 Port mode registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12)**, **4.3.2 Port registers 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13)**, and **4.3.5 Port mode control registers 0, 2 (PMC0, PMC2)**. For an example of settings when using a port pin for input and output of the comparator, see **4.5.3 Register setting examples for used port and alternate functions**.

When using the IVCMP0 and IVREF0 pins as analog inputs of the comparator, set the corresponding bits in the port mode register (PM0) and port mode control register (PMC0) to 1.

When using the VCOUT0 pin as a comparator output, set the bits in the port mode register (PM0), port register (P0), and port mode control register (PMC0) to 0. For details on the VCOUT0 pin output setting, follow the setting procedure in **11.4.3 Comparator n Output (n = 0, 1)**.

When using the IVCMP1 and IVREF1 pins as analog inputs of the comparator, set the corresponding bits in the port mode register (PM2) and port mode control register (PMC2) to 1.

When using the VCOUT1 pin as a comparator output, set the bits in the port mode register (PM4), port register (P4), and port mode control register (PMC4) to 0. For details on the VCOUT1 pin output setting, follow the setting procedure in **11.4.3 Comparator n Output (n = 0, 1)**.

11.4 Comparator n Operation (n = 0, 1)

The CnMON bit in the COMPMDR register is set to 1 when the analog input voltage on the IVCMPn (n = 0, 1) pin is higher than the reference voltage. When lower, the CnMON bit is set to 0.

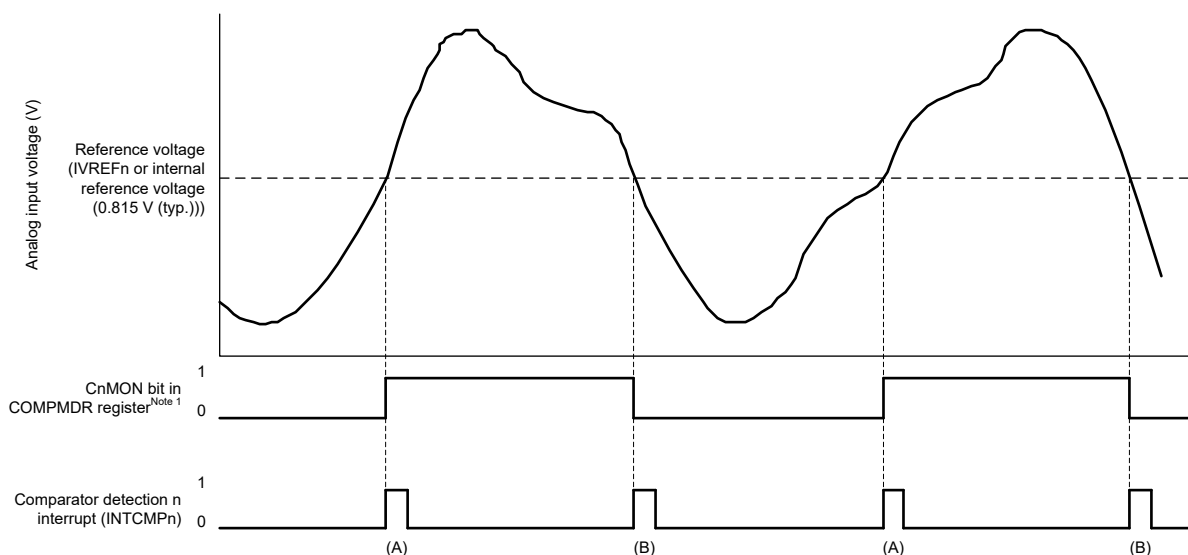
When using the comparator detection n interrupt (INTCMPn), set the CnIE bit in the COMPOCR register to 1 (interrupt request enabled). If the comparison result changes at this time, a comparator n interrupt request signal is generated. For details on the comparator 0 interrupt, refer to **11.4.2 Comparator n Interrupt Operation (n = 0, 1)**.

Remark n = 0, 1

Figure 11-6 shows an example of the comparator n operation (no digital filter (CnFCK1 and CnFCK0 in COMPFIR = 00B), both-edge detection on an interrupt (CnEDG = 1)).

Remark n = 0, 1

Figure 11-6. Example of Comparator n (n = 0, 1) Operation (No Digital Filter, Both-Edge Detection on Interrupt)



Note 1. The output delay time depends on the comparator operating mode. For details, see **23.6.2 Comparator characteristics** and **24.6.2 Comparator characteristics**.

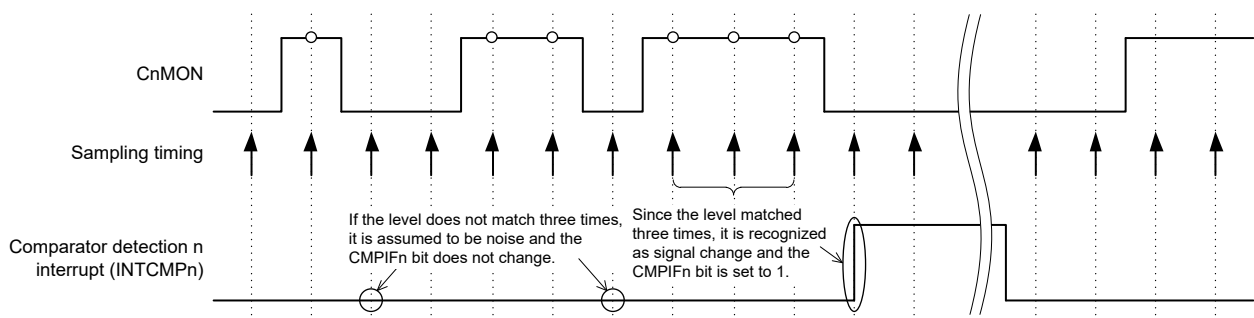
Caution When the rising edge is specified as an effective edge for an interrupt (CnEDG = 0 and CnEPO = 0), INTCMPn only changes at (A).
When the falling edge is specified as an effective edge for an interrupt (CnEDG = 0 and CnEPO = 1), INTCMPn only changes at (B).

11.4.1 Comparator n Digital Filter Operation (n = 0, 1)

Comparator n incorporates a digital filter. The sampling clock is selected by the CnFCK1 and CnFCK0 bits in the COMPFIR register. The comparator n output signal is sampled every sampling clock, and when the level of the output signal matches three times, the digital filter output changes at the next sampling clock.

Figure 11-7 shows the comparator n (n = 0, 1) digital filter and interrupt operation example.

Figure 11-7. Comparator n (n = 0, 1) Digital Filter and Interrupt Operation Example



Remark The operation example in Figure 11-7 applies when the digital filter is enabled (the CnFCK1 and CnFCK0 bits in the COMPFIR register = 01B, 10B, or 11B).

11.4.2 Comparator n Interrupt Operation (n = 0, 1)

When using the comparator n interrupt, set the CnIE bit in the COMPOCR register to 1 (interrupt request enabled). The condition for interrupt request generation can be set by the COMPFIR register. The comparator outputs can also be passed through the digital filter.

For details on the register settings, refer to 11.3.3 Comparator Filter Control Register (COMPFIR) and 11.3.4 Comparator Output Control Register (COMPOCR).

11.4.3 Comparator n Output (n = 0, 1)

The comparison result from the comparator can be output from the VCOUTn pin. The CnOP and CnOE bits in the COMPOCR register are used to set the output polarity (inverted or non-inverted output) of the VCOUTn pin and enable or disable the VCOUTn pin output, respectively. For details on the register settings, refer to 11.3.4 Comparator Output Control Register (COMPOCR).

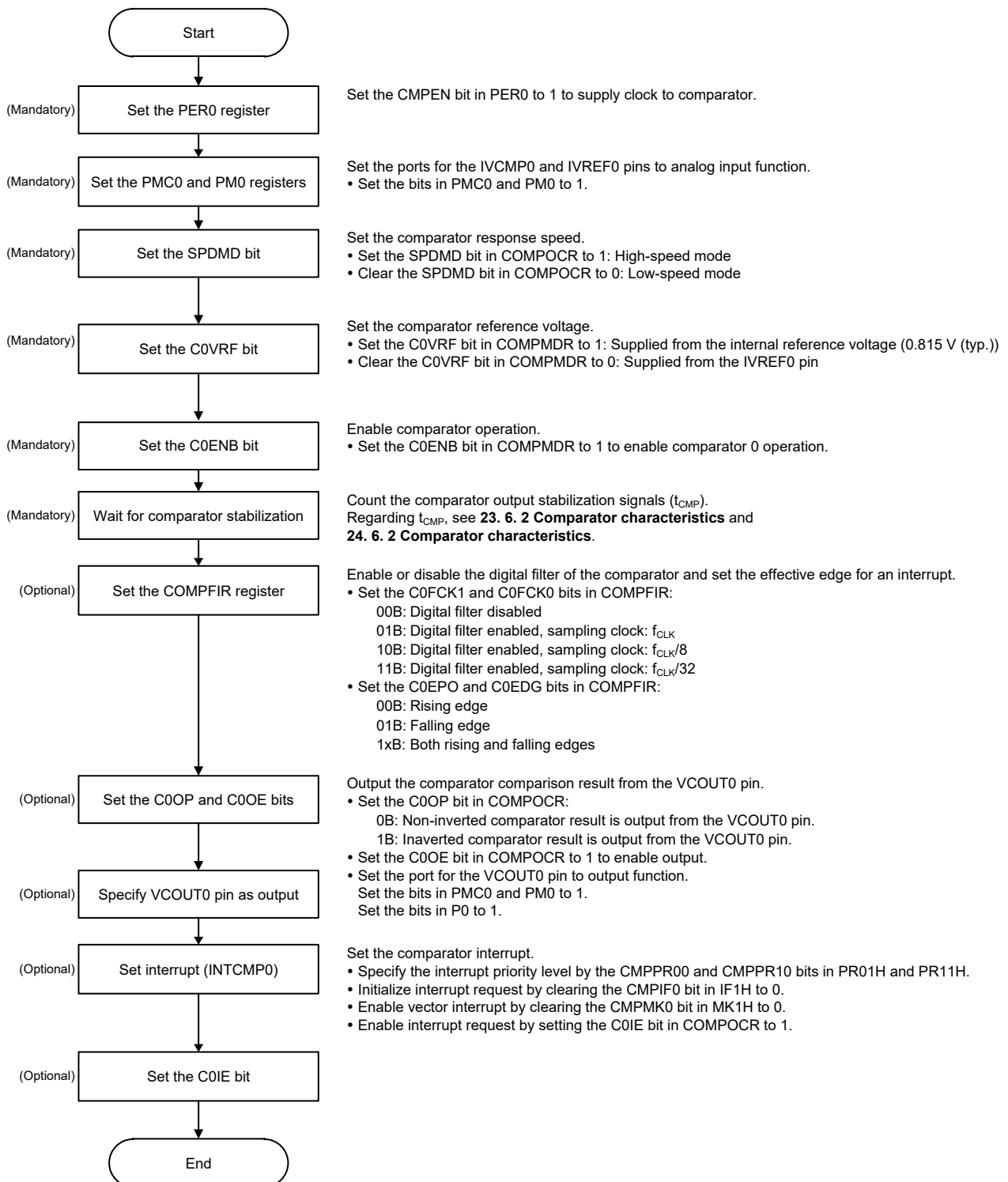
To output the comparator comparison result from the VCOUTn pin, follow the procedure shown in Figure 11-8 Procedure for Enabling Comparator Operation.

11.5 Comparator Setting Flowcharts

The following shows the comparator setting flowcharts.

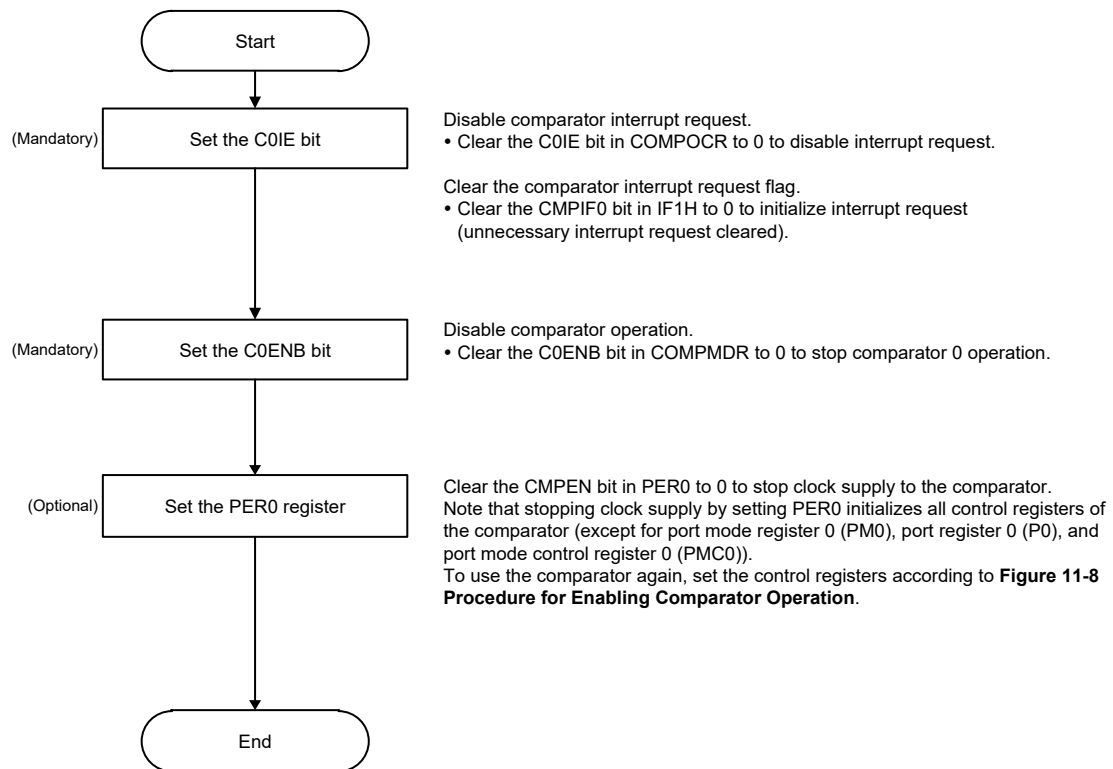
11.5.1 Enabling Comparator Operation (in the Case of CMP0)

Figure 11-8. Procedure for Enabling Comparator Operation



11.5.2 Disabling Comparator Operation (in the Case of CMP0)

Figure 11-9. Procedure for Disabling Comparator Operation



CHAPTER 12 SERIAL ARRAY UNIT

A single serial array unit has up to two serial channels. Each channel can achieve 3-wire serial (simplified SPI or CSI^{Note 1}), UART, and simplified I²C communication.

Function assignment of each channel supported by the RL78/G15 is as shown below.

Note 1. Although the CSI function is generally called SPI, it is also called CSI in this product, so it is referred to as such in this manual.

- 10- and 8-pin products

| Unit | Channel | Used as Simplified SPI (CSI) | Used as UART | Used as Simplified I ² C |
|------|---------|------------------------------|--------------|-------------------------------------|
| 0 | 0 | CSI00 | UART0 | IIC00 |
| | 1 | — | | — |

- 20- and 16-pin products

| Unit | Channel | Used as Simplified SPI (CSI) | Used as UART | Used as Simplified I ² C |
|------|---------|------------------------------|--------------|-------------------------------------|
| 0 | 0 | CSI00 | UART0 | IIC00 |
| | 1 | CSI01 | | IIC01 |

Caution Most of the following descriptions in this section use the units and channels of the 20-pin products as an example.

12.1 Functions of Serial Array Unit

Each serial interface supported by the RL78/G15 has the following features.

12.1.1 Simplified SPI (CSI00, CSI01)

Data is transmitted or received in synchronization with the serial clock (SCK) output from the master.

3-wire serial communication is clocked communication performed by using three communication lines: one for the serial clock (SCK), one for transmitting serial data (SO), one for receiving serial data (SI).

For details about the settings, see **12.5 Operation of Simplified SPI (CSI00, CSI01) Communication**.

[Data transmission/reception]

- Data length of 7 or 8 bits
- Phase control of transmit/receive data
- MSB/LSB first selectable

[Clock control]

- Master/slave selection
- Phase control of I/O clock
- Setting of transfer period by prescaler and internal counter of each channel
- Maximum transfer rate^{Note 1}
 - During master communication: Max. $f_{CLK}/4$
 - During slave communication: Max. $f_{MCK}/6$

[Interrupt function]

- Transfer end interrupt/buffer empty interrupt

[Error detection flag]

- Overrun error

Note 1. Set up the transfer rate within a range satisfying the SCK cycle time (t_{KCY}). For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+85^\circ\text{C}$)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+105^\circ\text{C}$, $T_A = -40$ to $+125^\circ\text{C}$)**.

12.1.2 UART (UART0)

This is a start-stop synchronization communication function using two lines: serial data transmission (TxD) and serial data reception (RxD) lines. By using these two communication lines, each data frame, which consist of a start bit, data, parity bit, and stop bit, is transferred asynchronously (using the internal baud rate) between the microcontroller and the other communication party. Full-duplex UART communication can be performed by using a channel dedicated to transmission (even-numbered channel) and a channel dedicated to reception (odd-numbered channel).

For details about the settings, see **12.6 Operation of UART (UART0) Communication**.

[Data transmission/reception]

- Data length of 7, 8, or 9 bits
- MSB/LSB first selectable
- Level setting of transmit/receive data and select of reverse
- Parity bit appending and parity check functions
- Stop bit appending

[Interrupt function]

- Transfer end interrupt/buffer empty interrupt
- Error interrupt in case of framing error, parity error, or overrun error

[Error detection flag]

- Framing error, parity error, or overrun error

The ISC register can be used to set up the input signal on the RxD0 pin of UART0 as an external interrupt input or as a timer input for the timer array unit. The input pulse interval measurement mode of the timer array unit can then be used to measure the width at the baud rate of the other party in communications and make the required adjustments in response.

12.1.3 Simplified I²C (IIC00, IIC01)

This is a clocked communication function to communicate with two or more devices by using two lines: serial clock (SCL) and serial data (SDA). This simplified I²C is designed for single communication with a device such as EEPROM, flash memory, or A/D converter, and therefore, it functions only as a master.

Make sure by using software, as well as operating the control registers, that the AC specifications of the start and stop conditions are observed.

For details about the settings, see **12.7 Operation of Simplified I2C (IIC00, IIC01) Communication**.

[Data transmission/reception]

- Master transmission, master reception (only master function with a single master)
- ACK output function^{Note 1} and ACK detection function
- Data length of 8 bits
(When an address is transmitted, the address is specified by the higher 7 bits, and the least significant bit is used for R/W control.)
- Manual generation of start condition and stop condition

[Interrupt function]

- Transfer end interrupt

[Error detection flag]

- ACK error, or overrun error

*[Functions not supported by simplified I²C]

- Slave transmission, slave reception
- Arbitration loss detection function
- Wait detection functions

Note 1. When receiving the last data, 0 is written to the SOEmn bit of the serial output enable register m (SOEm) and serial communication data output is stopped, disabling ACK output. See **12.7.3(2) Processing flow**.

Remark 1. To use an I²C bus of full function, see **CHAPTER 13 SERIAL INTERFACE IICA**.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1)

12.2 Configuration of Serial Array Unit

The serial array unit includes the following registers, and input and output pins.

Table 12-1. Configuration of Serial Array Unit

| Item | Configuration |
|--------------------|--|
| Shift register | 8 or 9 bits ^{Note 1} |
| Buffer register | Lower 8 bits or 9 bits of serial data register mn (SDRmn) ^{Note 1} |
| Serial clock I/O | SCK00, SCK01 pins (for simplified SPI), SCL00, SCL00, SCL01 pins (for simplified I ² C) |
| Serial data input | SI00, SI01 pins (for simplified SPI), RxD0 pin (for UART) |
| Serial data output | SO00, SO01 pins (for simplified SPI), TxD0 pin (for UART) |
| Serial data I/O | SDA00, SDA01 pins (for simplified I ² C) |
| Control registers | <Registers of unit setting block> <ul style="list-style-type: none"> • Peripheral enable register 0 (PER0) • Serial clock select register m (SPSm) • Serial channel enable status register m (SEm) • Serial channel start register m (SSm) • Serial channel stop register m (STm) • Serial output enable register m (SOEm) • Serial output register m (SOM) • Serial output level register m (SOLm) • Input switch control register (ISC) • Noise filter enable register 0 (NFEN0) <Registers of each channel> <ul style="list-style-type: none"> • Serial data register mn (SDRmn) • Serial mode register mn (SMRmn) • Serial communication operation setting register mn (SCRmn) • Serial status register mn (SSRmn) • Serial flag clear trigger register mn (SIRmn) <ul style="list-style-type: none"> • Port output mode registers 0, 2, 4 (POM0, POM2, POM4) • Port mode control registers 0, 2 (PMC0, PMC2) • Port mode registers 0, 2, 4 (PM0, PM2, PM4) • Port registers 0, 2, 4 (P0, P2, P4) |

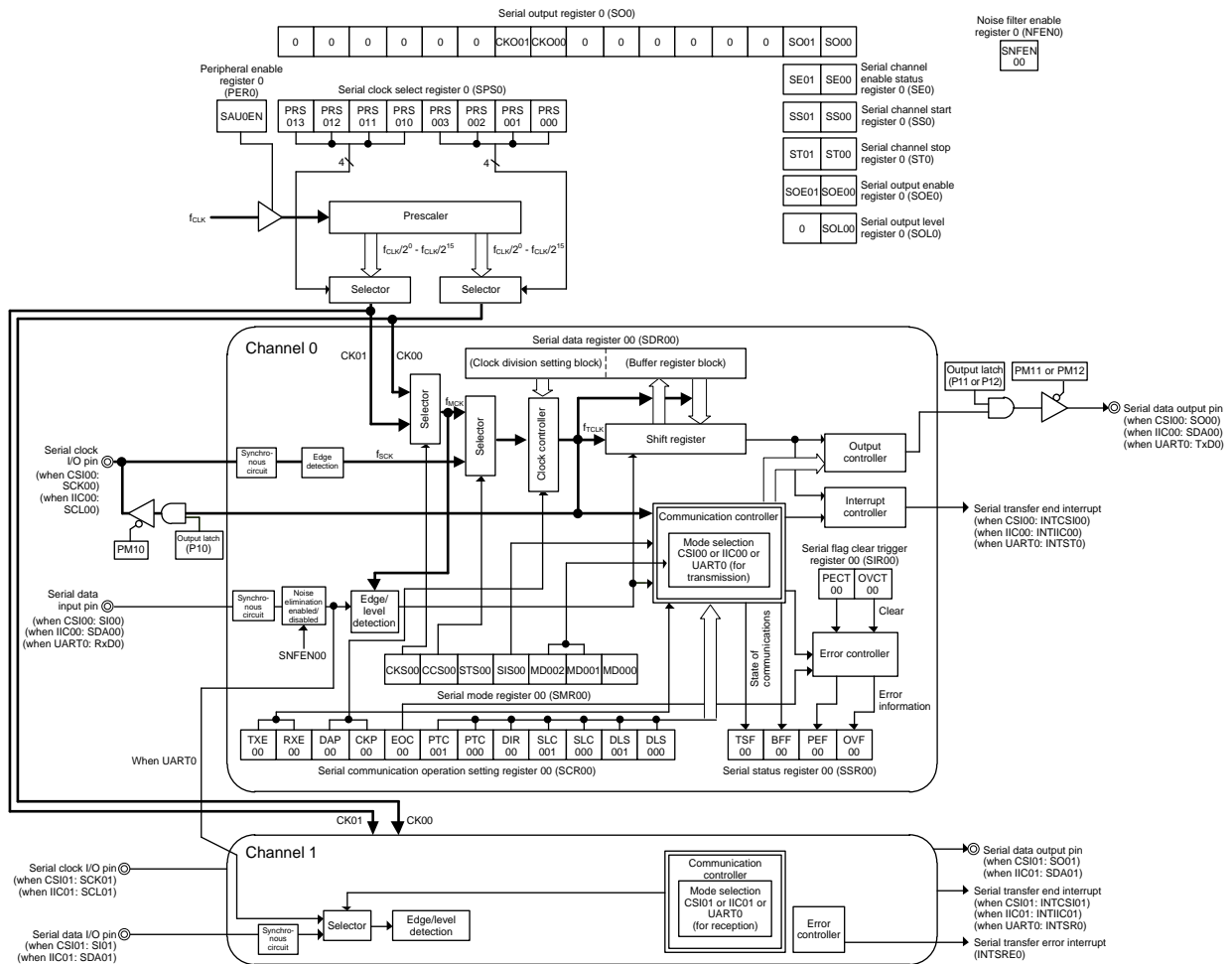
Note 1. The lower 8 bits of serial data register mn (SDRmn) can be read or written as the following SFR, depending on the communication mode.

- CSIp communication ... SIOp (CSIp data register)
- UARTq reception ... RXDq (UARTq receive data register)
- UARTq transmission ... TXDq (UARTq transmit data register)
- IICr communication ... SIOr (IICr data register)

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01)
 q: UART number (q = 0), r: IIC number (r = 00, 01)

Figure 12-1 shows the block diagram of serial array unit 0.

Figure 12-1. Block Diagram of Serial Array Unit 0



12.2.1 Shift Register

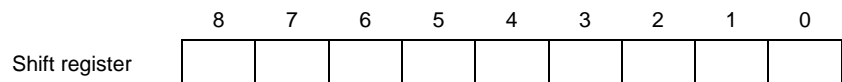
This is a 9-bit register that converts parallel data into serial data or vice versa.

In case of the UART communication of nine bits of data, nine bits (bits 0 to 8) are used.

During reception, it converts data input to the serial pin into parallel data. When data is transmitted, the value set to this register is output as serial data from the serial output pin.

The shift register cannot be directly manipulated by program.

To read or write the shift register, use the lower 8 or 9 bits of serial data register mn (SDRmn).



12.2.2 Lower 8 or 9 bits of the serial data register mn (SDRmn)

The SDRmn is the transmit/receive data register (16 bits) of channel n.

Bits 8 to 0 (lower 9 bits) or bits 7 to 0 (lower 8 bits) function as a transmit/receive buffer register, and bits 15 to 9 are used as a register that sets the division ratio of the operation clock (f_{MCK}).

When data is received, parallel data converted by the shift register is stored in the lower 8 or 9 bits. When data is to be transmitted, set transmit data to be transferred to the shift register to the lower 8 or 9 bits.

The data stored in the lower 8 or 9 bits of this register is as follows, depending on the setting of bits 0 and 1 (DLSmn0, DLSmn1) of serial communication operation setting register mn (SCRmn), regardless of the output sequence of the data.

- 7-bit data length (stored in bits 0 to 6 of the SDRmn register)
- 8-bit data length (stored in bits 0 to 7 of the SDRmn register)
- 9-bit data length (stored in bits 0 to 8 of the SDRmn register)

The SDRmn register can be read or written in 16-bit units.

The lower 8 or 9 bits of the SDRmn register can be read or written^{Note 1} as the following SFR, depending on the communication mode.

- CSIp communication ... SIOp (CSIp data register)
- UARTq reception ... RXDq (UARTq receive data register)
- UARTq transmission ... TXDq (UARTq transmit data register)
- IICr communication ... SIOr (IICr data register)

The value of each SDRmn register is 0000H following a reset.

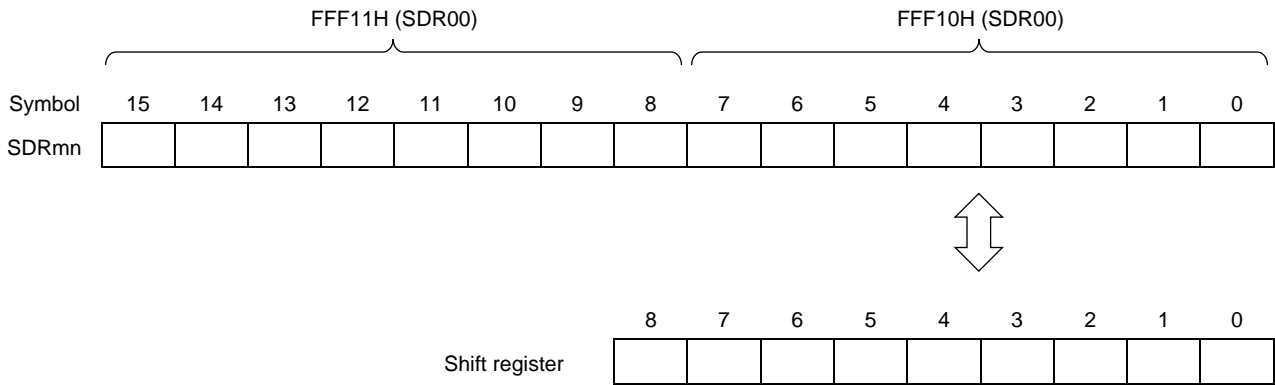
Note 1. When operation is stopped ($SEmn = 0$), do not rewrite SDRmn[7:0] by an 8-bit memory manipulation instruction (SDRmn[15:9] are all cleared to 0).

Remark 1. After data is received, 0 is stored in bits 0 to 8 in bit portions that exceed the data length.

Remark 2. m: Unit number ($m = 0$), n: Channel number ($n = 0, 1$), p: CSI number ($p = 00, 01$)
q: UART number ($q = 0$), r: IIC number ($r = 00, 01$)

Figure 12-2. Format of Serial Data Register mn (SDRmn) (mn = 00, 01)

Address: FFF10H, FFF11H (SDR00), FFF12H, FFF13H (SDR01) After reset: 0000H R/W



Remark For the function of the higher 7 bits of the SDRmn register, see **12.3 Registers to Control the Serial Array Unit**.

12.3 Registers to Control the Serial Array Unit

The following registers are used to control the serial array unit.

- Peripheral enable register 0 (PER0)
- Serial clock select register m (SPSm)
- Serial mode register mn (SMRmn)
- Serial communication operation setting register mn (SCRmn)
- Serial data register mn (SDRmn)
- Serial flag clear trigger register mn (SIRmn)
- Serial status register mn (SSRmn)
- Serial channel start register m (SSm)
- Serial channel stop register m (STm)
- Serial channel enable status register m (SEm)
- Serial output enable register m (SOEm)
- Serial output level register m (SOLm)
- Serial output register m (SOM)
- Input switch control register (ISC)
- Noise filter enable register 0 (NFEN0)
- Port output mode registers 0, 2, 4 (POM0, POM2, POM4)
- Port mode control registers 0, 2 (PMC0, PMC2)
- Port mode registers 0, 2, 4 (PM0, PM2, PM4)
- Port registers 0, 2, 4 (P0, P2, P4)

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1)

12.3.1 Peripheral enable register 0 (PER0)

The PER0 register is used to enable or disable the supply of a clock signal to various on-chip peripheral modules. Clock supply to an on-chip peripheral module that is not to be used can be stopped to decrease power consumption and noise.

If serial array unit 0 is to be used, be sure to set bit 2 (SAU0EN) of this register to 1.

The PER0 register can be set by a 1-bit or 8-bit memory manipulation instruction.

The value of the PER0 register is 00H following a reset.

Figure 12-3. Format of Peripheral Enable Register 0 (PER0)

Address: F00F0H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|---|----------|---|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PER0 | TMKAEN | CMPEN | ADCEN | IICA0EN | 0 | SAU0EN | 0 | TAU0EN |

| SAUmEN | Control of supply of an input clock to serial array unit m |
|--------|---|
| 0 | Stops supply of an input clock. <ul style="list-style-type: none"> The SFRs used by serial array unit m cannot be written. Serial array unit m is in the reset state. |
| 1 | Enables supply of an input clock. <ul style="list-style-type: none"> The SFRs used by serial array unit m can be read and written. |

Caution 1. When setting serial array unit m, make sure that the setting of the SAUmEN bit is 1 before setting the following registers. If SAUmEN = 0, the values of the registers which control serial array unit m are cleared to their initial values, and writing to them is ignored (except for the input switch control register (ISC), noise filter enable register 0 (NFEN0), port output mode registers 0, 2, 4 (POM0, POM2, POM4), port mode control registers 0, 2 (PMC0, PMC2), port mode registers 0, 2, 4 (PM0, PM2, PM4), and port registers 0, 2, 4 (P0, P2, P4)).

- Serial clock select register m (SPSm)
- Serial mode register mn (SMRmn)
- Serial communication operation setting register mn (SCRmn)
- Serial data register mn (SDRmn)
- Serial flag clear trigger register mn (SIRmn)
- Serial status register mn (SSRmn)
- Serial channel start register m (SSm)
- Serial channel stop register m (STm)
- Serial channel enable status register m (SEm)
- Serial output enable register m (SOEm)
- Serial output level register m (SOLm)
- Serial output register m (SOM)

Caution 2. Be sure to clear bits 3 and 1 to 0.

12.3.2 Serial clock select register m (SPSm)

The SPSm is a 16-bit register that is used to select two types of operation clocks (CKm0, CKm1) that are commonly supplied to each channel. CKm1 is selected by bits 7 to 4 of the SPSm register, and CKm0 is selected by bits 3 to 0.

Rewriting the SPSm register is prohibited when the register is in operation (when SEMn = 1).

The SPSm register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the SPSm register can be set with an 8-bit memory manipulation instruction with SPSmL.

The value of each SPSm register is 0000H following a reset.

Figure 12-4. Format of Serial Clock Select Register m (SPSm)

Address: F0126H, F0127H (SPS0) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|------------|------------|------------|------------|------------|------------|------------|------------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SPSm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | PRSm 13 | PRSm 12 | PRSm 11 | PRSm 10 | PRSm 03 | PRSm 02 | PRSm 01 | PRSm 00 |

| PRSmk3 | PRSmk2 | PRSmk1 | PRSmk0 | f _{CLK} | Selection of operation clock (CKmk) ^{Note 1} | | | | |
|--------|--------|--------|--------|-----------------------------------|---|-----------|-----------|-----------|-----------|
| | | | | | f _{CLK} (MHz) | | | | |
| | | | | | 1 | 2 | 4 | 8 | 16 |
| 0 | 0 | 0 | 0 | f _{CLK} | 1 MHz | 2 MHz | 4 MHz | 8 MHz | 16 MHz |
| 0 | 0 | 0 | 1 | f _{CLK} /2 | 500 kHz | 1 MHz | 2 MHz | 4 MHz | 8 MHz |
| 0 | 0 | 1 | 0 | f _{CLK} /2 ² | 250 kHz | 500 kHz | 1 MHz | 2 MHz | 4 MHz |
| 0 | 0 | 1 | 1 | f _{CLK} /2 ³ | 125 kHz | 250 kHz | 500 MHz | 1 MHz | 2 MHz |
| 0 | 1 | 0 | 0 | f _{CLK} /2 ⁴ | 62.5 kHz | 125 kHz | 250 kHz | 500 kHz | 1 MHz |
| 0 | 1 | 0 | 1 | f _{CLK} /2 ⁵ | 31.25 kHz | 62.5 kHz | 125 kHz | 250 kHz | 500 kHz |
| 0 | 1 | 1 | 0 | f _{CLK} /2 ⁶ | 15.63 kHz | 31.25 kHz | 62.5 kHz | 125 kHz | 250 kHz |
| 0 | 1 | 1 | 1 | f _{CLK} /2 ⁷ | 7.81 kHz | 15.63 kHz | 31.25 kHz | 62.5 kHz | 125 kHz |
| 1 | 0 | 0 | 0 | f _{CLK} /2 ⁸ | 3.91 kHz | 7.81 kHz | 15.63 kHz | 31.25 kHz | 62.5 kHz |
| 1 | 0 | 0 | 1 | f _{CLK} /2 ⁹ | 1.95 kHz | 3.91 kHz | 7.81 kHz | 15.63 kHz | 31.25 kHz |
| 1 | 0 | 1 | 0 | f _{CLK} /2 ¹⁰ | 977 Hz | 1.95 kHz | 3.91 kHz | 7.81 kHz | 15.63 kHz |
| 1 | 0 | 1 | 1 | f _{CLK} /2 ¹¹ | 488 Hz | 977 Hz | 1.95 kHz | 3.91 kHz | 7.81 kHz |
| 1 | 1 | 0 | 0 | f _{CLK} /2 ¹² | 244 Hz | 488 Hz | 977 Hz | 1.95 kHz | 3.91 kHz |
| 1 | 1 | 0 | 1 | f _{CLK} /2 ¹³ | 122 Hz | 244 Hz | 488 Hz | 977 Hz | 1.95 kHz |
| 1 | 1 | 1 | 0 | f _{CLK} /2 ¹⁴ | 61 Hz | 122 Hz | 244 Hz | 488 Hz | 977 Hz |
| 1 | 1 | 1 | 1 | f _{CLK} /2 ¹⁵ | 31 Hz | 61 Hz | 122 Hz | 244 Hz | 488 Hz |

Note 1. When changing the clock selected for f_{CLK} (by changing the system clock control register (CKC) value), do so after having stopped (serial channel stop register m (STm) = 000FH) the operation of the serial array unit (SAU).

Caution Be sure to clear bits 15 to 8 to 0.

Remark 1. f_{CLK}: CPU/peripheral hardware clock frequency

Remark 2. m: Unit number (m = 0)

Remark 3. k: Channel number (k = 0, 1)

12.3.3 Serial mode register mn (SMRmn)

The SMRmn register is used to set an operation mode of channel n. It is also used to select an operation clock (f_{MCK}), specify whether the serial clock (f_{SCK}) may be input or not, set a start trigger, the operating mode (as simplified SPI or CSI, UART, or simplified I²C), and an interrupt source. This register is also used to invert the level of the receive data only in the UART mode.

Rewriting the SMRmn register is prohibited when the register is in operation (when SE_{mn} = 1). However, the MD_{mn0} bit can be rewritten during operation.

The SMRmn register can be set by a 16-bit memory manipulation instruction.

The value of each SMRmn register is 0020H following a reset.

Figure 12-5. Format of Serial Mode Register mn (SMRmn) (1/2)

Address: F0110H, F0111H (SMR00) to F0112H, F0113H (SMR01) After reset: 0020H R/W

| | | | | | | | | | | | | | | | | |
|--------|-------------------|-------------------|----|----|----|----|---|-------------------------|---|-------------------------|---|---|---|-------------------|-------------------|-------------------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SMRmn | CKSm _n | CCSm _n | 0 | 0 | 0 | 0 | 0 | STSmn _{Note 1} | 0 | SISmn _{Note 1} | 1 | 0 | 0 | MDmn ₂ | MDmn ₁ | MDmn ₀ |

| | |
|---|---|
| CKSmn | Selection of operation clock (f_{MCK}) of channel n |
| 0 | Operation clock CKm0 set by the SPSm register |
| 1 | Operation clock CKm1 set by the SPSm register |
| Operation clock (f_{MCK}) is used by the edge detector. In addition, depending on the setting of the CCSmn bit and the higher 7 bits of the SDRmn register, a transfer clock (f_{TCLK}) is generated. | |

| | |
|---|--|
| CCSmn | Selection of transfer clock (f_{TCLK}) of channel n |
| 0 | Divided operation clock f_{MCK} specified by the CKSmn bit |
| 1 | Clock input f_{SCK} from the SCKp pin (slave transfer in simplified SPI or CSI mode) |
| Transfer clock f_{TCLK} is used for the shift register, communication controller, output controller, interrupt controller, and error controller. When CCSmn = 0, the division ratio of operation clock (f_{MCK}) is set by the higher 7 bits of the SDRmn register. | |

| | |
|--|--|
| STSmn _{Note 1} | Selection of start trigger source |
| 0 | Only software trigger is valid (selected for simplified SPI or CSI, UART transmission, and simplified I ² C). |
| 1 | Valid edge of the RxDq pin (selected for UART reception) |
| Transfer is started when the above source is satisfied after 1 is set to the SSm register. | |

Note 1. The SMR01 register only.

Caution Be sure to clear bits 13 to 9, 7, 4, and 3 (or bits 13 to 6, 4, and 3 for the SMR00 register) to 0. Be sure to set bit 5 to 1.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01)
q: UART number (q = 0), r: IIC number (r = 00, 01)

Figure 12-5. Format of Serial Mode Register mn (SMRmn) (2/2)

Address: F0110H, F0111H (SMR00) to F0112H, F0113H (SMR01) After reset: 0020H R/W

| | | | | | | | | | | | | | | | | |
|--------|-----------|-----------|----|----|----|----|---|-----------------|---|----------------------|---|---|---|-----------|-----------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SMRmn | CKSm n | CCSm n | 0 | 0 | 0 | 0 | 0 | STSmn Note 1 | 0 | SISmn 0 Note 1 | 1 | 0 | 0 | MDmn 2 | MDmn 1 | MDmn 0 |

| | | |
|------------------|---|--|
| SISmn0 Note 1 | Controls inversion of level of receive data of channel n in UART mode | |
| 0 | Falling edge is detected as the start bit. The input communication data is captured as is. | |
| 1 | Rising edge is detected as the start bit. The input communication data is inverted and captured. | |

| | | |
|-------|-------|--|
| MDmn2 | MDmn1 | Setting of operation mode of channel n |
| 0 | 0 | Simplified SPI (CSI) mode |
| 0 | 1 | UART mode |
| 1 | 0 | Simplified I ² C mode |
| 1 | 1 | Setting prohibited |

| | | |
|--|--|--|
| MDmn0 | Selection of interrupt source of channel n | |
| 0 | Transfer end interrupt | |
| 1 | Buffer empty interrupt (Occurs when data is transferred from the SDRmn register to the shift register.) | |
| For continuous transmission, set this bit to 1 and write the next transmit data when SDRmn data has run out. | | |

Note 1. The SMR01 register only.

Caution Be sure to clear bits 13 to 9, 7, 4, and 3 (or bits 13 to 6, 4, and 3 for the SMR00 register) to 0. Be sure to set bit 5 to 1.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01)
q: UART number (q = 0), r: IIC number (r = 00, 01)

12.3.4 Serial communication operation setting register mn (SCRmn)

The SCRmn is a communication operation setting register of channel n. It is used to set a data transmission/reception mode, phase of data and clock, whether an error signal is to be masked or not, parity bit, start bit, stop bit, and data length.

Rewriting the SCRmn register is prohibited when the register is in operation (when SEMn = 1).

The SCRmn register can be set by a 16-bit memory manipulation instruction.

The value of each SCRmn register is 0087H following a reset.

Figure 12-6. Format of Serial Communication Operation Setting Register mn (SCRmn) (1/2)

Address: F0118H, F0119H (SCR00) to F011AH, F011BH (SCR01) After reset: 0087H R/W

| | | | | | | | | | | | | | | | | |
|--------|-------|-------|-------|-------|----|-------|-------|-------|-------|---|---------------------|-------|---|---|-------|-------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SCRmn | TXEmn | RXEmn | DAPmn | CKPmn | 0 | EOCmn | PTCmn | PTCmn | DIRmn | 0 | SLCmn | SLCmn | 0 | 1 | DLSmn | DLSmn |
| | | n | n | n | | n | n1 | n0 | | | 1 ^{Note 1} | 0 | | | 1 | 0 |

| TXEmn | RXEmn | Setting of operation mode of channel n |
|-------|-------|--|
| 0 | 0 | Disable communication. |
| 0 | 1 | Reception only |
| 1 | 0 | Transmission only |
| 1 | 1 | Transmission/reception |

| DAPmn | CKPmn | Selection of data and clock phase in simplified SPI (CSI) mode | Type |
|-------|-------|--|------|
| 0 | 0 | | 1 |
| 0 | 1 | | 2 |
| 1 | 0 | | 3 |
| 1 | 1 | | 4 |

Be sure to set DAPmn, CKPmn = 0, 0 in the UART mode and simplified I²C mode.

Note 1. The SCR00 register only.

Caution Be sure to clear bits 3, 6, and 11 to 0 (Also clear bit 5 of the SCR01 register to 0). Be sure to set bit 2 to 1.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01)

Figure 12-6. Format of Serial Communication Operation Setting Register mn (SCRmn) (2/2)

Address: F0118H, F0119H (SCR00) to F011AH, F011BH (SCR01) After reset: 0087H R/W

| | | | | | | | | | | | | | | | | |
|--------|-------|-------|------|------|----|------|------|------|-------|---|---------------------|-------|---|---|-------|-------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SCRmn | TXEmn | RXEmn | DAPm | CKPm | 0 | EOCm | PTCm | PTCm | DIRmn | 0 | SLCmn | SLCmn | 0 | 1 | DLSmn | DLSmn |
| | | n | n | n | | n | n1 | n0 | | | 1 ^{Note 1} | 0 | | | 1 | 0 |

| | |
|---|---|
| EOCmn | Mask control of error interrupt signal (INTSREx (x = 0 to 3)) |
| 0 | Disables generation of error interrupt INTSREx (INTSRx is generated). |
| 1 | Enables generation of error interrupt INTSREx (INTSRx is not generated if an error occurs). |
| Set EOCmn = 0 in the simplified SPI (CSI) mode, simplified I ² C mode, and during UART transmission. ^{Note 2} | |

| | | | |
|---|-------|-------------------------------------|-------------------------|
| PTCmn | PTCmn | Setting of parity bit in UART mode | |
| 1 | 0 | Transmission | Reception |
| 0 | 0 | Does not output the parity bit. | Receives without parity |
| 0 | 1 | Outputs 0 parity. ^{Note 3} | No parity judgment |
| 1 | 0 | Outputs even parity. | Judged as even parity. |
| 1 | 1 | Outputs odd parity. | Judges as odd parity. |
| Be sure to set PTCmn1, PTCmn0 = 0, 0 in the simplified SPI (CSI) mode and simplified I ² C mode. | | | |

| | |
|---|--|
| DIRmn | Selection of data transfer sequence in simplified SPI (CSI) and UART modes |
| 0 | Inputs/outputs data with MSB first. |
| 1 | Inputs/outputs data with LSB first. |
| Be sure to clear DIRmn = 0 in the simplified I ² C mode. | |

| | | |
|--|-------|---|
| SLCmn | SLCmn | Setting of stop bit in UART mode |
| 1 ^{Note 1} | 0 | |
| 0 | 0 | No stop bit |
| 0 | 1 | Stop bit length = 1 bit |
| 1 | 0 | Stop bit length = 2 bits (mn = 00 only) |
| 1 | 1 | Setting prohibited |
| When the transfer end interrupt is selected, the interrupt is generated when all stop bits have been completely transferred. Set 1 bit (SLCmn1, SLCmn0 = 0, 1) during UART reception and in the simplified I ² C mode. Set no stop bit (SLCmn1, SLCmn0 = 0, 0) in the simplified SPI (CSI) mode. Set 1 bit (SLCmn1, SLCmn0 = 0, 1) or 2 bits (SLCmn1, SLCmn0 = 1, 0) during UART transmission. | | |

| | | |
|---|-------|--|
| DLSmn | DLSmn | Setting of data length in simplified SPI (CSI) and UART modes |
| 1 | 0 | |
| 0 | 1 | 9-bit data length (stored in bits 0 to 8 of the SDRmn register) (settable in UART mode only) |
| 1 | 0 | 7-bit data length (stored in bits 0 to 6 of the SDRmn register) |
| 1 | 1 | 8-bit data length (stored in bits 0 to 7 of the SDRmn register) |
| Other than above | | Setting prohibited |
| Be sure to set DLSmn1, DLSmn0 = 1, 1 in the simplified I ² C mode. | | |

Note 1. The SCR00 register only.

Note 2. When using CSImn not with EOCmn = 0, error interrupt INTSREn may be generated.

Note 3. 0 is always added regardless of the data contents.

Caution Be sure to clear bits 3, 6, and 11 to 0 (Also clear bit 5 of the SCR01 register to 0). Be sure to set bit 2 to 1.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01)

12.3.5 Serial data register mn (SDRmn)

The SDRmn is the transmit/receive data register (16 bits) of channel n.

Bits 8 to 0 (lower 9 bits) of SDR00 and SDR01 function as a transmit/receive buffer register, and bits 15 to 9 (higher 7 bits) are used as a register that sets the division ratio of the operation clock (f_{MCK}).

If the CCSmn bit of serial mode register mn (SMRmn) is cleared to 0, the clock set by dividing the operation clock by bits 15 to 9 (higher 7 bits) of the SDRmn register is used as the transfer clock.

If the CCSmn bit of serial mode register mn (SMRmn) is set to 1, set bits 15 to 9 (upper 7 bits) of SDR00 and SDR01 to 0000000B. The input clock f_{SCK} (slave transfer in simplified SPI or CSI mode) from the SCKp pin is used as the transfer clock.

The lower 8 or 9 bits of the SDRmn register function as a transmit/receive buffer register. During reception, the parallel data converted by the shift register is stored in the lower 8 or 9 bits, and during transmission, the data to be transmitted to the shift register is set to the lower 8 or 9 bits.

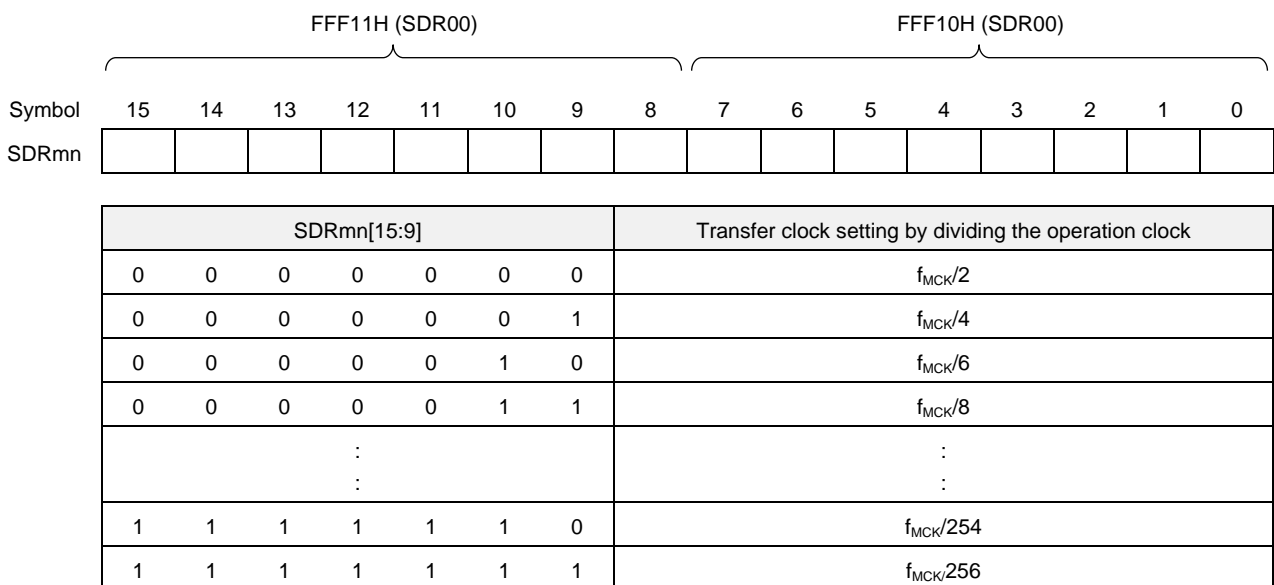
The SDRmn register can be read or written in 16-bit units.

However, the higher 7 bits can only be written or read when the operation is stopped ($SEmn = 0$). During operation ($SEmn = 1$), a value is written only to the lower 8 or 9 bits of the SDRmn register. When the SDRmn register is read during operation, the higher 7 bits are always read as 0.

The value of each SDRmn register is 0000H following a reset.

Figure 12-7. Format of Serial Data Register mn (SDRmn)

Address: FFF10H, FFF11H (SDR00), FFF12H, FFF13H (SDR01) After reset: 0000H R/W



(Cautions and Remarks are listed on the next page.)

- Caution 1.** Setting SDRmn[15:9] to 0000000B or 0000001B is prohibited when UART is used.
- Caution 2.** Setting SDRmn[15:9] to 0000000B is prohibited when simplified I²C is used. Set SDRmn[15:9] to 0000001B or greater.
- Caution 3.** When operation is stopped (SEmn = 0), do not rewrite SDRmn[7:0] by an 8-bit memory manipulation instruction (SDRmn[15:9] are all cleared to 0).
- Remark 1.** For the function of the lower 8 or 9 bits of the SDRmn register, see **12.2 Configuration of Serial Array Unit**.
- Remark 2.** m: Unit number (m = 0), n: Channel number (n = 0, 1)

12.3.6 Serial flag clear trigger register mn (SIRmn)

The SIRmn is a trigger register that is used to clear each error flag of channel n.

When each bit (FECTmn, PECTmn, OVCTmn) of this register is set to 1, the corresponding bit (FEFmn, PEFmn, OVFmn) of serial status register mn is cleared to 0. Because the SIRmn is a trigger register, it is cleared immediately when the corresponding bit of the SSRmn register is cleared.

The SIRmn register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the SIRmn register can be set with an 8-bit memory manipulation instruction with SIRmnL.

The value of each SIRmn register is 0000H following a reset.

Figure 12-8. Format of Serial Flag Clear Trigger Register mn (SIRmn)

Address: F0108H, F0109H (SIR00) to F010AH, F010BH (SIR01) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|---|---|---|---|---|------------------------------|------------|------------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SIRmn | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | FECT mn ^{Note 1} | PECT mn | OVCT mn |

| | |
|------------------------------|--|
| FECT mn ^{Note 1} | Clear trigger of framing error flag of channel n |
| 0 | Not cleared |
| 1 | Clears the FEFmn bit of the SSRmn register to 0. |

| | |
|------------|--|
| PECT mn | Clear trigger of parity error flag of channel n |
| 0 | Not cleared |
| 1 | Clears the PEFmn bit of the SSRmn register to 0. |

| | |
|------------|--|
| OVCT mn | Clear trigger of overrun error flag of channel n |
| 0 | Not cleared |
| 1 | Clears the OVFmn bit of the SSRmn register to 0. |

Note 1. The SIR01 register only.

Caution Be sure to clear bits 15 to 3 (or bits 15 to 2 for the SIR00 register) to 0

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1)

Remark 2. When the SIRmn register is read, 0000H is always read.

12.3.7 Serial status register mn (SSRmn)

The SSRmn register indicates the state of communications and occurrence of errors for channel n. The errors indicated by this register are a framing error, parity error, and overrun error.

The SSRmn register can be read by a 16-bit memory manipulation instruction.

The lower 8 bits of the SSRmn register can be read with an 8-bit memory manipulation instruction with SSRmnL.

The value of each SSRmn register is 0000H following a reset.

Figure 12-9. Format of Serial Status Register mn (SSRmn) (1/2)

Address: F0100H, F0101H (SSR00) to F0102H, F0103H (SSR01) After reset: 0000H R

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|---|------|------|---|---|-------------------------------|------|-----------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSRmn | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | TSMn | BFFm | 0 | 0 | FEFm <small>Note 1</small> | PEFm | OVFm n |

| | |
|--|---|
| TSMn | Flag indicating the state of communications for channel n |
| 0 | Communication is stopped or suspended. |
| 1 | Communication is in progress. |
| <Clear conditions> | |
| <ul style="list-style-type: none"> The STmn bit of the STm register is set to 1 (communication is stopped) or the SSmn bit of the SSm register is set to 1 (communication is suspended). Communication ends. | |
| <Set condition> | |
| <ul style="list-style-type: none"> Communication starts. | |

| | |
|--|--|
| BFFm | Flag indicating the state of the buffer register for channel n |
| 0 | Valid data is not stored in the SDRmn register. |
| 1 | Valid data is stored in the SDRmn register. |
| <Clear conditions> | |
| <ul style="list-style-type: none"> Transferring transmit data from the SDRmn register to the shift register ends during transmission. Reading receive data from the SDRmn register ends during reception. The STmn bit of the STm register is set to 1 (communication is stopped) or the SSmn bit of the SSm register is set to 1 (communication is enabled). | |
| <Set conditions> | |
| <ul style="list-style-type: none"> Transmit data is written to the SDRmn register while the TXEmn bit of the SCRmn register is set to 1 (transmission or transmission/reception mode in each communication mode). Receive data is stored in the SDRmn register while the RXEmn bit of the SCRmn register is set to 1 (reception or transmission/reception mode in each communication mode). A reception error occurs. | |

Note 1. The SSR01 register only.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1)

Figure 12-9. Format of Serial Status Register mn (SSRmn) (2/2)

Address: F0100H, F0101H (SSR00) to F0102H, F0103H (SSR01) After reset: 0000H R

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|---|-------|-------|---|---|-----------------|-------|------------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSRmn | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | TSFmn | BFFmn | 0 | 0 | FEFmn Note 1 | PEFmn | OVFmn n |

| | |
|--|---|
| FEFmn Note 1 | Framing error detection flag of channel n |
| 0 | No error occurs. |
| 1 | An error occurs (during UART reception). |
| <p><Clear condition></p> <ul style="list-style-type: none"> 1 is written to the FECTmn bit of the SIRmn register. <p><Set condition></p> <ul style="list-style-type: none"> A stop bit is not detected when UART reception ends. | |

| | |
|---|--|
| PEFmn | Parity/ACK error detection flag of channel n |
| 0 | No error occurs. |
| 1 | Parity error occurs (during UART reception) or ACK is not detected (during I ² C transmission). |
| <p><Clear condition></p> <ul style="list-style-type: none"> 1 is written to the PECTmn bit of the SIRmn register. <p><Set conditions></p> <ul style="list-style-type: none"> The parity of the transmit data and the parity bit do not match when UART reception ends (parity error). No ACK signal is returned from the slave at the ACK reception timing during I²C transmission (ACK is not detected). | |

| | |
|--|---|
| OVFmn | Overrun error detection flag of channel n |
| 0 | No error occurs. |
| 1 | An error occurs |
| <p><Clear condition></p> <ul style="list-style-type: none"> 1 is written to the OVCTmn bit of the SIRmn register. <p><Set conditions></p> <ul style="list-style-type: none"> Even though receive data is stored in the SDRmn register, that data is not read and transmit data or the next receive data is written while the RXEmn bit of the SCRmn register is set to 1 (reception or transmission/reception mode in each communication mode). Transmit data is not ready for slave transmission or transmission/reception in simplified SPI (CSI) mode. | |

Note 1. The SSR01 register only.

Caution If data is written to the SDRmn register when BFFmn = 1, the transmit/receive data stored in the register is discarded and an overrun error (OVFmn = 1) is detected.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1)

12.3.8 Serial channel start register m (SSm)

The SSm is a trigger register that is used to enable starting communication/count by each channel.

When 1 is written to a bit (SSmn) of this register, the corresponding bit (SEmn) of serial channel enable status register m (SEm) is set to 1 (operation is enabled). Because the SSmn bit is a trigger bit, it is cleared immediately when SEmn = 1.

The SSm register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the SSm register can be set with an 1-bit or 8-bit memory manipulation instruction with SSmL.

The value of each SSm register is 0000H following a reset.

Figure 12-10. Format of Serial Channel Start Register m (SSm)

Address: F0122H, F0123H (SS0) After reset: 0000H R/W

| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| SS0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | SS01 | SS00 |

| SSmn | Operation start trigger of channel n |
|------|---|
| 0 | No trigger operation |
| 1 | Set the SEmn bit to 1 to place the channel in the communications waiting state. ^{Note 1} |

Note 1. Setting an SSmn bit to 1 during communications stops communications through channel n and places the channel in the waiting state. At this time, the values of the control registers and shift register, the states of the SCKmn and SOMn pins, and the values of the FEFmn, PEFmn, and OVFmn flags are retained.

Caution 1. Be sure to clear bits 15 to 2 of the SS0 register to 0.

Caution 2. For the UART reception, set the RXEmn bit of SCRmn register to 1, and then be sure to set SSmn to 1 after at least 4 f_{MCK} clock cycles have elapsed.

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1)

Remark 2. When the SSm register is read, 0000H is always read.

12.3.9 Serial channel stop register m (STm)

The STm is a trigger register that is used to enable stopping communication/count by each channel.

When 1 is written to a bit (STmn) of this register, the corresponding bit (SEmn) of serial channel enable status register m (SEm) is cleared to 0 (operation is stopped). Because the STmn bit is a trigger bit, it is cleared immediately when SEmn = 0.

The STm register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the STm register can be set with a 1-bit or 8-bit memory manipulation instruction with STmL.

The value of each STm register is 0000H following a reset.

Figure 12-11. Format of Serial Channel Stop Register m (STm)

Address: F0124H, F0125H (ST0) After reset: 0000H R/W

| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| ST0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | ST01 | ST00 |

| STmn | Operation stop trigger of channel n |
|------|--|
| 0 | No trigger operation |
| 1 | Clears the SEmn bit to 0 and stops the communication operation ^{Note 1} |

Note 1. The values of the control registers and shift register, the states of the SCKmn and SOMn pins, and the values of the FEFmn, PEFmn, and OVFmn flags are retained.

Caution Be sure to clear bits 15 to 2 of the ST0 register to 0.

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1)

Remark 2. When the STm register is read, 0000H is always read.

12.3.10 Serial channel enable status register m (SEm)

The SE_m register indicates whether data transmission/reception operation of each channel is enabled or stopped.

When 1 is written to a bit of serial channel start register m (SS_m), the corresponding bit of this register is set to 1. When 1 is written to a bit of serial channel stop register m (ST_m), the corresponding bit is cleared to 0.

For channel n whose operation is enabled, the value of the CKO_{mn} bit of serial output register m (SO_m) to be described later cannot be rewritten by software, and a value reflected by a communication operation is output from the serial clock pin.

For channel n whose operation is stopped, the value of the CKO_{mn} bit of the SO_m register can be set by software and is output from the serial clock pin. In this way, any waveform, such as that of a start condition/stop condition, can be created by software.

The SE_m register can be read by a 16-bit memory manipulation instruction.

The lower 8 bits of the SE_m register can be read with a 1-bit or 8-bit memory manipulation instruction with SE_mL.

The value of each SE_m register is 0000H following a reset.

Figure 12-12. Format of Serial Channel Enable Status Register m (SE_m)

Address: F0120H, F0121H (SE0) After reset: 0000H R

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SE0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | SE01 | SE00 |

| SE _{mn} | Indication of whether operation of channel n is enabled or stopped |
|------------------|--|
| 0 | Operation stops. |
| 1 | Operation is enabled. |

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1)

12.3.11 Serial output enable register m (SOEm)

The SOEm register is used to enable or stop output of the serial communication operation of each channel.

For channel n whose serial output is enabled, the value of the SOmn bit of serial output register m (SOM) to be described later cannot be rewritten by software, and a value reflected by a communication operation is output from the serial data output pin.

For channel n, whose serial output is stopped, the SOmn bit value of the SOM register can be set by software, and that value can be output from the serial data output pin. In this way, any waveform, such as that of a start condition/stop condition, can be created by software.

The SOEm register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the SOEm register can be set with a 1-bit or 8-bit memory manipulation instruction with SOEmL.

The value of each SOEm register is 0000H following a reset.

Figure 12-13. Format of Serial Output Enable Register m (SOEm)

Address: F012AH, F012BH (SOE0) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|-------|-------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOE0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | SOE01 | SOE00 |

| SOEmn | Serial output enable/stop of channel n |
|-------|---|
| 0 | Stops output by serial communication operation. |
| 1 | Enables output by serial communication operation. |

Caution Be sure to clear bits 15 to 2 of the SOE0 register to 0.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1)

12.3.12 Serial output register m (SOm)

The SOm is a buffer register for serial output of each channel.

The value of the SOmn bit of this register is output from the serial data output pin of channel n.

The value of the CKOmn bit of this register is output from the serial clock output pin of channel n.

The SOmn bit of this register can be rewritten by software only when serial output is disabled (SOEmn = 0). When serial output is enabled (SOEmn = 1), rewriting by software is ignored, and the value of the register can be changed only by a serial communication operation.

The CKOmn bit of this register can be rewritten by software only when the channel operation is stopped (SEmn = 0). While channel operation is enabled (SEmn = 1), rewriting by software is ignored, and the value of the CKOmn bit can be changed only by a serial communication operation.

To use the pin for serial interface as a port function pin, set the corresponding CKOmn and SOmn bits to 1.

The SOm register can be set by a 16-bit memory manipulation instruction.

The values of each SOm register is 0303H following a reset.

Figure 12-14. Format of Serial Output Register m (SOm)

Address: F0128H, F0129H (SO0) After reset: 0303H R/W

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|-------|-------|---|---|---|---|---|---|------|------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SO0 | 0 | 0 | 0 | 0 | 0 | 0 | CKO01 | CKO00 | 0 | 0 | 0 | 0 | 0 | 0 | SO01 | SO00 |

| | |
|-------|----------------------------------|
| CKOmn | Serial clock output of channel n |
| 0 | Serial clock output value is 0. |
| 1 | Serial clock output value is 1. |

| | |
|------|---------------------------------|
| SOmn | Serial data output of channel n |
| 0 | Serial data output value is 0. |
| 1 | Serial data output value is 1. |

Caution Be sure to clear bits 15 to 10, and 7 to 2 of the SO0 register to 0.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1)

12.3.13 Serial output level register m (SOLm)

The SOLm register is used to set inversion of the data output level of each channel.

This register can be set only in the UART mode. Be sure to set 0 for the bit corresponding the channel used in the simplified SPI (CSI) mode or simplified I²C mode.

Inverting channel n by using this register is reflected on pin output only when serial output is enabled (SOEmn = 1). When serial output is disabled (SOEmn = 0), the value of the SOMn bit is output as is.

Rewriting the SOLm register is prohibited when the register is in operation (when SEMn = 1).

The SOLm register can be set by a 16-bit memory manipulation instruction.

The lower 8 bits of the SOLm register can be set with an 8-bit memory manipulation instruction with SOLmL.

The value of each SOLm register is 0000H following a reset.

Figure 12-15. Format of Serial Output Level Register m (SOLm)

Address: F0134H, F0135H (SOL0) After reset: 0000H R/W

| | | | | | | | | | | | | | | | | |
|--------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|-------|
| Symbol | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOL0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | SOL00 |

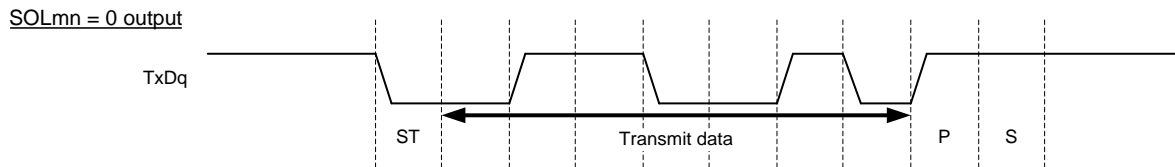
| SOLmn | Selects inversion of the level of the transmit data of channel n in UART mode |
|-------|---|
| 0 | Communication data is output as is. |
| 1 | Communication data is inverted and output. |

Caution Be sure to clear bits 15 to 1 of the SOL0 register to 0.

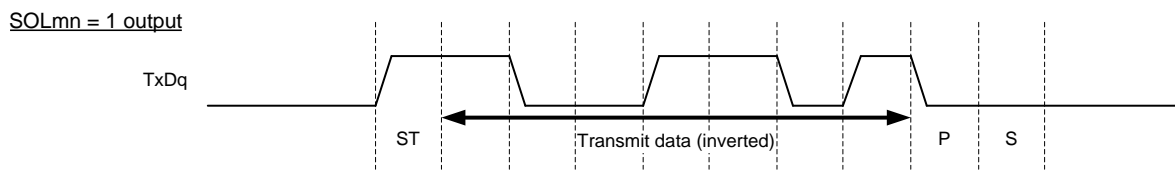
Figure 12-16 shows examples in which the level of transmit data is reversed during UART transmission.

Figure 12-16. Examples of Reverse Transmit Data

(a) Non-reverse Output (SOLmn = 0)



(b) Reverse Output (SOLmn = 1)



Remark m: Unit number (m = 0), n: Channel number (n = 0)

12.3.14 Input switch control register (ISC)

The ISC1 and ISC0 bits in the ISC register are used to handle the combination of the external interrupt and the timer array unit at the time of baud rate correction of UART0.

When bit 0 is set to 1, the input signal of the serial data input (RxD0) pin is selected as an external interrupt (INTP0) that can be used to detect a wakeup signal.

When bit 1 is set to 1, the input signal of the serial data input (RxD0) pin is selected as a timer input, so that wake up signal can be detected, the low width of the break field, and the pulse width of the sync field can be measured by the timer.

The ISC register can be set by a 1-bit or 8-bit memory manipulation instruction.

The value of the ISC register is 00H following a reset.

Figure 12-17. Format of Input Switch Control Register (ISC)

Address: F0073H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|---|---|---|------|------|
| ISC | 0 | 0 | 0 | 0 | 0 | 0 | ISC1 | ISC0 |
| ISC1 | Switching the channel 7 of the timer array unit | | | | | | | |
| 0 | Select the input signal on TI01 pin as the timer input (normal operation) | | | | | | | |
| 1 | Select the input signal on RxD0 pin as the timer input (Detection of the wake-up signal and pulse-width-measurement for baud rate correction) | | | | | | | |
| ISC0 | Switching the external interrupt (INTP0) | | | | | | | |
| 0 | Select the input signal on INTP0 pin as the external interrupt input (normal operation) | | | | | | | |
| 1 | Select the input signal on RxD0 pin as the external interrupt input (detection of the wake-up signal) | | | | | | | |

Caution Be sure to clear bits 7 to 2 to 0.

12.3.15 Noise filter enable register 0 (NFEN0)

The NFEN0 register is used to set whether the noise filter can be used for the input signal from the serial data input pin to each channel.

Disable the noise filter of the pin used for simplified SPI (CSI) or simplified I²C communication, by clearing the corresponding bit of this register to 0.

Enable the noise filter of the pin used for UART communication, by setting the corresponding bit of this register to 1. When the noise filter is enabled, after synchronization is performed with the operation clock (f_{MCK}) of the target channel, 2-clock match detection is performed. When the noise filter is disabled, only synchronization is performed with the operation clock (f_{MCK}) of the target channel.

The NFEN0 register can be set by a 1-bit or 8-bit memory manipulation instruction.

The value of the NFEN0 register is 00H following a reset.

Figure 12-18. Format of Noise Filter Enable Register 0 (NFEN0)

Address: F0070H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|---|---|---|---|---------|
| NFEN0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | SNFEN00 |

| SNFEN00 | Use of noise filter of RxD0 pin |
|---------|---------------------------------|
| 0 | Noise filter OFF |
| 1 | Noise filter ON |

Set the SNFEN00 bit to 1 to use the RxD0 pin.
Clear SNFEN00 to 0 to use the other than RxD0 pin.

Caution Be sure to clear bits 7 to 1 to 0.

12.3.16 Registers controlling port functions of serial input/output pins

Using the serial array unit requires setting of the registers that control the port functions multiplexed on the target channel (port mode register (PMxx), port register (Pxx), port output mode register (POMxx), port mode control register (PMCxx)).

For details, see **4.3.1 Port mode registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12)**, **4.3.2 Port registers 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13)**, **4.3.4 Port input mode registers 0, 2, 4 (POM0, POM2, POM4)**, and **4.3.5 Port mode control registers 0, 2 (PMC0, PMC2)**.

Specifically, using a port pin with a multiplexed serial data or serial clock output function (e.g. P00/SO00/TxD0/TOOLTxD/INTP6) for serial data or serial clock output, requires setting the corresponding bits in the port mode control register (PMCxx) and port mode register (PMxx) to 0, and the corresponding bit in the port register (Pxx) to 1.

When using the port pin in N-ch open-drain output (V_{DD} tolerance) mode, set the corresponding bit in the port output mode register (POMxx) to 1.

Example) When P00/SO00/TxD0/TOOLTxD/INTP6/(SCK01/SCL01)/(SCLA0) is to be used for serial data output

Set the PM00 bit of port mode register 0 to 0.

Set the P00 bit of port register 0 to 1.

Specifically, using a port pin with a multiplexed serial data or serial clock input function (e.g. P01/ANI0/SI00/RxD0/TOOLRxSD/SDA00/INTP5/(TI02/TO02)/(SI01)/(SDA01)/(SDAA0)) for serial data or serial clock input, requires setting the corresponding bit in the port mode register (PMxx) to 1, and the corresponding bit in the port mode control register (PMCxx) to 0. In this case, the corresponding bit in the port register (Pxx) can be set to 0 or 1.

Example) When P01/ANI0/SI00/RxD0/TOOLRxSD/SDA00/INTP5/(TI02/TO02)/(SI01)/(SDA01)/(SDAA0) is to be used for serial data input

Set the PMC01 bit of port mode control register 0 to 0.

Set the PM01 bit of port mode register 0 to 1.

Set the P01 bit of port register 0 to 0 or 1.

12.4 Operation Stop Mode

Each serial interface of serial array unit has the operation stop mode.

In this mode, serial communication cannot be executed, thus reducing the power consumption.

In addition, the pin for serial interface can be used as port function pins in this mode.

12.4.1 Stopping the Operation by Units

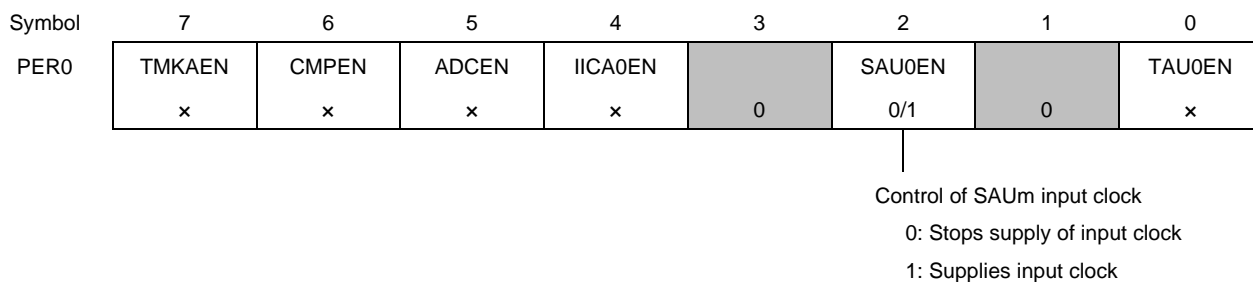
The stopping of the operation by units is set by using peripheral enable register 0 (PER0).

The PER0 register is used to enable or disable the supply of a clock signal to various on-chip peripheral modules. Clock supply to an on-chip peripheral module that is not to be used can be stopped to decrease power consumption and noise.

To stop the operation of serial array unit 0, set bit 2 (SAU0EN) to 0.

Figure 12-19. Peripheral Enable Register 0 (PER0) Setting When Stopping the Operation by Units

(a) Peripheral enable register 0 (PER0) ... Set only the bit of SAUm to be stopped to 0.



Caution 1. If SAUmEN = 0, writing to the registers which control serial array unit m is ignored, and, even if the register is read, only the initial value is read.

Note that this does not apply to the following registers.

- Input switch control register (ISC)
- Noise filter enable register 0 (NFEN0)
- Port output mode registers 0, 2, 4 (POM0, POM2, POM4)
- Port mode control registers 0, 2 (PMC0, PMC2)
- Port mode registers 0, 2, 4 (PM0, PM2, PM4)
- Port registers 0, 2, 4 (P0, P2, P4)

Caution 2. Be sure to clear bits 3 and 1 to 0.

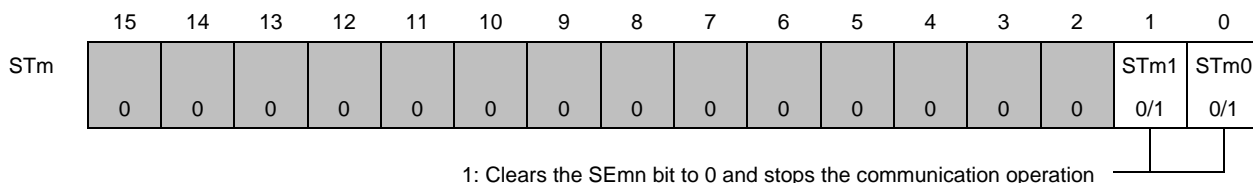
Remark □ : Setting disabled (set to the initial value)
x: Bits not used with serial array units (depending on the settings of other peripheral functions)
0/1: Set to 0 or 1 depending on the usage of the user.

12.4.2 Stopping the Operation by Channels

The stopping of the operation by channels is set using each of the following registers.

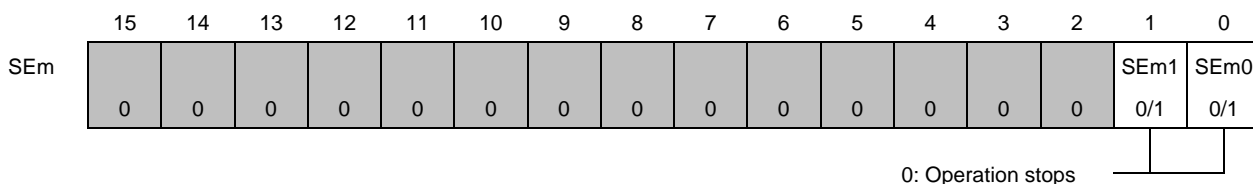
Figure 12-20. Each Register Setting When Stopping the Operation by Channels (1/2)

(a) Serial channel stop register m (STm) ... The STm is a trigger register that is used to enable stopping communication/count by each channel.



*Because the ST_mn bit is a trigger bit, it is cleared immediately when SE_mn = 0.

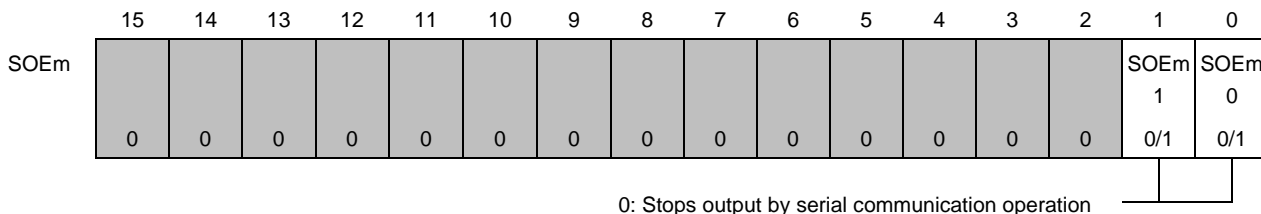
(b) Serial channel enable status register m (SEm) ... This register indicates whether data transmission/reception operation of each channel is enabled or stopped.



*The SEm is a read-only status register, whose operation is stopped by using the STm register.

With a channel whose operation is stopped, the value of the CKO_mn bit of the SOm register can be set by software.

(c) Serial output enable register m (SOEm) ... This register is used to enable or stop output of the serial communication operation of each channel.

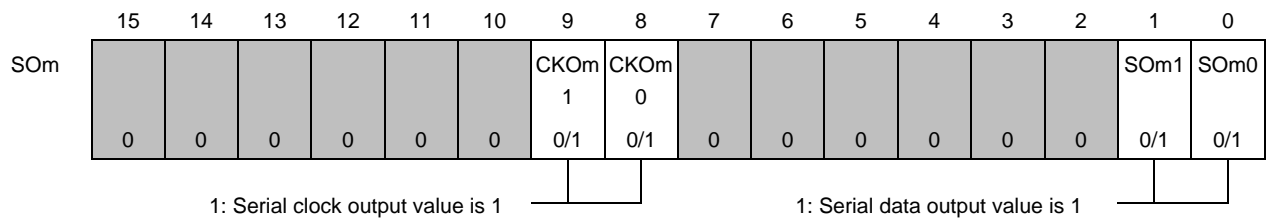


*For channel n, whose serial output is stopped, the SO_mn bit value of the SOm register can be set by software.

(Remarks are listed on the next page.)

Figure 12-20. Each Register Setting When Stopping the Operation by Channels (2/2)

(d) Serial output register m (SOM) ... The SOM is a buffer register for serial output of each channel.



*When using pins corresponding to each channel as port function pins, set the corresponding CKOm, SOMn bits to 1.

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1)

Remark 2. : Setting disabled (set to the initial value), 0/1: Set to 0 or 1 depending on the usage of the user.

12.5 Operation of Simplified SPI (CSI00, CSI01) Communication

This is a clocked communication function that uses three lines: serial clock (SCK) and serial data (SI and SO) lines.

[Data transmission/reception]

- Data length of 7 or 8 bits
- Phase control of transmit/receive data
- MSB/LSB first selectable

[Clock control]

- Master/slave selection
- Phase control of I/O clock
- Setting of transfer period by prescaler and internal counter of each channel
- Maximum transfer rate^{Note 1}

During master communication: Max. $f_{CLK}/4$

During slave communication: Max. $f_{MCK}/6$

[Interrupt function]

- Transfer end interrupt/buffer empty interrupt

[Error detection flag]

- Overrun error

Note 1. Set up the transfer rate within a range satisfying the SCK cycle time (t_{KCY}). For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+85^\circ\text{C}$)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+105^\circ\text{C}$, $T_A = -40$ to $+125^\circ\text{C}$)**.

The channels supporting simplified SPI (CSI00, CSI01) are channels 0 and 1 of SAU0.

● 10- and 8-pin products

| Unit | Channel | Used as simplified SPI (CSI) | Used as UART | Used as Simplified I ² C |
|------|---------|------------------------------|--------------|-------------------------------------|
| 0 | 0 | CSI00 | UART0 | IIC00 |
| | 1 | — | | — |

● 20- and 16-pin products

| Unit | Channel | Used as simplified SPI (CSI) | Used as UART | Used as Simplified I ² C |
|------|---------|------------------------------|--------------|-------------------------------------|
| 0 | 0 | CSI00 | UART0 | IIC00 |
| | 1 | CSI01 | | IIC01 |

Simplified SPI (CSI00, CSI01) performs the following six types of communication operations.

- Master transmission (See **12.5.1**).
- Master reception (See **12.5.2**).
- Master transmission/reception (See **12.5.3**).
- Slave transmission (See **12.5.4**).
- Slave reception (See **12.5.5**).
- Slave transmission/reception (See **12.5.6**).

12.5.1 Master Transmission

Master transmission is that the RL78 microcontroller outputs a transfer clock and transmits data to another device.

| Simplified SPI | CSI00 | CSI01 |
|---------------------------------|--|-------------------|
| Target channel | Channel 0 of SAU0 | Channel 1 of SAU0 |
| Pins used | SCK00, SO00 | SCK01, SO01 |
| Interrupt | INTCSI00 | INTCSI01 |
| | Transfer end interrupt (in single-transfer mode) or buffer empty interrupt (in continuous transfer mode) can be selected. | |
| Error detection flag | None | |
| Transfer data length | 7 or 8 bits | |
| Transfer rate ^{Note 1} | Max. $f_{CLK}/4$ [Hz] Min. $f_{CLK}/(2 \times 2^{15} \times 128)$ [Hz] f_{CLK} : System clock frequency | |
| Data phase | Selectable by the DAPmn bit of the SCRmn register <ul style="list-style-type: none"> • DAPmn = 0: Data output starts from the start of the operation of the serial clock. • DAPmn = 1: Data output starts half a clock cycle before the start of the serial clock operation. | |
| Clock phase | Selectable by the CKPmn bit of the SCRmn register <ul style="list-style-type: none"> • CKPmn = 0: Non-reverse • CKPmn = 1: Reverse | |
| Data direction | MSB or LSB first | |

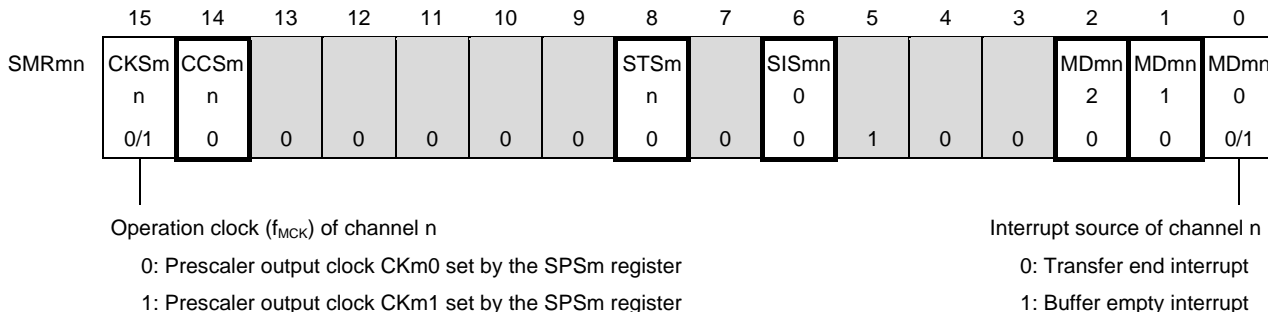
Note 1. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+85^\circ\text{C}$)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+105^\circ\text{C}$, $T_A = -40$ to $+125^\circ\text{C}$)**.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

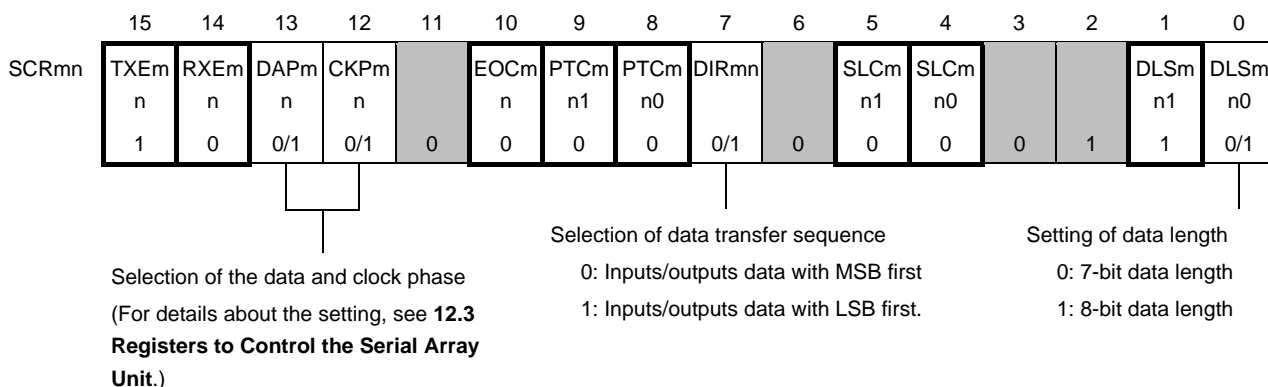
(1) Register setting

Figure 12-21. Example of Contents of Registers for Master Transmission of simplified SPI (CSI00, CSI01) (1/2)

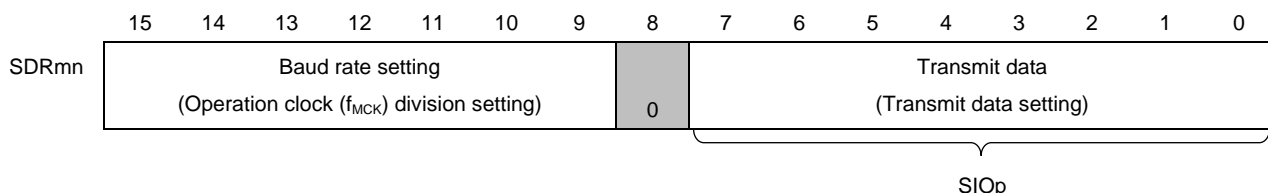
(a) Serial mode register mn (SMRmn)



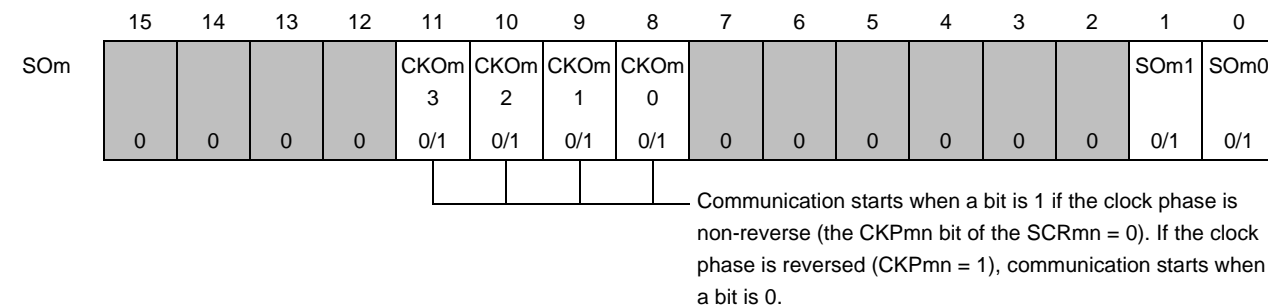
(b) Serial communication operation setting register mn (SCRmn)



(c) Serial data register mn (SDRmn) (lower 8 bits: SIOp)



(d) Serial output register m (SOM) ... Set only the bit of the target channel.



(Remarks are listed on the next page.)

Figure 12-21. Example of Contents of Registers for Master Transmission of simplified SPI (CSI00, CSI01) (2/2)

(e) Serial output enable register m (SOEm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | | |
| SOEm | | | | | | | | | | | | | | | | | SOEm | SOEm |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | | | | | | | | | | | | | | | | 0/1 | 0/1 |

(f) Serial channel start register m (SSm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | | |
| SSm | | | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 | 0/1 |
| | | | | | | | | | | | | | | | | | 0/1 | 0/1 |

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Remark 2. : Setting is fixed in the simplified SPI (CSI) master transmission mode,
 : Setting disabled (set to the initial value)
 0/1: Set to 0 or 1 depending on the usage of the user.

(2) Operation procedure

Figure 12-22. Initial Setting Procedure for Master Transmission

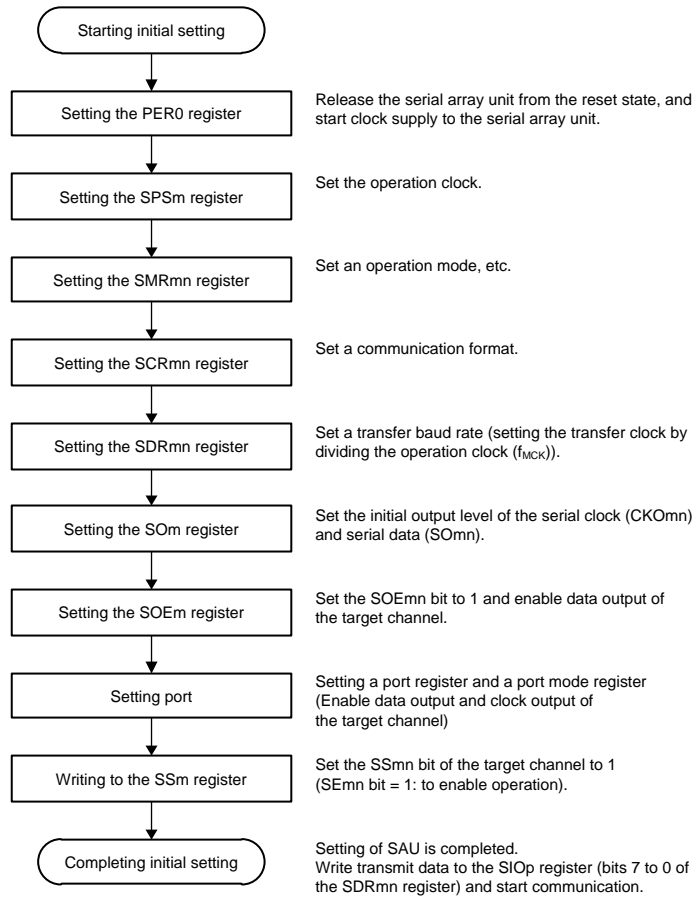


Figure 12-23. Procedure for Stopping Master Transmission

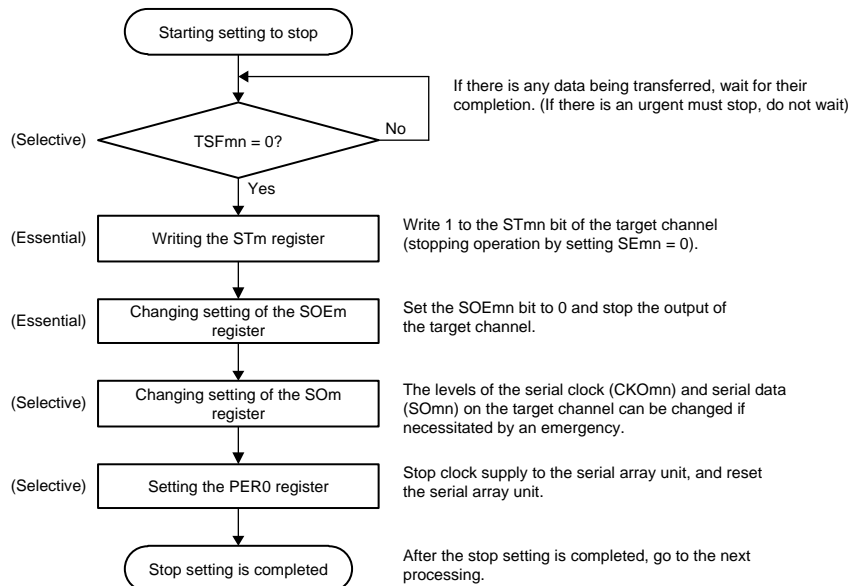
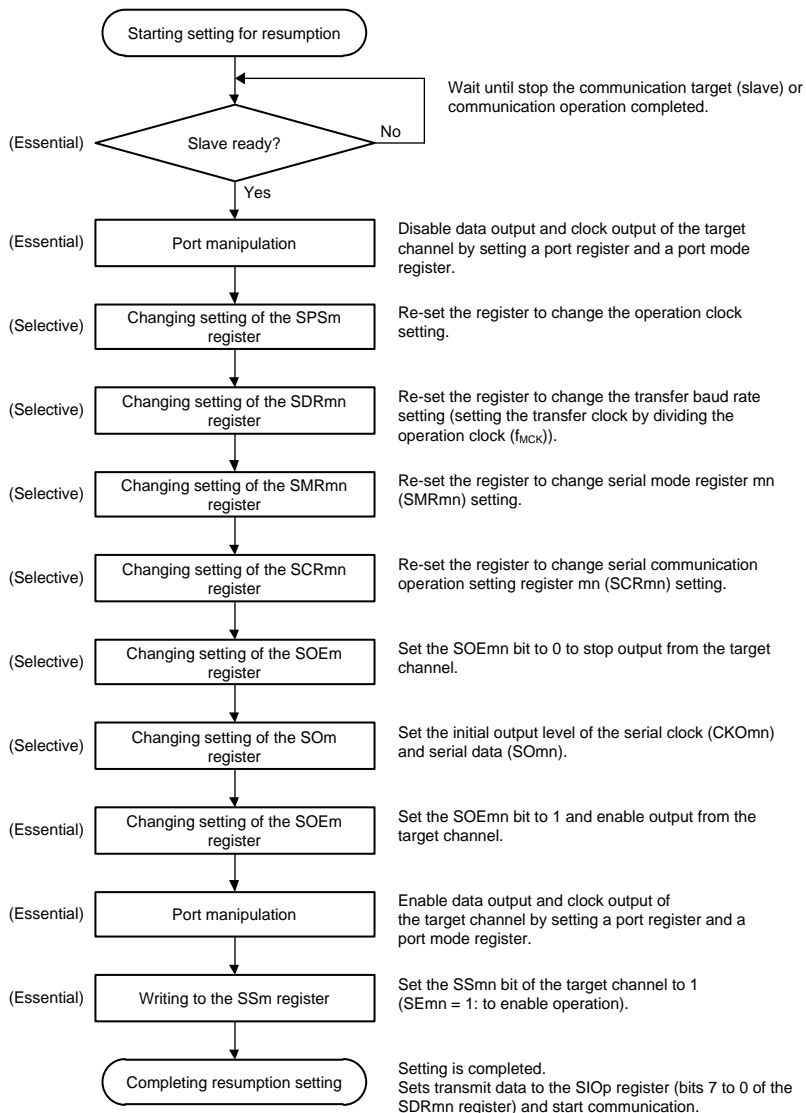


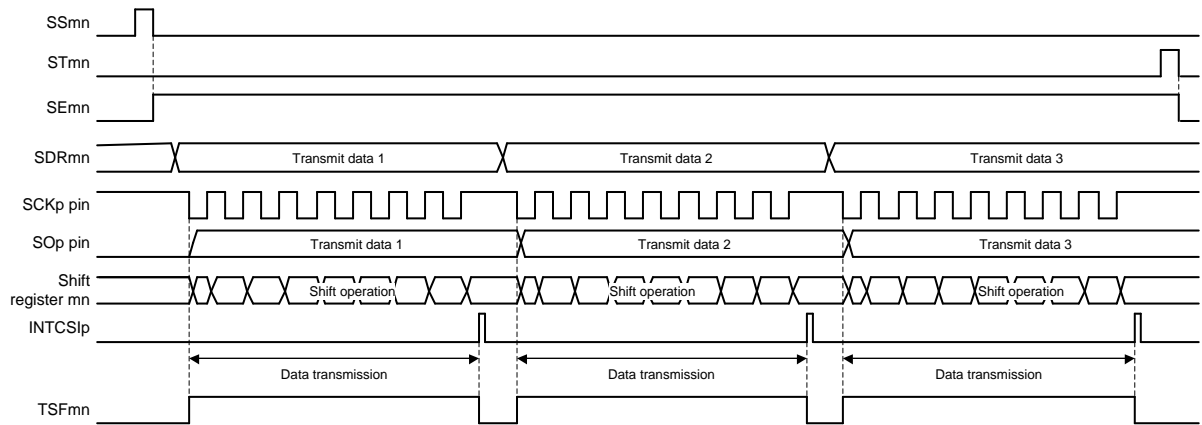
Figure 12-24. Procedure for Resuming Master Transmission



Remark If PER0 is rewritten while stopping the master transmission and the clock supply is stopped, wait until the transmission target (slave) stops or transmission finishes, and then perform initialization instead of restarting the transmission.

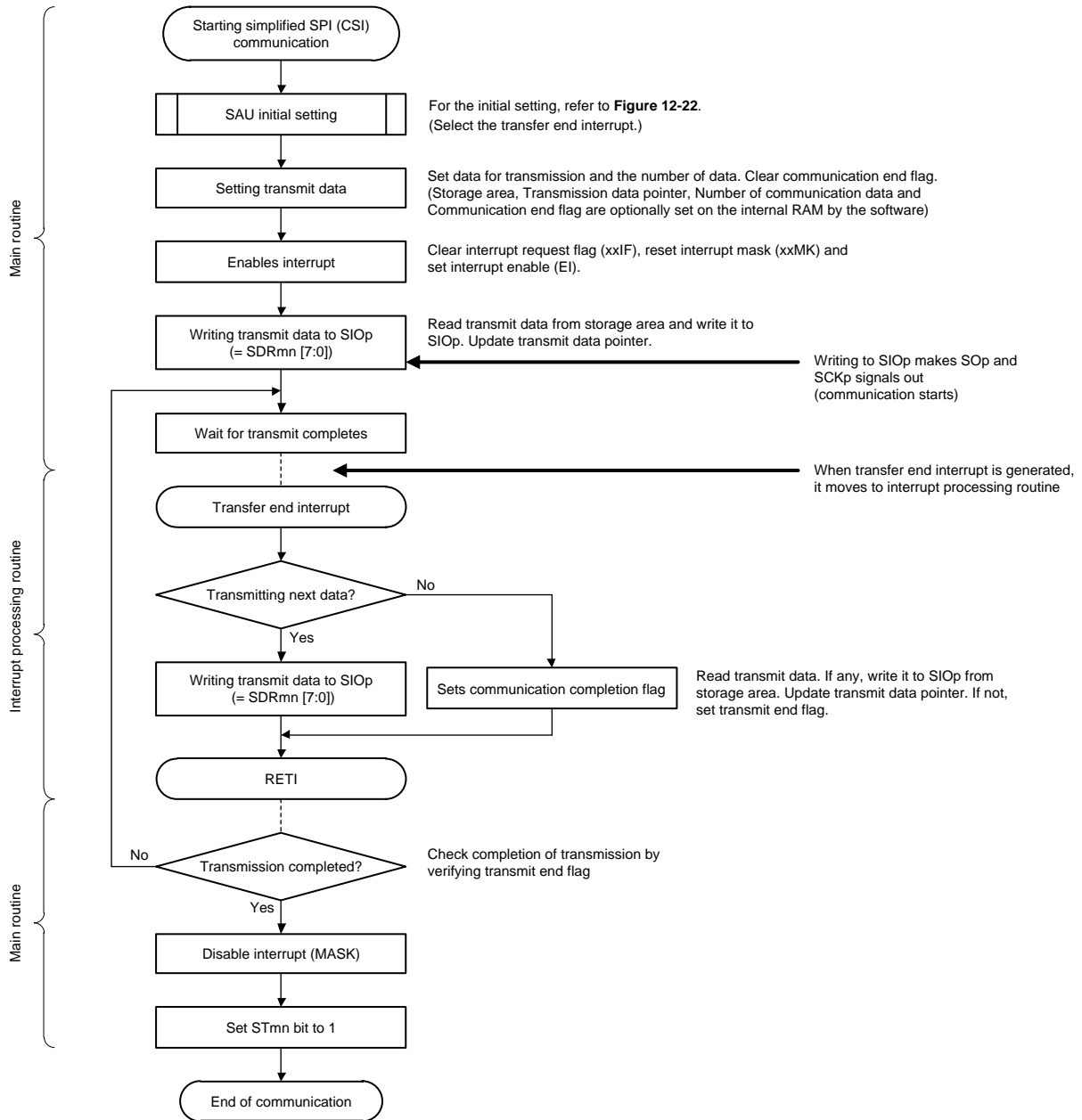
(3) Processing flow (in single-transmission mode)

Figure 12-25. Timing Chart of Master Transmission (in Single-Transmission Mode) (Type 1: DAPmn = 0, CKPmn = 0)



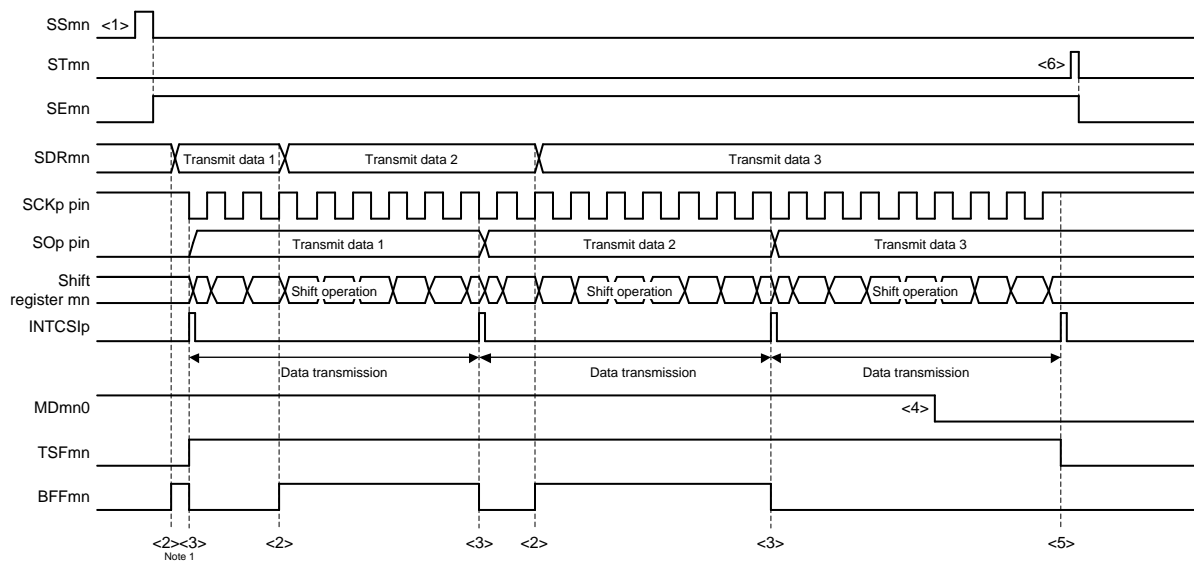
Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-26. Flowchart of Master Transmission (in Single-Transmission Mode)



(4) Processing flow (in continuous transmission mode)

Figure 12-27. Timing Chart of Master Transmission (in Continuous Transmission Mode) (Type 1: DAPmn = 0, CKPmn = 0)

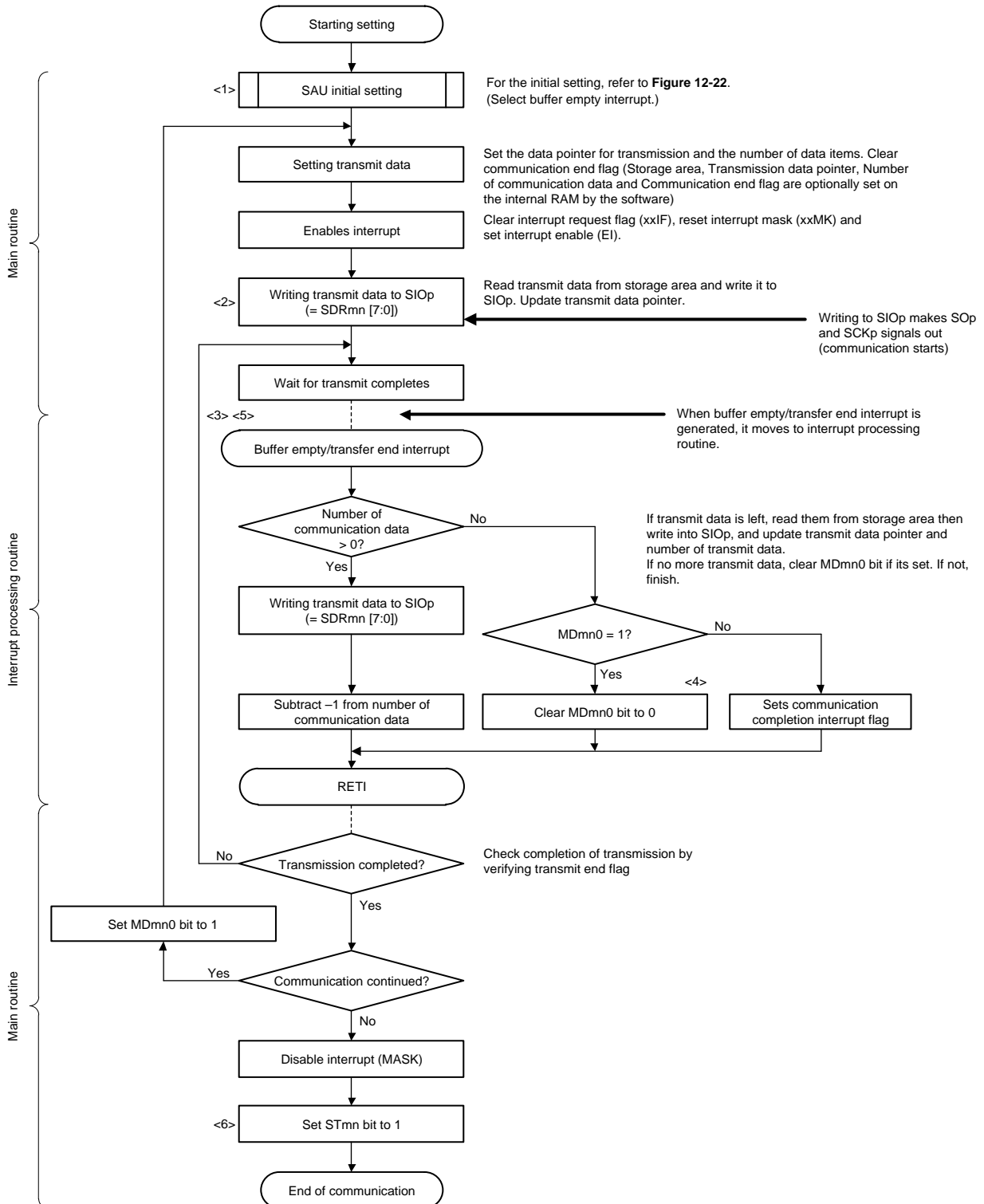


Note 1. If transmit data is written to the SDRmn register while the BFFmn bit of serial status register mn (SSRmn) is 1 (valid data is stored in serial data register mn (SDRmn)), the transmit data is overwritten.

Caution The MDmn0 bit of serial mode register mn (SMRmn) can be rewritten even during operation. However, rewrite it before transfer of the last bit is started, so that it has been rewritten before the transfer end interrupt of the last transmit data.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-28. Flowchart of Master Transmission (in Continuous Transmission Mode)



Remark <1> to <6> in the figure correspond to <1> to <6> in **Figure 12-27 Timing Chart of Master Transmission (in Continuous Transmission Mode) (Type 1: DAPmn = 0, CKPmn = 0)**.

12.5.2 Master Reception

Master reception is that the RL78 microcontroller outputs a transfer clock and receives data from another device.

| Simplified SPI | CSI00 | CSI01 |
|---------------------------------|--|-------------------|
| Target channel | Channel 0 of SAU0 | Channel 1 of SAU0 |
| Pins used | SCK00, SO00 | SCK01, SO01 |
| Interrupt | INTCSI00 | INTCSI01 |
| | Transfer end interrupt (in single-transfer mode) or buffer empty interrupt (in continuous transfer mode) can be selected. | |
| Error detection flag | Overrun error detection flag (OVFmn) only | |
| Transfer data length | 7 or 8 bits | |
| Transfer rate ^{Note 1} | Max. $f_{CLK}/4$ [Hz] Min. $f_{CLK}/(2 \times 2^{15} \times 128)$ [Hz] f_{CLK} : System clock frequency | |
| Data phase | Selectable by the DAPmn bit of the SCRmn register <ul style="list-style-type: none"> • DAPmn = 0: Data input starts from the start of the operation of the serial clock. • DAPmn = 1: Data input starts half a clock cycle before the start of the serial clock operation. | |
| Clock phase | Selectable by the CKPmn bit of the SCRmn register <ul style="list-style-type: none"> • CKPmn = 0: Non-reverse • CKPmn = 1: Reverse | |
| Data direction | MSB or LSB first | |

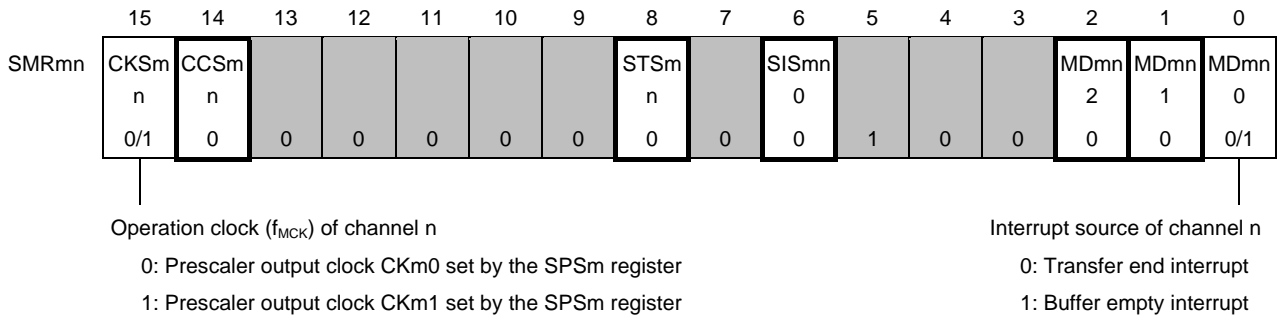
Note 1. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS (T_A = -40 to +105°C, T_A = -40 to +125°C)**.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

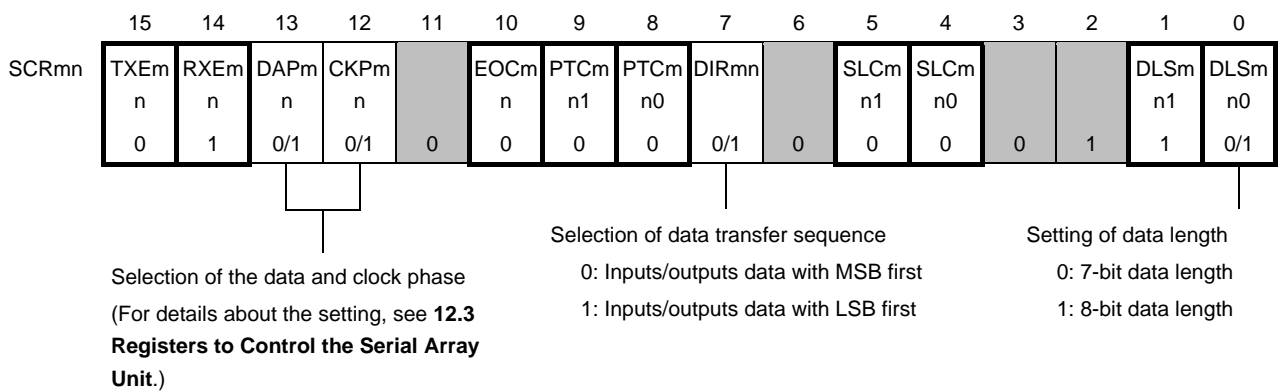
(1) Register setting

Figure 12-29. Example of Contents of Registers for Master Reception of simplified SPI (CSI00, CSI01) (1/2)

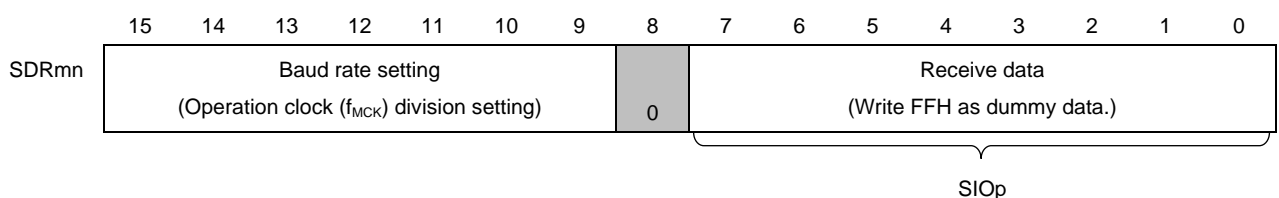
(a) Serial mode register mn (SMRmn)



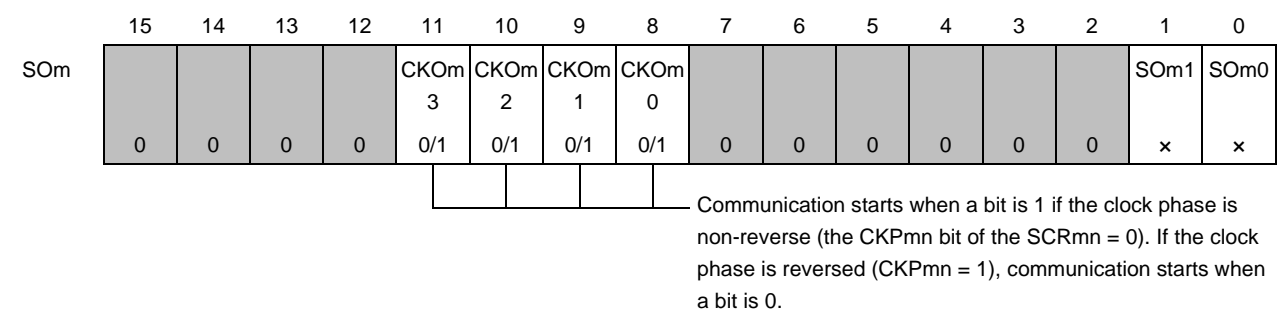
(b) Serial communication operation setting register mn (SCRmn)



(c) Serial data register mn (SDRmn) (lower 8 bits: SIOp)



(d) Serial output register m (SOM) ... Set only the bit of the target channel.



(Remarks are listed on the next page.)

Figure 12-29. Example of Contents of Registers for Master Reception of simplified SPI (CSI00, CSI01) (2/2)

(e) Serial output enable register m (SOEm) ... This register is not used in this mode.

| | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOEm | | | | | | | | | | | | | | | SOEm | SOEm |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | | | | | | | | | | | | | | x | x |

(f) Serial channel start register m (SSm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSm | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 | 0/1 |

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Remark 2. : Setting is fixed in the simplified SPI (CSI) master reception mode,
 : Setting disabled (set to the initial value)
 x: Bit that cannot be used in this mode (set to the initial value when not used in any mode)
 0/1: Set to 0 or 1 depending on the usage of the user.

(2) Operation procedure

Figure 12-30. Initial Setting Procedure for Master Reception

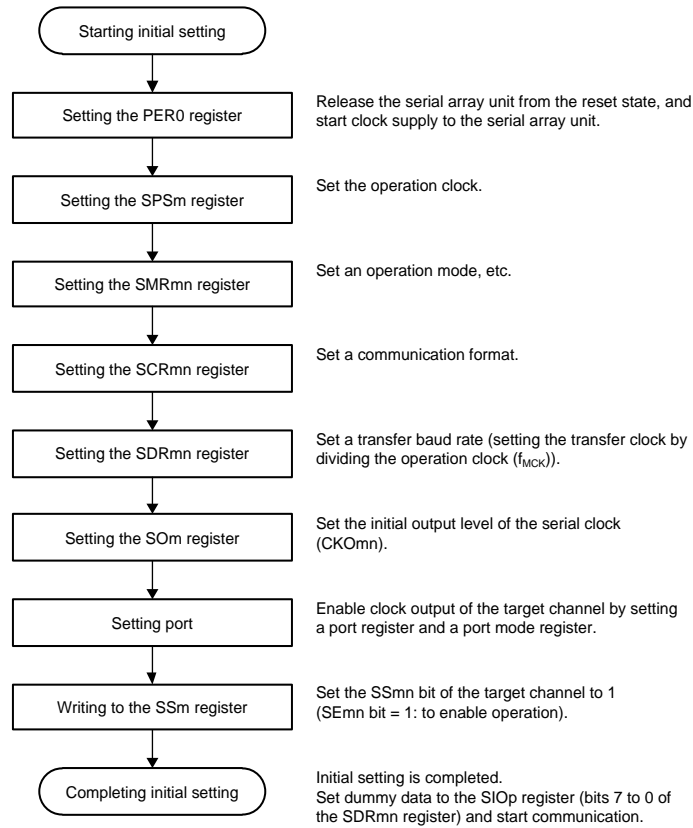


Figure 12-31. Procedure for Stopping Master Reception

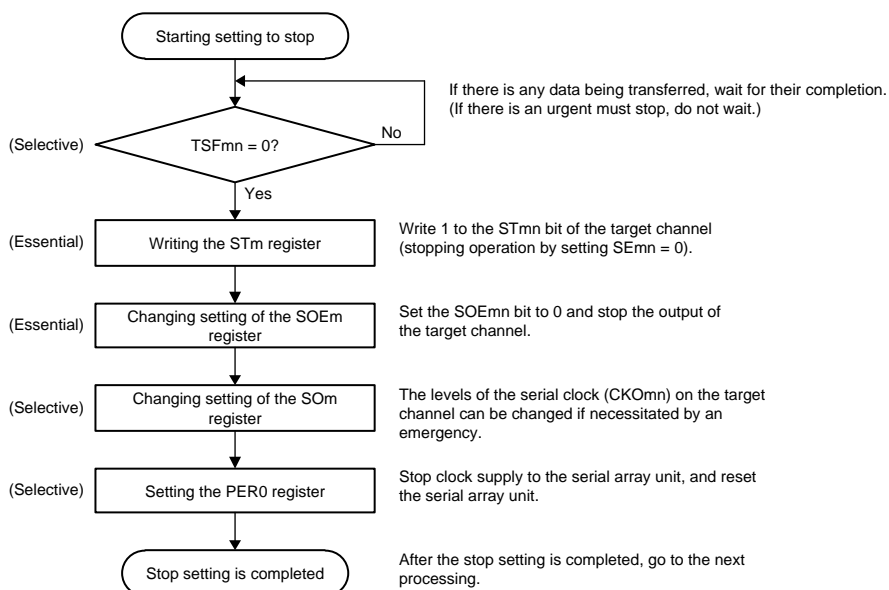
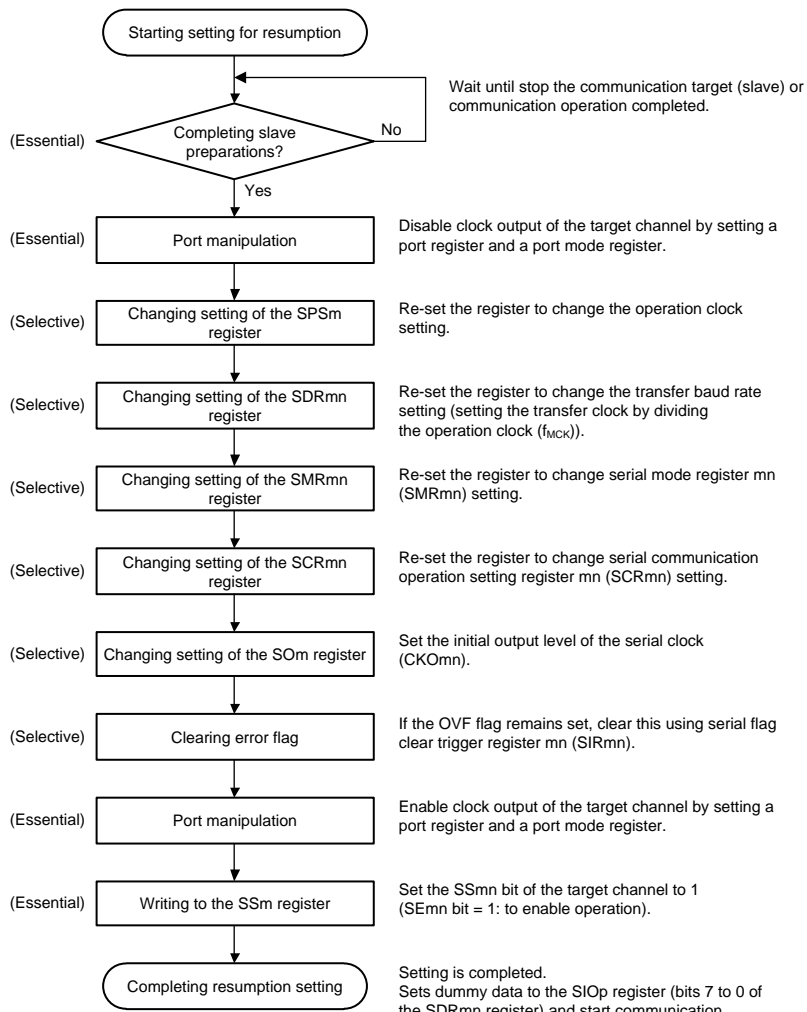


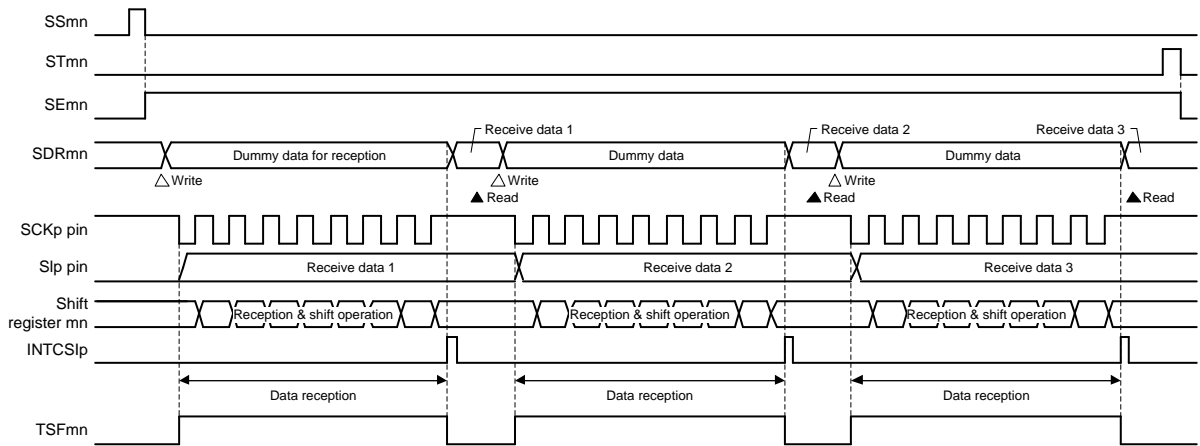
Figure 12-32. Procedure for Resuming Master Reception



Remark If PER0 is rewritten while stopping the communication to reset the serial array unit, wait until the communication target (slave) stops or communication finishes, and then perform initialization instead of restarting the communication.

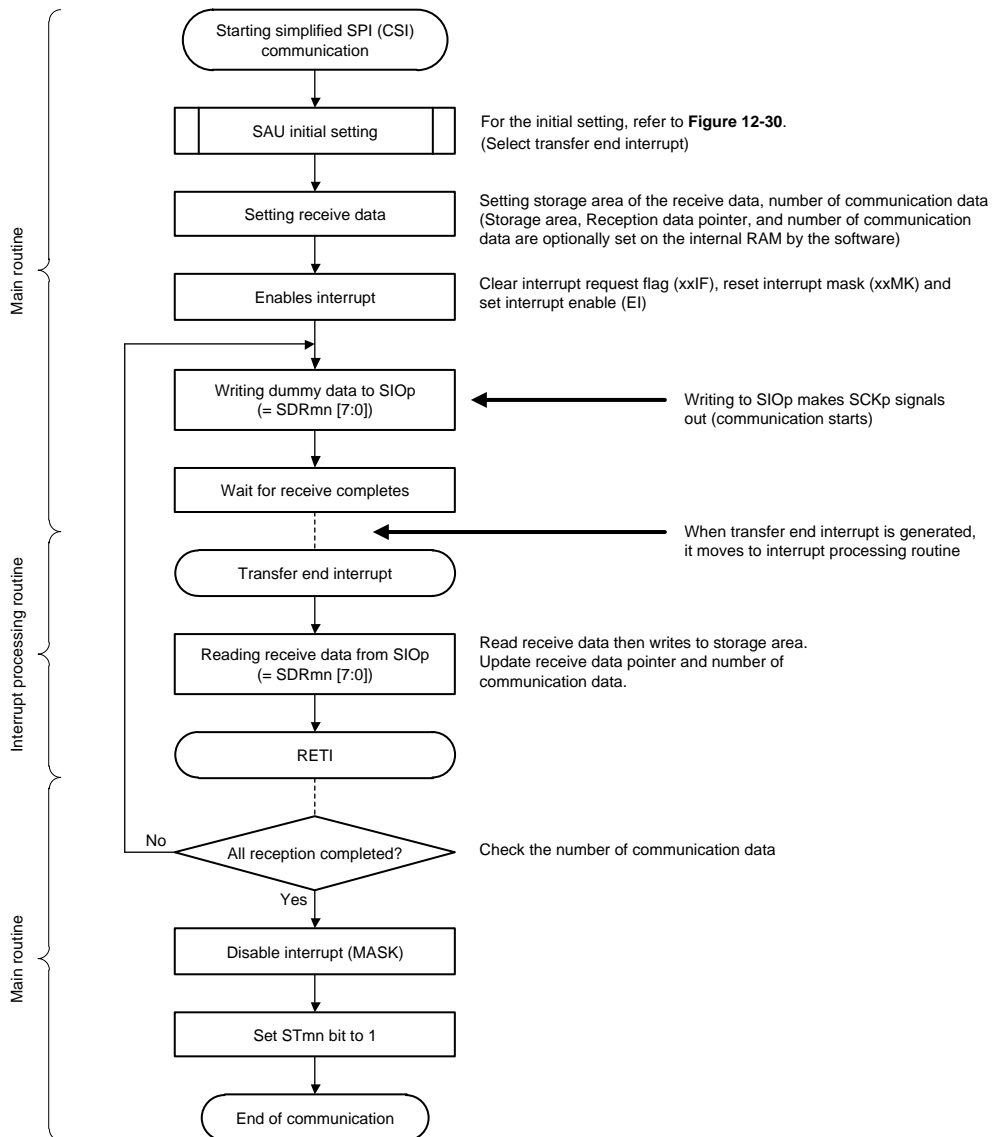
(3) Processing flow (in single-reception mode)

Figure 12-33. Timing Chart of Master Reception (in Single-Reception Mode) (Type 1: DAPmn = 0, CKPmn = 0)



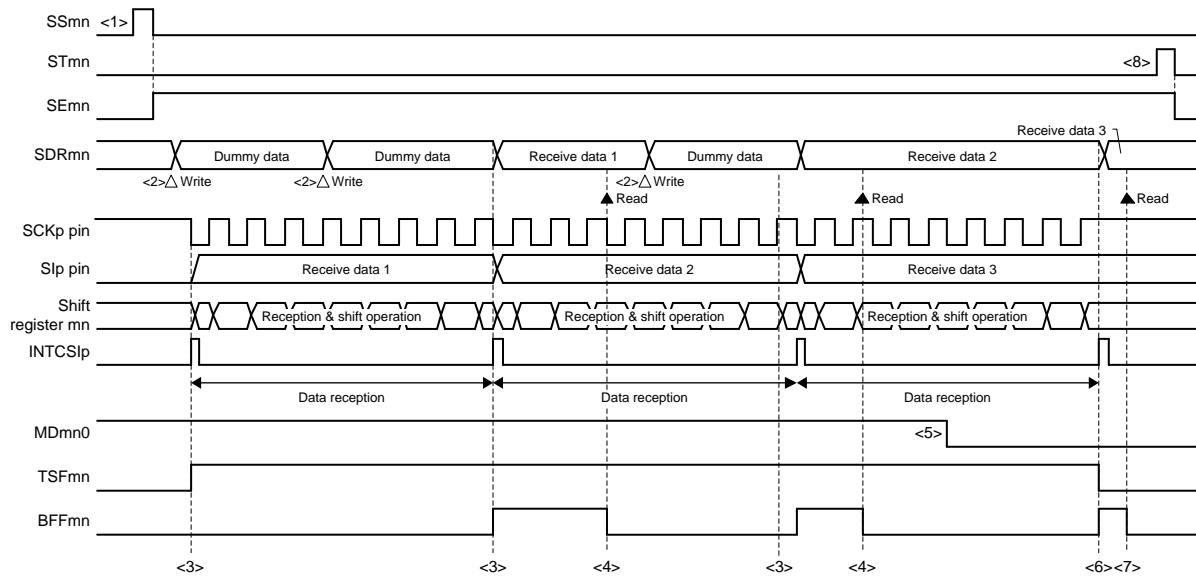
Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-34. Flowchart of Master Reception (in Single-Reception Mode)



(4) Processing flow (in continuous reception mode)

Figure 12-35. Timing Chart of Master Reception (in Continuous Reception Mode) (Type 1: DAPmn = 0, CKPmn = 0)



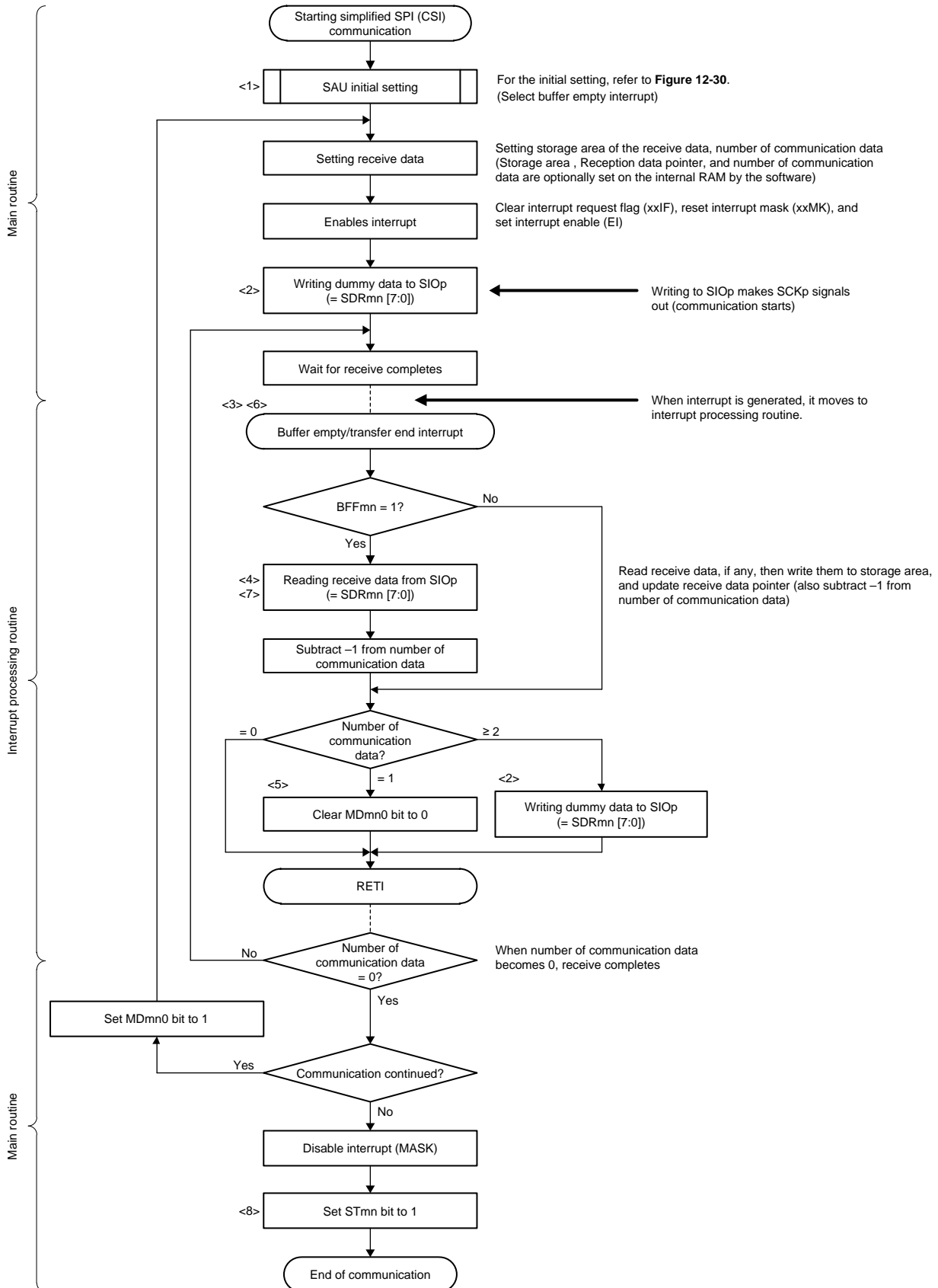
Caution The MDmn0 bit can be rewritten even during operation.

However, rewrite it before receive of the last bit is started, so that it has been rewritten before the transfer end interrupt of the last receive data.

Remark 1. <1> to <8> in the figure correspond to <1> to <8> in **Figure 12-36 Flowchart of Master Reception (in Continuous Reception Mode)**.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-36. Flowchart of Master Reception (in Continuous Reception Mode)



(Remark is listed on the next page.)

Remark <1> to <8> in the figure correspond to <1> to <8> in **Figure 12-35 Timing Chart of Master Reception (in Continuous Reception Mode) (Type 1: DAPmn = 0, CKPmn = 0)**.

12.5.3 Master Transmission/Reception

Master transmission/reception is that the RL78 microcontroller outputs a transfer clock and transmits/receives data to/from another device.

| Simplified SPI | CSI00 | CSI01 |
|---------------------------------|--|-------------------|
| Target channel | Channel 0 of SAU0 | Channel 1 of SAU0 |
| Pins used | SCK00, SI00, SO00 | SCK01, SI01, SO01 |
| Interrupt | INTCSI00 | INTCSI01 |
| | Transfer end interrupt (in single-transfer mode) or buffer empty interrupt (in continuous transfer mode) can be selected. | |
| Error detection flag | Overrun error detection flag (OVFmn) only | |
| Transfer data length | 7 or 8 bits | |
| Transfer rate ^{Note 1} | Max. $f_{CLK}/4$ [Hz] Min. $f_{CLK}/(2 \times 2^{15} \times 128)$ [Hz] f_{CLK} : System clock frequency | |
| Data phase | Selectable by the DAPmn bit of the SCRmn register <ul style="list-style-type: none"> • DAPmn = 0: Data I/O starts at the start of the operation of the serial clock. • DAPmn = 1: Data I/O starts half a clock cycle before the start of the serial clock operation. | |
| Clock phase | Selectable by the CKPmn bit of the SCRmn register <ul style="list-style-type: none"> • CKPmn = 0: Non-reverse • CKPmn = 1: Reverse | |
| Data direction | MSB or LSB first | |

Note 1. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS (T_A = -40 to +105°C, T_A = -40 to +125°C)**.

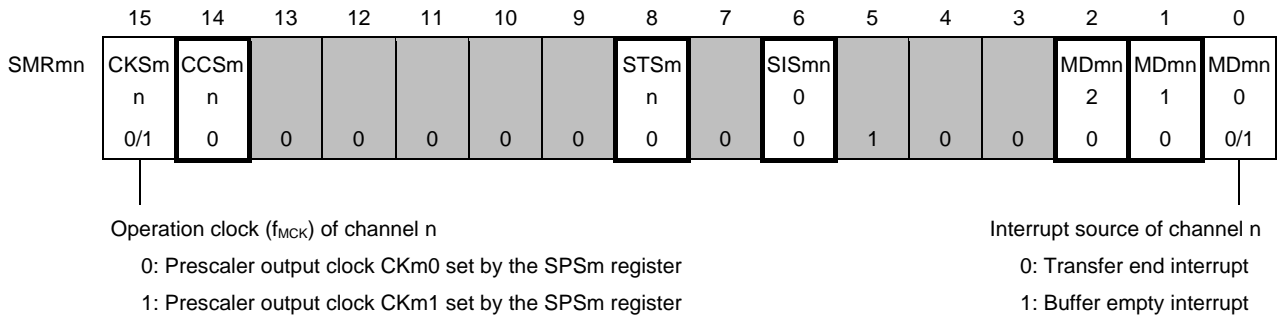
Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

(1) Register setting

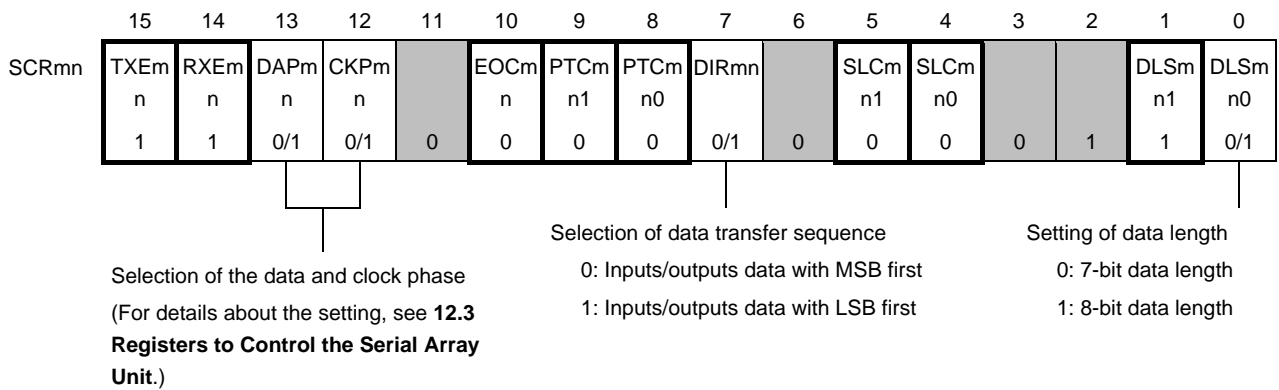
Figure 12-37. Example of Contents of Registers for Master Transmission/Reception of simplified SPI (CSI00, CSI01)

(1/2)

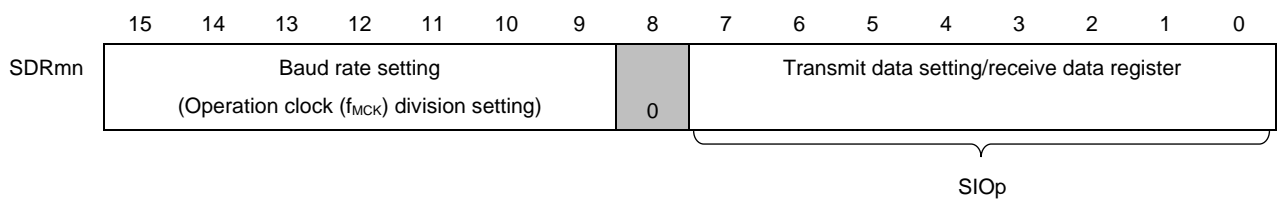
(a) Serial mode register mn (SMRmn)



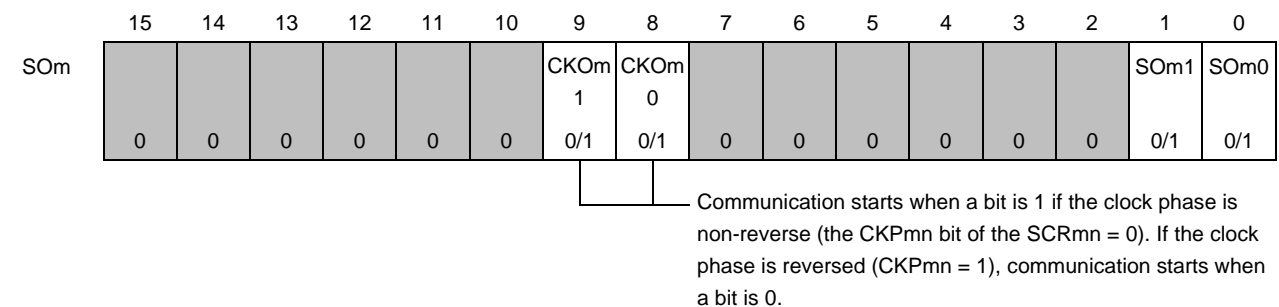
(b) Serial communication operation setting register mn (SCRmn)



(c) Serial data register mn (SDRmn) (lower 8 bits: SIOp)



(d) Serial output register m (SOM) ... Set only the bit of the target channel.



(Remarks are listed on the next page.)

Figure 12-37. Example of Contents of Registers for Master Transmission/Reception of simplified SPI (CSI00, CSI01)
(2/2)

(e) Serial output enable register m (SOEm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOEm | | | | | | | | | | | | | | | SOEm | SOEm |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | | | | | | | | | | | | | | 0/1 | 0/1 |

(f) Serial channel start register m (SSm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSm | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 | 0/1 |

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Remark 2. : Setting is fixed in the simplified SPI (CSI) master transmission/reception mode,
 : Setting disabled (set to the initial value)
 0/1: Set to 0 or 1 depending on the usage of the user.

(2) Operation procedure

Figure 12-38. Initial Setting Procedure for Master Transmission/Reception

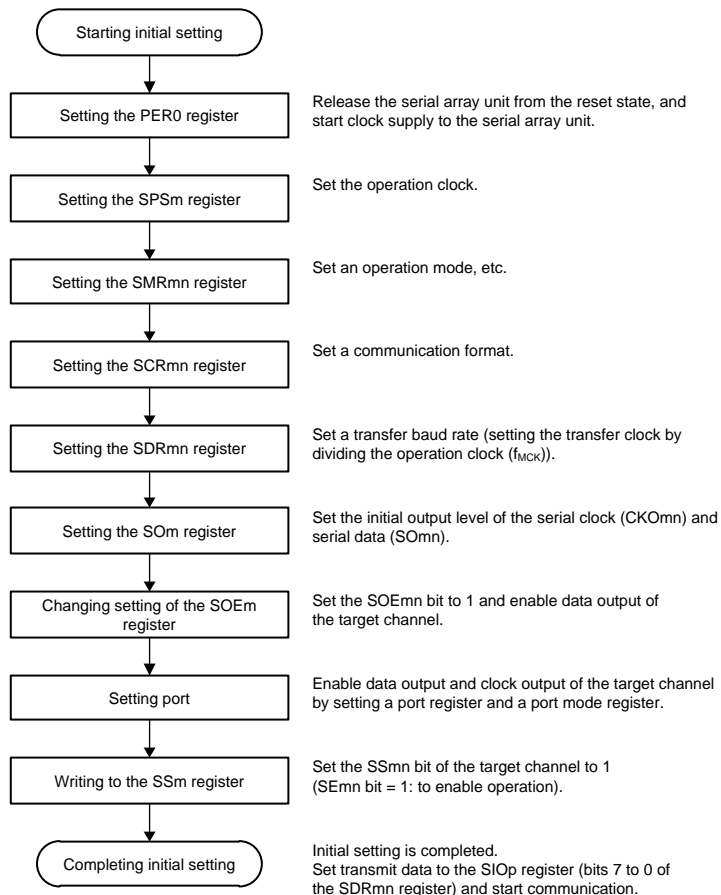


Figure 12-39. Procedure for Stopping Master Transmission/Reception

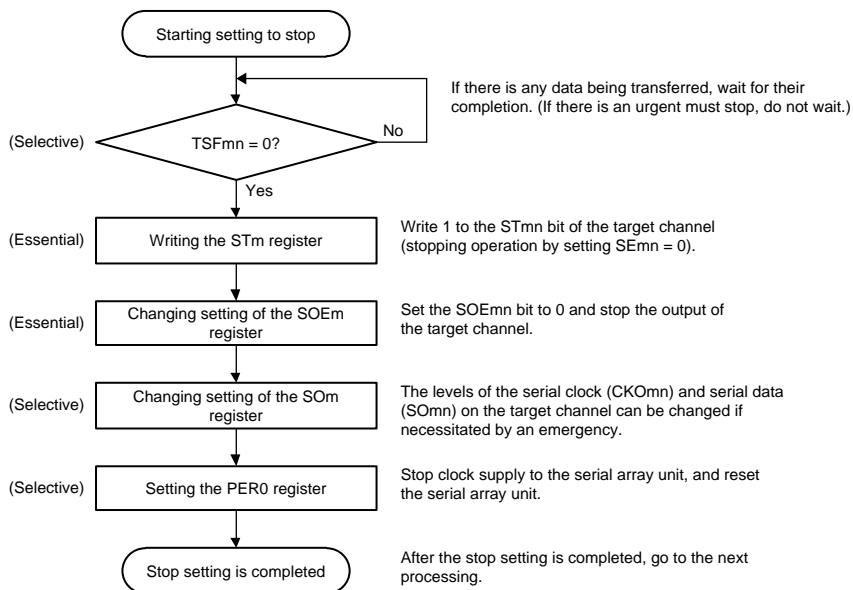
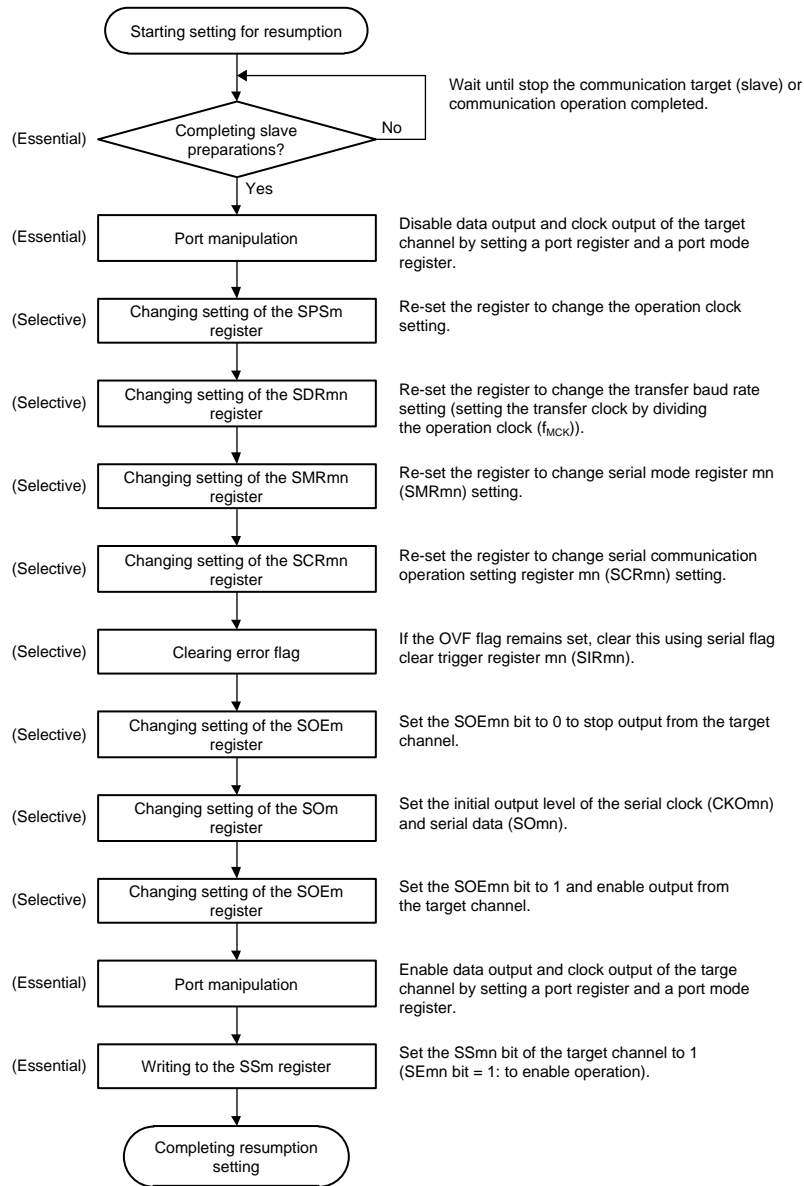
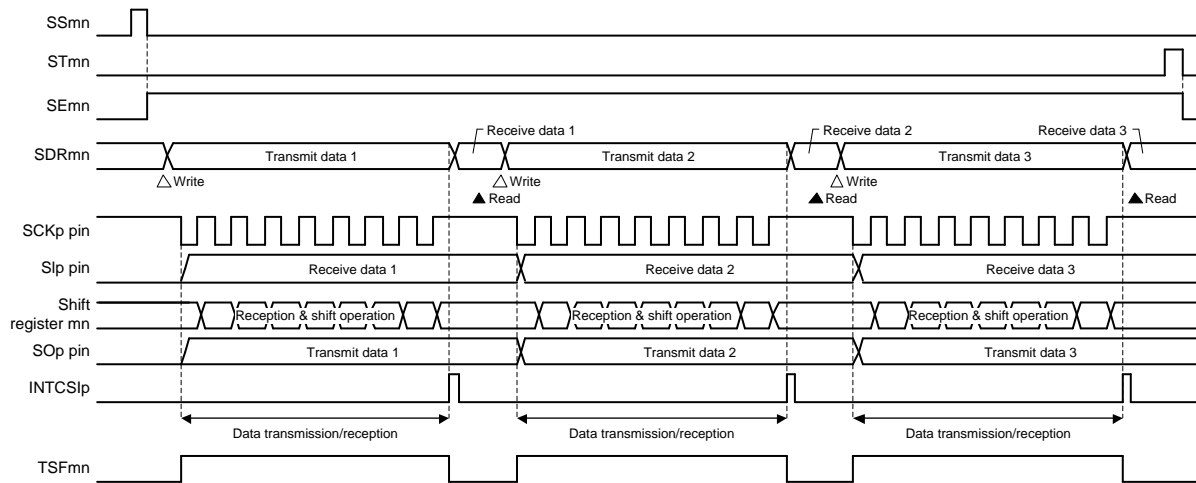


Figure 12-40. Procedure for Resuming Master Transmission/Reception



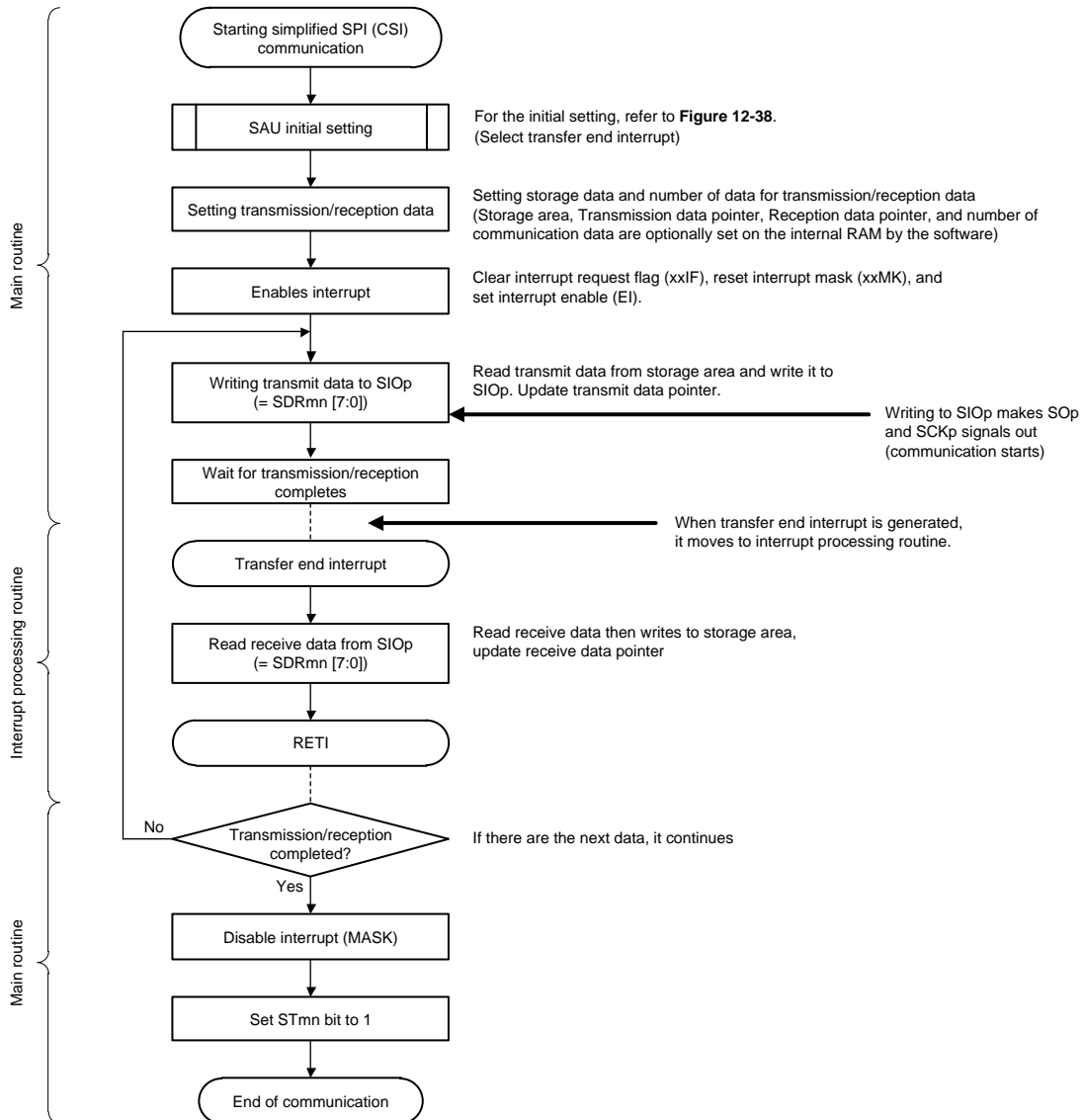
(3) Processing flow (in single-transmission/reception mode)

Figure 12-41. Timing Chart of Master Transmission/Reception (in Single-Transmission/Reception Mode) (Type 1: DAPmn = 0, CKPmn = 0)



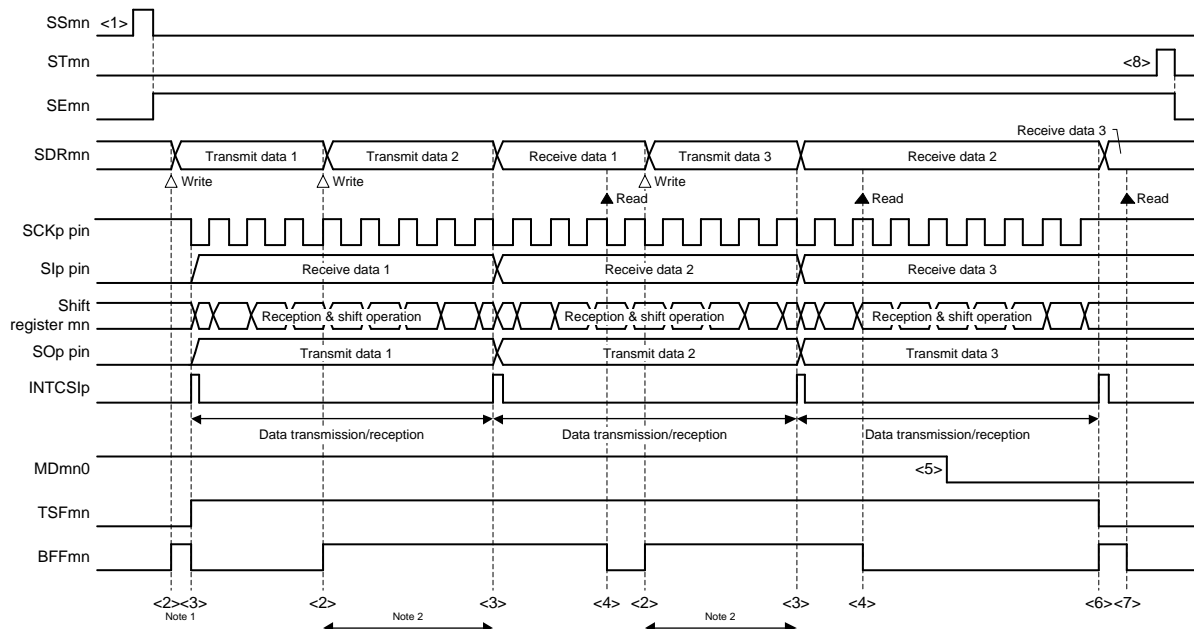
Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-42. Flowchart of Master Transmission/Reception (in Single-Transmission/Reception Mode)



(4) Processing flow (in continuous transmission/reception mode)

Figure 12-43. Timing Chart of Master Transmission/Reception (in Continuous Transmission/Reception Mode) (Type 1:
DAPmn = 0, CKPmn = 0)



Note 1. If transmit data is written to the SDRmn register while the BFFmn bit of serial status register mn (SSRmn) is 1 (valid data is stored in serial data register mn (SDRmn)), the transmit data is overwritten.

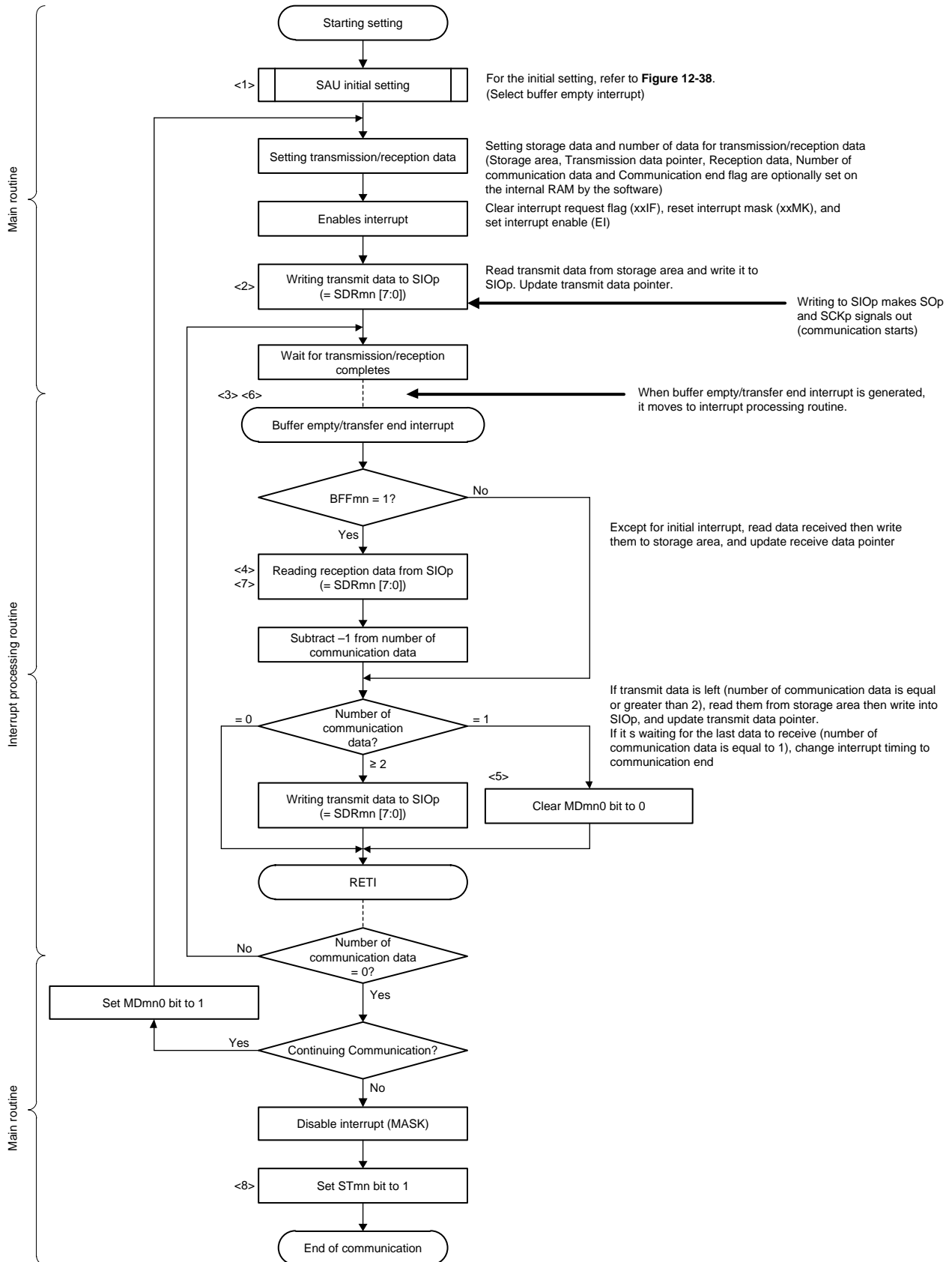
Note 2. The transmit data can be read by reading the SDRmn register during this period. Reading this register does not affect the transfer operation.

Caution The MDmn0 bit of serial mode register mn (SMRmn) can be rewritten even during operation. However, rewrite it before transfer of the last bit is started, so that it has been rewritten before the transfer end interrupt of the last transmit data.

Remark 1. <1> to <8> in the figure correspond to <1> to <8> in **Figure 12-44 Flowchart of Master Transmission/Reception (in Continuous Transmission/Reception Mode)**.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-44. Flowchart of Master Transmission/Reception (in Continuous Transmission/Reception Mode)



(Remark is listed on the next page.)

Remark <1> to <8> in the figure correspond to <1> to <8> in **Figure 12-43 Timing Chart of Master Transmission/Reception (in Continuous Transmission/Reception Mode) (Type 1: DAPmn = 0, CKPmn = 0)**.

12.5.4 Slave Transmission

Slave transmission is that the RL78 microcontroller transmits data to another device in the state of a transfer clock being input from another device.

| Simplified SPI | CSI00 | CSI01 |
|----------------------|--|-------------------|
| Target channel | Channel 0 of SAU0 | Channel 1 of SAU0 |
| Pins used | SCK00, SO00 | SCK01, SO01 |
| Interrupt | INTCSI00 | INTCSI01 |
| | Transfer end interrupt (in single-transfer mode) or buffer empty interrupt (in continuous transfer mode) can be selected. | |
| Error detection flag | Overrun error detection flag (OVFmn) only | |
| Transfer data length | 7 or 8 bits | |
| Transfer rate | Max. $f_{MCK}/6$ [Hz] ^{Note 1, Note 2} | |
| Data phase | Selectable by the DAPmn bit of the SCRmn register <ul style="list-style-type: none"> • DAPmn = 0: Data output starts from the start of the operation of the serial clock. • DAPmn = 1: Data output starts half a clock cycle before the start of the serial clock operation. | |
| Clock phase | Selectable by the CKPmn bit of the SCRmn register <ul style="list-style-type: none"> • CKPmn = 0: Non-reverse • CKPmn = 1: Reverse | |
| Data direction | MSB or LSB first | |

Note 1. Because the external serial clock input to the SCK00 and SCK01 pins is sampled internally and used, the fastest transfer rate is $f_{MCK}/6$ [Hz].

Note 2. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS (T_A = -40 to +105°C, T_A = -40 to +125°C)**.

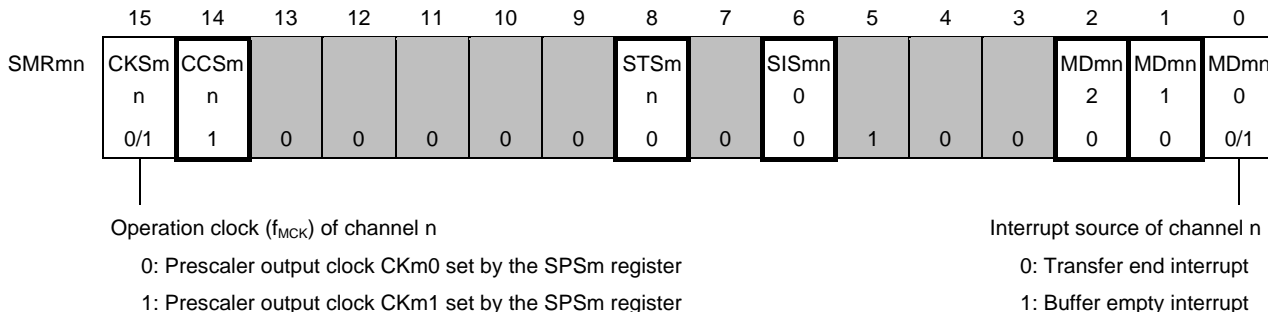
Remark 1. f_{MCK} : Operation clock frequency of target channel
 f_{SCK} : Serial clock frequency

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

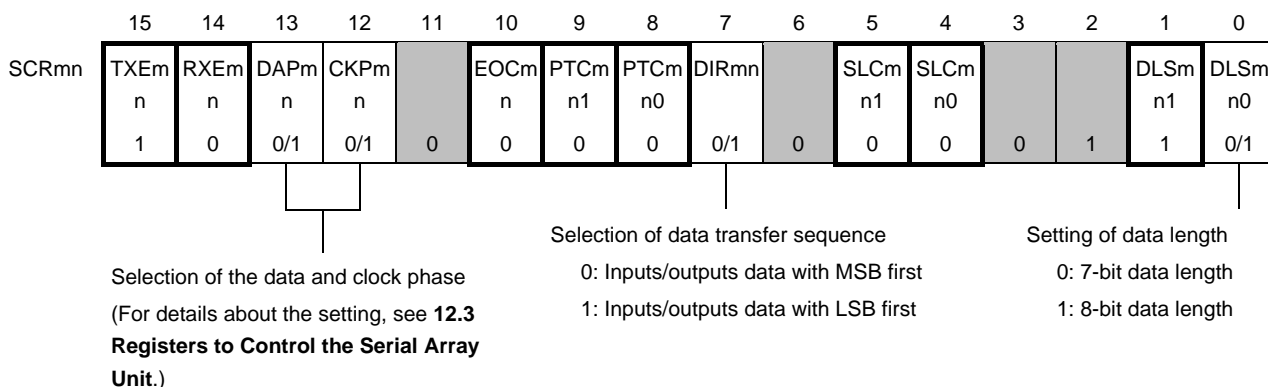
(1) Register setting

Figure 12-45. Example of Contents of Registers for Slave Transmission of simplified SPI (CSI00, CSI01) (1/2)

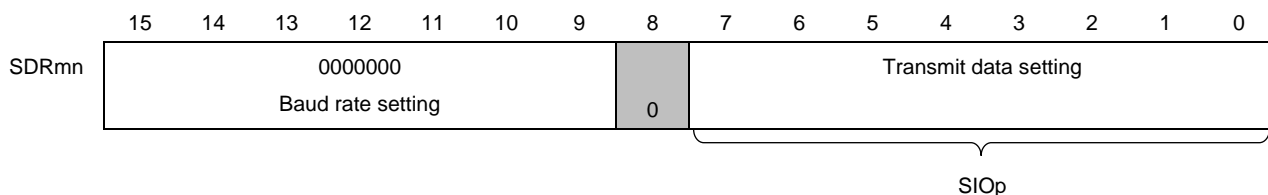
(a) Serial mode register mn (SMRmn)



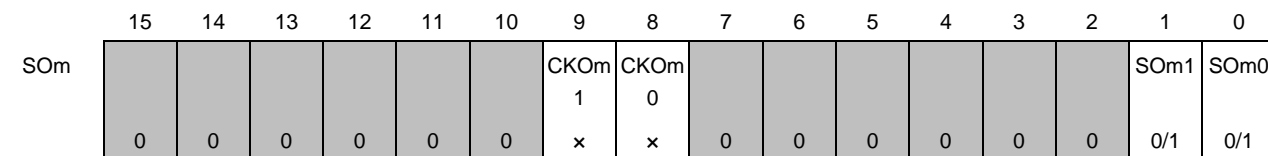
(b) Serial communication operation setting register mn (SCRmn)



(c) Serial data register mn (SDRmn) (lower 8 bits: SIOp)



(d) Serial output register m (SOM) ... Set only the bit of the target channel.



(Remarks are listed on the next page.)

Figure 12-45. Example of Contents of Registers for Slave Transmission of simplified SPI (CSI00, CSI01) (2/2)

(e) Serial output enable register m (SOEm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOEm | | | | | | | | | | | | | | | SOEm | SOEm |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | | | | | | | | | | | | | | 0/1 | 0/1 |

(f) Serial channel start register m (SSm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSm | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 | 0/1 |
| | | | | | | | | | | | | | | | 0/1 | 0/1 |

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Remark 2. : Setting is fixed in the simplified SPI (CSI) slave transmission mode,
 : Setting disabled (set to the initial value)
 x: Bit that cannot be used in this mode (set to the initial value when not used in any mode)
 0/1: Set to 0 or 1 depending on the usage of the user.

(2) Operation procedure

Figure 12-46. Initial Setting Procedure for Slave Transmission

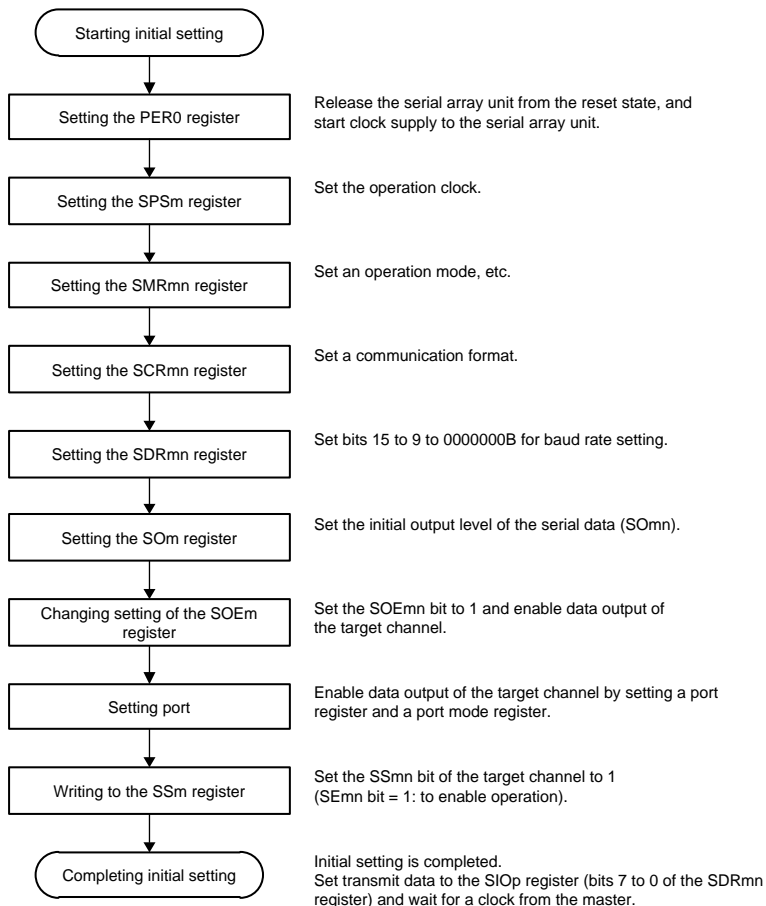


Figure 12-47. Procedure for Stopping Slave Transmission

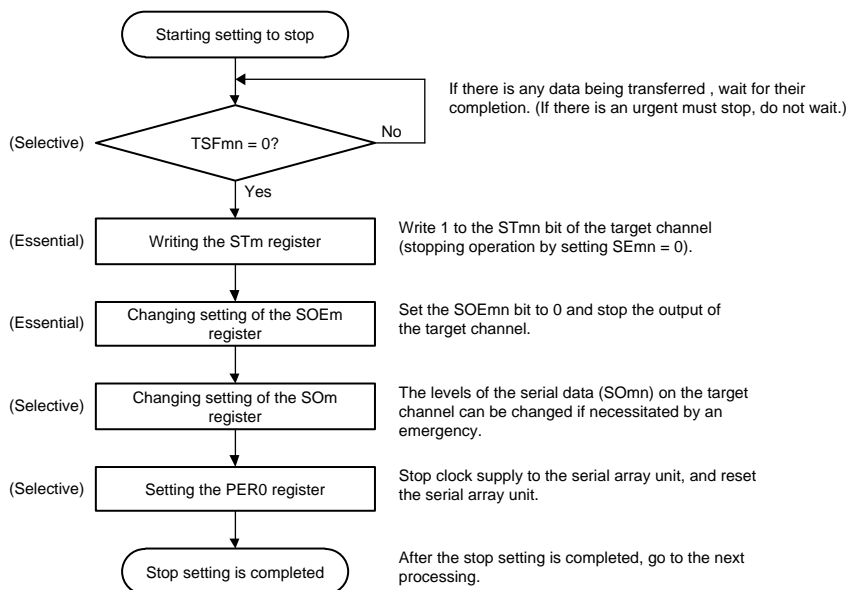
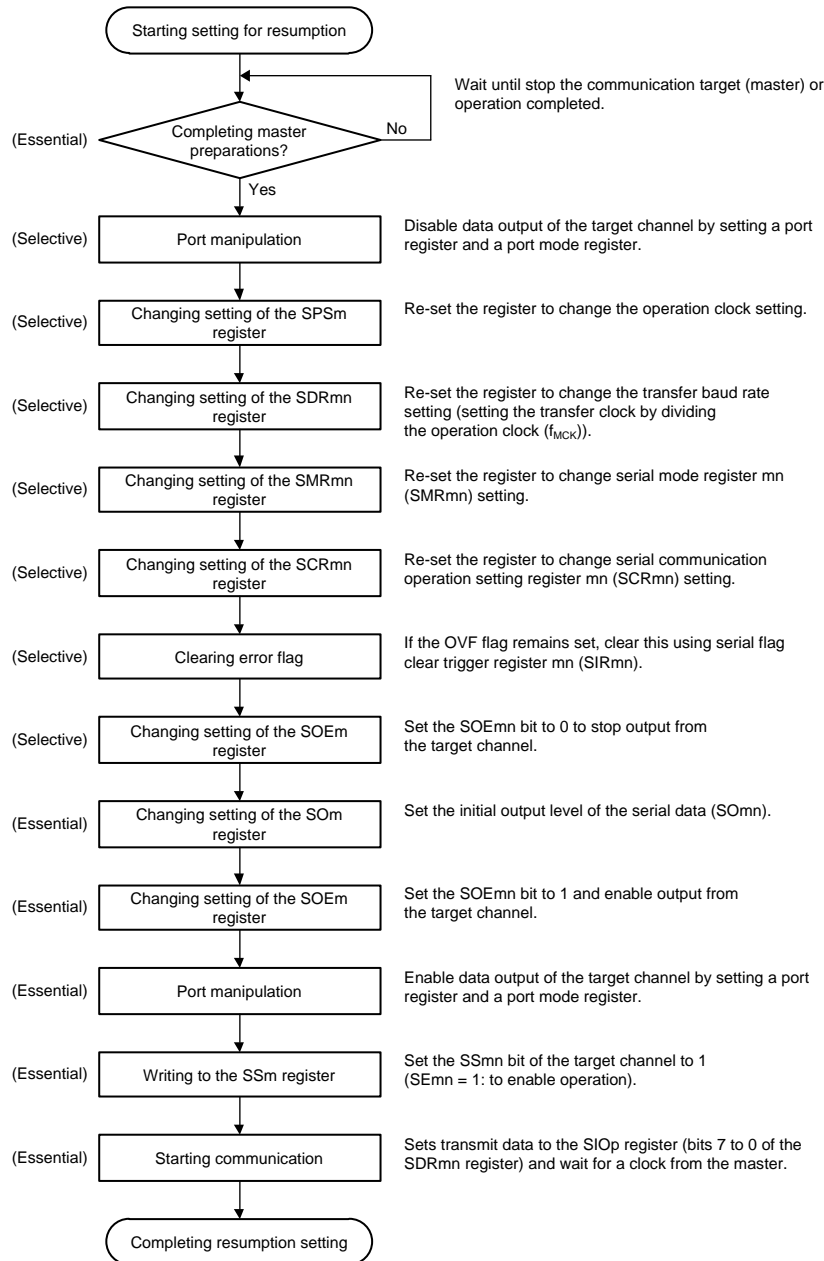


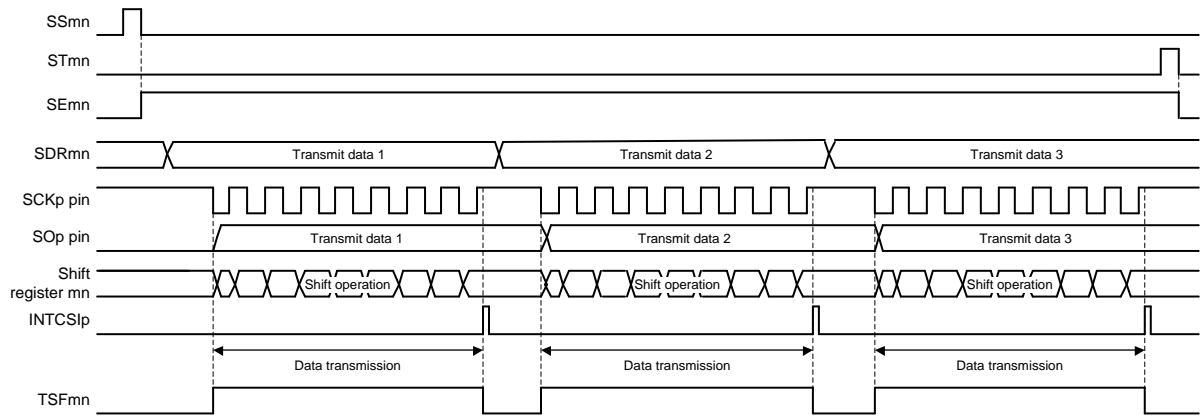
Figure 12-48. Procedure for Resuming Slave Transmission



Remark If PER0 is rewritten while stopping the communication to reset the serial array unit, wait until the communication target (master) stops or communication finishes, and then perform initialization instead of restarting the communication.

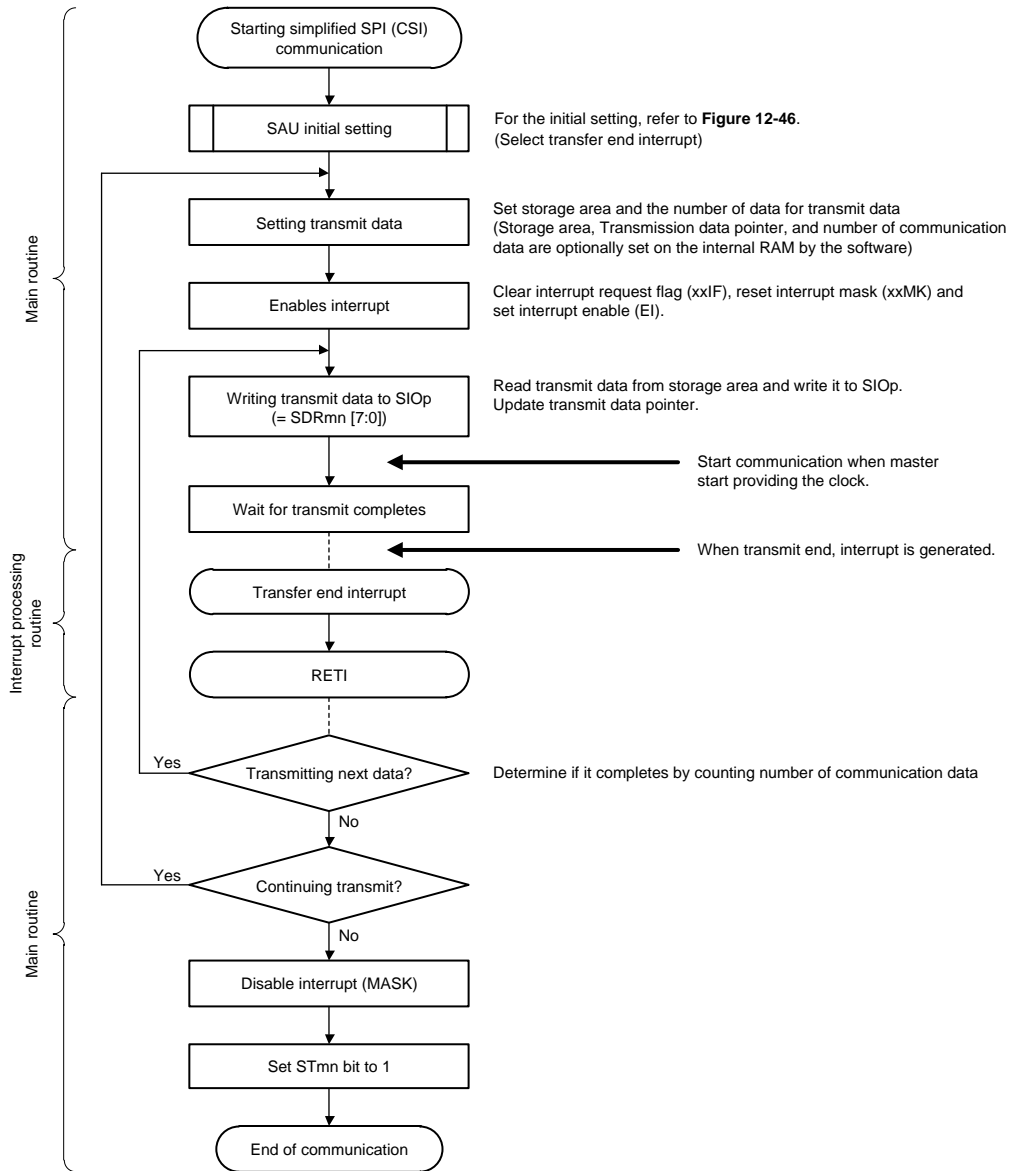
(3) Processing flow (in single-transmission mode)

Figure 12-49. Timing Chart of Slave Transmission (in Single-Transmission Mode) (Type 1: DAPmn = 0, CKPmn = 0)



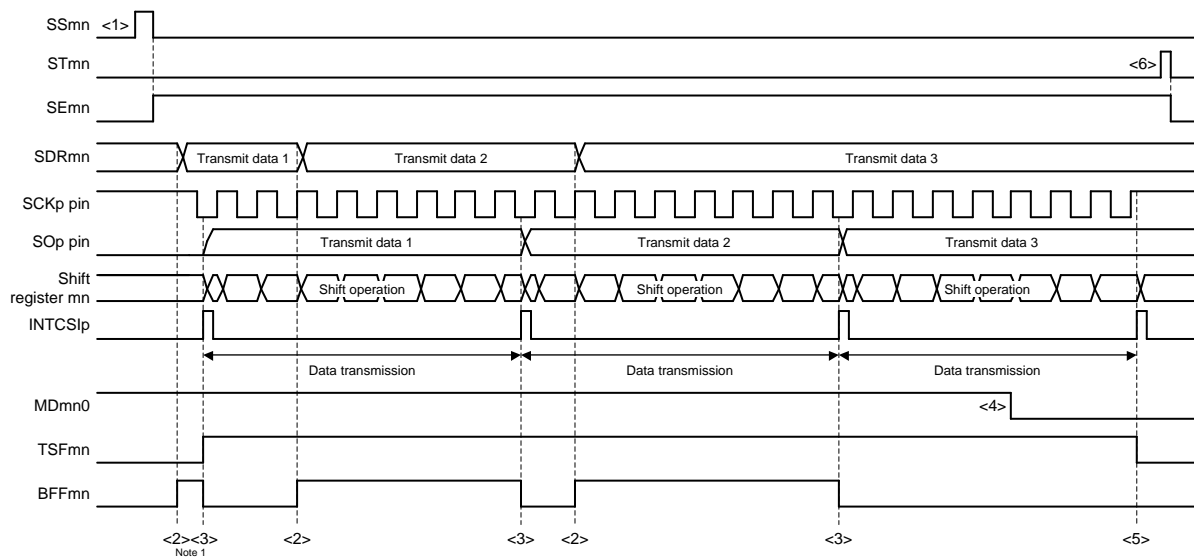
Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-50. Flowchart of Slave Transmission (in Single-Transmission Mode)



(4) Processing flow (in continuous transmission mode)

Figure 12-51. Timing Chart of Slave Transmission (in Continuous Transmission Mode) (Type 1: DAPmn = 0, CKPmn = 0)

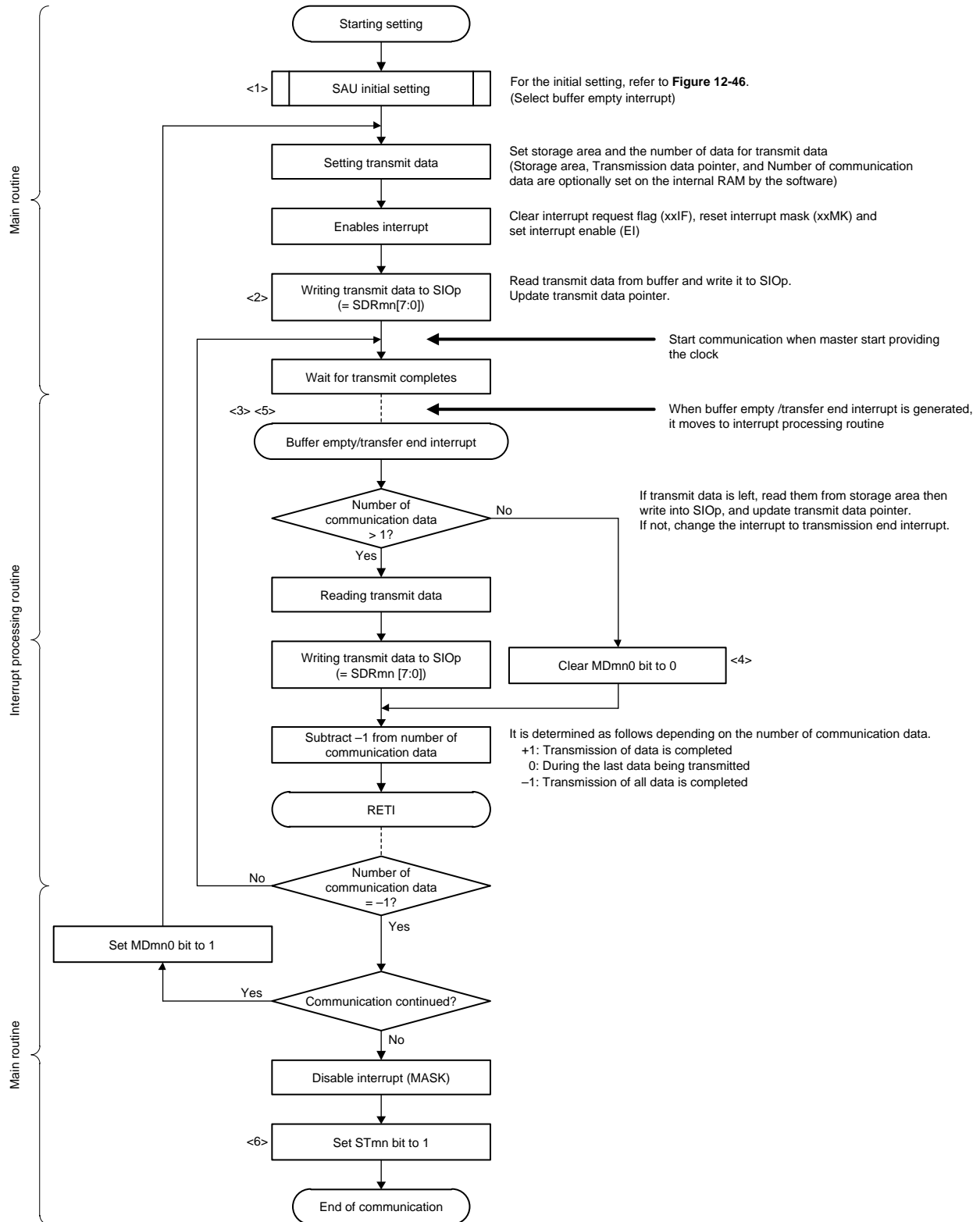


Note 1. If transmit data is written to the SDRmn register while the BFFmn bit of serial status register mn (SSRmn) is 1 (valid data is stored in serial data register mn (SDRmn)), the transmit data is overwritten.

Caution The MDmn0 bit of serial mode register mn (SMRmn) can be rewritten even during operation. However, rewrite it before transfer of the last bit is started.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-52. Flowchart of Slave Transmission (in Continuous Transmission Mode)



Remark <1> to <6> in the figure correspond to <1> to <6> in Figure 12-51 Timing Chart of Slave Transmission (in Continuous Transmission Mode) (Type 1: DAPmn = 0, CKPmn = 0).

12.5.5 Slave Reception

Slave reception is that the RL78 microcontroller receives data from another device in the state of a transfer clock being input from another device.

| Simplified SPI | CSI00 | CSI01 |
|----------------------|--|-------------------|
| Target channel | Channel 0 of SAU0 | Channel 1 of SAU0 |
| Pins used | SCK00, SI00 | SCK01, SI01 |
| Interrupt | INTCSI00 | INTCSI01 |
| | Transfer end interrupt only (Setting the buffer empty interrupt is prohibited.) | |
| Error detection flag | Overflow error detection flag (OVFmn) only | |
| Transfer data length | 7 or 8 bits | |
| Transfer rate | Max. $f_{MCK}/6$ [Hz] ^{Note 1, Note 2} | |
| Data phase | Selectable by the DAPmn bit of the SCRmn register <ul style="list-style-type: none"> • DAPmn = 0: Data input starts from the start of the operation of the serial clock. • DAPmn = 1: Data input starts half a clock cycle before the start of the serial clock operation. | |
| Clock phase | Selectable by the CKPmn bit of the SCRmn register <ul style="list-style-type: none"> • CKPmn = 0: Non-reverse • CKPmn = 1: Reverse | |
| Data direction | MSB or LSB first | |

Note 1. Because the external serial clock input to the SCK00 and SCK01 pins is sampled internally and used, the fastest transfer rate is $f_{MCK}/6$ [Hz].

Note 2. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS (T_A = -40 to +105°C, T_A = -40 to +125°C)**.

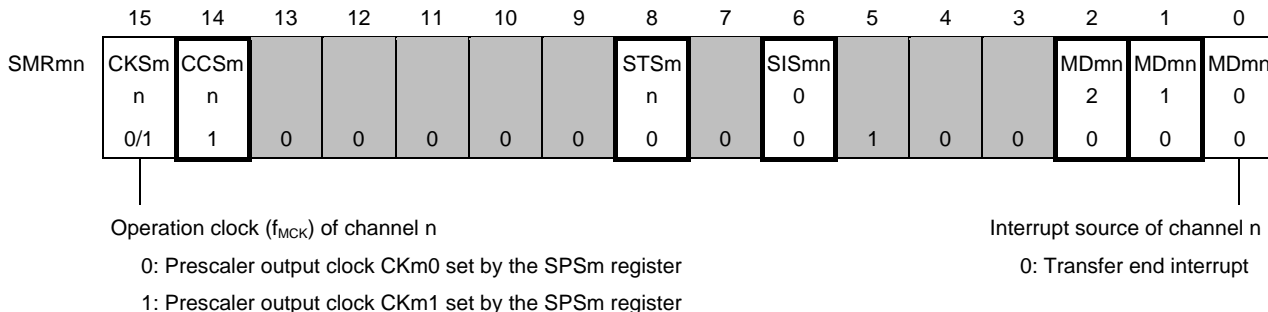
Remark 1. f_{MCK} : Operation clock frequency of target channel
 f_{SCK} : Serial clock frequency

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

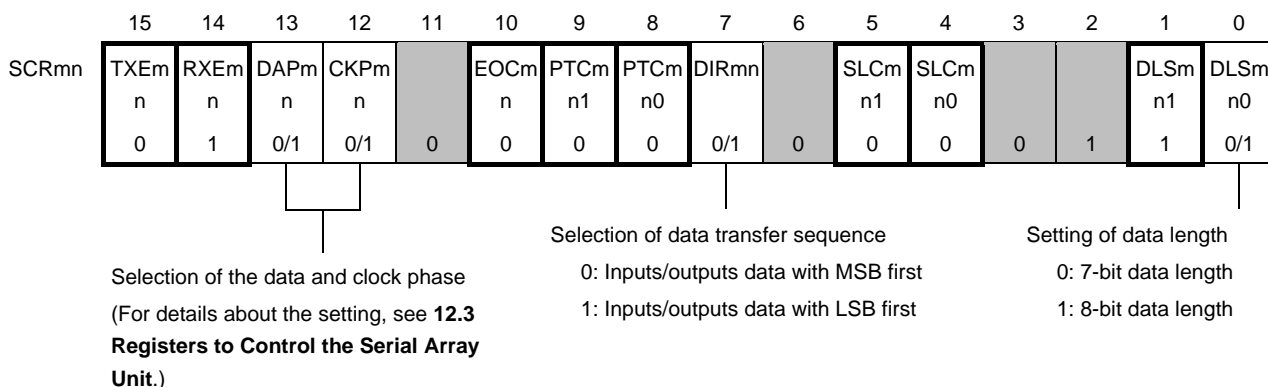
(1) Register setting

Figure 12-53. Example of Contents of Registers for Slave Reception of simplified SPI (CSI00, CSI01) (1/2)

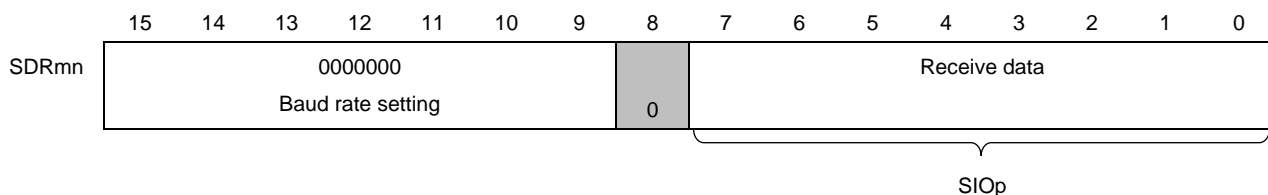
(a) Serial mode register mn (SMRmn)



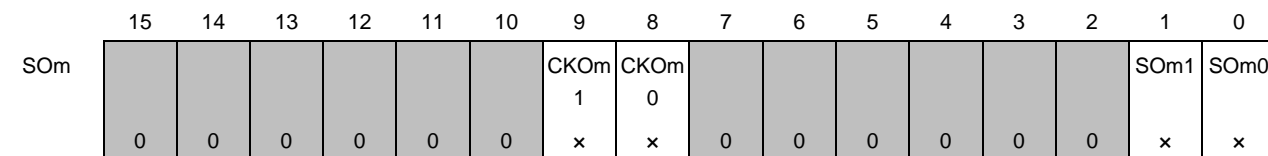
(b) Serial communication operation setting register mn (SCRmn)



(c) Serial data register mn (SDRmn) (lower 8 bits: SIOp)



(d) Serial output register m (SOM) ... This register is not used in this mode.



(Remarks are listed on the next page.)

Figure 12-53. Example of Contents of Registers for Slave Reception of simplified SPI (CSI00, CSI01) (2/2)

(e) Serial output enable register m (SOEm) ... This register is not used in this mode.

| | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOEm | | | | | | | | | | | | | | | SOEm | SOEm |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | x |

(f) Serial channel start register m (SSm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSm | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 | 0/1 |

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Remark 2. : Setting is fixed in the simplified SPI (CSI) slave reception mode,
 : Setting disabled (set to the initial value)
 x: Bit that cannot be used in this mode (set to the initial value when not used in any mode)
 0/1: Set to 0 or 1 depending on the usage of the user.

(2) Operation procedure

Figure 12-54. Initial Setting Procedure for Slave Reception

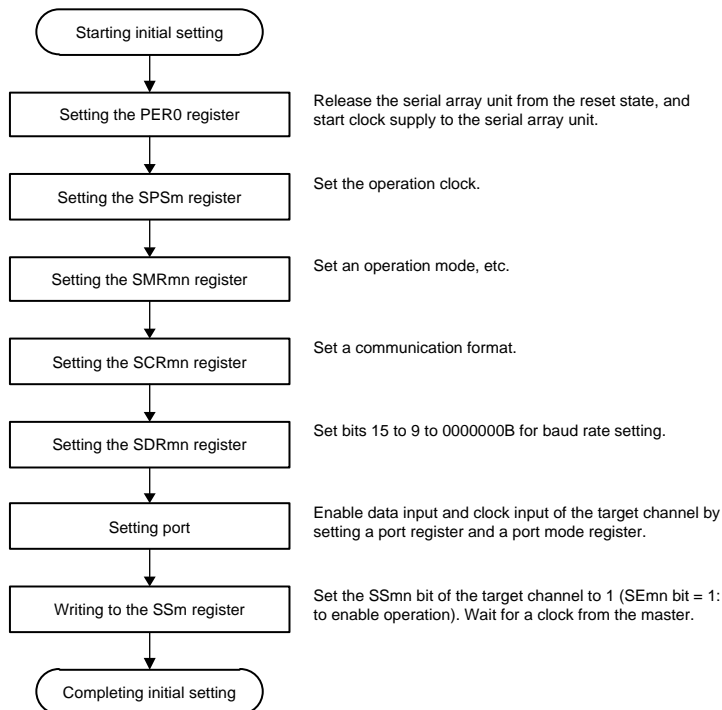


Figure 12-55. Procedure for Stopping Slave Reception

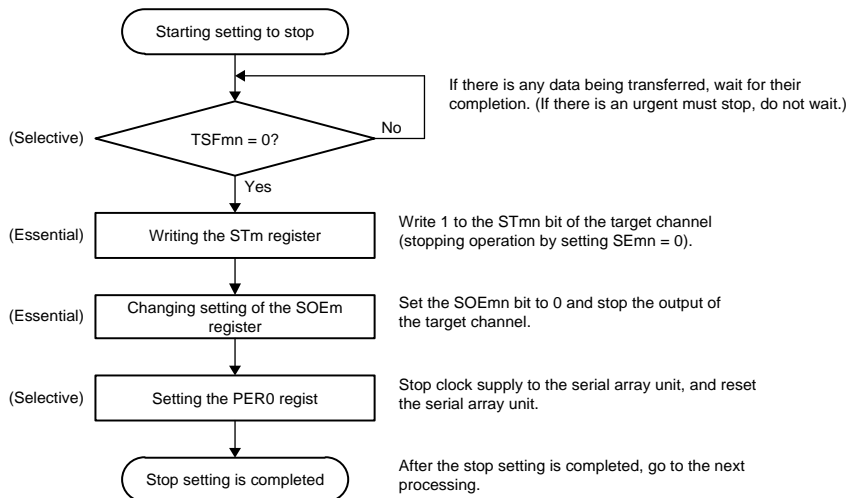
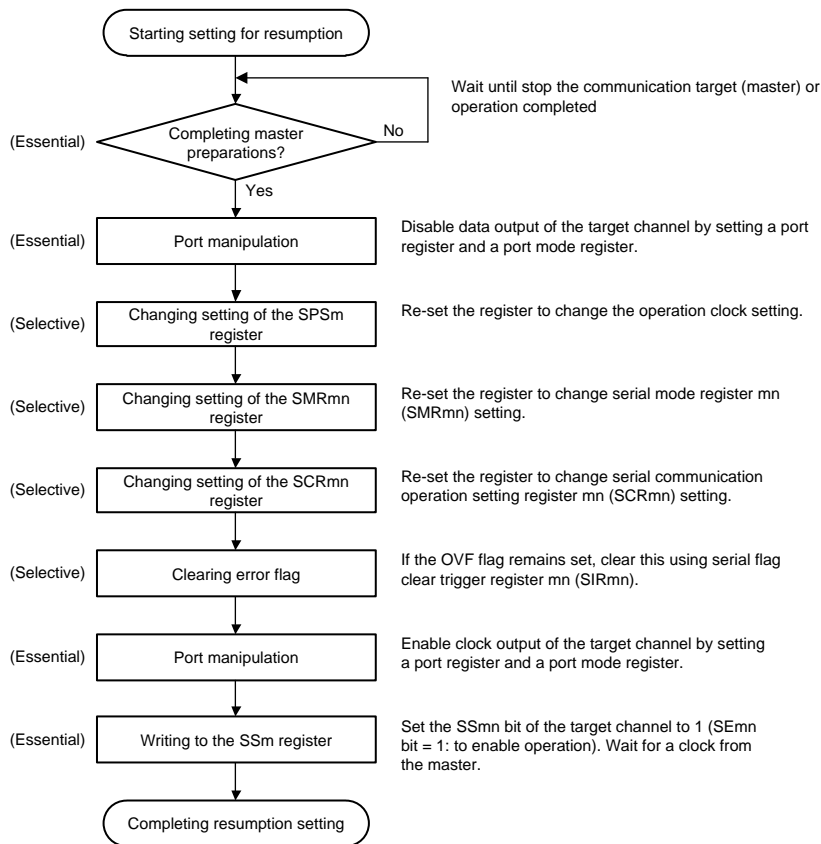


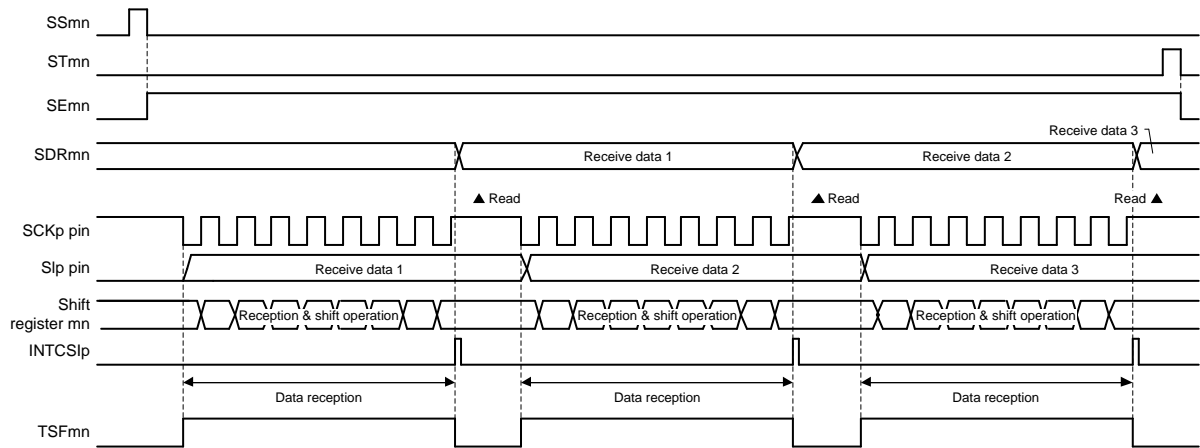
Figure 12-56. Procedure for Resuming Slave Reception



Remark If PER0 is rewritten while stopping the communication to reset the serial array unit, wait until the communication target (master) stops or communication finishes, and then perform initialization instead of restarting the communication.

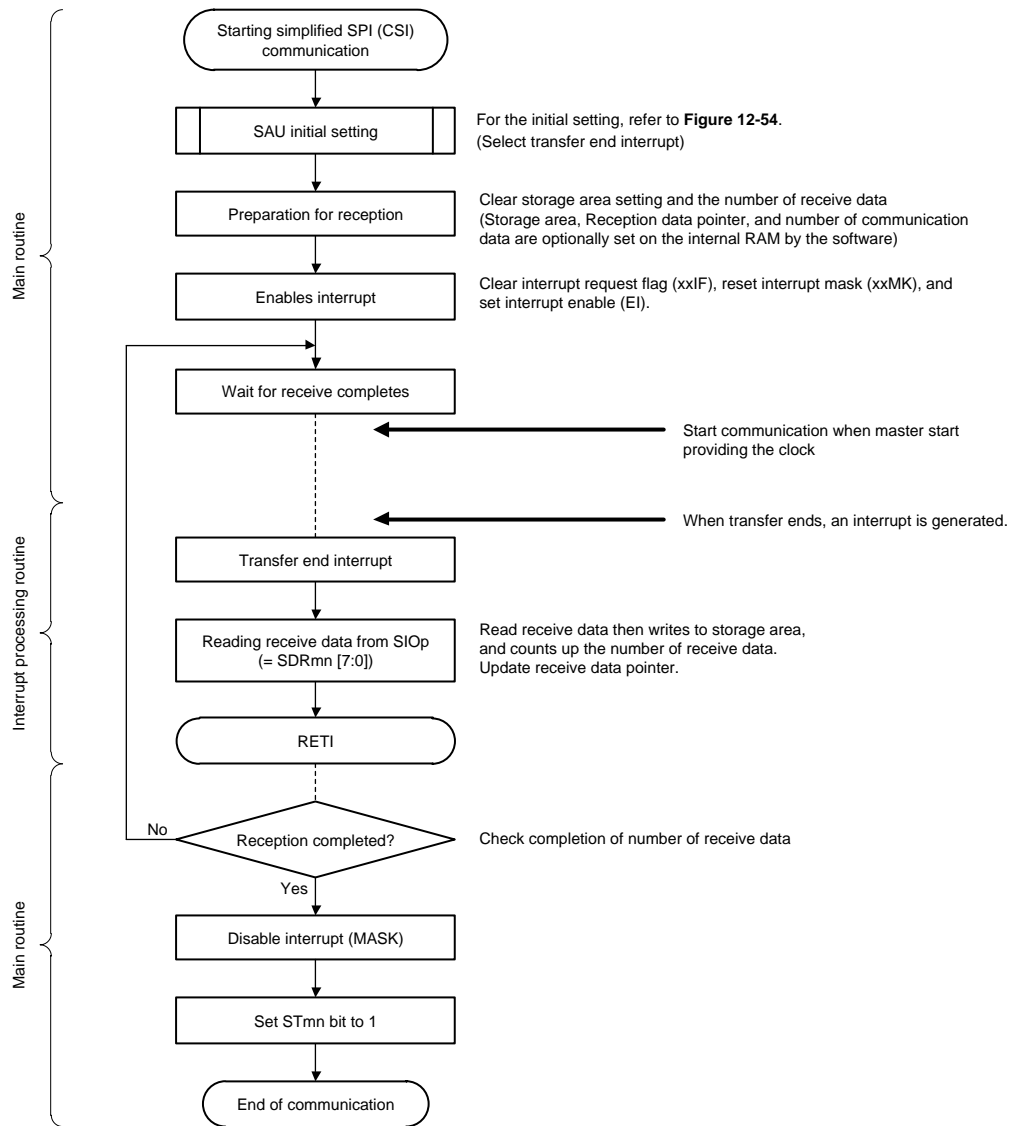
(3) Processing flow (in single-reception mode)

Figure 12-57. Timing Chart of Slave Reception (in Single-Reception Mode) (Type 1: DAPmn = 0, CKPmn = 0)



Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-58. Flowchart of Slave Reception (in Single-Reception Mode)



12.5.6 Slave Transmission/Reception

Slave transmission/reception is that the RL78 microcontroller transmits/receives data to/from another device in the state of a transfer clock being input from another device.

| Simplified SPI | CSI00 | CSI01 |
|----------------------|--|-------------------|
| Target channel | Channel 0 of SAU0 | Channel 1 of SAU0 |
| Pins used | SCK00, SI00, SO00 | SCK01, SI01, SO01 |
| Interrupt | INTCSI00 | INTCSI01 |
| | Transfer end interrupt (in single-transfer mode) or buffer empty interrupt (in continuous transfer mode) can be selected. | |
| Error detection flag | Overrun error detection flag (OVFmn) only | |
| Transfer data length | 7 or 8 bits | |
| Transfer rate | Max. $f_{MCK}/6$ [Hz] ^{Note 1, Note 2} | |
| Data phase | Selectable by the DAPmn bit of the SCRmn register <ul style="list-style-type: none"> • DAPmn = 0: Data I/O starts at the start of the operation of the serial clock. • DAPmn = 1: Data I/O starts half a clock cycle before the start of the serial clock operation. | |
| Clock phase | Selectable by the CKPmn bit of the SCRmn register <ul style="list-style-type: none"> • CKPmn = 0: Non-reverse • CKPmn = 1: Reverse | |
| Data direction | MSB or LSB first | |

Note 1. Because the external serial clock input to the SCK00 and SCK01 pins is sampled internally and used, the fastest transfer rate is $f_{MCK}/6$ [Hz].

Note 2. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS (T_A = -40 to +105°C, T_A = -40 to +125°C)**.

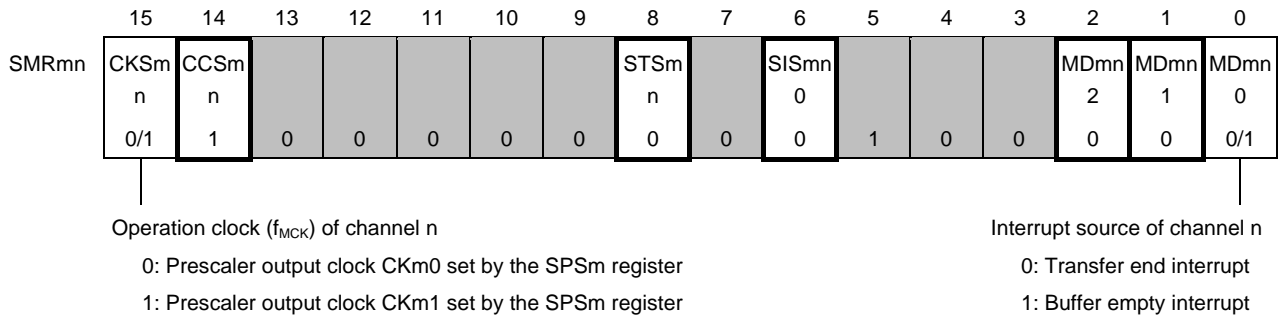
Remark 1. f_{MCK} : Operation clock frequency of target channel
 f_{SCK} : Serial clock frequency

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

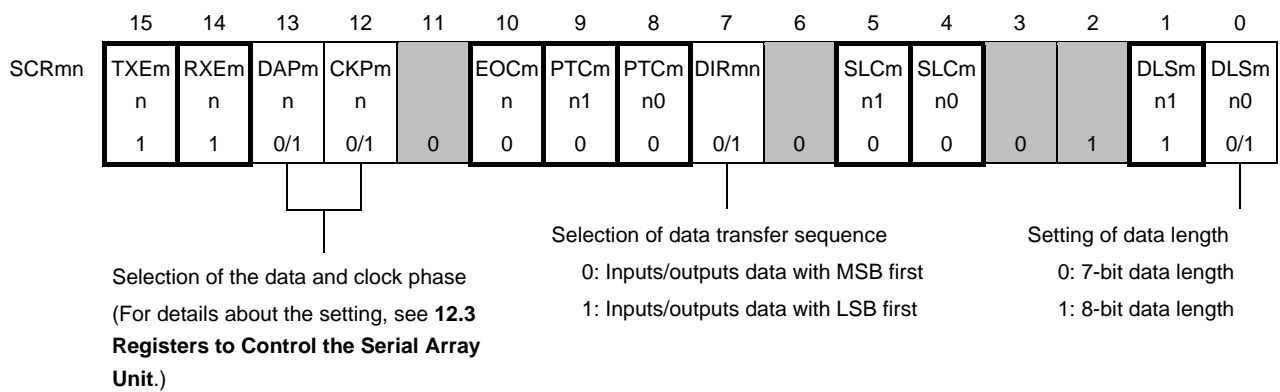
(1) Register setting

Figure 12-59. Example of Contents of Registers for Slave Transmission/Reception of simplified SPI (CSI00, CSI01) (1/2)

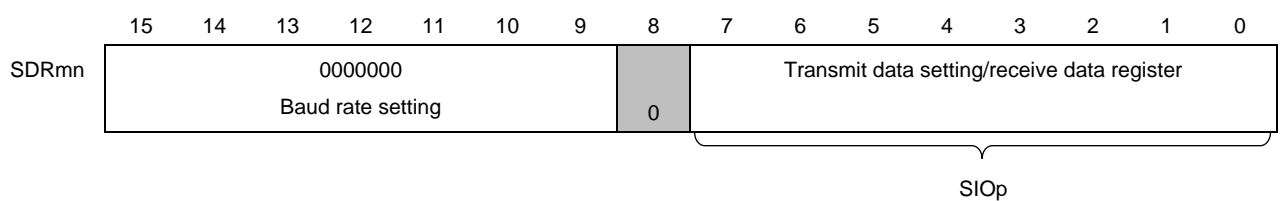
(a) Serial mode register mn (SMRmn)



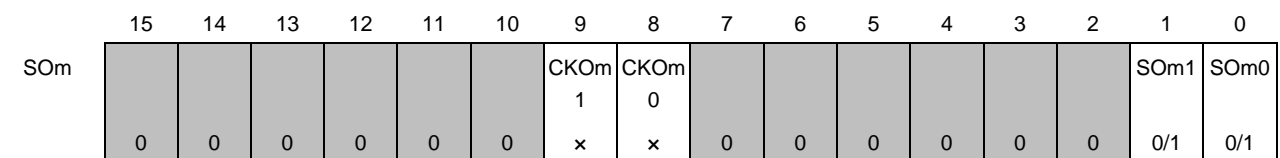
(b) Serial communication operation setting register mn (SCRmn)



(c) Serial data register mn (SDRmn) (lower 8 bits: SIOp)



(d) Serial output register m (SOM) ... Set only the bit of the target channel.



(Caution and Remarks are listed on the next page.)

Figure 12-59. Example of Contents of Registers for Slave Transmission/Reception of simplified SPI (CSI00, CSI01) (2/2)

(e) Serial output enable register m (SOEm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | | |
| SOEm | | | | | | | | | | | | | | | | | SOEm | SOEm |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| | | | | | | | | | | | | | | | | | 0/1 | 0/1 |

(f) Serial channel start register m (SSm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | | |
| SSm | | | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 | 0/1 |
| | | | | | | | | | | | | | | | | | 0/1 | 0/1 |

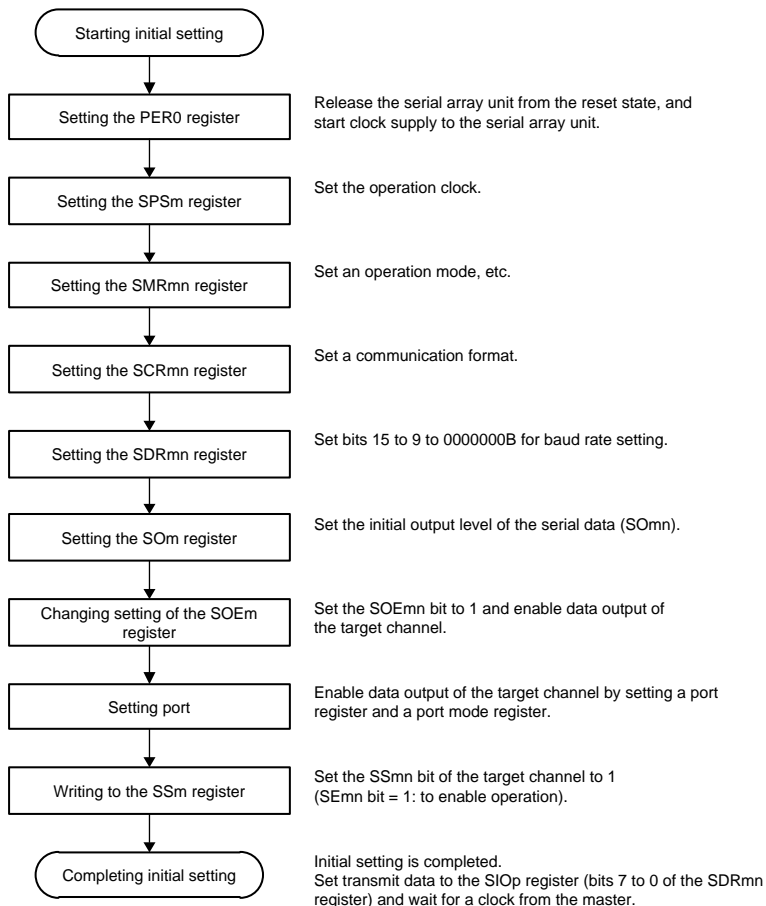
Caution Be sure to set transmit data to the SIOp register before the clock from the master is started.

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Remark 2. : Setting is fixed in the simplified SPI (CSI) slave transmission/reception mode,
 : Setting disabled (set to the initial value)
 x: Bit that cannot be used in this mode (set to the initial value when not used in any mode)
 0/1: Set to 0 or 1 depending on the usage of the user.

(2) Operation procedure

Figure 12-60. Initial Setting Procedure for Slave Transmission/Reception



Caution Be sure to set transmit data to the SIOp register before the clock from the master is started.

Figure 12-61. Procedure for Stopping Slave Transmission/Reception

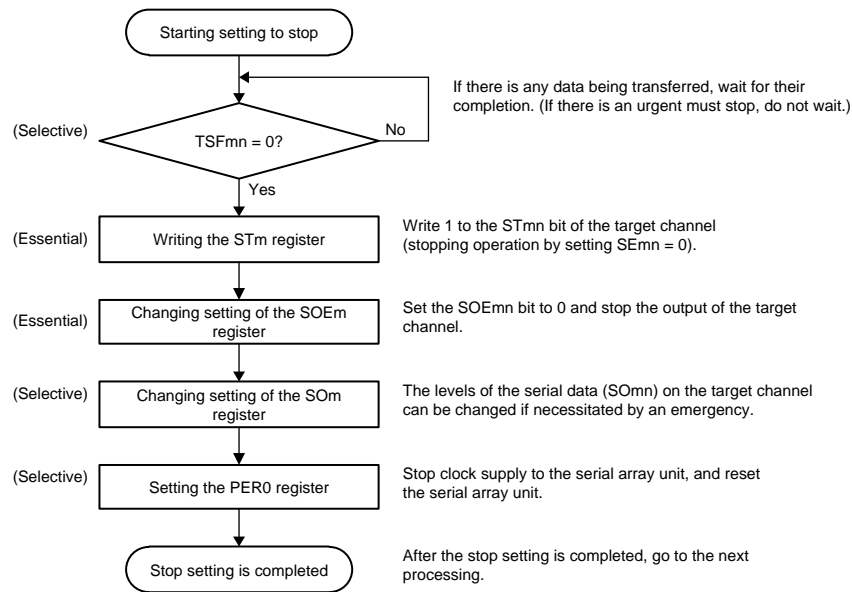
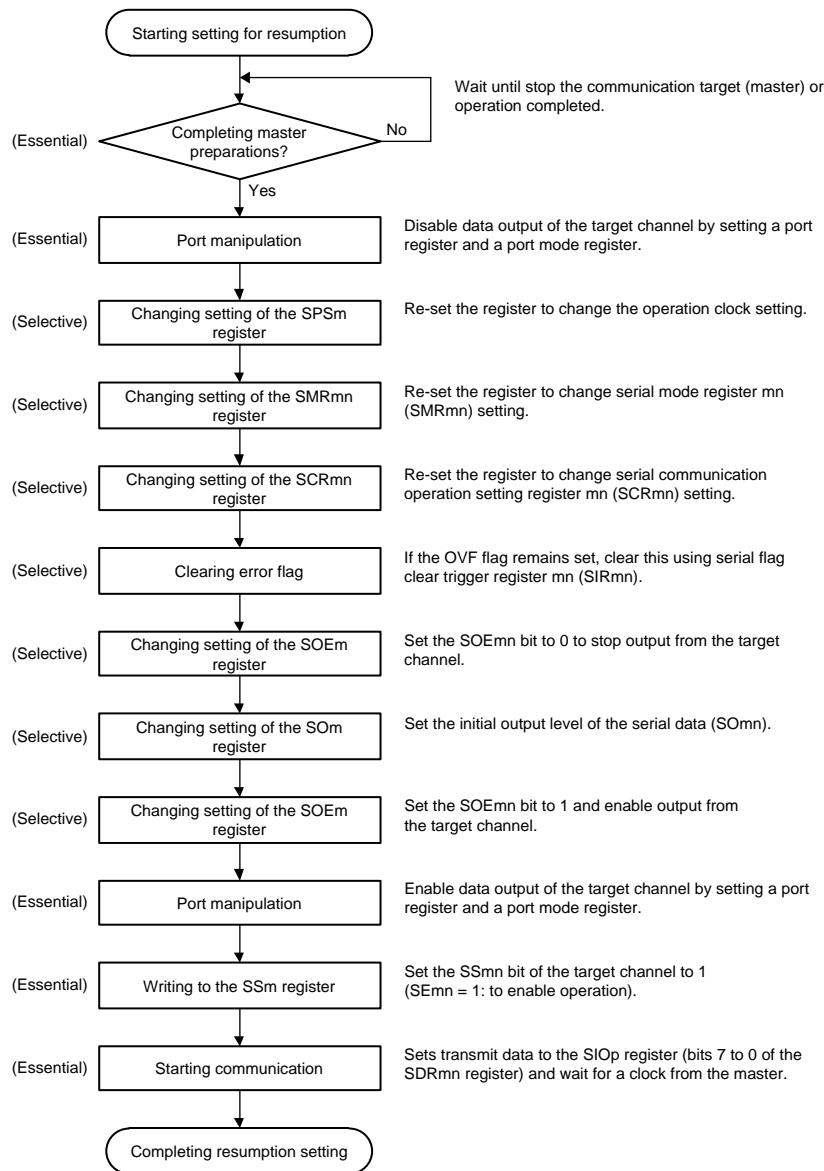


Figure 12-62. Procedure for Resuming Slave Transmission/Reception

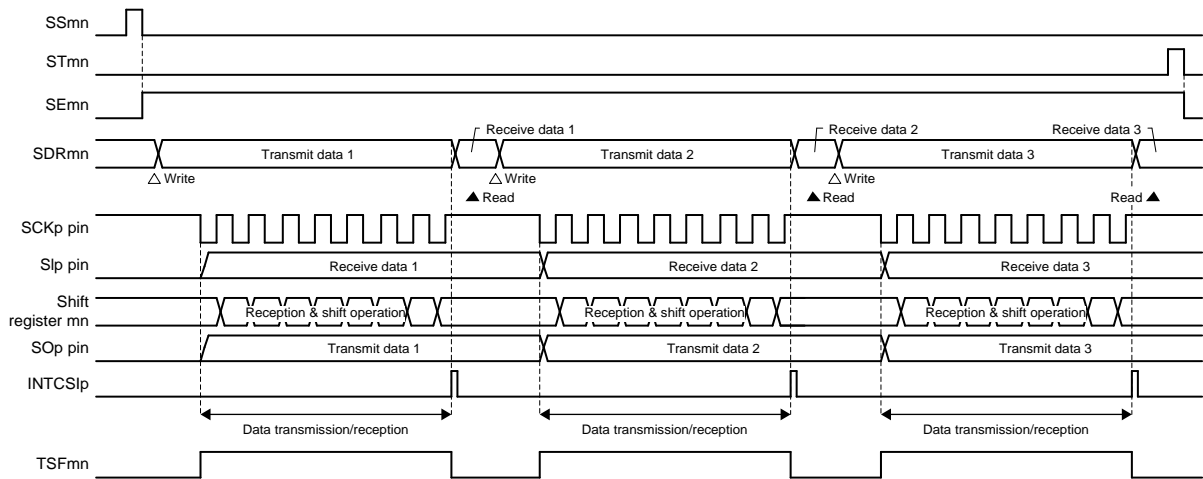


Caution 1. Be sure to set transmit data to the SIOp register before the clock from the master is started.

Caution 2. If PER0 is rewritten while stopping the communication to reset the serial array unit, wait until the communication target (master) stops or communication finishes, and then perform initialization instead of restarting the communication.

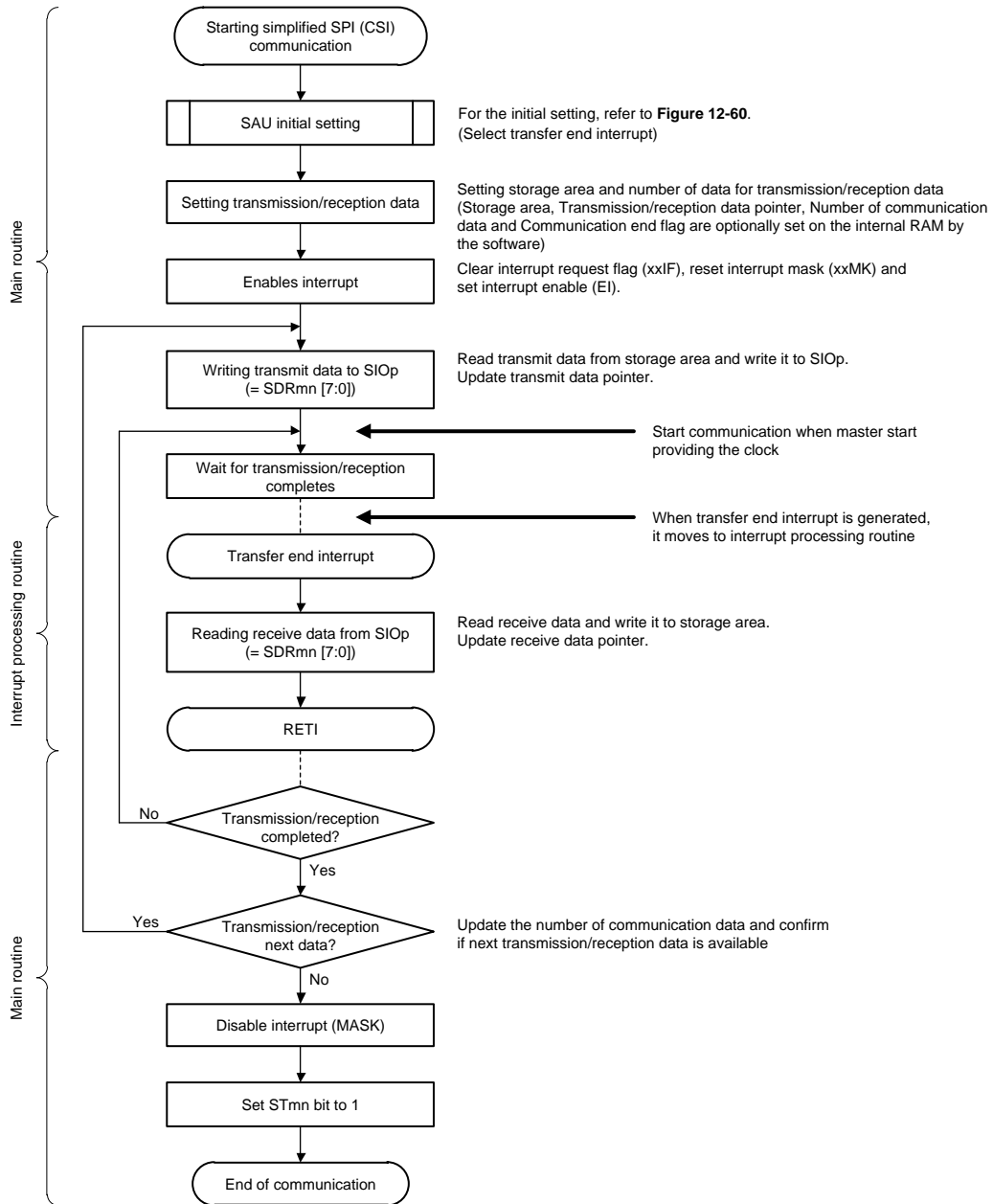
(3) Processing flow (in single-transmission/reception mode)

Figure 12-63. Timing Chart of Slave Transmission/Reception (in Single-Transmission/Reception Mode) (Type 1: DAPmn = 0, CKPmn = 0)



Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

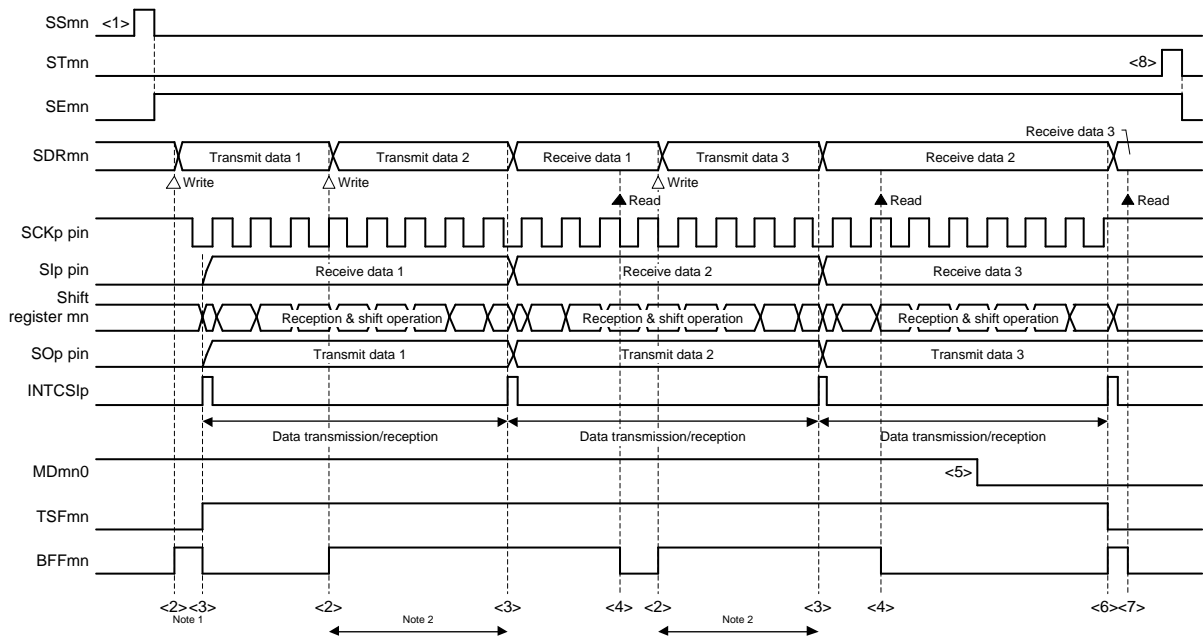
Figure 12-64. Flowchart of Slave Transmission/Reception (in Single-Transmission/Reception Mode)



Caution Be sure to set transmit data to the SIOp register before the clock from the master is started.

(4) Processing flow (in continuous transmission/reception mode)

Figure 12-65. Timing Chart of Slave Transmission/Reception (in Continuous Transmission/Reception Mode) (Type 1: DAPmn = 0, CKPmn = 0)



Note 1. If transmit data is written to the SDRmn register while the BFFmn bit of serial status register mn (SSRmn) is 1 (valid data is stored in serial data register mn (SDRmn)), the transmit data is overwritten.

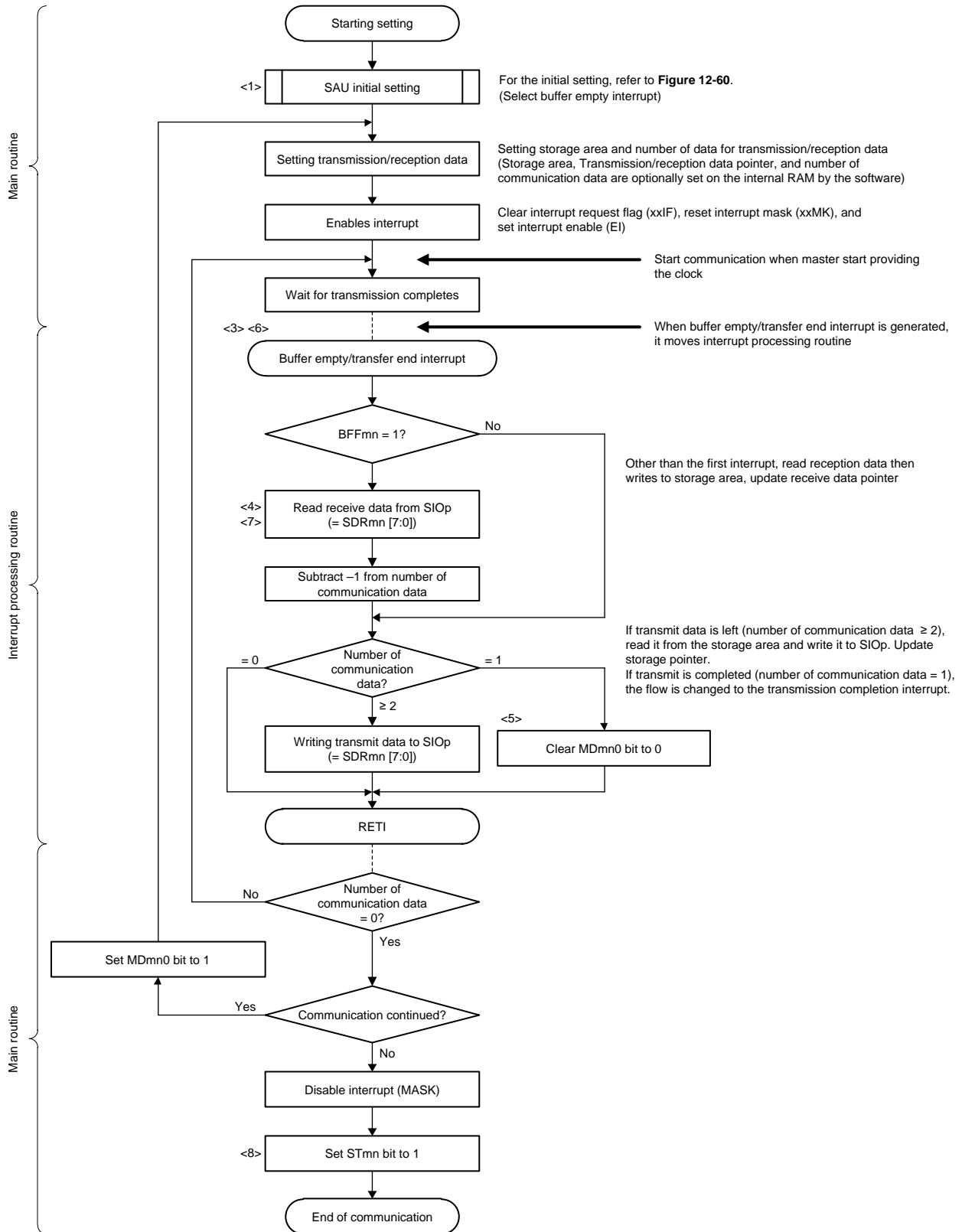
Note 2. The transmit data can be read by reading the SDRmn register during this period. At this time, the transfer operation is not affected.

Caution The MDmn0 bit of serial mode register mn (SMRmn) can be rewritten even during operation. However, rewrite it before transfer of the last bit is started, so that it has been rewritten before the transfer end interrupt of the last transmit data.

Remark 1. <1> to <8> in the figure correspond to <1> to <8> in **Figure 12-66 Flowchart of Slave Transmission/Reception (in Continuous Transmission/Reception Mode)**.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), p: CSI number (p = 00, 01), mn = 00, 01

Figure 12-66. Flowchart of Slave Transmission/Reception (in Continuous Transmission/Reception Mode)



(Caution and Remark are listed on the next page.)

Caution Be sure to set transmit data to the SIOp register before the clock from the master is started.

Remark <1> to <8> in the figure correspond to <1> to <8> in **Figure 12-65 Timing Chart of Slave Transmission/Reception (in Continuous Transmission/Reception Mode) (Type 1: DAPmn = 0, CKPmn = 0)**.

12.5.7 Calculating Transfer Clock Frequency

The transfer clock frequency for simplified SPI (CSI00, CSI01) communication can be calculated by the following expressions.

(1) Master

$$(\text{Transfer clock frequency}) = \{\text{Operation clock (} f_{\text{MCK}} \text{) frequency of target channel}\} \div (\text{SDRmn}[15:9] + 1) \div 2[\text{Hz}]$$

(2) Slave

$$(\text{Transfer clock frequency}) = \{\text{Frequency of serial clock (SCK) supplied by master}\}^{\text{Note 1}} \quad [\text{Hz}]$$

Note 1. The permissible maximum transfer clock frequency is $f_{\text{MCK}}/6$.

Remark The value of SDRmn[15:9] is the value of bits 15 to 9 of serial data register mn (SDRmn) (0000000B to 1111111B) and therefore is 0 to 127.

The operation clock (f_{MCK}) is determined by serial clock select register m (SPSm) and bit 15 (CKSmn) of serial mode register mn (SMRmn).

Table 12-2. Selection of Operation Clock For Simplified SPI

| SMRmn Register | SPSm Register | | | | | | | | Operation Clock (f _{CLK}) ^{Note 1} | |
|------------------|---------------|---------|---------|---------|---------|---------|---------|---------|---|---------------------------|
| | CKSmn | PRS m13 | PRS m12 | PRS m11 | PRS m10 | PRS m03 | PRS m02 | PRS m01 | PRS m00 | f _{CLK} = 16 MHz |
| 0 | X | X | X | X | 0 | 0 | 0 | 0 | f _{CLK} | 16 MHz |
| | X | X | X | X | 0 | 0 | 0 | 1 | f _{CLK} /2 | 8 MHz |
| | X | X | X | X | 0 | 0 | 1 | 0 | f _{CLK} /2 ² | 4 MHz |
| | X | X | X | X | 0 | 0 | 1 | 1 | f _{CLK} /2 ³ | 2 MHz |
| | X | X | X | X | 0 | 1 | 0 | 0 | f _{CLK} /2 ⁴ | 1 MHz |
| | X | X | X | X | 0 | 1 | 0 | 1 | f _{CLK} /2 ⁵ | 500 kHz |
| | X | X | X | X | 0 | 1 | 1 | 0 | f _{CLK} /2 ⁶ | 250 kHz |
| | X | X | X | X | 0 | 1 | 1 | 1 | f _{CLK} /2 ⁷ | 125 kHz |
| | X | X | X | X | 1 | 0 | 0 | 0 | f _{CLK} /2 ⁸ | 62.5 kHz |
| | X | X | X | X | 1 | 0 | 0 | 1 | f _{CLK} /2 ⁹ | 31.25 kHz |
| | X | X | X | X | 1 | 0 | 1 | 0 | f _{CLK} /2 ¹⁰ | 15.63 kHz |
| | X | X | X | X | 1 | 0 | 1 | 1 | f _{CLK} /2 ¹¹ | 7.81 kHz |
| | X | X | X | X | 1 | 1 | 0 | 0 | f _{CLK} /2 ¹² | 3.91 kHz |
| | X | X | X | X | 1 | 1 | 0 | 1 | f _{CLK} /2 ¹³ | 1.95 kHz |
| | X | X | X | X | 1 | 1 | 1 | 0 | f _{CLK} /2 ¹⁴ | 977 Hz |
| | X | X | X | X | 1 | 1 | 1 | 1 | f _{CLK} /2 ¹⁵ | 488 Hz |
| 1 | 0 | 0 | 0 | 0 | X | X | X | X | f _{CLK} | 16 MHz |
| | 0 | 0 | 0 | 1 | X | X | X | X | f _{CLK} /2 | 8 MHz |
| | 0 | 0 | 1 | 0 | X | X | X | X | f _{CLK} /2 ² | 4 MHz |
| | 0 | 0 | 1 | 1 | X | X | X | X | f _{CLK} /2 ³ | 2 MHz |
| | 0 | 1 | 0 | 0 | X | X | X | X | f _{CLK} /2 ⁴ | 1 MHz |
| | 0 | 1 | 0 | 1 | X | X | X | X | f _{CLK} /2 ⁵ | 500 kHz |
| | 0 | 1 | 1 | 0 | X | X | X | X | f _{CLK} /2 ⁶ | 250 kHz |
| | 0 | 1 | 1 | 1 | X | X | X | X | f _{CLK} /2 ⁷ | 125 kHz |
| | 1 | 0 | 0 | 0 | X | X | X | X | f _{CLK} /2 ⁸ | 62.5 kHz |
| | 1 | 0 | 0 | 1 | X | X | X | X | f _{CLK} /2 ⁹ | 31.25 kHz |
| | 1 | 0 | 1 | 0 | X | X | X | X | f _{CLK} /2 ¹⁰ | 15.63 kHz |
| | 1 | 0 | 1 | 1 | X | X | X | X | f _{CLK} /2 ¹¹ | 7.81 kHz |
| | 1 | 1 | 0 | 0 | X | X | X | X | f _{CLK} /2 ¹² | 3.91 kHz |
| | 1 | 1 | 0 | 1 | X | X | X | X | f _{CLK} /2 ¹³ | 1.95 kHz |
| | 1 | 1 | 1 | 0 | X | X | X | X | f _{CLK} /2 ¹⁴ | 977 Hz |
| | 1 | 1 | 1 | 1 | X | X | X | X | f _{CLK} /2 ¹⁵ | 488 Hz |
| Other than above | | | | | | | | | Setting prohibited | |

(Note 1 and Remarks are listed on the next page.)

Note 1. When changing the clock selected for f_{CLK} (by changing the system clock control register (CKC) value), do so after having stopped (serial channel stop register m (STm) = 000FH) the operation of the serial array unit (SAU).

Remark 1. X: Don't care

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

12.5.8 Procedure for Processing Errors that Occurred During Simplified SPI (CSI00, CSI01) Communication

The procedure for processing errors that occurred during simplified SPI (CSI00, CSI01) communication is described in Figure 12-67.

Figure 12-67. Processing Procedure in Case of Overrun Error

| Software Manipulation | State of the Hardware | Remark |
|--|---|---|
| Reads serial data register mn (SDRmn). | → The BFFmn bit of the SSRmn register is set to 0 and channel n is enabled to receive data. | This is to prevent an overrun error if the next reception is completed during error processing. |
| Reads serial status register mn (SSRmn). | | The error type is identified and the read value is used to clear the error flag. |
| Writes 1 to serial flag clear trigger register mn (SIRmn). | → The error flag is cleared. | The error only during reading can be cleared, by writing the value read from the SSRmn register to the SIRmn register without modification. |

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

12.6 Operation of UART (UART0) Communication

This is a start-stop synchronization communication function using two lines: serial data transmission (TxD) and serial data reception (RxD) lines. By using these two communication lines, each data frame, which consist of a start bit, data, parity bit, and stop bit, is transferred asynchronously (using the internal baud rate) between the microcontroller and the other communication party. Full-duplex asynchronous communication UART communication can be performed by using a channel dedicated to transmission (even-numbered channel) and a channel dedicated to reception (odd-numbered channel).

[Data transmission/reception]

- Data length of 7, 8, or 9 bits
- MSB/LSB first selectable
- Level setting of transmit/receive data (selecting whether to reverse the level)
- Parity bit appending and parity check functions
- Stop bit appending, stop bit check function

[Interrupt function]

- Transfer end interrupt/buffer empty interrupt
- Error interrupt in case of framing error, parity error, or overrun error

[Error detection flag]

- Framing error, parity error, or overrun error

The ISC register can be used to set up the input signal on the RxD0 pin of UART0 as an external interrupt input or as a timer input for the timer array unit. The input pulse interval measurement mode of the timer array unit can then be used to measure the width at the baud rate of the other party in communications and make the required adjustments in response.

UART0 uses channels 0 and 1 of SAU0.

● 10- and 8-pin products

| Unit | Channel | Used as simplified SPI (CSI) | Used as UART | Used as Simplified I ² C |
|------|---------|------------------------------|--------------|-------------------------------------|
| 0 | 0 | CSI00 | UART0 | IIC00 |
| | 1 | — | | — |

● 20- and 16-pin products

| Unit | Channel | Used as simplified SPI (CSI) | Used as UART | Used as Simplified I ² C |
|------|---------|------------------------------|--------------|-------------------------------------|
| 0 | 0 | CSI00 | UART0 | IIC00 |
| | 1 | CSI01 | | IIC01 |

Select any function for each channel. Only the selected function is possible. If UART0 is selected for channels 0 and 1 of unit 0, for example, these channels cannot be used for CSI00 and CSI01

Caution When using a serial array unit for UART, both the transmitter side (even-numbered channel) and the receiver side (odd-numbered channel) can only be used for UART.

UART performs the following two types of communication operations.

- UART transmission (See 12.6.1)
- UART reception (See 12.6.2)

12.6.1 UART Transmission

UART transmission is an operation to transmit data from the RL78 microcontroller to another device asynchronously (start-stop synchronization).

Of two channels used for UART, the even channel is used for UART transmission.

| UART | UART0 |
|---------------------------------|---|
| Target channel | Channel 0 of SAU0 |
| Pins used | TxD0 |
| Interrupt | INTST0 Transfer end interrupt (in single-transfer mode) or buffer empty interrupt (in continuous transfer mode) can be selected. |
| Error detection flag | None |
| Transfer data length | 7, 8, or 9 bits |
| Transfer rate ^{Note 1} | Max. $f_{MCK}/6$ [bps] (SDRmn[15:9] = 2 or more), Min. $f_{CLK}/(2 \times 2^{15} \times 128)$ [bps] |
| Data phase | Non-reverse output (default: high level) Reverse output (default: low level) |
| Parity bit | The following selectable <ul style="list-style-type: none"> • No parity bit • Appending 0 parity • Appending even parity • Appending odd parity |
| Stop bit | The following selectable <ul style="list-style-type: none"> • Appending 1 bit • Appending 2 bit |
| Data direction | MSB or LSB first |

Note 1. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS (T_A = -40 to +105°C, T_A = -40 to +125°C)**.

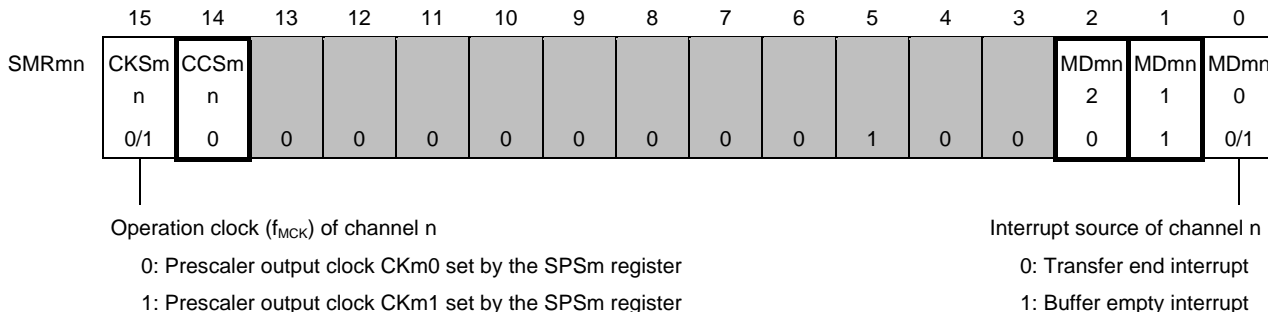
Remark 1. f_{MCK} : Operation clock frequency of target channel
 f_{CLK} : System clock frequency

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0), mn = 00

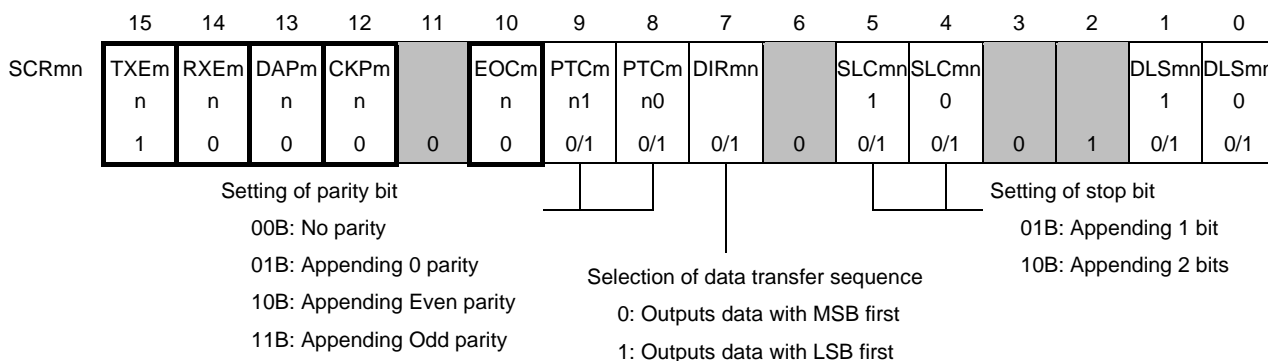
(1) Register setting

Figure 12-68. Example of Contents of Registers for UART Transmission of UART (UART0) (1/2)

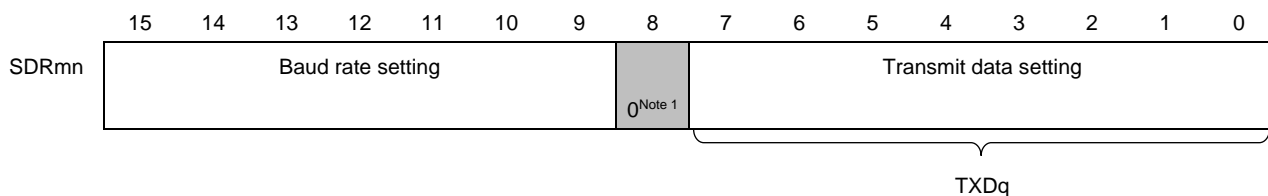
(a) Serial mode register mn (SMRmn)



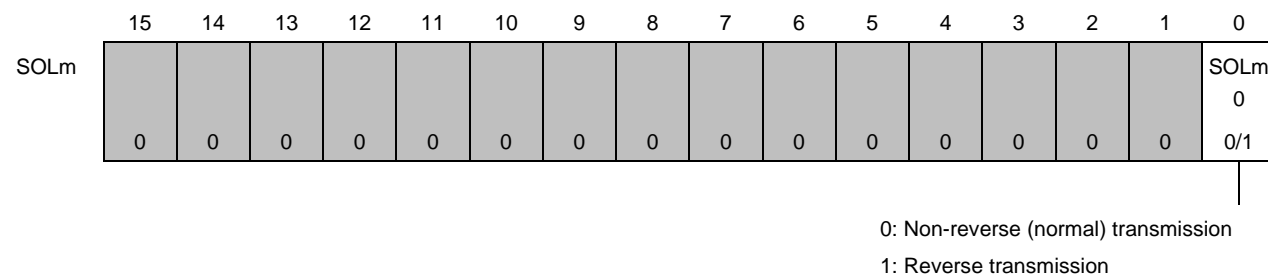
(b) Serial communication operation setting register mn (SCRmn)



(c) Serial data register mn (SDRmn) (lower 8 bits: TXDq)



(d) Serial output level register m (SOLm) ... Set only the bit of the target channel.



(Note 1, Note 2, and Remarks are listed on the next page.)

Figure 12-68. Example of Contents of Registers for UART Transmission of UART (UART0) (2/2)

(e) Serial output register m (SOm) ... Set only the bit of the target channel.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|------|------|---|---|---|---|---|---|------|-----------------------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOm | | | | | | | CKOm | CKOm | | | | | | | SOM1 | SOM0 |
| | | | | | | | 1 | 0 | | | | | | | x | 0/1 ^{Note 2} |
| | 0 | 0 | 0 | 0 | 0 | 0 | x | x | 0 | 0 | 0 | 0 | 0 | 0 | x | 0/1 ^{Note 2} |

0: Serial data output value is 0
1: Serial data output value is 1

(f) Serial output enable register m (SOEm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOEm | | | | | | | | | | | | | | | SOEm | SOEm |
| | | | | | | | | | | | | | | | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | 0/1 |

(g) Serial channel start register m (SSm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSm | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | | | | | | | | | | | | | | | x | 0/1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | 0/1 |

Note 1. When UART0 performs 9-bit communication, bits 0 to 8 of the SDRm0 register are used as the transmission data specification area.

Note 2. Before transmission is started, be sure to set to 1 when the SOLmn bit of the target channel is set to 0, and set to 0 when the SOLmn bit of the target channel is set to 1. The value varies depending on the communication data during communication operation.

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0), q: UART number (q = 0), mn = 00

Remark 2. : Setting is fixed in the UART transmission mode,
 : Setting disabled (set to the initial value)
 x: Bit that cannot be used in this mode (set to the initial value when not used in any mode)
 0/1: Set to 0 or 1 depending on the usage of the user.

(2) Operation procedure

Figure 12-69. Initial Setting Procedure for UART Transmission

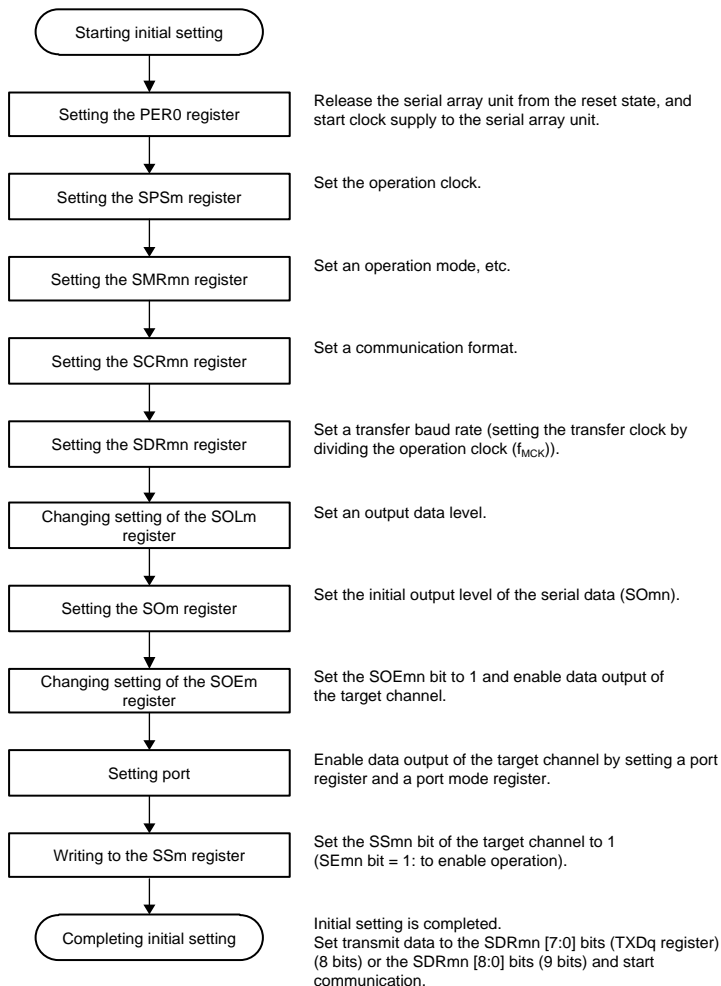


Figure 12-70. Procedure for Stopping UART Transmission

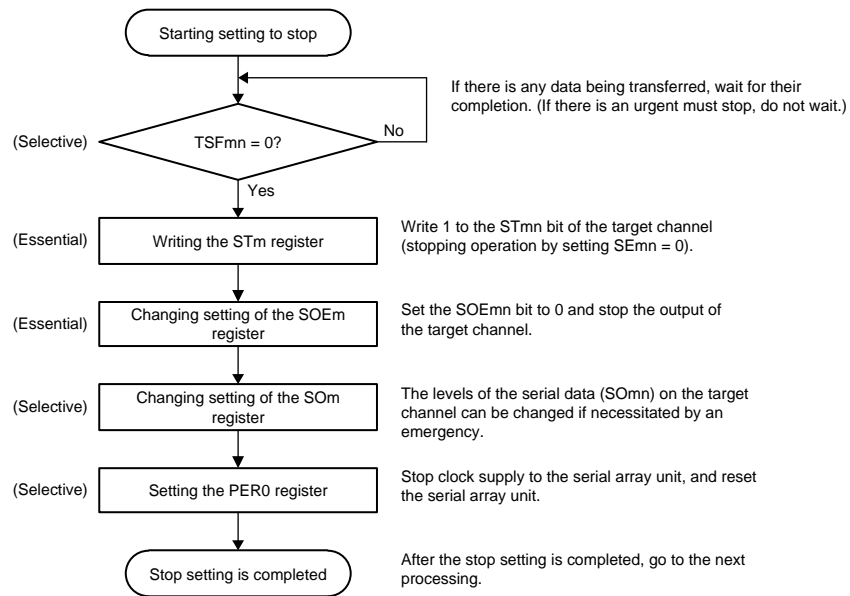
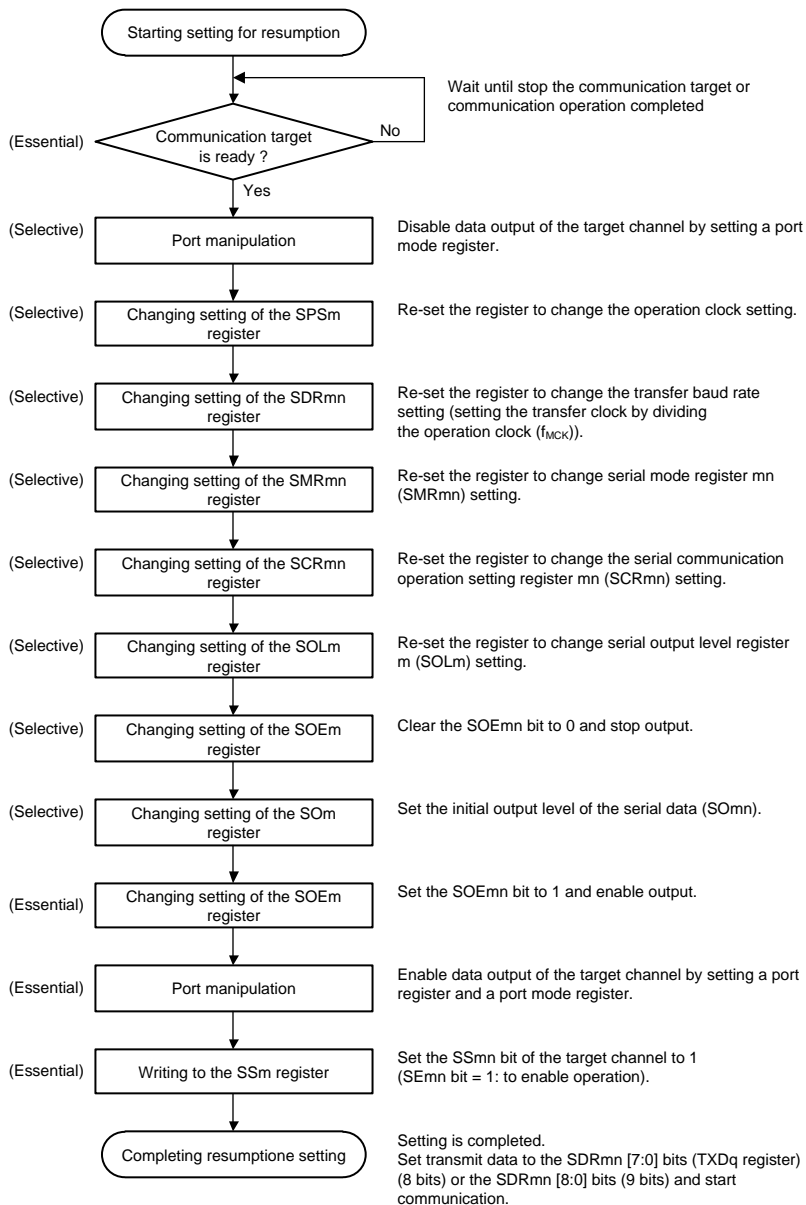


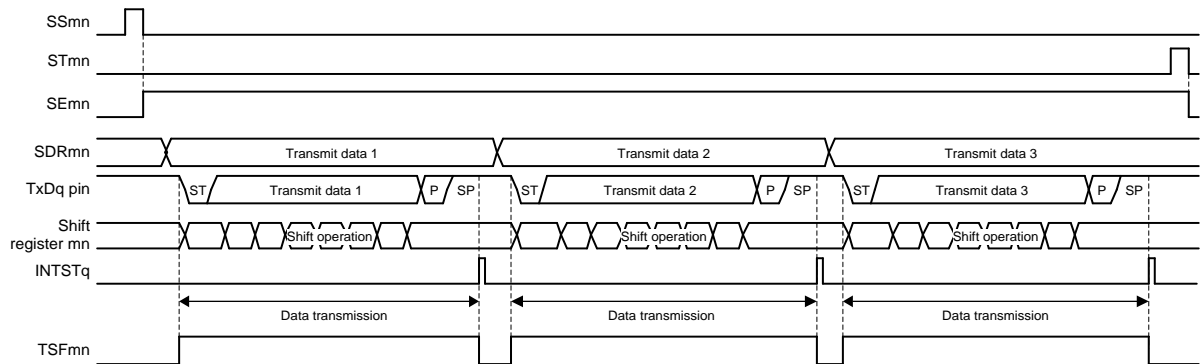
Figure 12-71. Procedure for Resuming UART Transmission



Remark If PER0 is rewritten while stopping the communication to reset the serial array unit, wait until the communication target stops or communication finishes, and then perform initialization instead of restarting the communication.

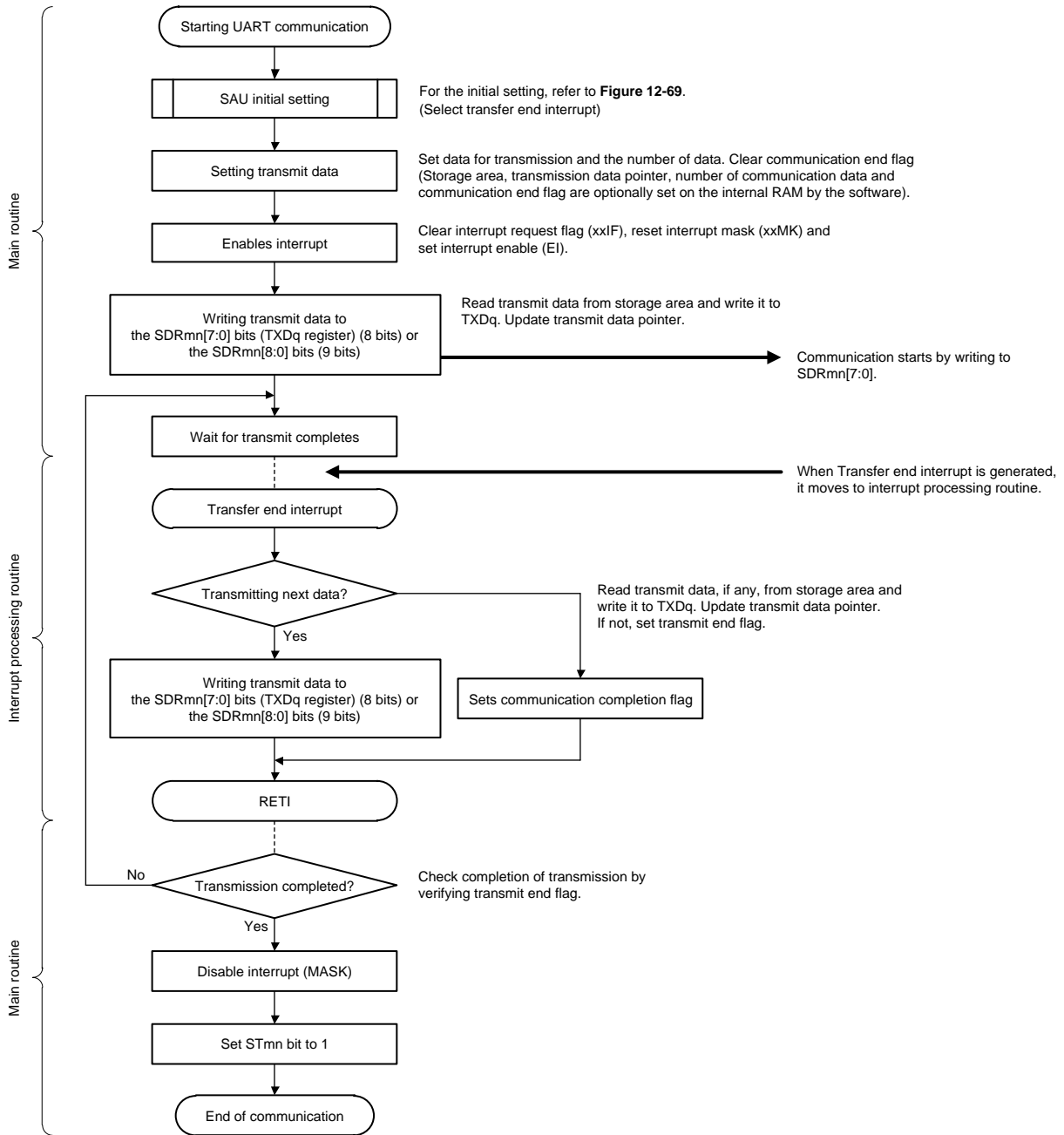
(3) Processing flow (in single-transmission mode)

Figure 12-72. Timing Chart of UART Transmission (in Single-Transmission Mode)



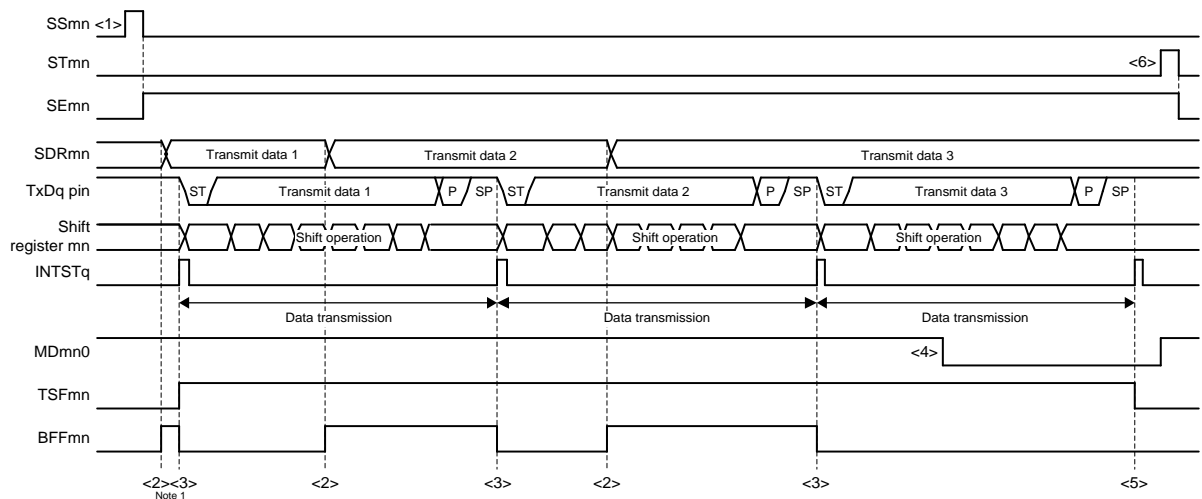
Remark m: Unit number (m = 0), n: Channel number (n = 0), q: UART number (q = 0), mn = 00

Figure 12-73. Flowchart of UART Transmission (in Single-Transmission Mode)



(4) Processing flow (in continuous transmission mode)

Figure 12-74. Timing Chart of UART Transmission (in Continuous Transmission Mode)

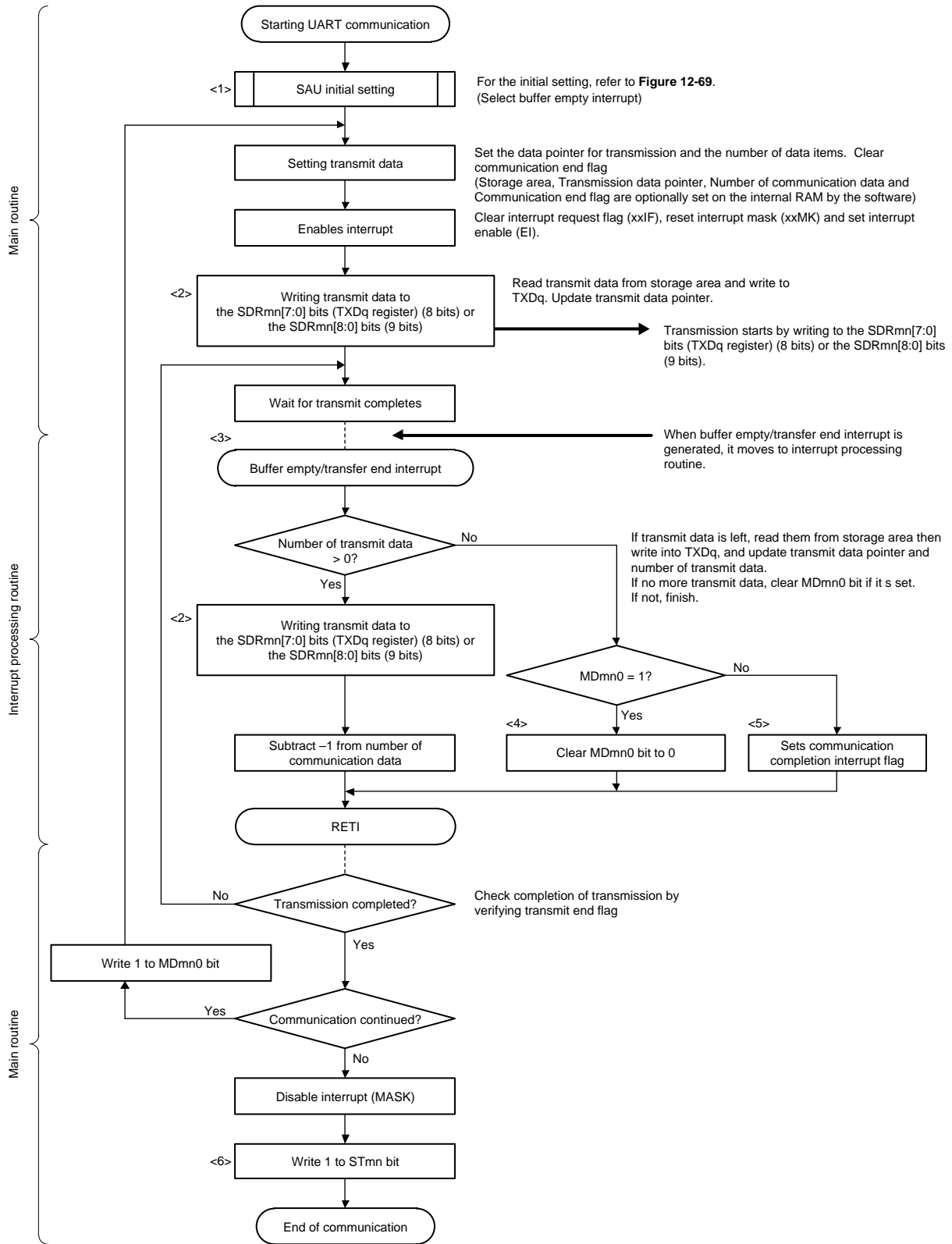


Note 1. If transmit data is written to the SDRmn register while the BFFmn bit of serial status register mn (SSRmn) is 1 (valid data is stored in serial data register mn (SDRmn)), the transmit data is overwritten.

Caution The MDmn0 bit of serial mode register mn (SMRmn) can be rewritten even during operation. However, rewrite it before transfer of the last bit is started, so that it has been rewritten before the transfer end interrupt of the last transmit data.

Remark m: Unit number (m = 0), n: Channel number (n = 0), q: UART number (q = 0), mn = 00

Figure 12-75. Flowchart of UART Transmission (in Continuous Transmission Mode)



Remark <1> to <6> in the figure correspond to <1> to <6> in Figure 12-74 Timing Chart of UART Transmission (in Continuous Transmission Mode).

12.6.2 UART Reception

UART reception is an operation wherein the RL78 microcontroller asynchronously receives data from another device (start-stop synchronization).

For UART reception, the odd-number channel of the two channels used for UART is used. The SMR register of both the odd- and even-numbered channels must be set.

| UART | UART0 |
|---------------------------------|--|
| Target channel | Channel 1 of SAU0 |
| Pins used | RxD0 |
| Interrupt | INTSR0 |
| | Transfer end interrupt only (Setting the buffer empty interrupt is prohibited.) |
| Error interrupt | INTSRE0 |
| Error detection flag | <ul style="list-style-type: none"> • Framing error detection flag (FEFmn) • Parity error detection flag (PEFmn) • Overrun error detection flag (OVFmn) |
| Transfer data length | 7, 8, or 9 bits |
| Transfer rate ^{Note 1} | Max. $f_{MCK}/6$ [bps] (SDRmn[15:9] = 2 or more), Min. $f_{CLK}/(2 \times 2^{15} \times 128)$ [bps] |
| Data phase | Non-reverse output (default: high level) Reverse output (default: low level) |
| Parity bit | The following selectable <ul style="list-style-type: none"> • No parity bit (no parity check) • No parity judgment (0 parity) • Even parity check • Odd parity check |
| Stop bit | Appending 1 bit |
| Data direction | MSB or LSB first |

Note 1. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS (T_A = -40 to +105°C, T_A = -40 to +125°C)**.

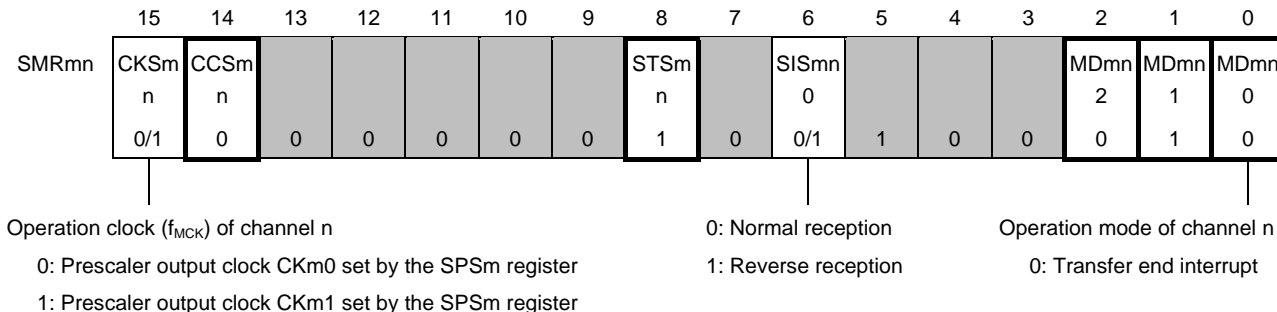
Remark 1. f_{MCK} : Operation clock frequency of target channel
 f_{CLK} : System clock frequency

Remark 2. m: Unit number (m = 0), n: Channel number (n = 1), mn = 01

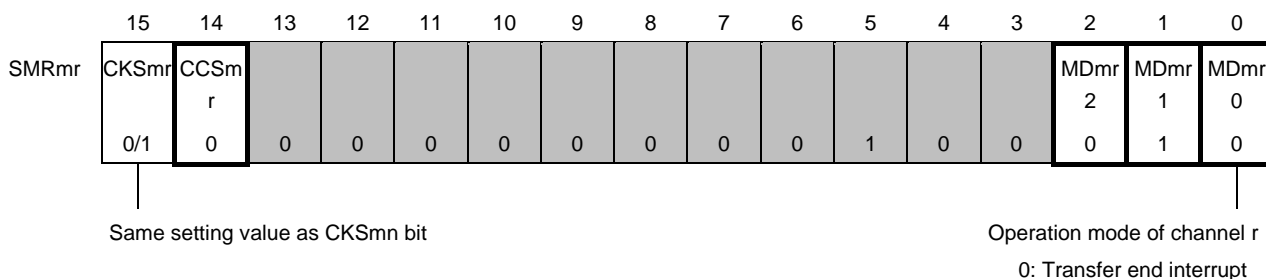
(1) Register setting

Figure 12-76. Example of Contents of Registers for UART Reception of UART (UART0) (1/2)

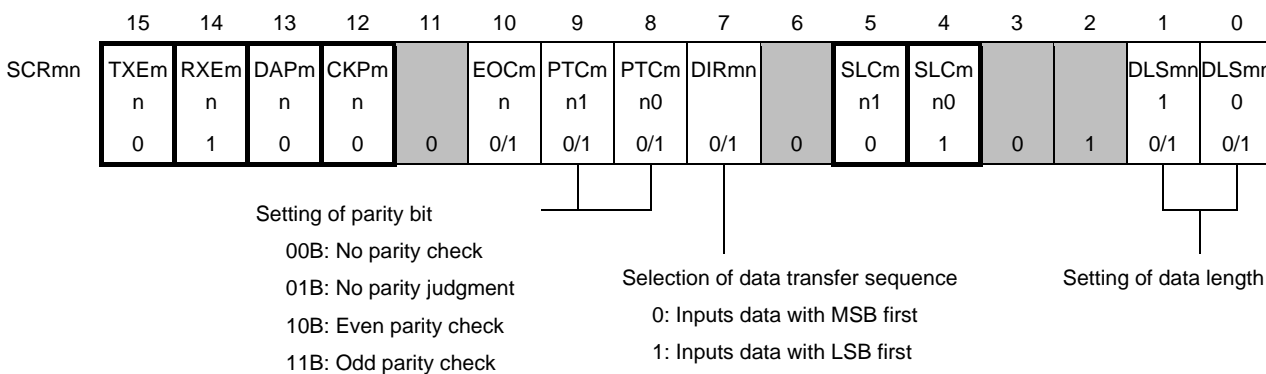
(a) Serial mode register mn (SMRmn)



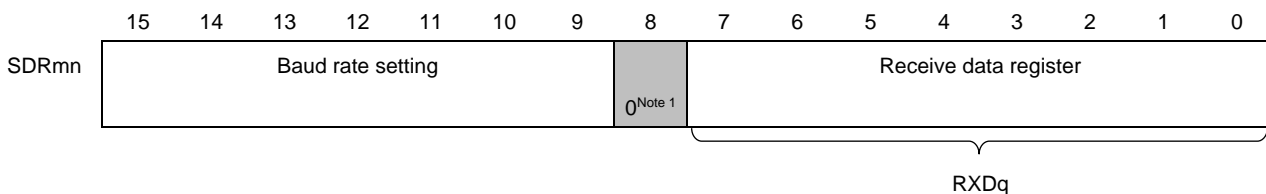
(b) Serial mode register mr (SMRmr)



(c) Serial communication operation setting register mn (SCRmn)



(d) Serial data register mn (SDRmn) (lower 8 bits: RXDq)



(Note 1, Caution, and Remarks are listed on the next page.)

Figure 12-76. Example of Contents of Registers for UART Reception of UART (UART0) (2/2)

(e) Serial output register m (SOm) ... This register is not used in this mode.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|------|------|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOm | | | | | | | CKOm | CKOm | | | | | | | SOM1 | SOM0 |
| | | | | | | | 1 | 0 | | | | | | | | |
| | 0 | 0 | 0 | 0 | 0 | 0 | x | x | 0 | 0 | 0 | 0 | 0 | 0 | x | x |

(f) Serial output enable register m (SOEm) ... This register is not used in this mode.

| | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOEm | | | | | | | | | | | | | | | SOEm | SOEm |
| | | | | | | | | | | | | | | | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | x | x |

(g) Serial channel start register m (SSm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSm | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | | | | | | | | | | | | | | | 0/1 | x |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | |

Note 1. When UART performs 9-bit communication, bits 0 to 8 of the SDRm0 register are used as the reception data specification area.

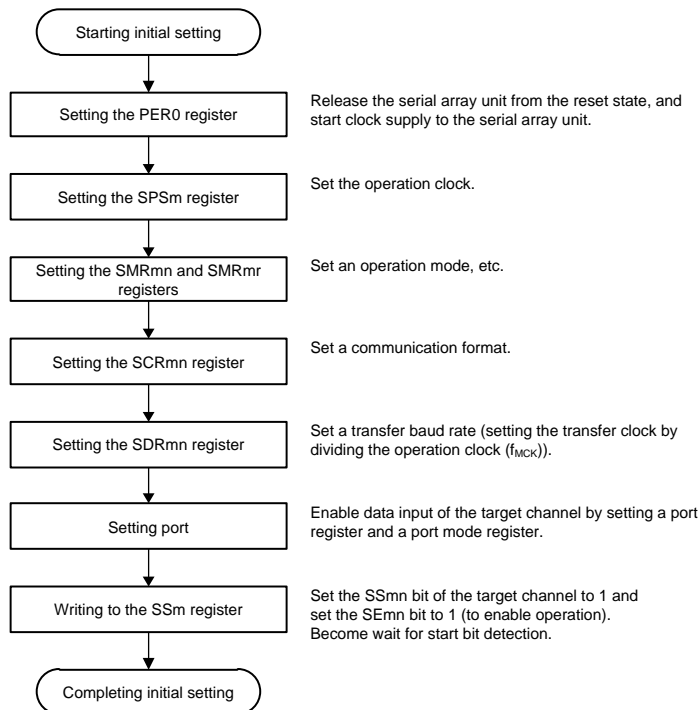
Caution For the UART reception, be sure to set the SMRmr register of channel r to UART transmission mode that is to be paired with channel n.

Remark 1. m: Unit number (m = 0), n: Channel number (n = 1), r: Channel number (r = n - 1),
q: UART number (q = 0), mn = 01

Remark 2. : Setting is fixed in the UART reception mode,
 : Setting disabled (set to the initial value)
x: Bit that cannot be used in this mode (set to the initial value when not used in any mode)
0/1: Set to 0 or 1 depending on the usage of the user.

(2) Operation procedure

Figure 12-77. Initial Setting Procedure for UART Reception



Caution Set the RXEmn bit of SCRmn register to 1, and then be sure to set SSmn to 1 after at least 4 f_{MCK} clock cycles have elapsed.

Figure 12-78. Procedure for Stopping UART Reception

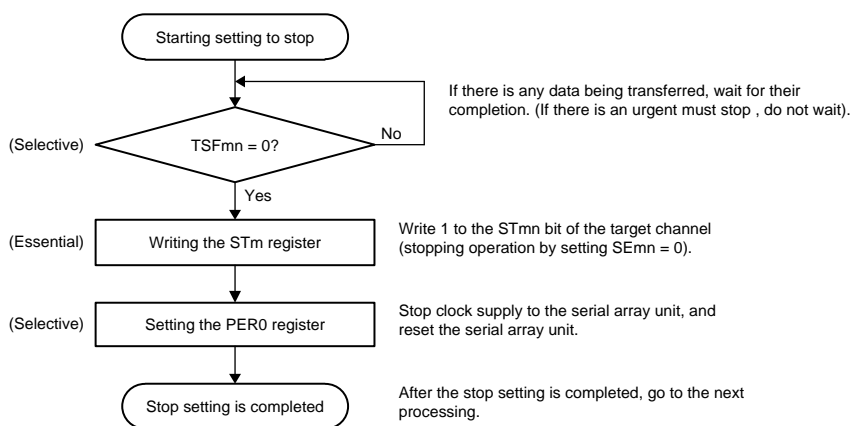
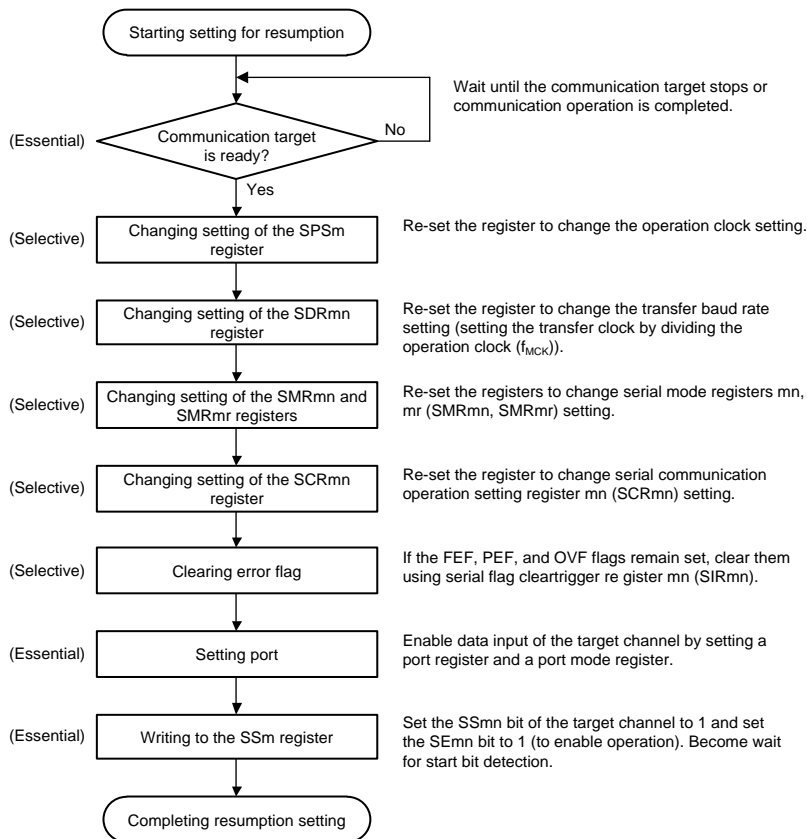


Figure 12-79. Procedure for Resuming UART Reception

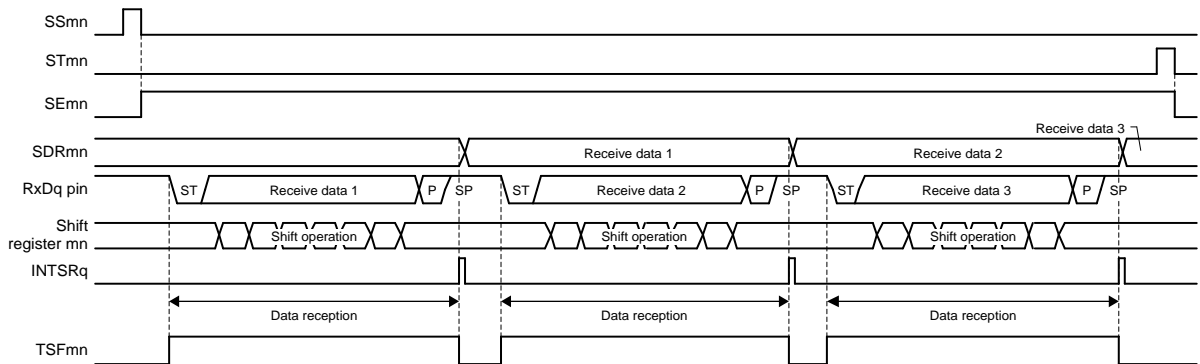


Caution Set the RXEmn bit of SCRmn register to 1, and then be sure to set SSmn to 1 after at least 4 fMCK clocks have elapsed.

Remark If PER0 is rewritten while stopping the communication to reset the serial array unit, wait until the communication target stops or communication finishes, and then perform initialization instead of restarting the communication.

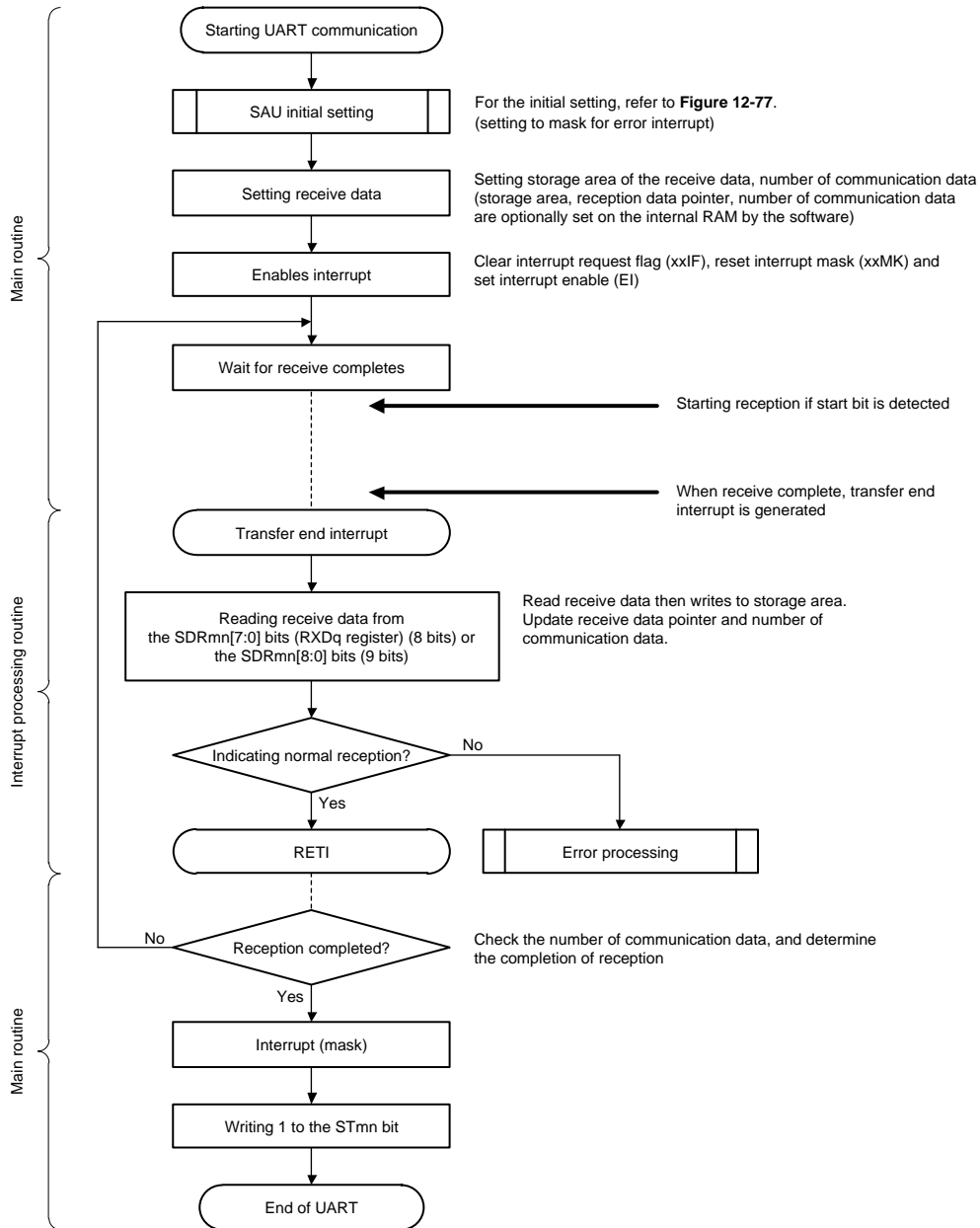
(3) Processing flow

Figure 12-80. Timing Chart of UART Reception



Remark m: Unit number (m = 0), n: Channel number (n = 1), r: Channel number (r = n - 1),
 q: UART number (q = 0), mn = 01

Figure 12-81. Flowchart of UART Reception



12.6.3 Calculating Baud Rate

(1) Baud rate calculation expression

The baud rate for UART (UART0) communication can be calculated by the following expressions.

$$(\text{Baud rate}) = \{\text{Operation clock (} f_{\text{MCK}} \text{) frequency of target channel}\} \div (\text{SDRmn}[15:9] + 1) \div 2[\text{bps}]$$

Caution Setting serial data register mn (SDRmn) SDRmn[15:9] = (000000B, 000001B) is prohibited.

Remark 1. When UART is used, the value of SDRmn[15:9] is the value of bits 15 to 9 of the SDRmn register (0000010B to 1111111B) and therefore is 2 to 127.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0), mn = 00

The operation clock (f_{MCK}) is determined by serial clock select register m (SPSm) and bit 15 (CKSmn) of serial mode register mn (SMRmn).

Table 12-3. Selection of Operation Clock For UART

| SMRmn Register | SPSm Register | | | | | | | | Operation Clock (f _{CLK}) ^{Note 1} | |
|------------------|---------------|---------|---------|---------|---------|---------|---------|---------|---|---------------------------|
| | CKSmn | PRS m13 | PRS m12 | PRS m11 | PRS m10 | PRS m03 | PRS m02 | PRS m01 | PRS m00 | f _{CLK} = 16 MHz |
| 0 | X | X | X | X | 0 | 0 | 0 | 0 | f _{CLK} | 16 MHz |
| | X | X | X | X | 0 | 0 | 0 | 1 | f _{CLK} /2 | 8 MHz |
| | X | X | X | X | 0 | 0 | 1 | 0 | f _{CLK} /2 ² | 4 MHz |
| | X | X | X | X | 0 | 0 | 1 | 1 | f _{CLK} /2 ³ | 2 MHz |
| | X | X | X | X | 0 | 1 | 0 | 0 | f _{CLK} /2 ⁴ | 1 MHz |
| | X | X | X | X | 0 | 1 | 0 | 1 | f _{CLK} /2 ⁵ | 500 kHz |
| | X | X | X | X | 0 | 1 | 1 | 0 | f _{CLK} /2 ⁶ | 250 kHz |
| | X | X | X | X | 0 | 1 | 1 | 1 | f _{CLK} /2 ⁷ | 125 kHz |
| | X | X | X | X | 1 | 0 | 0 | 0 | f _{CLK} /2 ⁸ | 62.5 kHz |
| | X | X | X | X | 1 | 0 | 0 | 1 | f _{CLK} /2 ⁹ | 31.25 kHz |
| | X | X | X | X | 1 | 0 | 1 | 0 | f _{CLK} /2 ¹⁰ | 15.63 kHz |
| | X | X | X | X | 1 | 0 | 1 | 1 | f _{CLK} /2 ¹¹ | 7.81 kHz |
| | X | X | X | X | 1 | 1 | 0 | 0 | f _{CLK} /2 ¹² | 3.91 kHz |
| | X | X | X | X | 1 | 1 | 0 | 1 | f _{CLK} /2 ¹³ | 1.95 kHz |
| | X | X | X | X | 1 | 1 | 1 | 0 | f _{CLK} /2 ¹⁴ | 977 Hz |
| | X | X | X | X | 1 | 1 | 1 | 1 | f _{CLK} /2 ¹⁵ | 488 Hz |
| 1 | 0 | 0 | 0 | 0 | X | X | X | X | f _{CLK} | 16 MHz |
| | 0 | 0 | 0 | 1 | X | X | X | X | f _{CLK} /2 | 8 MHz |
| | 0 | 0 | 1 | 0 | X | X | X | X | f _{CLK} /2 ² | 4 MHz |
| | 0 | 0 | 1 | 1 | X | X | X | X | f _{CLK} /2 ³ | 2 MHz |
| | 0 | 1 | 0 | 0 | X | X | X | X | f _{CLK} /2 ⁴ | 1 MHz |
| | 0 | 1 | 0 | 1 | X | X | X | X | f _{CLK} /2 ⁵ | 500 kHz |
| | 0 | 1 | 1 | 0 | X | X | X | X | f _{CLK} /2 ⁶ | 250 kHz |
| | 0 | 1 | 1 | 1 | X | X | X | X | f _{CLK} /2 ⁷ | 125 kHz |
| | 1 | 0 | 0 | 0 | X | X | X | X | f _{CLK} /2 ⁸ | 62.5 kHz |
| | 1 | 0 | 0 | 1 | X | X | X | X | f _{CLK} /2 ⁹ | 31.25 kHz |
| | 1 | 0 | 1 | 0 | X | X | X | X | f _{CLK} /2 ¹⁰ | 15.63 kHz |
| | 1 | 0 | 1 | 1 | X | X | X | X | f _{CLK} /2 ¹¹ | 7.81 kHz |
| | 1 | 1 | 0 | 0 | X | X | X | X | f _{CLK} /2 ¹² | 3.91 kHz |
| | 1 | 1 | 0 | 1 | X | X | X | X | f _{CLK} /2 ¹³ | 1.95 kHz |
| | 1 | 1 | 1 | 0 | X | X | X | X | f _{CLK} /2 ¹⁴ | 977 Hz |
| | 1 | 1 | 1 | 1 | X | X | X | X | f _{CLK} /2 ¹⁵ | 488 Hz |
| Other than above | | | | | | | | | Setting prohibited | |

(Note 1 and Remarks are listed on the next page.)

Note 1. When changing the clock selected for f_{CLK} (by changing the system clock control register (CKC) value), do so after having stopped (serial channel stop register m (STm) = 000FH) the operation of the serial array unit (SAU).

Remark 1. X: Don't care

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

(2) Baud rate error during transmission

The baud rate error of UART (UART0) communication during transmission can be calculated by the following expression. Make sure that the baud rate at the transmission side is within the permissible baud rate range at the reception side.

$$(\text{Baud rate error}) = (\text{Calculated baud rate value}) \div (\text{Target baud rate}) \times 100 - 100[\%]$$

Here is an example of setting a UART baud rate at $f_{\text{CLK}} = 16 \text{ MHz}$.

| UART Baud Rate (Target Baud Rate) | $f_{\text{CLK}} = 16 \text{ MHz}$ | | | |
|--------------------------------------|--------------------------------------|-------------|----------------------|-----------------------------|
| | Operation Clock (f_{MCK}) | SDRmn[15:9] | Calculated Baud Rate | Error from Target Baud Rate |
| 300 bps | $f_{\text{CLK}}/2^9$ | 51 | 300.48 bps | +0.16% |
| 600 bps | $f_{\text{CLK}}/2^8$ | 51 | 600.96 bps | +0.16% |
| 1200 bps | $f_{\text{CLK}}/2^7$ | 51 | 1201.92 bps | +0.16% |
| 2400 bps | $f_{\text{CLK}}/2^6$ | 51 | 2403.85 bps | +0.16% |
| 4800 bps | $f_{\text{CLK}}/2^5$ | 51 | 4807.69 bps | +0.16% |
| 9600 bps | $f_{\text{CLK}}/2^4$ | 51 | 9615.38 bps | +0.16% |
| 19200 bps | $f_{\text{CLK}}/2^3$ | 51 | 19230.8 bps | +0.16% |
| 31250 bps | $f_{\text{CLK}}/2^3$ | 31 | 31250.0 bps | $\pm 0.0\%$ |
| 38400 bps | $f_{\text{CLK}}/2^2$ | 51 | 38461.5 bps | +0.16% |
| 76800 bps | $f_{\text{CLK}}/2$ | 51 | 76923.1 bps | +0.16% |
| 153600 bps | f_{CLK} | 51 | 153846 bps | +0.16% |
| 312500 bps | f_{CLK} | 25 | 307692.3 bps | -1.54% |

Remark m: Unit number ($m = 0$), n: Channel number ($n = 0$), mn = 00

(3) Permissible baud rate range for reception

The permissible baud rate range for reception during UART (UART0) communication can be calculated by the following expression. Make sure that the baud rate at the transmission side is within the permissible baud rate range at the reception side.

$$\text{(Maximum receivable baud rate)} = \frac{2 \times k \times \text{Nfr}}{2 \times k \times \text{Nfr} - k + 2} \times \text{Brate}$$

$$\text{(Minimum receivable baud rate)} = \frac{2 \times k \times (\text{Nfr} - 1)}{2 \times k \times \text{Nfr} - k - 2} \times \text{Brate}$$

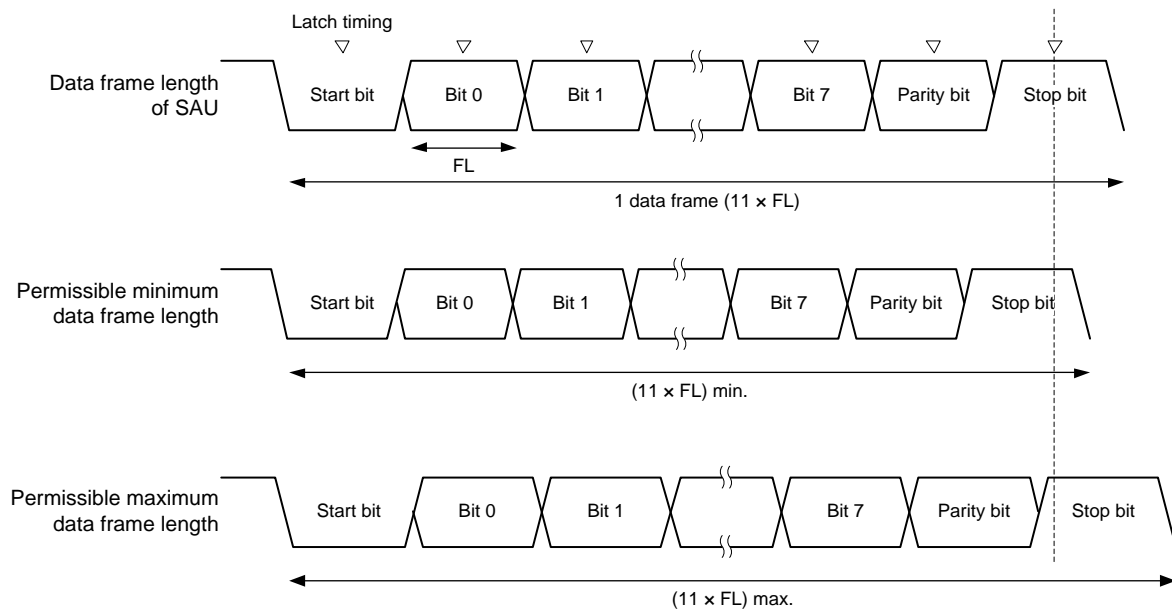
Brate: Calculated baud rate value at the reception side (See **12.6.3(1) Baud rate calculation expression.**)

k: SDRmn[15:9] + 1

Nfr: 1 data frame length [bits] = (Start bit) + (Data length) + (Parity bit) + (Stop bit)

Remark m: Unit number (m = 0), n: Channel number (n = 1), mn = 01

Figure 12-82. Permissible Baud Rate Range for Reception (1 Data Frame Length = 11 Bits)



As shown in **Figure 12-82**, the timing of latching receive data is determined by the division ratio set by bits 15 to 9 of serial data register mn (SDRmn) after the start bit is detected. If the last data (stop bit) is received before this latch timing, the data can be correctly received.

12.6.4 Procedure for Processing Errors that Occurred During UART (UART0) Communication

The procedure for processing errors that occurred during UART (UART0) communication is described in **Figure 12-83** and **Figure 12-84**.

Figure 12-83. Processing Procedure in Case of Parity Error or Overrun Error

| Software Manipulation | State of the Hardware | Remark |
|--|---|---|
| Reads serial data register mn (SDRmn). | ▶ The BFFmn bit of the SSRmn register is set to 0 and channel n is enabled to receive data. | This is to prevent an overrun error if the next reception is completed during error processing. |
| Reads serial status register mn (SSRmn). | | The error type is identified and the read value is used to clear the error flag. |
| Writes 1 to serial flag clear trigger register mn (SIRmn). | ▶ The error flag is cleared. | Only the error generated during reading can be cleared, by writing the value read from the SSRmn register to the SIRmn register without modification. |

Figure 12-84. Processing Procedure in Case of Framing Error

| Software Manipulation | State of the Hardware | Remark |
|--|--|---|
| Reads serial data register mn (SDRmn). | ▶ The BFFmn bit of the SSRmn register is set to 0 and channel n is enabled to receive data. | This is to prevent an overrun error if the next reception is completed during error processing. |
| Reads serial status register mn (SSRmn). | | The error type is identified and the read value is used to clear the error flag. |
| Writes serial flag clear trigger register mn (SIRmn). | ▶ The error flag is cleared. | Only the error generated during reading can be cleared, by writing the value read from the SSRmn register to the SIRmn register without modification. |
| Sets the STmn bit of serial channel stop register m (STm) to 1. | ▶ The SEMn bit of serial channel enable status register m (SEm) is set to 0 and channel n stops operation. | |
| Synchronization with other party of communication | | Synchronization with the other party of communication is re-established and communication is resumed because it is considered that a framing error has occurred because the start bit has been shifted. |
| Sets the SSmn bit of serial channel start register m (SSm) to 1. | ▶ The SEMn bit of serial channel enable status register m (SEm) is set to 1 and channel n is enabled to operate. | |

Remark m: Unit number (m = 0), n: Channel number (n = 1), mn = 01

12.7 Operation of Simplified I²C (IIC00, IIC01) Communication

This is a clocked communication function to communicate with two or more devices by using two lines: serial clock (SCL) and serial data (SDA). This simplified I²C is designed for single communication with a device such as EEPROM, flash memory, or A/D converter, and therefore, it functions only as a master.

Operate the control registers by software for setting the start and stop conditions while observing the specifications of the I²C bus line.

[Data transmission/reception]

- Master transmission, master reception (only master function with a single master)
- ACK output function^{Note 1}, ACK detection function
- Data length of 8 bits
(When an address is transmitted, the address is specified by the higher 7 bits, and the least significant bit is used for R/W control.)
- Generation of start condition and stop condition for software

[Interrupt function]

- Transfer end interrupt

[Error detection flag]

- Overrun error
- ACK error

*[Functions not supported by simplified I²C]

- Slave transmission, slave reception
- Multi-master function (arbitration loss detection function)
- Wait detection functions

Note 1. When receiving the last data, ACK will not be output if 0 is written to the SOEmn (SOEm register) bit and serial communication data output is stopped. See **12.7.3(2) Processing flow** for details.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

The channel supporting simplified I²C (IIC00, IIC01) is channels 0 and 1 of SAU0.

● 10- and 8-pin products

| Unit | Channel | Used as simplified SPI (CSI) | Used as UART | Used as Simplified I ² C |
|------|---------|------------------------------|--------------|-------------------------------------|
| 0 | 0 | CSI00 | UART0 | IIC00 |
| | 1 | — | | — |

● 20- and 16-pin products

| Unit | Channel | Used as simplified SPI (CSI) | Used as UART | Used as Simplified I ² C |
|------|---------|------------------------------|--------------|-------------------------------------|
| 0 | 0 | CSI00 | UART0 | IIC00 |
| | 1 | CSI01 | | IIC01 |

Simplified I²C (IIC00, IIC01) performs the following four types of communication operations.

- Address field transmission (See **12.7.1.**)
- Data transmission (See **12.7.2.**)
- Data reception (See **12.7.3.**)
- Stop condition generation (See **12.7.4.**)

12.7.1 Address Field Transmission

Address field transmission is a transmission operation that first executes in I²C communication to identify the target for transfer (slave). After a start condition is generated, an address (7 bits) and a transfer direction (1 bit) are transmitted in one frame.

| Simplified I ² C | IIC00 | IIC01 |
|---------------------------------|--|--------------------------------|
| Target channel | Channel 0 of SAU0 | Channel 1 of SAU0 |
| Pins used | SCL00, SDA00 ^{Note 1} | SCL01, SDA01 ^{Note 1} |
| Interrupt | INTIIC00 | INTIIC01 |
| | Transfer end interrupt only (Setting the buffer empty interrupt is prohibited.) | |
| Error detection flag | ACK error detection flag (PEFmn) | |
| Transfer data length | 8 bits (transmitted with specifying the higher 7 bits as address and the least significant bit as R/W control) | |
| Transfer rate ^{Note 2} | Max. $f_{MCK}/4$ [Hz] (SDRmn[15:9] = 1 or more) f_{MCK} : Operation clock frequency of target channel However, the following condition must be satisfied in each mode of I ² C. <ul style="list-style-type: none"> • Max. 400 kHz (fast mode) • Max. 100 kHz (standard mode) | |
| Data level | Non-reverse output (default: high level) | |
| Parity bit | No parity bit | |
| Stop bit | Appending 1 bit (for ACK transmission/reception timing) | |
| Data direction | MSB first | |

Note 1. To perform communication via simplified I²C, set the N-ch open-drain output (V_{DD} tolerance) mode (POMxx = 1) with the port output mode register (POMxx). See **4.3 Registers Controlling Port Function** and **4.5 Register Settings When Using Alternate Function** for details.

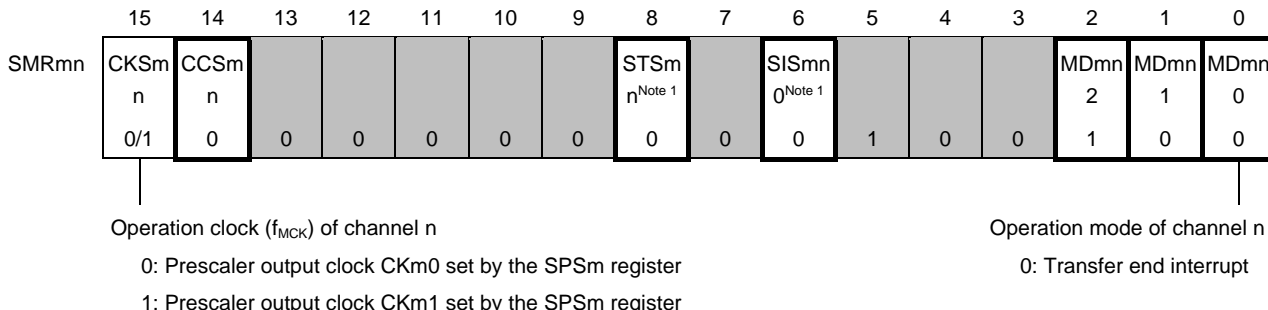
Note 2. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+85^\circ\text{C}$)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+105^\circ\text{C}$, $T_A = -40$ to $+125^\circ\text{C}$)**.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

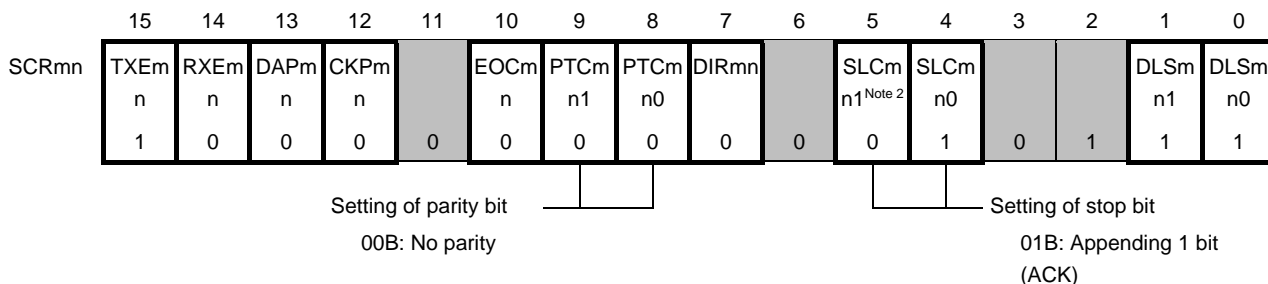
(1) Register setting

Figure 12-85. Example of Contents of Registers for Address Field Transmission of Simplified I²C (IIC00, IIC01) (1/2)

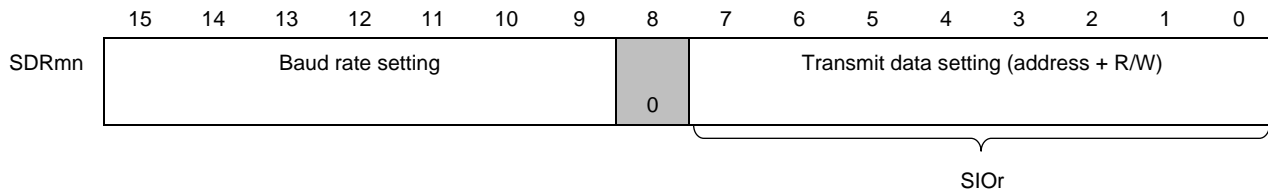
(a) Serial mode register mn (SMRmn)



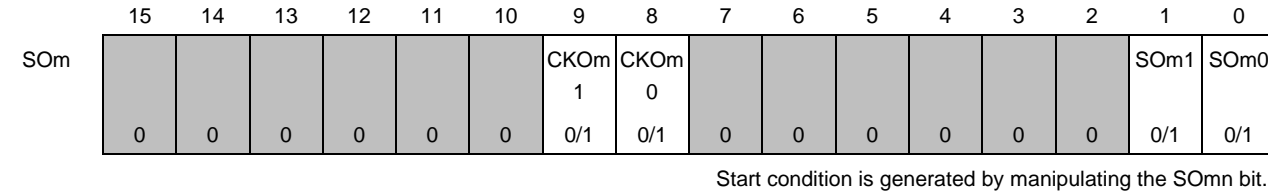
(b) Serial communication operation setting register mn (SCRmn)



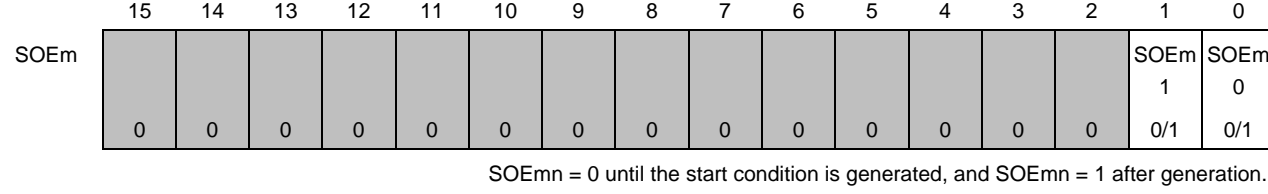
(c) Serial data register mn (SDRmn) (lower 8 bits: SIO_r)



(d) Serial output register m (SO_m)



(e) Serial output enable register m (SO_{Em})



(Note 1, Note 2, and Remarks are listed on the next page.)

Figure 12-85. Example of Contents of Registers for Address Field Transmission of Simplified I²C (IIC00, IIC01) (2/2)

(f) Serial channel start register m (SSm) ... Set only the bit of the target channel to 1.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSm | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | SSm1 | SSm0 |
| | | | | | | | | | | | | | | | 0/1 | 0/1 |

SSmn = 0 until the start condition is generated, and SSmn = 1 after generation.

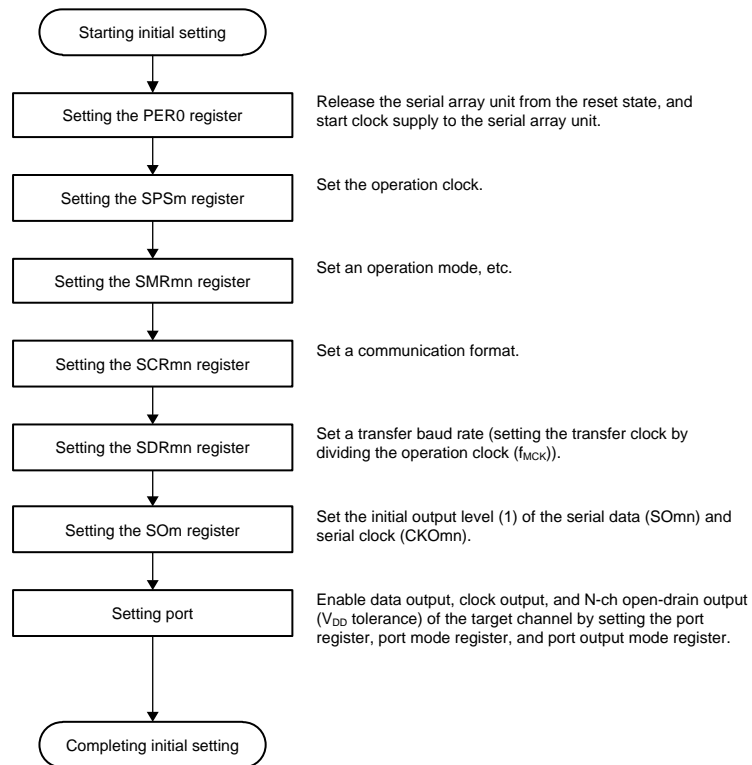
Note 1. The SMR00 register only.

Note 2. The SCR00 register only.

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1), r: IIC number (r = 00, 01), mn = 00, 01

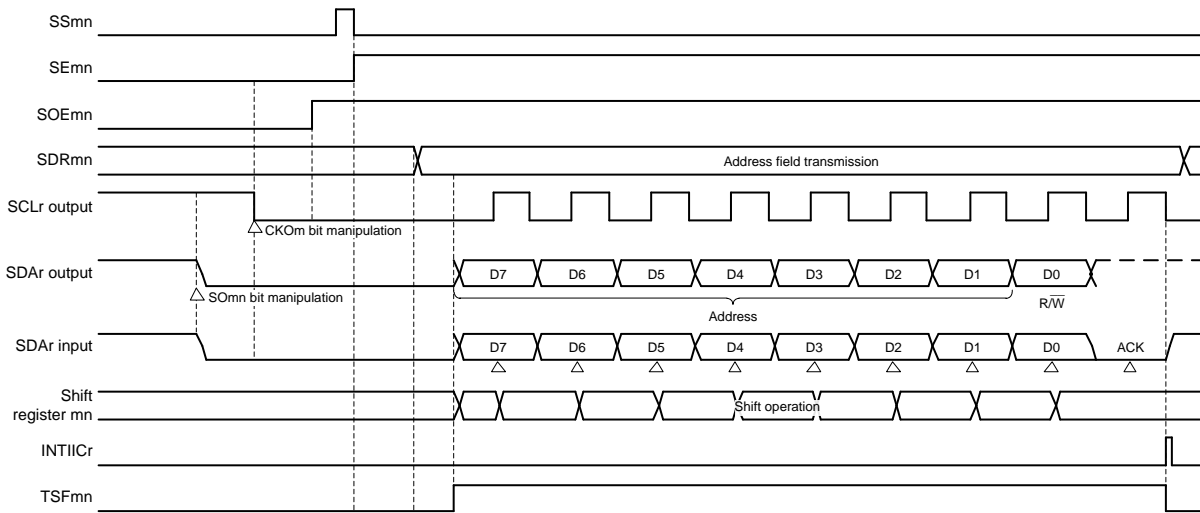
Remark 2. : Setting is fixed in the IIC mode, : Setting disabled (set to the initial value)
 0/1: Set to 0 or 1 depending on the usage of the user.

(2) Operation procedure

Figure 12-86. Initial Setting Procedure for Simplified I²C Address Field Transmission

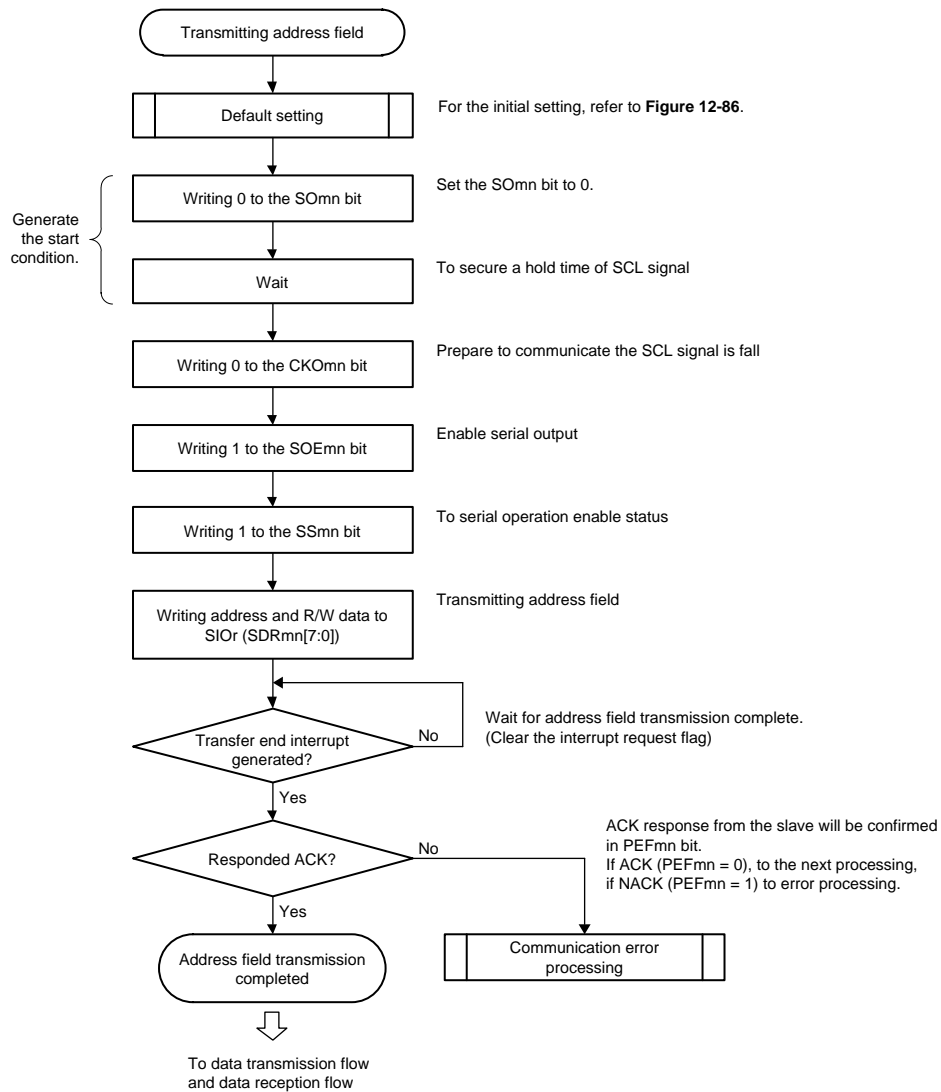
(3) Processing flow

Figure 12-87. Timing Chart of Address Field Transmission



Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), r: IIC number (r = 00, 01), mn = 00, 01

Figure 12-88. Flowchart of Simplified I²C Address Field Transmission



12.7.2 Data Transmission

Data transmission is an operation to transmit data to the target for transfer (slave) after transmission of an address field. After all data are transmitted to the slave, a stop condition is generated and the bus is released.

| Simplified I ² C | IIC00 | IIC01 |
|---------------------------------|--|--------------------------------|
| Target channel | Channel 0 of SAU0 | Channel 1 of SAU0 |
| Pins used | SCL00, SDA00 ^{Note 1} | SCL01, SDA01 ^{Note 1} |
| Interrupt | INTIIC00 | INTIIC01 |
| | Transfer end interrupt only (Setting the buffer empty interrupt is prohibited.) | |
| Error detection flag | ACK error detection flag (PEFmn) | |
| Transfer data length | 8 bits | |
| Transfer rate ^{Note 2} | Max. $f_{MCK}/4$ [Hz] (SDRmn[15:9] = 1 or more) f_{MCK} : Operation clock frequency of target channel However, the following condition must be satisfied in each mode of I ² C. <ul style="list-style-type: none"> • Max. 400 kHz (fast mode) • Max. 100 kHz (standard mode) | |
| Data level | Non-reverse output (default: high level) | |
| Parity bit | No parity bit | |
| Stop bit | Appending 1 bit (for ACK reception timing) | |
| Data direction | MSB first | |

Note 1. To perform communication via simplified I²C, set the N-ch open-drain output (V_{DD} tolerance) mode (POMxx = 1) with the port output mode register (POMxx). For details, see **4.3 Registers Controlling Port Function** and **4.5 Register Settings When Using Alternate Function**.

Note 2. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS (T_A = -40 to +105°C, T_A = -40 to +125°C)**.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

(1) Register setting

Figure 12-89. Example of Contents of Registers for Data Transmission of Simplified I²C (IIC00, IIC01)

(a) Serial mode register mn (SMRmn) ... Do not manipulate this register during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|-------|------|------|----|----|----|----|---|---------------------|---|---------------------|---|---|---|------|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SMRmn | CKSm | CCSm | | | | | | STSm | | SISmn | | | | MDmn | MDmn | MDmn |
| | n | n | | | | | | n | | 0 | | | | 2 | 1 | 0 |
| | 0/1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 ^{Note 1} | 0 | 0 ^{Note 1} | 1 | 0 | 0 | 1 | 0 | 0 |

(b) Serial communication operation setting register mn (SCRmn) ... Do not manipulate the bits of this register, except the TXEmn and RXEmn bits, during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|-------|------|------|------|------|----|------|------|------|-------|---|---------------------|------|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SCRmn | TXEm | RXEm | DAPm | CKPm | | EOCm | PTCm | PTCm | DIRmn | | SLCm | SLCm | | | DLSm | DLSm |
| | n | n | n | n | | n | n1 | n0 | | | n1 | n0 | | | n1 | n0 |
| | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 ^{Note 2} | 1 | 0 | 1 | 1 | 1 |

(c) Serial data register mn (SDRmn) (lower 8 bits: SIO_r) ... During data transmission/reception, valid only lower 8-bits (SIO_r)

| | | | | | | | | | | | | | | | | | |
|-------|-------------------------------------|----|----|----|----|----|---|---|-----------------------|---|---|---|---|---|---|---|--|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| SDRmn | Baud rate setting ^{Note 3} | | | | | | | 0 | Transmit data setting | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |

SIO_r

(d) Serial output register m (SOM) ... Do not manipulate this register during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|-----------------------|-----------------------|---|---|---|---|---|---|-----------------------|-----------------------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOM | | | | | | | CKOm | CKOm | | | | | | | SOm1 | SOm0 |
| | | | | | | | 1 | 0 | | | | | | | | |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 ^{Note 4} | 0/1 ^{Note 4} | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 ^{Note 4} | 0/1 ^{Note 4} |

(e) Serial output enable register m (SOEm) ... Do not manipulate this register during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOEm | | | | | | | | | | | | | | | SOEm | SOEm |
| | | | | | | | | | | | | | | | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |

(f) Serial channel start register m (SSm) ... Do not manipulate this register during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSm | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | | | | | | | | | | | | | | | 0/1 | 0/1 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 | 0/1 |

(Note 1 to Note 4, and Remarks are listed on the next page.)

Note 1. The SMR01 register only.

Note 2. The SCR00 register only.

Note 3. Because the setting is completed by address field transmission, setting is not required.

Note 4. The value varies depending on the communication data during communication operation.

Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1), r: IIC number (r = 00, 01), mn = 00, 01

Remark 2. : Setting is fixed in the IIC mode, : Setting disabled (set to the initial value)
0/1: Set to 0 or 1 depending on the usage of the user.

(2) Processing flow

Figure 12-90. Timing Chart of Data Transmission

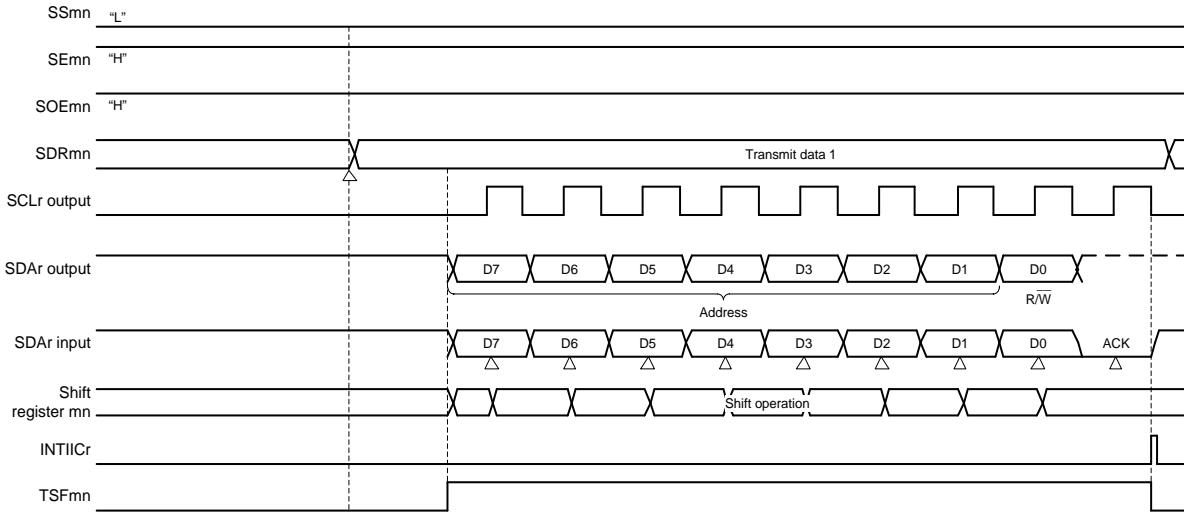
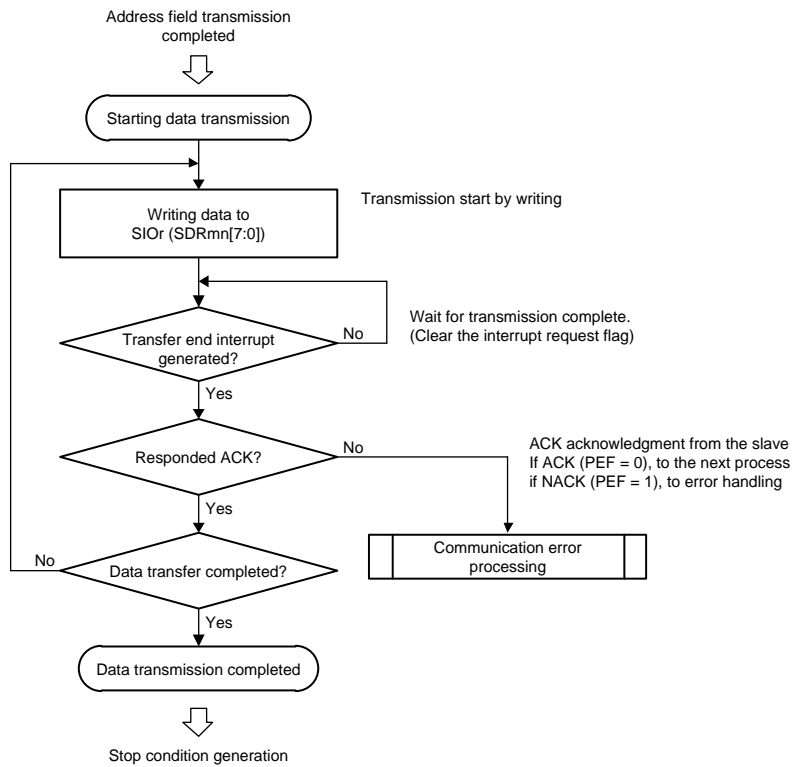


Figure 12-91. Flowchart of Simplified I²C Data Transmission



12.7.3 Data Reception

Data reception is an operation to receive data from the target for transfer (slave) after transmission of an address field. After all data are received from the slave, a stop condition is generated and the bus is released.

| Simplified I ² C | IIC00 | IIC01 |
|---------------------------------|---|--------------------------------|
| Target channel | Channel 0 of SAU0 | Channel 1 of SAU0 |
| Pins used | SCL00, SDA00 ^{Note 1} | SCL01, SDA01 ^{Note 1} |
| Interrupt | INTIIC00 | INTIIC01 |
| | Transfer end interrupt only (Setting the buffer empty interrupt is prohibited.) | |
| Error detection flag | Overflow error detection flag (OVFmn) only | |
| Transfer data length | 8 bits | |
| Transfer rate ^{Note 2} | Max. $f_{MCK}/4$ [Hz] (SDRmn[15:9] = 1 or more) f_{MCK} : Operation clock frequency of target channel However, the following condition must be satisfied in each mode of I ² C. <ul style="list-style-type: none"> • Max. 400 kHz (fast mode) • Max. 100 kHz (standard mode) | |
| Data level | Non-reverse output (default: high level) | |
| Parity bit | No parity bit | |
| Stop bit | Appending 1 bit (ACK transmission) | |
| Data direction | MSB first | |

Note 1. To perform communication via simplified I²C, set the N-ch open-drain output (V_{DD} tolerance) mode (POMxx = 1) with the port output mode register (POMxx). For details, see **4.3 Registers Controlling Port Function** and **4.5 Register Settings When Using Alternate Function**.

Note 2. Use this operation within a range that satisfies the conditions above and the peripheral functions characteristics specified in the electrical characteristics. For details, see **CHAPTER 23 ELECTRICAL SPECIFICATIONS (T_A = -40 to +85°C)** and **CHAPTER 24 ELECTRICAL SPECIFICATIONS (T_A = -40 to +105°C, T_A = -40 to +125°C)**.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

(1) Register setting

Figure 12-92. Example of Contents of Registers for Data Reception of Simplified I²C (IIC00, IIC01)

(a) Serial mode register mn (SMRmn) ... Do not manipulate this register during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|-------|------|------|----|----|----|----|---|---------------------|---|---------------------|---|---|---|------|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SMRmn | CKSm | CCSm | | | | | | STSm | | SISmn | | | | MDmn | MDmn | MDmn |
| | n | n | | | | | | n | | 0 | | | | 2 | 1 | 0 |
| | 0/1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 ^{Note 1} | 0 | 0 ^{Note 1} | 1 | 0 | 0 | 1 | 0 | 0 |

(b) Serial communication operation setting register mn (SCRmn) ... Do not manipulate the bits of this register, except the TXEmn and RXEmn bits, during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|-------|------|------|------|------|----|------|------|------|-------|---|---------------------|------|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SCRmn | TXEm | RXEm | DAPm | CKPm | | EOCm | PTCm | PTCm | DIRmn | | SLCm | SLCm | | | DLSm | DLSm |
| | n | n | n | n | | n | n1 | n0 | | | n1 | n0 | | | n1 | n0 |
| | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 ^{Note 2} | 1 | 0 | 1 | 1 | 1 |

(c) Serial data register mn (SDRmn) (lower 8 bits: SIO_r)

| | | | | | | | | | | | | | | | | |
|-------|-------------------------------------|----|----|----|----|----|---|---|-----------------------------------|---|---|---|---|---|---|---|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SDRmn | Baud rate setting ^{Note 3} | | | | | | | 0 | Dummy transmit data setting (FFH) | | | | | | | |
| | SIO _r | | | | | | | | | | | | | | | |

(d) Serial output register m (SOM) ... Do not manipulate this register during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|-----------------------|-----------------------|---|---|---|---|---|---|-----------------------|-----------------------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOM | | | | | | | CKOm | CKOm | | | | | | | SOM1 | SOM0 |
| | | | | | | | 1 | 0 | | | | | | | | |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 ^{Note 4} | 0/1 ^{Note 4} | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 ^{Note 4} | 0/1 ^{Note 4} |

(e) Serial output enable register m (SOEm) ... Do not manipulate this register during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|------|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SOEm | | | | | | | | | | | | | | | SOEm | SOEm |
| | | | | | | | | | | | | | | | 1 | 0 |
| | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0/1 | 0/1 |

(f) Serial channel start register m (SSm) ... Do not manipulate this register during data transmission/reception.

| | | | | | | | | | | | | | | | | |
|-----|----|----|----|----|----|----|---|---|---|---|---|---|---|---|------|------|
| | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| SSm | | | | | | | | | | | | | | | SSm1 | SSm0 |
| | | | | | | | | | | | | | | | 0/1 | 0/1 |

(Note 1 to Note 4, and Remarks are listed on the next page.)

Note 1. The SMR01 and SMR03 registers only

Note 2. The SCR00 and SCR02 registers only

Note 3. Because the setting is completed by address field transmission, setting is not required.

Note 4. The value varies depending on the communication data during communication operation.

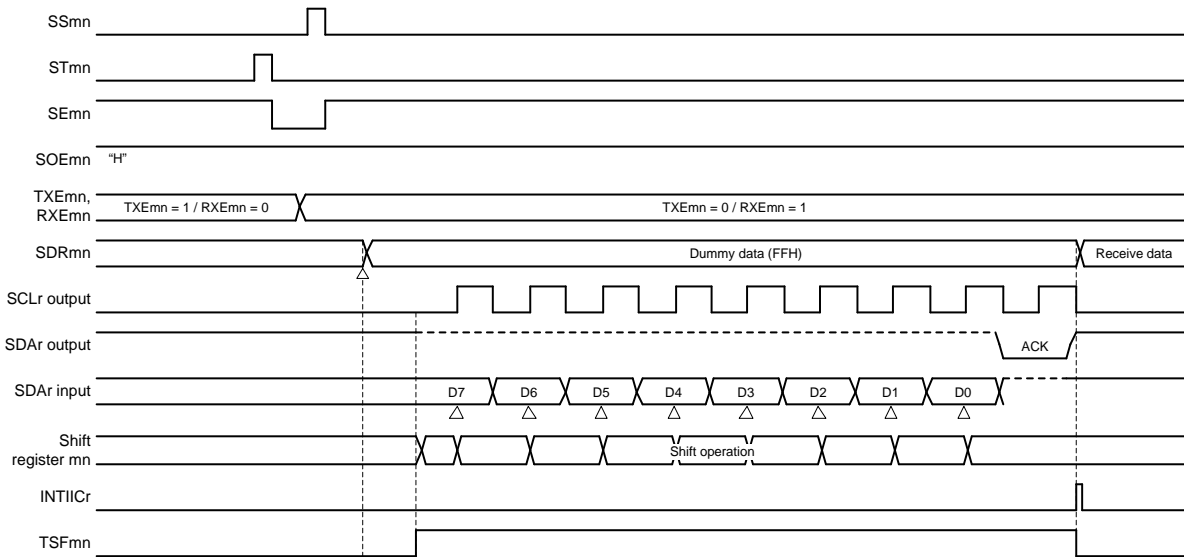
Remark 1. m: Unit number (m = 0), n: Channel number (n = 0, 1), r: IIC number (r = 00, 01),
mn = 00, 01

Remark 2. : Setting is fixed in the IIC mode, : Setting disabled (set to the initial value)
0/1: Set to 0 or 1 depending on the usage of the user.

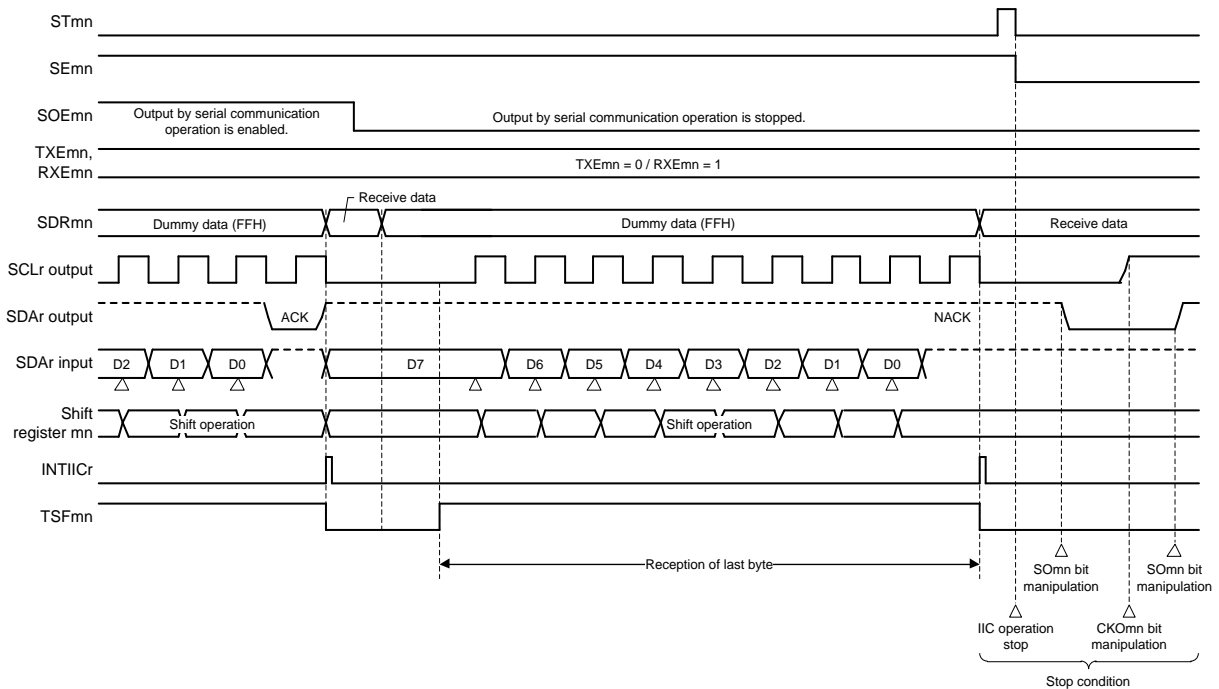
(2) Processing flow

Figure 12-93. Timing Chart of Data Reception

(a) When starting data reception

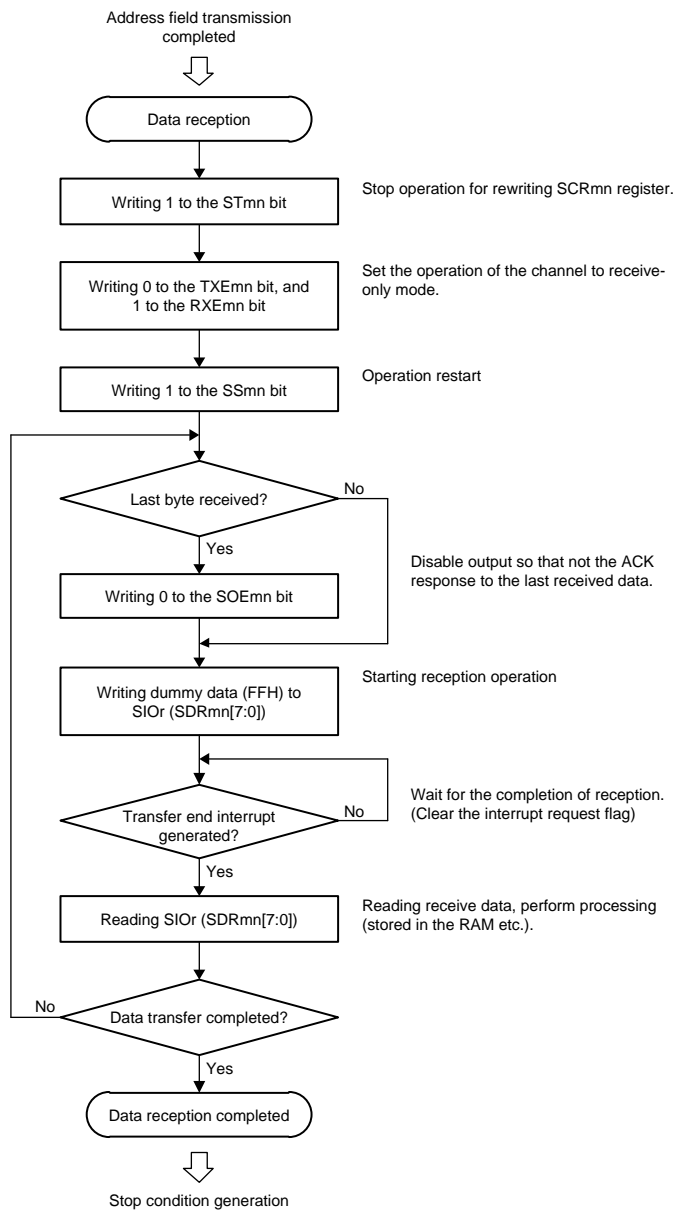


(b) When receiving last data



Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), r: IIC number (r = 00, 01), mn = 00, 01

Figure 12-94. Flowchart of Data Reception



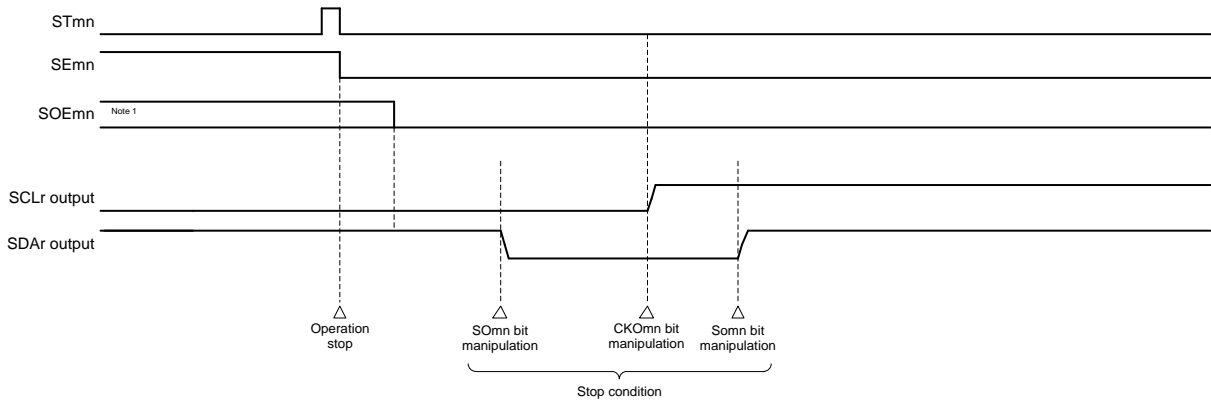
Caution ACK is not output when the last data is received (NACK). Communication is then completed by setting 1 in the STmn bit of serial channel stop register m (STM) to stop operation and generating a stop condition.

12.7.4 Stop Condition Generation

After all data are transmitted to or received from the target slave, a stop condition is generated and the bus is released.

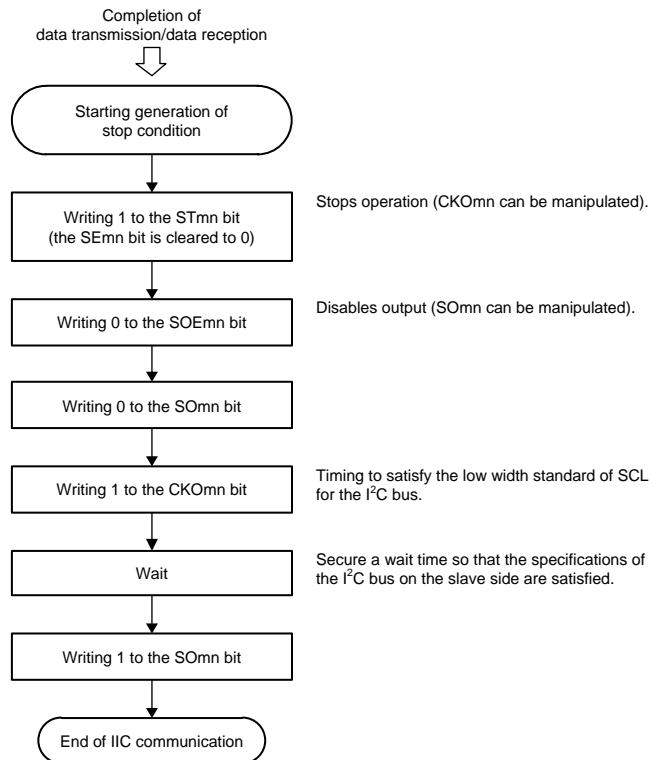
(1) Processing flow

Figure 12-95. Timing Chart of Stop Condition Generation



Note 1. During a receive operation, the SOEmn bit of serial output enable register m (SOEm) is cleared to 0 before receiving the last data.

Figure 12-96. Flowchart of Stop Condition Generation



12.7.5 Calculating Transfer Rate

The transfer rate for simplified I²C (IIC00, IIC01) communication can be calculated by the following expressions.

$$(\text{Transfer rate}) = \{\text{Operation clock (}f_{\text{MCK}}\text{) frequency of target channel}\} \div (\text{SDRmn}[15:9] + 1) \div 2$$

Caution SDRmn[15:9] must not be set to 0000000B. Set SDRmn[15:9] to 0000001B or greater.

The duty ratio of the SCL signal output by the simplified I²C is 50%. The I²C bus specifications define that the low-level width of the SCL signal is longer than the high-level width. If 400 kbps (fast mode) or 1 Mbps (fast mode plus) is specified, therefore, the low-level width of the SCL output signal becomes shorter than the value specified in the I²C bus specifications. Make sure that the SDRmn[15:9] value satisfies the I²C bus specifications.

Remark 1. The value of SDRmn[15:9] is the value of bits 15 to 9 of the SDRmn register (0000001B to 1111111B) and therefore is 1 to 127.

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

The operation clock (f_{MCK}) is determined by serial clock select register m (SPSm) and bit 15 (CKSmn) of serial mode register mn (SMRmn).

Table 12-4. Selection of Operation Clock For Simplified I²C

| SMRmn Register | SPSm Register | | | | | | | | Operation Clock (f _{CLK}) ^{Note 1} | |
|------------------|---------------|---------|---------|---------|---------|---------|---------|---------|---|---------------------------|
| | CKSmn | PRS m13 | PRS m12 | PRS m11 | PRS m10 | PRS m03 | PRS m02 | PRS m01 | PRS m00 | f _{CLK} = 16 MHz |
| 0 | X | X | X | X | 0 | 0 | 0 | 0 | f _{CLK} | 16 MHz |
| | X | X | X | X | 0 | 0 | 0 | 1 | f _{CLK} /2 | 8 MHz |
| | X | X | X | X | 0 | 0 | 1 | 0 | f _{CLK} /2 ² | 4 MHz |
| | X | X | X | X | 0 | 0 | 1 | 1 | f _{CLK} /2 ³ | 2 MHz |
| | X | X | X | X | 0 | 1 | 0 | 0 | f _{CLK} /2 ⁴ | 1 MHz |
| | X | X | X | X | 0 | 1 | 0 | 1 | f _{CLK} /2 ⁵ | 500k Hz |
| | X | X | X | X | 0 | 1 | 1 | 0 | f _{CLK} /2 ⁶ | 250 kHz |
| | X | X | X | X | 0 | 1 | 1 | 1 | f _{CLK} /2 ⁷ | 125 kHz |
| | X | X | X | X | 1 | 0 | 0 | 0 | f _{CLK} /2 ⁸ | 62.5 kHz |
| | X | X | X | X | 1 | 0 | 0 | 1 | f _{CLK} /2 ⁹ | 31.25 kHz |
| | X | X | X | X | 1 | 0 | 1 | 0 | f _{CLK} /2 ¹⁰ | 15.63 kHz |
| | X | X | X | X | 1 | 0 | 1 | 1 | f _{CLK} /2 ¹¹ | 7.81 kHz |
| 1 | 0 | 0 | 0 | 0 | X | X | X | X | f _{CLK} | 16 MHz |
| | 0 | 0 | 0 | 1 | X | X | X | X | f _{CLK} /2 | 8 MHz |
| | 0 | 0 | 1 | 0 | X | X | X | X | f _{CLK} /2 ² | 4 MHz |
| | 0 | 0 | 1 | 1 | X | X | X | X | f _{CLK} /2 ³ | 2 MHz |
| | 0 | 1 | 0 | 0 | X | X | X | X | f _{CLK} /2 ⁴ | 1 MHz |
| | 0 | 1 | 0 | 1 | X | X | X | X | f _{CLK} /2 ⁵ | 500 kHz |
| | 0 | 1 | 1 | 0 | X | X | X | X | f _{CLK} /2 ⁶ | 250 kHz |
| | 0 | 1 | 1 | 1 | X | X | X | X | f _{CLK} /2 ⁷ | 125 kHz |
| | 1 | 0 | 0 | 0 | X | X | X | X | f _{CLK} /2 ⁸ | 62.5 kHz |
| | 1 | 0 | 0 | 1 | X | X | X | X | f _{CLK} /2 ⁹ | 31.25 kHz |
| | 1 | 0 | 1 | 0 | X | X | X | X | f _{CLK} /2 ¹⁰ | 15.63 kHz |
| | 1 | 0 | 1 | 1 | X | X | X | X | f _{CLK} /2 ¹¹ | 7.81 kHz |
| Other than above | | | | | | | | | Setting prohibited | |

Note 1. When changing the clock selected for f_{CLK} (by changing the system clock control register (CKC) value), do so after having stopped (serial channel stop register m (STm) = 000FH) the operation of the serial array unit (SAU).

Remark 1. X: Don't care

Remark 2. m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

Here is an example of setting an I²C transfer rate where $f_{MCK} = f_{CLK} = 16$ MHz.

| I ² C Transfer Mode (Desired Transfer Rate) | $f_{CLK} = 16$ MHz | | | |
|---|-------------------------------|-------------|--------------------------|----------------------------------|
| | Operation Clock (f_{MCK}) | SDRmn[15:9] | Calculated Transfer Rate | Error from Desired Transfer Rate |
| 100 kHz | $f_{CLK}/2$ | 39 | 100 kHz | 0.0% |
| 400 kHz | f_{CLK} | 20 | 380 kHz | 5.0% ^{Note 1} |
| 1 MHz | f_{CLK} | 8 | 0.88 MHz | 11.0% ^{Note 1} |

Note 1. The error cannot be set to about 0% because the duty ratio of the SCL signal is 50%.

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), mn = 00, 01

12.7.6 Procedure for Processing Errors that Occurred during Simplified I²C (IIC00, IIC01) Communication

The procedure for processing errors that occurred during simplified I²C (IIC00, IIC01) communication is described in **Figure 12-97** and **Figure 12-98**.

Figure 12-97. Processing Procedure in Case of Overrun Error

| Software Manipulation | State of the Hardware | Remark |
|--|---|---|
| Reads serial data register mn (SDRmn). | → The BFFmn bit of the SSRmn register is set to 0 and channel n is enabled to receive data. | This is to prevent an overrun error if the next reception is completed during error processing. |
| Reads serial status register mn (SSRmn). | | The error type is identified and the read value is used to clear the error flag. |
| Writes 1 to serial flag clear trigger register mn (SIRmn). | → The error flag is cleared. | Only the error during reading can be cleared, by writing the value read from the SSRmn register to the SIRmn register without modification. |

Figure 12-98. Processing Procedure in Case of ACK Error in Simplified I²C Mode

| Software Manipulation | State of the Hardware | Remark |
|--|--|--|
| Reads serial status register mn (SSRmn). | | The error type is identified and the read value is used to clear the error flag. |
| Writes serial flag clear trigger register mn (SIRmn). | → The error flag is cleared. | Only the error during reading can be cleared, by writing the value read from the SSRmn register to the SIRmn register without modification. |
| Sets the STmn bit of serial channel stop register m (STm) to 1. | → The SEMn bit of serial channel enable status register m (SEm) is set to 0 and channel n stops operation. | The slave is not ready for reception because ACK is not returned. |
| Creates a stop condition. | | Therefore, a stop condition is created, the bus is released, and communication is started again from the start condition. Or, a restart condition is generated and transmission can be redone from address transmission. |
| Creates a start condition. | | |
| Sets the SSmn bit of serial channel start register m (SSm) to 1. | → The SEMn bit of serial channel enable status register m (SEm) is set to 1 and channel n is enabled to operate. | |

Remark m: Unit number (m = 0), n: Channel number (n = 0, 1), r: IIC number (r = 00, 01), mn = 00, 01

CHAPTER 13 SERIAL INTERFACE IICA

13.1 Functions of Serial Interface IICA

The serial interface IICA has the following three modes.

1) Operation stop mode

This mode is used when serial transfers are not performed. The operating power can be reduced in this mode.

2) I²C bus mode (multi-master supported)

This mode is used for 8-bit data transfers with several devices via two lines: a serial clock (SCLA0) line and a serial data bus (SDAA0) line.

It complies with the I²C bus format and the master can generate “start condition”, “address”, “transfer direction specification”, “data”, and “stop condition” to the slave on the serial data bus. The slave automatically detects these received states and data by hardware. This function can simplify the part of application program that controls the I²C bus.

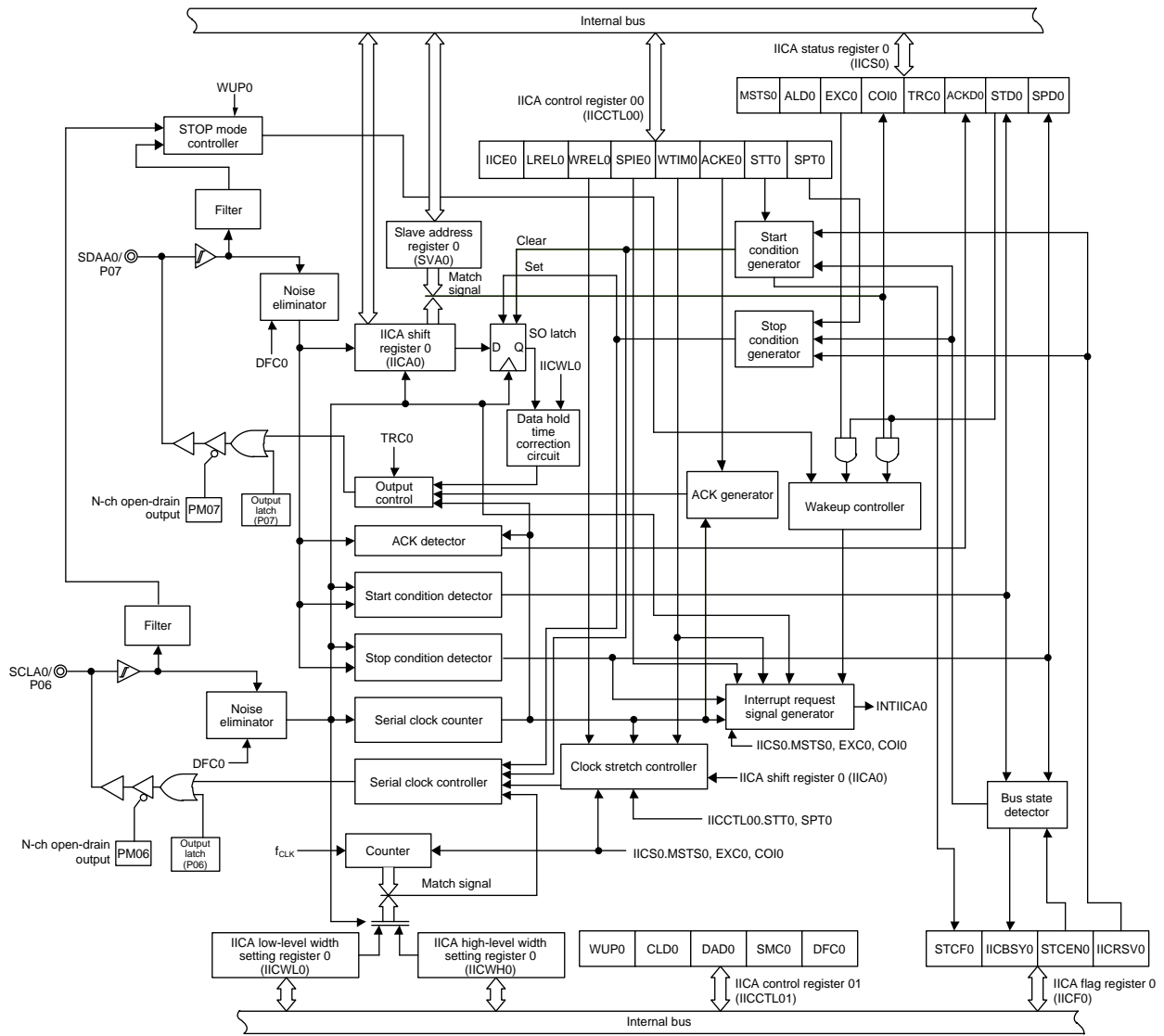
Since the SCLA0 and SDAA0 pins are used for open drain outputs, serial interface IICA requires pull-up resistors for the serial clock line and the serial data bus line.

3) Wakeup mode

The STOP mode can be released by generating an interrupt request signal (INTIICA0) when an extension code from the master or the local address has been received while in STOP mode. This can be set by using the WUP0 bit of IICA control register 01 (IICCTL01).

Figure 13-1 shows a block diagram of serial interface IICA.

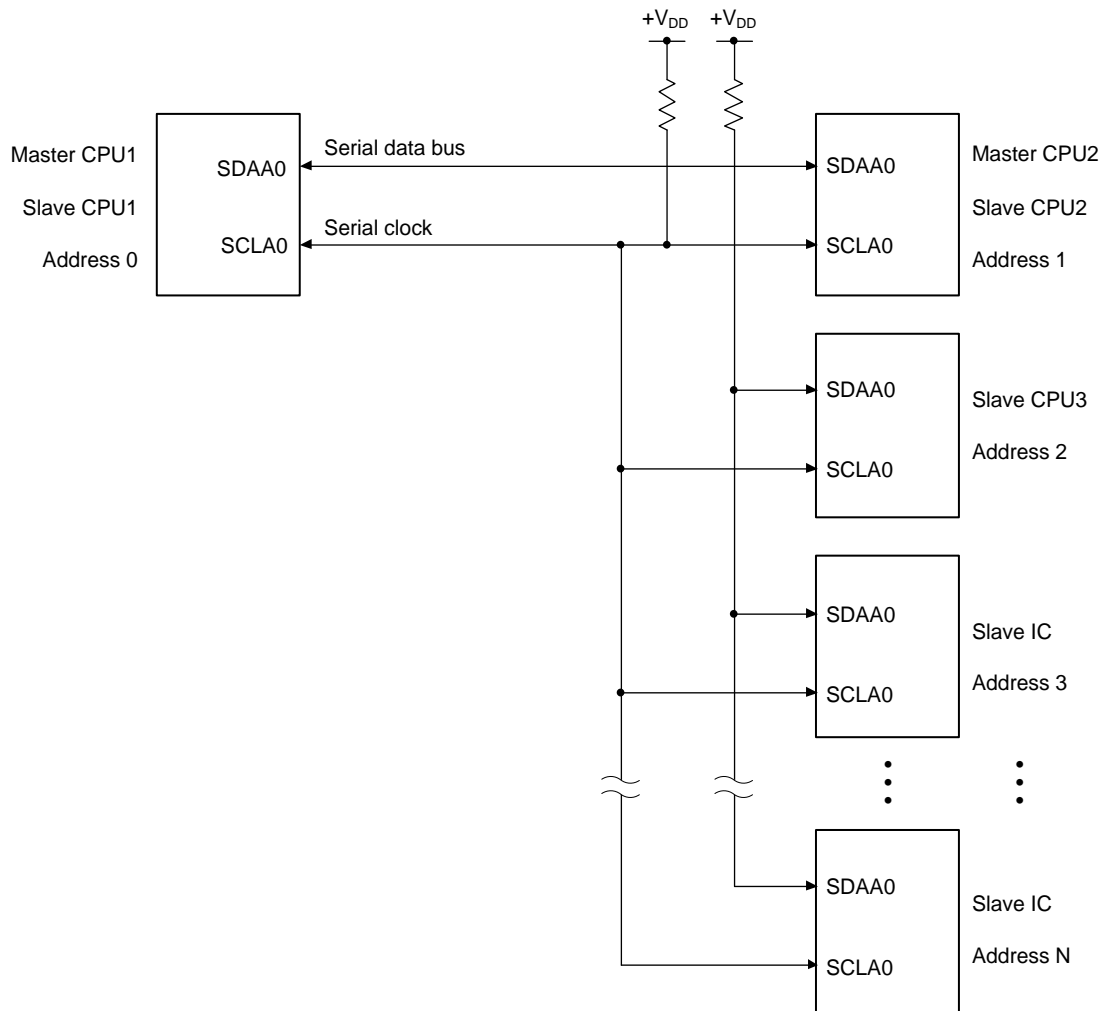
Figure 13-1. Block Diagram of Serial Interface IICA



Remark The IICA pins in this figure are when PIOR14 = 0 for 16- and 20-pin products.

Figure 13-2 shows a serial bus configuration example.

Figure 13-2. Serial Bus Configuration Example Using I²C Bus



13.2 Configuration of Serial Interface IICA

Serial interface IICA includes the following hardware.

Table 13-1. Configuration of Serial Interface IICA

| Item | Configuration |
|-------------------|---|
| Registers | IICA shift register 0 (IICA0) Slave address register 0 (SVA0) |
| Control registers | Peripheral enable register 0 (PER0) IICA control register 00 (IICCTL00) IICA status register 0 (IICS0) IICA flag register 0 (IICF0) IICA control register 01 (IICCTL01) IICA low-level width setting register 0 (IICWL0) IICA high-level width setting register 0 (IICWH0) Port mode register 0 (PM0) Port register 0 (P0) Port output mode register 0 (POM0) Port mode control register 0 (PMC0) |

(1) IICA shift register 0 (IICA0)

The IICA0 register is used to convert 8-bit serial data to 8-bit parallel data and vice versa in synchronization with the serial clock. The IICA0 register can be used for both transmission and reception.

The actual transmit and receive operations can be controlled by writing to and reading from the IICA0 register.

Writing to the IICA0 register during the clock stretch period releases clock stretching and starts data transfer.

The IICA0 register can be set by an 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 13-3. Format of IICA Shift Register 0 (IICA0)

Address: FFF50H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|---|---|---|---|---|
| IICA0 | | | | | | | | |

Caution 1. Do not write data to the IICA0 register during data transfer.

Caution 2. Write to or read from the IICA0 register only during the clock stretch period. Access to the IICA0 register in the communication state other than during the clock stretch period is prohibited. When the device serves as the master, however, the IICA0 register can be written only once after the communication trigger bit (STT0) is set to 1.

Caution 3. When communication is reserved, write data to the IICA0 register after the interrupt triggered by a stop condition is detected.

(2) Slave address register 0 (SVA0)

This register holds seven bits (A6, A5, A4, A3, A2, A1, and A0) of the local address when in slave mode.

The SVA0 register can be set by an 8-bit memory manipulation instruction.

However, rewriting to this register is prohibited while STD0 = 1 (the start condition is detected).

Reset signal generation clears this register to 00H.

Figure 13-4. Format of Slave Address Register 0 (SVA0)

Address: F0234H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|----|----|----|----|----|----|----|---------------------|
| SVA0 | A6 | A5 | A4 | A3 | A2 | A1 | A0 | 0 ^{Note 1} |

Note 1. Be sure to clear bit 0 to 0.

(3) SO latch

The SO latch is used to retain the output level of the SDAA0 pin.

(4) Wakeup controller

This circuit generates an interrupt request (INTIICA0) when the received address matches the address value set in slave address register 0 (SVA0) or when an extension code is received.

(5) Serial clock counter

This counter counts the serial clock cycles that are output or input during transmit/receive operations and is used to verify that 8-bit data has been transmitted or received.

(6) Interrupt request signal generator

This circuit controls the generation of an interrupt request signal (INTIICA0).

An I²C interrupt request is generated by the following two triggers.

- Falling edge of 8th or 9th clock of the serial clock (set by the WTIM0 bit)
- Interrupt request generated when a stop condition is detected (set by the SPIE0 bit)

Remark WTIM0 bit: Bit 3 of IICA control register 00 (IICCTL00)
SPIE0 bit: Bit 4 of IICA control register 00 (IICCTL00)

(7) Serial clock controller

In master mode, this circuit generates the clock for output to the SCLA0 pin from a sampling clock.

(8) Clock stretch controller

This circuit controls the timing of clock stretching.

(9) ACK generator, stop condition detector, start condition detector, and ACK detector

These circuits generate and detect each state.

(10) Data hold time correction circuit

This circuit generates the hold time for data after the falling edge of the serial clock.

(11) Start condition generator

This circuit generates a start condition when the STT0 bit is set to 1.

However, while communication reservation is disabled (IICRSV0 bit = 1) and the bus is not released (IICBSY0 bit = 1), start condition requests are ignored and the STCF0 bit is set to 1.

(12) Stop condition generator

This circuit generates a stop condition when the SPT0 bit is set to 1.

(13) Bus state detector

This circuit detects whether or not the bus is released by detecting a start condition or stop condition.

However, as the bus state cannot be detected immediately after the operation, use the STCEN0 bit to set the initial state of this circuit.

Remark STT0 bit: Bit 1 of IICA control register 00 (IICCTL00)
SPT0 bit: Bit 0 of IICA control register 00 (IICCTL00)
IICRSV0 bit: Bit 0 of IICA flag register 0 (IICF0)
IICBSY0 bit: Bit 6 of IICA flag register 0 (IICF0)
STCF0 bit: Bit 7 of IICA flag register 0 (IICF0)
STCEN0 bit: Bit 1 of IICA flag register 0 (IICF0)

13.3 Registers Controlling Serial Interface IICA

Serial interface IICA is controlled by the following registers.

- Peripheral enable register 0 (PER0)
- IICA control register 00 (IICCTL00)
- IICA flag register 0 (IICF0)
- IICA status register 0 (IICS0)
- IICA control register 01 (IICCTL01)
- IICA low-level width setting register 0 (IICWLO)
- IICA high-level width setting register 0 (IICWH0)
- Port mode register 0 (PM0)
- Port register 0 (P0)
- Port output mode register 0 (POM0)
- Port mode control register 0 (PMC0)

13.3.1 Peripheral enable register 0 (PER0)

The PER0 register is used to enable or disable the supply of a clock signal to various on-chip peripheral modules. Clock supply to an on-chip peripheral module that is not to be used can be stopped to decrease power consumption and noise.

When serial interface IICA is used, be sure to set bit 4 (IICA0EN) to 1.

The PER0 register can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears this register to 00H.

Figure 13-5. Format of Peripheral Enable Register 0 (PER0)

Address: F00F0H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|---|----------|---|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PER0 | TMKAEN | CMPEN | ADCEN | IICA0EN | 0 | SAU0EN | 0 | TAU0EN |

| IICA0EN | Control of serial interface IICA input clock supply |
|---------|---|
| 0 | Stops supply of an input clock. <ul style="list-style-type: none"> The SFRs used by serial interface IICA cannot be written. Serial interface IICA is in the reset state. |
| 1 | Enables supply of an input clock. <ul style="list-style-type: none"> The SFRs used by serial interface IICA can be read/written. |

Caution 1. When setting serial interface IICA, make sure that the setting of the IICA0EN bit is 1 before setting the following registers. If IICA0EN = 0, the values of the registers which control the serial interface IICA are cleared to their initial values, and writing to them is ignored (except for port mode register 0 (PM0), port register 0 (P0), port output mode register 0 (POM0), and port mode control register 0 (PMC0)).

- IICA control register 00 (IICCTL00)
- IICA flag register 0 (IICF0)
- IICA status register 0 (IICS0)
- IICA control register 01 (IICCTL01)
- IICA low-level width setting register 0 (IICWL0)
- IICA high-level width setting register 0 (IICWH0)

Caution 2. Be sure to clear bits 1 and 3 to 0.

13.3.2 IICA control register 00 (IICCTL00)

This register is used to enable or stop I²C operations, set the timing of clock stretching, and set other I²C operations.

The IICCTL00 register can be set by a 1-bit or 8-bit memory manipulation instruction. Note that the SPIE0, WTIM0, and ACKE0 bits must be set while the setting of IICE0 is 0 or during the clock stretch period. These bits can be set at the same time when the IICE0 bit is set from 0 to 1.

Reset signal generation clears this register to 00H.

Figure 13-6. Format of IICA Control Register 00 (IICCTL00) (1/4)

Address: F0230H After reset: 00H R/W

| | | | | | | | | |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| IICCTL00 | IICE0 | LRELO | WRELO | SPIE0 | WTIM0 | ACEK0 | STT0 | SPT0 |

| | |
|---|---|
| IICE0 | I ² C operation enable |
| 0 | Stops operation. Resets IICA status register 0 (IICS0) ^{Note 1} . Also stops internal operation. |
| 1 | Enables operation. |
| Be sure to set this bit (1) while the SCLA0 and SDAA0 lines are at the high level. | |
| Condition for clearing (IICE0 = 0) | |
| <ul style="list-style-type: none"> • Cleared by instruction • Reset | Condition for setting (IICE0 = 1) |
| | <ul style="list-style-type: none"> • Set by instruction |

| | |
|--|---|
| LRELO Note 2, Note 3 | Exit from communications |
| 0 | Normal operation |
| 1 | <p>The device exits from the current communications and enters standby mode. This setting is automatically cleared to 0 after having been executed.</p> <p>This bit is used when an extension code not related to the local station is received.</p> <p>The SCLA0 and SDAA0 lines go into the high impedance state.</p> <p>The following flags of IICA control register 00 (IICCTL00) and IICA status register 0 (IICS0) are cleared to 0.</p> <p>STT0, SPT0, MSTS0, EXC0 COI0, TRC0, ACKD0, STD0</p> |
| The standby mode following exit from communications remains in effect until the following communication participation conditions are met. | |
| <ul style="list-style-type: none"> • After a stop condition is detected, startup is in master mode. • An address match or extension code reception after the start condition | |
| Condition for clearing (LRELO = 0) | |
| <ul style="list-style-type: none"> • Automatically cleared after execution • Reset | Condition for setting (LRELO = 1) |
| | <ul style="list-style-type: none"> • Set by instruction |

Figure 13-6. Format of IICA Control Register 00 (IICCTL00) (2/4)

| WRELO Note 2, Note 3 | Release clock stretching |
|---|--|
| 0 | Clock stretching is not released. |
| 1 | Clock stretching is released. This bit is automatically cleared to 0 after clock stretching has been released. |
| When the WRELO bit is set (clock stretching is released) during the clock stretch period at the 9th clock pulse in the transmission state (TRC0 = 1), the SDAA0 line goes into the high impedance state (TRC0 = 0). | |
| Condition for clearing (WRELO = 0) | |
| <ul style="list-style-type: none"> Automatically cleared after execution Reset | Condition for setting (WRELO = 1) |
| | <ul style="list-style-type: none"> Set by instruction |

| SPIE0 ^{Note 4} | Enable/disable generation of interrupt request when stop condition is detected |
|---|--|
| 0 | Disable |
| 1 | Enable |
| If the WUP0 bit of IICA control register 01 (IICCTL01) is 1, no stop condition interrupt will be generated even if SPIE0 = 1. | |
| Condition for clearing (SPIE0 = 0) | |
| <ul style="list-style-type: none"> Cleared by instruction Reset | Condition for setting (SPIE0 = 1) |
| | <ul style="list-style-type: none"> Set by instruction |

| WTIM0 ^{Note 4} | Control of clock stretching and interrupt request generation |
|---|---|
| 0 | An interrupt request is generated on the falling edge of the 8th clock. Master mode: After the output of 8 clock pulses, the clock is stretched while the clock output is at the low level. Slave mode: After the input of 8 clock pulses, the clock is set to the low level to stretch the master's clock. |
| 1 | An interrupt request is generated on the falling edge of the 9th clock. Master mode: After the output of 9 clock pulses, the clock is stretched while the clock output is at the low level. Slave mode: After the input of 9 clock pulses, the clock is set to the low level to stretch the master's clock. |
| An interrupt is generated on the falling edge of the 9th clock during address transfer independently of the setting of this bit. The setting of this bit is valid after the completion of address transfer. In master mode, clock stretching is applied at the falling edge of the 9th clock during address transfer. For a slave that has received its local address, clock stretching is applied at the falling edge of the 9th clock after an acknowledge (ACK) has been issued. However, if the slave has received an extension code, clock stretching is applied at the falling edge of the 8th clock. | |
| Condition for clearing (WTIM0 = 0) | |
| <ul style="list-style-type: none"> Cleared by instruction Reset | Condition for setting (WTIM0 = 1) |
| | <ul style="list-style-type: none"> Set by instruction |

Figure 13-6. Format of IICA Control Register 00 (IICCTL00) (3/4)

| | |
|---|--|
| ACKE0 <small>Note 4, Note 5</small> | Acknowledgment control |
| 0 | Disables acknowledgment. |
| 1 | Enables acknowledgment. During the 9th clock period, the SDAA0 line is set to low level. |
| Condition for clearing (ACKE0 = 0) | |
| <ul style="list-style-type: none"> • Cleared by instruction • Reset | Condition for setting (ACKE0 = 1) |
| | <ul style="list-style-type: none"> • Set by instruction |

| | |
|---|--|
| STT0 <small>Note 2, Note 6</small> | Start condition trigger |
| 0 | A start condition is not generated. |
| 1 | When the bus is released (in standby state, when IICBSY0 = 0): If this bit is set (1), a start condition is generated (startup as the master). When a third party is communicating: <ul style="list-style-type: none"> • When communication reservation is enabled (IICRSV0 = 0) Functions as the start condition reservation flag. When set to 1, automatically generates a start condition after the bus has been released. • When communication reservation is disabled (IICRSV0 = 1) The STT0 bit is cleared even if it is set (1), and the STT0 clear flag (STCF0) is set (1). No start condition is generated. In the clock stretch state (in master mode): Releases clock stretching to generate a restart condition. |
| Cautions concerning set timing | |
| <ul style="list-style-type: none"> • For master reception: Setting this bit to 1 during transfer is prohibited. It can be set to 1 only during the clock stretch period after the ACKE0 bit has been cleared to 0 and the slave has been notified of final reception. • For master transmission: A start condition cannot be generated normally during the acknowledge period. Set to 1 during the clock stretch period following the output of the 9th clock. • Setting this bit to 1 at the same time as the stop condition trigger (SPT0) is prohibited. • Once the STT0 bit is set to 1, setting it to 1 again before the clear condition is met is prohibited. | |
| Condition for clearing (STT0 = 0) | |
| <ul style="list-style-type: none"> • Setting the STT0 bit to 1 while communication reservation is prohibited • A loss in arbitration • A start condition is generated by the master • Cleared by LREL0 = 1 (exit from communications) • When IICE0 = 0 (operation stop) • Reset | Condition for setting (STT0 = 1) |
| | <ul style="list-style-type: none"> • Set by instruction |

Figure 13-6. Format of IICA Control Register 00 (IICCTL00) (4/4)

| SPT0 ^{Note 7} | Stop condition trigger | | | | |
|--|--|-----------------------------------|----------------------------------|---|--|
| 0 | A stop condition is not generated. | | | | |
| 1 | A stop condition is generated (termination of transfer as a master). | | | | |
| Cautions concerning set timing <ul style="list-style-type: none"> For master reception: Setting this bit to 1 during transfer is prohibited. It can be set to 1 only during the clock stretch period after the ACKE0 bit has been cleared to 0 and the slave has been notified of final reception. For master transmission: A stop condition cannot be generated normally during the acknowledge period. Therefore, set it to 1 during the clock stretch period following the output of the 9th clock. Setting this bit to 1 at the same time as the start condition trigger (STT0) is prohibited. Set the SPT0 bit to 1 only when in master mode. Note that if the SPT0 bit is set to 1 during the clock stretch period following the output of 8 clock pulses while WTIM0 = 0, a stop condition is generated during the high-level period of the 9th clock after clock stretching has been released. The WTIM0 bit should be changed from 0 to 1 during the clock stretch period following the output of 8 clock pulses, and the SPT0 bit should be set to 1 during the clock stretch period following the 9th clock output. Once the SPT0 bit is set to 1, setting it to 1 again before the clear condition is met is prohibited. | | | | | |
| <table border="1"> <thead> <tr> <th>Condition for clearing (STT0 = 0)</th> <th>Condition for setting (STT0 = 1)</th> </tr> </thead> <tbody> <tr> <td> <ul style="list-style-type: none"> A loss in arbitration Automatically cleared after the detection of the stop condition Cleared by LREL0 = 1 (exit from communications) When IICE0 = 0 (operation stop) Reset </td> <td> <ul style="list-style-type: none"> Set by instruction </td> </tr> </tbody> </table> | | Condition for clearing (STT0 = 0) | Condition for setting (STT0 = 1) | <ul style="list-style-type: none"> A loss in arbitration Automatically cleared after the detection of the stop condition Cleared by LREL0 = 1 (exit from communications) When IICE0 = 0 (operation stop) Reset | <ul style="list-style-type: none"> Set by instruction |
| Condition for clearing (STT0 = 0) | Condition for setting (STT0 = 1) | | | | |
| <ul style="list-style-type: none"> A loss in arbitration Automatically cleared after the detection of the stop condition Cleared by LREL0 = 1 (exit from communications) When IICE0 = 0 (operation stop) Reset | <ul style="list-style-type: none"> Set by instruction | | | | |

Note 1. The IICA status register 0 (IICA0), the STCF0 and IICBSY0 bits of IICA flag register 0 (IICF0), and the CLD0 and DAD0 bits of IICA control register 01 (IICCTL01) are reset.

Note 2. The signal of this bit is invalid while IICE0 = 0.

Note 3. Reading the LREL0 and WREL0 bits always returns 0.

Note 4. The signal of this bit is invalid while IICE0 = 0. Set this bit during that period.

Note 5. The set value is invalid during address transfer and if the code is not an extension code.

When the device serves as a slave and the addresses match, an acknowledgment is generated regardless of the set value.

Note 6. The STT0 bit is always read as 0.

Note 7. The SPT0 bit is always read as 0.

Caution 1. If the operation of I²C is enabled (IICE0 = 1) when the SCLA0 line is at the high level, the SDAA0 line is at the low level, and the digital filter is turned on (DFC0 of the IICCTL01 register = 1), a start condition will be inadvertently detected immediately. In this case, set (1) the LREL0 bit by using a 1-bit memory manipulation instruction immediately after enabling operation of I²C (IICE0 = 1).

Caution 2. While bit 3 (TRC0) of IICA status register 0 (IICS0) is 1 (transmission state), if bit 5 (WREL0) of IICA control register 00 (IICCTL00) is set to 1 at the 9th clock to release clock stretching, the TRC0 bit is cleared (reception state) and the SDAA0 line is set to the high impedance state. Release clock stretching while the TRC0 bit is 1 (transmission state) by writing to IICA shift register 0.

Remark IICRSV0: Bit 0 of IICA flag register 0 (IICF0)
STCF0: Bit 7 of IICA flag register 0 (IICF0)

13.3.3 IICA status register 0 (IICS0)

This register indicates the state of the I²C.

The IICS0 register can only be read by a 1-bit or 8-bit memory manipulation instruction while the setting of STT0 is 1 or during the clock stretch period.

Reset signal generation clears this register to 00H.

Caution Reading the IICS0 register while the address match wakeup function is enabled (WUP0 = 1) in STOP mode is prohibited. When the WUP0 bit is changed from 1 to 0 (wakeup operation is stopped), regardless of the INTIICA0 interrupt request signal, the change in the state is not reflected until the next start condition or stop condition is detected. To use the wakeup function, therefore, enable the generation of an interrupt on detection of a stop condition (SPIE0 = 1) and read the IICS0 register after the interrupt has been detected.

Remark STT0: Bit 1 of IICA control register 00 (IICCTL00)
 WUP0: Bit 7 of IICA control register 01 (IICCTL01)

Figure 13-7. Format of IICA Status Register 0 (IICS0) (1/3)

Address: FFF51H After reset: 00H R

| | | | | | | | | |
|--------|----------|----------|----------|----------|----------|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| IICS0 | MSTS0 | ALD0 | EXC0 | COI0 | TRC0 | ACKD0 | STD0 | SPD0 |

| | |
|--|--|
| MSTS0 | Master state check flag |
| 0 | Slave state or communication standby state |
| 1 | Master communication state |
| Condition for clearing (MSTS0 = 0) | |
| <ul style="list-style-type: none"> When a stop condition is detected When ALD0 = 1 (arbitration loss) Cleared by LREL0 = 1 (exit from communications) When the IICE0 bit changes from 1 to 0 (operation stop) Reset | |
| Condition for setting (MSTS0 = 1) | |
| <ul style="list-style-type: none"> When a start condition is generated | |

| | |
|---|---|
| ALD0 | Detection of arbitration loss |
| 0 | Indicates that no arbitration has occurred or a win in arbitration. |
| 1 | Indicates a loss in arbitration. The MSTS0 bit is cleared. |
| Condition for clearing (ALD0 = 0) | |
| <ul style="list-style-type: none"> Automatically cleared after the IICS0 register has been read^{Note 1} When the IICE0 bit changes from 1 to 0 (operation stop) Reset | |
| Condition for setting (ALD0 = 1) | |
| <ul style="list-style-type: none"> A loss in arbitration | |

Figure 13-7. Format of IICA Status Register 0 (IICS0) (2/3)

| EXC0 | Detection of extension code reception | |
|--|---------------------------------------|--|
| 0 | Extension code was not received. | |
| 1 | Extension code was received. | |
| Condition for clearing (EXC0 = 0) | | Condition for setting (EXC0 = 1) |
| <ul style="list-style-type: none"> When a start condition is detected When a stop condition is detected Cleared by LREL0 = 1 (exit from communications) When the IICE0 bit changes from 1 to 0 (operation stop) Reset | | <ul style="list-style-type: none"> When the higher four bits of the received address data is either "0000" or "1111" (set at the rising edge of the 8th clock). |

| COI0 | Address match detection | |
|--|-----------------------------|--|
| 0 | The addresses do not match. | |
| 1 | The addresses match. | |
| Condition for clearing (COI0 = 0) | | Condition for setting (COI0 = 1) |
| <ul style="list-style-type: none"> When a start condition is detected When a stop condition is detected Cleared by LREL0 = 1 (exit from communications) When the IICE0 bit changes from 1 to 0 (operation stop) Reset | | <ul style="list-style-type: none"> When the received address matches the local address (slave address register 0 (SVA0)) (set at the rising edge of the 8th clock). |

| TRC0 | Transmission/reception state detection | |
|--|--|---|
| 0 | Reception state (not in the transmission state). The SDAA0 line is set to high impedance. | |
| 1 | Transmission state. Enable the output of the value in the SO0 latch to the SDAA0 line (valid after the falling edge of the 9th clock of the first byte). | |
| Condition for clearing (TRC0 = 0) | | Condition for setting (TRC0 = 1) |
| <p><Both master and slave></p> <ul style="list-style-type: none"> When a stop condition is detected Cleared by LREL0 = 1 (exit from communications) When the IICE0 bit changes from 1 to 0 (operation stop) Cleared by WREL0 = 1 (clock stretching released)^{Note 2} When the ALD0 bit changes from 0 to 1 (arbitration loss) Reset When not participating in communications (MSTS0, EXC0, COI0 = 0) <p><Master></p> <ul style="list-style-type: none"> When 1 is output to the LSB (transfer direction specification bit) of the first byte <p><Slave></p> <ul style="list-style-type: none"> When a start condition is detected When 0 is input to the LSB (transfer direction specification bit) of the first byte | | <p><Master></p> <ul style="list-style-type: none"> When a start condition is generated When 0 (master transmission) is output to the LSB (transfer direction specification bit) of the first byte (during address transfer) <p><Slave></p> <ul style="list-style-type: none"> When 1 (slave transmission) is input to the LSB (transfer direction specification bit) of the first byte from the master (during address transfer) |

Figure 13-7. Format of IICA Status Register 0 (IICS0) (3/3)

| ACKD0 | Acknowledge (ACK) detection | |
|--|-------------------------------|--|
| 0 | Acknowledge was not detected. | |
| 1 | Acknowledge was detected. | |
| Condition for clearing (ACKD0 = 0) | | Condition for setting (ACKD0 = 1) |
| <ul style="list-style-type: none"> When a stop condition is detected At the rising edge of the first clock of the next byte Cleared by LREL0 = 1 (exit from communications) When the IICE0 bit changes from 1 to 0 (operation stop) Reset | | <ul style="list-style-type: none"> When the SDA0 line is at the low level at the rising edge of the 9th clock of the SCLA0 line |

| STD0 | Start condition detection | |
|---|---|--|
| 0 | A start condition was not detected. | |
| 1 | A start condition was detected. This indicates that the address transfer period is in effect. | |
| Condition for clearing (STD0 = 0) | | Condition for setting (STD0 = 1) |
| <ul style="list-style-type: none"> When a stop condition is detected At the rising edge of the first clock of the next byte following address transfer Cleared by LREL0 = 1 (exit from communications) When the IICE0 bit changes from 1 to 0 (operation stop) Reset | | <ul style="list-style-type: none"> When a start condition is detected |

| SPD0 | Stop condition detection | |
|--|---|---|
| 0 | A stop condition was not detected. | |
| 1 | A stop condition was detected. Communication by the master is terminated and the bus is released. | |
| Condition for clearing (SPD0 = 0) | | Condition for setting (SPD0 = 1) |
| <ul style="list-style-type: none"> At the rising edge of the first clock of the address transfer byte following setting of this bit and detection of a start condition When the WUP0 bit changes from 1 to 0 When the IICE0 bit changes from 1 to 0 (operation stop) Reset | | <ul style="list-style-type: none"> When a stop condition is detected |

Note 1. The ALD0 bit is also cleared when a 1-bit memory manipulation instruction is executed for another bit in the IICS0 register. Therefore, when using the ALD0 bit, read the data of this bit before the data of the other bits.

Note 2. While bit 3 (TRC0) of IICA status register 0 (IICS0) is 1 (transmission state), if bit 5 (WREL0) of IICA control register 00 (IICCTL00) is set to 1 at the 9th clock to release clock stretching, the TRC0 bit is cleared (reception state) and the SDA0 line is set to the high impedance state. Release clock stretching while the TRC0 bit is 1 (transmission state) by writing to IICA shift register 0.

Remark LREL0: Bit 6 of IICA control register 00 (IICCTL00)
IICE0: Bit 7 of IICA control register 00 (IICCTL00)

13.3.4 IICA flag register 0 (IICF0)

This register sets the operation mode of I²C and indicates the state of the I²C bus.

The IICF0 register can be set by a 1-bit or 8-bit memory manipulation instruction. However, the STT0 clear flag (STCF0) and I²C bus status flag (IICBSY0) bits are read-only.

The IICRSV0 bit can be used to enable or disable communication reservation.

The STCEN0 bit can be used to set the initial value of the IICBSY0 bit.

The IICRSV0 and STCEN0 bits can only be written while operation of I²C is disabled (bit 7 (IICE0) of IICA control register 00 (IICCTL00) = 0). The IICF0 register is only readable after the operation is enabled.

Reset signal generation clears this register to 00H.

Figure 13-8. Format of IICA Flag Register 0 (IICF0) (1/2)

Address: FFF52H After reset: 00H R/W^{Note 1}

| | | | | | | | | |
|--------|-------|---------|---|---|---|---|--------|---------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| IICF0 | STCF0 | IICBSY0 | 0 | 0 | 0 | 0 | STCEN0 | IICRSV0 |

| | |
|--|---|
| STCF0 | STT0 clear flag |
| 0 | A start condition is generated. |
| 1 | A start condition cannot be generated and the STT0 flag is cleared. |
| Condition for clearing (STCF0 = 0) | |
| <ul style="list-style-type: none"> • Cleared by STT0 = 1 • When IICE0 = 0 (operation stop) • Reset | |
| Condition for setting (STCF0 = 1) | |
| <ul style="list-style-type: none"> • A start condition cannot be generated when communication reservation is disabled (IICRSV0 = 1) and the STT0 bit is cleared to 0. | |

| | |
|---|--|
| IICBSY0 | I ² C bus status flag |
| 0 | Bus released state (the initial state of communication when STCEN0 = 1) |
| 1 | Bus communication state (the initial state of communication when STCEN0 = 0) |
| Condition for clearing (IICBSY0 = 0) | |
| <ul style="list-style-type: none"> • When a stop condition is detected • When IICE0 = 0 (operation stop) • Reset | |
| Condition for setting (IICBSY0 = 1) | |
| <ul style="list-style-type: none"> • When a start condition is detected • Setting of the IICE0 bit when STCEN0 = 0 | |

| | |
|---|--|
| STCEN0 | Initial start enable trigger |
| 0 | After operation is enabled (IICE0 = 1), enable generation of a start condition upon detection of a stop condition. |
| 1 | After operation is enabled (IICE0 = 1), enable generation of a start condition without detecting a stop condition. |
| Condition for clearing (STCEN0 = 0) | |
| <ul style="list-style-type: none"> • Cleared by instruction • When a start condition is detected • Reset | |
| Condition for setting (STCEN0 = 1) | |
| <ul style="list-style-type: none"> • Set by instruction | |

Figure 13-8. Format of IICA Flag Register 0 (IICF0) (2/2)

| | | |
|---|--|--|
| IICRSV0 | Communication reservation function disable bit | |
| 0 | Enable communication reservation. | |
| 1 | Disable communication reservation. | |
| Condition for clearing (IICRSV0 = 0) | | Condition for setting (IICRSV0 = 1) |
| <ul style="list-style-type: none"> • Cleared by instruction • Reset | | <ul style="list-style-type: none"> • Set by instruction |

Note 1. Bits 7 and 6 are read-only.

Caution 1. Write to the STCEN0 bit only when the operation is stopped (IICE0 = 0).

Caution 2. When STCEN0 = 1, the bus released state (IICBSY0 = 0) is recognized regardless of the actual bus state. Therefore, when generating a first start condition (STT0 = 1), it is necessary to verify that third party communications are not being conducted in order to prevent other communications from being destroyed.

Caution 3. Write to the IICRSV0 bit only when the operation is stopped (IICE0 = 0).

Remark STT0: Bit 1 of IICA control register 00 (IICCTL00)

IICE0: Bit 7 of IICA control register 00 (IICCTL00)

13.3.5 IICA control register 01 (IICCTL01)

This register is used to set the operation mode of I²C and detect the states of the SCLA0 and SDAA0 pins.

The IICCTL01 register can be set by a 1-bit or 8-bit memory manipulation instruction. However, the CLD0 and DAD0 bits are read-only.

Set the IICCTL01 register, except the WUP0 bit, while operation of I²C is disabled (bit 7 (IICE0) of IICA control register 00 (IICCTL00) = 0).

Reset signal generation clears this register to 00H.

Figure 13-9. Format of IICA Control Register 01 (IICCTL01) (1/2)

Address: F0231H After reset: 00H R/W^{Note 1}

| | | | | | | | | |
|----------|----------|---|----------|----------|----------|----------|---|---|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| IICCTL01 | WUP0 | 0 | CLD0 | DAD0 | SMC0 | DFC0 | 0 | 0 |

| | | | | | |
|--|---|-----------------------------------|----------------------------------|--|---|
| WUP0 | Control of address match wakeup | | | | |
| 0 | Stops operation of address match wakeup while in STOP mode. | | | | |
| 1 | Enables operation of address match wakeup while in STOP mode. | | | | |
| <p>To shift to STOP mode when WUP0 = 1, execute the STOP instruction at least three cycles of f_{CLK} after setting (1) the WUP0 bit (see Figure 13-21 Flow when Setting WUP0 = 1).</p> <p>Clear (0) the WUP0 bit after an address match or reception of an extension code. Clearing (0) the WUP0 bit allows participation in subsequent communications (releasing clock stretching and writing transmit data must follow clearing (0) the WUP0 bit).</p> <p>The interrupt timing on an address match or extension code reception while WUP0 = 1 is the same as the interrupt timing when WUP0 = 0 (a delay difference equivalent to the sampling error by the clock is generated). Furthermore, when WUP0 = 1, a stop condition interrupt is not generated even if the SPIE0 bit is set to 1.</p> | | | | | |
| <table border="1"> <tr> <td>Condition for clearing (WUP0 = 0)</td> <td>Condition for setting (WUP0 = 1)</td> </tr> <tr> <td> <ul style="list-style-type: none"> Cleared by instruction (after address match or extension code reception) </td> <td> <ul style="list-style-type: none"> Set by instruction (when MSTS0, EXC0, and COI0 = 0 and STD0 = 0 (non-participation in communications)^{Note 2}) </td> </tr> </table> | | Condition for clearing (WUP0 = 0) | Condition for setting (WUP0 = 1) | <ul style="list-style-type: none"> Cleared by instruction (after address match or extension code reception) | <ul style="list-style-type: none"> Set by instruction (when MSTS0, EXC0, and COI0 = 0 and STD0 = 0 (non-participation in communications)^{Note 2}) |
| Condition for clearing (WUP0 = 0) | Condition for setting (WUP0 = 1) | | | | |
| <ul style="list-style-type: none"> Cleared by instruction (after address match or extension code reception) | <ul style="list-style-type: none"> Set by instruction (when MSTS0, EXC0, and COI0 = 0 and STD0 = 0 (non-participation in communications)^{Note 2}) | | | | |

Figure 13-9. Format of IICA Control Register 01 (IICCTL01) (2/2)

| CLD0 | SCLA0 pin level detection (valid only when IICE0 = 1) | |
|--|---|---|
| 0 | The SCLA0 pin was detected to be at the low level. | |
| 1 | The SCLA0 pin was detected to be at the high level. | |
| Condition for clearing (CLD0 = 0) | | Condition for setting (CLD0 = 1) |
| <ul style="list-style-type: none"> When the SCLA0 pin is at the low level When IICE0 = 0 (operation stop) Reset | | <ul style="list-style-type: none"> When the SCLA0 pin is at the high level |

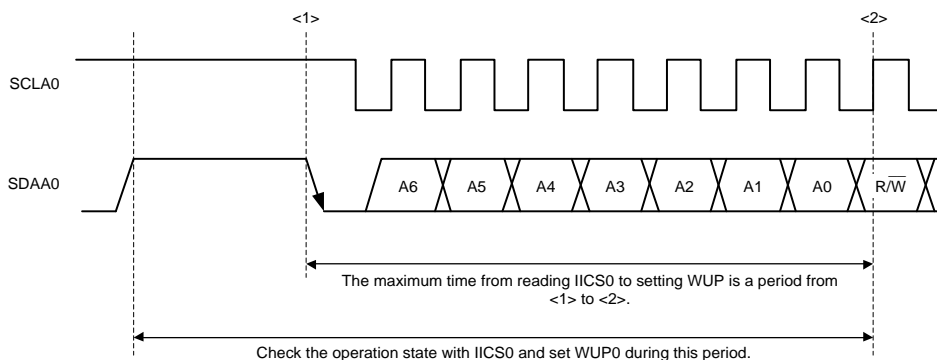
| DAD0 | SDAA0 pin level detection (valid only when IICE0 = 1) | |
|--|---|---|
| 0 | The SDAA0 pin was detected to be at the low level. | |
| 1 | The SDAA0 pin was detected to be at high level. | |
| Condition for clearing (DAD0 = 0) | | Condition for setting (DAD0 = 1) |
| <ul style="list-style-type: none"> When the SDAA0 pin is at the low level When IICE0 = 0 (operation stop) Reset | | <ul style="list-style-type: none"> When the SDAA0 pin is at the high level |

| SMC0 | Operation mode switching | |
|------|--|--|
| 0 | Operates in standard mode (maximum transfer rate: 100 kbps). | |
| 1 | Operates in fast mode (maximum transfer rate: 400 kbps) | |

| DFC0 | Digital filter operation control | |
|--|----------------------------------|--|
| 0 | Digital filter off | |
| 1 | Digital filter on | |
| Use the digital filter only in fast mode. | | |
| The digital filter is used for noise elimination. | | |
| Set (1) or clearing (0) the DFC0 bit does not vary the transfer clock. | | |

Note 1. Bits 5 and 4 are read-only.

Note 2. The WUP0 bit must be set after checking the state of IICA status register 0 (IICS0) during the period shown below.



Caution When setting the transfer clock, take care with the minimum operation frequency of f_{CLK} . The minimum operation frequency of f_{CLK} for serial interface IICA is determined according to the mode.

Normal mode: $f_{CLK} = 1 \text{ MHz (min.)}$

Fast mode: $f_{CLK} = 3.5 \text{ MHz (min.)}$

Remark IICE0: Bit 7 of IICA control register 00 (IICCTL00)

13.3.6 IICA low-level width setting register 0 (IICWLO)

This register is used to set the low-level width (tLOW) of the SCLA0 pin signal that is output by serial interface IICA and to control the SDAA0 pin signal.

The IICWLO register can be set by an 8-bit memory manipulation instruction.

Set the IICWLO register while operation of I²C is disabled (bit 7 (IICE0) of IICA control register 00 (IICCTL00) = 0).

Reset signal generation set this register to FFH.

For details about setting the IICWLO register, see **13.4.2 Setting transfer clock by using IICWLO and IICWH0 registers.**

The data hold time is one-quarter of the time set by the IICWLO register.

Figure 13-10. Format of IICA Low-Level Width Setting Register 0 (IICWLO)

Address: F0232H After reset: FFH R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|---|---|---|---|---|
| IICWLO | | | | | | | | |

13.3.7 IICA high-level width setting register 0 (IICWH0)

This register is used to set the high-level width of the SCLA0 pin signal that is output by serial interface IICA and to control the SDAA0 pin signal.

The IICWH0 register can be set by an 8-bit memory manipulation instruction.

Set the IICWH0 register while operation of I²C is disabled (bit 7 (IICE0) of IICA control register 00 (IICCTL00) = 0).

Reset signal generation set this register to FFH.

Figure 13-11. Format of IICA High-Level Width Setting Register 0 (IICWH0)

Address: F0233H After reset: FFH R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|---|---|---|---|---|
| IICWH0 | | | | | | | | |

Remark For the procedure of setting the transfer clock on the master side, see **13.4.2(1) Setting transfer clock on master side.** For the procedure of setting the IICWLO and IICWH0 registers on the slave side, see **13.4.2(2) Setting IICWLO and IICWH0 registers on slave side.**

13.3.8 Registers controlling port functions of IICA serial input/output pins

When the IICA is to be used, set the registers that control the port functions multiplexed on the IICA serial I/O pins (SCLA0 and SDAA0 pins): port mode register (PM0), port register (P0), port output mode register (POM0), and port mode control register (PMC0).

For details on the registers that control the port functions, see **4.3.1 Port mode registers 0, 2, 4, 12 (PM0, PM2, PM4, PM12)**, **4.3.2 Port registers 0, 2, 4, 12, 13 (P0, P2, P4, P12, P13)**, **4.3.4 Port input mode registers 0, 2, 4 (POM0, POM2, POM4)**, and **4.3.5 Port mode control registers 0, 2 (PMC0, PMC2)**.

When you intend to use the clock I/O pin (SCLA0) and serial data I/O pin (SDAA0) of IICA0, set the corresponding bits in port mode register (PM0) and port mode control register (PMC0) to 0 and the corresponding bits in port register (P0) and port output mode register (POM0) to 1. For details, see **4.5.3 Register setting examples for used port and alternate functions**.

Since these pins are used as N-ch open-drain outputs (with a withstand voltage of V_{DD}), use a resistor to pull them up to the power-supply voltage of the external device.

13.4 I²C Bus Mode Functions

13.4.1 Pin configuration

The serial clock pin (SCLA0) and the serial data bus pin (SDAA0) are configured as follows.

(1) SCLA0

This pin is used for serial clock input and output.

This pin is an N-ch open-drain output for both master and slave. Input is Schmitt input.

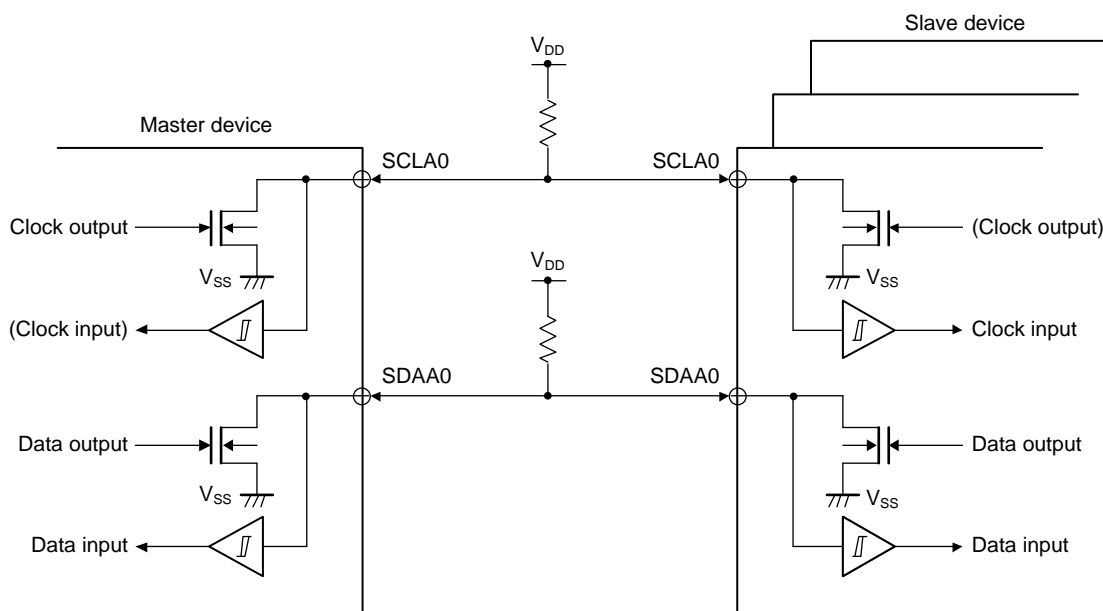
(2) SDAA0

This pin is used for serial data input and output.

This pin is an N-ch open-drain output for both master and slave. Input is Schmitt input.

Since outputs from the serial clock line and the serial data bus line are N-ch open-drain outputs, an external pull-up resistor is required.

Figure 13-12. Pin Configuration Diagram



13.4.2 Setting transfer clock by using IICWL0 and IICWH0 registers

(1) Setting transfer clock on master side

$$\text{Transfer clock} = \frac{f_{\text{CLK}}}{\text{IICWL} + \text{IICWH} + f_{\text{CLK}}(t_{\text{R}} + t_{\text{F}})}$$

At this time, the optimal setting values of the IICWL0 and IICWH0 registers are as follows.

(The fractional parts of all setting values are rounded up.)

- In fast mode

$$\text{IICWL0} = \frac{0.52}{\text{Transfer clock}} \times f_{\text{CLK}}$$

$$\text{IICWH0} = \left(\frac{0.48}{\text{Transfer clock}} - t_{\text{R}} - t_{\text{F}} \right) \times f_{\text{CLK}}$$

- In normal mode

$$\text{IICWL0} = \frac{0.47}{\text{Transfer clock}} \times f_{\text{CLK}}$$

$$\text{IICWH0} = \left(\frac{0.53}{\text{Transfer clock}} - t_{\text{R}} - t_{\text{F}} \right) \times f_{\text{CLK}}$$

(2) Setting IICWL0 and IICWH0 registers on slave side

(The fractional parts of all setting values are rounded up.)

- In fast mode

$$\text{IICWL0} = 1.3 \mu\text{s} \times f_{\text{CLK}}$$

$$\text{IICWH0} = (1.2 \mu\text{s} - t_{\text{R}} - t_{\text{F}}) \times f_{\text{CLK}}$$

- In normal mode

$$\text{IICWL0} = 4.7 \mu\text{s} \times f_{\text{CLK}}$$

$$\text{IICWH0} = (5.3 \mu\text{s} - t_{\text{R}} - t_{\text{F}}) \times f_{\text{CLK}}$$

Caution When setting the transfer clock, take care with the minimum operation frequency of f_{CLK} . The minimum operation frequency of f_{CLK} for serial interface IICA is determined according to the mode.

Fast mode: $f_{\text{CLK}} = 3.5 \text{ MHz (min.)}$

Normal mode: $f_{\text{CLK}} = 1 \text{ MHz (min.)}$

Remark 1. Calculate the rise time (t_{R}) and fall time (t_{F}) of the SDAA0 and SCLA0 signals separately, because they differ depending on the pull-up resistance and wiring capacity.

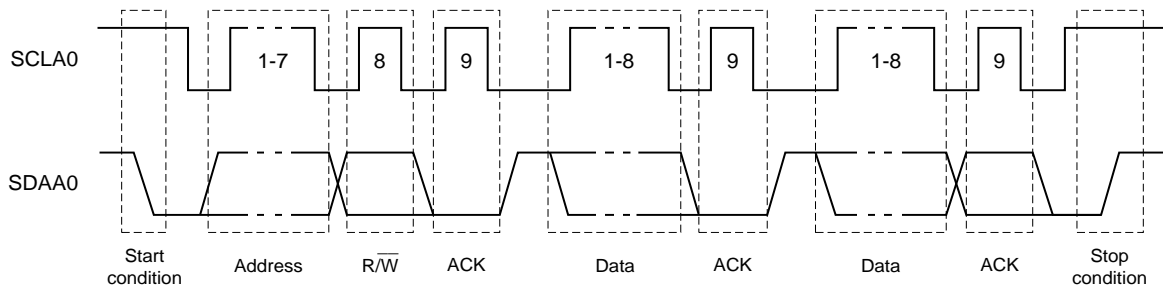
Remark 2. IICWL0: IICA low-level width setting register 0
 IICWH0: IICA high-level width setting register 0
 t_{F} : SDAA0 and SCLA0 signal fall time
 t_{R} : SDAA0 and SCLA0 signal rise time
 f_{CLK} : CPU/peripheral hardware clock frequency

13.5 I²C Bus Definitions and Control Methods

The following describes the serial data communication format of the I²C bus and the signals to be used.

Figure 13-13 shows the timing of transfer of the “start condition”, “address”, “data”, and “stop condition” which are generated on the serial data bus of the I²C bus.

Figure 13-13. I²C Bus Serial Data Transfer Timing



The master generates a start condition, slave address, and stop condition.

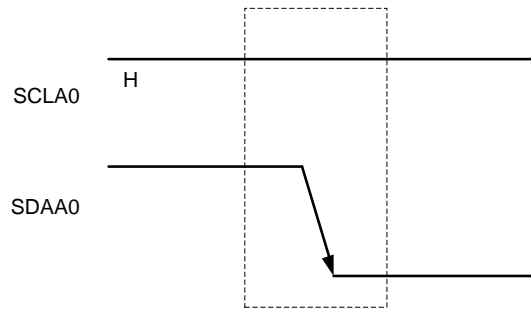
The acknowledge (ACK) can be generated by either the master or slave (normally, it is output by the receiver of 8-bit data).

The serial clock (SCLA0) is continuously output by the master. However, for the slave, a low-level period of the SCLA0 pin can be extended and clock stretching can be inserted.

13.5.1 Start condition

A start condition is generated when the SDAA0 pin changes from the high to the low level while the SCLA0 pin is at the high level. A start condition is a signal that the master generates to the slave when starting a serial transfer. When the device is used as a slave, a start condition can be detected.

Figure 13-14. Start Condition



A start condition is output when bit 1 (STT0) of IICA control register 00 (IICCTL00) is set (1) after a stop condition has been detected (SPD0: Bit 0 of IICA status register 0 (IICS0) = 1). When a start condition is detected, bit 1 (STD0) of the IICS0 register is set (1).

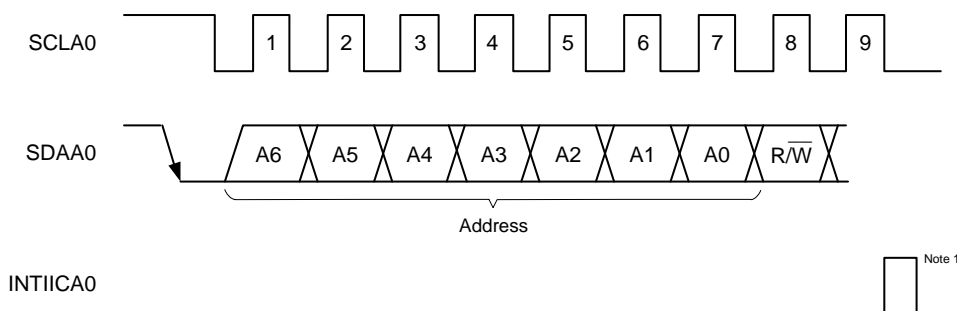
13.5.2 Address

7-bit data that follows a start condition is defined as address.

An address is a 7-bit data segment that is output in order for the master to select a certain slave from among multiple slaves connected to the bus line. Therefore, slaves on the bus line must have different addresses.

A slave detects this condition by the hardware and checks whether the 7-bit data matches the value of slave address register 0 (SVA0). If the 7-bit data matches the value of the SVA0 register at this time, that slave is selected and it communicates with the master until the master generates a start condition or stop condition.

Figure 13-15. Address



Note 1. INTIICA0 is not generated if data other than the local address or extension code is received in slave operation.

The address is output when 8 bits consisting of the slave address and the transfer direction described in **13.5.3 Transfer direction specification** are written to IICA shift register 0 (IICA0). The received address is written to the IICA0 register.

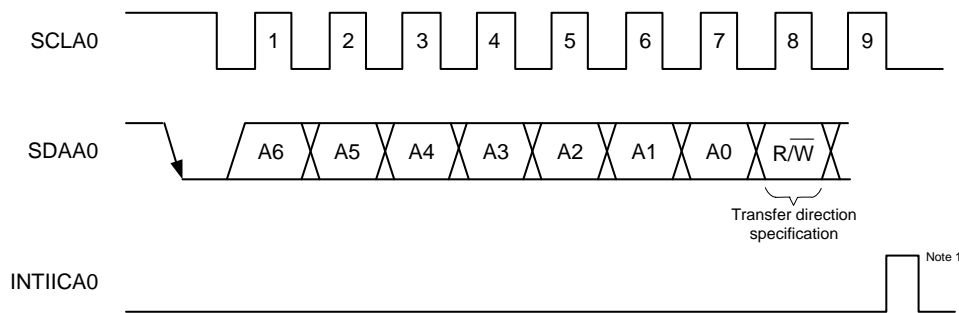
The slave address is assigned to the higher 7 bits of the IICA0 register.

13.5.3 Transfer direction specification

Following the 7-bit address, the master sends 1-bit data to specify the transfer direction.

When this transfer direction specification bit is 0, it indicates that the master is transmitting data to a slave. When the transfer direction specification bit is 1, it indicates that the master is receiving data from a slave.

Figure 13-16. Transfer Direction Specification



Note 1. INTIICA0 is not generated if data other than the local address or extension code is received in slave operation.

13.5.4 Acknowledge (ACK)

ACK is used to check the state of serial data on the transmission and reception sides.

The reception side returns ACK each time it receives 8-bit data.

The transmission side usually receives ACK after transmitting 8-bit data. When ACK is returned from the reception side, it is assumed that reception has been correctly performed and processing is continued. The detection of ACK can be checked by using bit 2 (ACKD0) of IICA status register 0 (IICS0).

When the master receives the last data item, it does not return ACK but generates a stop condition. If a slave does not return ACK in reception, the master outputs a stop condition or restart condition and stops transmission. If ACK is not returned, the following causes can be considered.

- <1> Reception was not performed normally.
- <2> The final data item was received.
- <3> The reception side specified by the address does not exist.

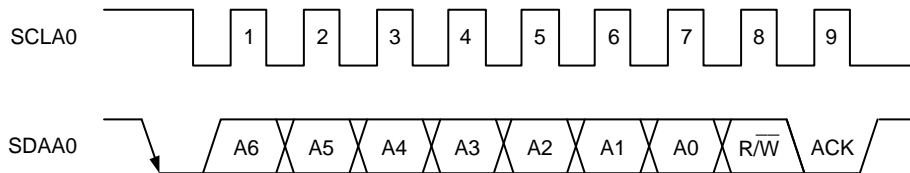
To generate ACK, the reception side sets the SDAA0 line to the low level at the 9th clock (normal reception).

Automatic generation of ACK is enabled by setting bit 2 (ACKE0) of IICA control register 00 (IICCTL00) to 1. Bit 3 (TRC0) of the IICS0 register is set by the 8th bit data that follows 7-bit address information. Usually, set the ACKE0 bit to 1 for reception (TRC0 = 0).

When the slave can no longer receive data during reception (TRC0 = 0) or does not require the next data item, the slave must clear the ACKE0 bit to 0 to inform the master that it cannot receive any more data.

When the master does not require the next data item during reception ($TRC0 = 0$), it must clear the $ACKE0$ bit to 0 so that ACK is not generated. In this way, the master informs the slave (transmission side) of the end of data (transmission will be stopped).

Figure 13-17. ACK



When the local address is received, ACK is automatically generated, regardless of the value of the $ACKE0$ bit. When an address other than the local address is received, ACK is not generated (NACK).

When an extension code is received, ACK is generated if the $ACKE0$ bit is set to 1 in advance.

How ACK is generated in data reception differs with the setting of the clock stretch timing as follows.

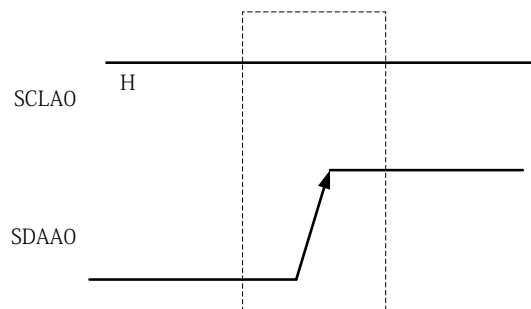
- When the falling edge of the 8th clock is set (bit 3 (WTIM0) of the IICCTL00 register = 0):
By setting the $ACKE0$ bit to 1 before releasing clock stretching, ACK is generated at the falling edge of the 8th clock of the SCLA0 pin.
- When the falling edge of the 9th clock is set (bit 3 (WTIM0) of the IICCTL00 register = 1):
ACK is generated by setting the $ACKE0$ bit to 1 in advance.

13.5.5 Stop condition

A stop condition is generated when the SDA0 pin changes from the low to the high level while the SCLA0 pin is at the high level.

A stop condition is a signal that the master generates to the slave when serial transfer has been completed. A stop condition can be detected when the device is used as a slave.

Figure 13-18. Stop Condition



A stop condition is generated when bit 0 (SPT0) of IICA control register 00 (IICCTL00) is set to 1. When the stop condition is detected, bit 0 (SPD0) of IICA status register 0 (IICS0) is set to 1 and INTIICA0 is generated when bit 4 (SPIE0) of the IICCTL00 register is set to 1.

13.5.6 Clock stretching

Clock stretching is used to notify the other party in communications that a master or slave is preparing to transmit or receive data (i.e., in the clock stretch state).

By setting the SCLA0 pin to the low level, the other party is notified of the clock stretch state. When both the master and slave are released from the clock stretch state, the next data transfer can be started.

Figure 13-19. Clock Stretching (1/2)

(1) When clock stretching occurs at the falling edge of the 9th clock for the master and at the falling edge of the 8th clock for the slave (master: transmission, slave: reception, and ACKE0 = 1)

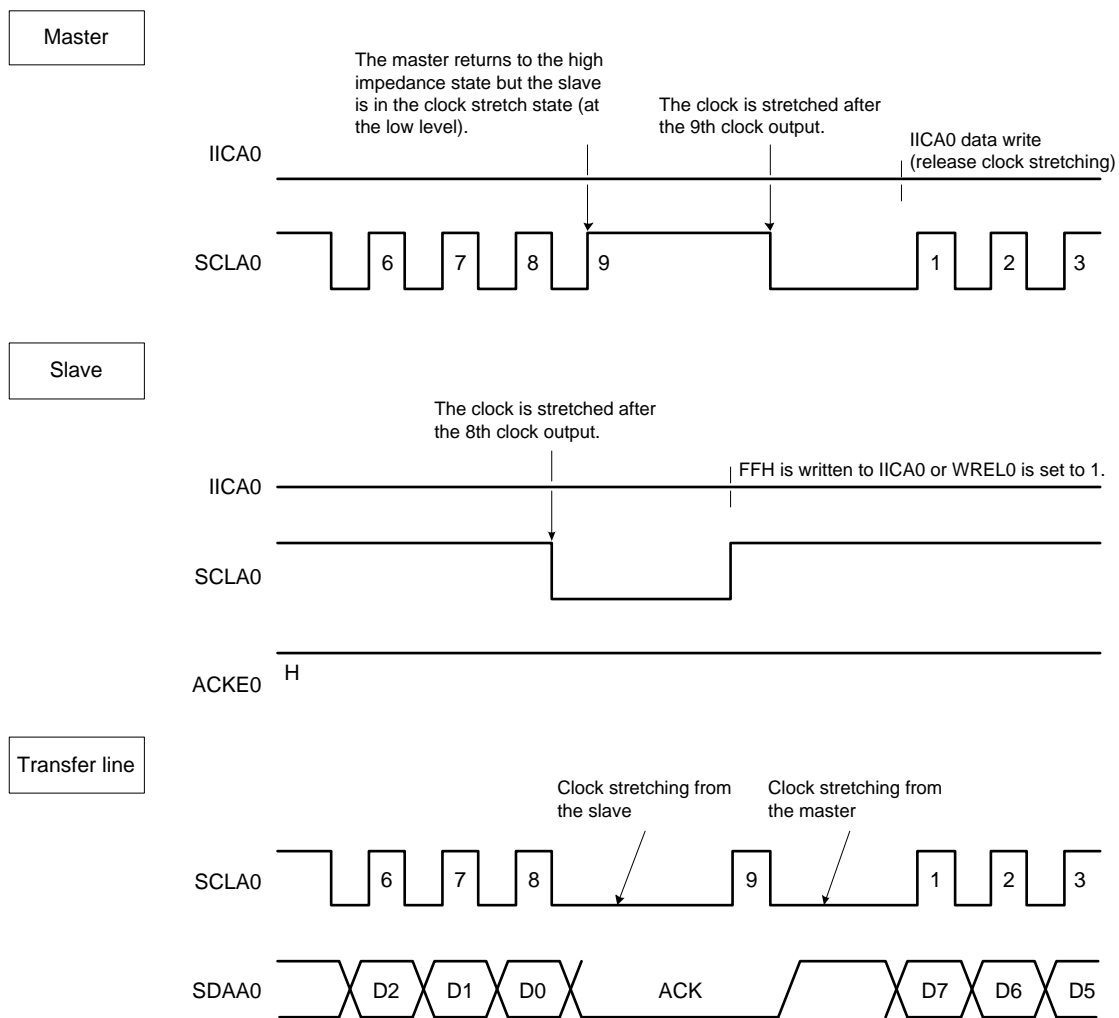
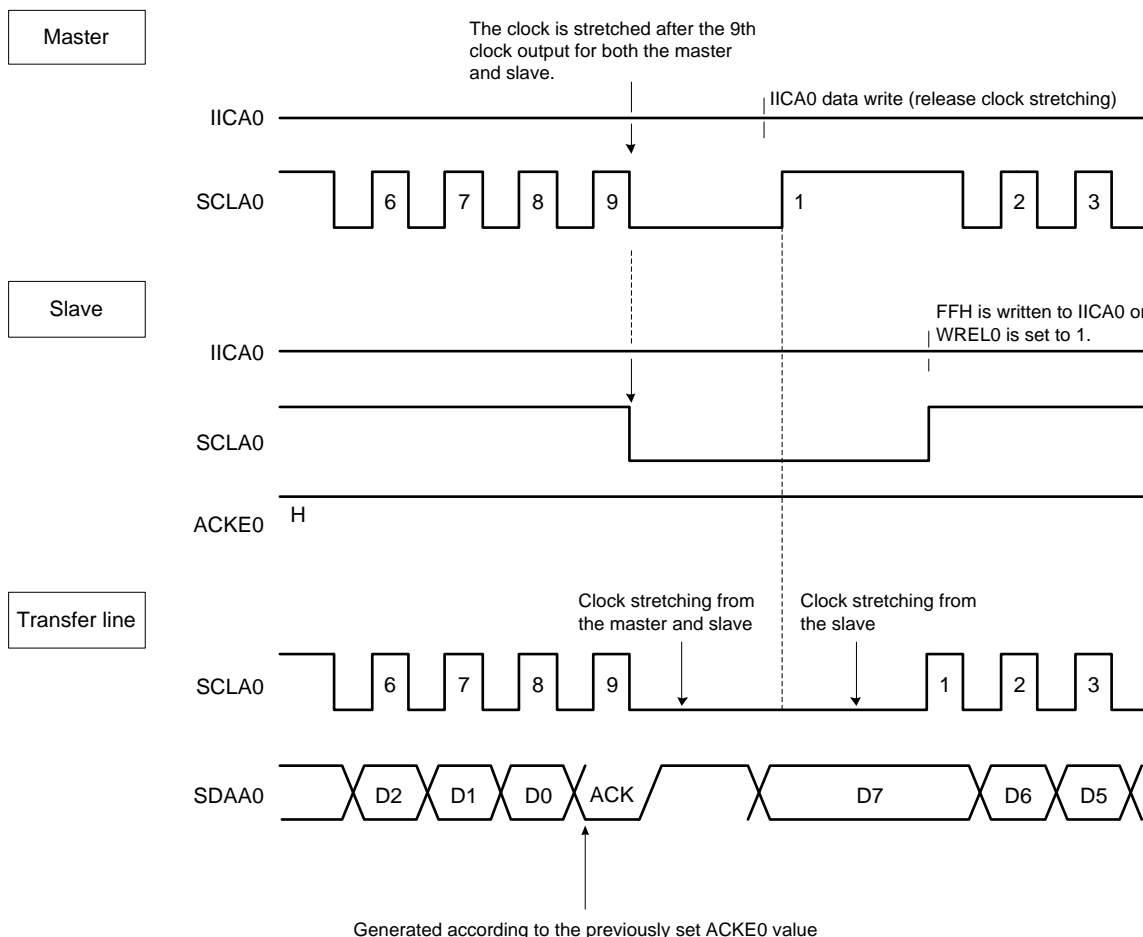


Figure 13-19. Clock Stretching (2/2)

(2) When clock stretching occurs at the falling edge of the 9th clock for both master and slave
 (master: transmission, slave: reception, and ACKE0 = 1)



Remark ACKE0: Bit 2 of IICA control register 00 (IICCTL00)
 WRELO: Bit 5 of IICA control register 00 (IICCTL00)

Clock stretching is automatically generated depending on the setting of bit 3 (WTIM0) of IICA control register 00 (IICCTL00).

Normally, the reception side releases clock stretching when bit 5 (WRELO) of the IICCTL00 register is set to 1 or FFH is written to IICA shift register 0 (IICA0), and the transmission side releases clock stretching when data is written to the IICA0 register.

The master can also release clock stretching through either of the following methods.

- By setting bit 1 (STT0) of the IICCTL00 register to 1
- By setting bit 0 (SPT0) of the IICCTL00 register to 1

13.5.7 Releasing clock stretching

The I²C interface usually releases clock stretching by the following processing.

- Writing data to IICA shift register 0 (IICA0)
- Setting bit 5 (WREL0) of IICA control register 00 (IICCTL00) (releasing clock stretching)
- Setting bit 1 (STT0) of the IICCTL00 register (generating a start condition)^{Note 1}
- Setting bit 0 (SPT0) of the IICCTL00 register (generating a stop condition)^{Note 1}

Note 1. For the master in I²C communications only

When the above processing for releasing clock stretching is executed, I²C releases clock stretching and communications are resumed.

To release clock stretching and transmit data (including the address), write the data to the IICA0 register.

To receive data after clock stretching has been released, or to complete data transmission, set bit 5 (WREL0) of the IICCTL00 register to 1.

To generate a restart condition after clock stretching has been released, set bit 1 (STT0) of the IICCTL00 register to 1.

To generate a stop condition after clock stretching has been released, set bit 0 (SPT0) of the IICCTL00 register to 1.

Execute the release processing only once for each period of the clock stretch state.

If, for example, data is written to the IICA0 register after clock stretching has been released by setting the WREL0 bit to 1, an incorrect value may be output to the SDAA0 line because the timing for changing the SDAA0 line conflicts with the timing for writing to the IICA0 register.

In addition to the above, when communications are aborted, clock stretching can be released because clearing the IICE0 bit to 0 stops communications.

If the I²C bus has deadlocked due to noise, clock stretching can be released because the device exits from communications when bit 6 (LREL0) of the IICCTL00 register is set to 1.

Caution If the processing for releasing clock stretching is executed while WUP0 = 1, clock stretching will not be released.

13.5.8 Interrupt request (INTIICA0) generation timing and clock stretching control

The setting of bit 3 (WTIM0) of IICA control register 00 (IICCTL00) generates INTIICA0 and controls clock stretching at the timing shown in **Table 13-2**.

Table 13-2. INTIICA0 Generation Timing and Clock Stretching Control

| WTIM0 | In Slave Operation | | | In Master Operation | | |
|-------|-----------------------------|---------------------|---------------------|---------------------|----------------|-------------------|
| | Address | Data Reception | Data Transmission | Address | Data Reception | Data Transmission |
| 0 | 9 ^{Note 1, Note 2} | 8 ^{Note 2} | 8 ^{Note 2} | 9 | 8 | 8 |
| 1 | 9 ^{Note 1, Note 2} | 9 ^{Note 2} | 9 ^{Note 2} | 9 | 9 | 9 |

Note 1. The slave's INTIICA0 signal and clock stretching occur at the falling edge of the 9th clock only on matches with the address set in slave address register 0 (SVA0).

At this point, ACK is generated regardless of the value set in bit 2 (ACKE0) of the IICCTL00 register. The slave that has received an extension code generates INTIICA0 at the falling edge of the 8th clock.

However, if an address mismatch occurs after restart, INTIICA0 is generated at the falling edge of the 9th clock, but clock stretching does not occur.

Note 2. If the received address does not match the setting of slave address register 0 (SVA0) and the extension code is not received, neither INTIICA0 nor clock stretching occurs.

Remark The numbers in the table indicate the numbers of clock cycles of the serial clock. Interrupt requests and control of clock stretching are both synchronized with the falling edge of the serial clock.

(1) In address transmission/reception

- Slave operation: The timing of the interrupt and clock stretching is determined by the conditions described in Note 1 and Note 2 above, regardless of the setting of the WTIM0 bit.
- Master operation: The interrupt and clock stretching occur at the falling edge of the 9th clock, regardless of the setting of the WTIM0 bit.

(2) In data reception

- Master/slave operation: The timing of the interrupt and clock stretching is determined by the setting of the WTIM0 bit.

(3) In data transmission

- Master/slave operation: The timing of the interrupt and clock stretching is determined by the setting of the WTIM0 bit.

(4) Releasing clock stretching

There are four methods for releasing clock stretching as follows.

- Writing data to the IICA shift register 0 (IICA0)
- Setting bit 5 (WRELO) of IICA control register 00 (IICCTL00) (releasing clock stretching)
- Setting bit 1 (STT0) of the IICCTL00 register (generating a start condition)^{Note 1}
- Setting bit 0 (SPT0) of the IICCTL00 register (generating a stop condition)^{Note 1}

Note 1. Master only

When the clock stretch timing has been set to the falling edge of the 8th clock cycle (WTIM0 = 0), whether or not ACK is to be generated must be determined before releasing clock stretching.

(5) Stop condition detection

INTIICA0 is generated when a stop condition is detected (only when SPIE0 = 1).

13.5.9 Address match detection method

In I²C bus mode, the master can select a particular slave device by transmitting the corresponding slave address.

An address match can be detected automatically by the hardware. An INTIICA0 interrupt request is only generated when the address set in slave address register 0 (SVA0) matches the slave address sent by the master or when an extension code is received.

13.5.10 Error detection

In I²C bus mode, the state of the serial data bus (SDAA0) during transmission is captured in IICA shift register 0 (IICA0) of the transmitting device, so a transmission error can be detected by comparing the IICA data before the start of transmission and after the end of transmission. A transmission error is judged to having occurred when the two data values do not match.

13.5.11 Extension code

- (1) When the higher 4 bits of the receive address are either “0000” or “1111”, the extension code reception flag (EXC0) is set to 1 for extension code reception and an interrupt request (INTIICA0) is generated at the falling edge of the 8th clock.

The local address stored in slave address register 0 (SVA0) is not affected.

- (2) If 11110xx0 is transferred from the master in 10-bit address transfer while the SVA0 register is set to 11110xx0, the settings are as follows. Note that an interrupt request (INTIICA0) occurs at the falling edge of the 8th clock.

- Higher four bits of data match: EXC0 = 1
- Seven bits of data match: COI0 = 1

Remark EXC0: Bit 5 of IICA status register 0 (IICS0)
COI0: Bit 4 of IICA status register 0 (IICS0)

- (3) Since the processing after the interrupt request occurs differs according to the data that follows the extension code, such processing is performed by software.

If the extension code is received in slave operation, the slave is participating in communications even with an address mismatch.

For example, after the extension code is received, if you do not wish to operate the target device as a slave, set bit 6 (LREL0) of IICA control register 00 (IICCTL00) to 1 to set the standby mode for the next communication operation.

Table 13-3. Bit Definitions of Major Extension Codes

| Slave Address | R/W Bit | Description |
|---------------|---------|--|
| 0000_000 | 0 | General call address |
| 1111_0xx | 0 | 10-bit slave address specification (for address authentication) |
| 1111_0xx | 1 | 10-bit slave address specification (when read command is issued after address match) |

Remark See the I²C bus specifications issued by NXP Semiconductors for details of extension codes other than those described above.

13.5.12 Arbitration

When several masters simultaneously generate a start condition (when the STT0 bit is set to 1 before the STD0 bit is set to 1), master communication is performed while adjusting the clock cycles until the data differs. This kind of operation is called arbitration.

A master which lost in arbitration sets the arbitration loss flag (ALD0) in the IICA status register 0 (IICS0) to 1 at the timing it lost in arbitration and sets both the SCLA0 and SDAA0 lines to high impedance to release the bus.

A loss in arbitration is detected by checking ALD0 = 1 by software at the timing of the next interrupt request (the 8th or 9th clock cycle, when a stop condition is detected, etc.).

For details of interrupt request timing, see **13.5.8 Interrupt request (INTIICA0) generation timing and clock stretching control.**

Remark STD0: Bit 1 of IICA status register 0 (IICS0)
 STT0: Bit 1 of IICA control register 00 (IICCTL00)

Figure 13-20. Arbitration Timing Example

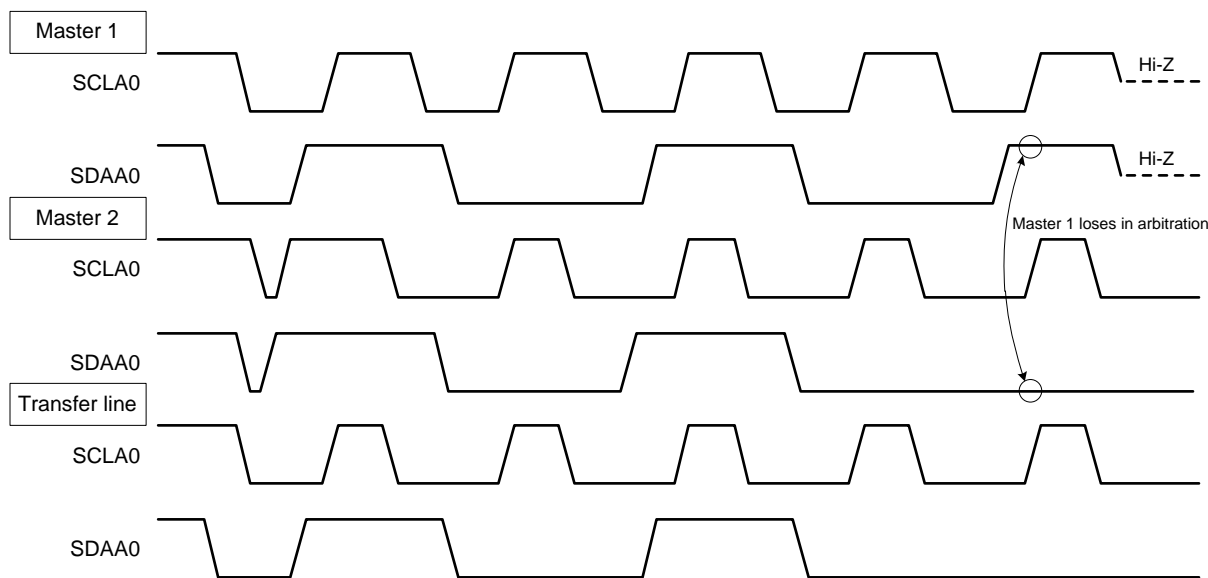


Table 13-4. State when Arbitration Occurred and Interrupt Request Generation Timing

| State when Arbitration Occurred | Interrupt Request Generation Timing |
|---|--|
| During address transmission | Falling edge of 8th or 9th clock following byte transfer ^{Note 1} |
| Read/write data after address transmission | |
| During extension code transmission | |
| Read/write data after extension code transmission | |
| During data transmission | |
| During ACK transfer period after data transmission | |
| Restart condition is detected during data transfer | |
| Stop condition is detected during data transfer | When stop condition is generated (when SPIE0 = 1) ^{Note 2} |
| Data is at low level while attempting to generate a restart condition | Falling edge of 8th or 9th clock following byte transfer ^{Note 1} |
| Stop condition is detected while attempting to generate restart condition | When stop condition is generated (when SPIE0 = 1) ^{Note 2} |
| Data is at low level while attempting to generate a stop condition | Falling edge of 8th or 9th clock following byte transfer ^{Note 1} |
| When SCLA0 is at low level while attempting to generate a restart condition | |

Note 1. When the WTIM0 bit (bit 3 of IICA control register 00 (IICCTL00)) = 1, an interrupt request occurs at the falling edge of the 9th clock. When WTIM0 = 0, the extension code's slave address is received, an interrupt request occurs at the falling edge of the 8th clock.

Note 2. If there is a possibility that arbitration will occur, set SPIE0 = 1 for master operation.

Remark SPIE0: Bit 4 of IICA control register 00 (IICCTL00)

13.5.13 Wakeup function

This is a slave function of I²C to generate an interrupt request signal (INTIICA0) when the local address and an extension code are received.

When the addresses do not match, an unnecessary INTIICA0 signal is not generated to allow efficient processing.

When a start condition is detected, the wakeup standby state is entered. Even a master that has generated a start condition enters the wakeup standby state while transmitting an address because the master may become a slave due to an arbitration loss.

To use the wakeup function while in the STOP mode, set the WUP0 bit to 1. The address can be received regardless of the operation clock. An interrupt request signal (INTIICA0) is also generated when the local address and an extension code are received. Operation returns to normal operation by using an instruction to clear the WUP0 bit to 0 after this interrupt has been generated.

Figure 13-21 shows the flow when setting WUP0 = 1 and **Figure 13-22** shows the flow when setting WUP0 = 0 upon an address match.

Figure 13-21. Flow when Setting WUP0 = 1

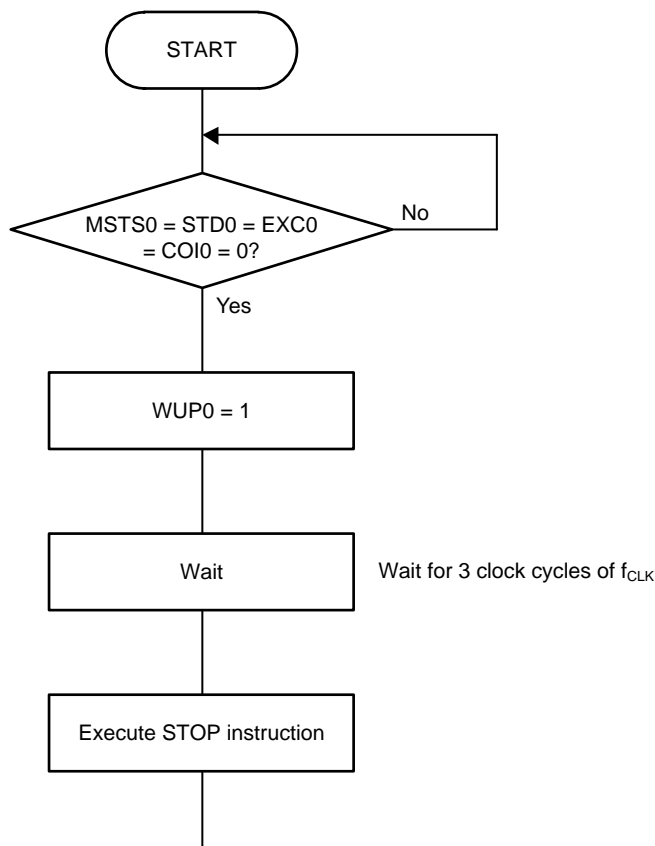
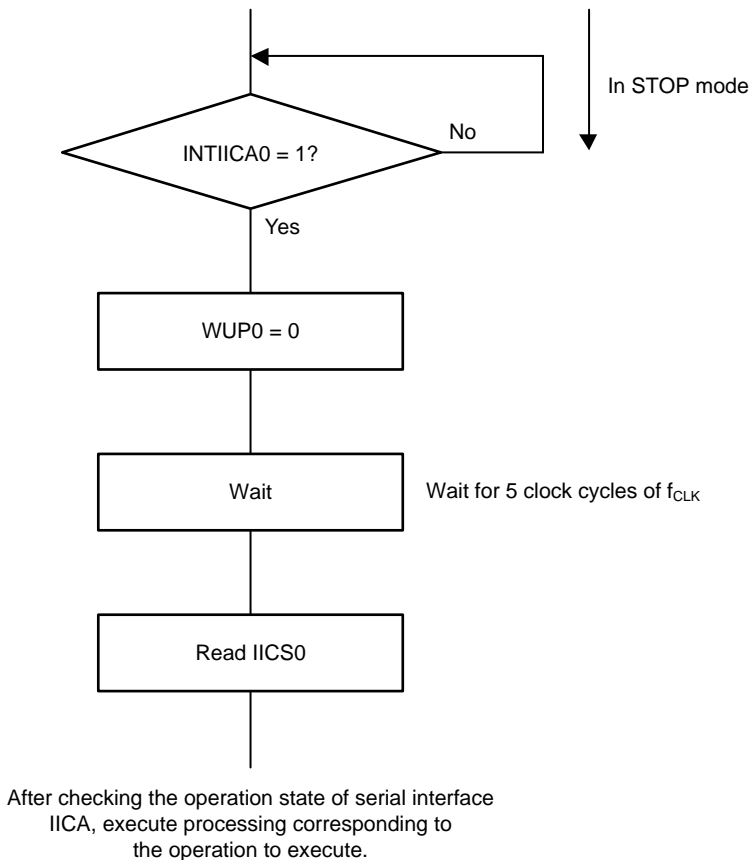


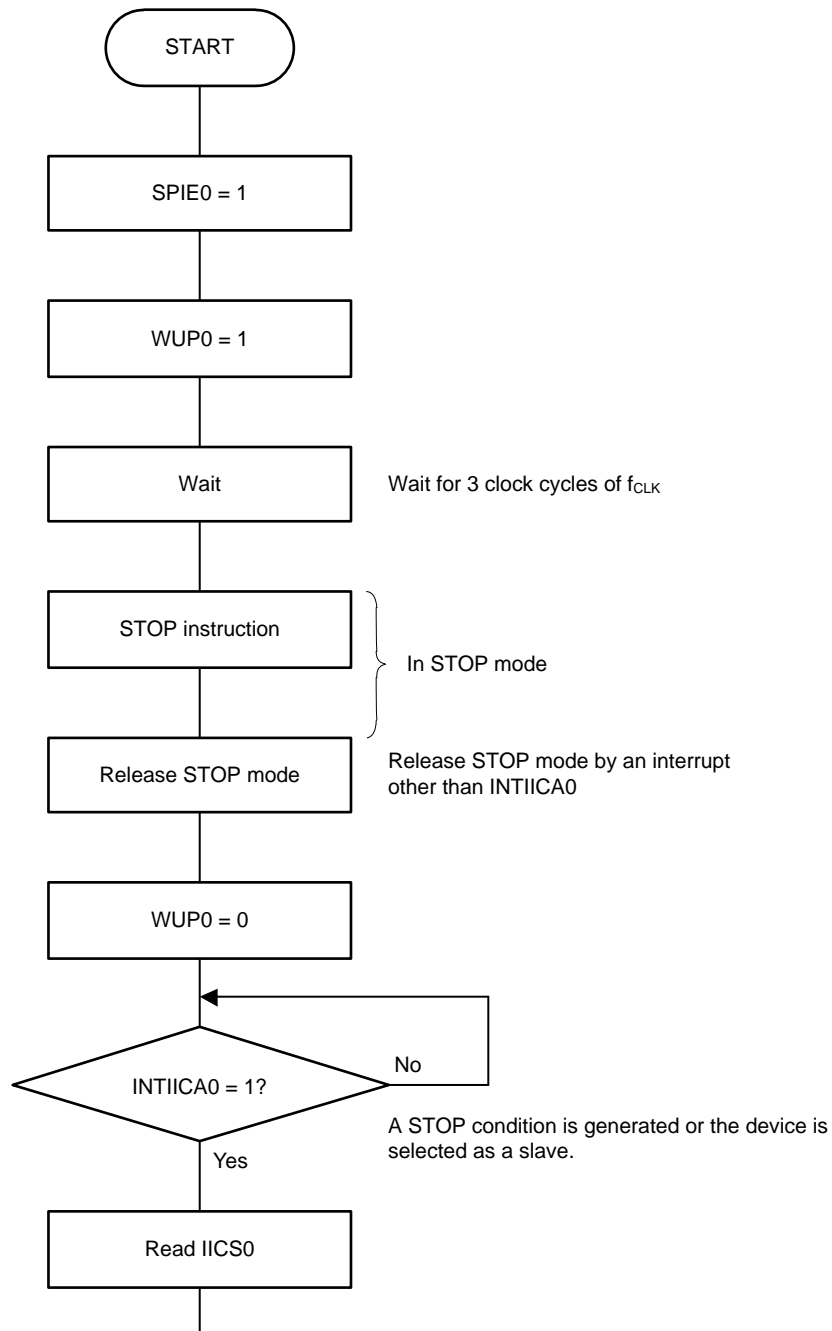
Figure 13-22. Flow when Setting WUP0 = 0 upon Address Match (Including Extension Code Reception)



Follow the flow below to perform the processing to release the STOP mode other than by an interrupt request signal (INTIICA0) from serial interface IICA.

- When operating next I²C communication as a master:
 - Flow shown in **Figure 13-23**
- When operating next I²C communication as a slave:
 - When recovered by the INTIICA0 interrupt: Same as the flow in **Figure 13-22**.
 - When recovered by an interrupt other than the INTIICA0 interrupt: Continue operation with WUP0 set to 1 until the INTIICA0 interrupt is generated.

Figure 13-23. When Operating as Master after Release from STOP Mode by Interrupt Other than INTIICA0



After checking the operation state of serial interface IICA, execute processing corresponding to the operation to execute.

13.5.14 Communication reservation

(1) When communication reservation is enabled (bit 0 (IICRSV0) of IICA flag register 0 (IICF0) = 0)

To proceed with master communications next while not currently participating in the bus, a communication reservation can be made to enable transmission of a start condition when the bus is released. There are two modes for not participating in the bus.

- When arbitration results in neither master nor slave operation
- When an extension code is received and slave operation is disabled (ACK was not returned and the bus was released by setting bit 6 (LRELO) of IICA control register 00 (IICCTL00) to 1 and exiting from communication)

If bit 1 (STT0) of the IICCTL00 register is set to 1 while not participating in the bus, a start condition is automatically generated and the wait state is entered after the bus has been released (when a stop condition is detected).

If the address is written to IICA shift register 0 (IICA0) after bit 4 (SPIE0) of the IICCTL00 register is set to 1, and release of the bus is detected (detection of the stop condition) by generation of an interrupt request signal (INTIICA0), the device automatically starts communication as the master. Data written to the IICA0 register before detecting the stop condition is invalid.

When the STT0 bit has been set to 1, the operation mode (operation as start condition or as communication reservation) is determined according to the state of the bus.

- If the bus has been released start condition generation
- If the bus has not been released (standby mode) ... communication reservation

Check whether the communication reservation operates or not by using the MSTS0 bit (bit 7 of IICA status register 0 (IICS0)) after the STT0 bit is set to 1 and the wait time elapses.

Use software to secure the wait time calculated by the following expression.

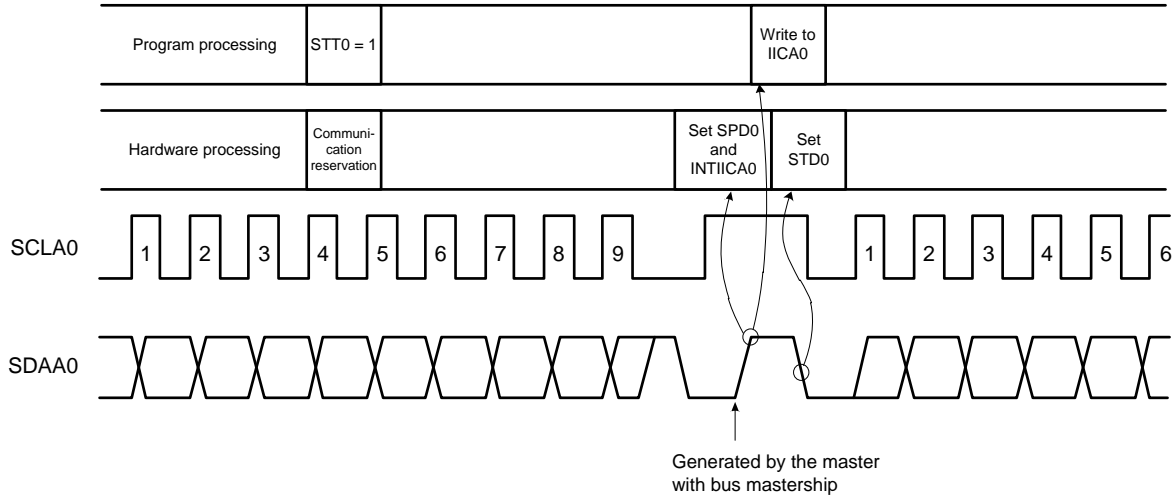
Wait time from setting STT0 = 1 to checking the MSTS0 flag:

$$(IICWL0 \text{ setting value} + IICWH0 \text{ setting value} + 4) / f_{CLK} + t_F \times 2$$

Remark IICWL0: IICA low-level width setting register 0
 IICWH0: IICA high-level width setting register 0
 t_F: SDAA0 and SCLA0 signal falling time
 f_{CLK}: CPU/peripheral hardware clock frequency

Figure 13-24 shows the communication reservation timing.

Figure 13-24. Communication Reservation Timing



- Remark** IICA0: IICA shift register 0
- STT0: Bit 1 of IICA control register 00 (IICCTL00)
- STD0: Bit 1 of IICA status register 0 (IICS0)
- SPD0: Bit 0 of IICA status register 0 (IICS0)

Communication reservations are accepted at the timing shown in **Figure 13-25**. After bit 1 (STD0) of IICA status register 0 (IICS0) is set to 1, a communication reservation can be made by setting bit 1 (STT0) of IICA control register 00 (IICCTL00) to 1 before a stop condition is detected.

Figure 13-25. Timing for Accepting Communication Reservations

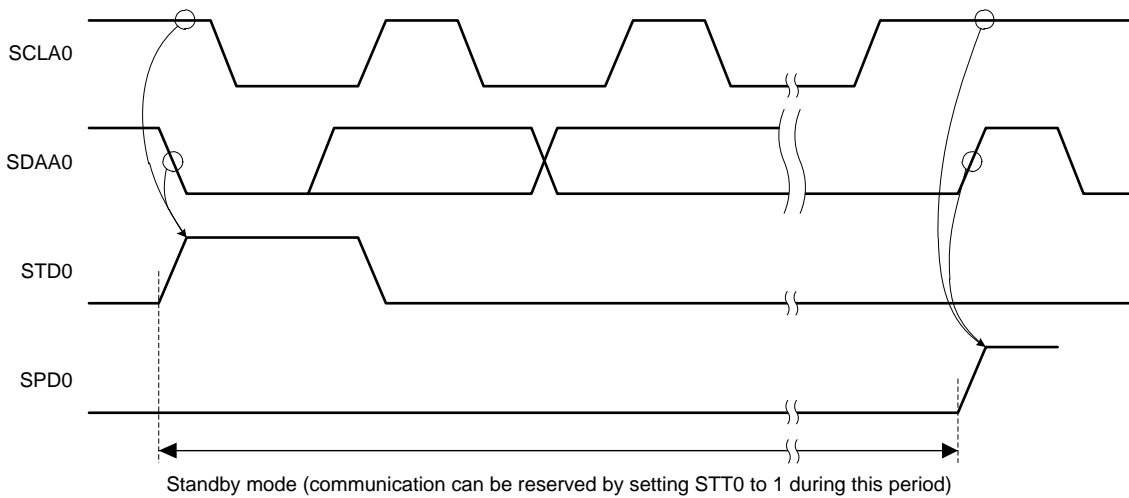
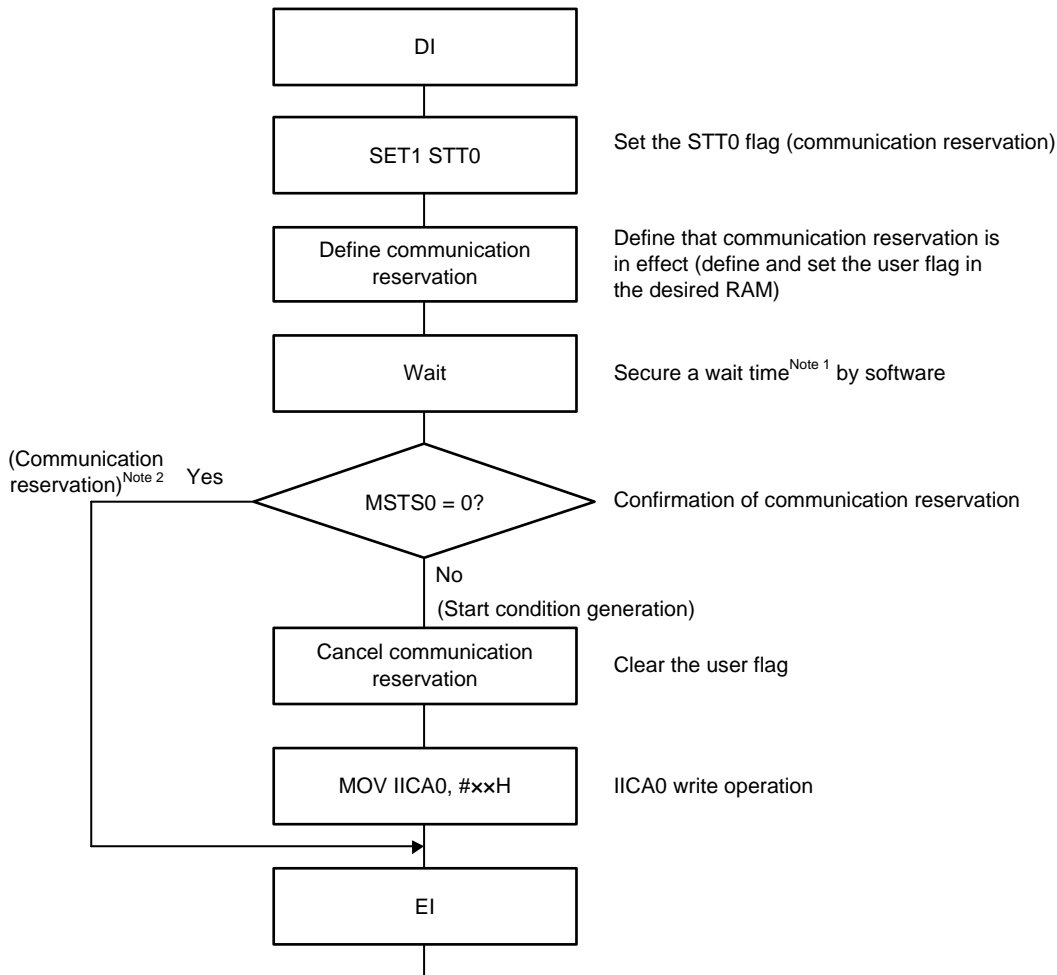


Figure 13-26 shows the procedure for communication reservation.

Figure 13-26. Communication Reservation Procedure



Note 1. A wait time is as follows.
 $(IICWLO \text{ setting value} + IICWH0 \text{ setting value} + 4) / f_{CLK} + t_F \times 2$

Note 2. In communication reservation operation, writing to IICA shift register 0 (IICA0) is executed in response to a stop condition interrupt request.

Remark STT0: Bit 1 of IICA control register 00 (IICCTL00)
 MSTS0: Bit 7 of IICA status register 0 (IICS0)
 IICA0: IICA shift register 0
 IICWLO: IICA low-level width setting register 0
 IICWH0: IICA high-level width setting register 0
 t_F: SDAA0 and SCLA0 signal falling time
 f_{CLK}: CPU/peripheral hardware clock frequency

(2) When communication reservation is disabled (bit 0 (IICRSV0) of IICA flag register 0 (IICF0) = 1)

When bit 1 (STT0) of IICA control register 00 (IICCTL00) is set to 1 while the bus is not participating in this communication during communication, this request is rejected and a start condition is not generated. Non-participation of the bus in this case includes the following two states.

- When arbitration results in neither master nor slave operation
- When an extension code is received and slave operation is disabled (ACK was not returned and the bus was released by setting bit 6 (LREL0) of the IICCTL00 register to 1 and exiting from communication)

Whether the start condition was generated or rejected can be checked by reading STCF0 (bit 7 of the IICF0 register). Since up to 5 clock cycles are taken until the STCF0 bit is set to 1 after setting STT0 = 1, secure this time by software.

13.5.15 Cautions

(1) When STCEN0 = 0

Immediately after I²C operation is enabled (IICE0 = 1), the bus communication state (IICBSY0 = 1) is recognized regardless of the actual bus state. When performing master communication from the state where a stop condition is not detected, first generate a stop condition to release the bus, then perform master communication.

When using multiple masters, it is not possible to perform master communication while the bus is not released (a stop condition is not detected).

Follow the following sequence to generate a stop condition.

- <1> Set IICA control register 01 (IICCTL01).
- <2> Set bit 7 (IICE0) of IICA control register 00 (IICCTL00) to 1.
- <3> Set bit 0 (SPT0) of the IICCTL00 register to 1.

(2) When STCEN0 = 1

Immediately after I²C operation is enabled (IICE0 = 1), the bus released state (IICBSY0 = 0) is recognized regardless of the actual bus state. To generate the first start condition (STT0 = 1), it is necessary to confirm that the bus has been released, so as to not disturb other communications.

(3) If I²C communication with the other party is already in progress

If I²C operation is enabled and the device participates in communication already in progress when the SDAA0 pin is at the low level and the SCLA0 pin is at the high level, the macro of I²C recognizes that the SDAA0 pin has changed from the high to the low level (start condition detection). If the value on the bus at this time can be recognized as an extension code, ACK is returned, but this interferes with I²C communications with the other party. To avoid this, start the I²C in the following sequence.

- <1> Clear bit 4 (SPIE0) of the IICCTL00 register to 0 to disable generation of an interrupt request signal (INTIICA0) in response to the detection of a stop condition.
 - <2> Set bit 7 (IICE0) of the IICCTL00 register to 1 to enable operation of the I²C.
 - <3> Wait for detection of a start condition.
 - <4> Set bit 6 (LRELO) of the IICCTL00 register to 1 before ACK is returned (in 4 to 72 clock cycles after setting the IICE0 bit to 1) to forcibly disable detection.
- (4) After setting the STT0 and SPT0 bits (bits 1 and 0 of the IICCTL00 register), re-setting these bits before they are cleared to 0 is prohibited.

- (5) When transmission is reserved, set the SPIE0 bit (bit 4 of the IICCTL00 register) to 1 so that an interrupt request is generated when a stop condition is detected. Transfer is started when communication data is written to IICA shift register 0 (IICA0) after the interrupt request has been generated. If the interrupt is not generated in response to the detection of a stop condition, the device stops in the wait state because the interrupt request is not generated when communication is started. However, it is not necessary to set the SPIE0 bit to 1 when detecting the MSTSO bit (bit 7 of IICA status register 0 (IICS0)) by software.

13.5.16 Communication operations

The following describes three operation procedures as flows.

1) Master operation in single master system

The flow when the device is used as a master in the single master system is described.

This flow is broadly divided into the initial settings and communication processing. Execute the initial settings at startup. If communication with the slave is required, make necessary preparation for communication and then execute communication processing.

2) Master operation in multi-master system

In the I²C bus multi-master system, whether the bus is released or used cannot be judged only by the I²C bus specifications at the stage when a device participates in communications. Here, when the data and clock are at the high level for a certain period (1 frame), the device participates in communications in the bus released state.

This flow is broadly divided into the initial settings, communication waiting, and communication processing. The processing when the device loses in arbitration and is specified as a slave is omitted here, and only the processing as a master is shown. Execute the initial settings at startup to participate in communications. Then, wait for a communication request as a master or wait for specification as a slave. The actual communication is performed in the communication processing, and it supports transmission/reception with the slave and the arbitration with other masters.

3) Slave operation

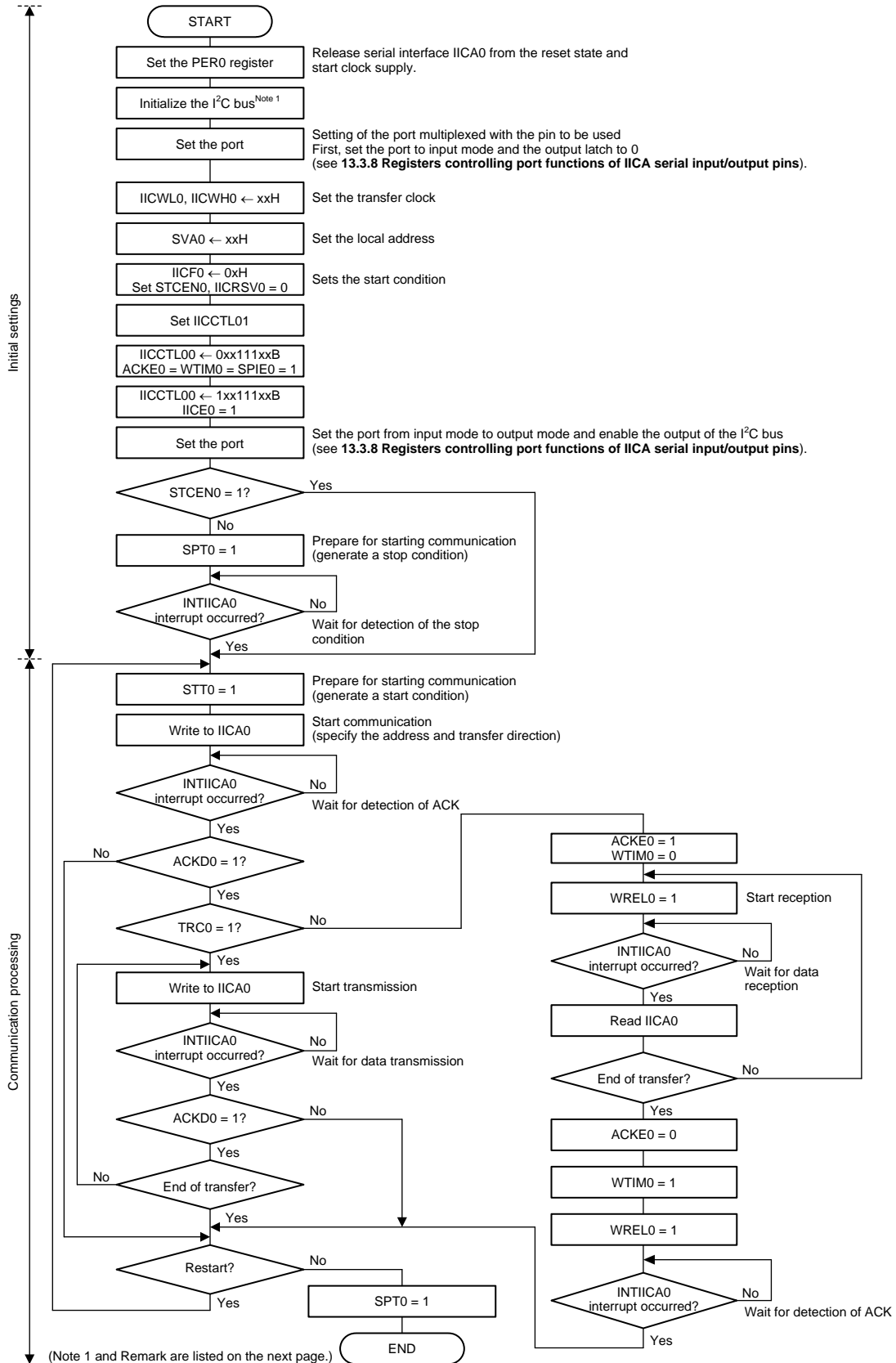
An example when the device is used as a slave of the I²C bus is explained below.

When used as a slave, operation is started by an interrupt. Execute the initial settings at startup, then wait for the INTIICA0 interrupt occurrence (communication waiting). When an INTIICA0 interrupt occurs, the communication state is judged and the result is passed to the main processing as a flag.

By checking each flag, the required communication processing is performed.

(1) Master operation in single master system

Figure 13-27. Master Operation in Single Master System

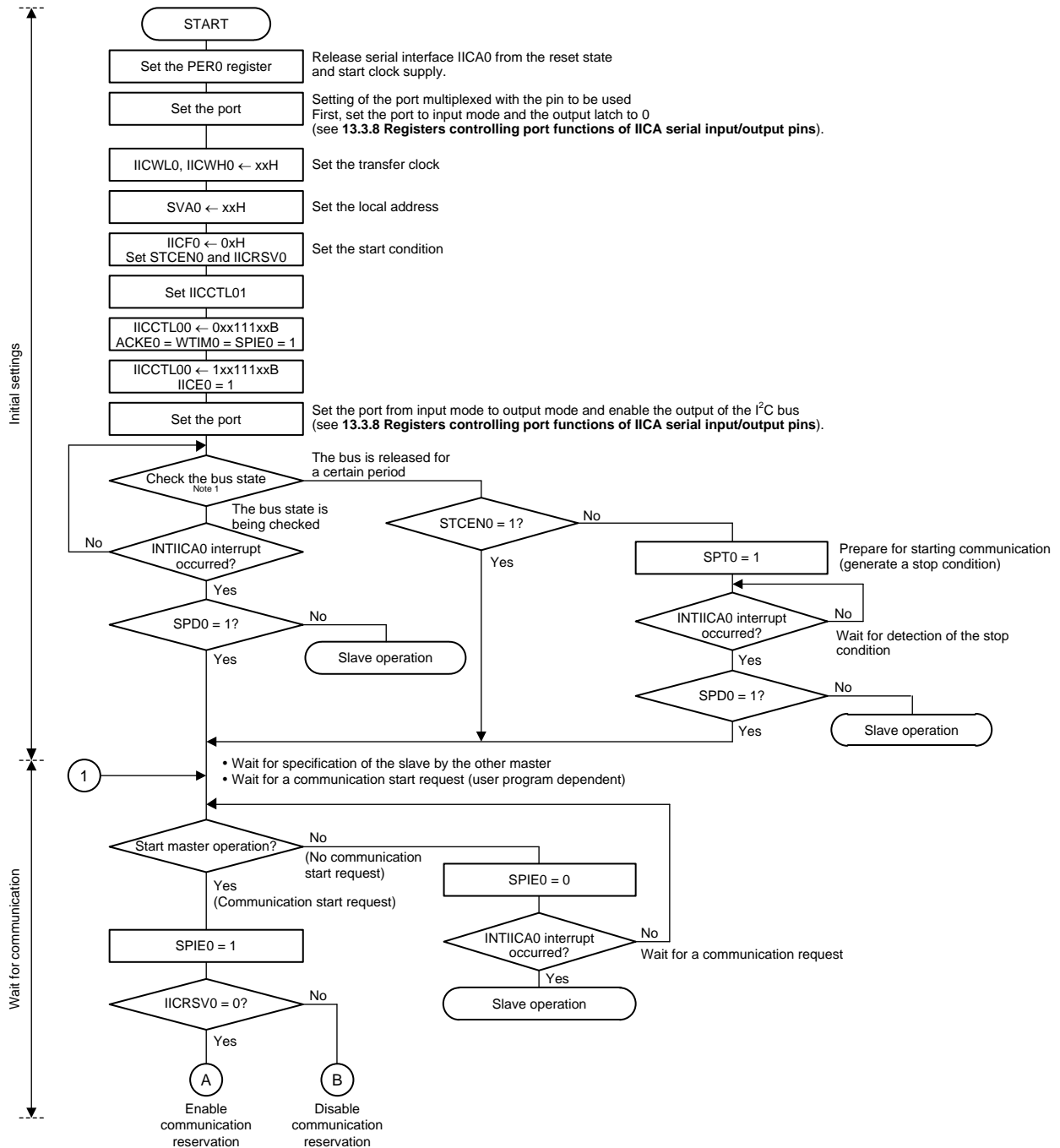


Note 1. Release the I²C bus (SCLA0 and SDAA0 pins = high level) in conformance with the specifications of the product that is communicating. If EEPROM is outputting a low level to the SDAA0 pin, set the SCLA0 pin to the output port, and output a clock pulse from the output port until the SDAA0 pin is constantly at the high level.

Remark Conform to the specifications of the product that is communicating, with respect to the transmission and reception formats.

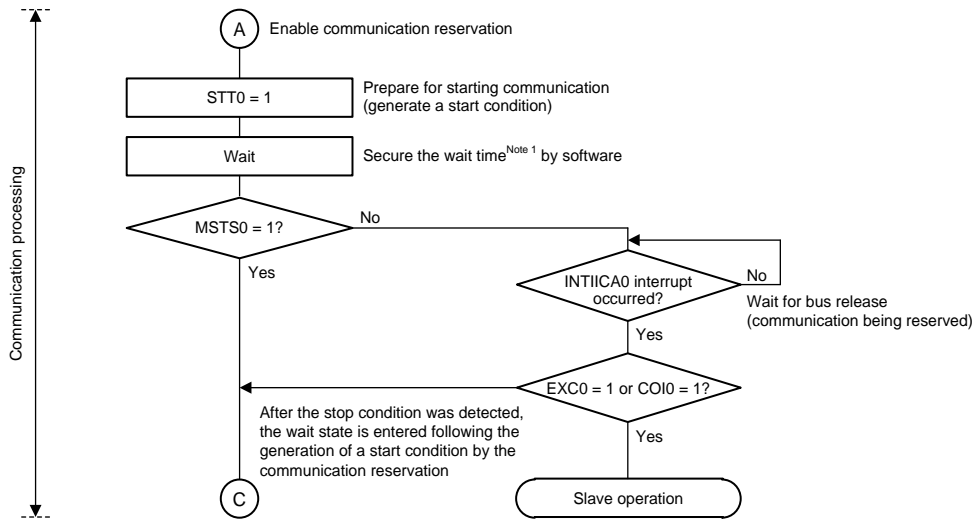
(2) Master operation in multi-master system

Figure 13-28. Master operation in Multi-master System (1/3)

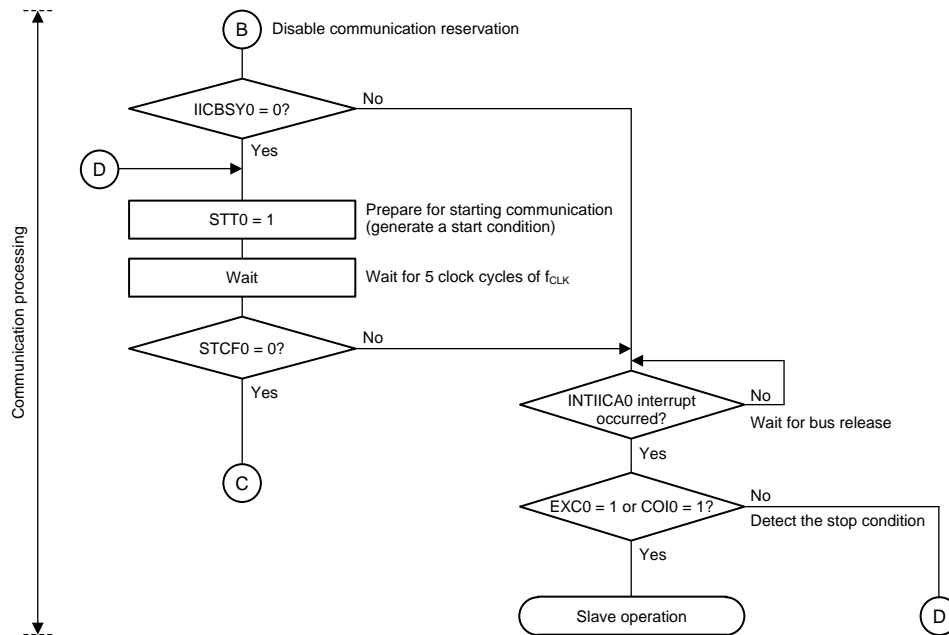


Note 1. Confirm that the bus is released (CLD0 bit = 1, DAD0 bit = 1) for a certain period (for example, for a period of one frame). If the SDAA0 pin is constantly at the low level, decide whether to release the I²C bus (SCLA0 and SDAA0 pins = high level) in conformance with the specifications of the product that is communicating.

Figure 13-28. Master Operation in Multi-master System (2/3)

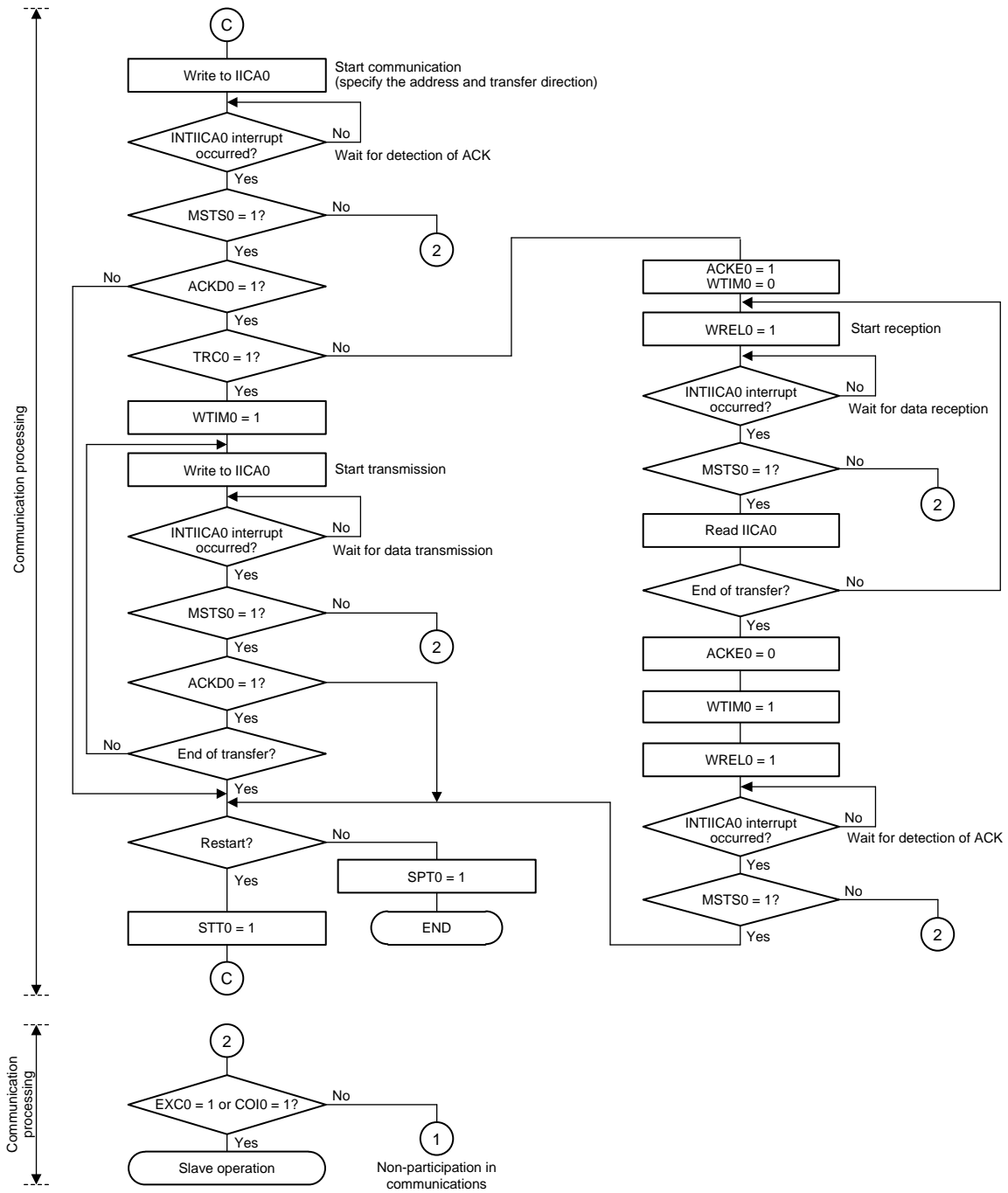


Note 1. A wait time is as follows.
 $(IICWL0 \text{ setting value} + IICWH0 \text{ setting value} + 4)/f_{CLK} + t_F \times 2$



Remark IICWL0: IICA low-level width setting register 0
 IICWH0: IICA high-level width setting register 0
 t_F: SDAA0 and SCLA0 signal falling time
 f_{CLK}: CPU/peripheral hardware clock frequency

Figure 13-28. Master Operation in Multi-master System (3/3)



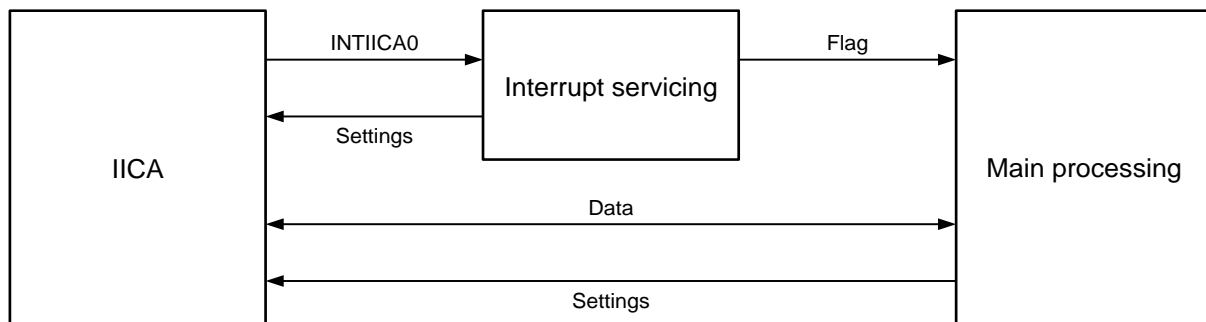
- Remark 1.** Conform to the specifications of the product that is communicating, with respect to the transmission and reception formats.
- Remark 2.** To use the device as a master in the multi-master system, read the MSTS0 bit to check the arbitration result each time interrupt INTIICA0 is generated.
- Remark 3.** To use the device as a slave in the multi-master system, check the status by reading IICA status register 0 (IICS0) and IICA flag register 0 (IICF0) each time interrupt INTIICA0 is generated, and determine next processing to be performed.

(3) Slave operation

The processing procedure of slave operation is as follows.

Basically, slave operation is event-driven. This requires processing by the INTIICA0 interrupt (processing that requires substantially changing the operation state such as detection of a stop condition during communication).

In the following explanation, it is assumed that the extension code is not supported for data communication. It is also assumed that the INTIICA0 interrupt servicing only performs processing for state transition and actual data communication is performed by the main processing.



Therefore, data communication processing is performed by preparing the following three flags and passing them to the main processing instead of INTIICA0.

<1> Communication mode flag

This flag indicates the following two communication states.

- Clear mode: State in which data communication is not performed
- Communication mode: State in which data communication is performed (from valid address detection to stop condition detection, no detection of ACK from master, address mismatch)

<2> Ready flag

This flag indicates that data communication is enabled. Its function is the same as the INTIICA0 interrupt in ordinary data communications. This flag is set by interrupt servicing and cleared by the main processing. Clear this flag by interrupt servicing when communication is started. However, the ready flag is not set by interrupt servicing when the first data is transmitted. Therefore, the first data is transmitted without the flag being cleared (an address match is interpreted as a request for the next data).

<3> Communication direction flag

This flag indicates the direction of communication. Its value is the same as the TRC0 bit.

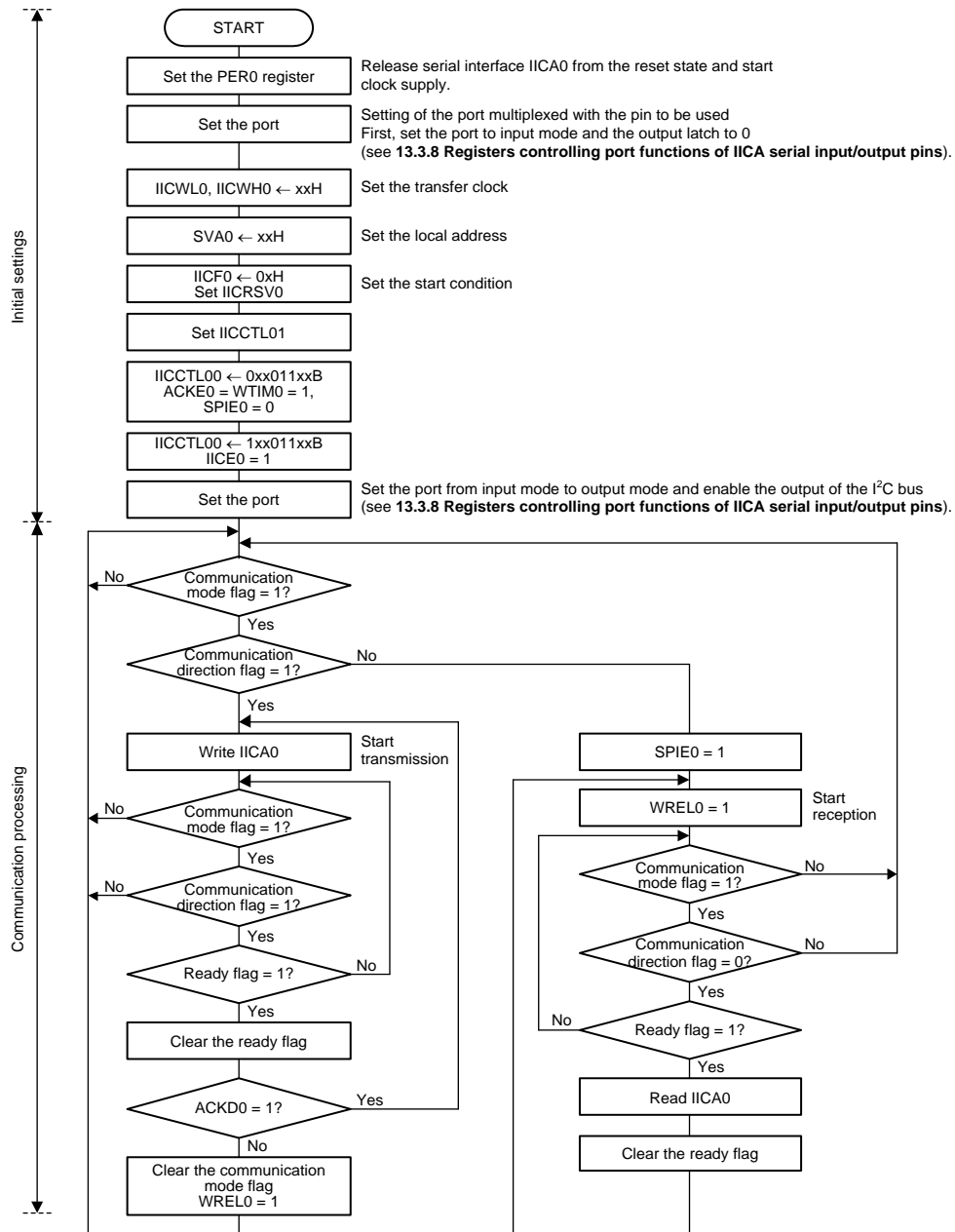
Next, the main processing of slave operation is explained.

Start serial interface IICA and wait until communication is enabled. When communication is enabled, execute communication by using the communication mode flag and ready flag (processing of the stop condition and start condition is performed in response to an interrupt. Here, check the state by using the flags).

The transmission operation is repeated until the master no longer returns ACK. If ACK is not returned from the master, communication is completed.

In reception, the necessary amount of data is received. When communication is completed, ACK is not returned for the next data. After that, the master generates a stop condition or restart condition. The device exits the communication state in this way.

Figure 13-29. Slave Operation Procedure (1)



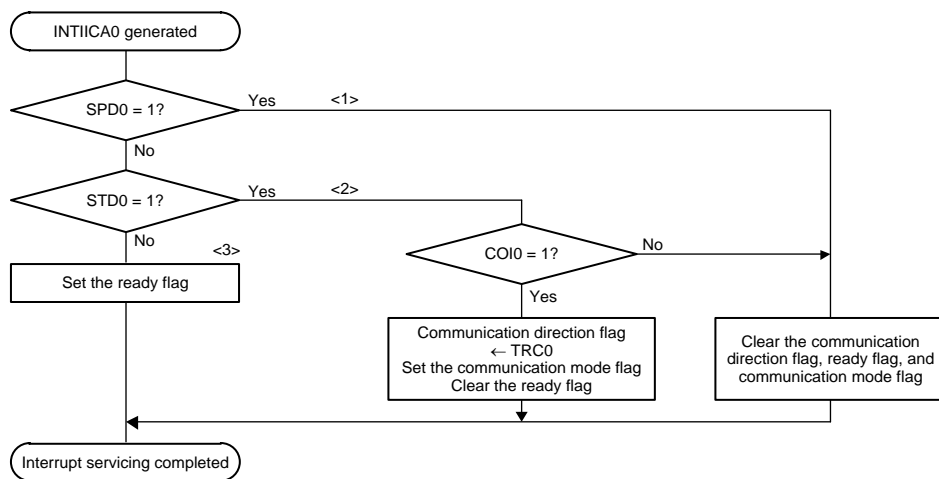
Remark Conform to the specifications of the product that is communicating, with respect to the transmission and reception formats.

An example of the processing procedure of the slave with the INTIICA0 interrupt is explained below (processing is performed assuming that no extension code is used). The INTIICA0 interrupt checks the status, and the following operations are performed.

- <1> Communication is stopped if the stop condition is issued.
- <2> If the start condition is issued, the address is checked and communication is completed if the address is not matched.
If the address is matched, the communication mode is set, the wait state is released, and processing returns from the interrupt (the ready flag is cleared).
- <3> For data transmission/reception, only the ready flag is set. Processing returns from the interrupt while the I²C bus remains in the wait state.

Remark <1> to <3> above correspond to <1> to <3> in **Figure 13-30 Slave Operation Procedure (2)**.

Figure 13-30. Slave Operation Procedure (2)



13.5.17 I²C interrupt request (INTIICA0) generation timing

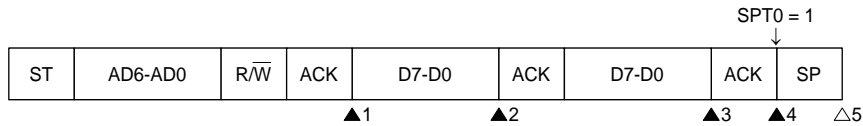
The timing of data transmission/reception and generation of interrupt request signal INTIICA0 and the value of IICA status register 0 (IICS0) with the INTIICA0 signal timing are shown below.

Remark ST: Start condition
AD6 to AD0: Address
R \bar{W} : Transfer direction specification
ACK: Acknowledge
D7 to D0: Data
SP: Stop condition

(1) Master operation

(a) Start ~ Address ~ Data ~ Data ~ Stop (transmission/reception)

(i) When WTIM0 = 0

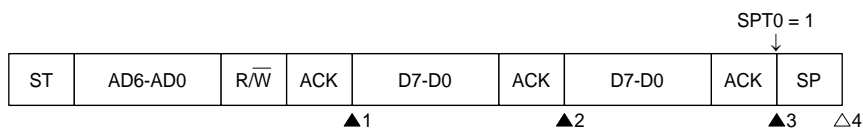


- ▲1: IICS0 = 1000x110B
- ▲2: IICS0 = 1000x000B
- ▲3: IICS0 = 1000x000B (Sets the WTIM0 bit to 1)^{Note 1}
- ▲4: IICS0 = 1000xx00B (Sets the SPT0 bit to 1)
- △5: IICS0 = 00000001B

Note 1. To generate a stop condition, set the WTIM0 bit to 1 and change the timing for generating the INTIICA0 interrupt request signal.

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1

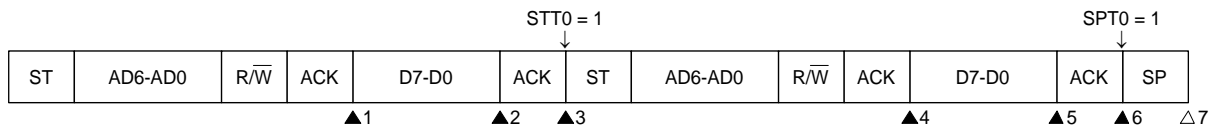


- ▲1: IICS0 = 1000x110B
- ▲2: IICS0 = 1000x100B
- ▲3: IICS0 = 1000xx00B (Sets the SPT0 bit to 1)
- △4: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(b) Start ~ Address ~ Data ~ Start ~ Address ~ Data ~ Stop (restart)

(i) When WTIM0 = 0



- ▲1: IICS0 = 1000x110B
- ▲2: IICS0 = 1000x000B (Sets the WTIM0 bit to 1^{Note 1})
- ▲3: IICS0 = 1000xx00B (Clears the WTIM0 bit to 0^{Note 2}, sets the STT0 bit to 1)
- ▲4: IICS0 = 1000x110B
- ▲5: IICS0 = 1000x000B (Sets the WTIM0 bit to 1^{Note 3})
- ▲6: IICS0 = 1000xx00B (Sets the SPT0 bit to 1)
- △7: IICS0 = 00000001B

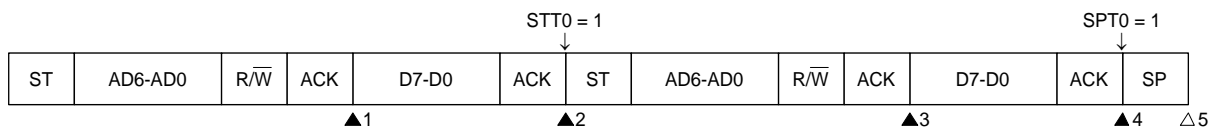
Note 1. To generate a start condition, set the WTIM0 bit to 1 and change the timing for generating the INTIICA0 interrupt request signal.

Note 2. Clear the WTIM0 bit to 0 to restore the original setting.

Note 3. To generate a stop condition, set the WTIM0 bit to 1 and change the timing for generating the INTIICA0 interrupt request signal.

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1

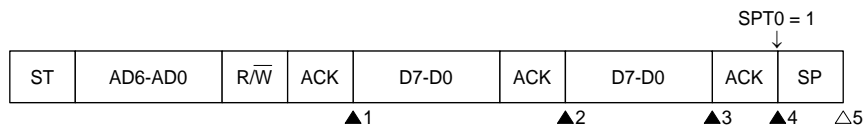


- ▲1: IICS0 = 1000x110B
- ▲2: IICS0 = 1000xx00B (Sets the STT0 bit to 1)
- ▲3: IICS0 = 1000x110B
- ▲4: IICS0 = 1000xx00B (Sets the SPT0 bit to 1)
- △5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(c) Start ~ Code ~ Data ~ Data ~ Stop (extension code transmission)

(i) When WTIM0 = 0



▲1: IICS0 = 1010x110B

▲2: IICS0 = 1010x000B

▲3: IICS0 = 1010x000B (Sets the WTIM0 bit to 1^{Note 1})

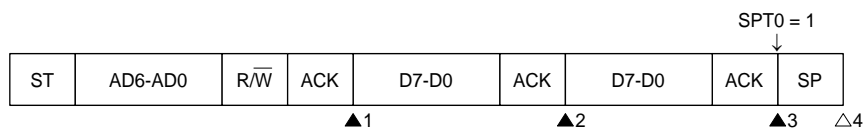
▲4: IICS0 = 1010xx00B (Sets the SPT0 bit to 1)

△5: IICS0 = 00000001B

Note 1. To generate a start condition, set the WTIM0 bit to 1 and change the timing for generating the INTIICA0 interrupt request signal.

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1



▲1: IICS0 = 1010x110B

▲2: IICS0 = 1010x100B

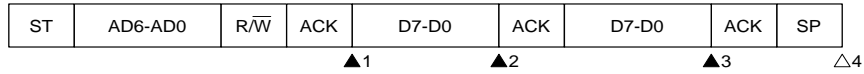
▲3: IICS0 = 1010xx00B (Sets the SPT0 bit to 1)

△4: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(2) Slave operation (slave address data reception)**(a) Start ~ Address ~ Data ~ Data ~ Stop**

(i) When WTIM0 = 0



▲1: IICS0 = 0001x110B

▲2: IICS0 = 0001x000B

▲3: IICS0 = 0001x000B

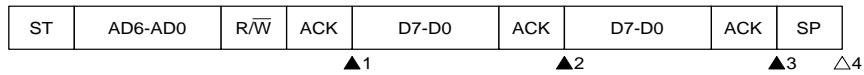
△4: IICS0 = 00000001B

Remark ▲: Always generated

△: Generated only when SPIE0 = 1

x: Don't care

(ii) When WTIM0 = 1



▲1: IICS0 = 0001x110B

▲2: IICS0 = 0001x100B

▲3: IICS0 = 0001xx00B

△4: IICS0 = 00000001B

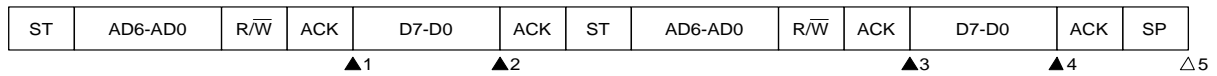
Remark ▲: Always generated

△: Generated only when SPIE0 = 1

x: Don't care

(b) Start ~ Address ~ Data ~ Start ~ Address ~ Data ~ Stop

(i) When WTIM0 = 0 (a match with SVA0 after restart)



▲1: IICS0 = 0001x110B

▲2: IICS0 = 0001x000B

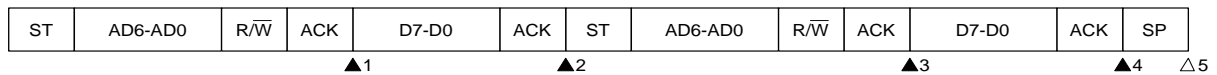
▲3: IICS0 = 0001x110B

▲4: IICS0 = 0001x000B

△5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1 (a match with SVA0 after restart)



▲1: IICS0 = 0001x110B

▲2: IICS0 = 0001xx00B

▲3: IICS0 = 0001x110B

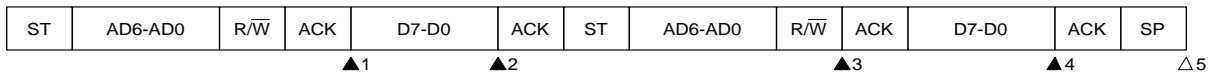
▲4: IICS0 = 0001xx00B

△5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(c) Start ~ Address ~ Data ~ Start ~ Code ~ Data ~ Stop

(i) When WTIM0 = 0 (an address mismatch after restart (extension code))



▲1: IICS0 = 0001x110B

▲2: IICS0 = 0001x000B

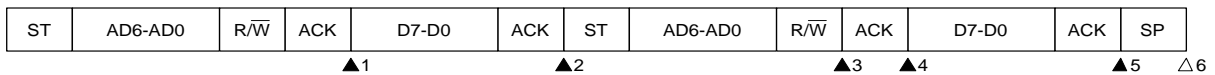
▲3: IICS0 = 0010x010B

▲4: IICS0 = 0010x000B

△5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1 (an address mismatch after restart (extension code))



▲1: IICS0 = 0001x110B

▲2: IICS0 = 0001xx00B

▲3: IICS0 = 0010x010B

▲4: IICS0 = 0010x110B

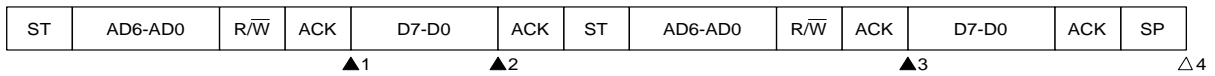
▲5: IICS0 = 0010xx00B

△6: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(d) Start ~ Address ~ Data ~ Start ~ Address ~ Data ~ Stop

(i) When WTIM0 = 0 (an address mismatch after restart (other than extension code))



▲1: IICS0 = 0001x110B

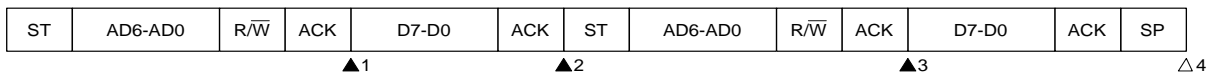
▲2: IICS0 = 0001x000B

▲3: IICS0 = 00000x10B

△4: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1 (an address mismatch after restart (other than extension code))



▲1: IICS0 = 0001x110B

▲2: IICS0 = 0001xx00B

▲3: IICS0 = 00000x10B

△4: IICS0 = 00000001B

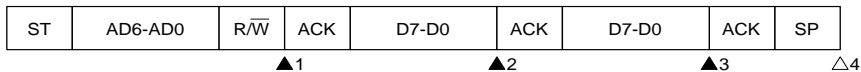
Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(3) Slave operation (when receiving extension code)

The device always participates in communications when it receives an extension code.

(a) Start ~ Code ~ Data ~ Data ~ Stop

(i) When WTIM0 = 0



▲1: IICS0 = 0010x010B

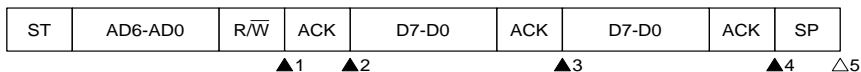
▲2: IICS0 = 0010x000B

▲3: IICS0 = 0010x000B

△4: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1



▲1: IICS0 = 0010x010B

▲2: IICS0 = 0010x110B

▲3: IICS0 = 0010x100B

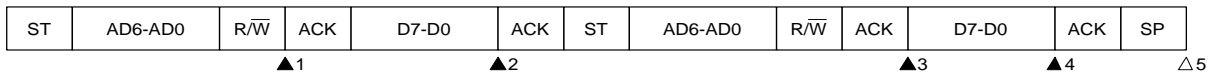
▲4: IICS0 = 0010xx00B

△5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(b) Start ~ Code ~ Data ~ Start ~ Address ~ Data ~ Stop

(i) When WTIM0 = 0 (a match with SVA0 after restart)



▲1: IICS0 = 0010x010B

▲2: IICS0 = 0010x000B

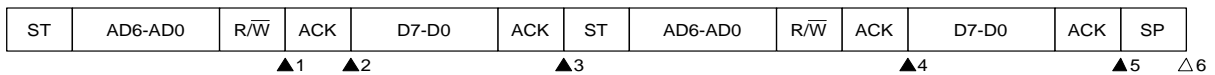
▲3: IICS0 = 0001x110B

▲4: IICS0 = 0001x000B

△5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1 (a match with SVA0 after restart)



▲1: IICS0 = 0010x010B

▲2: IICS0 = 0010x110B

▲3: IICS0 = 0010xx00B

▲4: IICS0 = 0001x110B

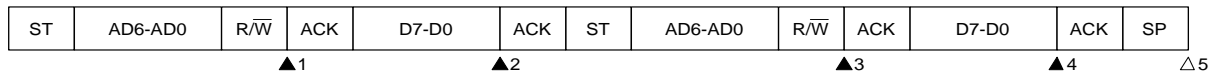
▲5: IICS0 = 0001xx00B

△6: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(c) Start ~ Code ~ Data ~ Start ~ Code ~ Data ~ Stop

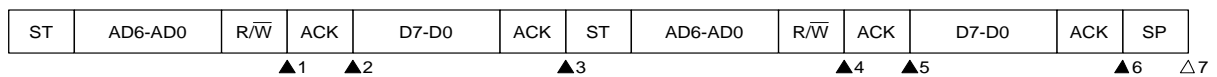
(i) When WTIM0 = 0 (extension code reception after restart)



- ▲1: IICS0 = 0010x010B
- ▲2: IICS0 = 0010x000B
- ▲3: IICS0 = 0010x010B
- ▲4: IICS0 = 0010x000B
- △5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1 (extension code reception after restart)

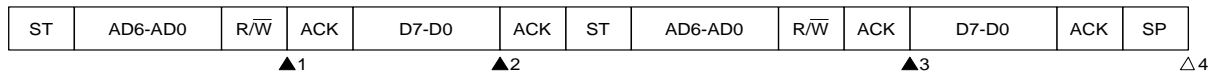


- ▲1: IICS0 = 0010x010B
- ▲2: IICS0 = 0010x110B
- ▲3: IICS0 = 0010xx00B
- ▲4: IICS0 = 0010x010B
- ▲5: IICS0 = 0010x110B
- ▲6: IICS0 = 0010xx00B
- △7: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(d) Start ~ Code ~ Data ~ Start ~ Address ~ Data ~ Stop

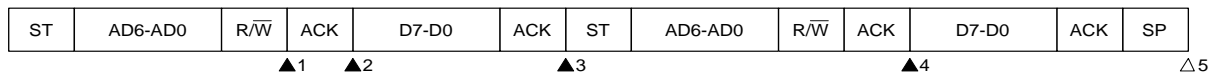
(i) When WTIM0 = 0 (an address mismatch after restart (other than extension code))



- ▲1: IICS0 = 0010x010B
- ▲2: IICS0 = 0010x000B
- ▲3: IICS0 = 00000x10B
- △4: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1 (an address mismatch after restart (other than extension code))

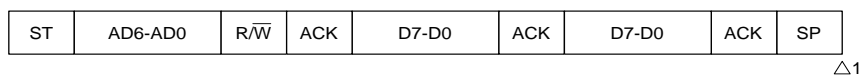


- ▲1: IICS0 = 0010x010B
- ▲2: IICS0 = 0010x110B
- ▲3: IICS0 = 0010xx00B
- ▲4: IICS0 = 00000x10B
- △5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(4) Operation when not participating in communications

(a) Start ~ Code ~ Data ~ Data ~ Stop



- △1: IICS0 = 00000001B

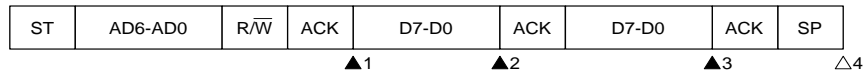
Remark △: Generated only when SPIE0 = 1

(5) Arbitration loss operation (operation as slave after arbitration loss)

To use the device as a master in the multi-master system, read the MSTS0 bit to check the arbitration result each time interrupt request signal INTIICA0 is generated.

(a) When lost in arbitration during transmission of slave address data

(i) When WTIM0 = 0



▲1: IICS0 = 0101x110B

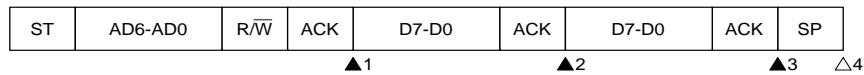
▲2: IICS0 = 0001x000B

▲3: IICS0 = 0001x000B

△4: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1



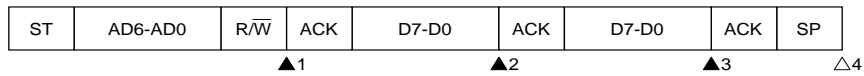
▲1: IICS0 = 0101x110B

▲2: IICS0 = 0001x100B

▲3: IICS0 = 0001xx00B

△4: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(b) When lost in arbitration during transmission of extension code(i) When $WTIM0 = 0$ 

▲1: IICS0 = 0110x010B

▲2: IICS0 = 0010x000B

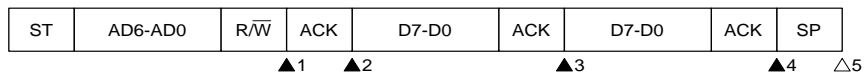
▲3: IICS0 = 0010x000B

△4: IICS0 = 00000001B

Remark ▲: Always generated

△: Generated only when SPIE0 = 1

x: Don't care

(ii) When $WTIM0 = 1$ 

▲1: IICS0 = 0110x010B

▲2: IICS0 = 0010x110B

▲3: IICS0 = 0010x100B

▲4: IICS0 = 0010xx00B

△5: IICS0 = 00000001B

Remark ▲: Always generated

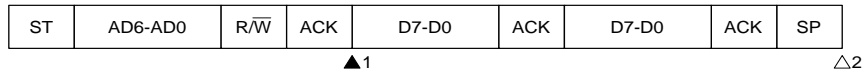
△: Generated only when SPIE0 = 1

x: Don't care

(6) Arbitration loss operation (not participating in communications after arbitration loss)

When the device is used as a master in the multi-master system, read the MSTS0 bit to check the arbitration result each time interrupt request signal INTIICA0 is generated.

(a) When lost in arbitration during transmission of slave address data (when WTIM0 = 1)

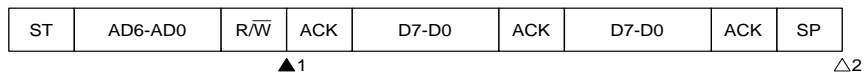


▲1: IICS0 = 01000110B

△2: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1

(b) When lost in arbitration during transmission of extension code



▲1: IICS0 = 0110x010B

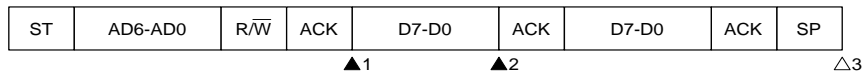
Sets LREL0 = 1 by software

△2: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(c) When lost in arbitration during data transfer

(i) When WTIM0 = 0



▲1: IICS0 = 10001110B

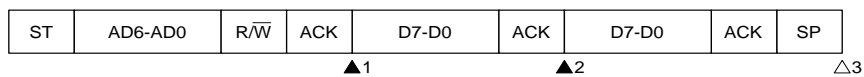
▲2: IICS0 = 01000000B

△3: IICS0 = 00000001B

Remark ▲: Always generated

△: Generated only when SPIE0 = 1

When WTIM0 = 1



▲1: IICS0 = 10001110B

▲2: IICS0 = 01000100B

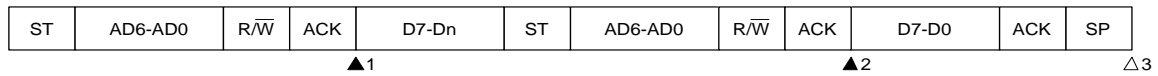
△3: IICS0 = 00000001B

Remark ▲: Always generated

△: Generated only when SPIE0 = 1

(d) When lost in the restart condition during data transfer

(i) Other than extension code (e.g., a mismatch with SVA0)



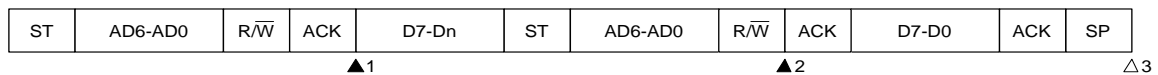
▲1: IICS0 = 1000x110B

▲2: IICS0 = 01000110B

△3: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care
 n = 6 to 0

(ii) Extension code



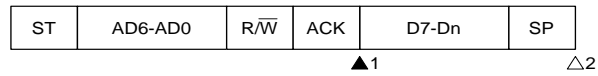
▲1: IICS0 = 1000x110B

▲2: IICS0 = 01100010B

Sets LREL0 = 1 by software

△3: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care
 n = 6 to 0

(e) When lost in the stop condition during data transfer

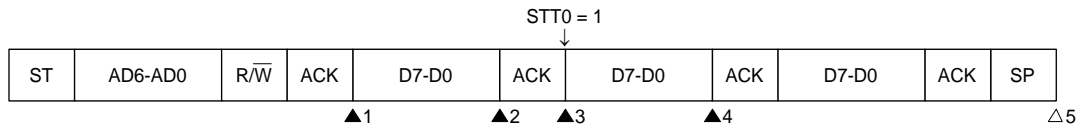
▲1: IICS0 = 10000110B

△2: IICS0 = 01000001B

Remark ▲: Always generated
△: Generated only when SPIE0 = 1
n = 6 to 0

(f) When lost in arbitration due to the data being at the low level when attempting to generate a restart condition

(i) When WTIM0 = 0



▲1: IICS0 = 1000x110B

▲2: IICS0 = 1000x000B (Sets the WTIM0 bit to 1)

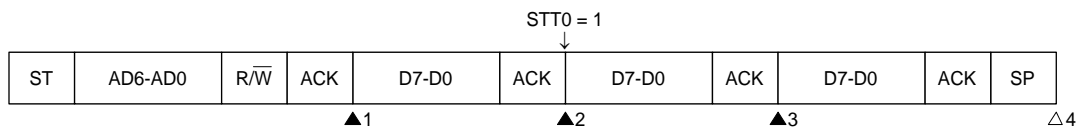
▲3: IICS0 = 1000x100B (Clears the WTIM0 bit to 0)

▲4: IICS0 = 01000000B

△5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1



▲1: IICS0 = 1000x110B

▲2: IICS0 = 1000x100B (Sets the STT0 bit to 1)

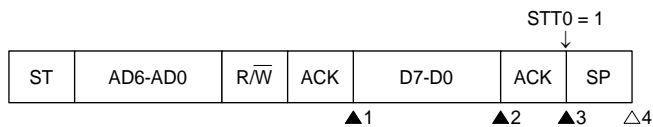
▲3: IICS0 = 01000100B

△4: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(g) When lost in arbitration at the stop condition when attempting to generate a restart condition

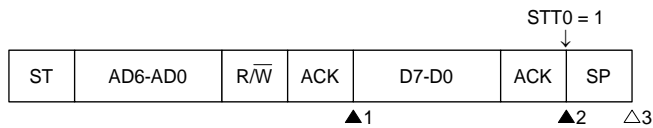
(i) When WTIM0 = 0



- ▲1: IICS0 = 1000x110B
- ▲2: IICS0 = 1000x000B (Sets the WTIM0 bit to 1)
- ▲3: IICS0 = 1000xx00B (Sets the STT0 bit to 1)
- △4: IICS0 = 01000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1

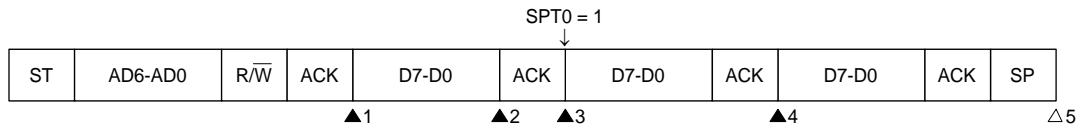


- ▲1: IICS0 = 1000x110B
- ▲2: IICS0 = 1000xx00B (Sets the STT0 bit to 1)
- △3: IICS0 = 01000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(h) When lost in arbitration due to the data being at the low level when attempting to generate a stop condition

(i) When WTIM0 = 0



▲1: IICS0 = 1000x110B

▲2: IICS0 = 1000x000B (Sets the WTIM0 bit to 1)

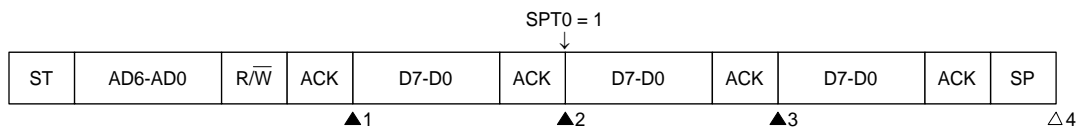
▲3: IICS0 = 1000x100B (Clears the WTIM0 bit to 0)

▲4: IICS0 = 01000100B

△5: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

(ii) When WTIM0 = 1



▲1: IICS0 = 1000x110B

▲2: IICS0 = 1000x100B (Sets the SPT0 bit to 1)

▲3: IICS0 = 01000100B

△4: IICS0 = 00000001B

Remark ▲: Always generated
 △: Generated only when SPIE0 = 1
 x: Don't care

13.6 Timing Charts

In the I²C bus mode, the master outputs an address on the serial bus to select a target slave device from among several slave devices.

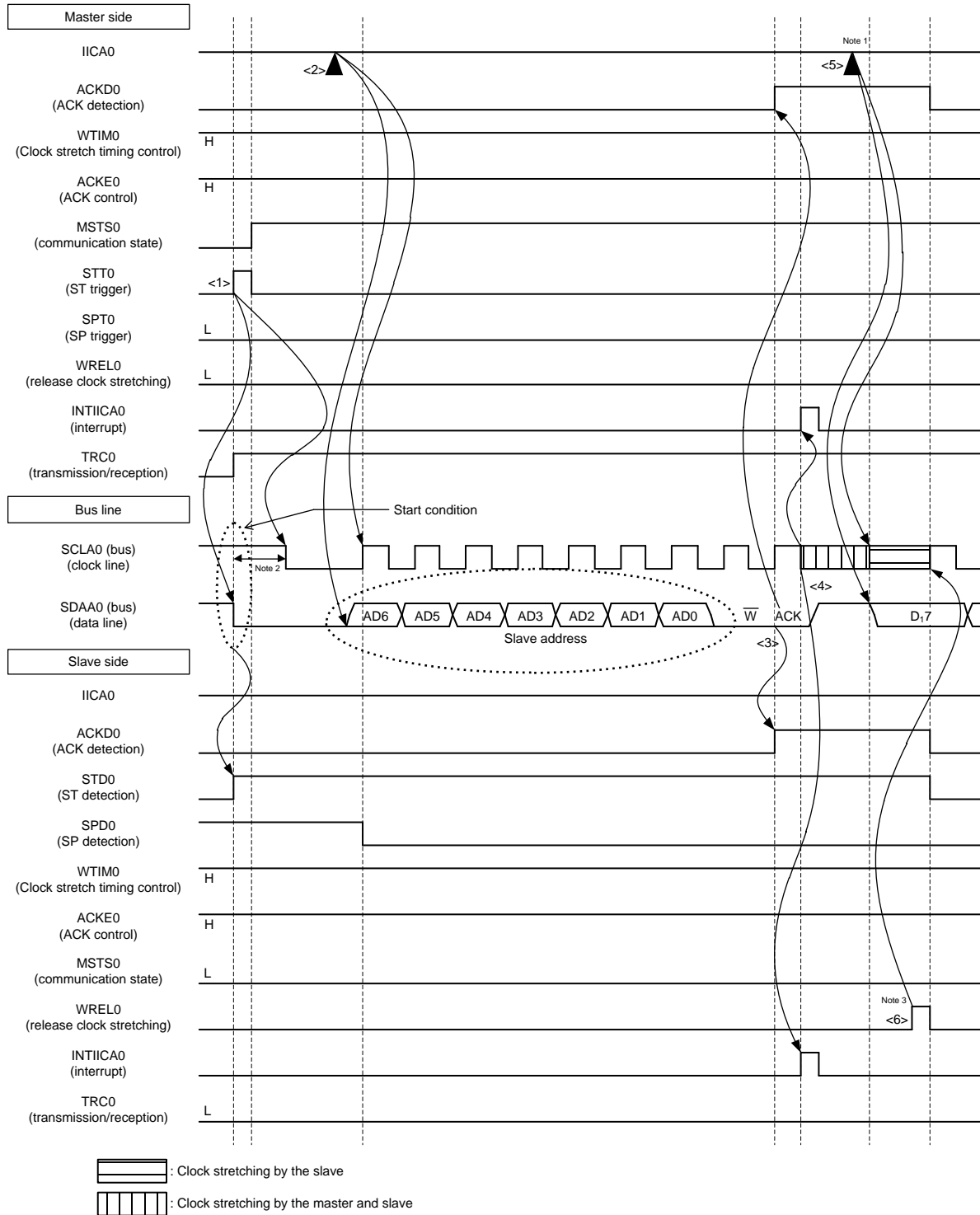
The master transmits the TRC0 bit (bit 3 of IICA status register 0 (IICS0)) that indicates the data transfer direction following the slave address and starts serial communication with the slave.

Figure 13-31 and **Figure 13-32** show timing charts of data communication.

Shift operation of IICA shift register 0 (IICA0) proceeds in synchronization with the falling edge of the serial clock (SCLA0), and the transmit data is transferred to the SO latch and output from the SDAA0 pin with the MSB first.

The data input to the SDAA0 pin is captured in IICA0 at the rising edge of SCLA0.

Figure 13-31. Example of Master to Slave Communications
 (9th Cycle Clock Stretching is Selected for Both Master and Slave) (1/4)
 (1) Start condition ~ address ~ data



Note 1. To release clock stretching in transmission by the master, write data to the IICA0 register instead of setting the WRELO bit.

- Note 2. Make sure that the time between the fall of the SDAA0 pin signal and the fall of the SCLA0 pin signal is at least 4.0 μ s when standard mode is set and at least 0.6 μ s when fast mode is set.
- Note 3. To release clock stretching in reception by the slave, write FFH to IICA0 or set the WRELO bit.

Explanation of <1> to <6> in **Figure 13-31 (1) Start condition ~ address ~ data** is given below.

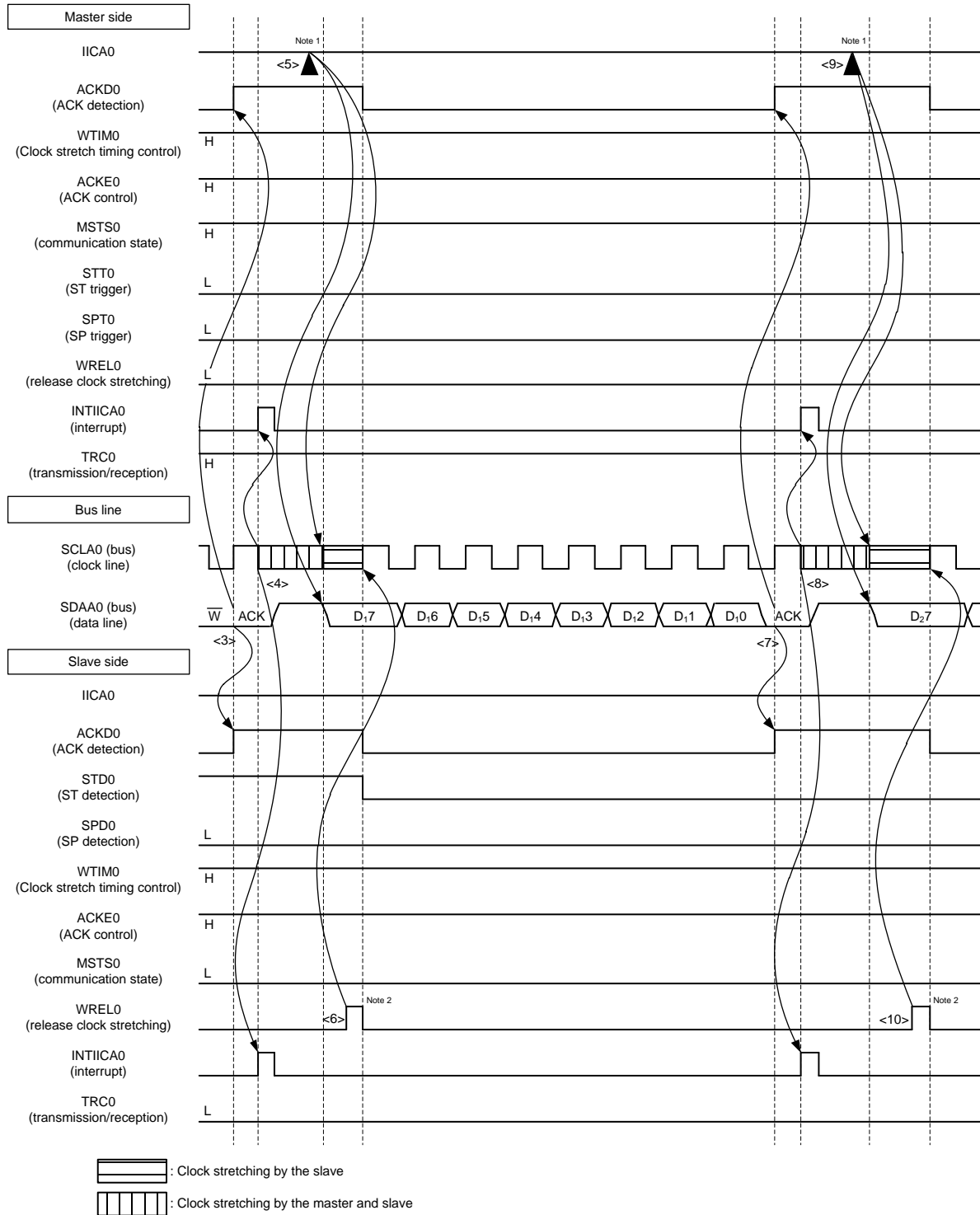
- <1> When the start condition trigger is set by the master (STT0 = 1), the bus data line (SDAA0) goes low and a start condition (SDAA0 = 0, SCLA0 = 1) is generated. After that, when the start condition is detected, the master enters the master communication state (MSTS0 = 1). It is ready for communications when the bus clock line goes low (SCLA0 = 0) after the hold time has elapsed.
- <2> When the master writes the address + W (transmission) to IICA shift register 0 (IICA0), the slave address is transmitted.
- <3> In the slave, if the address received matches its local address (SVA0 value)^{Note 1}, an ACK is sent to the master by the hardware. The ACK is detected by the master (ACKD0 = 1) at the rising edge of the 9th clock.
- <4> The master issues an interrupt (INTIICA0: address transmission end interrupt) at the falling edge of the 9th clock. The slave with the matching address applies clock stretching (SCLA0 = 0) and issues an interrupt (INTIICA0: address match interrupt)^{Note 1}.
- <5> The master writes transmit data to the IICA0 register and releases clock stretching by the master.
- <6> If the slave releases clock stretching (WRELO = 1), the master starts to transfer data to the slave.

- Note 1. If the transmitted address does not match the address of the slave, the slave does not return an ACK to the master (NACK: SDAA0 = 1). The slave also neither issue the INTIICA0 interrupt (address match interrupt) nor apply clock stretching. The master, however, issues the INTIICA0 interrupt (address transmission end interrupt) in response to an ACK or NACK.

Remark <1> to <15> in **Figure 13-31** represent a series of operation procedures for data communications via the I²C bus.

- **Figure 13-31 (1) Start condition ~ address ~ data** shows steps <1> to <6>.
- **Figure 13-31 (2) Address ~ data ~ data** shows steps <3> to <10>.
- **Figure 13-31 (3) Data ~ data ~ stop condition** shows steps <7> to <15>.

Figure 13-31. Example of Master to Slave Communications
 (9th Cycle Clock Stretching is Selected for Both Master and Slave) (2/4)
 (2) Address ~ data ~ data



Note 1. To release clock stretching in transmission by the master, write data to the IICA0 register instead of setting the WRELO bit.

Note 2. To release clock stretching in reception by the slave, write FFH to IICA0 or set the WREL0 bit.

Explanation of <3> to <10> in **Figure 13-31 (2) Address ~ data ~ data** is given below.

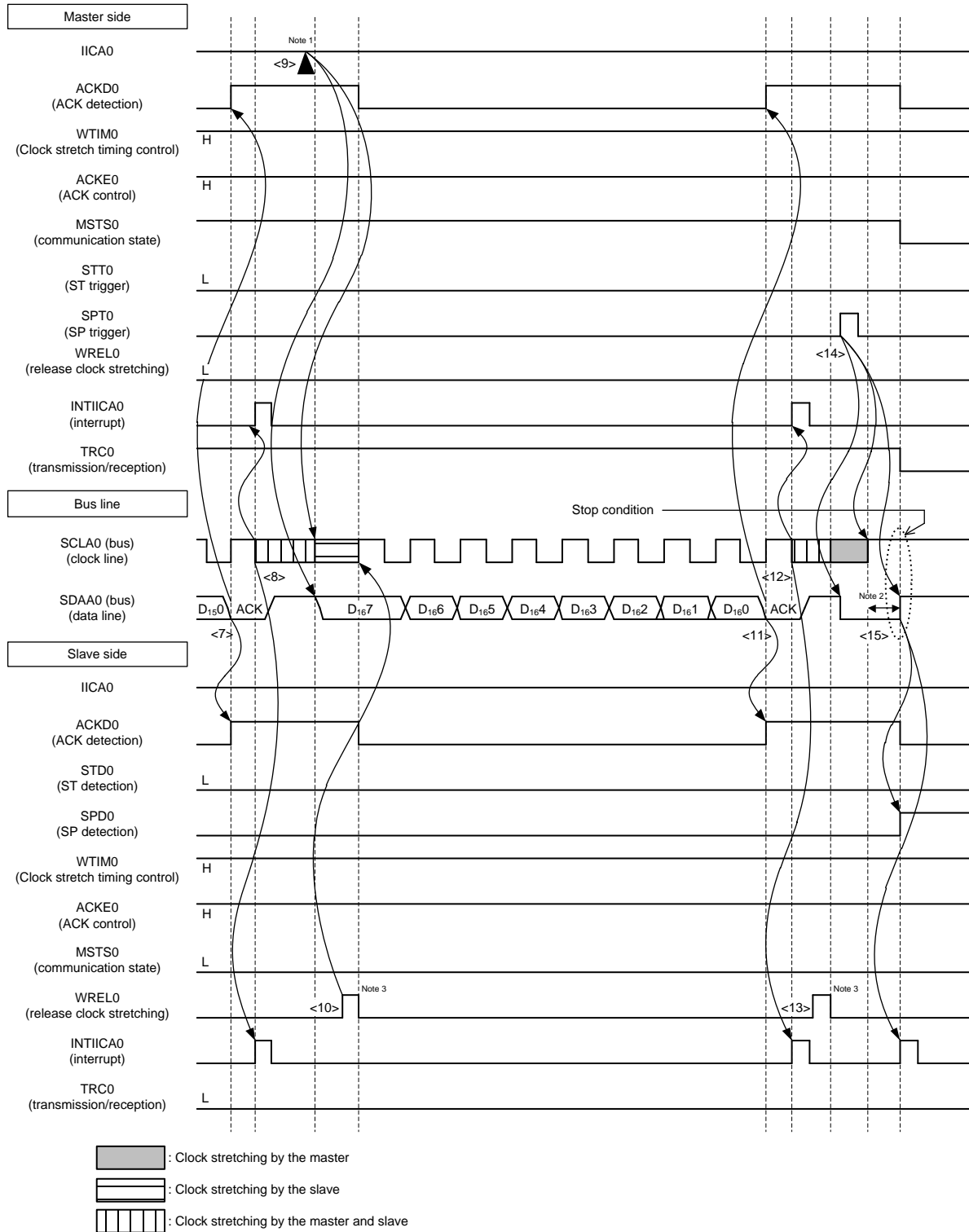
- <3> In the slave, if the address received matches its local address (SVA0 value)^{Note 1}, an ACK is sent to the master by the hardware. The ACK is detected by the master (ACKD0 = 1) at the rising edge of the 9th clock.
- <4> The master issues an interrupt (INTIICA0: address transmission end interrupt) at the falling edge of the 9th clock. The slave with the matching address applies clock stretching (SCLA0 = 0) and issues an interrupt (INTIICA0: address match interrupt)^{Note 1}.
- <5> The master writes transmit data to the IICA shift register 0 (IICA0) and releases clock stretching by the master.
- <6> If the slave releases clock stretching (WREL0 = 1), the master starts to transfer data to the slave.
- <7> After data transfer is completed, because ACKE0 = 1 for the slave, an ACK is sent to the master by the hardware. The ACK is detected by the master (ACKD0 = 1) at the rising edge of the 9th clock.
- <8> The master and slave apply clock stretching (SCLA0 = 0) at the falling edge of the 9th clock, and both the master and slave issue an interrupt (INTIICA0: transfer end interrupt).
- <9> The master writes transmit data to the IICA0 register and releases clock stretching by the master.
- <10> When the slave reads the received data and releases clock stretching (WREL0 = 1), the master starts to transmit data to the slave.

Note 1. If the transmitted address does not match the address of the slave, the slave does not return an ACK to the master (NACK: SDAA0 = 1). The slave also neither issue the INTIICA0 interrupt (address match interrupt) nor apply clock stretching.
The master, however, issues the INTIICA0 interrupt (address transmission end interrupt) in response to an ACK or NACK.

Remark <1> to <15> in **Figure 13-31** represent a series of operation procedures for data communications via the I²C bus.

- **Figure 13-31 (1) Start condition ~ address ~ data** shows steps <1> to <6>.
- **Figure 13-31 (2) Address ~ data ~ data** shows steps <3> to <10>.
- **Figure 13-31 (3) Data ~ data ~ stop condition** shows steps <7> to <15>.

Figure 13-31. Example of Master to Slave Communications
 (9th Cycle Clock Stretching is Selected for Both Master and Slave) (3/4)
 (3) Data ~ data ~ stop condition



Note 1. To release clock stretching in transmission by the master, write data to the IICA0 register instead of setting the WRELO bit.

- Note 2. Make sure that the time between the rise of the SCLA0 pin signal and the generation of the stop condition after a stop condition has been issued is at least 4.0 μ s when standard mode is set and at least 0.6 μ s when fast mode is set.
- Note 3. To release clock stretching in reception by the slave, write FFH to IICA0 or set the WREL0 bit.

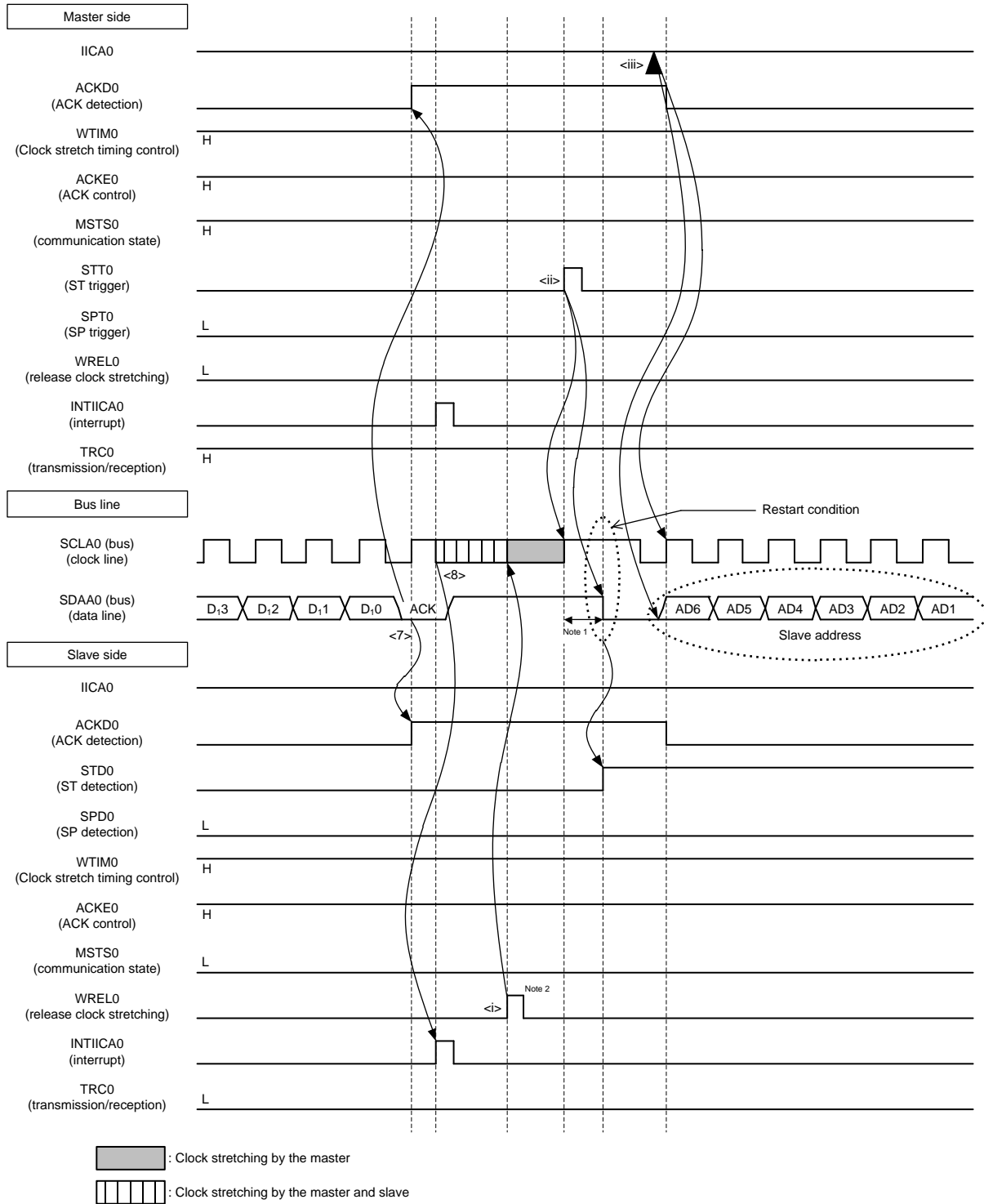
Explanation of <7> to <15> in **Figure 13-31 (3) Data ~ data ~ stop condition** is given below.

- <7> After data transfer is completed, because ACKE0 = 1 for the slave, an ACK is sent to the master by the hardware. The ACK is detected by the master (ACKD0 = 1) at the rising edge of the 9th clock.
- <8> The master and slave apply clock stretching (SCLA0 = 0) at the falling edge of the 9th clock, and both the master and slave issue an interrupt (INTIICA0: transfer end interrupt).
- <9> The master writes transmit data to the IICA shift register 0 (IICA0) and releases clock stretching by the master.
- <10> When the slave reads the received data and releases clock stretching (WREL0 = 1), the master starts to transmit data to the slave.
- <11> After data transfer is completed, an ACK is sent to the master by the hardware of the slave (ACKE0 = 1). The ACK is detected by the master (ACKD0 = 1) at the rising edge of the 9th clock.
- <12> The master and slave apply clock stretching (SCLA0 = 0) at the falling edge of the 9th clock, and both the master and slave issue an interrupt (INTIICA0: transfer end interrupt).
- <13> The slave reads the received data and releases clock stretching (WREL0 = 1).
- <14> When the master sets a stop condition trigger (SPT0 = 1), the bus data line is cleared (SDAA0 = 0) and the bus clock line is set (SCLA0 = 1). After the stop condition setup time has elapsed, a stop condition (SDAA0 changes from 0 to 1 with SCLA0 = 1) is generated by the bus data line being set (SDAA0 = 1).
- <15> The slave detects the stop condition and issues an interrupt (INTIICA0: stop condition interrupt).

Remark <1> to <15> in **Figure 13-31** represent a series of operation procedures for data communications via the I²C bus.

- **Figure 13-31 (1) Start condition ~ address ~ data** shows steps <1> to <6>.
- **Figure 13-31 (2) Address ~ data ~ data** shows steps <3> to <10>.
- **Figure 13-31 (3) Data ~ data ~ stop condition** shows steps <7> to <15>.

Figure 13-31. Example of Master to Slave Communications
 (9th Cycle Clock Stretching is Selected for Both Master and Slave) (4/4)
 (4) Data ~ restart condition ~ address



Note 1. Make sure that the time between the rise of the SCLA0 pin signal and the generation of the start condition after a restart condition has been issued is at least 4.7 μs when standard mode is set and at least 0.6 μs when fast mode is set.

Note 2. To release clock stretching in reception by the slave, write FFH to IICA0 or set the WRELO bit.

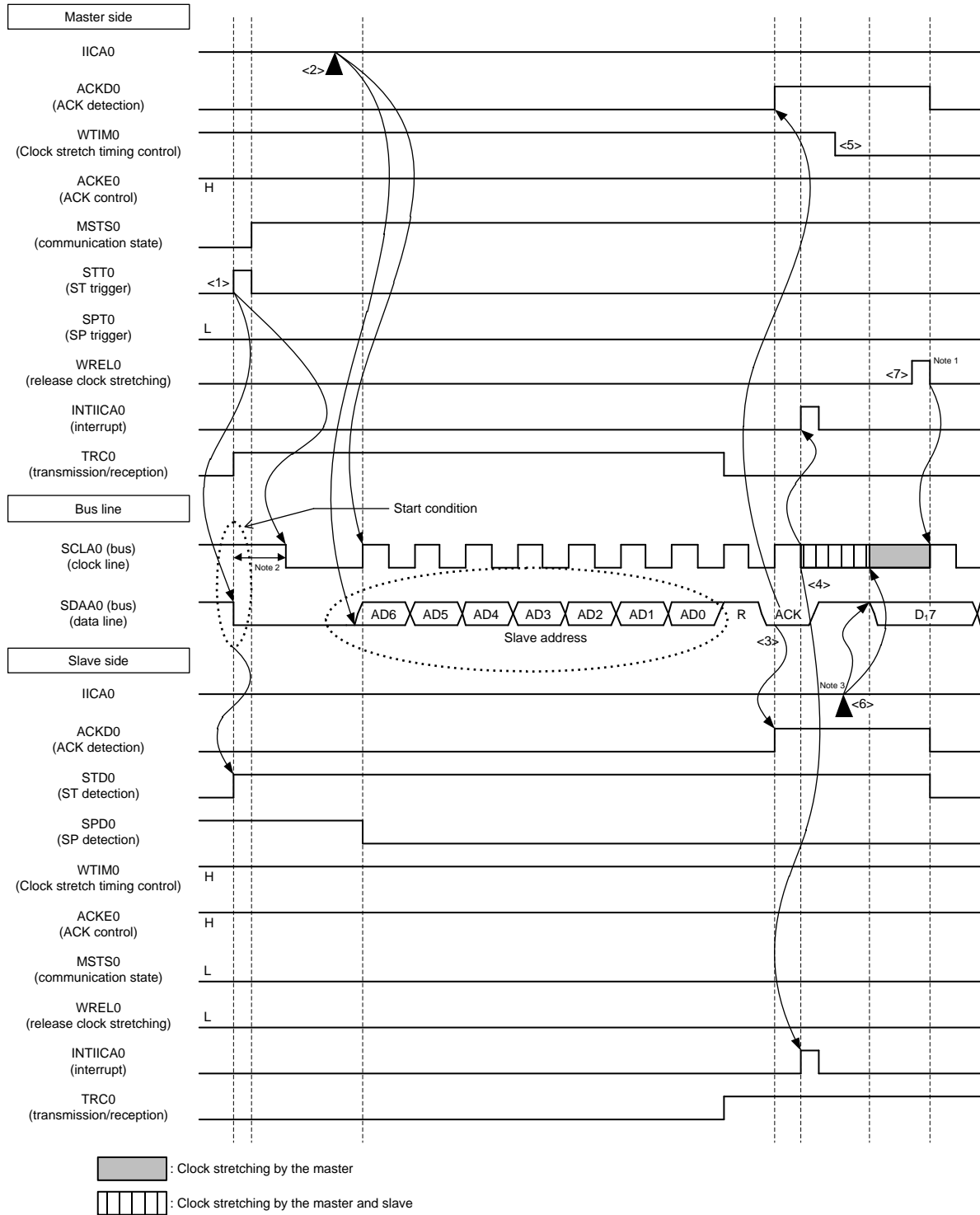
The following describes the operations in **Figure 13-31 (4) Data ~ restart condition ~ address**. After the operations of steps <7> and <8>, the operations of steps <i> to <iii> are performed. As a result, processing returns to the data transmission procedure in step <3>.

- <7> After data transfer is completed, because ACKE0 = 1 for the slave, an ACK is sent to the master by the hardware. The ACK is detected by the master (ACKD0 = 1) at the rising edge of the 9th clock.
- <8> The master and slave apply clock stretching (SCLA0 = 0) at the falling edge of the 9th clock, and both the master and slave issue an interrupt (INTIICA0: transfer end interrupt).
- <i> The slave reads the received data and releases clock stretching (WRELO = 1).
- <ii> When the start condition trigger is set again by the master (STT0 = 1), the bus clock line goes high (SCLA0 = 1), the bus data line goes low (SDAA0 = 0) after the restart condition setup time has elapsed, and a start condition (SDAA0 changes from 1 to 0 with SCLA0 = 1) is generated. After that, when the start condition is detected, the master is ready for communications when the bus clock line goes low (SCLA0 = 0) after the hold time has elapsed.
- <iii> When the master writes the address + R/W (transmission) to the IICA shift register 0 (IICA0), the slave address is transmitted.

Figure 13-32. Example of Slave to Master Communications

(8th Cycle Clock Stretching is Selected for Master, 9th Cycle Clock Stretching is Selected for Slave) (1/3)

(1) Start condition ~ address ~ data



Note 1. To release clock stretching in reception by the master, write FFH to IICA0 or set the WRELO bit.

Note 2. Make sure that the time between the fall of the SDAA0 pin signal and the fall of the SCLA0 pin signal is at least 4.0 μs when standard mode is set and at least 0.6 μs when fast mode is set.

Note 3. To release clock stretching in transmission by the slave, write data to the IICA0 register instead of setting the WRELO bit.

Explanation of <1> to <7> in **Figure 13-32 (1) Start condition ~ address ~ data** is given below.

- <1> When the start condition trigger is set by the master (STT0 = 1), the bus data line (SDAA0) goes low and a start condition (SDAA0 changes from 1 to 0 with SCLA0 = 1) is generated. After that, when the start condition is detected, the master enters the master communication state (MSTS0 = 1). It is ready for communications when the bus clock line goes low (SCLA0 = 0) after the hold time has elapsed.
- <2> When the master writes the address + R (reception) to IICA shift register 0 (IICA0), the slave address is transmitted.
- <3> In the slave, if the address received matches its local address (SVA0 value)^{Note 1}, an ACK is sent to the master by the hardware. The ACK is detected by the master (ACKD0 = 1) at the rising edge of the 9th clock.
- <4> The master issues an interrupt (INTIICA0: address transmission end interrupt) at the falling edge of the 9th clock. The slave with the matching address applies clock stretching (SCLA0 = 0) and issues an interrupt (INTIICA0: address match interrupt)^{Note 1}.
- <5> The timing of clock stretching by the master is changed to the 8th clock (WTIM0 = 0).
- <6> The slave writes transmit data to the IICA0 register and releases clock stretching by the slave.
- <7> The master releases clock stretching (WRELO = 1) and starts data transfer with the slave.

Note 1. If the transmitted address does not match the address of the slave, the slave does not return an ACK to the master (NACK: SDAA0 = 1). The slave also neither issue the INTIICA0 interrupt (address match interrupt) nor apply clock stretching.
The master, however, issues the INTIICA0 interrupt (address transmission end interrupt) in response to an ACK or NACK.

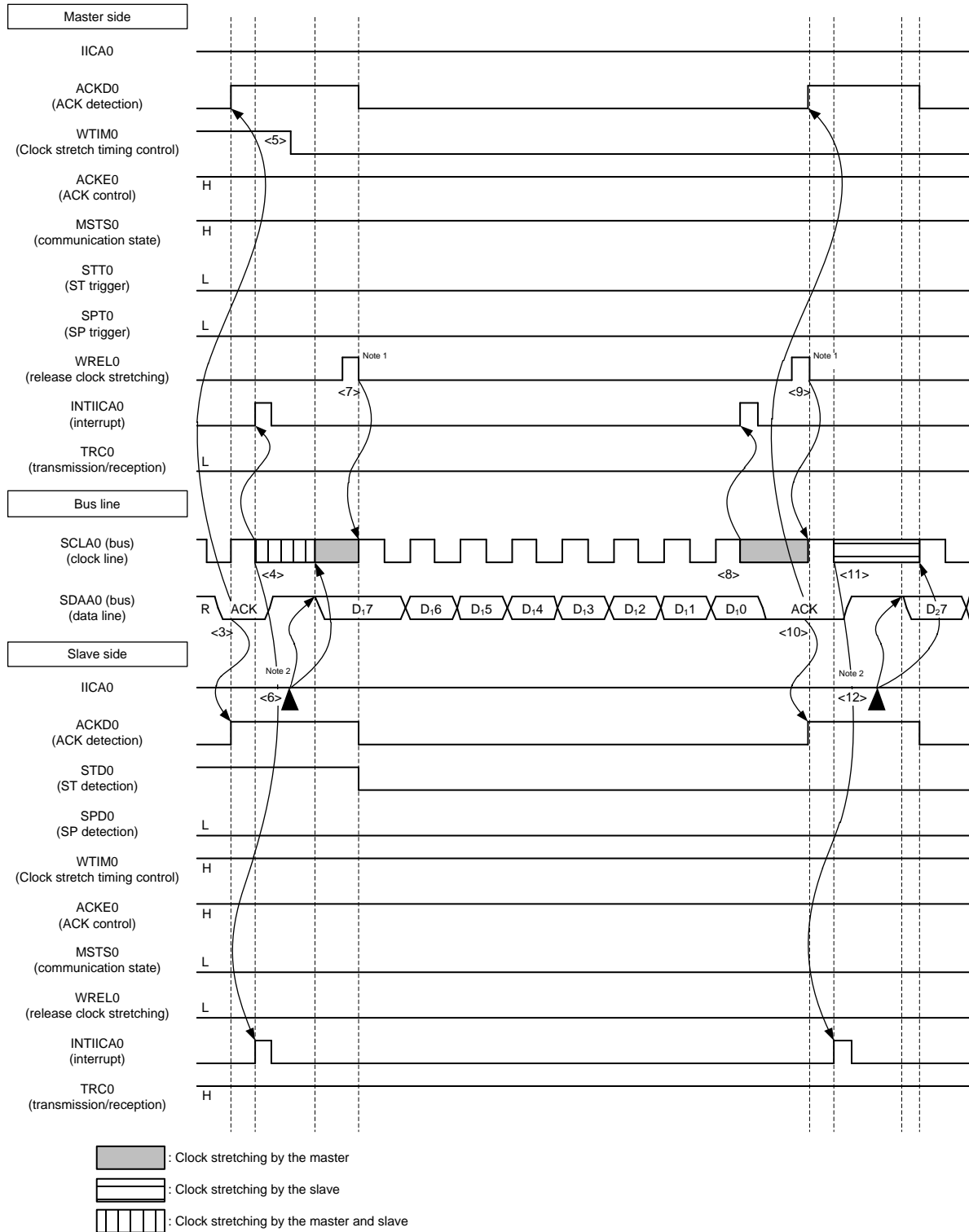
Remark <1> to <19> in **Figure 13-32** represent a series of operation procedures for data communications via the I²C bus.

- **Figure 13-32 (1) Start condition ~ address ~ data** shows steps <1> to <7>.
- **Figure 13-32 (2) Address ~ data ~ data** shows steps <3> to <12>.
- **Figure 13-32 (3) Data ~ data ~ stop condition** shows steps <8> to <19>.

Figure 13-32. Example of Slave to Master Communications

(8th Cycle Clock Stretching is Selected for Master, 9th Cycle Clock Stretching is Selected for Slave) (2/3)

(2) Address ~ data ~ data



Note 1. To release clock stretching in reception by the master, write FFH to IICA0 or set the WRELO bit.

Note 2. To release clock stretching in transmission by the slave, write data to the IICA0 register instead of setting the WRELO bit.

Explanation of <3> to <12> in **Figure 13-32 (2) Address ~ data ~ data** is given below.

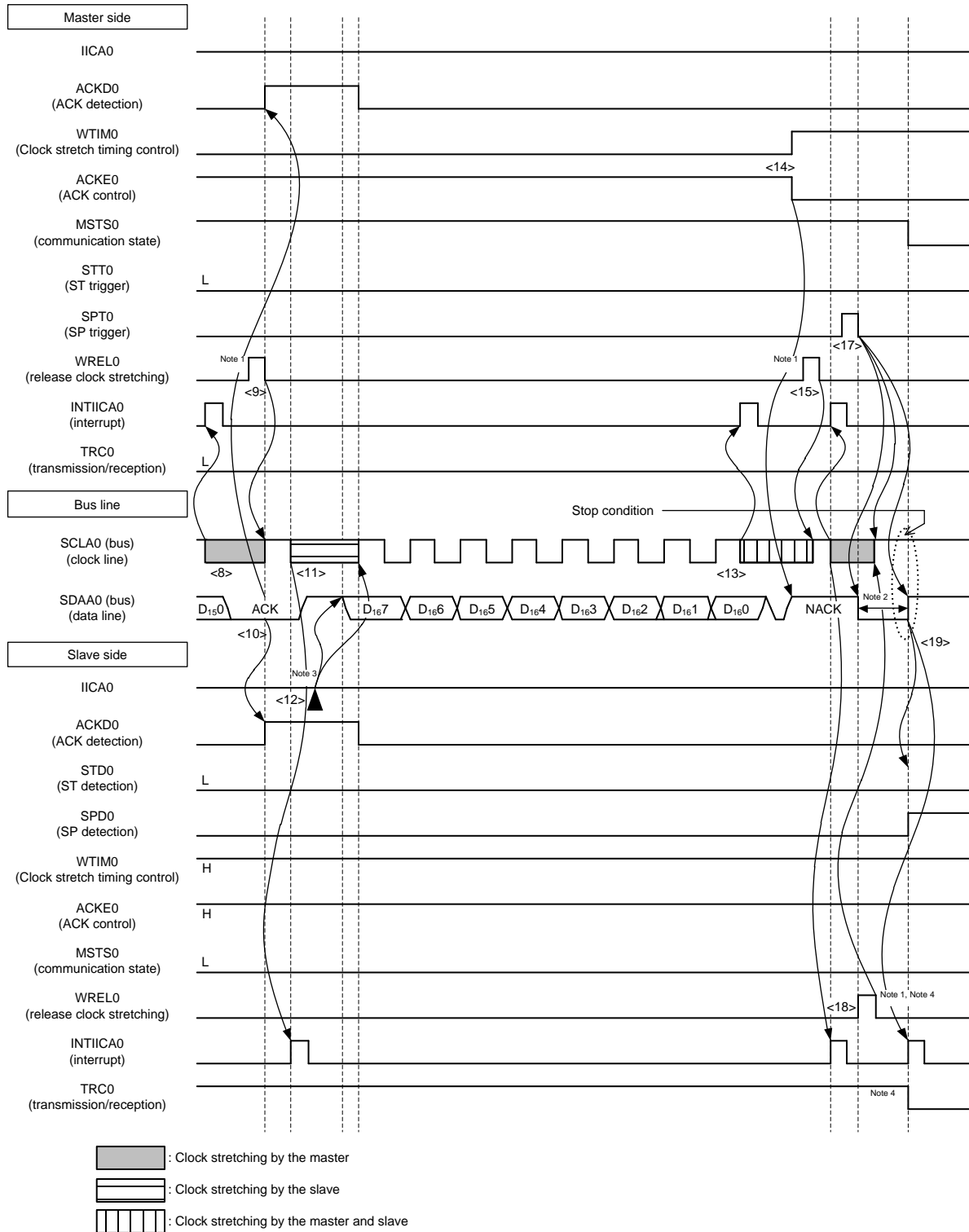
- <3> In the slave, if the address received matches its local address (SVA0 value)^{Note 1}, an ACK is sent to the master by the hardware. The ACK is detected by the master (ACKD0 = 1) at the rising edge of the 9th clock.
- <4> The master issues an interrupt (INTIICA0: address transmission end interrupt) at the falling edge of the 9th clock. The slave with the matching address applies clock stretching (SCLA0 = 0) and issues an interrupt (INTIICA0: address match interrupt)^{Note 1}.
- <5> The timing of clock stretching by the master is changed to the 8th clock (WTIM0 = 0).
- <6> The slave writes transmit data to the IICA shift register 0 (IICA0) and releases clock stretching by the slave.
- <7> The master releases clock stretching (WRELO = 1) and starts data transfer with the slave.
- <8> The master applies clock stretching (SCLA0 = 0) at the falling edge of the 8th clock and issues an interrupt (INTIICA0: transfer end interrupt). Because ACKE0 = 0 for the master, an ACK is sent to the slave by the hardware.
- <9> The master reads the received data and releases clock stretching (WRELO = 1).
- <10> The ACK is detected by the slave (ACKD0 = 1) at the rising edge of the 9th clock.
- <11> The slave applies clock stretching (SCLA0 = 0) at the falling edge of the 9th clock and issues an interrupt (INTIICA0: transfer end interrupt).
- <12> When the slave writes transmit data to the IICA0 register, clock switching by the slave is released. The slave then starts to transfer data to the master.

Note 1. If the transmitted address does not match the address of the slave, the slave does not return an ACK to the master (NACK: SDAA0 = 1). The slave also neither issue the INTIICA0 interrupt (address match interrupt) nor apply clock stretching.
The master, however, issues the INTIICA0 interrupt (address transmission end interrupt) in response to an ACK or NACK.

Remark <1> to <19> in **Figure 13-32** represent a series of operation procedures for data communications via the I²C bus.

- **Figure 13-32 (1) Start condition ~ address ~ data** shows steps <1> to <7>.
- **Figure 13-32 (2) Address ~ data ~ data** shows steps <3> to <12>.
- **Figure 13-32 (3) Data ~ data ~ stop condition** shows steps <8> to <19>.

Figure 13-32. Example of Slave to Master Communications
 (8th Cycle Clock Stretching is Changed to 9th Cycle Clock Stretching for Master,
 9th Cycle Clock Stretching is Selected for Slave)
 (3) Data ~ data ~ stop condition



Note 1. To release clock stretching, write FFH to IICA0 or set the WRELO bit.

- Note 2. Make sure that the time between the rise of the SCLA0 pin signal and the generation of the stop condition after a stop condition has been issued is at least 4.0 μ s when standard mode is set and at least 0.6 μ s when fast mode is set.
- Note 3. To release clock stretching in transmission by the slave, write data to the IICA0 register instead of setting the WRELO bit.
- Note 4. If clock stretching in transmission by the slave is released by setting the WRELO bit, the TRC0 bit will be cleared.

Explanation of <8> to <19> in **Figure 13-32 (3) Data ~ data ~ stop condition** is given below.

- <8> The master applies clock stretching (SCLA0 = 0) at the falling edge of the 8th clock and issues an interrupt (INTIICA0: transfer end interrupt). Because ACKE0 = 0 for the master, an ACK is sent to the slave by the hardware.
- <9> The master reads the received data and releases clock stretching (WRELO = 1).
- <10> The ACK is detected by the slave (ACKD0 = 1) at the rising edge of the 9th clock.
- <11> The slave applies clock stretching (SCLA0 = 0) at the falling edge of the 9th clock and issues an interrupt (INTIICA0: transfer end interrupt).
- <12> When the slave writes transmit data to the IICA0 register, clock stretching by the slave is released. The slave then starts to transfer data to the master.
- <13> The master issues an interrupt (INTIICA0: transfer end interrupt) at the falling edge of the 8th clock and applies clock stretching (SCLA0 = 0). Because ACK control (ACKE0 = 1) is used, the bus data line is at the low level (SDAA0 = 0) at this stage.
- <14> The master sets NACK as the response (ACKE0 = 0) and changes the timing of clock stretching to the 9th clock (WTIM0 = 1).
- <15> If the master releases clock stretching (WRELO = 1), the slave detects the NACK (ACK = 0) at the rising edge of the 9th clock.
- <16> The master and slave apply clock stretching (SCLA0 = 0) at the falling edge of the 9th clock, and both the master and slave issue an interrupt (INTIICA0: transfer end interrupt).
- <17> When the master issues a stop condition (SPT0 = 1), the bus data line is cleared (SDAA0 = 0) and the master releases clock stretching. The master then waits until the bus clock line is set (SCLA0 = 1).
- <18> The slave acknowledges the NACK, halts transmission, and releases clock stretching (WRELO = 1) to end communications. Once the slave releases clock stretching, the bus clock line is set (SCLA0 = 1).
- <19> When the master confirms that the bus clock line has been set (SCLA0 = 1), it sets the bus data line (SDAA0 = 1) and issues a stop condition (SDAA0 changes from 0 to 1 with SCLA0 = 1) after the stop condition setup time has elapsed. The slave detects this stop condition and issues an interrupt (INTIICA0: stop condition interrupt).

Remark <1> to <19> in **Figure 13-32** represent a series of operation procedures for data communications via the I²C bus.

- **Figure 13-32 (1) Start condition ~ address ~ data** shows steps <1> to <7>.
- **Figure 13-32 (2) Address ~ data ~ data** shows steps <3> to <12>.
- **Figure 13-32 (3) Data ~ data ~ stop condition** shows steps <8> to <19>.

CHAPTER 14 INTERRUPT FUNCTIONS

The interrupt function switches the program execution to other processing. When the branch processing is finished, the program returns to the interrupted processing.

The number of interrupt sources differs depending on the product.

| | | 20-pin | 16-pin | 10-pin | 8-pin |
|---------------------|----------|--------|--------|--------|-------|
| Maskable interrupts | External | 8 | 8 | 8 | 6 |
| | Internal | 19 | 16 | 10 | 10 |

14.1 Interrupt Function Types

The following two types of interrupt functions are used.

1) Maskable interrupts

These interrupts undergo mask control. Maskable interrupts can be divided into four priority groups by setting the priority specification flag registers (PR00L, PR00H, PR01L, PR01H, PR10L, PR10H, PR11L, PR11H). Multiple interrupt servicing can be applied to low-priority interrupts when high-priority interrupts are generated. If two or more interrupt requests, each having the same priority, are simultaneously generated, then they are processed according to the default priority of vectored interrupt servicing. For default priority, see **Table 14-1**.

A standby release signal is generated and STOP and HALT modes are released.

External interrupt requests and internal interrupt requests are provided as maskable interrupts.

2) Software interrupt

This is a vectored interrupt generated by executing the BRK instruction. It is acknowledged even when interrupts are disabled. The software interrupt does not undergo interrupt priority control.

14.2 Interrupt Sources and Configuration

Interrupt sources include maskable interrupts and software interrupts. In addition, they also have up to five reset sources (see **Table 14-1**). The vector codes that store the program start address when branching due to the generation of a reset or various interrupt requests are two bytes each, so interrupts jump to a 64 K address of 00000H to 0FFFFH.

Table 14-1. Interrupt Source List (1/2)

| Interrupt Type | Default Priority ^{Note 1} | Interrupt Source | | Internal/External | Vector Table Address | Basic Configuration Type ^{Note 2} | 20-pin | 16-pin | 10-pin | 8-pin |
|----------------|------------------------------------|--------------------------------------|---|-------------------|----------------------|--|--------|-------------|-------------|-------------|
| | | Name | Trigger | | | | | | | |
| Maskable | 0 | INTWDT1 | Watchdog timer interval (75% of the overflow time + 3/(4 × f _{IL})) | Internal | 00004H | (A) | ✓ | ✓ | ✓ | ✓ |
| | 1 | INTP0 | Pin input edge detection | External | 00006H | (B) | ✓ | ✓ | ✓ | ✓ |
| | 2 | INTP1 | | | 00008H | | ✓ | ✓ | ✓ | ✓ |
| | 3 | INTP2 | | | 0000AH | | ✓ | ✓ | ✓ | ✓ |
| | 4 | INTP3 | | | 0000CH | | ✓ | ✓ | ✓ | ✓ |
| | 5 | INTP4 | | | 0000EH | | ✓ | ✓ | ✓ | ✓ |
| | 6 | INTP5 | | | 00010H | | ✓ | ✓ | ✓ | ✓ |
| | 7 | INTST0/ INTCSI00/ INTIIC00 | UART0 transmission transfer end, buffer empty interrupt/CSI00 transfer end, buffer empty interrupt/IIC00 transfer end | Internal | 00012H | (A) | ✓ | ✓ | ✓ | ✓ |
| | 8 | INTSR0/ INTCSI01/ INTIIC01 | UART0 reception transfer end/CSI01 transfer end, buffer empty interrupt/IIC01 transfer end | | 00014H | | ✓ | ✓ | ✓ | ✓ |
| | 9 | INTSRE0 | UART0 reception communication error occurrence | | 00016H | | ✓ | ✓ | ✓ | ✓ |
| | 10 | INTTM01H | End of counting or capture by timer channel 01 (at higher 8-bit timer operation) | | 00018H | | ✓ | ✓ | ✓ | ✓ |
| | 11 | INTTM00 | End of counting or capture by timer channel 00 | | 0001AH | | ✓ | ✓ | ✓ | ✓ |
| | 12 | INTTM01 | End of counting or capture by timer channel 01 (at 16-bit/lower 8-bit timer operation) | | 0001CH | | ✓ | ✓ | ✓ | ✓ |
| | 13 | INTAD | End of A/D conversion | | 0001EH | | ✓ | ✓ | ✓ | ✓ |
| | 14 | INTP6 | Pin input edge detection | External | 00020H | | (B) | ✓ | ✓ | ✓ |
| | 15 | INTP7 | Pin input edge detection | | 00022H | ✓ | | ✓ | ✓ | — |
| | 16 | INTTM03H | End of counting or capture by timer channel 03 (at higher 8-bit timer operation) | Internal | 00024H | (A) | ✓ | ✓ | ✓ Note 4 | ✓ Note 4 |
| | 17 | INTIICA0 | End of IICA0 communication | | 00026H | | ✓ | ✓ | ✓ | ✓ |
| | 18 | INTTM02 | End of counting or capture by timer channel 02 | | 00028H | | ✓ | ✓ | ✓ | ✓ |
| | 19 | INTTM03 | End of counting or capture by timer channel 03 | | 0002AH | | ✓ | ✓ | ✓ Note 4 | ✓ Note 4 |
| | 20 | INTIT | 12-bit interval timer interval signal detection | | 0002CH | | ✓ | ✓ | ✓ | ✓ |
| | 21 | INTTM04 | End of counting or capture by timer channel 04 | | 0002EH | | ✓ | ✓ Note 4 | ✓ Note 4 | ✓ Note 4 |
| | 22 | INTTM05 | End of counting or capture by timer channel 05 | | 00030H | | ✓ | ✓ | ✓ Note 4 | ✓ Note 4 |
| | 23 | INTTM06 | End of counting or capture by timer channel 06 | | 00032H | | ✓ | ✓ Note 4 | ✓ Note 4 | ✓ Note 4 |
| | 24 | INTTM07 | End of counting or capture by timer channel 07 | | 00034H | | ✓ | ✓ | ✓ Note 4 | ✓ Note 4 |
| | 25 | INTCMP0 | Valid edge detection by comparator 0 | | | | 00036H | ✓ | ✓ | ✓ |
| 26 | INTCMP1 | Valid edge detection by comparator 1 | | 00038H | ✓ | — | — | — | | |

Table 14-1. Interrupt Source List (2/2)

| Interrupt Type | Default Priority ^{Note 1} | Interrupt Source | | Internal/External | Vector Table Address | Basic Configuration Type ^{Note 2} | 20-pin | 16-pin | 10-pin | 8-pin |
|----------------|------------------------------------|------------------|--|-------------------|----------------------|--|--------|--------|--------|-------|
| | | Name | Trigger | | | | | | | |
| Software | — | BRK | Execution of BRK instruction | — | 0007EH | (C) | ✓ | ✓ | ✓ | ✓ |
| Reset | — | RESET | RESET pin input | — | 00000H | — | ✓ | ✓ | ✓ | ✓ |
| | | SPOR | Selectable power-on-reset | | | | ✓ | ✓ | ✓ | ✓ |
| | | WDT | Overflow of watchdog timer | | | | ✓ | ✓ | ✓ | ✓ |
| | | TRAP | Execution of illegal instruction ^{Note 3} | | | | ✓ | ✓ | ✓ | ✓ |
| | | IAW | Illegal memory access | | | | ✓ | ✓ | ✓ | ✓ |

Note 1. The default priority determines the sequence of interrupts if two or more maskable interrupts occur simultaneously. 0 indicates the highest priority and 26 indicates the lowest priority.

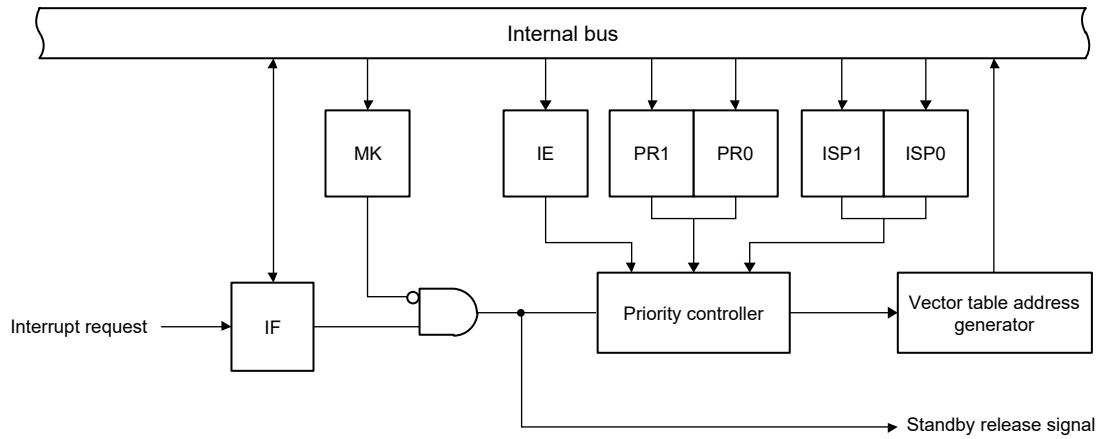
Note 2. Basic configuration types (A) to (C) correspond to (A) to (C) in **Figure 14-1**.

Note 3. A reset is generated when the instruction code in FFH is executed.
No reset is generated if an illegal instruction is executed during emulation by the on-chip debug emulator.

Note 4. Completion of counting by a channel of the array unit is only possible.

Figure 14-1. Basic Configuration of Interrupt Function (1/2)

(A) Internal maskable interrupt



(B) External maskable interrupt (INTPn)

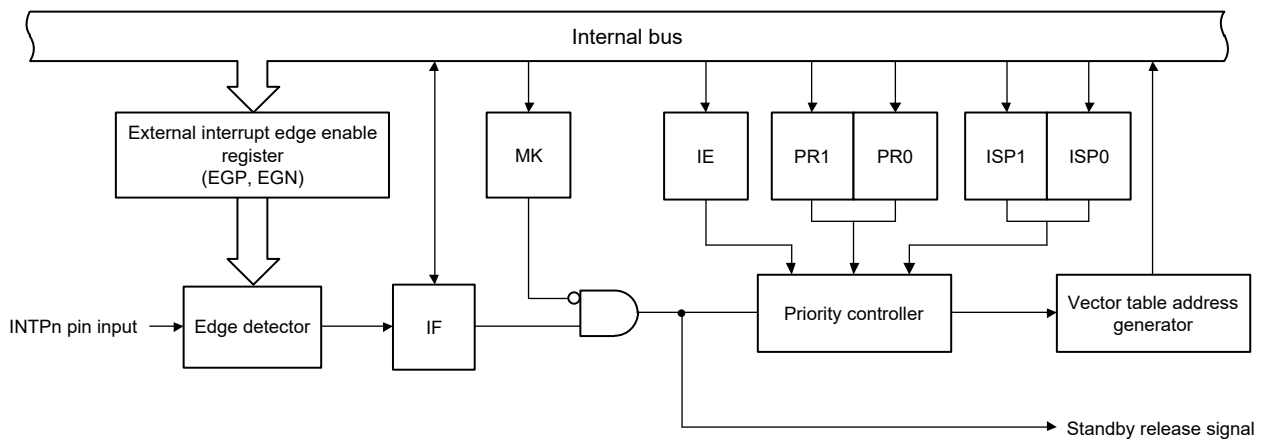
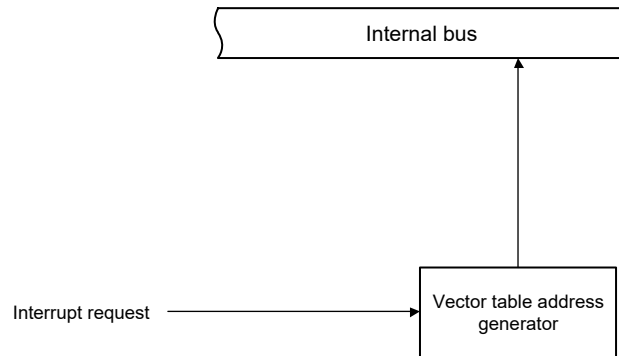


Figure 14-1. Basic Configuration of Interrupt Function (2/2)

(C) Software interrupt

IF: Interrupt request flag

IE: Interrupt enable flag

ISP0: In-service priority flag 0

ISP1: In-service priority flag 1

MK: Interrupt mask flag

PR0: Priority specification flag 0

PR1: Priority specification flag 1

Remark 10-, 16-, and 20-pin: n = 0 to 7,
8-pin: n = 0 to 5

14.3 Registers Controlling Interrupt Functions

The following 6 types of registers are used to control the interrupt functions.

- Interrupt request flag registers (IF0L, IF0H, IF1L, IF1H)
- Interrupt mask flag registers (MK0L, MK0H, MK1L, MK1H)
- Priority specification flag registers (PR00L, PR00H, PR01L, PR01H, PR10L, PR10H, PR11L, PR11H)
- External interrupt rising edge enable register (EGP0)
- External interrupt falling edge enable register (EGN0)
- Program status word (PSW)

Table 14-2 shows a list of interrupt request flags, interrupt mask flags, and priority specification flags corresponding to interrupt request sources.

Table 14-2. Flags Corresponding to Interrupt Request Sources (1/2)

| Interrupt Source | Interrupt Request Flag | | Interrupt Mask Flag | | Priority Specification Flag | | 20-pin | 16-pin | 10-pin | 8-pin |
|----------------------------|---------------------------|----------|---------------------------|----------|--------------------------------------|--------------|--------|--------|--------|-------|
| | | Register | | Register | | Register | | | | |
| INTWDTI | WDTIIF | IF0L | WDTIMK | MK0L | WDTIPR0, WDTIPR1 | PR00L, PR10L | ✓ | ✓ | ✓ | ✓ |
| INTP0 | PIF0 | | PMK0 | | PPR00, PPR10 | | ✓ | ✓ | ✓ | ✓ |
| INTP1 | PIF1 | | PMK1 | | PPR01, PPR11 | | ✓ | ✓ | ✓ | ✓ |
| INTP2 | PIF2 | | PMK2 | | PPR02, PPR12 | | ✓ | ✓ | ✓ | ✓ |
| INTP3 | PIF3 | | PMK3 | | PPR03, PPR13 | | ✓ | ✓ | ✓ | ✓ |
| INTP4 | PIF4 | | PMK4 | | PPR04, PPR14 | | ✓ | ✓ | ✓ | ✓ |
| INTP5 | PIF5 | | PMK5 | | PPR05, PPR15 | | ✓ | ✓ | ✓ | ✓ |
| INTST0 ^{Note 1} | STIF0 ^{Note 1} | | STMK0 ^{Note 1} | | STPR00, STPR10 ^{Note 1} | | ✓ | ✓ | ✓ | ✓ |
| INTCSI00 ^{Note 1} | CSIIF00 ^{Note 1} | | CSIMK00 ^{Note 1} | | CSIPR000, CSIPR100 ^{Note 1} | | ✓ | ✓ | ✓ | ✓ |
| INTIIC00 ^{Note 1} | IICIF00 ^{Note 1} | | IICMK00 ^{Note 1} | | IICPR000, IICPR100 ^{Note 1} | | ✓ | ✓ | ✓ | ✓ |
| INTSR0 ^{Note 2} | SRIF0 ^{Note 2} | IF0H | SRMK0 ^{Note 2} | MK0H | SRPR00, SRPR10 ^{Note 2} | PR00H, PR10H | ✓ | ✓ | ✓ | ✓ |
| INTCSI01 ^{Note 2} | CSIIF01 ^{Note 2} | | CSIMK01 ^{Note 2} | | CSIPR001, CSIPR101 ^{Note 2} | | ✓ | ✓ | ✓ | ✓ |
| INTIIC01 ^{Note 2} | IICIF01 ^{Note 2} | | IICMK01 ^{Note 2} | | IICPR001, IICPR101 ^{Note 2} | | ✓ | ✓ | ✓ | ✓ |
| INTSRE0 | SREIF0 | | SREMK0 | | SREPR00, SREPR10 | | ✓ | ✓ | ✓ | ✓ |
| INTTM01H | TMIF01H | | TMMK01H | | TMPR001H, TMPR101H | | ✓ | ✓ | ✓ | ✓ |
| INTTM00 | TMIF00 | | TMMK00 | | TMPR000, TMPR100 | | ✓ | ✓ | ✓ | ✓ |
| INTTM01 | TMIF01 | | TMMK01 | | TMPR001, TMPR101 | | ✓ | ✓ | ✓ | ✓ |
| INTAD | ADIF | | ADMK | | ADPR0, ADPR1 | | ✓ | ✓ | ✓ | ✓ |
| INTP6 | PIF6 | | PMK6 | | PPR06, PPR16 | | ✓ | ✓ | ✓ | — |
| INTP7 | PIF7 | | PMK7 | | PPR07, PPR17 | | ✓ | ✓ | ✓ | — |

Table 14-2. Flags Corresponding to Interrupt Request Sources (2/2)

| Interrupt Source | Interrupt Request Flag | | Interrupt Mask Flag | | Priority Specification Flag | | 20-pin | 16-pin | 10-pin | 8-pin |
|------------------|------------------------|----------|---------------------|----------|-----------------------------|-----------------|--------|--------|--------|-------|
| | | Register | | Register | | Register | | | | |
| INTTM03H | TMIF03H | IF1L | TMMK03H | MK1L | TMPR003H, TMPR103H | PR01L, PR11L | ✓ | ✓ | ✓ | ✓ |
| INTIICA0 | IICAIF0 | | IICAMK0 | | IICAPR00, IICAPR10 | | ✓ | ✓ | ✓ | ✓ |
| INTTM02 | TMIF02 | | TMMK02 | | TMPR002, TMPR102 | | ✓ | ✓ | ✓ | ✓ |
| INTTM03 | TMIF03 | | TMMK03 | | TMPR003, TMPR103 | | ✓ | ✓ | ✓ | ✓ |
| INTIT | ITIF | | ITMK | | ITPR0, ITPR1 | | ✓ | ✓ | ✓ | ✓ |
| INTTM04 | TMIF04 | | TMMK04 | | TMPR004, TMPR104 | | ✓ | ✓ | ✓ | ✓ |
| INTTM05 | TMIF05 | | TMMK05 | | TMPR005, TMPR105 | | ✓ | ✓ | ✓ | ✓ |
| INTTM06 | TMIF06 | | TMMK06 | | TMPR006, TMPR106 | | ✓ | ✓ | ✓ | ✓ |
| INTTM07 | TMIF07 | IF1H | TMMK07 | MK1H | TMPR007, TMPR107 | PR01H, PR11H | ✓ | ✓ | ✓ | ✓ |
| INTCMP0 | CMPIF0 | | CMPMK0 | | CMPPR00, CMPPR10 | | ✓ | ✓ | ✓ | ✓ |
| INTCMP1 | CMPIF1 | | CMPMK1 | | CMPPR01, CMPPR11 | | ✓ | — | — | — |

Note 1. If one of the interrupt sources INTST0, INTCSI00, and INTIIC00 is generated, bit 7 of the IF0L register is set to 1. Bit 7 of the MK0L, PR00L, and PR10L registers supports these three interrupt sources.

Note 2. If one of the interrupt sources INTSR01, INTCSI01, INTIIC01 is generated, bit 0 of the IF0H register is set to 1. Bit 0 of the MK0H, PR00H, and PR10H registers supports these three interrupt sources.

14.3.1 Interrupt request flag registers (IF0L, IF0H, IF1L, IF1H)

The interrupt request flags are set to 1 when the corresponding interrupt request is generated or an instruction is executed. They are cleared to 0 when an instruction is executed upon acknowledgment of an interrupt request or upon reset signal generation.

When an interrupt is acknowledged, the interrupt request flag is automatically cleared and then the interrupt routine is entered.

The IF0L, IF0H, IF1L, and IF1H registers can be set by a 1-bit or 8-bit memory manipulation instruction. When the IF0L and IF0H registers, and the IF1L and IF1H registers are combined to form 16-bit registers IF0 and IF1, they can be set by a 16-bit memory manipulation instruction.

Reset signal generation clears these registers to 00H.

Remark If an instruction that writes data to this register is executed, the number of instruction execution clocks increases by 2 clocks

Figure 14-2. Format of Interrupt Request Flag Registers (IF0L, IF0H, IF1L, IF1H)

Address: FFFE0H After reset: 00H R/W

| | | | | | | | | |
|--------|----------------------------|----------|----------|----------|----------|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| IF0L | STIF0 CSIF00 IICIF00 | PIF5 | PIF4 | PIF3 | PIF2 | PIF1 | PIF0 | WDTIIF |

Address: FFFE1H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|----------|----------|----------|----------------------------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| IF0H | PIF7 | PIF6 | ADIF | TMIF01 | TMIF00 | TMIF01H | SREIF0 | SRIF0 CSIF01 IICIF01 |

Address: FFFE2H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|----------|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| IF1L | TMIF06 | TMIF05 | TMIF04 | ITIF | TMIF03 | TMIF02 | IICAIF0 | TMIF03H |

Address: FFFE3H After reset: 00H R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|----------|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| IF1H | 0 | 0 | 0 | 0 | 0 | CMPIF1 | CMPIF0 | TMIF07 |

| | |
|-------|--|
| XXIFX | Interrupt request flag |
| 0 | No interrupt request signal is generated |
| 1 | An interrupt request signal is generated and the interrupt is requested. |

Caution 1. The available registers and bits differ depending on the product. For details about the registers and bits available for each product, see Table 14-2. Be sure to set bits that are not available to the initial value.

Caution 2. When manipulating a flag of the interrupt request flag register, use a 1-bit memory manipulation instruction (CLR1). When describing in C language, use a bit manipulation instruction such as “IF0L.0 = 0;” or “_asm(“clr1 IF0L.0”);” because the compiled assembler must be a 1-bit memory manipulation instruction (CLR1).

If a program is described in C language using an 8-bit memory manipulation instruction such as “IF0L &= 0xfe;” and compiled, it becomes the assembler of three instructions.

```
mov a, IF0L
and a, #0FEH
mov IF0L, a
```

In this case, even if the request flag of the another bit of the same interrupt request flag register (IF0L) is set to 1 at the timing between “mov a, IF0L” and “mov IF0L, a”, the flag is cleared to 0 at “mov IF0L, a”. Therefore, care must be exercised when using an 8-bit memory manipulation instruction in C language.

14.3.2 Interrupt mask flag registers (MK0L, MK0H, MK1L, MK1H)

The interrupt mask flags are used to enable/disable the corresponding maskable interrupt.

The MK0L, MK0H, MK1L, and MK1H registers can be set by a 1-bit or 8-bit memory manipulation instruction.

When the MK0L and MK0H registers, and the MK1L and MK1H registers are combined to form 16-bit registers MK0 and MK1, they can be set by a 16-bit memory manipulation instruction.

Reset signal generation sets these registers to F

Remark If an instruction that writes data to this register is executed, the number of instruction execution clocks increases by 2 clocks.

Figure 14-3. Format of Interrupt Mask Flag Registers (MK0L, MK0H, MK1L, MK1H)

Address: FFFE4H After reset: FFH R/W

| | | | | | | | | |
|--------|-----------------------------|----------|----------|----------|----------|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| MK0L | STMK0 CSIMK00 IICMK00 | PMK5 | PMK4 | PMK3 | PMK2 | PMK1 | PMK0 | WDTIMK |

Address: FFFE5H After reset: FFH R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|----------|----------|----------|-----------------------------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| MK0H | PMK7 | PMK6 | ADMK | TMMK01 | TMMK00 | TMMK01H | SREMK0 | SRMK0 CSIMK01 IICMK01 |

Address: FFFE6H After reset: FFH R/W

| | | | | | | | | |
|--------|----------|----------|----------|----------|----------|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| MK1L | TMMK06 | TMMK05 | TMMK04 | ITMK | TMMK03 | TMMK02 | IICAMK0 | TMMK03H |

Address: FFFE7H After reset: FFH R/W

| | | | | | | | | |
|--------|---|---|---|---|---|----------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| MK1H | 1 | 1 | 1 | 1 | 1 | CMPMK1 | CMPMK0 | TMMK07 |

| | |
|-------|------------------------------|
| XXMKX | Interrupt servicing control |
| 0 | Interrupt servicing enabled |
| 1 | Interrupt servicing disabled |

Caution The available registers and bits differ depending on the product. For details about the registers and bits available for each product, see Table 14-2. Be sure to set bits that are not available to the initial value.

14.3.3 Priority specification flag registers (PR00L, PR00H, PR01L, PR01H, PR10L, PR10H, PR11L, PR11H)

The priority specification flag registers are used to set the corresponding maskable interrupt priority level.

A priority level is set by using the PR0xy and PR1xy registers in combination (xy = 0L, 0H, 1L, 1H).

The PR00L, PR00H, PR01L, PR01H, PR10L, PR10H, PR11L, and PR11H registers can be set by a 1-bit or 8-bit memory manipulation instruction. If the PR00L and PR00H registers, the PR01L and PR01H registers, the PR10L and PR10H registers, and the PR11L and PR11H registers are combined to form 16-bit registers PR00, PR01, PR10, and PR11, they can be set by a 16-bit memory manipulation instruction.

Reset signal generation sets these registers to FFH.

Remark If an instruction that writes data to this register is executed, the number of instruction execution clocks increases by 2 clocks.

Figure 14-4. Format of Priority Specification Flag Registers
(PR00L, PR00H, PR01L, PR01H, PR10L, PR10H, PR11L, PR11H)

Address: FFFE8H After reset: FFH R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|--------------------------------|-------|-------|-------|-------|-------|-------|---------|
| PR00L | STPR00 CSIPR000 IICPR000 | PPR05 | PPR04 | PPR03 | PPR02 | PPR01 | PPR00 | WDTIPR0 |

Address: FFECH After reset: FFH R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|--------------------------------|-------|-------|-------|-------|-------|-------|---------|
| PR10L | STPR10 CSIPR100 IICPR100 | PPR15 | PPR14 | PPR13 | PPR12 | PPR11 | PPR10 | WDTIPR1 |

Address: FFFE9H After reset: FFH R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|-------|-------|-------|---------|---------|----------|---------|--------------------------------|
| PR00H | PPR07 | PPR06 | ADPR0 | TMPR001 | TMPR000 | TMPR001H | SREPR00 | SRPR00 CSIPR001 IICPR001 |

Address: FFFEDH After reset: FFH R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|-------|-------|-------|---------|---------|----------|---------|--------------------------------|
| PR10H | PPR17 | PPR16 | ADPR1 | TMPR101 | TMPR100 | TMPR101H | SREPR10 | SRPR10 CSIPR101 IICPR101 |

Address: FFFEAH After reset: FFH R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---------|---------|---------|-------|---------|---------|----------|----------|
| PR01L | TMPR006 | TMPR005 | TMPR004 | ITPR0 | TMPR003 | TMPR002 | IICAPR00 | TMPR003H |

Address: FFFEEH After reset: FFH R/W

| | | | | | | | | |
|--------|---------|---------|---------|-------|---------|---------|----------|----------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PR11L | TMPR106 | TMPR105 | TMPR104 | ITPR1 | TMPR103 | TMPR102 | IICAPR10 | TMPR103H |

Address: FFFEBH After reset: FFH R/W

| | | | | | | | | |
|--------|---|---|---|---|---|---------|---------|---------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PR01H | 1 | 1 | 1 | 1 | 1 | CMPPR01 | CMPPR00 | TMPR007 |

Address: FFFEFH After reset: FFH R/W

| | | | | | | | | |
|--------|---|---|---|---|---|---------|---------|---------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| PR11H | 1 | 1 | 1 | 1 | 1 | CMPPR11 | CMPPR10 | TMPR107 |

| XXPR1X | XXPR0X | Priority level selection |
|--------|--------|---------------------------------------|
| 0 | 0 | Specify level 0 (high priority level) |
| 0 | 1 | Specify level 1 |
| 1 | 0 | Specify level 2 |
| 1 | 1 | Specify level 3 (low priority level) |

Caution The available registers and bits differ depending on the product. For details about the registers and bits available for each product, see Table 14-2. Be sure to set bits that are not available to the initial value.

14.3.4 External interrupt rising edge enable register (EGP0), external interrupt falling edge enable register (EGN0)

These registers specify the valid edge for INTP0 to INTP7.

The EGP0 and EGN0 registers can be set by a 1-bit or 8-bit memory manipulation instruction.

Reset signal generation clears these registers to 00H.

Figure 14-5. Format of External Interrupt Rising Edge Enable Register (EGP0) and External Interrupt Falling Edge Enable Register (EGN0)

Address: FFF38H After reset: 00H R/W

| | | | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| EGP0 | EGP07 | EGP06 | EGP05 | EGP04 | EGP03 | EGP02 | EGP01 | EGP00 |

Address: FFF39H After reset: 00H R/W

| | | | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| EGN0 | EGN07 | EGN06 | EGN05 | EGN04 | EGN03 | EGN02 | EGN01 | EGN00 |

| EGP0n | EGN0n | INTPn pin valid edge selection (n = 0 to 7) |
|-------|-------|---|
| 0 | 0 | Edge detection disabled |
| 0 | 1 | Falling edge |
| 1 | 0 | Rising edge |
| 1 | 1 | Both rising and falling edges |

Table 14-3 shows the ports corresponding to the EGP0 and EGN0 bits.

Table 14-3. Interrupt Request Signals Corresponding to EGP0 and EGN0 Bits

| Detection Enable Bit | | Interrupt Request Signal | 10-, 16-, 20-pin | 8-pin |
|----------------------|-------|--------------------------|------------------|-------|
| EGP00 | EGN00 | INTP0 | ✓ | ✓ |
| EGP01 | EGN01 | INTP1 | ✓ | ✓ |
| EGP02 | EGN02 | INTP2 | ✓ | ✓ |
| EGP03 | EGN03 | INTP3 | ✓ | ✓ |
| EGP04 | EGN04 | INTP4 | ✓ | ✓ |
| EGP05 | EGN05 | INTP5 | ✓ | ✓ |
| EGP06 | EGN06 | INTP6 | ✓ | — |
| EGP07 | EGN07 | INTP7 | ✓ | — |

Caution When the input port pins used for the external interrupt functions are switched to the output mode, the INTPn interrupt might be generated upon detection of a valid edge.

When switching the input port pins to the output mode, set the port mode register (PMxx) to 0 after disabling the edge detection (by setting EGPn and EGNn to 0).

Remark 1. For edge detection port, see 2.1 Port Function.

Remark 2. n = 0 to 7

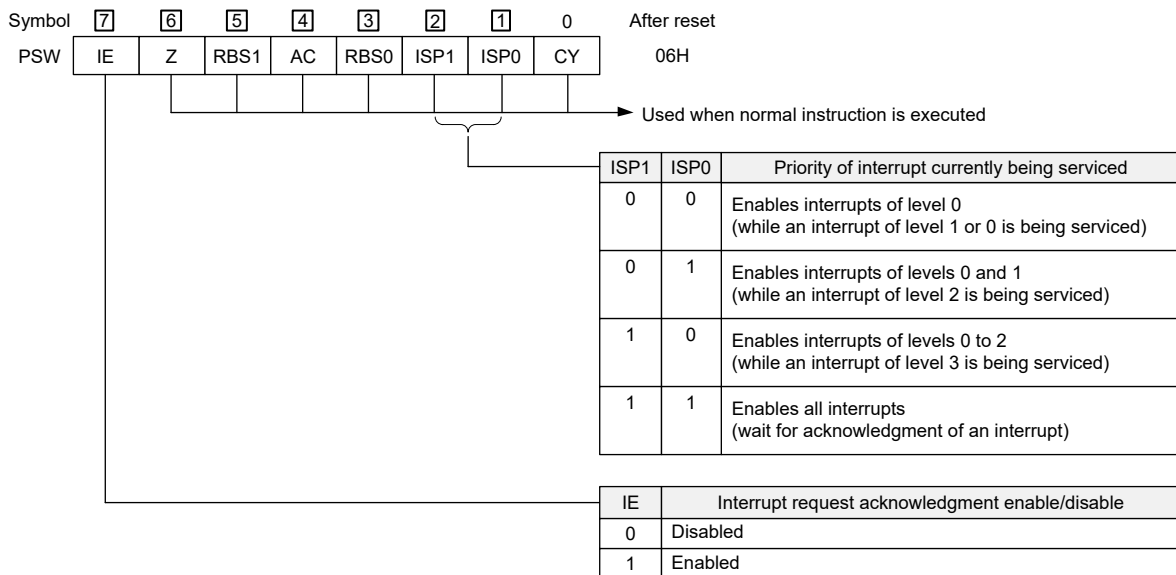
14.3.5 Program status word (PSW)

The program status word is a register used to hold the instruction execution result and the current status for an interrupt request. The IE flag that sets maskable interrupt enable/disable and the ISP0 and ISP1 flags that control multiple interrupt servicing are mapped to the PSW.

Besides 8-bit read/write, this register can carry out operations using bit manipulation instructions and dedicated instructions (EI and DI). When a vectored interrupt request is acknowledged, if the BRK instruction is executed, the contents of the PSW are automatically saved into a stack and the IE flag is reset to 0. Upon acknowledgment of a maskable interrupt request, if the value of the priority specification flag register of the acknowledged interrupt is not 00, its value minus 1 is transferred to the ISP0 and ISP1 flags. The PSW contents are also saved into the stack with the PUSH PSW instruction. They are restored from the stack with the RETI, RETB, and POP PSW instructions.

Reset signal generation sets PSW to 06H.

Figure 14-6. Configuration of Program Status Word



14.4 Interrupt Servicing Operations

14.4.1 Maskable interrupt request acknowledgment

A maskable interrupt request becomes acknowledgeable when the interrupt request flag is set to 1 and the mask (MK) flag corresponding to that interrupt request is cleared to 0. A vectored interrupt request is acknowledged if interrupts are in the interrupt enabled state (when the IE flag is set to 1). However, a low-priority interrupt request is not acknowledged during servicing of a higher priority interrupt request.

The times from generation of a maskable interrupt request until vectored interrupt servicing is performed are listed in **Table 14-4**.

For the interrupt request acknowledgment timing, see **Figure 14-8** and **Figure 14-9**.

Table 14-4. Time from Generation of Maskable Interrupt until Servicing

| | Minimum Time | Maximum Time ^{Note 1} |
|----------------|--------------|--------------------------------|
| Servicing time | 9 clocks | 16 clocks |

Note 1. Maximum time does not apply when an instruction from the internal RAM area is executed.

Remark 1 clock: $1/f_{CLK}$ (f_{CLK} : CPU clock)

If two or more maskable interrupt requests are generated simultaneously, the request with a higher priority level specified in the priority specification flag is acknowledged first. If two or more interrupts requests have the same priority level, the request with the highest default priority is acknowledged first.

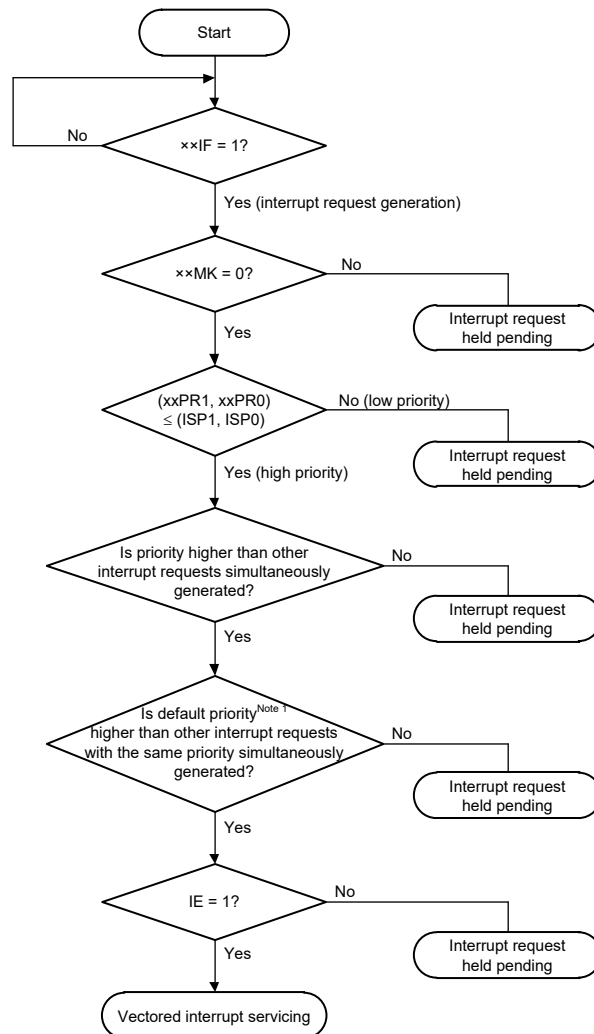
An interrupt request that is held pending is acknowledged when it becomes acknowledgeable.

Figure 14-7 shows the interrupt request acknowledgment algorithm.

If a maskable interrupt request is acknowledged, the contents are saved into the stacks in the order of PSW, then PC, the IE flag is reset (0), and the contents of the priority specification flag corresponding to the acknowledged interrupt are transferred to the ISP1 and ISP0 flags. The vector table data determined for each interrupt request is the loaded into the PC and branched.

Returning from an interrupt is possible by using the RETI instruction.

Figure 14-7. Interrupt Request Acknowledgment Processing Algorithm



xxIF: Interrupt request flag

xxMK: Interrupt mask flag

xxPR0: Priority specification flag 0

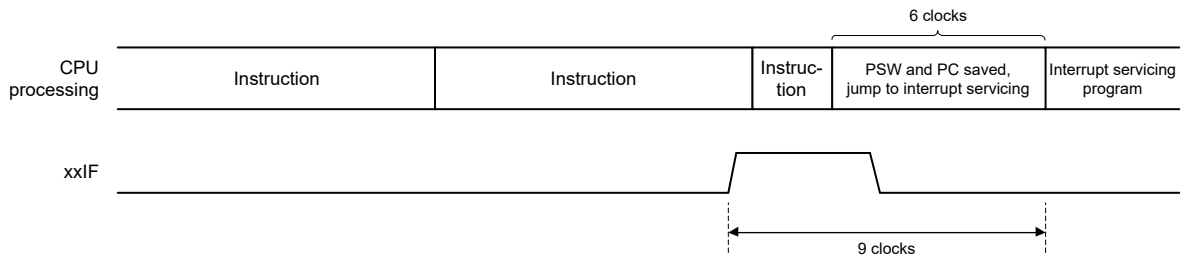
xxPR1: Priority specification flag 1

IE: Flag that controls acknowledgment of maskable interrupt request (1 = Enable, 0 = Disable)

ISP0, ISP1: Flag that indicates the priority level of the interrupt currently being serviced (see **Figure 14-6**)

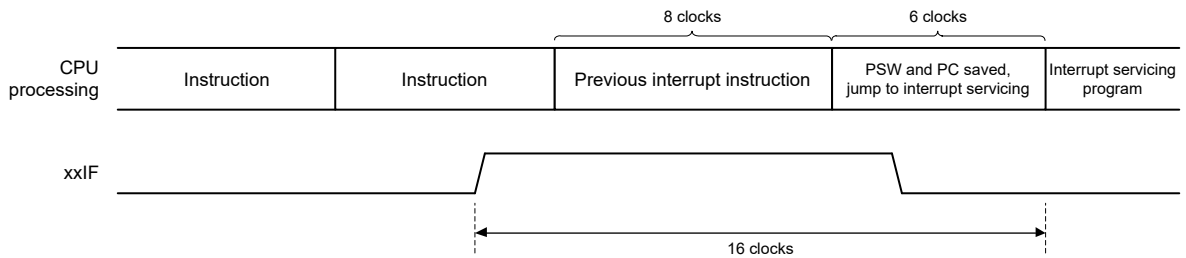
Note 1. For the default priority, refer to **Table 14-1 Interrupt Source List**.

Figure 14-8. Interrupt Request Acknowledgment Timing (Minimum Time)



Remark 1 clock: $1/f_{CLK}$ (f_{CLK} : CPU clock)

Figure 14-9. Interrupt Request Acknowledgment Timing (Maximum Time)



Remark 1 clock: $1/f_{CLK}$ (f_{CLK} : CPU clock)

14.4.2 Software interrupt request acknowledgment

A software interrupt request is acknowledged by BRK instruction execution. Software interrupts cannot be disabled.

If a software interrupt request is acknowledged, the contents are saved into the stacks in the order of the program status word (PSW), then program counter (PC), the IE flag is reset (0), and the contents of the vector table (0007EH, 0007FH) are loaded into the PC and branched.

Returning from a software interrupt is possible by using the RETB instruction.

Caution The RETI instruction cannot be used for return from the software interrupt.

14.4.3 Multiple interrupt servicing

Multiple interrupt servicing occurs when another interrupt request is acknowledged during execution of an interrupt.

Multiple interrupt servicing does not occur unless the interrupt request acknowledgment enabled state is selected (IE = 1). When an interrupt request is acknowledged, interrupt request acknowledgment becomes disabled (IE = 0). Therefore, to enable multiple interrupt servicing, it is necessary to set (1) the IE flag with the EI instruction during interrupt servicing to enable interrupt acknowledgment.

Moreover, even if interrupts are enabled, multiple interrupt servicing may not be enabled, this being subject to interrupt priority control. Two types of priority control are available: default priority control and programmable priority control. Programmable priority control is used for multiple interrupt servicing.

In the interrupt enabled state, if an interrupt request with a priority higher than that of the interrupt currently being serviced is generated, it is acknowledged for multiple interrupt servicing. If an interrupt with a priority equal to or lower than that of the interrupt currently being serviced is generated during interrupt servicing, it is not acknowledged for multiple interrupt servicing. However, when setting the IE flag to 1 during the interruption at level 0, other level 0 interruptions can be allowed.

Interrupt requests that are not enabled because interrupts are in the interrupt disabled state or because they have a lower priority are held pending. When servicing of the current interrupt ends, the pending interrupt request is acknowledged following execution of at least one main processing instruction execution.

Table 14-5 shows relationship between interrupt requests enabled for multiple interrupt servicing and **Figure 14-10** shows multiple interrupt servicing examples.

Table 14-5. Relationship between Interrupt Requests Enabled for Multiple Interrupt Servicing during Interrupt Servicing

| Multiple Interrupt Request Interrupt Being Serviced | | Maskable Interrupt Request | | | | | | | | Software Interrupt Request |
|--|----------------------|-------------------------------|--------|-------------------------------|--------|-------------------------------|--------|-------------------------------|--------|----------------------------|
| | | Priority Level 0 (PR = 00) | | Priority Level 1 (PR = 01) | | Priority Level 2 (PR = 10) | | Priority Level 3 (PR = 11) | | |
| | | IE = 1 | IE = 0 | IE = 1 | IE = 0 | IE = 1 | IE = 0 | IE = 1 | IE = 0 | |
| Maskable interrupt | ISP1 = 0 ISP0 = 0 | ✓ | × | × | × | × | × | × | × | ✓ |
| | ISP1 = 0 ISP0 = 1 | ✓ | × | ✓ | × | × | × | × | × | ✓ |
| | ISP1 = 1 ISP0 = 0 | ✓ | × | ✓ | × | ✓ | × | × | × | ✓ |
| | ISP1 = 1 ISP0 = 1 | ✓ | × | ✓ | × | ✓ | × | ✓ | × | ✓ |
| Software interrupt | | ✓ | × | ✓ | × | ✓ | × | ✓ | × | ✓ |

Remark 1. ✓: Multiple interrupt servicing enabled

Remark 2. ×: Multiple interrupt servicing disabled

Remark 3. ISP0, ISP1, and IE are flags contained in the PSW.

ISP1 = 0, ISP0 = 0: An interrupt of level 1 or level 0 is being serviced.

ISP1 = 0, ISP0 = 1: An interrupt of level 2 is being serviced.

ISP1 = 1, ISP0 = 0: An interrupt of level 3 is being serviced.

ISP1 = 1, ISP0 = 1: Wait for an interrupt acknowledgment (all interrupts are enabled).

IE = 0: Interrupt request acknowledgment is disabled.

IE = 1: Interrupt request acknowledgment is enabled.

Remark 4. PR is a flag contained in the PR00L, PR00H, PR01L, PR01H, PR10L, PR10H, PR11L, and PR11H registers.

PR = 00: Specify level 0 with xxPR1x = 0, xxPR0x = 0 (higher priority level)

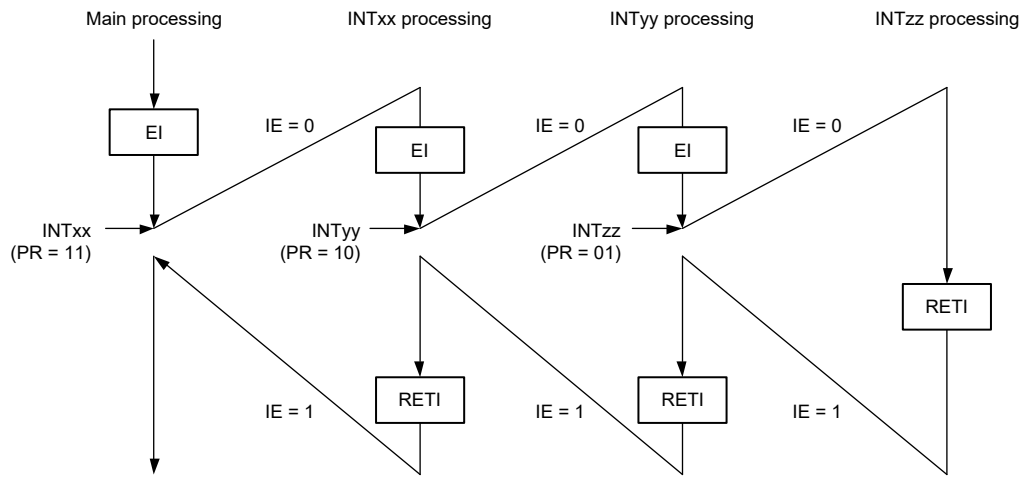
PR = 01: Specify level 1 with xxPR1x = 0, xxPR0x = 1

PR = 10: Specify level 2 with xxPR1x = 1, xxPR0x = 0

PR = 11: Specify level 3 with xxPR1x = 1, xxPR0x = 1 (lower priority level)

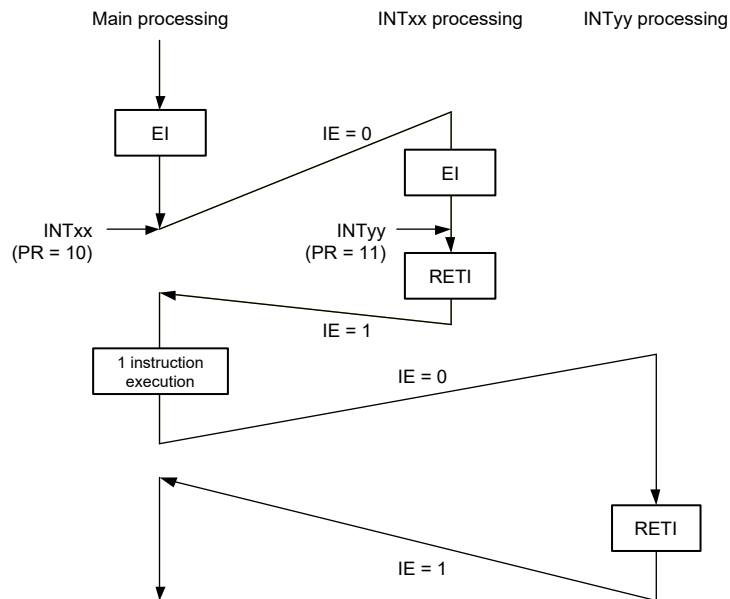
Figure 14-10. Examples of Multiple Interrupt Servicing (1/2)

Example 1. Multiple interrupt servicing occurs twice



During servicing of interrupt INTxx, two interrupt requests, INTyy and INTzz, are acknowledged, and multiple interrupt servicing takes place. Before each interrupt request is acknowledged, the EI instruction must always be issued to enable interrupt request acknowledgment.

Example 2. Multiple interrupt servicing does not occur due to priority control



Interrupt request INTyy issued during servicing of interrupt INTxx is not acknowledged because its priority is lower than that of INTxx, and multiple interrupt servicing does not take place. The INTyy interrupt request is held pending, and is acknowledged following execution of one main processing instruction.

PR = 00: Specify level 0 with xxPR1x = 0, xxPR0x = 0 (higher priority level)

PR = 01: Specify level 1 with xxPR1x = 0, xxPR0x = 1

PR = 10: Specify level 2 with xxPR1x = 1, xxPR0x = 0

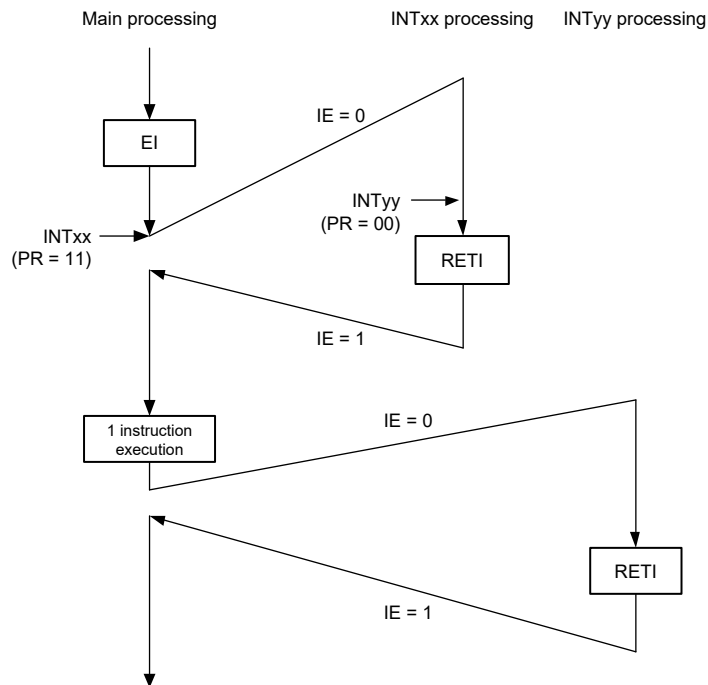
PR = 11: Specify level 3 with xxPR1x = 1, xxPR0x = 1 (lower priority level)

IE = 0: Interrupt request acknowledgment is disabled

IE = 1: Interrupt request acknowledgment is enabled.

Figure 14-10. Examples of Multiple Interrupt Servicing (2/2)

Example 3. Multiple interrupt servicing does not occur because interrupts are not enabled



Interrupts are not enabled during servicing of interrupt INTxx (EI instruction is not issued), therefore, interrupt request INTyy is not acknowledged and multiple interrupt servicing does not take place. The INTyy interrupt request is held pending, and is acknowledged following execution of one main processing instruction.

PR = 00: Specify level 0 with xxPR1x = 0, xxPR0x = 0 (higher priority level)

PR = 01: Specify level 1 with xxPR1x = 0, xxPR0x = 1

PR = 10: Specify level 2 with xxPR1x = 1, xxPR0x = 0

PR = 11: Specify level 3 with xxPR1x = 1, xxPR0x = 1 (lower priority level)

IE = 0: Interrupt request acknowledgment is disabled

IE = 1: Interrupt request acknowledgment is enabled.

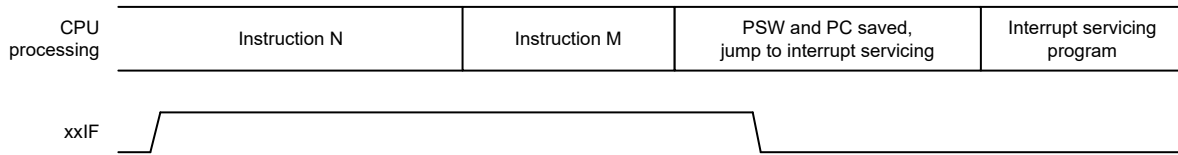
14.4.4 Interrupt request pending

There are instructions where, even if an interrupt request is issued while the instructions are being executed, interrupt request acknowledgment is held pending until the end of execution of the next instruction. These instructions (instructions that hold interrupt requests pending) are listed below.

- MOV PSW, #byte
- MOV PSW, A
- MOV1 PSW. bit, CY
- SET1 PSW. bit
- CLR1 PSW. bit
- RETB
- RETI
- POP PSW
- BTCLR PSW. bit, \$addr20
- EI
- DI
- SKC
- SKNC
- SKZ
- SKNZ
- SKH
- SKNH
- Write instructions for the IF0L, IF0H, IF1L, IF1H, MK0L, MK0H, MK1L, MK1H, PR00L, PR00H, PR01L, PR01H, PR10L, PR10H, PR11L, and PR11H registers

Figure 14-11 shows the timing at which interrupt requests are held pending.

Figure 14-11. Interrupt Request Pending



Remark Instruction N: Instruction to hold interrupt requests pending
 Instruction M: Instruction other than the instruction to hold interrupt requests pending

CHAPTER 15 STANDBY FUNCTION

15.1 Overview

The standby function reduces the operating current of the system, and the following two modes are available.

1) HALT mode

HALT instruction execution sets the HALT mode. In the HALT mode, the CPU operation clock is stopped. If the high-speed system clock oscillator or high-speed on-chip oscillator is operating before the HALT mode is set, oscillation of each clock continues. In this mode, the operating current is not decreased as much as in the STOP mode, but the HALT mode is effective for restarting operation immediately upon interrupt request generation and carrying out intermittent operations frequently.

2) STOP mode

STOP instruction execution sets the STOP mode. In the STOP mode, the high-speed system clock oscillator and high-speed on-chip oscillator stop, stopping the whole system, thereby considerably reducing the CPU operating current.

Because this mode can be cleared by an interrupt request, it enables intermittent operations to be carried out. However, because a wait time is required to secure the oscillation stabilization time after the STOP mode is released when the X1 clock is selected, select the HALT mode if it is necessary to start processing immediately upon interrupt request generation.

In either of these two modes, all the contents of registers, flags and data memory just before the standby mode is set are held. The I/O port output latches and output buffer status are also held.

- Caution 1.** When shifting to the STOP mode, be sure to stop the peripheral hardware operation operating with X1 oscillation or EXCLK input before executing STOP instruction^{Note 1}.
- Caution 2.** The following sequence is recommended for operating current reduction of the A/D converter when the standby function is used: First clear bit 7 (ADCS) and bit 0 (ADCE) of A/D converter mode register 0 (ADM0) to 0 to stop the A/D conversion operation, and then execute the STOP instruction.
- Caution 3.** It can be selected by the option byte whether the low-speed on-chip oscillator continues oscillating or stops in the HALT or STOP mode. For details, see CHAPTER 18 OPTION BYTE.

Note 1. 16-pin and 20-pin products only.

15.2 Registers controlling standby function

The standby function is controlled by the following registers.

For details of each register, see **CHAPTER 5 CLOCK GENERATOR**.

Register which enables or stops the operation of the low-speed on-chip oscillator in the HALT or STOP mode.

- Operation speed mode control register (OSMC)

Registers which controls oscillation stabilization time of the X1 clock when the STOP mode is released.

- Oscillation stabilization time counter status register (OSTC)^{Note 1}
- Oscillation stabilization time select register (OSTS)^{Note 1}

Note 1. 16-pin and 20-pin products only.

15.3 Standby Function Operation

15.3.1 HALT mode

(1) HALT mode

The HALT mode is set by executing the HALT instruction.

The HALT mode can be set regardless of whether the CPU clock before the setting was the high-speed system clock (16-pin and 20-pin products only) or the high-speed on-chip oscillator clock. The operating status in the HALT mode are shown below.

Caution Because the interrupt request signal is used to clear the HALT mode, if the interrupt mask flag is 0 (the interrupt processing is enabled) and the interrupt request flag is 1 (the interrupt request signal is generated), the HALT mode is not entered even if the HALT instruction is executed in such a situation.

Table 15-1. Operating Status in HALT Mode

| HALT Mode Setting | | When HALT Instruction is Executed While CPU is Operating on Main System Clock | | |
|--|----------|--|---|--|
| | | When CPU is Operating on High-speed On-chip Oscillator Clock (f_{IH}) | When CPU is Operating on X1 Clock (f_X) | When CPU is Operating on External Main System Clock (f_{EX}) |
| Item | | | | |
| System clock | | Clock supply to the CPU is stopped | | |
| Main system clock | f_{IH} | Operation continues (cannot be stopped) | Operation disabled | |
| | f_X | Operation disabled | Operation continues (cannot be stopped) | Cannot operate |
| | f_{EX} | | Cannot operate | Operation continues (cannot be stopped) |
| f_{IL} | | Set by bits 0 (WDSTBYON) and 4 (WDTON) of option byte (000C0H), and bit 4 (WUTMMCK0) of operation speed mode control register (OSMC) <ul style="list-style-type: none"> WUTMMCK0 = 1: Oscillates WUTMMCK0 = 0 and WDTON = 0: Stops WUTMMCK0 = 0, WDTON = 1, and WDSTBYON = 1: Oscillates WUTMMCK0 = 0, WDTON = 1, and WDSTBYON = 0: Stops | | |
| CPU | | Operation stopped | | |
| Code flash memory | | | | |
| Data flash memory | | | | |
| RAM | | | | |
| Illegal-memory access detection function | | | | |
| Port (latch) | | Status before HALT mode was set is retained | | |
| Timer array unit | | Operable | | |
| 12-bit interval timer | | | | |
| Watchdog timer | | | | |
| | | Set by bit 0 (WDSTBYON) of option byte (000C0H) WDSTBYON = 0: Operation stopped WDSTBYON = 1: Operation continues | | |
| Clock output/buzzer output | | Operable | | |
| A/D converter | | | | |
| Comparator | | | | |
| Serial array unit (SAU) | | | | |
| Serial interface (IICA) | | | | |
| Selectable power-on-reset function | | | | |
| External interrupt | | | | |

Remark Operation stopped: Operation is automatically stopped before switching to the HALT mode.

Operation disabled: Operation is stopped before switching to the HALT mode.

f_{IH} : High-speed on-chip oscillator clock

f_{IL} : Low-speed on-chip oscillator clock

f_X : X1 clock^{Note 1}

f_{EX} : External main system clock^{Note 1}

Note 1. 16-pin and 20-pin products only.

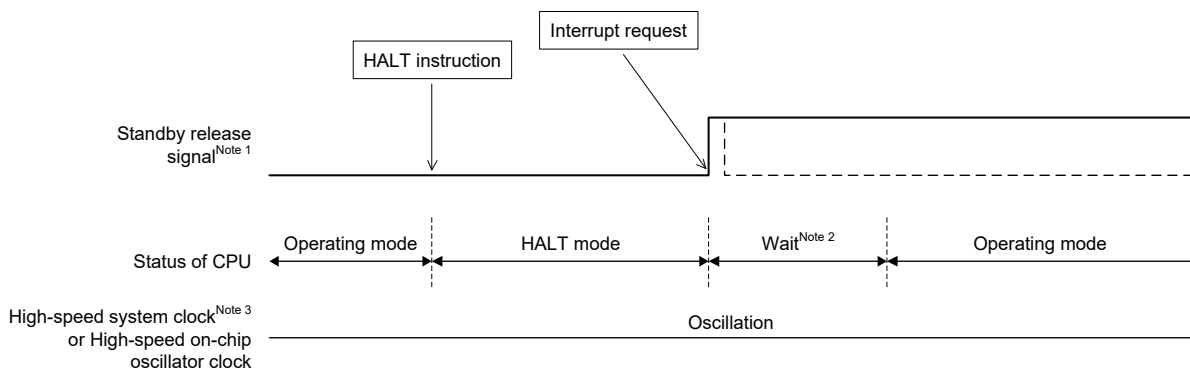
(2) HALT mode release

The HALT mode can be released by the following two sources.

a) Release by unmasked interrupt request

When an unmasked interrupt request is generated, the HALT mode is released. If interrupt acknowledgment is enabled, vectored interrupt servicing is carried out. If interrupt acknowledgment is disabled, the next address instruction is executed.

Figure 15-1. HALT Mode Release by Interrupt Request Generation



Note 1. For details of the standby release signal, see **Figure 14-1 Basic Configuration of Interrupt Function**.

Note 2. Wait time for HALT mode release:

- When vectored interrupt servicing is carried out: 24 or 25 clocks
- When vectored interrupt servicing is not carried out: 18 or 19 clocks

Note 3. 16-pin and 20-pin products only.

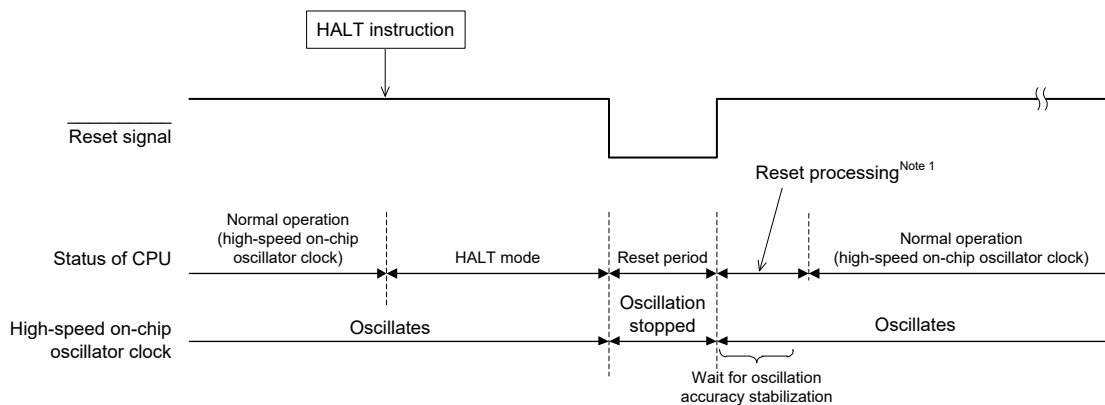
Remark The broken lines indicate the case when the interrupt request which has released the standby mode is acknowledged.

b) HALT mode release by reset signal generation

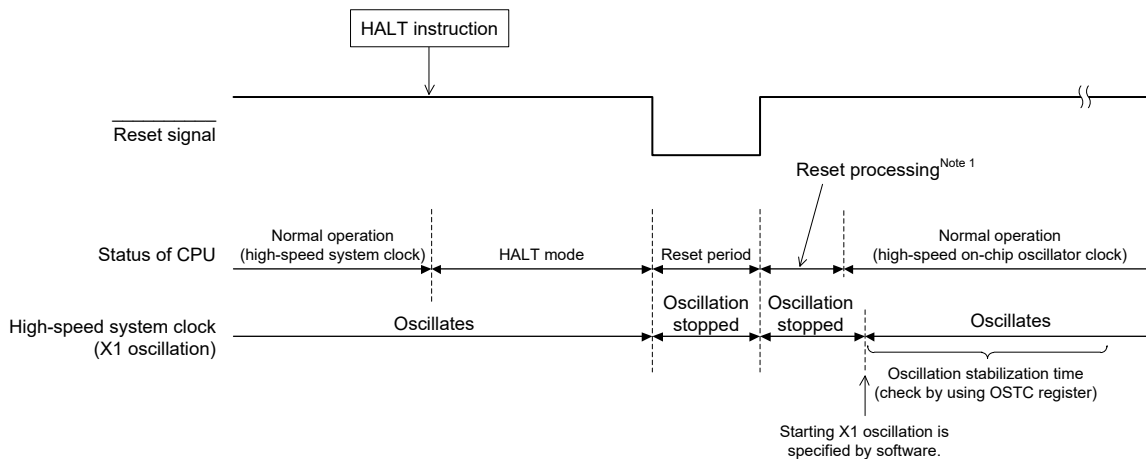
When the reset signal is generated, HALT mode is released, and then, as in the case with a normal reset operation, the program is executed after branching to the reset vector address.

Figure 15-2. HALT Mode Release by Reset Signal Generation

(1) When high-speed on-chip oscillator clock is used as CPU clock



(2) When high-speed system clock is used as CPU clock (16-pin and 20-pin products only)



Note 1. For the reset processing time, see **CHAPTER 16 RESET FUNCTION**. For the reset processing time of the SPOR circuit, see **CHAPTER 17 SELECTABLE POWER-ON-RESET CIRCUIT**.

15.3.2 STOP mode

(1) STOP mode setting and operating status

The STOP mode is set by executing the STOP instruction.

Caution Because the interrupt request signal is used to clear the STOP mode, if the interrupt mask flag is 0 (the interrupt processing is enabled) and the interrupt request flag is 1 (the interrupt request signal is generated), the STOP mode is immediately cleared if set when the STOP instruction is executed in such a situation. Accordingly, once the STOP instruction is executed, the system returns to its normal operating mode after the elapse of release time from the STOP mode.

The operating status in the STOP mode are shown below.

Table 15-2. Operating Status in STOP Mode (1/2)

| STOP Mode Setting | | When STOP Instruction is Executed While CPU is Operating | | |
|--|--|--|---|--|
| | | When CPU is Operating on High-speed On-chip Oscillator Clock (f_{IH}) | When CPU is Operating on X1 Clock (f_X) | When CPU is Operating on External Main System Clock (f_{EX}) |
| Item | | | | |
| System clock | | Clock supply to the CPU is stopped | | |
| Main system clock | f_{IH} | Stopped | | |
| | f_X | | | |
| | f_{EX} | | | |
| f_{IL} | Set by bits 0 (WDSTBYON) and 4 (WDTON) of option byte (000C0H), and bit 4 (WUTMMCK0) of operation speed mode control register (OSMC) | | | |
| | | <ul style="list-style-type: none"> • WUTMMCK0 = 1: Oscillates • WUTMMCK0 = 0 and WDTON = 0: Stops • WUTMMCK0 = 0, WDTON = 1, and WDSTBYON = 1: Oscillates • WUTMMCK0 = 0, WDTON = 1, and WDSTBYON = 0: Stops | | |
| CPU | | Operation stopped | | |
| Code flash memory | | | | |
| Data flash memory | | | | |
| RAM | | | | |
| Illegal-memory access detection function | | | | |
| Port (latch) | | | | |
| Timer array unit | | Operation disabled | | |
| 12-bit interval timer | | Operable | | |
| Watchdog timer | | Set by bit 0 (WDSTBYON) of option byte (000C0H) WDSTBYON = 0: Operation stopped WDSTBYON = 1: Operation continues | | |
| Clock output/buzzer output | | Operation disabled | | |
| A/D converter | | | | |

Table 15-2. Operating Status in STOP Mode (2/2)

| STOP Mode Setting Item | When STOP Instruction is Executed While CPU is Operating | | |
|------------------------------------|---|---|--|
| | When CPU is Operating on High-speed On-chip Oscillator Clock (f_{IH}) | When CPU is Operating on X1 Clock (f_X) | When CPU is Operating on External Main System Clock (f_{EX}) |
| Comparator | Operable (only when the digital filter is not in use) | | |
| Serial array unit (SAU) | Operation disabled | | |
| Serial interface (IICA) | Wakeup by address match operable | | |
| Selectable power-on-reset function | Operable | | |
| External interrupt | | | |

Remark Operation stopped: Operation is automatically stopped before switching to the STOP mode.

Operation disabled: Operation is stopped before switching to the STOP mode.

f_{IH} : High-speed on-chip oscillator clock

f_{IL} : Low-speed on-chip oscillator clock

f_X : X1 clock^{Note 1}

f_{EX} : External main system clock^{Note 1}

Note 1. 16-pin and 20-pin products only.

(2) STOP mode release

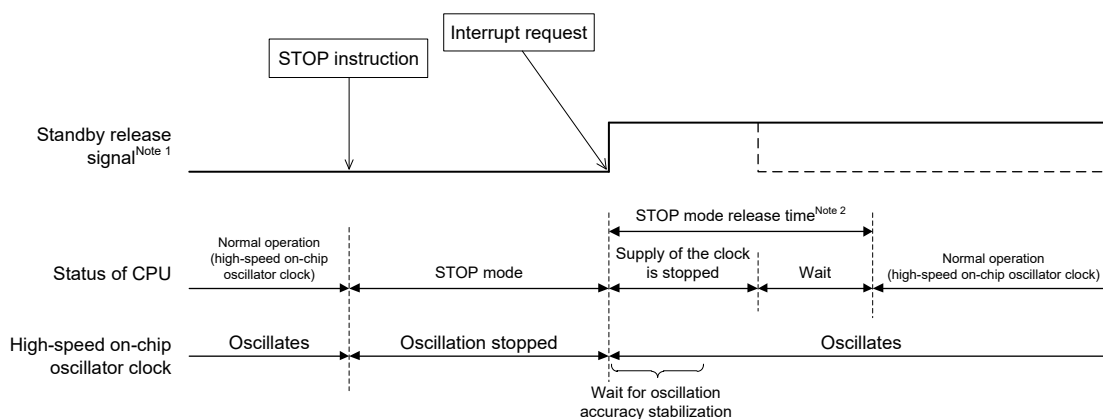
The STOP mode can be released by the following two sources.

a) STOP mode release by unmasked interrupt request

When an unmasked interrupt request is generated, the STOP mode is released. After the oscillation stabilization time has elapsed, if interrupt acknowledgment is enabled, vectored interrupt servicing is carried out. If interrupt acknowledgment is disabled, the next address instruction is executed.

Figure 15-3. STOP Mode Release by Interrupt Request Generation (1/3)

(1) When high-speed on-chip oscillator clock is used as CPU clock



Note 1. For details of the standby release signal, see **Figure 14-1 Basic Configuration of Interrupt Function**.

Note 2. STOP mode release time: Supply of the clock is stopped: 27 μs (TYP.)

[Wait]

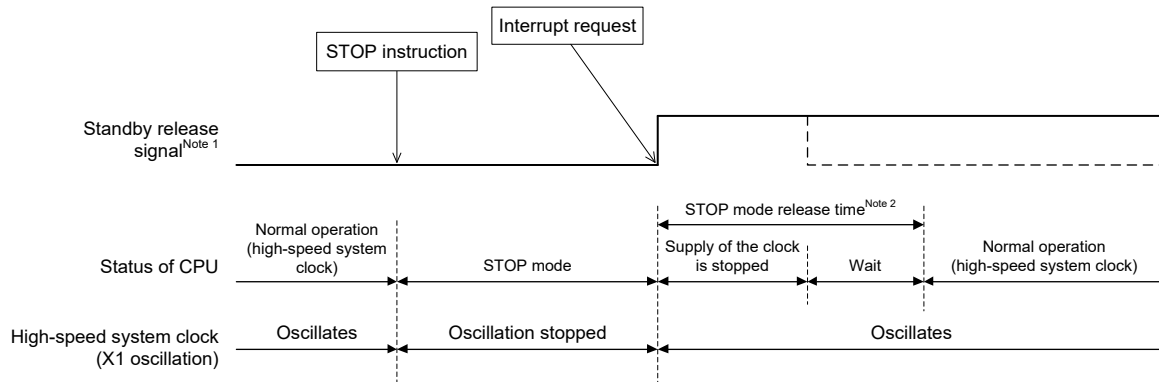
- When vectored interrupt servicing is carried out: 8 clocks
- When vectored interrupt servicing is not carried out: 2 clocks

Remark 1. The clock supply stop time varies depending on the temperature conditions and STOP mode period.

Remark 2. The broken lines indicate the case when the interrupt request that has released the standby mode is acknowledged.

Figure 15-3. STOP Mode Release by Interrupt Request Generation (2/3)

(2) When high-speed system clock (X1 oscillation) is used as CPU clock (16-pin and 20-pin products only)



Note 1. For details of the standby release signal, see **Figure 14-1 Basic Configuration of Interrupt Function**.

Note 2. STOP mode release time: Whichever is longer, 27 μ s (TYP.) or the oscillation stabilization time (set by OSTs)

[Wait]

- When vectored interrupt servicing is carried out: 10 or 11 clocks
- When vectored interrupt servicing is not carried out: 4 or 5 clocks

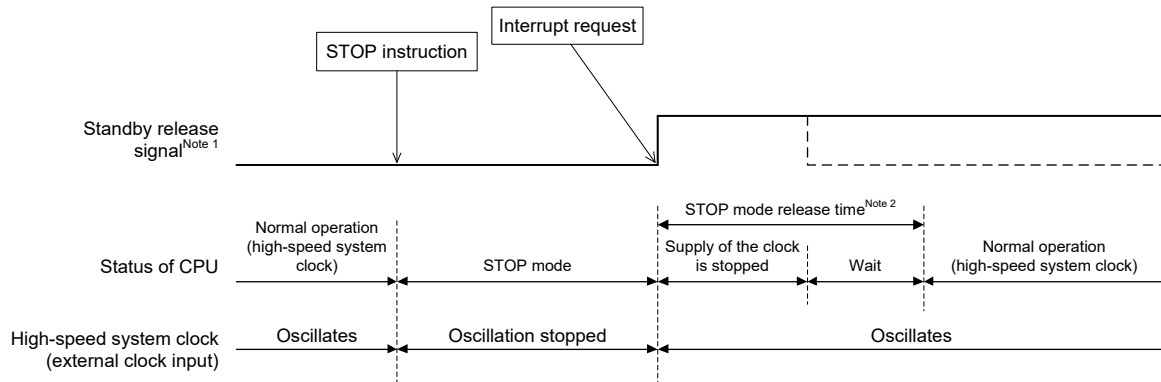
Caution To reduce the oscillation stabilization time after release from the STOP mode while CPU operates based on the high-speed system clock (X1 oscillation), switch the clock to the high-speed on-chip oscillator clock temporarily before executing the STOP instruction.

Remark 1. The clock supply stop time varies depending on the temperature conditions and STOP mode period.

Remark 2. The broken lines indicate the case when the interrupt request that has released the standby mode is acknowledged.

Figure 15-3. STOP Mode Release by Interrupt Request Generation (3/3)

(3) When high-speed system clock (external clock input) is used as CPU clock (16-pin and 20-pin products only)



Note 1. For details of the standby release signal, see **Figure 14-1 Basic Configuration of Interrupt Function**.

Note 2. STOP mode release time: 27 μ s

[Wait]

- When vectored interrupt servicing is carried out: 8 clocks
- When vectored interrupt servicing is not carried out: 2 clocks

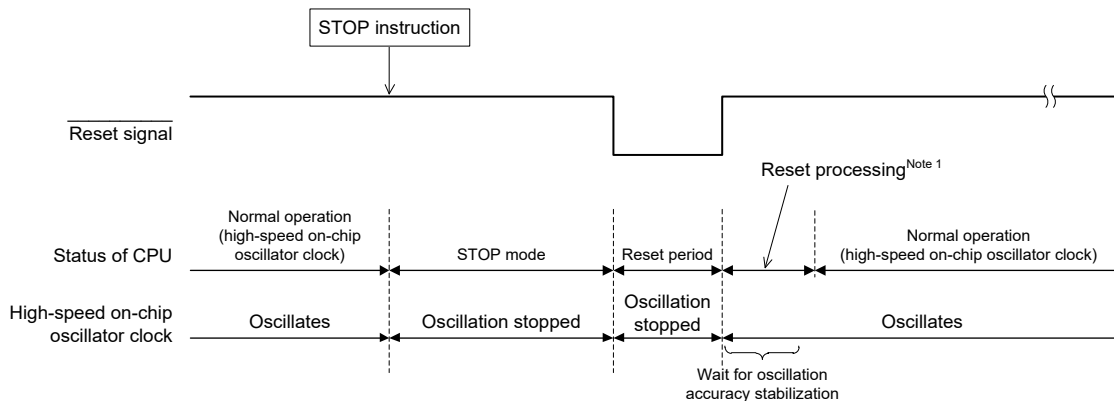
Remark The broken lines indicate the case when the interrupt request that has released the standby mode is acknowledged.

b) STOP mode release by reset signal generation

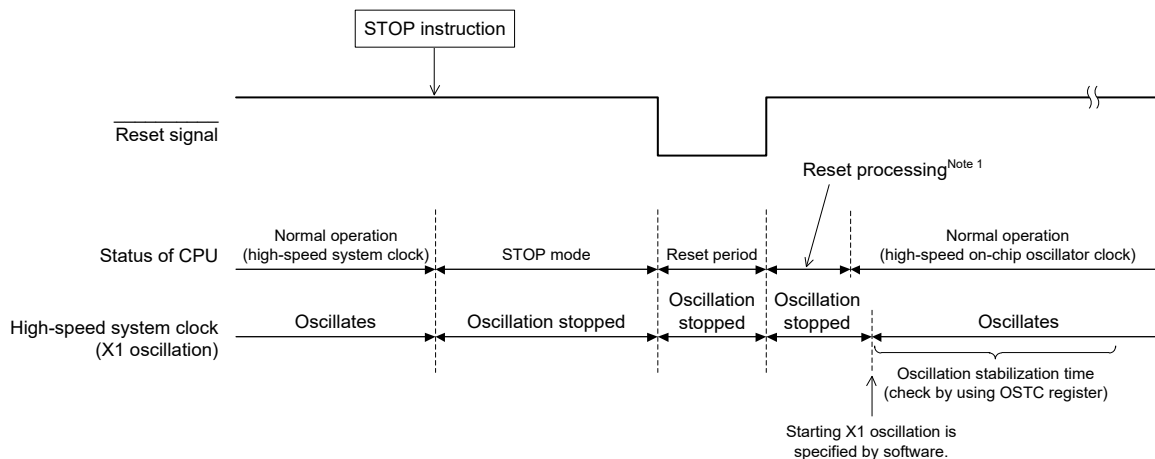
When the reset signal is generated, STOP mode is released, and then, as in the case with a normal reset operation, the program is executed after branching to the reset vector address.

Figure 15-4. STOP Mode Release by Reset Signal Generation

(1) When high-speed on-chip oscillator clock is used as CPU clock



(2) When high-speed system clock is used as CPU clock (16-pin and 20-pin products only)



Note 1. For the reset processing time, see **CHAPTER 16 RESET FUNCTION**. For the reset processing time of the SPOR circuit, see **CHAPTER 17 SELECTABLE POWER-ON-RESET CIRCUIT**.

CHAPTER 16 RESET FUNCTION

The following six operations are available to generate a reset signal.

- (1) External reset input via $\overline{\text{RESET}}$ pin
- (2) Internal reset by watchdog timer program loop detection
- (3) Internal reset by comparison of supply voltage and detection voltage of selectable power-on-reset (SPOR) circuit
- (4) Internal reset by execution of illegal instruction^{Note 1}
- (5) Internal reset by data retention power supply voltage
- (6) Internal reset by illegal-memory access

External and internal resets start program execution from the address stored at 0000H and 0001H when the reset signal is generated.

Note 1. The illegal instruction is generated when instruction code FFH is executed.
Reset by the illegal instruction execution not issued by emulation with the on-chip debug emulator.

Caution 1. For an external reset, set the PORTSELB bit of the user option byte (000C1H) to 1 so that the P125 pin operates as $\overline{\text{RESET}}$, and input a low level for 10 μs or more to the $\overline{\text{RESET}}$ pin.
(To perform an external reset upon power application, input a low level to the $\overline{\text{RESET}}$ pin, and then apply power supply. The $\overline{\text{RESET}}$ pin must be kept low for at least 10 μs during the period in which the supply voltage is within the operating range shown in 23.4 AC Characteristics and 24.4 AC Characteristics before inputting a high level to the $\overline{\text{RESET}}$ pin.)

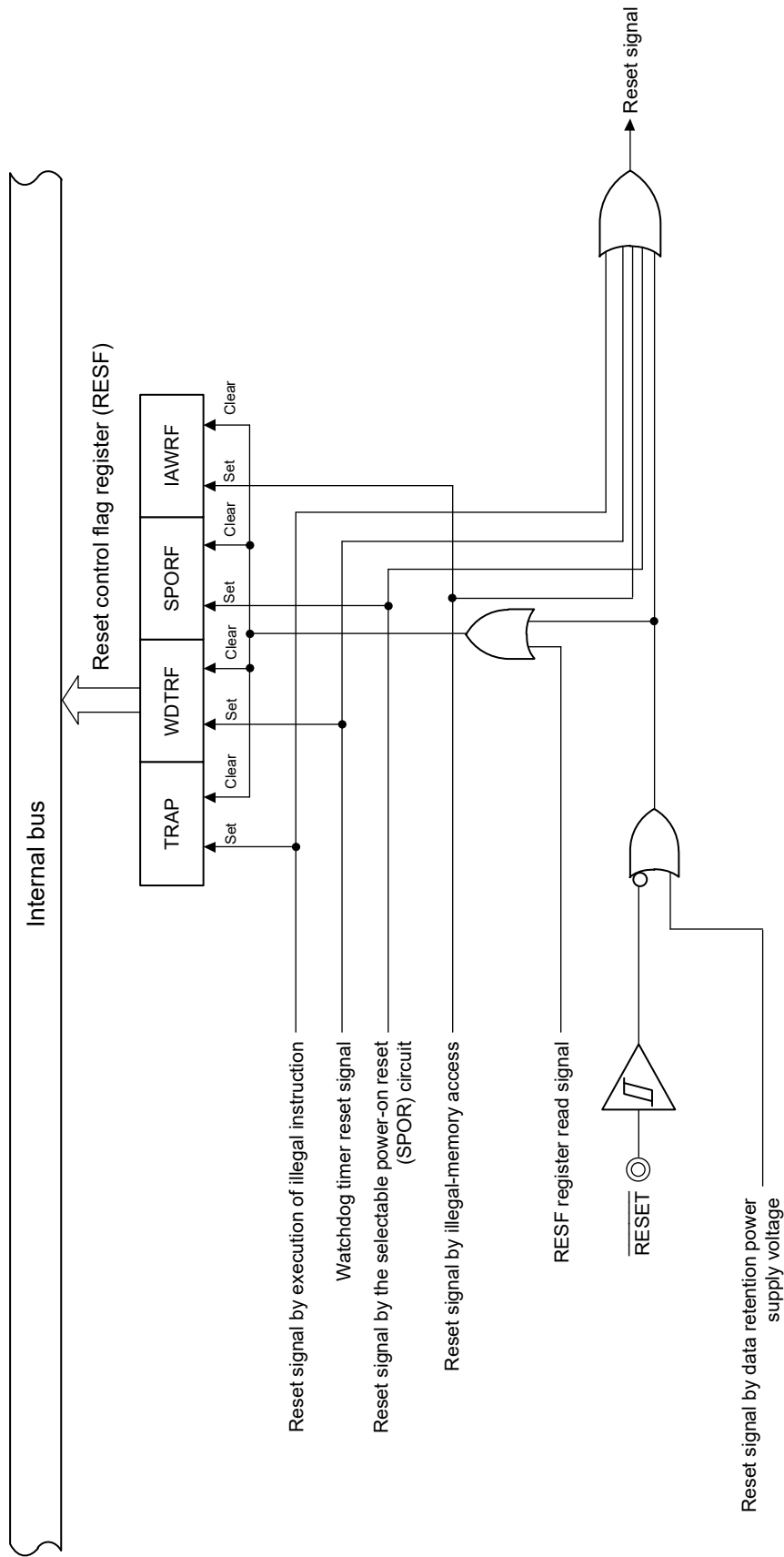
Caution 2. During reset input, the X1clock^{Note 2}, high-speed on-chip oscillator clock, and low-speed on-chip oscillator clock stop oscillating, and external main system clock^{Note 2} input is invalid.

Caution 3. The port pin becomes the following status because each SFR and 2nd SFR are initialized after reset.

- P40
High-impedance during external reset period or reset period by the data retention power supply voltage. High level during other types of reset or after receiving a reset (connected to the internal pull-up resistor).
- P125
Low level during external reset period (low level input to $\overline{\text{RESET}}$ pin). High level during other types of reset period or after receiving a reset (connected to the internal pull-up resistor).
- Ports other than P40 and P125
High-impedance during reset period or after receiving a reset.

Note 2. 16-pin and 20-pin products only.

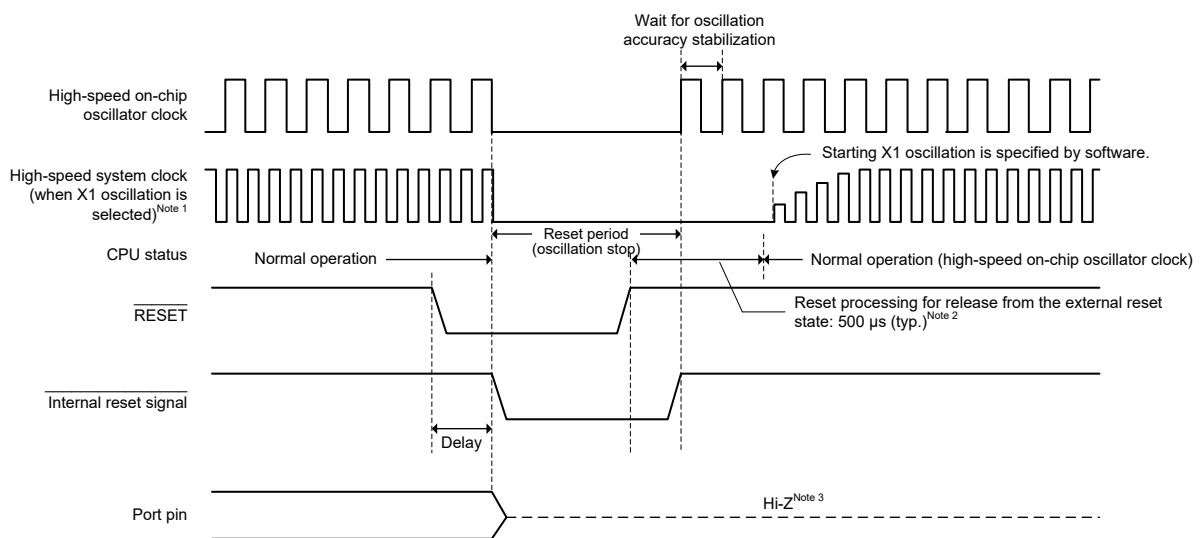
Figure 16-1. Block Diagram of Reset Function



16.1 Timing of Reset Operation

This LSI is reset by input of the low level on the $\overline{\text{RESET}}$ pin and released from the reset state by input of the high level on the $\overline{\text{RESET}}$ pin. After reset processing, execution of the program with the high-speed on-chip oscillator clock as the operating clock starts.

Figure 16-2. Timing of Reset by $\overline{\text{RESET}}$ Input



Note 1. 16-pin and 20-pin products only.

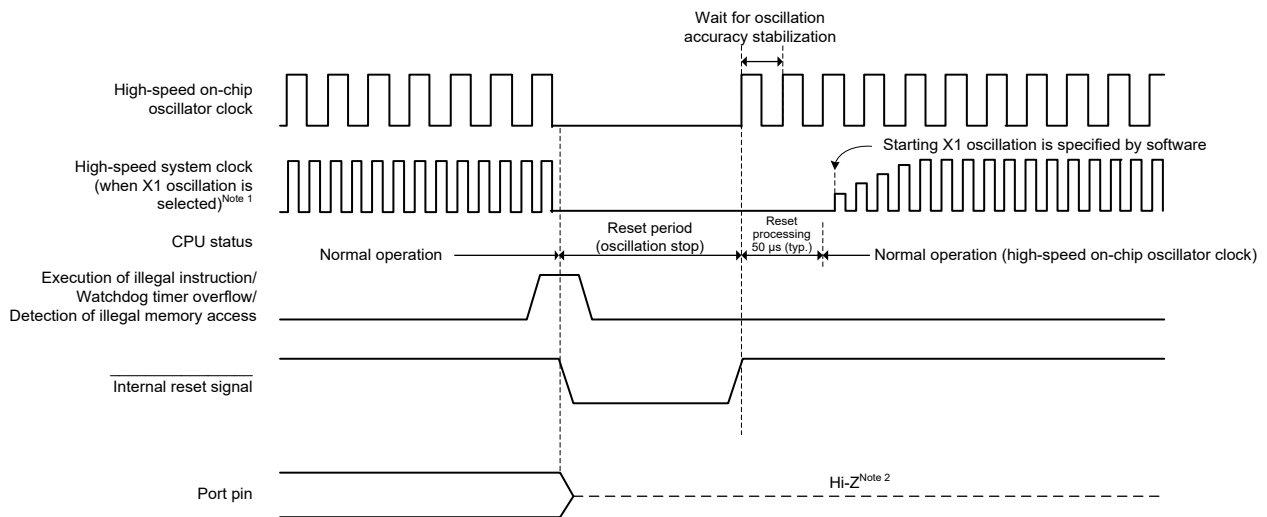
Note 2. After power is supplied, an SPOR reset processing time of 3.01 ms (MAX.) is required before reset processing starts after release of the external reset.

Note 3. Status of port pin P40 is as follows.

- High-impedance during external reset period or reset period by the data retention power supply voltage
- High level after receiving a reset (connected to the internal pull-up resistor)

Release from the reset state is automatic in the case of a reset due to a watchdog timer overflow, execution of an illegal instruction, or detection of illegal memory access. After reset processing, execution of the program with the high-speed on-chip oscillator clock as the operating clock starts.

Figure 16-3. Timing of Reset Due to Watchdog Timer Overflow, Execution of Illegal Instruction, or Detection of Illegal Memory Access



Note 1. 16-pin and 20-pin products only.

Note 2. Statuses of port pins P40 and P125 pins are as follows.

- High level during reset period or after receiving a reset (connected to the internal pull-up resistor).

Remark For the reset timing due to the voltage detection by the selectable power-on-reset (SPOR) circuit, see **CHAPTER 17 SELECTABLE POWER-ON-RESET CIRCUIT**.

16.2 States of Operation During Reset Periods

Table 16-1 shows the states of operation during reset periods. **Table 16-2** shows the state of the hardware after acceptance of a reset.

Table 16-1. States of Operation During Reset Period

| Item | During Reset Period | |
|--|-------------------------------------|--|
| System clock | Clock supply to the CPU is stopped. | |
| Main system clock | f_{IH} | Operation stopped |
| | $f_X^{\text{Note 1}}$ | Operation stopped (the X1 and X2 pins are input port mode) |
| | $f_{EX}^{\text{Note 1}}$ | Clock input invalid (the pin is input port mode) |
| f_{IL} | Operation stopped | |
| CPU | | |
| Code flash memory | Operation stopped | |
| Data flash memory | Operation stopped | |
| RAM | Operation stopped | |
| Port (latch) | High impedance ^{Note 2} | |
| Timer array unit | Operation stopped | |
| 12-bit interval timer | | |
| Watchdog timer | | |
| Clock output/buzzer output | | |
| A/D converter | | |
| Comparator | | |
| Serial array unit (SAU) | | |
| Serial interface (IICA) | | |
| Selectable power-on-reset function | | Detection operation possible |
| External interrupt | | Operation stopped |
| Illegal-memory access detection function | | |

Note 1. 16-pin and 20-pin products only.

Note 2. Statuses of P40 and P125 pins are as follows

- P40
High-impedance during external reset period or reset period by the data retention power supply voltage.
High level during other types of reset or after receiving a reset (connected to the internal pull-up resistor).
- P125
Low level during external reset period (low level input to $\overline{\text{RESET}}$ pin). High level during other types of reset period or after receiving a reset (connected to the internal pull-up resistor).

Remark f_{IH} : Highspeed on-chip oscillator clock
 f_X : X1 clock
 f_{EX} : External main system clock
 f_{IL} : Low-speed on-chip oscillator clock

Table 16-2. State of Hardware After Receiving a Reset Signal

| Hardware | | After Reset Acknowledgment ^{Note 1} |
|---------------------------|---------------------------|--|
| Program counter (PC) | | The contents of the reset vector table (00000H, 00001H) are set. |
| Stack pointer (SP) | | Undefined |
| Program status word (PSW) | | 06H |
| RAM | Data memory | Undefined |
| | General-purpose registers | Undefined |

Note 1. During reset signal generation or oscillation stabilization time wait, only the PC contents among the hardware statuses become undefined. All other hardware statuses remain unchanged after reset.

Remark For the state of the special function register (SFR) after receiving a reset signal, see **3.1.4 Special function register (SFR) area** and **3.1.5 Extended special function register (2nd SFR: 2nd Special Function Register) area**.

16.3 Register for Confirming Reset Source

16.3.1 Reset Control Flag Register (RESF)

Many internal reset generation sources exist in the RL78 microcontroller. The reset control flag register (RESF) is used to store which source has generated the reset request.

The RESF register can be read by an 8-bit memory manipulation instruction.

The external reset, a reset by the data retention lower limit voltage, and reading the RESF register clear TRAP, WDTRF, IAWRF, and SPORF flags.

Figure 16-4. Format of Reset Control Flag Register (RESF)

Address: FFFA8H After reset: Undefined^{Note 1} R

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|--|---|---|-------|---|---|-------|-------|
| RESF | TRAP | 0 | 0 | WDTRF | 0 | 0 | IAWRF | SPORF |
| TRAP | Internal reset request by execution of illegal instruction ^{Note 2} | | | | | | | |
| 0 | Internal reset request is not generated, or the RESF register is cleared. | | | | | | | |
| 1 | Internal reset request is generated. | | | | | | | |
| WDTRF | Internal reset request by watchdog timer (WDT) | | | | | | | |
| 0 | Internal reset request is not generated, or the RESF register is cleared. | | | | | | | |
| 1 | Internal reset request is generated. | | | | | | | |
| IAWRF | Internal reset request t by illegal-memory access | | | | | | | |
| 0 | Internal reset request is not generated, or the RESF register is cleared. | | | | | | | |
| 1 | Internal reset request is generated. | | | | | | | |
| SPORF | Internal reset request by selectable power-on reset (SPOR) circuit | | | | | | | |
| 0 | Internal reset request is not generated, or the RESF register is cleared. | | | | | | | |
| 1 | Internal reset request is generated. | | | | | | | |

Note 1. The value after reset varies depending on the reset source.

Note 2. The illegal instruction is generated when instruction code FFH is executed.
Reset by the illegal instruction execution not issued by emulation with the on-chip debug emulator.

Caution Do not read data by a 1-bit memory manipulation instruction.

The status of the RESF register when a reset request is generated is shown in **Table 16-3**.

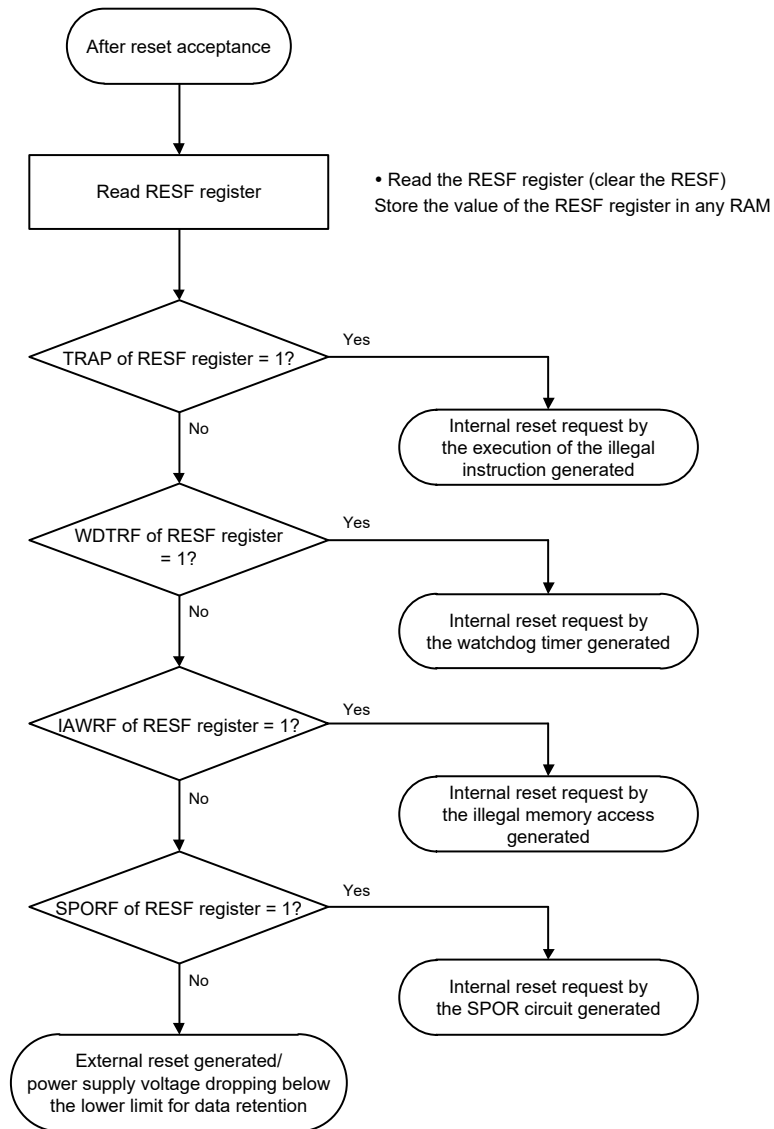
Table 16-3. RESF Register Status When Reset Request Is Generated

| Reset Source Flag | RESET Input | Reset by Execution of Illegal Instruction | Reset by WDT | Reset by Illegal- Memory Access | Reset by SPOR | Reset by Data Retention Lower Limit Voltage |
|----------------------|-------------|---|--------------|------------------------------------|---------------|---|
| TRAP | Cleared (0) | Set (1) | Held | Held | Held | Cleared (0) |
| WDTRF | | Held | Set (1) | Held | Held | |
| IAWRF | | Held | Held | Set (1) | Held | |
| SPORF | | Held | Held | Held | Set (1) | |

The RESF register is automatically cleared when it is read by an 8-bit memory manipulation instruction.

Figure 16-5 shows the procedure for checking a reset source.

Figure 16-5. Example of Procedure for Checking Reset Source



* The flow described above is an example of the procedure for checking.

CHAPTER 17 SELECTABLE POWER-ON-RESET CIRCUIT

17.1 Functions of Selectable Power-on-reset Circuit

The selectable power-on-reset (SPOR) circuit has the following functions.

- Generates internal reset signal at power on.
The reset signal is released when the supply voltage (V_{DD}) exceeds the detection voltage (V_{SPOR}) ($V_{DD} \geq V_{SPOR}$).
- The SPOR circuit compares the supply voltage (V_{DD}) with the detection voltage (V_{SPDR}), and generates an internal reset signal when $V_{DD} < V_{SPDR}$.
- The detection level for the power supply detection voltage (V_{SPOR} , V_{SPDR}) can be selected by using the option byte (000C1H) as one of 4 levels (for details, see **18.2 Format of User Option Byte**).

Bit 0 (SPORF) of the reset control flag register (RESF) is set to 1 if reset occurs. For details of the RESF register, see **CHAPTER 16 RESET FUNCTION**.

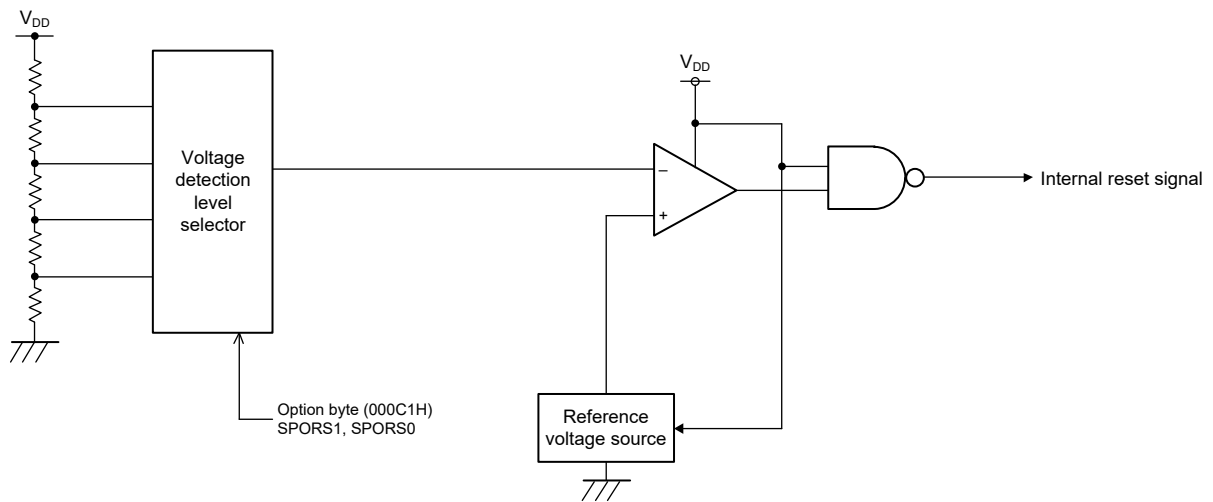
Caution The values of all flags in the reset control flag register (RESF) are retained until V_{DD} reaches data retention lower limit voltage.

Remark V_{SPOR} : SPOR power supply rise detection voltage
 V_{SPDR} : SPOR power supply fall detection voltage
For details, see **23.6.4 SPOR circuit characteristics** and **24.6.4 SPOR circuit characteristics**.

17.2 Configuration of Selectable Power-on-reset Circuit

The block diagram of the selectable power-on-reset circuit is shown in **Figure 17-1**.

Figure 17-1. Block Diagram of Selectable Power-on-reset Circuit



17.3 Operation of Selectable Power-on-reset Circuit

Specify the voltage detection level by using the option byte 000C1H.

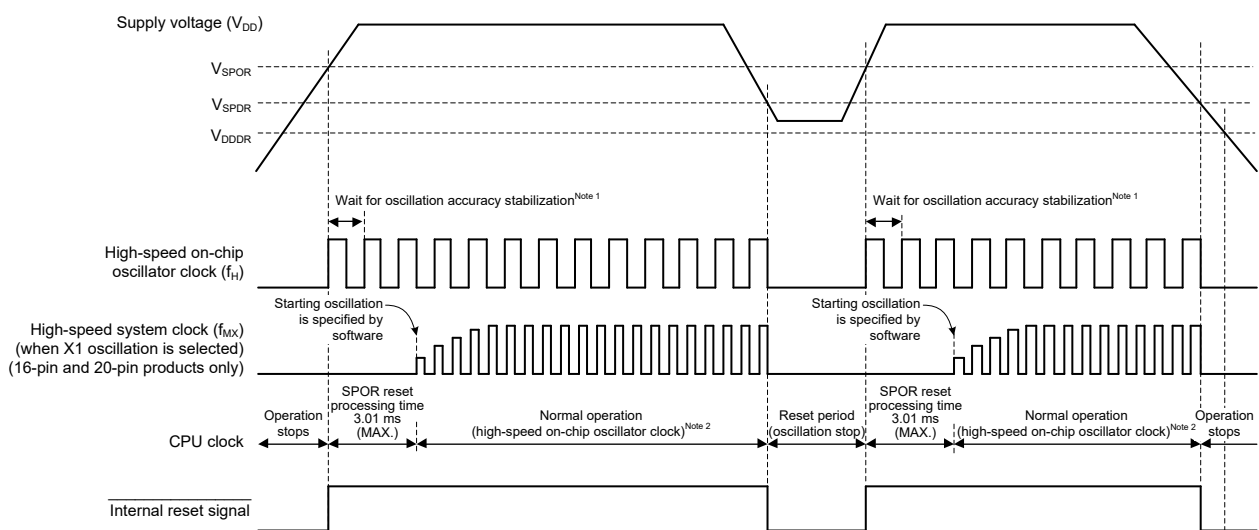
The internal reset signal is generated at power on.

The internal reset status is retained until the supply voltage (V_{DD}) exceeds the voltage detection level (V_{SPOR}). The internal reset is cleared when the supply voltage (V_{DD}) exceeds the voltage detection level (V_{SPOR}).

The internal reset is generated when the supply voltage (V_{DD}) drops lower than the voltage detection level (V_{SPDR}).

Figure 17-2 shows the timing of generation of the internal reset signal by the selectable power-on-reset circuit.

Figure 17-2. Timing of Internal Reset Signal Generation



Note 1. The internal reset processing time includes the oscillation accuracy stabilization time of the high-speed on-chip oscillator clock.

Note 2. The high-speed on-chip oscillator clock and a high-speed system clock can be selected as the CPU clock (16-pin and 20-pin products only).

To use the X1 clock, use the oscillation stabilization time counter status register (OSTC) to confirm the lapse of the oscillation stabilization time.

Remark V_{SPOR} : SPOR power supply rise detection voltage
 V_{SPDR} : SPOR power supply fall detection voltage
 V_{DDDR} : Data retention lower limit voltage

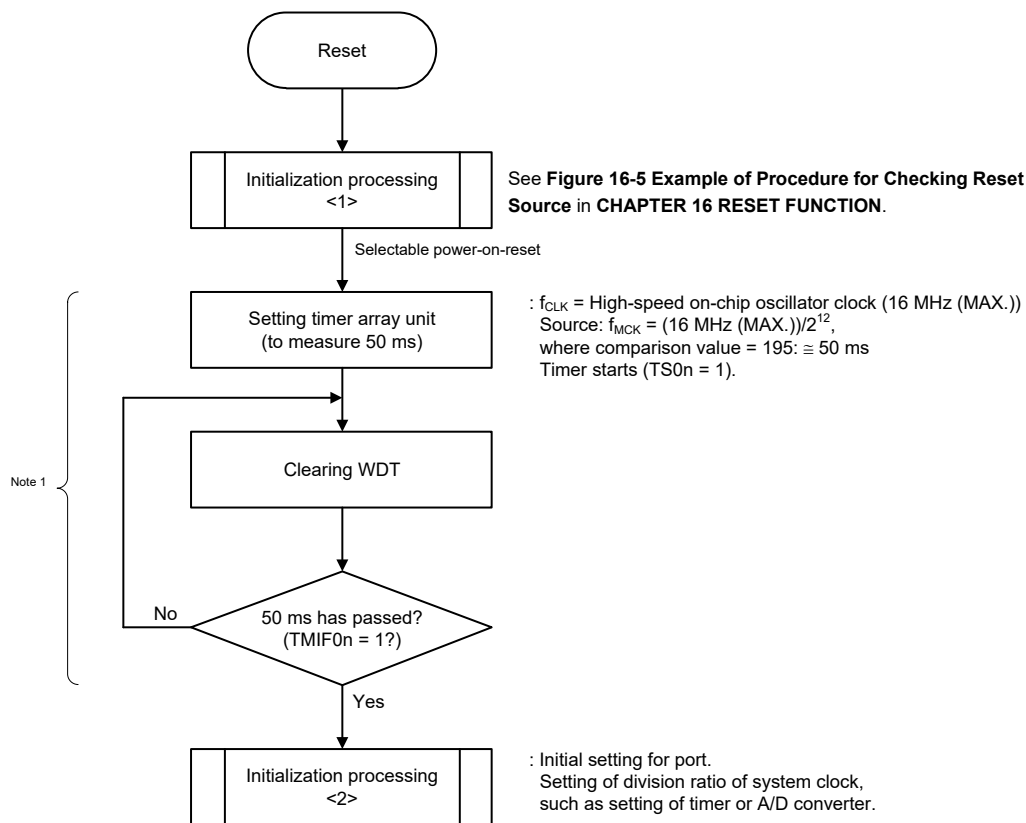
17.4 Cautions for Selectable Power-on-reset Circuit

In a system where the supply voltage (V_{DD}) fluctuates for a certain period in the vicinity of the SPOR detection voltage (V_{SPOR} , V_{SPDR}), the system may be repeatedly reset and released from the reset status. In this case, the time from release of reset to the start of the operation of the microcontroller can be arbitrarily set by taking the following action.

<Action>

After releasing the reset signal, wait for the supply voltage fluctuation period of each system by means of a timer and etc., and then initialize the ports.

Figure 17-3. Example of Software Processing When Supply Voltage Fluctuation is 50 ms or Less in Vicinity of the Voltage Detection Level



Note 1. If reset is generated again during this period, initialization processing <2> is not started.

Remark n: Channel number
 For 8-pin and 10-pin products, n = 0, 1; for 16-pin products, n = 0 to 3, 5, and 7; and for 20-pin products, n = 0 to 7.

CHAPTER 18 OPTION BYTE

18.1 Functions of Option Bytes

Addresses 000C0H to 000C3H of the flash memory form an option byte area.

Option bytes consist of user option byte (000C0H to 000C2H) and on-chip debug option byte (000C3H).

Upon power application or resetting and starting, an option byte is automatically referenced and a specified function is set. When using the product, be sure to set the following functions by using the option bytes.

Caution The option bytes should always be set regardless of whether each function is used.

18.1.1 User option byte (000C0H to 000C2H)

1) 000C0H

- Setting of watchdog timer operation
 - Enabling or disabling of counter operation
 - Enabling or disabling of counter operation in the HALT or STOP mode
- Time setting of watchdog timer
 - Setting of overflow time of watchdog timer
 - Setting of interval interrupt time of watchdog timer

2) 000C1H

- Setting of SPOR detection level (V_{SPOR})
- Controlling of P125/ \overline{RESET} /INTP1/(VCOUT0)/(VCOUT1)/(SI01)^{Note 1} pin
 - Select P125/INTP1/(VCOUT0)/(VCOUT1)/(SI01)^{Note 1} or \overline{RESET} .

Note 1. For 20-pin products

3) 000C2H

- Setting of the frequency of the high-speed on-chip oscillator
 - Select from 1 to 16 MHz.

18.1.2 On-chip debug option byte (000C3H)

- Control of on-chip debug operation
 - On-chip debug operation is disabled or enabled.

18.2 Format of User Option Byte

Figure 18-1. Format of User Option Byte (000C0H)

Address: 000C0H

| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|----------|-------|--|---|-------|---|-------|----------|
| 1 | 1 | 1 | WDTON | WDCS2 | WDCS1 | WDCS0 | WDSTBYON |
| WDTON | | Operation control of watchdog timer counter | | | | | |
| 0 | | Counter operation disabled (counting stopped after reset) | | | | | |
| 1 | | Counter operation enabled (counting started after reset) | | | | | |
| WDCS2 | WDCS1 | WDCS0 | Watchdog timer overflow time ($f_{IL} = 17.25 \text{ kHz (MAX.)}$) | | Watchdog timer interval interrupt time ($f_{IL} = 17.25 \text{ kHz (MAX.)}$) | | |
| 0 | 0 | 0 | $(2^6 - 1)/f_{IL}$ (3.65 ms) | | $2^6/f_{IL} \times 0.75$ (2.78 ms) | | |
| 0 | 0 | 1 | $(2^7 - 1)/f_{IL}$ (7.36 ms) | | $2^7/f_{IL} \times 0.75$ (5.56 ms) | | |
| 0 | 1 | 0 | $(2^8 - 1)/f_{IL}$ (14.7 ms) | | $2^8/f_{IL} \times 0.75$ (11.1 ms) | | |
| 0 | 1 | 1 | $(2^9 - 1)/f_{IL}$ (29.6 ms) | | $2^9/f_{IL} \times 0.75$ (22.2 ms) | | |
| 1 | 0 | 0 | $(2^{11} - 1)/f_{IL}$ (118 ms) | | $2^{11}/f_{IL} \times 0.75$ (89.0 ms) | | |
| 1 | 0 | 1 | $(2^{13} - 1)/f_{IL}$ (474 ms) | | $2^{13}/f_{IL} \times 0.75$ (356 ms) | | |
| 1 | 1 | 0 | $(2^{14} - 1)/f_{IL}$ (949 ms) | | $2^{14}/f_{IL} \times 0.75$ (712 ms) | | |
| 1 | 1 | 1 | $(2^{16} - 1)/f_{IL}$ (3799 ms) | | $2^{16}/f_{IL} \times 0.75$ (2849 ms) | | |
| WDSTBYON | | Operation control of watchdog timer counter (HALT/STOP mode) | | | | | |
| 0 | | Counter operation stopped in HALT/STOP mode | | | | | |
| 1 | | Counter operation enabled in HALT/STOP mode | | | | | |

Caution 1. Be sure to write 1 to bits 7 to 5.

Caution 2. Setting WDTON = 0 and WDSTBYON = 1 is prohibited.

Caution 3. The watchdog timer always generates an interval interrupt when the specified time is reached unless this is specifically disabled. If the interval interrupt from the watchdog timer is not to be used, be sure to disable the interrupt by setting the WDTIMK bit to 1.

Remark f_{IL} : Low-speed on-chip oscillator clock frequency

Figure 18-2. Format of User Option Byte (000C1H)

Address: 000C1H

| | | | | | | | |
|---|---|---|----------|--------|--------|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 1 | 1 | 1 | PORTSELB | SPORS1 | SPORS0 | 1 | 1 |

- Setting of SPOR detection voltage

| Detection voltage (V_{SPOR}) | | Option byte setting value | |
|----------------------------------|--------------|---------------------------|--------|
| Rising edge | Falling edge | SPORS1 | SPORS0 |
| 4.28 V | 4.20 V | 0 | 0 |
| 2.90 V | 2.84 V | 0 | 1 |
| 2.57 V | 2.52 V | 1 | 0 |
| 2.16 V | 2.11 V | 1 | 1 |

- P125/ $\overline{\text{RESET}}$ /INTP1/(VCOUT0)/(VCOUT1)/(SI01)^{Note 1} pin control

| PORTSELB | P125/ $\overline{\text{RESET}}$ /INTP1/(VCOUT0)/(VCOUT1)/(SI01) ^{Note 1} pin control |
|----------|---|
| 0 | Port function (P125/INTP1/(VCOUT0)/(VCOUT1)/(SI01) ^{Note 1}) |
| 1 | $\overline{\text{RESET}}$ input (internal pull-up resistor can be always connected.) |

Note 1. For 20-pin products

Caution 1. Be sure to write 1 to bits 7 to 5, 1, and 0.

Caution 2. Set the detection voltage (V_{SPOR}) to be within the operating voltage range.
The operating voltage range is as follows.

For CPU operating frequencies from 1 MHz to 16 MHz: $V_{DD} = 2.4$ to 5.5 V

Remark 1. For details on the SPOR circuit, see CHAPTER 17 SELECTABLE POWER-ON-RESET CIRCUIT.

Remark 2. The detection voltage is a typical value. For details, see 23.6.4 SPOR circuit characteristics and 24.6.4 SPOR circuit characteristics.

Figure 18-3. Format of User Option Byte (000C2H)

Address: 000C2H

| | | | | | | | |
|---|---|---|---|---|---------|---------|---------|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| 1 | 1 | 1 | 1 | 1 | FRQSEL2 | FRQSEL1 | FRQSEL0 |

| FRQSEL2 | FRQSEL1 | FRQSEL0 | Frequency of the high-speed on-chip oscillator | |
|------------------|---------|---------|--|--------------------------------------|
| | | | Operating frequency (f_{MAIN}) | Operating voltage range (V_{DD}) |
| 0 | 0 | 1 | 16 MHz | 2.4 V to 5.5 V |
| 0 | 1 | 0 | 8 MHz | |
| 0 | 1 | 1 | 4 MHz | |
| 1 | 0 | 0 | 2 MHz | |
| 1 | 0 | 1 | 1 MHz | |
| Other than above | | | Setting prohibited | |

Caution Be sure to write 1 to bits 7 to 3.

18.3 Format of On-chip Debug Option Byte

The format of on-chip debug option byte is shown below.

Figure 18-4. Format of On-chip Debug Option Byte (000C3H)

Address: 000C3H

| | | | | | | | |
|----------|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| OCDENSET | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

| | |
|----------|--|
| OCDENSET | Control of on-chip debug operation |
| 0 | Disables on-chip debug operation. |
| 1 | Enables on-chip debugging. ^{Note 1} |

Note 1. Does not erase data of flash memory in case of failures in authenticating on-chip debug security ID.

Caution Bit 7 (OCDENSET) can only be specified a value.
Be sure to set 0000101B to bits 6 to 0.

Remark The value on bits 3 and 1 will be written over when the on-chip debug function is in use and thus it will become unstable after the setting. However, be sure to set the default values (0, 1, and 0) to bits 3 to 1 at setting.

18.4 Setting of Option Byte

The user option byte and on-chip debug option byte can be set using the link option in addition to describing to the source. When doing so, the contents set by using the link option take precedence, even if descriptions exist in the source, as mentioned below.

A software description example of the option byte setting is shown below.

| OPT | CSEG | OPT_BYTE | |
|-----|------|----------|--|
| | DB | F7H | ; Enables watchdog timer operation, ; Overflow time of watchdog timer is $2^9/f_{IL}$, ; Stops watchdog timer operation during HALT/STOP mode |
| | DB | E7H | ; Select 2.90 V for rising and 2.84 V for falling for V_{SPOR} ; Use the port function (P125/KR1) |
| | DB | FDH | Select 1 MHz as the frequency of the high-speed on-chip oscillator clock |
| | DB | 85H | ; Enables on-chip debug operation |

Caution To specify the option byte by using assembly language, use `OPT_BYTE` as the relocation attribute name of the CSEG pseudo instruction.

CHAPTER 19 FLASH MEMORY

The RL78 microcontroller incorporates the flash memory to which a program can be written, erased, and overwritten while mounted on the board. The flash memory includes the “code flash memory”, in which programs can be executed, and the “data flash memory”, an area for storing data.

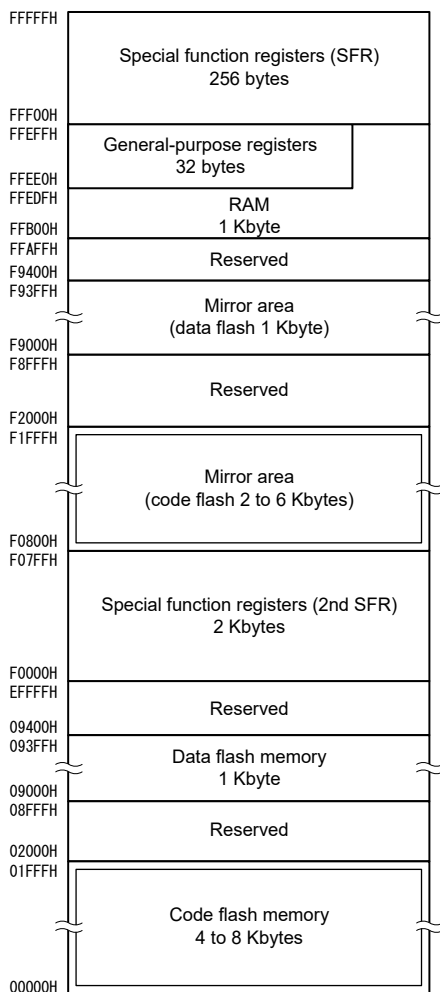


Table 19-1. Overview of Flash Memory

| | |
|------------------------------------|--|
| Flash capacity | Code flash: 4 to 8 Kbytes Data flash: 1 Kbyte |
| Block size | Code flash: 1 Kbyte (blocks 0 to 7) Data flash: 512 bytes (blocks 0 and 1) |
| Unit for writing and block erasure | [Writing] Code flash/data flash: 32 bits [Block erasure] Code flash: 1 Kbyte Data flash: 512 bytes |

The following methods for programming the flash memory are available.

- The code flash memory and data flash memory can be rewritten to through serial programming using a flash memory programmer or an external device (UART communication), or through self-programming.

- Serial programming using flash memory programmer (see **19.1 Serial Programming Using Flash Memory Programmer**)

Data can be written to the flash memory on-board or off-board by using a dedicated flash memory programmer.

- Serial programming using external device (UART communication) (see **19.2 Writing to Flash Memory by Using External Device (that Incorporates UART)**)

Data can be written to the flash memory on-board through UART communication with an external device (microcontroller or ASIC).

- Self-programming (see **19.6 Self-Programming**)

The user application can execute self-programming of the code flash memory or data flash memory by using the flash self-programming code.

Caution The data flash memory can be rewritten by using the flash self-programming code, but cannot be rewritten in background operation during user program execution.

19.1 Serial Programming Using Flash Memory Programmer

The following dedicated flash memory programmer can be used to write data to the internal flash memory of the RL78 microcontroller.

- PR5PG-FP6
- E2 or E2 Lite on-chip debugging emulator

Data can be written to the flash memory on-board or off-board, by using a dedicated flash memory programmer.

1) On-board programming

The contents of the flash memory can be rewritten after the RL78 microcontroller has been mounted on the target system. The connectors that connect the dedicated flash memory programmer must be mounted on the target system.

2) Off-board programming

Data can be written to the flash memory with a dedicated program adapter before the RL78 microcontroller is mounted on the target system.

Table 19-2. Wiring between RL78/G15 and Dedicated Flash Memory Programmer

| Pin Configuration of Dedicated Flash Memory Programmer | | | Pin Name | Pin No. | | | | | |
|--|--|--------|--|---------------------------|-------|--------|--------|------|--------|
| Signal Name | | I/O | | Pin Function | 8-pin | 10-pin | 16-pin | | 20-pin |
| PG-FP6 | E2 or E2 Lite on-chip debugging emulator | | WDFN | | SSOP | SSOP | HWQFN | SSOP | |
| — | TOOL0 | I/O | Transmit/ receive signal | TOOL0/P40 | 1 | 1 | 2 | 16 | 4 |
| SI/RxD | — | I/O | Transmit/ receive signal | | | | | | |
| — | RESET_OUT | Output | Reset signal | $\overline{\text{RESET}}$ | 2 | 2 | 3 | 1 | 5 |
| $\overline{\text{RESET}}$ | — | Output | | | | | | | |
| V_{DD} ^{Note 1} | | I/O | V_{DD} voltage generation/ power monitoring | V_{DD} | 4 | 5 | 8 | 6 | 10 |
| GND | | — | Ground | V_{SS} | 3 | 4 | 7 | 5 | 9 |
| FLMD1 | EMV _{DD} | — | Driving power for TOOL0 pin | V_{DD} | 4 | 5 | 8 | 6 | 10 |

Note 1. The signal name for the PG-FP6 is V_{CC} .

Remark Pins that are not indicated in the above table can be left open when using the flash memory programmer for flash programming.

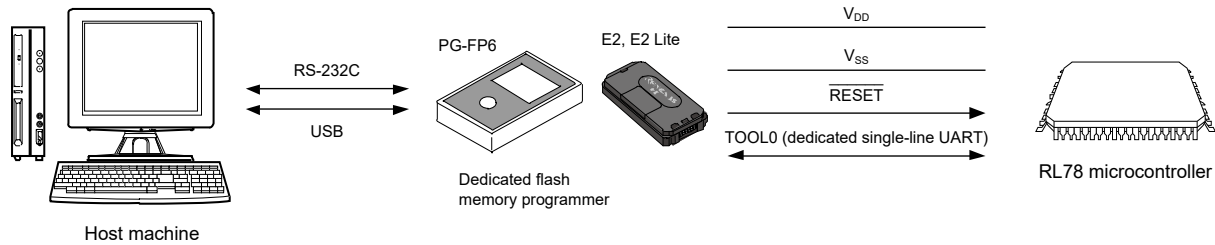
About a connection between RL78 microcontroller and a connector, refer to the user's manual of each programmer.

About a connection with E2 or E2 Lite, see **20.1 Connecting E2, E2 Lite On-chip Debugging Emulator**.

19.1.1 Programming environment

The environment required for writing a program to the flash memory of the RL78 microcontroller is illustrated below.

Figure 19-1. Environment for Writing Program to Flash Memory



A host machine that controls the dedicated flash memory programmer is necessary.

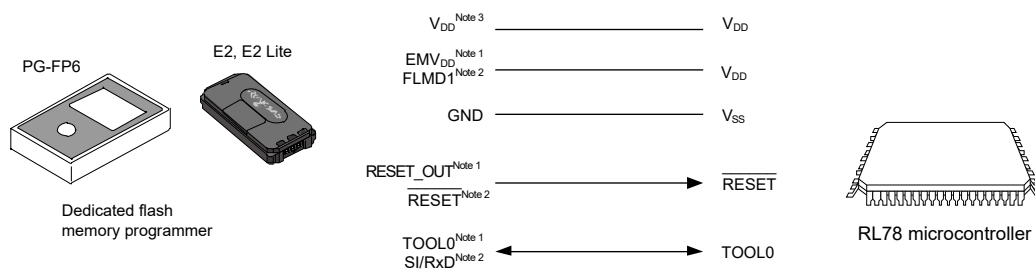
To interface between the dedicated flash memory programmer and the RL78 microcontroller, the TOOL0 pin is used for manipulation such as writing and erasing via a dedicated single-line UART.

19.1.2 Communication mode

Communication between the dedicated flash memory programmer and the RL78 microcontroller is established by serial communication using the TOOL0 pin via a dedicated single-line UART of the RL78 microcontroller.

Transfer rate: Fixed to 115200 bps

Figure 19-2. Communication with Dedicated Flash Memory Programmer



Note 1. When using E2 or E2 Lite on-chip debugging emulator.

Note 2. When using PG-FP6.

Note 3. The signal name for the PG-FP6 is V_{CC}.

The dedicated flash memory programmer generates the following signals for the RL78 microcontroller. See the manual for the PG-FP6 or, E2 or E2 Lite on-chip debugging emulator for details.

Table 19-3. Pin Connection

| Dedicated Flash Memory Programmer | | | RL78 Microcontroller | |
|-----------------------------------|--|--------|--|----------------------------|
| Signal Name | | I/O | Pin Function | Pin Name ^{Note 1} |
| PG-FP6 | E2 or E2 Lite on-chip debugging emulator | | | |
| V_{DD} ^{Note 2} | | I/O | V_{DD} voltage generation/ power monitoring | V_{DD} |
| GND | | — | Ground | V_{SS} |
| FLMD1 | EMV _{DD} | | Driving power for TOOL0 pin | V_{DD} |
| $\overline{\text{RESET}}$ | — | Output | Reset signal | $\overline{\text{RESET}}$ |
| — | RESET_OUT | Output | | |
| — | TOOL0 | I/O | Transmit/receive signal | TOOL0 |
| SI/RxD | — | I/O | Transmit/receive signal | |

Note 1. Pins to be connected differ with the product. For details, see **Table 19-1**.

Note 2. The signal name for the PG-FP6 is V_{CC} .

19.2 Writing to Flash Memory by Using External Device (that Incorporates UART)

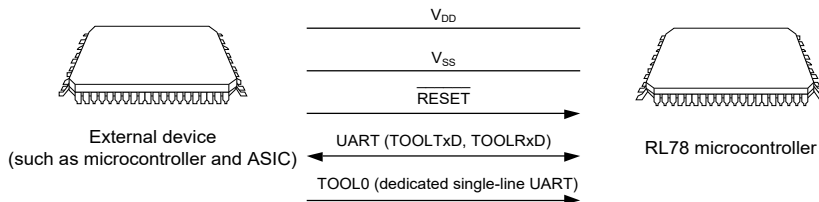
On-board data writing to the internal flash memory is possible by using the RL78 microcontroller and an external device (a microcontroller or ASIC) connected to a UART.

On the development of flash memory programmer by user, refer to the RL78 Microcontrollers (RL78 Protocol B) Serial Programming Edition Application Note (R01AN6332).

19.2.1 Programming environment

The environment required for writing a program to the flash memory of the RL78 microcontroller is illustrated below.

Figure 19-3. Environment for Writing Program to Flash Memory



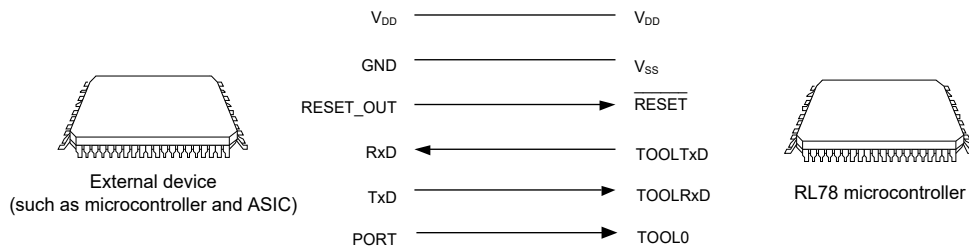
Processing to write data to or erase data from the RL78 microcontroller by using an external device is performed on-board. Off-board writing is not possible.

19.2.2 Communication mode

Communication between the external device and the RL78 microcontroller is established by serial communication using the TOOL0 pin via the dedicated UART of the RL78 microcontroller.

Transfer rate: Fixed to 115200 bps

Figure 19-4. Communication with External Device



The external device generates the following signals for the RL78 microcontroller.

Table 19-4. Pin Connection

| External Device | | | RL78 microcontroller |
|-----------------|--------|---|---------------------------|
| Signal Name | I/O | Pin Function | Pin Name |
| V _{DD} | I/O | V _{DD} voltage generation/ power monitoring | V _{DD} |
| GND | — | Ground | V _{SS} |
| RESET_OUT | Output | Reset signal output | $\overline{\text{RESET}}$ |
| RxD | Input | Receive signal | TOOLTxD |
| TxD | Output | Transmit signal | TOOLRxD |
| PORT | Output | Mode signal | TOOL0 |

19.3 Connection of Pins on Board

To write the flash memory on-board by using the flash memory programmer, connectors that connect the dedicated flash memory programmer must be provided on the target system. First provide a function that selects the normal operation mode or flash memory programming mode on the board.

When the flash memory programming mode is set, all the pins not used for programming the flash memory are in the same status as immediately after reset. Therefore, if the external device does not recognize the state immediately after reset, the pins must be handled as described below.

Remark For the flash memory programming mode, see **19.4.2 Flash memory programming mode**.

19.3.1 P40/TOOL0 pin

In the flash memory programming mode, connect this pin to the dedicated flash memory programmer via an external 1k Ω pull-up resistor.

When this pin is used as the port pin, use that by the following method.

When used as an input pin: Input of low-level is prohibited for t_{HD} period after external pin reset release. However, when this pin is used via pull-down resistors, use the 500 k Ω or more resistors.

When used as an output pin: When this pin is used via pull-down resistors, use the 500 k Ω or more resistors.

Remark 1. t_{HD} : How long to keep the TOOL0 pin at the low level from when the external and internal resets end for setting of the flash memory programming mode (see **23.10 Timing of Entry to Flash Memory Programming Mode** and **24.10 Timing of Entry to Flash Memory Programming Mode**).

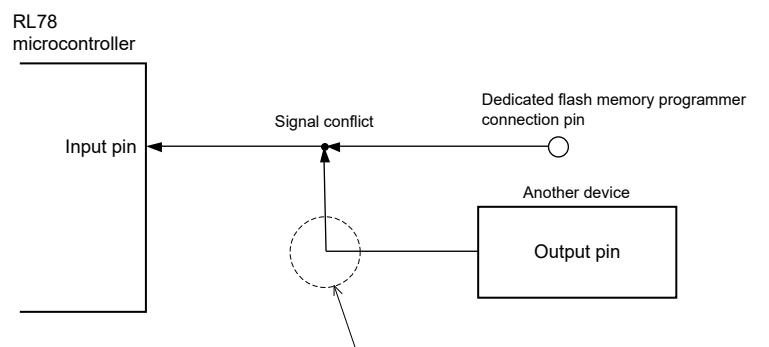
Remark 2. The SAU and IICA pins are not used for communication between the RL78 microcontroller and dedicated flash memory programmer, because single-line UART (TOOL0 pin) is used.

19.3.2 $\overline{\text{RESET}}$ pin

Signal conflict will occur if the reset signal of the dedicated flash memory programmer and external device are connected to the $\overline{\text{RESET}}$ pin that is connected to the reset signal generator on the board. To prevent this conflict, isolate the connection with the reset signal generator.

The flash memory will not be correctly programmed if the reset signal is input from the user system while the flash memory programming mode is set. Do not input any signal other than the reset signal of the dedicated flash memory programmer and external device.

Figure 19-5. Signal Conflict ($\overline{\text{RESET}}$ Pin)



In the flash memory programming mode, a signal output by another device will conflict with the signal output by the dedicated flash memory programmer. Therefore, isolate the signal of another device.

19.3.3 Port pins

When the flash memory programming mode is set, all the pins not used for flash memory programming enter the same status as that immediately after reset. If external devices connected to the ports do not recognize the port status immediately after reset, the port pin must be connected to either V_{DD} or V_{SS} via a resistor.

19.3.4 X1 and X2 pins (16-pin and 20-pin products)

Connect X1 and X2 pins in the same status as in the normal operation mode.

Remark In the flash memory programming mode, the high-speed on-chip oscillator clock (f_{IH}) is used.

19.3.5 Power supply

To use the supply voltage output of the flash memory programmer, connect the V_{DD} pin to $V_{DD}^{\text{Note 1}}$ of the flash memory programmer, and the V_{SS} pin to GND of the flash memory programmer.

To use the on-board supply voltage, connect in compliance with the normal operation mode.

Note that the operating voltage during flash memory programming must be in the range from 2.4 V to 5.5 V. If the on-board supply voltage is less than 2.4 V, satisfy the requirement for operating voltage (2.4 V to 5.5 V) by, for example, switching to the voltage from a dedicated flash memory programmer, and isolate the on-board supply voltage.

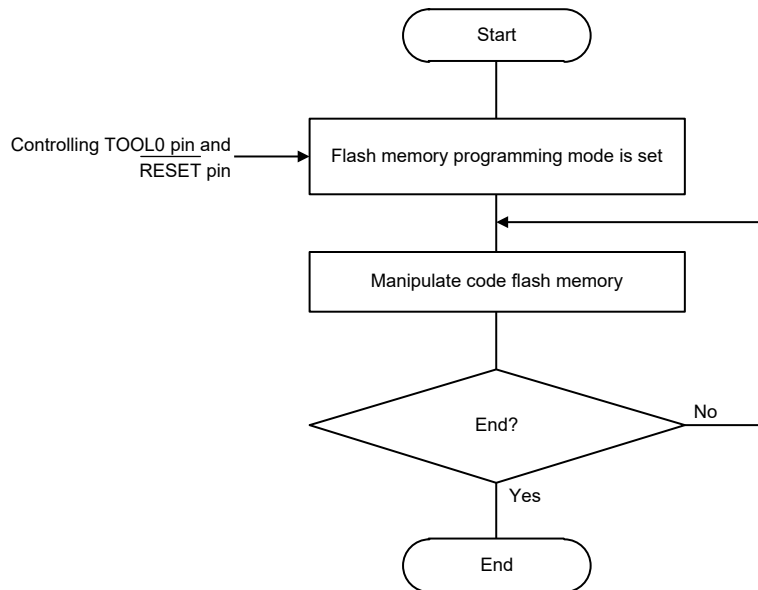
Note 1. The signal name for the PG-FP6 is V_{CC} .

19.4 Serial Programming Method

19.4.1 Serial programming procedure

The following figure illustrates a flow for rewriting the code flash memory through serial programming.

Figure 19-6. Code Flash Memory Manipulation Procedure



For the flash memory programming mode, see **19.4.2 Flash memory programming mode**.

19.4.2 Flash memory programming mode

To rewrite the contents of the code flash memory by serial programming, the flash memory programming mode must be entered.

<Serial programming using the dedicated flash memory programmer>

Connect the RL78 microcontroller to a dedicated flash memory programmer. Communication from the dedicated flash memory programmer is performed to automatically switch to the flash memory programming mode. The operating voltage during the flash memory programming mode is 2.4 V to 5.5 V.

<Serial programming using an external device (UART communication)>

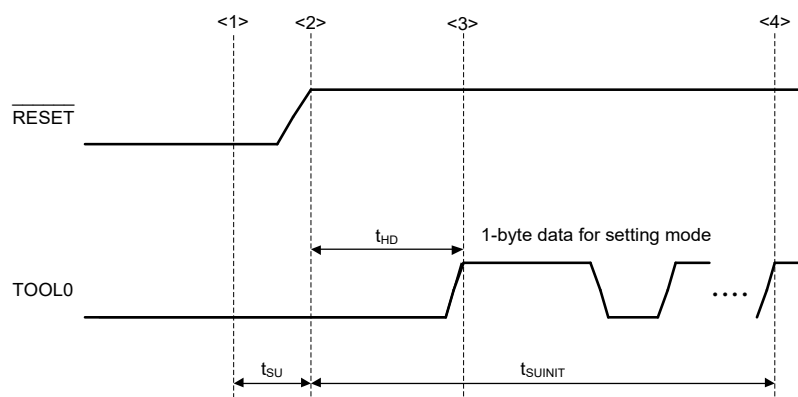
Set the TOOL0 pin to the low level, and then cancel the reset (see **Table 19-5**). After that, enter flash memory programming mode according to the procedures <1> to <4> shown in **Figure 19-7**.

The operating voltage during the flash memory programming mode is 2.4 V to 5.5 V.

Table 19-5. Relationship between TOOL0 Pin and Operation Mode after Reset Release

| TOOL0 | Operation Mode |
|-----------------|-------------------------------|
| V _{DD} | Normal operation mode |
| 0 V | Flash memory programming mode |

Figure 19-7. Setting of Flash Memory Programming Mode



- <1> The low level is input to the TOOL0 pin.
- <2> The external reset ends (SPOR reset must end before the external reset ends.).
- <3> The TOOL0 pin is set to the high level.
- <4> Setting of entry to the flash memory programming mode by UART reception.

Remark t_{SUNIT}: The segment shows that it is necessary to finish specifying the initial communication settings within 100 ms from when the resets end.

t_{SU}: How long from when the TOOL0 pin is placed at the low level until an external reset ends

t_{HD}: How long to keep the TOOL0 pin at the low level from when the external reset ends

For details, see **23.10 Timing of Entry to Flash Memory Programming Mode** and **24.10 Timing of Entry to Flash Memory Programming Mode**.

19.4.3 Selecting communication mode

Communication modes of the RL78 microcontroller are as follows.

Table 19-6. Communication Modes

| Communication Mode | Standard Setting ^{Note 1} | | | | Pins Used |
|---|------------------------------------|-------------------------|-----------|---------------|---------------------|
| | Port | Speed ^{Note 2} | Frequency | Multiply Rate | |
| 1-line UART (when flash memory programmer is used, or when external device is used) | UART | 115200 bps | — | — | TOOL0 |
| Dedicated UART (when external device is used) | UART | 115200 bps | — | — | TOOLTxD, TOOLRxD |

Note 1. Selection items for Standard settings on GUI of the flash memory programmer.

Note 2. Because factors other than the baud rate error, such as the signal waveform slew, also affect UART communication, thoroughly evaluate the slew as well as the baud rate error.

19.4.4 Communication commands

The RL78 microcontroller executes serial programming through the commands listed in **Table 19-7**.

The signals sent from the dedicated flash memory programmer or external device to the RL78 microcontroller are called commands, and programming functions corresponding to the commands are executed.

Table 19-7. Flash Memory Control Commands

| Classification | Command Name | Function |
|-----------------------|--|---|
| CRC checking | CRC check (code flash memory) | Calculate the checksum of the code flash memory. |
| | CRC check (data flash memory) | Calculate the checksum of the data flash memory. |
| Writing after erasure | Write after erase (code flash memory) | Write data after erasing data in the code flash memory. |
| | Write after erase (data flash memory) | Write data after erasing data in the data flash memory. |

19.5 Processing Time for Each Command When PG-FP5 Is in Use (Reference Values)

The following tables show the processing time for each command (reference value) when PG-FP5 is used as a dedicated flash memory programmer.

Table 19-8. Processing Time for Each Command When PG-FP5 Is in Use (Reference Values)

| Command of PG-FP5 | Code Flash | | Data Flash |
|-------------------|--|--|--------------|
| | 4 KB | 8 KB | 1 KB |
| | R5F12067xSP, R5F12047xNA, R5F12047xSP, R5F12017xSP, R5F12007xNS (x = M,G,A) | R5F12068xSP, R5F12048xNA, R5F12048xSP, R5F12018xSP, R5F12008xNS (x = M,G,A) | All products |
| Write after erase | 1.5 s | 2.0 s | 1.0 s |
| CRC check | 0.5 s | 1.0 s | 0.5 s |

Remark The command processing times (reference values) shown in the table are typical values under the following conditions.

Port: TOOL0 (single-line UART)

Speed: 115,200 bps

19.6 Self-Programming

The RL78 microcontroller supports a self-programming function that can be used to rewrite the code flash memory via a user program. Because this function allows a user application to rewrite the code flash memory by using the flash self-programming library, it can be used to upgrade the program in the field.

Caution 1. To prohibit an interrupt during self-programming, in the same way as in the normal operation mode, execute the flash self-programming library in the state where the IE flag is cleared (0) by the DI instruction.

Since the CPU is stopped while rewriting the flash memory, an interrupt cannot be accepted during this period.

Caution 2. The high-speed on-chip oscillator should be kept operating during self-programming. If it is kept stopping, the high-speed on-chip oscillator clock should be operated (HIOSTOP = 0). The flash self-programming code should be executed after 30 μ s have elapsed.

19.6.1 Registers controlling self-programming

- Flash address pointer registers (FLAPH, FLAPL)
- Flash end address specification registers (FLSEDH, FLSEDL)
- Flash write buffer registers (FLWHH, FLWHL, FLWLH, FLWLL)
- Flash programming mode control register (FLPMC)
- Flash memory sequencer initial setting register (FSSET)
- Flash memory sequencer control register (FSSQ)
- Flash memory sequencer status registers (FSASTH, FSASTL)

19.6.1.1 Flash address pointer registers H and L (FLAPH, FLAPL)

The FLAPH and FLAPL registers specify the address where programming of the flash memory is to start.

The FLAPH and FLAPL registers can be set by an 8-bit memory manipulation instruction.

These registers are set to 00H following a reset.

Figure 19-8. Format of Flash Address Pointer Registers H and L (FLAPH, FLAPL)

Address: F00C3H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|--------|--------|--------|-------|-------|
| FLAPH | 0 | 0 | 0 | FLAP12 | FLAP11 | FLAP10 | FLAP9 | FLAP8 |

Address: F00C2H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| FLAPL | FLAP7 | FLAP6 | FLAP5 | FLAP4 | FLAP3 | FLAP2 | FLAP1 | FLAP0 |

19.6.1.2 Flash end address specification registers H and L (FLSEDH, FLSEDL)

The FLSEDH and FLSEDL registers specify the address where programming of the flash memory is to end.

The FLSEDH and FLSEDL registers can be set by an 8-bit memory manipulation instruction.

These registers are set to 00H following a reset.

Figure 19-9. Format of Flash End Address Specification Registers H and L (FLSEDH, FLSEDL)

Address: F00C5H After reset: 00H R/W

| | | | | | | | | |
|--------|---|---|---|-------|-------|-------|------|------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| FLSEDH | 0 | 0 | 0 | EWA12 | EWA11 | EWA10 | EWA9 | EWA8 |

Address: F00C4H After reset: 00H R/W

| | | | | | | | | |
|--------|------|------|------|------|------|------|---|---|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| FLSEDL | EWA7 | EWA6 | EWA5 | EWA4 | EWA3 | EWA2 | 0 | 0 |

Table 19-9. Method of Setting the FLAPH/L and FLSEDH/L Registers

| Commands exclusively for use with the flash memory sequencer | | Settings of the FLAPH/L and FLSEDH/L Registers | |
|--|-------------|--|---|
| FSSQ | Write | Code flash | FLAPH/L registers: Bits 12 to 0 = bits 12 to 0 of the address from which writing is to proceed FLSEDH/L registers: Bits 12 to 0 = All 0s (can be unset) |
| | | Data flash | FLAPH/L registers: Bits 12 to 10 = All 0s Bits 9 to 0 = Bits 9 to 0 of the address from which writing is to proceed FLSEDH/L registers: Bits 12 to 0 = All 0s (can be unset) |
| | Block erase | Code flash | FLAPH/L registers: Bits 12 to 10 = bits 12 to 10 of the block start address Bits 9 to 0 = All 0s FLSEDH/L registers: Bits 12 to 10 = bits 12 to 10 of the block start address Bits 9 to 2 = All 1s |
| | | Data flash | FLAPH/L registers: Bits 12 to 10 = All 0s Bit 9 = bit 9 of the block start address Bits 8 to 0 = All 0s FLSEDH/L registers: Bits 12 to 10 = All 0s Bit 9 = bit 9 of the block start address Bits 8 to 2 = All 1s |

Caution Set the FLAPH/L registers and the FLSEDH/L registers so that the following condition is met.
FLAPH/L setting ≤ FLSEDH/L setting

Block configuration of code flash memory

Bits 12 to 10 of block start address

| | |
|--------|-------|
| 01FFFH | |
| 01C00H | (007) |
| 01BFFH | |
| 01800H | (006) |
| 017FFH | |
| 01400H | (005) |
| 013FFH | |
| 01000H | (004) |
| 00FFFH | |
| 00C00H | (003) |
| 00BFFH | |
| 00800H | (002) |
| 007FFH | |
| 00400H | (001) |
| 003FFH | |
| 00000H | (000) |

Block configuration of data flash memory

Bit 9 of block start address

| | |
|--------|-----|
| 093FFH | |
| 09200H | (1) |
| 091FFH | |
| 09000H | (0) |

19.6.1.3 Flash write buffer registers HH, HL, LH, and LL (FLWHH, FLWHL, FLWLH, FLWLL)

The FLWHH, FLWHL, FLWLH, and FLWLL registers hold data to be written during programming of the flash memory.

The FLWHH, FLWHL, FLWLH, and FLWLL registers can be set by an 8-bit memory manipulation instruction.

These registers are set to 00H following a reset.

Figure 19-10. Format of Flash Write Buffer Registers HH, HL, LH, and LL (FLWHH, FLWHL, FLWLH, FLWLL)

Address: F00CBH After reset: 00H R/W

| | | | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| FLWHH | FLW31 | FLW30 | FLW29 | FLW28 | FLW27 | FLW26 | FLW25 | FLW24 |

Address: F00CAH After reset: 00H R/W

| | | | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| FLWHL | FLW23 | FLW22 | FLW21 | FLW20 | FLW19 | FLW18 | FLW17 | FLW16 |

Address: F00C9H After reset: 00H R/W

| | | | | | | | | |
|--------|-------|-------|-------|-------|-------|-------|------|------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| FLWLH | FLW15 | FLW14 | FLW13 | FLW12 | FLW11 | FLW10 | FLW9 | FLW8 |

Address: F00C8H After reset: 00H R/W

| | | | | | | | | |
|--------|------|------|------|------|------|------|------|------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| FLWLL | FLW7 | FLW6 | FLW5 | FLW4 | FLW3 | FLW2 | FLW1 | FLW0 |

19.6.1.4 Flash programming mode control register (FLPMC)

The FLPMC register sets the flash memory to the self-programming mode.

The FLPMC register can be set by an 8-bit memory manipulation instruction.

This register is set to 08H following a reset.

Figure 19-11. Format of Flash Programming Mode Control Register (FLPMC)

Address: F00C0H After reset: 08H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|--------|---|--------|---|-------|---|
| FLPMC | 0 | 0 | SELDFL | 0 | FWEDIS | 0 | FLSPM | 0 |

| SELDFL | Flash programming area selection |
|--------|----------------------------------|
| 0 | Selects the code flash area. |
| 1 | Selects the data flash area. |

| FWEDIS | Software control over enabling or disabling erasure and programming of the flash memory ^{Note 1} |
|--------|---|
| 0 | Enables programming and erasure. |
| 1 | Disables programming and erasure. |

| FLSPM | Flash programming mode selection ^{Note 1} |
|-------|---|
| 0 | The flash memory is in the read mode (normal mode). |
| 1 | The flash memory is in the self-programming mode. |

Note 1. Be sure to keep the value of this bit at 0 until erasure or programming of the flash memory is completed.

19.6.1.5 Flash memory sequencer initial setting register (FSSET)

The FSSET register sets the operating frequency of the flash memory sequencer.

The FSSET register can be set by an 8-bit memory manipulation instruction.

This register is set to 00H following a reset.

Figure 19-12. Format of Flash Memory Sequencer Initial Setting Register (FSSET)

Address: F00BEH After reset: 00H R/W

| | | | | | | | | |
|--------|---|---|---|-------|-------|-------|-------|-------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| FSSET | 0 | 0 | 0 | FSET4 | FSET3 | FSET2 | FSET1 | FSET0 |

| | |
|---------|--|
| FSET4-0 | Setting of the operating frequency of the flash memory sequencer |
| — | Set the operating frequency of the flash memory sequencer. For the correspondence between the operating frequency of the flash memory sequencer and the setting of the FSET4-0 bits, see Table 19-10 . |

Caution Set the value corresponding to that obtained by rounding the CPU operating frequency up to the nearest whole number in the FSET4-0 bits. For example, when the CPU operating frequency is 4.5 MHz, set the bits for 5 MHz.

Note that frequencies that are not whole numbers, such as 1.5 MHz, are not available as CPU operating frequencies below 4 MHz.

Table 19-10. Correspondence between the Operating Frequency of the Flash Memory Sequencer and the Setting of the FSET4-0 Bits

| Operating frequency [MHz] | Setting of the FSET4-0 bits | Operating frequency [MHz] | Setting of the FSET4-0 bits | Operating frequency [MHz] | Setting of the FSET4-0 bits |
|---------------------------|-----------------------------|---------------------------|-----------------------------|---------------------------|-----------------------------|
| 16 | 01111B | 10 | 01001B | 4 | 00011B |
| 15 | 01110B | 9 | 01000B | 3 | 00010B |
| 14 | 01101B | 8 | 00111B | 2 | 00001B |
| 13 | 01100B | 7 | 00110B | 1 | 00000B |
| 12 | 01011B | 6 | 00101B | — | — |
| 11 | 01010B | 5 | 00100B | — | — |

19.6.1.6 Flash memory sequencer control register (FSSQ)

The FSSQ register defines the commands to be used when the flash memory sequencer is activated.

The FSSQ register can be set by an 8-bit memory manipulation instruction.

This register is set to 00H following a reset.

Figure 19-13. Format of Flash Memory Sequencer Control Register (FSSQ)

Address: F00C1H After reset: 00H R/W

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|------|---|---|---|---|-------|-------|-------|
| FSSQ | SQST | 0 | 0 | 0 | 0 | SQMD2 | SQMD1 | SQMD0 |

| SQST | Flash memory sequencer operation control |
|------|--|
| 0 | Stops operation. |
| 1 | Starts operation. |

| SQMD2-0 | Flash memory sequencer command selection |
|------------------|--|
| 000b | Initial value (commands not selected) |
| 001b | Write Writes data specified in the FLWHH, FLWHL, FLWLH, and FLWLL registers to the address specified in the FLAPH and FLAPL registers. Unit for writing (code flash area): 1 word (4 bytes) (when the SELDFL bit is set to 0) Unit for writing (data flash area): 1 word (4 bytes) (when the SELDFL bit is set to 1) |
| 100b | Block erasure Erases blocks in the range from the block start address specified in the FLAPH and FLAPL registers to the block end address specified in the FLSEDH and FLSEDL registers. Unit for block erasing (code flash area): 1 block (1 Kbyte) (when the SELDFL bit is set to 0) Unit for block erasing (data flash area): 1 block (512 bytes) (when the SELDFL bit is set to 1) |
| Other than above | Setting prohibited |

19.6.1.7 Flash memory sequencer status registers H and L (FSASTH, FSASTL)

The FSASTH and FSASTL registers indicate the results of the operations of the flash memory sequencer.

The FSASTH and FSASTL registers can be read by an 8-bit memory manipulation instruction.

Figure 19-14. Format of Flash Memory Sequencer Status Registers H and L (FSASTH, FSASTL)

Address: F00C7H After reset: 00H R

| | | | | | | | | |
|--------|---|-------|---|---|---|---|---|---|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| FSASTH | 0 | SQEND | 0 | 0 | 0 | 0 | 0 | 0 |

Address: F00C6H After reset: 00H R

| | | | | | | | | |
|--------|---|---|---|-------|---|---|------|------|
| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
| FSASTL | 0 | 0 | 0 | SEQER | 0 | 0 | WRER | ERER |

| | |
|---|--|
| SQEND | Flash memory sequencer operation status flag |
| 0 | Operation is in progress. |
| 1 | Operation has ended. |
| <Clearing condition> The SQST bit being cleared. | |

| | |
|---|-----------------------------------|
| SEQER | Flash memory sequencer error flag |
| 0 | No error has occurred. |
| 1 | An error has occurred. |
| <Clearing condition> Next activation of the flash memory sequencer | |

| | |
|---|--------------------------|
| WRER | Write command error flag |
| 0 | No error has occurred. |
| 1 | An error has occurred. |
| <Clearing condition> Activation of the next command action | |

| | |
|---|--------------------------------|
| ERER | Block erase command error flag |
| 0 | No error has occurred. |
| 1 | An error has occurred. |
| <Clearing condition> Next activation of the flash memory sequencer | |

19.6.2 Procedure for executing self-programming of code/data flash memory

The following figure illustrates a flow for rewriting the code/data flash memory by using the flash self-programming code.

For details of the registers to be used for execution of self-programming, see **19.6.1 Registers controlling self-programming**.

Figure 19-15. Flash Memory Self-Programming Execution Procedure

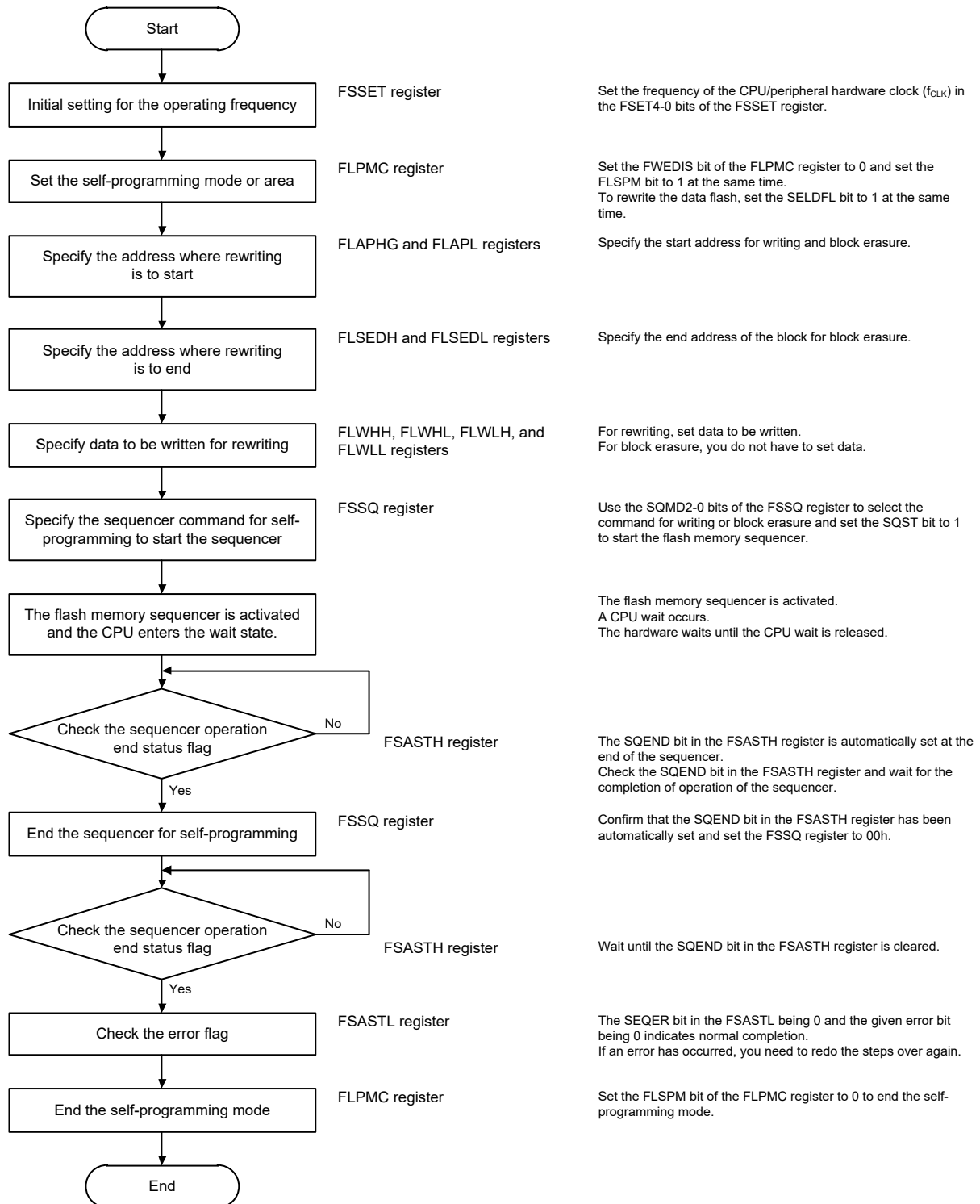
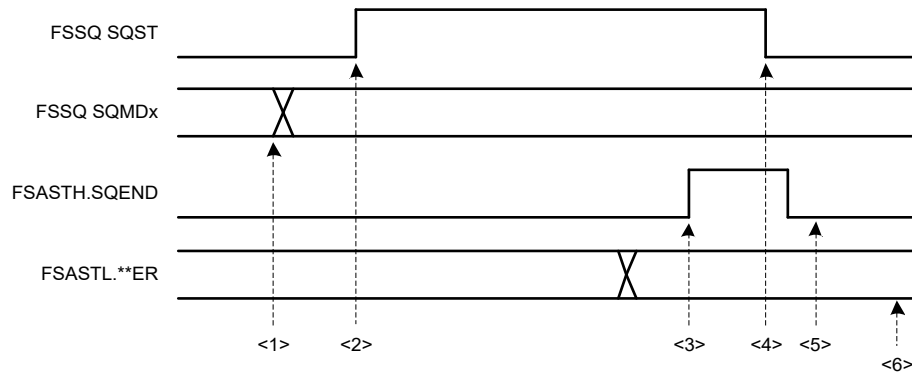


Figure 19-16. Flash Memory Sequencer Starting and Ending Processing



- <1> Set up operation.
- <2> Set the SQST bit (the sequencer starts operating and the CPU enters the wait state).
- <3> The CPU wait state is released.
- <4> Clear the SQST bit (the sequencer stops operating).
- <5> Check the sequencer operation end status flag.
- <6> Check the error flag.

19.6.3 Notes on self-programming

- (1) Allocate the self-programming code for rewriting the code/data flash area to the code flash area. Self-programming by fetching from the RAM is prohibited. Additionally, rewriting the boot area and the block for storing the self-programming code is prohibited.
- (2) Prohibit an interrupt before setting the self-programming mode. To prohibit an interrupt, clear (0) the IE flag by the DI instruction in the same way as in the normal operation mode.
- (3) When using the flash memory sequencer to rewrite the code/data flash memory, set the value corresponding to the CPU operating frequency in the FSET4-0 bits of the FSSET register before proceeding. Note that if rewriting is attempted while the value corresponding to the CPU operating frequency is not correct, operation is undefined and written data are not guaranteed. Even if the values in the flash memory are as expected immediately after rewriting, retaining the values for any specified period is not guaranteed.
- (4) The high-speed on-chip oscillator should be kept operating before executing self-programming. If it is stopped, it should be made to operate again (HIOSTOP = 0), and the flash self-programming code should be re-executed after 30 μ s have elapsed.
- (5) Do not execute other settings or instructions which are not related to the self-programming procedure during the self-programming execution flow shown in **19.6.2 Procedure for executing self-programming of code/data flash memory**.
- (6) The CPU is stopped during rewriting through self-programming. The code flash or data flash memory cannot be accessed while it is being rewritten.

19.7 Data Flash

19.7.1 Data flash overview

An overview of the data flash memory is provided below.

- The user program can rewrite the data flash memory by using the self-programming code.
- The data flash memory can also be rewritten through serial programming using the dedicated flash memory programmer or an external device.
- The data flash can be erased in 1-block (512-byte) units.
- The data flash can be accessed in 8-bit or 16-bit units.
- The data flash can be directly read by CPU instructions.
- Instructions cannot be executed from the code flash memory while rewriting the data flash memory since the CPU is stopped during this period (that is, background operation (BGO) is not supported).
- Because the data flash memory is an area exclusively used for data, it cannot be used to execute instructions.
- The data flash memory cannot be accessed while rewriting the code flash memory since the CPU is stopped during this period.
- The high-speed on-chip oscillator should be kept operating while rewriting the data flash memory. If it is stopped, it should be made to operate again (HIOSTOP = 0), and the flash self-programming code should be re-executed after 30 μ s have elapsed.

19.7.2 Procedure for accessing data flash memory

The data flash memory is accessible at any time after a reset ends. Reading the data flash memory by CPU instructions does not require initial settings of the registers. For the procedure for rewriting the data flash memory, see **19.6.2 Procedure for executing self-programming of code/data flash memory**.

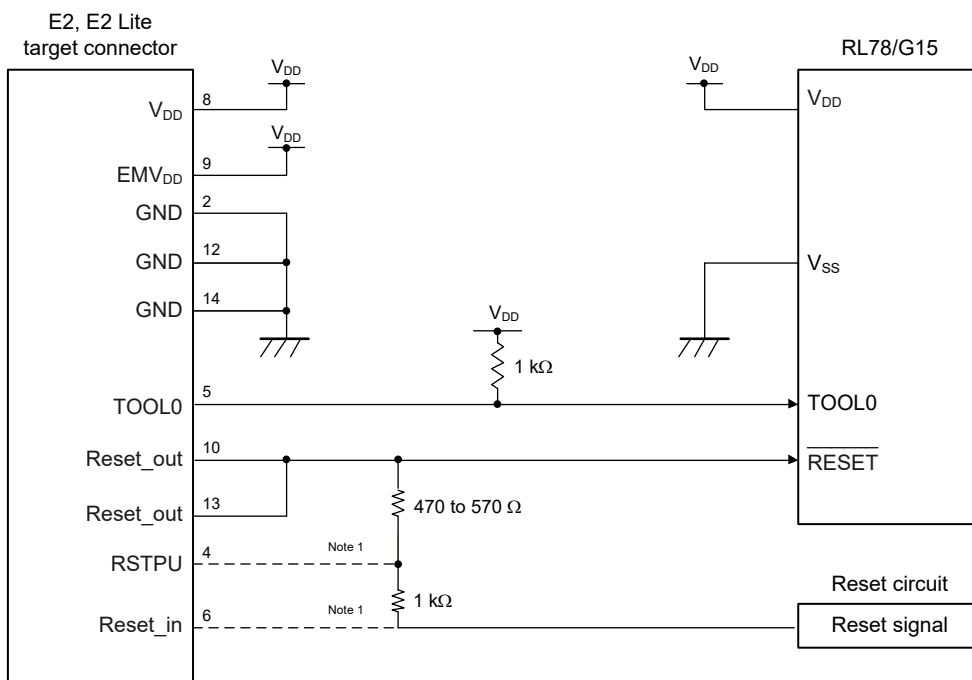
CHAPTER 20 ON-CHIP DEBUG FUNCTION

20.1 Connecting E2, E2 Lite On-chip Debugging Emulator

The RL78 microcontroller uses the V_{DD} , $\overline{\text{RESET}}$, TOOL0, and V_{SS} pins to communicate with the host machine via an E2, E2 Lite on-chip debugging emulator. Serial communication is performed by using a single-line UART that uses the TOOL0 pin.

Caution The RL78 microcontroller has an on-chip debug function, which is provided for development and evaluation. Do not use the on-chip debug function in products designated for mass production, because the guaranteed number of rewritable times of the flash memory may be exceeded when this function is used, and product reliability therefore cannot be guaranteed. Renesas Electronics is not liable for problems occurring when the on-chip debug function is used.

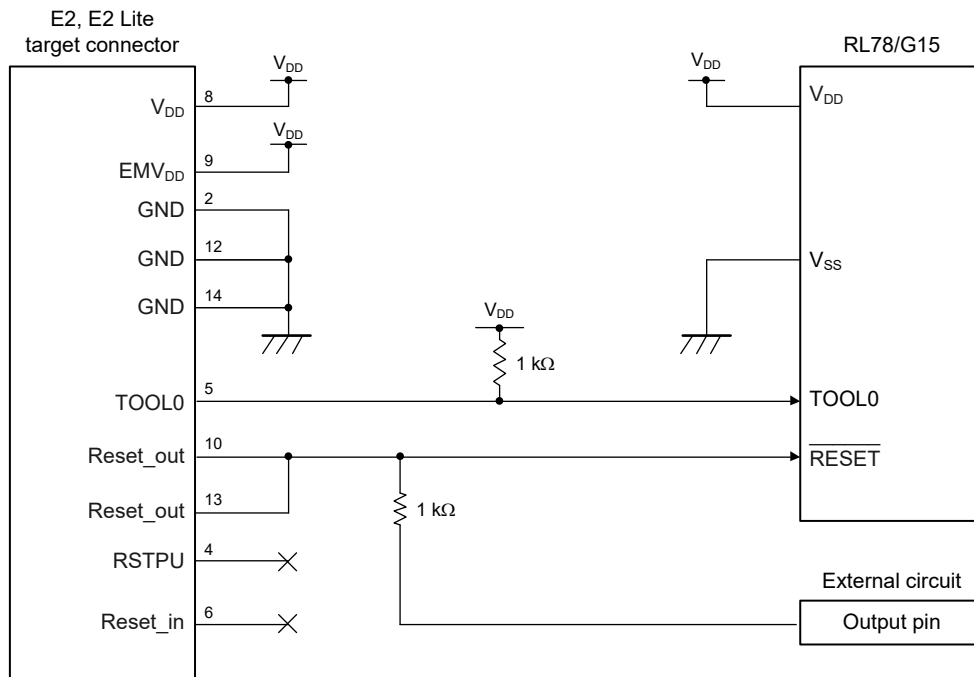
Figure 20-1. Connection Example of E2, E2 Lite On-chip Debugging Emulator



Note 1. Connecting is not necessary during flash programming.

For the target system which uses the multi-use feature of $\overline{\text{RESET}}$ pin, its connection to an external circuit should be isolated.

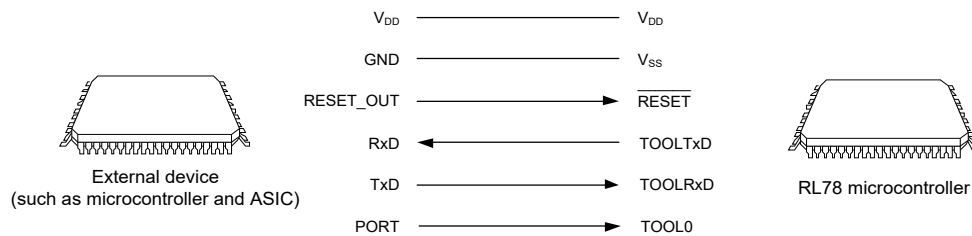
Figure 20-2. Connection Example of E2, E2 Lite On-chip Debugging Emulator and RL78 microcontroller
(When using to the alternative function of $\overline{\text{RESET}}$ pin)



20.2 Connecting External Device (that Incorporates UART)

The V_{DD} , $\overline{\text{RESET}}$, TOOL0 , V_{SS} , TOOLTxD , and TOOLRxD pins are used to communicate with the host machine on board via the RL78 microcontroller and an external device (a microcontroller or ASIC) connected to a UART.

Communication between the external device and the RL78 microcontroller is established by serial communication via the dedicated UART using the TOOLTxD and TOOLRxD pins of the RL78 microcontroller.



20.3 On-Chip Debug Security ID

The RL78 microcontroller has an on-chip debug operation control bit in the flash memory at 000C3H (see **CHAPTER 18 OPTION BYTE**) and an on-chip debug security ID setting area at 000C4H to 000CDH, to prevent third parties from reading memory content.

Table 20-1. On-Chip Debug Security ID

| Address | On-Chip Debug Security ID |
|------------------|---------------------------|
| 000C4H to 000CDH | Any ID code of 10 bytes |

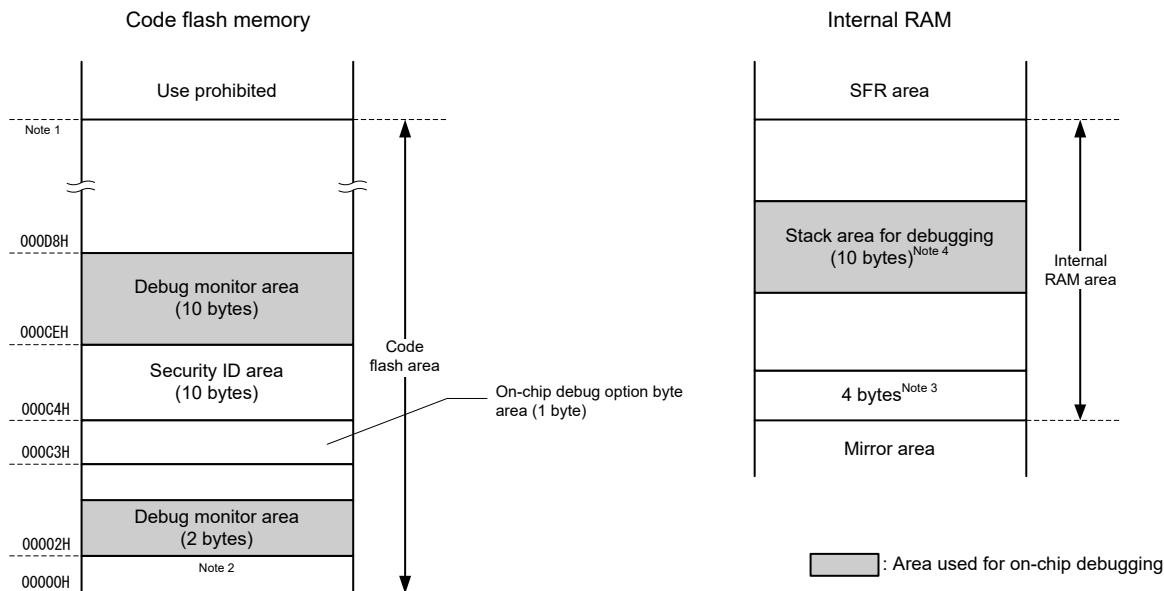
20.4 Securing of User Resources

To perform communication between the RL78 microcontroller and E2, E2 Lite on-chip debugging emulator, as well as each debug function, the securing of memory space must be done beforehand. If Renesas Electronics assembler or compiler is used, the items can be set by using link options.

1) Securement of memory space

The shaded portions in **Figure 20-3** are the areas reserved for placing the debug monitor program, so user programs or data cannot be allocated in these spaces. When using the on-chip debug function, these spaces must be secured so as not to be used by the user program. Moreover, this area must not be rewritten by the user program.

Figure 20-3. Memory Spaces Where Debug Monitor Programs Are Allocated



Note 1. Address differs depending on products as follows.

| Products | Address |
|--|---------|
| R5F12067, R5F12047, R5F12017, R5F12007 | 00FFFH |
| R5F12068, R5F12048, R5F12018, R5F12008 | 01FFFH |

Note 2. In debugging, reset vector is rewritten to address allocated to a monitor program.

Note 3. When the pseudo-RRM function and the pseudo-DMM function are used, four bytes in the RAM area are consumed.

The RAM area is set by the build tool, when the pseudo-RRM function and the pseudo-DMM function are used.

If the RAM area has not been set, the first four bytes of the RAM area will be used.

(For details on the setting, refer to the user's manual of the build tool.)

When the pseudo-RRM function and pseudo-DMM function are not used, this area can be used as the internal RAM.

- Note 4. Since this area is allocated immediately before the stack area, the address of this area varies depending on the stack increase and decrease. That is, 10 extra bytes are consumed for the stack area used.

CHAPTER 21 BCD CORRECTION CIRCUIT

21.1 BCD Correction Circuit Function

The result of addition/subtraction of the BCD (binary-coded decimal) code and BCD code can be obtained as BCD code with this circuit.

The decimal correction operation result is obtained by performing addition/subtraction having the A register as the operand and then adding/subtracting the BCD correction result register (BCDADJ).

21.2 Registers Used by BCD Correction Circuit

The BCD correction circuit uses the following registers.

- BCD correction result register (BCDADJ)

21.2.1 BCD correction result register (BCDADJ)

The BCDADJ register stores correction values for obtaining the add/subtract result as BCD code through add/subtract instructions using the A register as the operand.

The value read from the BCDADJ register varies depending on the value of the A register when it is read and those of the CY and AC flags.

The BCDADJ register is read by an 8-bit memory manipulation instruction.

Reset input sets this register to undefined.

Figure 21-1. Format of BCD Correction Result Register (BCDADJ)

Address: F00FEH After reset: undefined R

| Symbol | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|--------|---|---|---|---|---|---|---|---|
| BCDADJ | | | | | | | | |

21.3 BCD Correction Circuit Operation

The basic operation of the BCD correction circuit is as follows.

1) Addition: Calculating the result of adding a BCD code value and another BCD code value by using a BCD code value

- <1> The BCD code value to which addition is performed is stored in the A register.
- <2> By adding the value of the A register and the second operand (value of one more BCD code to be added) as are in binary, the binary operation result is stored in the A register and the correction value is stored in the BCD correction result register (BCDADJ).
- <3> Decimal correction is performed by adding in binary the value of the A register (addition result in binary) and the BCDADJ register (correction value), and the correction result is stored in the A register and CY flag.

Caution The value read from the BCDADJ register varies depending on the value of the A register when it is read and those of the CY and AC flags. Therefore, execute the instruction <3> after the instruction <2> instead of executing any other instructions. To perform BCD correction in the interrupt enabled state, saving and restoring the A register is required within the interrupt function. PSW (CY flag and AC flag) is restored by the RETI instruction.

An example is shown below.

Examples 1: $99 + 89 = 188$

| Instruction | A Register | CY Flag | AC Flag | BCDADJ Register |
|----------------------|------------|---------|---------|-----------------|
| MOV A, #99H ; <1> | 99H | — | — | — |
| ADD A, #89H ; <2> | 22H | 1 | 1 | 66H |
| ADD A, !BCDADJ ; <3> | 88H | 1 | 0 | — |

Examples 2: $85 + 15 = 100$

| Instruction | A Register | CY Flag | AC Flag | BCDADJ Register |
|----------------------|------------|---------|---------|-----------------|
| MOV A, #85H ; <1> | 85H | — | — | — |
| ADD A, #15H ; <2> | 9AH | 0 | 0 | 66H |
| ADD A, !BCDADJ ; <3> | 00H | 1 | 1 | — |

Examples 3: $80 + 80 = 160$

| Instruction | A Register | CY Flag | AC Flag | BCDADJ Register |
|----------------------|------------|---------|---------|-----------------|
| MOV A, #80H ; <1> | 80H | — | — | — |
| ADD A, #80H ; <2> | 00H | 1 | 0 | 60H |
| ADD A, !BCDADJ ; <3> | 60H | 1 | 0 | — |

2) Subtraction: Calculating the result of subtracting a BCD code value from another BCD code value by using a BCD code value

- <1> The BCD code value from which subtraction is performed is stored in the A register.
- <2> By subtracting the value of the second operand (value of BCD code to be subtracted) from the A register as is in binary, the calculation result in binary is stored in the A register, and the correction value is stored in the BCD correction result register (BCDADJ).
- <3> Decimal correction is performed by subtracting the value of the BCDADJ register (correction value) from the A register (subtraction result in binary) in binary, and the correction result is stored in the A register and CY flag.

Caution The value read from the BCDADJ register varies depending on the value of the A register when it is read and those of the CY and AC flags. Therefore, execute the instruction <3> after the instruction <2> instead of executing any other instructions. To perform BCD correction in the interrupt enabled state, saving and restoring the A register is required within the interrupt function. PSW (CY flag and AC flag) is restored by the RETI instruction.

An example is shown below.

Example: $91 - 52 = 39$

| Instruction | A Register | CY Flag | AC Flag | BCDADJ Register |
|----------------------|------------|---------|---------|-----------------|
| MOV A, #91H ; <1> | 91H | — | — | — |
| SUB A, #52H ; <2> | 3FH | 0 | 1 | 06H |
| SUB A, !BCDADJ ; <3> | 39H | 0 | 0 | — |

CHAPTER 22 INSTRUCTION SET

This chapter lists the instructions in the RL78 microcontroller instruction set. For details of each operation and operation code, refer to the separate document **RL78 Family User's Manual: Software (R01US0015E)**.

22.1 Conventions Used in Operation List

22.1.1 Operand identifiers and specification methods

Operands are described in the "Operand" column of each instruction in accordance with the description method of the instruction operand identifier (refer to the assembler specifications for details). When there are two or more description methods, select one of them. Alphabetic letters in capitals and the symbols, #, !, !!, \$, \$!, [], and ES: are keywords and are described as they are. Each symbol has the following meaning.

- #: Immediate data specification
- !: 16-bit absolute address specification
- !!: 20-bit absolute address specification
- \$: 8-bit relative address specification
- \$!: 16-bit relative address specification
- []: Indirect address specification
- ES:: Extension address specification

In the case of immediate data, describe an appropriate numeric value or a label. When using a label, be sure to describe the #, !, !!, \$, \$!, [], and ES: symbols.

For operand register identifiers, r and rp, either function names (X, A, C, etc.) or absolute names (names in parentheses in **Table 22-1**, R0, R1, R2, etc.) can be used for description.

Table 22-1. Operand Identifiers and Specification Methods

| Identifier | Description Method |
|------------|---|
| r | X(R0), A(R1), C(R2), B(R3), E(R4), D(R5), L(R6), H(R7) |
| rp | AX(RP0), BC(RP1), DE(RP2), HL(RP3) |
| sfr | Special-function register symbols (SFR symbols) FFF00H to FFFFFH |
| sfrp | Special-function register symbols (16-bit manipulatable SFR symbols. Even addresses only ^{Note 1}) FFF00H to FFFFFH |
| saddr | FFE20H to FFF1FH Immediate data or labels |
| saddrp | FFE20H to FFF1FH Immediate data or labels (even addresses only ^{Note 1}) |
| addr20 | 00000H to FFFFFH Immediate data or labels |
| addr16 | 0000H to FFFFH Immediate data or labels (even addresses only for 16-bit data transfer instructions ^{Note 1}) |
| addr5 | 0080H to 00BFH Immediate data or labels (even addresses only ^{Note 1}) |
| word | 16-bit immediate data or label |
| byte | 8-bit immediate data or label |
| bit | 3-bit immediate data or label |
| RBn | RB0 to RB3 |

Note 1. Bit 0 = 0 when an odd address is specified.

Remark The special function registers can be described to operand sfr as symbols. See **Table 3-5 SFR List** for the symbols of the special function registers.

The extended special function registers can be described to operand !addr16 as symbols. See **Table 3-6 Extended SFR (2nd SFR) List** for the symbols of the extended special function registers.

22.1.2 Description of operation column

The operation when the instruction is executed is shown in the “Operation” column using the following symbols.

Table 22-2. Symbols in “Operation” Column

| Symbol | Function |
|-----------------|--|
| A | A register: 8-bit accumulator |
| X | X register |
| B | B register |
| C | C register |
| D | D register |
| E | E register |
| H | H register |
| L | L register |
| ES | ES register |
| CS | CS register |
| AX | AX register pair: 16-bit accumulator |
| BC | BC register pair |
| DE | DE register pair |
| HL | HL register pair |
| PC | Program counter |
| SP | Stack pointer |
| PSW | Program status word |
| CY | Carry flag |
| AC | Auxiliary carry flag |
| Z | Zero flag |
| RBS | Register bank select flag |
| IE | Interrupt request enable flag |
| () | Memory contents indicated by address or register contents in parentheses |
| X_H, X_L | 16-bit registers: X_H = higher 8 bits, X_L = lower 8 bits |
| X_S, X_H, X_L | 20-bit registers: X_S = (bits 19 to 16), X_H = (bits 15 to 8), X_L = (bits 7 to 0) |
| \wedge | Logical product (AND) |
| \vee | Logical sum (OR) |
| ∇ | Exclusive logical sum (exclusive OR) |
| $\bar{\quad}$ | Inverted data |
| addr5 | 16-bit immediate data (even addresses only in 0080H to 00BFH) |
| addr16 | 16-bit immediate data |
| addr20 | 20-bit immediate data |
| jdisp8 | Signed 8-bit data (displacement value) |
| jdisp16 | Signed 16-bit data (displacement value) |

22.1.3 Description of flag operation column

The change of the flag value when the instruction is executed is shown in the “Flag” column using the following symbols.

Table 22-3. Symbols in “Flag” Column

| Symbol | Change of Flag Value |
|---------|-------------------------------------|
| (Blank) | Unchanged |
| 0 | Cleared to 0 |
| 1 | Set to 1 |
| × | Set/cleared according to the result |
| R | Previously saved value is restored |

22.1.4 PREFIX instruction

Instructions with “ES:” have a PREFIX operation code as a prefix to extend the accessible data area to the 1 MB space (00000H to FFFFFH), by adding the ES register value to the 64 KB space from F0000H to FFFFFH. When a PREFIX operation code is attached as a prefix to the target instruction, only one instruction immediately after the PREFIX operation code is executed as the addresses with the ES register value added.

An interrupt and DMA transfer are not acknowledged between a PREFIX instruction code and the following one instruction.

Table 22-4. Use Example of PREFIX Operation Code

| Instruction | Opcode | | | | |
|-----------------------|--------|---------|---------|-------|-------|
| | 1 | 2 | 3 | 4 | 5 |
| MOV !addr16, #byte | CFH | !addr16 | | #byte | — |
| MOV ES:!addr16, #byte | 11H | CFH | !addr16 | | #byte |
| MOV A, [HL] | 8BH | — | — | — | — |
| MOV A, ES:[HL] | 11H | 8BH | — | — | — |

Caution Set the ES register value with MOV ES, A, etc., before executing the PREFIX instruction.

22.2 Operation List

Table 22-5. Operation List (1/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|---------------------|----------|------------------------|-------|--|--------|---|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| 8-bit data transfer | MOV | r, #byte | 2 | 1 | — | $r \leftarrow \text{byte}$ | | | |
| | | PSW, #byte | 3 | 3 | — | $\text{PSW} \leftarrow \text{byte}$ | x | x | x |
| | | CS, #byte | 3 | 1 | — | $\text{CS} \leftarrow \text{byte}$ | | | |
| | | ES, #byte | 2 | 1 | — | $\text{ES} \leftarrow \text{byte}$ | | | |
| | | !addr16, #byte | 4 | 1 | — | $(\text{addr16}) \leftarrow \text{byte}$ | | | |
| | | ES:!addr16, #byte | 5 | 2 | — | $(\text{ES}, \text{addr16}) \leftarrow \text{byte}$ | | | |
| | | saddr, #byte | 3 | 1 | — | $(\text{saddr}) \leftarrow \text{byte}$ | | | |
| | | sfr, #byte | 3 | 1 | — | $\text{sfr} \leftarrow \text{byte}$ | | | |
| | | [DE+byte], #byte | 3 | 1 | — | $(\text{DE} + \text{byte}) \leftarrow \text{byte}$ | | | |
| | | ES:[DE+byte],#byte | 4 | 2 | — | $((\text{ES}, \text{DE}) + \text{byte}) \leftarrow \text{byte}$ | | | |
| | | [HL+byte], #byte | 3 | 1 | — | $(\text{HL} + \text{byte}) \leftarrow \text{byte}$ | | | |
| | | ES:[HL+byte],#byte | 4 | 2 | — | $((\text{ES}, \text{HL}) + \text{byte}) \leftarrow \text{byte}$ | | | |
| | | [SP+byte], #byte | 3 | 1 | — | $(\text{SP} + \text{byte}) \leftarrow \text{byte}$ | | | |
| | | word[B], #byte | 4 | 1 | — | $(\text{B} + \text{word}) \leftarrow \text{byte}$ | | | |
| | | ES:word[B], #byte | 5 | 2 | — | $((\text{ES}, \text{B}) + \text{word}) \leftarrow \text{byte}$ | | | |
| | | word[C], #byte | 4 | 1 | — | $(\text{C} + \text{word}) \leftarrow \text{byte}$ | | | |
| | | ES:word[C], #byte | 5 | 2 | — | $((\text{ES}, \text{C}) + \text{word}) \leftarrow \text{byte}$ | | | |
| | | word[BC], #byte | 4 | 1 | — | $(\text{BC} + \text{word}) \leftarrow \text{byte}$ | | | |
| | | ES:word[BC], #byte | 5 | 2 | — | $((\text{ES}, \text{BC}) + \text{word}) \leftarrow \text{byte}$ | | | |
| | | A, r ^{Note 3} | 1 | 1 | — | $\text{A} \leftarrow r$ | | | |
| | | r, A ^{Note 3} | 1 | 1 | — | $r \leftarrow \text{A}$ | | | |
| | | A, PSW | 2 | 1 | — | $\text{A} \leftarrow \text{PSW}$ | | | |
| | | PSW, A | 2 | 3 | — | $\text{PSW} \leftarrow \text{A}$ | x | x | x |
| | | A, CS | 2 | 1 | — | $\text{A} \leftarrow \text{CS}$ | | | |
| | | CS, A | 2 | 1 | — | $\text{CS} \leftarrow \text{A}$ | | | |
| | | A, ES | 2 | 1 | — | $\text{A} \leftarrow \text{ES}$ | | | |
| | | ES, A | 2 | 1 | — | $\text{ES} \leftarrow \text{A}$ | | | |
| | | A, !addr16 | 3 | 1 | 4 | $\text{A} \leftarrow (\text{addr16})$ | | | |
| | | A, ES:!addr16 | 4 | 2 | 5 | $\text{A} \leftarrow (\text{ES}, \text{addr16})$ | | | |
| | | !addr16, A | 3 | 1 | — | $(\text{addr16}) \leftarrow \text{A}$ | | | |
| | | ES:!addr16, A | 4 | 2 | — | $(\text{ES}, \text{addr16}) \leftarrow \text{A}$ | | | |
| | | A, saddr | 2 | 1 | — | $\text{A} \leftarrow (\text{saddr})$ | | | |
| saddr, A | 2 | 1 | — | $(\text{saddr}) \leftarrow \text{A}$ | | | | | |
| A, sfr | 2 | 1 | — | $\text{A} \leftarrow \text{sfr}$ | | | | | |
| sfr, A | 2 | 1 | — | $\text{sfr} \leftarrow \text{A}$ | | | | | |
| A, [DE] | 1 | 1 | 4 | $\text{A} \leftarrow (\text{DE})$ | | | | | |
| [DE], A | 1 | 1 | — | $(\text{DE}) \leftarrow \text{A}$ | | | | | |
| A, ES:[DE] | 2 | 2 | 5 | $\text{A} \leftarrow (\text{ES}, \text{DE})$ | | | | | |
| ES:[DE], A | 2 | 2 | — | $(\text{ES}, \text{DE}) \leftarrow \text{A}$ | | | | | |
| A, [HL] | 1 | 1 | 4 | $\text{A} \leftarrow (\text{HL})$ | | | | | |

Table 22-5. Operation List (2/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|---------------------|----------|-----------------|-------|------------------|--------|-----------------------|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| 8-bit data transfer | MOV | [HL], A | 1 | 1 | — | (HL) ← A | | | |
| | | A, ES:[HL] | 2 | 2 | 5 | A ← (ES, HL) | | | |
| | | ES:[HL], A | 2 | 2 | — | (ES, HL) ← A | | | |
| | | A, [DE+byte] | 2 | 1 | 4 | A ← (DE + byte) | | | |
| | | [DE+byte], A | 2 | 1 | — | (DE + byte) ← A | | | |
| | | A, ES:[DE+byte] | 3 | 2 | 5 | A ← ((ES, DE) + byte) | | | |
| | | ES:[DE+byte], A | 3 | 2 | — | ((ES, DE) + byte) ← A | | | |
| | | A, [HL+byte] | 2 | 1 | 4 | A ← (HL + byte) | | | |
| | | [HL+byte], A | 2 | 1 | — | (HL + byte) ← A | | | |
| | | A, ES:[HL+byte] | 3 | 2 | 5 | A ← ((ES, HL) + byte) | | | |
| | | ES:[HL+byte], A | 3 | 2 | — | ((ES, HL) + byte) ← A | | | |
| | | A, [SP+byte] | 2 | 1 | — | A ← (SP + byte) | | | |
| | | [SP+byte], A | 2 | 1 | — | (SP + byte) ← A | | | |
| | | A, word[B] | 3 | 1 | 4 | A ← (B + word) | | | |
| | | word[B], A | 3 | 1 | — | (B + word) ← A | | | |
| | | A, ES:word[B] | 4 | 2 | 5 | A ← ((ES, B) + word) | | | |
| | | ES:word[B], A | 4 | 2 | — | ((ES, B) + word) ← A | | | |
| | | A, word[C] | 3 | 1 | 4 | A ← (C + word) | | | |
| | | word[C], A | 3 | 1 | — | (C + word) ← A | | | |
| | | A, ES:word[C] | 4 | 2 | 5 | A ← ((ES, C) + word) | | | |
| | | ES:word[C], A | 4 | 2 | — | ((ES, C) + word) ← A | | | |
| | | A, word[BC] | 3 | 1 | 4 | A ← (BC + word) | | | |
| | | word[BC], A | 3 | 1 | — | (BC + word) ← A | | | |
| | | A, ES:word[BC] | 4 | 2 | 5 | A ← ((ES, BC) + word) | | | |
| | | ES:word[BC], A | 4 | 2 | — | ((ES, BC) + word) ← A | | | |
| | | A, [HL+B] | 2 | 1 | 4 | A ← (HL + B) | | | |
| | | [HL+B], A | 2 | 1 | — | (HL + B) ← A | | | |
| | | A, ES:[HL+B] | 3 | 2 | 5 | A ← ((ES, HL) + B) | | | |
| | | ES:[HL+B], A | 3 | 2 | — | ((ES, HL) + B) ← A | | | |
| | | A, [HL+C] | 2 | 1 | 4 | A ← (HL + C) | | | |
| | | [HL+C], A | 2 | 1 | — | (HL + C) ← A | | | |
| | | A, ES:[HL+C] | 3 | 2 | 5 | A ← ((ES, HL) + C) | | | |
| | | ES:[HL+C], A | 3 | 2 | — | ((ES, HL) + C) ← A | | | |
| | | X, !addr16 | 3 | 1 | 4 | X ← (addr16) | | | |
| X, ES:!addr16 | 4 | 2 | 5 | X ← (ES, addr16) | | | | | |
| X, saddr | 2 | 1 | — | X ← (saddr) | | | | | |
| B, !addr16 | 3 | 1 | 4 | B ← (addr16) | | | | | |
| B, ES:!addr16 | 4 | 2 | 5 | B ← (ES, addr16) | | | | | |
| B, saddr | 2 | 1 | — | B ← (saddr) | | | | | |

Table 22-5. Operation List (3/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|---------------------|------------|------------------------|-----------------------------------|--------|--------|--|---------------------------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| 8-bit data transfer | MOV | C, laddr16 | 3 | 1 | 4 | $C \leftarrow (\text{addr16})$ | | | |
| | | C, ES:laddr16 | 4 | 2 | 5 | $C \leftarrow (\text{ES}, \text{addr16})$ | | | |
| | | C, saddr | 2 | 1 | — | $C \leftarrow (\text{saddr})$ | | | |
| | | ES, saddr | 3 | 1 | — | $\text{ES} \leftarrow (\text{saddr})$ | | | |
| | XCH | A, r ^{Note 3} | 1 (r = X) 2 (other than r = X) | 1 | — | $A \leftrightarrow r$ | | | |
| | | A, laddr16 | 4 | 2 | — | $A \leftrightarrow (\text{addr16})$ | | | |
| | | A, ES:laddr16 | 5 | 3 | — | $A \leftrightarrow (\text{ES}, \text{addr16})$ | | | |
| | | A, saddr | 3 | 2 | — | $A \leftrightarrow (\text{saddr})$ | | | |
| | | A, sfr | 3 | 2 | — | $A \leftrightarrow \text{sfr}$ | | | |
| | | A, [DE] | 2 | 2 | — | $A \leftrightarrow (\text{DE})$ | | | |
| | | A, ES:[DE] | 3 | 3 | — | $A \leftrightarrow (\text{ES}, \text{DE})$ | | | |
| | | A, [HL] | 2 | 2 | — | $A \leftrightarrow (\text{HL})$ | | | |
| | | A, ES:[HL] | 3 | 3 | — | $A \leftrightarrow (\text{ES}, \text{HL})$ | | | |
| | | A, [DE+byte] | 3 | 2 | — | $A \leftrightarrow (\text{DE} + \text{byte})$ | | | |
| | | A, ES:[DE+byte] | 4 | 3 | — | $A \leftrightarrow ((\text{ES}, \text{DE}) + \text{byte})$ | | | |
| | | A, [HL+byte] | 3 | 2 | — | $A \leftrightarrow (\text{HL} + \text{byte})$ | | | |
| | | A, ES:[HL+byte] | 4 | 3 | — | $A \leftrightarrow ((\text{ES}, \text{HL}) + \text{byte})$ | | | |
| | | A, [HL+B] | 2 | 2 | — | $A \leftrightarrow (\text{HL} + \text{B})$ | | | |
| | | A, ES:[HL+B] | 3 | 3 | — | $A \leftrightarrow ((\text{ES}, \text{HL}) + \text{B})$ | | | |
| | | A, [HL+C] | 2 | 2 | — | $A \leftrightarrow (\text{HL} + \text{C})$ | | | |
| | | A, ES:[HL+C] | 3 | 3 | — | $A \leftrightarrow ((\text{ES}, \text{HL}) + \text{C})$ | | | |
| | | ONEB | A | 1 | 1 | — | $A \leftarrow 01\text{H}$ | | |
| | X | | 1 | 1 | — | $X \leftarrow 01\text{H}$ | | | |
| | B | | 1 | 1 | — | $B \leftarrow 01\text{H}$ | | | |
| | C | | 1 | 1 | — | $C \leftarrow 01\text{H}$ | | | |
| | laddr16 | | 3 | 1 | — | $(\text{addr16}) \leftarrow 01\text{H}$ | | | |
| | ES:laddr16 | | 4 | 2 | — | $(\text{ES}, \text{addr16}) \leftarrow 01\text{H}$ | | | |
| | saddr | | 2 | 1 | — | $(\text{saddr}) \leftarrow 01\text{H}$ | | | |
| | CLRB | A | 1 | 1 | — | $A \leftarrow 00\text{H}$ | | | |
| | | X | 1 | 1 | — | $X \leftarrow 00\text{H}$ | | | |
| | | B | 1 | 1 | — | $B \leftarrow 00\text{H}$ | | | |
| | | C | 1 | 1 | — | $C \leftarrow 00\text{H}$ | | | |
| | | laddr16 | 3 | 1 | — | $(\text{addr16}) \leftarrow 00\text{H}$ | | | |
| | | ES:laddr16 | 4 | 2 | — | $(\text{ES}, \text{addr16}) \leftarrow 00\text{H}$ | | | |
| | | saddr | 2 | 1 | — | $(\text{saddr}) \leftarrow 00\text{H}$ | | | |
| | MOVS | [HL+byte], X | 3 | 1 | — | $(\text{HL} + \text{byte}) \leftarrow X$ | x | | x |
| | | ES:[HL+byte], X | 4 | 2 | — | $(\text{ES}, \text{HL} + \text{byte}) \leftarrow X$ | x | | x |

Table 22-5. Operation List (4/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|----------------------|----------|--------------------------|-------|--|--------|--|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| 16-bit data transfer | MOVW | rp, #word | 3 | 1 | — | $rp \leftarrow \text{word}$ | | | |
| | | saddrp, #word | 4 | 1 | — | $(\text{saddrp}) \leftarrow \text{word}$ | | | |
| | | sfrp, #word | 4 | 1 | — | $\text{sfrp} \leftarrow \text{word}$ | | | |
| | | AX, rp ^{Note 4} | 1 | 1 | — | $AX \leftarrow rp$ | | | |
| | | rp, AX ^{Note 4} | 1 | 1 | — | $rp \leftarrow AX$ | | | |
| | | AX, !addr16 | 3 | 1 | 4 | $AX \leftarrow (\text{addr16})$ | | | |
| | | !addr16, AX | 3 | 1 | — | $(\text{addr16}) \leftarrow AX$ | | | |
| | | AX, ES:!addr16 | 4 | 2 | 5 | $AX \leftarrow (ES, \text{addr16})$ | | | |
| | | ES:!addr16, AX | 4 | 2 | — | $(ES, \text{addr16}) \leftarrow AX$ | | | |
| | | AX, saddrp | 2 | 1 | — | $AX \leftarrow (\text{saddrp})$ | | | |
| | | saddrp, AX | 2 | 1 | — | $(\text{saddrp}) \leftarrow AX$ | | | |
| | | AX, sfrp | 2 | 1 | — | $AX \leftarrow \text{sfrp}$ | | | |
| | | sfrp, AX | 2 | 1 | — | $\text{sfrp} \leftarrow AX$ | | | |
| | | AX, [DE] | 1 | 1 | 4 | $AX \leftarrow (DE)$ | | | |
| | | [DE], AX | 1 | 1 | — | $(DE) \leftarrow AX$ | | | |
| | | AX, ES:[DE] | 2 | 2 | 5 | $AX \leftarrow (ES, DE)$ | | | |
| | | ES:[DE], AX | 2 | 2 | — | $(ES, DE) \leftarrow AX$ | | | |
| | | AX, [HL] | 1 | 1 | 4 | $AX \leftarrow (HL)$ | | | |
| | | [HL], AX | 1 | 1 | — | $(HL) \leftarrow AX$ | | | |
| | | AX, ES:[HL] | 2 | 2 | 5 | $AX \leftarrow (ES, HL)$ | | | |
| | | ES:[HL], AX | 2 | 2 | — | $(ES, HL) \leftarrow AX$ | | | |
| | | AX, [DE+byte] | 2 | 1 | 4 | $AX \leftarrow (DE + \text{byte})$ | | | |
| | | [DE+byte], AX | 2 | 1 | — | $(DE + \text{byte}) \leftarrow AX$ | | | |
| | | AX, ES:[DE+byte] | 3 | 2 | 5 | $AX \leftarrow ((ES, DE) + \text{byte})$ | | | |
| | | ES:[DE+byte], AX | 3 | 2 | — | $((ES, DE) + \text{byte}) \leftarrow AX$ | | | |
| | | AX, [HL+byte] | 2 | 1 | 4 | $AX \leftarrow (HL + \text{byte})$ | | | |
| | | [HL+byte], AX | 2 | 1 | — | $(HL + \text{byte}) \leftarrow AX$ | | | |
| | | AX, ES:[HL+byte] | 3 | 2 | 5 | $AX \leftarrow ((ES, HL) + \text{byte})$ | | | |
| | | ES:[HL+byte], AX | 3 | 2 | — | $((ES, HL) + \text{byte}) \leftarrow AX$ | | | |
| | | AX, [SP+byte] | 2 | 1 | — | $AX \leftarrow (SP + \text{byte})$ | | | |
| | | [SP+byte], AX | 2 | 1 | — | $(SP + \text{byte}) \leftarrow AX$ | | | |
| | | AX, word[B] | 3 | 1 | 4 | $AX \leftarrow (B + \text{word})$ | | | |
| | | word[B], AX | 3 | 1 | — | $(B + \text{word}) \leftarrow AX$ | | | |
| | | AX, ES:word[B] | 4 | 2 | 5 | $AX \leftarrow ((ES, B) + \text{word})$ | | | |
| | | ES:word[B], AX | 4 | 2 | — | $((ES, B) + \text{word}) \leftarrow AX$ | | | |
| | | AX, word[C] | 3 | 1 | 4 | $AX \leftarrow (C + \text{word})$ | | | |
| | | word[C], AX | 3 | 1 | — | $(C + \text{word}) \leftarrow AX$ | | | |
| | | AX, ES:word[C] | 4 | 2 | 5 | $AX \leftarrow ((ES, C) + \text{word})$ | | | |
| | | ES:word[C], AX | 4 | 2 | — | $((ES, C) + \text{word}) \leftarrow AX$ | | | |
| | | AX, word[BC] | 3 | 1 | 4 | $AX \leftarrow (BC + \text{word})$ | | | |
| word[BC], AX | 3 | 1 | — | $(BC + \text{word}) \leftarrow AX$ | | | | | |
| AX, ES:word[BC] | 4 | 2 | 5 | $AX \leftarrow ((ES, BC) + \text{word})$ | | | | | |
| ES:word[BC], AX | 4 | 2 | — | $((ES, BC) + \text{word}) \leftarrow AX$ | | | | | |
| BC, !addr16 | 3 | 1 | 4 | $BC \leftarrow (\text{addr16})$ | | | | | |

Table 22-5. Operation List (5/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|----------------------|----------|--------------------------|-------|--------|------------|------------------------------------|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| 16-bit data transfer | MOVW | BC, ES:!addr16 | 4 | 2 | 5 | BC ← (ES, addr16) | | | |
| | | DE, !addr16 | 3 | 1 | 4 | DE ← (addr16) | | | |
| | | DE, ES:!addr16 | 4 | 2 | 5 | DE ← (ES, addr16) | | | |
| | | HL, !addr16 | 3 | 1 | 4 | HL ← (addr16) | | | |
| | | HL, ES:!addr16 | 4 | 2 | 5 | HL ← (ES, addr16) | | | |
| | | BC, saddrp | 2 | 1 | — | BC ← (saddrp) | | | |
| | | DE, saddrp | 2 | 1 | — | DE ← (saddrp) | | | |
| | | HL, saddrp | 2 | 1 | — | HL ← (saddrp) | | | |
| | XCHW | AX, rp ^{Note 4} | 1 | 1 | — | AX ↔ rp | | | |
| | ONEW | AX | 1 | 1 | — | AX ← 0001H | | | |
| | | BC | 1 | 1 | — | BC ← 0001H | | | |
| | CLRW | AX | 1 | 1 | — | AX ← 0000H | | | |
| BC | | 1 | 1 | — | BC ← 0000H | | | | |
| 8-bit operation | ADD | A, #byte | 2 | 1 | — | A, CY ← A + byte | x | x | x |
| | | saddr, #byte | 3 | 2 | — | (saddr), CY ← (saddr) + byte | x | x | x |
| | | A, r ^{Note 3} | 2 | 1 | — | A, CY ← A + r | x | x | x |
| | | r, A | 2 | 1 | — | r, CY ← r + A | x | x | x |
| | | A, !addr16 | 3 | 1 | 4 | A, CY ← A + (addr16) | x | x | x |
| | | A, ES:!addr16 | 4 | 2 | 5 | A, CY ← A + (ES, addr16) | x | x | x |
| | | A, saddr | 2 | 1 | — | A, CY ← A + (saddr) | x | x | x |
| | | A, [HL] | 1 | 1 | 4 | A, CY ← A + (HL) | x | x | x |
| | | A, ES:[HL] | 2 | 2 | 5 | A, CY ← A + (ES, HL) | x | x | x |
| | | A, [HL+byte] | 2 | 1 | 4 | A, CY ← A + (HL + byte) | x | x | x |
| | | A, ES:[HL+byte] | 3 | 2 | 5 | A, CY ← A + ((ES, HL) + byte) | x | x | x |
| | | A, [HL+B] | 2 | 1 | 4 | A, CY ← A + (HL + B) | x | x | x |
| | | A, ES:[HL+B] | 3 | 2 | 5 | A, CY ← A + ((ES, HL) + B) | x | x | x |
| | | A, [HL+C] | 2 | 1 | 4 | A, CY ← A + (HL + C) | x | x | x |
| | | A, ES:[HL+C] | 3 | 2 | 5 | A, CY ← A + ((ES, HL) + C) | x | x | x |
| | ADDC | A, #byte | 2 | 1 | — | A, CY ← A + byte + CY | x | x | x |
| | | saddr, #byte | 3 | 2 | — | (saddr), CY ← (saddr) + byte + CY | x | x | x |
| | | A, r ^{Note 3} | 2 | 1 | — | A, CY ← A + r + CY | x | x | x |
| | | r, A | 2 | 1 | — | r, CY ← r + A + CY | x | x | x |
| | | A, !addr16 | 3 | 1 | 4 | A, CY ← A + (addr16) + CY | x | x | x |
| | | A, ES:!addr16 | 4 | 2 | 5 | A, CY ← A + (ES, addr16) + CY | x | x | x |
| | | A, saddr | 2 | 1 | — | A, CY ← A + (saddr) + CY | x | x | x |
| | | A, [HL] | 1 | 1 | 4 | A, CY ← A + (HL) + CY | x | x | x |
| | | A, ES:[HL] | 2 | 2 | 5 | A, CY ← A + (ES, HL) + CY | x | x | x |
| | | A, [HL+byte] | 2 | 1 | 4 | A, CY ← A + (HL + byte) + CY | x | x | x |
| | | A, ES:[HL+byte] | 3 | 2 | 5 | A, CY ← A + ((ES, HL) + byte) + CY | x | x | x |
| | | A, [HL+B] | 2 | 1 | 4 | A, CY ← A + (HL + B) + CY | x | x | x |
| | | A, ES:[HL+B] | 3 | 2 | 5 | A, CY ← A + ((ES, HL) + B) + CY | x | x | x |
| | | A, [HL+C] | 2 | 1 | 4 | A, CY ← A + (HL + C) + CY | x | x | x |
| | | A, ES:[HL+C] | 3 | 2 | 5 | A, CY ← A + ((ES, HL) + C) + CY | x | x | x |

Table 22-5. Operation List (6/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|-------------------|----------|------------------------|-------|-----------------------|--------|------------------------------------|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| 8-bit operation | SUB | A, #byte | 2 | 1 | — | A, CY ← A - byte | x | x | x |
| | | saddr, #byte | 3 | 2 | — | (saddr), CY ← (saddr) - byte | x | x | x |
| | | A, r ^{Note 3} | 2 | 1 | — | A, CY ← A - r | x | x | x |
| | | r, A | 2 | 1 | — | r, CY ← r - A | x | x | x |
| | | A, !addr16 | 3 | 1 | 4 | A, CY ← A - (addr16) | x | x | x |
| | | A, ES:!addr16 | 4 | 2 | 5 | A, CY ← A - (ES, addr16) | x | x | x |
| | | A, saddr | 2 | 1 | — | A, CY ← A - (saddr) | x | x | x |
| | | A, [HL] | 1 | 1 | 4 | A, CY ← A - (HL) | x | x | x |
| | | A, ES:[HL] | 2 | 2 | 5 | A, CY ← A - (ES, HL) | x | x | x |
| | | A, [HL+byte] | 2 | 1 | 4 | A, CY ← A - (HL + byte) | x | x | x |
| | | A, ES:[HL+byte] | 3 | 2 | 5 | A, CY ← A - ((ES, HL) + byte) | x | x | x |
| | | A, [HL+B] | 2 | 1 | 4 | A, CY ← A - (HL + B) | x | x | x |
| | | A, ES:[HL+B] | 3 | 2 | 5 | A, CY ← A - ((ES, HL) + B) | x | x | x |
| | | A, [HL+C] | 2 | 1 | 4 | A, CY ← A - (HL + C) | x | x | x |
| | | A, ES:[HL+C] | 3 | 2 | 5 | A, CY ← A - ((ES, HL) + C) | x | x | x |
| | SUBC | A, #byte | 2 | 1 | — | A, CY ← A - byte - CY | x | x | x |
| | | saddr, #byte | 3 | 2 | — | (saddr), CY ← (saddr) - byte - CY | x | x | x |
| | | A, r ^{Note 3} | 2 | 1 | — | A, CY ← A - r - CY | x | x | x |
| | | r, A | 2 | 1 | — | r, CY ← r - A - CY | x | x | x |
| | | A, !addr16 | 3 | 1 | 4 | A, CY ← A - (addr16) - CY | x | x | x |
| | | A, ES:!addr16 | 4 | 2 | 5 | A, CY ← A - (ES, addr16) - CY | x | x | x |
| | | A, saddr | 2 | 1 | — | A, CY ← A - (saddr) - CY | x | x | x |
| | | A, [HL] | 1 | 1 | 4 | A, CY ← A - (HL) - CY | x | x | x |
| | | A, ES:[HL] | 2 | 2 | 5 | A, CY ← A - (ES, HL) - CY | x | x | x |
| | | A, [HL+byte] | 2 | 1 | 4 | A, CY ← A - (HL + byte) - CY | x | x | x |
| | | A, ES:[HL+byte] | 3 | 2 | 5 | A, CY ← A - ((ES, HL) + byte) - CY | x | x | x |
| | | A, [HL+B] | 2 | 1 | 4 | A, CY ← A - (HL + B) - CY | x | x | x |
| | | A, ES:[HL+B] | 3 | 2 | 5 | A, CY ← A - ((ES, HL) + B) - CY | x | x | x |
| | | A, [HL+C] | 2 | 1 | 4 | A, CY ← A - (HL + C) - CY | x | x | x |
| | | A, ES:[HL+C] | 3 | 2 | 5 | A, CY ← A - ((ES:HL) + C) - CY | x | x | x |
| | AND | A, #byte | 2 | 1 | — | A ← A ∧ byte | x | | |
| | | saddr, #byte | 3 | 2 | — | (saddr) ← (saddr) ∧ byte | x | | |
| | | A, r ^{Note 3} | 2 | 1 | — | A ← A ∧ r | x | | |
| | | r, A | 2 | 1 | — | r ← r ∧ A | x | | |
| | | A, !addr16 | 3 | 1 | 4 | A ← A ∧ (addr16) | x | | |
| | | A, ES:!addr16 | 4 | 2 | 5 | A ← A ∧ (ES:addr16) | x | | |
| | | A, saddr | 2 | 1 | — | A ← A ∧ (saddr) | x | | |
| | | A, [HL] | 1 | 1 | 4 | A ← A ∧ (HL) | x | | |
| | | A, ES:[HL] | 2 | 2 | 5 | A ← A ∧ (ES:HL) | x | | |
| | | A, [HL+byte] | 2 | 1 | 4 | A ← A ∧ (HL + byte) | x | | |
| | | A, ES:[HL+byte] | 3 | 2 | 5 | A ← A ∧ ((ES:HL) + byte) | x | | |
| | | A, [HL+B] | 2 | 1 | 4 | A ← A ∧ (HL + B) | x | | |
| A, ES:[HL+B] | 3 | 2 | 5 | A ← A ∧ ((ES:HL) + B) | x | | | | |

Table 22-5. Operation List (7/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|-------------------|------------------------|------------------------|----------|--------|---------------------------------------|---|-------------------------------------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| 8-bit operation | AND | A, [HL+C] | 2 | 1 | 4 | $A \leftarrow A \wedge (HL + C)$ | x | | |
| | | A, ES:[HL+C] | 3 | 2 | 5 | $A \leftarrow A \wedge ((ES:HL) + C)$ | x | | |
| | OR | A, #byte | 2 | 1 | — | $A \leftarrow A \vee \text{byte}$ | x | | |
| | | saddr, #byte | 3 | 2 | — | $(saddr) \leftarrow (saddr) \vee \text{byte}$ | x | | |
| | | A, r ^{Note 3} | 2 | 1 | — | $A \leftarrow A \vee r$ | x | | |
| | | r, A | 2 | 1 | — | $r \leftarrow r \vee A$ | x | | |
| | | A, !addr16 | 3 | 1 | 4 | $A \leftarrow A \vee (\text{addr}16)$ | x | | |
| | | A, ES:!addr16 | 4 | 2 | 5 | $A \leftarrow A \vee (ES:\text{addr}16)$ | x | | |
| | | A, saddr | 2 | 1 | — | $A \leftarrow A \vee (saddr)$ | x | | |
| | | A, [HL] | 1 | 1 | 4 | $A \leftarrow A \vee (HL)$ | x | | |
| | | A, ES:[HL] | 2 | 2 | 5 | $A \leftarrow A \vee (ES:HL)$ | x | | |
| | | A, [HL+byte] | 2 | 1 | 4 | $A \leftarrow A \vee (HL + \text{byte})$ | x | | |
| | | A, ES:[HL+byte] | 3 | 2 | 5 | $A \leftarrow A \vee ((ES:HL) + \text{byte})$ | x | | |
| | | A, [HL+B] | 2 | 1 | 4 | $A \leftarrow A \vee (HL + B)$ | x | | |
| | | A, ES:[HL+B] | 3 | 2 | 5 | $A \leftarrow A \vee ((ES:HL) + B)$ | x | | |
| | | A, [HL+C] | 2 | 1 | 4 | $A \leftarrow A \vee (HL + C)$ | x | | |
| | | A, ES:[HL+C] | 3 | 2 | 5 | $A \leftarrow A \vee ((ES:HL) + C)$ | x | | |
| | | XOR | A, #byte | 2 | 1 | — | $A \leftarrow A \nabla \text{byte}$ | x | |
| | saddr, #byte | | 3 | 2 | — | $(saddr) \leftarrow (saddr) \nabla \text{byte}$ | x | | |
| | A, r ^{Note 3} | | 2 | 1 | — | $A \leftarrow A \nabla r$ | x | | |
| | r, A | | 2 | 1 | — | $r \leftarrow r \nabla A$ | x | | |
| | A, !addr16 | | 3 | 1 | 4 | $A \leftarrow A \nabla (\text{addr}16)$ | x | | |
| | A, ES:!addr16 | | 4 | 2 | 5 | $A \leftarrow A \nabla (ES:\text{addr}16)$ | x | | |
| | A, saddr | | 2 | 1 | — | $A \leftarrow A \nabla (saddr)$ | x | | |
| | A, [HL] | | 1 | 1 | 4 | $A \leftarrow A \nabla (HL)$ | x | | |
| | A, ES:[HL] | | 2 | 2 | 5 | $A \leftarrow A \nabla (ES:HL)$ | x | | |
| | A, [HL+byte] | | 2 | 1 | 4 | $A \leftarrow A \nabla (HL + \text{byte})$ | x | | |
| | A, ES:[HL+byte] | | 3 | 2 | 5 | $A \leftarrow A \nabla ((ES:HL) + \text{byte})$ | x | | |
| | A, [HL+B] | | 2 | 1 | 4 | $A \leftarrow A \nabla (HL + B)$ | x | | |
| | A, ES:[HL+B] | | 3 | 2 | 5 | $A \leftarrow A \nabla ((ES:HL) + B)$ | x | | |
| | A, [HL+C] | | 2 | 1 | 4 | $A \leftarrow A \nabla (HL + C)$ | x | | |
| | A, ES:[HL+C] | 3 | 2 | 5 | $A \leftarrow A \nabla ((ES:HL) + C)$ | x | | | |

Table 22-5. Operation List (8/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|-------------------|-----------------|------------------------|-------|--------------------------------|----------------------|---------------------------|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| 8-bit operation | CMP | A, #byte | 2 | 1 | — | A - byte | x | x | x |
| | | !addr16, #byte | 4 | 1 | 4 | (addr16) - byte | x | x | x |
| | | ES:!addr16, #byte | 5 | 2 | 5 | (ES:addr16) - byte | x | x | x |
| | | saddr, #byte | 3 | 1 | — | (saddr) - byte | x | x | x |
| | | A, r ^{Note 3} | 2 | 1 | — | A - r | x | x | x |
| | | r, A | 2 | 1 | — | r - A | x | x | x |
| | | A, !addr16 | 3 | 1 | 4 | A - (addr16) | x | x | x |
| | | A, ES:!addr16 | 4 | 2 | 5 | A - (ES:addr16) | x | x | x |
| | | A, saddr | 2 | 1 | — | A - (saddr) | x | x | x |
| | | A, [HL] | 1 | 1 | 4 | A - (HL) | x | x | x |
| | | A, ES:[HL] | 2 | 2 | 5 | A - (ES:HL) | x | x | x |
| | | A, [HL+byte] | 2 | 1 | 4 | A - (HL + byte) | x | x | x |
| | | A, ES:[HL+byte] | 3 | 2 | 5 | A - ((ES:HL) + byte) | x | x | x |
| | | A, [HL+B] | 2 | 1 | 4 | A - (HL + B) | x | x | x |
| | | A, ES:[HL+B] | 3 | 2 | 5 | A - ((ES:HL) + B) | x | x | x |
| | | A, [HL+C] | 2 | 1 | 4 | A - (HL + C) | x | x | x |
| | A, ES:[HL+C] | 3 | 2 | 5 | A - ((ES:HL) + C) | x | x | x | |
| | CMP0 | A | 1 | 1 | — | A - 00H | x | 0 | 0 |
| | | X | 1 | 1 | — | X - 00H | x | 0 | 0 |
| | | B | 1 | 1 | — | B - 00H | x | 0 | 0 |
| | | C | 1 | 1 | — | C - 00H | x | 0 | 0 |
| | | !addr16 | 3 | 1 | 4 | (addr16) - 00H | x | 0 | 0 |
| | | ES:!addr16 | 4 | 2 | 5 | (ES:addr16) - 00H | x | 0 | 0 |
| | | saddr | 2 | 1 | — | (saddr) - 00H | x | 0 | 0 |
| CMPS | X, [HL+byte] | 3 | 1 | 4 | X - (HL + byte) | x | x | x | |
| | X, ES:[HL+byte] | 4 | 2 | 5 | X - ((ES:HL) + byte) | x | x | x | |
| 16-bit operation | ADDW | AX, #word | 3 | 1 | — | AX, CY ← AX + word | x | x | x |
| | | AX, AX | 1 | 1 | — | AX, CY ← AX + AX | x | x | x |
| | | AX, BC | 1 | 1 | — | AX, CY ← AX + BC | x | x | x |
| | | AX, DE | 1 | 1 | — | AX, CY ← AX + DE | x | x | x |
| | | AX, HL | 1 | 1 | — | AX, CY ← AX + HL | x | x | x |
| | | AX, !addr16 | 3 | 1 | 4 | AX, CY ← AX + (addr16) | x | x | x |
| | | AX, ES:!addr16 | 4 | 2 | 5 | AX, CY ← AX + (ES:addr16) | x | x | x |
| | | AX, saddrp | 2 | 1 | — | AX, CY ← AX + (saddrp) | x | x | x |
| | | AX, [HL+byte] | 3 | 1 | 4 | AX, CY ← AX + (HL + byte) | x | x | x |
| AX, ES: [HL+byte] | 4 | 2 | 5 | AX, CY ← AX + ((ES:HL) + byte) | x | x | x | | |

Table 22-5. Operation List (9/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|-------------------------|----------|-------------------|-------|--------|--|--|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| 16-bit operation | SUBW | AX, #word | 3 | 1 | — | $AX, CY \leftarrow AX - \text{word}$ | x | x | x |
| | | AX, BC | 1 | 1 | — | $AX, CY \leftarrow AX - BC$ | x | x | x |
| | | AX, DE | 1 | 1 | — | $AX, CY \leftarrow AX - DE$ | x | x | x |
| | | AX, HL | 1 | 1 | — | $AX, CY \leftarrow AX - HL$ | x | x | x |
| | | AX, !addr16 | 3 | 1 | 4 | $AX, CY \leftarrow AX - (\text{addr16})$ | x | x | x |
| | | AX, ES:!addr16 | 4 | 2 | 5 | $AX, CY \leftarrow AX - (\text{ES:addr16})$ | x | x | x |
| | | AX, saddrp | 2 | 1 | — | $AX, CY \leftarrow AX - (\text{saddrp})$ | x | x | x |
| | | AX, [HL+byte] | 3 | 1 | 4 | $AX, CY \leftarrow AX - (\text{HL} + \text{byte})$ | x | x | x |
| | | AX, ES: [HL+byte] | 4 | 2 | 5 | $AX, CY \leftarrow AX - ((\text{ES:HL}) + \text{byte})$ | x | x | x |
| | CMPW | AX, #word | 3 | 1 | — | $AX - \text{word}$ | x | x | x |
| | | AX, BC | 1 | 1 | — | $AX - BC$ | x | x | x |
| | | AX, DE | 1 | 1 | — | $AX - DE$ | x | x | x |
| | | AX, HL | 1 | 1 | — | $AX - HL$ | x | x | x |
| | | AX, !addr16 | 3 | 1 | 4 | $AX - (\text{addr16})$ | x | x | x |
| | | AX, ES:!addr16 | 4 | 2 | 5 | $AX - (\text{ES:addr16})$ | x | x | x |
| | | AX, saddrp | 2 | 1 | — | $AX - (\text{saddrp})$ | x | x | x |
| | | AX, [HL+byte] | 3 | 1 | 4 | $AX - (\text{HL} + \text{byte})$ | x | x | x |
| | | AX, ES: [HL+byte] | 4 | 2 | 5 | $AX - ((\text{ES:HL}) + \text{byte})$ | x | x | x |
| Multiply | MULU | X | 1 | 1 | — | $AX \leftarrow A \times X$ | | | |
| Increment/ decrement | INC | r | 1 | 1 | — | $r \leftarrow r + 1$ | x | x | |
| | | !addr16 | 3 | 2 | — | $(\text{addr16}) \leftarrow (\text{addr16}) + 1$ | x | x | |
| | | ES:!addr16 | 4 | 3 | — | $(\text{ES, addr16}) \leftarrow (\text{ES, addr16}) + 1$ | x | x | |
| | | saddr | 2 | 2 | — | $(\text{saddr}) \leftarrow (\text{saddr}) + 1$ | x | x | |
| | | [HL+byte] | 3 | 2 | — | $(\text{HL} + \text{byte}) \leftarrow (\text{HL} + \text{byte}) + 1$ | x | x | |
| | | ES: [HL+byte] | 4 | 3 | — | $((\text{ES:HL}) + \text{byte}) \leftarrow ((\text{ES:HL}) + \text{byte}) + 1$ | x | x | |
| | DEC | r | 1 | 1 | — | $r \leftarrow r - 1$ | x | x | |
| | | !addr16 | 3 | 2 | — | $(\text{addr16}) \leftarrow (\text{addr16}) - 1$ | x | x | |
| | | ES:!addr16 | 4 | 3 | — | $(\text{ES, addr16}) \leftarrow (\text{ES, addr16}) - 1$ | x | x | |
| | | saddr | 2 | 2 | — | $(\text{saddr}) \leftarrow (\text{saddr}) - 1$ | x | x | |
| | | [HL+byte] | 3 | 2 | — | $(\text{HL} + \text{byte}) \leftarrow (\text{HL} + \text{byte}) - 1$ | x | x | |
| | | ES: [HL+byte] | 4 | 3 | — | $((\text{ES:HL}) + \text{byte}) \leftarrow ((\text{ES:HL}) + \text{byte}) - 1$ | x | x | |
| | INCW | rp | 1 | 1 | — | $rp \leftarrow rp + 1$ | | | |
| | | !addr16 | 3 | 2 | — | $(\text{addr16}) \leftarrow (\text{addr16}) + 1$ | | | |
| | | ES:!addr16 | 4 | 3 | — | $(\text{ES, addr16}) \leftarrow (\text{ES, addr16}) + 1$ | | | |
| | | saddrp | 2 | 2 | — | $(\text{saddrp}) \leftarrow (\text{saddrp}) + 1$ | | | |
| | | [HL+byte] | 3 | 2 | — | $(\text{HL} + \text{byte}) \leftarrow (\text{HL} + \text{byte}) + 1$ | | | |
| | | ES: [HL+byte] | 4 | 3 | — | $((\text{ES:HL}) + \text{byte}) \leftarrow ((\text{ES:HL}) + \text{byte}) + 1$ | | | |
| | DECW | rp | 1 | 1 | — | $rp \leftarrow rp - 1$ | | | |
| | | !addr16 | 3 | 2 | — | $(\text{addr16}) \leftarrow (\text{addr16}) - 1$ | | | |
| | | ES:!addr16 | 4 | 3 | — | $(\text{ES, addr16}) \leftarrow (\text{ES, addr16}) - 1$ | | | |
| saddrp | | 2 | 2 | — | $(\text{saddrp}) \leftarrow (\text{saddrp}) - 1$ | | | | |
| [HL+byte] | | 3 | 2 | — | $(\text{HL} + \text{byte}) \leftarrow (\text{HL} + \text{byte}) - 1$ | | | | |
| ES: [HL+byte] | | 4 | 3 | — | $((\text{ES:HL}) + \text{byte}) \leftarrow ((\text{ES:HL}) + \text{byte}) - 1$ | | | | |

Table 22-5. Operation List (10/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|-------------------|-----------------|-----------------|-------|--------|---|---|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| Shift | SHR | A, cnt | 2 | 1 | — | $(CY \leftarrow A_0, A_{m-1} \leftarrow A_m, A_7 \leftarrow 0) \times cnt$ | | | × |
| | SHRW | AX, cnt | 2 | 1 | — | $(CY \leftarrow AX_0, AX_{m-1} \leftarrow AX_m, AX_{15} \leftarrow 0) \times cnt$ | | | × |
| | SHL | A, cnt | 2 | 1 | — | $(CY \leftarrow A_7, A_m \leftarrow A_{m-1}, A_0 \leftarrow 0) \times cnt$ | | | × |
| | | B, cnt | 2 | 1 | — | $(CY \leftarrow B_7, B_m \leftarrow B_{m-1}, B_0 \leftarrow 0) \times cnt$ | | | × |
| | | C, cnt | 2 | 1 | — | $(CY \leftarrow C_7, C_m \leftarrow C_{m-1}, C_0 \leftarrow 0) \times cnt$ | | | × |
| | SHLW | AX, cnt | 2 | 1 | — | $(CY \leftarrow AX_{15}, AX_m \leftarrow AX_{m-1}, AX_0 \leftarrow 0) \times cnt$ | | | × |
| | | BC, cnt | 2 | 1 | — | $(CY \leftarrow BC_{15}, BC_m \leftarrow BC_{m-1}, BC_0 \leftarrow 0) \times cnt$ | | | × |
| SAR | A, cnt | 2 | 1 | — | $(CY \leftarrow A_0, A_{m-1} \leftarrow A_m, A_7 \leftarrow A_7) \times cnt$ | | | × | |
| SARW | AX, cnt | 2 | 1 | — | $(CY \leftarrow AX_0, AX_{m-1} \leftarrow AX_m, AX_{15} \leftarrow AX_{15}) \times cnt$ | | | × | |
| Rotate | ROR | A, 1 | 2 | 1 | — | $(CY, A_7 \leftarrow A_0, A_{m-1} \leftarrow A_m) \times 1$ | | | × |
| | ROL | A, 1 | 2 | 1 | — | $(CY, A_0 \leftarrow A_7, A_{m+1} \leftarrow A_m) \times 1$ | | | × |
| | RORC | A, 1 | 2 | 1 | — | $(CY \leftarrow A_0, A_7 \leftarrow CY, A_{m-1} \leftarrow A_m) \times 1$ | | | × |
| | ROLC | A, 1 | 2 | 1 | — | $(CY \leftarrow A_7, A_0 \leftarrow CY, A_{m+1} \leftarrow A_m) \times 1$ | | | × |
| | ROLWC | AX, 1 | 2 | 1 | — | $(CY \leftarrow AX_{15}, AX_0 \leftarrow CY, AX_{m+1} \leftarrow AX_m) \times 1$ | | | × |
| | | BC, 1 | 2 | 1 | — | $(CY \leftarrow BC_{15}, BC_0 \leftarrow CY, BC_{m+1} \leftarrow BC_m) \times 1$ | | | × |
| Bit manipulate | MOV1 | CY, A.bit | 2 | 1 | — | $CY \leftarrow A.bit$ | | | × |
| | | A.bit, CY | 2 | 1 | — | $A.bit \leftarrow CY$ | | | |
| | | CY, PSW.bit | 3 | 1 | — | $CY \leftarrow PSW.bit$ | | | × |
| | | PSW.bit, CY | 3 | 4 | — | $PSW.bit \leftarrow CY$ | × | × | |
| | | CY, saddr.bit | 3 | 1 | — | $CY \leftarrow (saddr).bit$ | | | × |
| | | saddr.bit, CY | 3 | 2 | — | $(saddr).bit \leftarrow CY$ | | | |
| | | CY, sfr.bit | 3 | 1 | — | $CY \leftarrow sfr.bit$ | | | × |
| | | sfr.bit, CY | 3 | 2 | — | $sfr.bit \leftarrow CY$ | | | |
| | | CY, [HL].bit | 2 | 1 | 4 | $CY \leftarrow (HL).bit$ | | | × |
| | | [HL].bit, CY | 2 | 2 | — | $(HL).bit \leftarrow CY$ | | | |
| | CY, ES:[HL].bit | 3 | 2 | 5 | $CY \leftarrow (ES, HL).bit$ | | | × | |
| | ES:[HL].bit, CY | 3 | 3 | — | $(ES, HL).bit \leftarrow CY$ | | | | |
| | AND1 | CY, A.bit | 2 | 1 | — | $CY \leftarrow CY \wedge A.bit$ | | | × |
| | | CY, PSW.bit | 3 | 1 | — | $CY \leftarrow CY \wedge PSW.bit$ | | | × |
| | | CY, saddr.bit | 3 | 1 | — | $CY \leftarrow CY \wedge (saddr).bit$ | | | × |
| | | CY, sfr.bit | 3 | 1 | — | $CY \leftarrow CY \wedge sfr.bit$ | | | × |
| | | CY, [HL].bit | 2 | 1 | 4 | $CY \leftarrow CY \wedge (HL).bit$ | | | × |
| | | CY, ES:[HL].bit | 3 | 2 | 5 | $CY \leftarrow CY \wedge (ES, HL).bit$ | | | × |
| | OR1 | CY, A.bit | 2 | 1 | — | $CY \leftarrow CY \vee A.bit$ | | | × |
| | | CY, PSW.bit | 3 | 1 | — | $CY \leftarrow CY \vee PSW.bit$ | | | × |
| | | CY, saddr.bit | 3 | 1 | — | $CY \leftarrow CY \vee (saddr).bit$ | | | × |
| | | CY, sfr.bit | 3 | 1 | — | $CY \leftarrow CY \vee sfr.bit$ | | | × |
| | | CY, [HL].bit | 2 | 1 | 4 | $CY \leftarrow CY \vee (HL).bit$ | | | × |
| CY, ES:[HL].bit | | 3 | 2 | 5 | $CY \leftarrow CY \vee (ES, HL).bit$ | | | × | |

Table 22-5. Operation List (11/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | | |
|-------------------|-------------|-----------------|---------|--------|---|--|--|----|----|--|
| | | | | Note 1 | Note 2 | | Z | AC | CY | |
| Bit manipulate | XOR1 | CY, A.bit | 2 | 1 | — | $CY \leftarrow CY \vee A.bit$ | | | x | |
| | | CY, PSW.bit | 3 | 1 | — | $CY \leftarrow CY \vee PSW.bit$ | | | x | |
| | | CY, saddr.bit | 3 | 1 | — | $CY \leftarrow CY \vee (saddr).bit$ | | | x | |
| | | CY, sfr.bit | 3 | 1 | — | $CY \leftarrow CY \vee sfr.bit$ | | | x | |
| | | CY, [HL].bit | 2 | 1 | 4 | $CY \leftarrow CY \vee (HL).bit$ | | | x | |
| | | CY, ES:[HL].bit | 3 | 2 | 5 | $CY \leftarrow CY \vee (ES, HL).bit$ | | | x | |
| | SET1 | A.bit | 2 | 1 | — | $A.bit \leftarrow 1$ | | | | |
| | | PSW.bit | 3 | 4 | — | $PSW.bit \leftarrow 1$ | x | x | x | |
| | | laddr16.bit | 4 | 2 | — | $(addr16).bit \leftarrow 1$ | | | | |
| | | ES:laddr16.bit | 5 | 3 | — | $(ES, addr16).bit \leftarrow 1$ | | | | |
| | | saddr.bit | 3 | 2 | — | $(saddr).bit \leftarrow 1$ | | | | |
| | | sfr.bit | 3 | 2 | — | $sfr.bit \leftarrow 1$ | | | | |
| | | [HL].bit | 2 | 2 | — | $(HL).bit \leftarrow 1$ | | | | |
| | | ES:[HL].bit | 3 | 3 | — | $(ES, HL).bit \leftarrow 1$ | | | | |
| | CLR1 | A.bit | 2 | 1 | — | $A.bit \leftarrow 0$ | | | | |
| | | PSW.bit | 3 | 4 | — | $PSW.bit \leftarrow 0$ | x | x | x | |
| | | laddr16.bit | 4 | 2 | — | $(addr16).bit \leftarrow 0$ | | | | |
| | | ES:laddr16.bit | 5 | 3 | — | $(ES, addr16).bit \leftarrow 0$ | | | | |
| | | saddr.bit | 3 | 2 | — | $(saddr).bit \leftarrow 0$ | | | | |
| | | sfr.bit | 3 | 2 | — | $sfr.bit \leftarrow 0$ | | | | |
| | | [HL].bit | 2 | 2 | — | $(HL).bit \leftarrow 0$ | | | | |
| | | ES:[HL].bit | 3 | 3 | — | $(ES, HL).bit \leftarrow 0$ | | | | |
| | SET1 | CY | 2 | 1 | — | $CY \leftarrow 1$ | | | 1 | |
| | CLR1 | CY | 2 | 1 | — | $CY \leftarrow 0$ | | | 0 | |
| | NOT1 | CY | 2 | 1 | — | $CY \leftarrow \overline{CY}$ | | | x | |
| | Call/return | CALL | rp | 2 | 3 | — | $(SP - 2) \leftarrow (PC + 2)_s, (SP - 3) \leftarrow (PC + 2)_H,$ $(SP - 4) \leftarrow (PC + 2)_L, PC \leftarrow CS, rp,$ $SP \leftarrow SP - 4$ | | | |
| | | | !addr20 | 3 | 3 | — | $(SP - 2) \leftarrow (PC + 3)_s, (SP - 3) \leftarrow (PC + 3)_H,$ $(SP - 4) \leftarrow (PC + 3)_L, PC \leftarrow PC + 3 +$ $jdisp16, SP \leftarrow SP - 4$ | | | |
| laddr16 | | | 3 | 3 | — | $(SP - 2) \leftarrow (PC + 3)_s, (SP - 3) \leftarrow (PC + 3)_H,$ $(SP - 4) \leftarrow (PC + 3)_L, PC \leftarrow 0000, addr16,$ $SP \leftarrow SP - 4$ | | | | |
| !!addr20 | | | 4 | 3 | — | $(SP - 2) \leftarrow (PC + 4)_s, (SP - 3) \leftarrow (PC + 4)_H,$ $(SP - 4) \leftarrow (PC + 4)_L, PC \leftarrow addr20,$ $SP \leftarrow SP - 4$ | | | | |
| CALLT | | [addr5] | 2 | 5 | — | $(SP - 2) \leftarrow (PC + 2)_s, (SP - 3) \leftarrow (PC + 2)_H,$ $(SP - 4) \leftarrow (PC + 2)_L, PCS \leftarrow 0000,$ $PC_H \leftarrow (0000, addr5 + 1),$ $PC_L \leftarrow (0000, addr5),$ $SP \leftarrow SP - 4$ | | | | |
| BRK | | — | 2 | 5 | — | $(SP - 1) \leftarrow PSW, (SP - 2) \leftarrow (PC + 2)_s,$ $(SP - 3) \leftarrow (PC + 2)_H, (SP - 4) \leftarrow (PC + 2)_L,$ $PC_s \leftarrow 0000,$ $PC_H \leftarrow (0007FH), PC_L \leftarrow (0007EH),$ $SP \leftarrow SP - 4, IE \leftarrow 0$ | | | | |
| RET | — | 1 | 6 | — | $PC_L \leftarrow (SP), PC_H \leftarrow (SP + 1),$ $PC_s \leftarrow (SP + 2), SP \leftarrow SP + 4$ | | | | | |

Table 22-5. Operation List (12/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|-----------------------|-----------|-----------------------|-----------------------|-----------------------|---|---|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| Call/return | RETI | — | 2 | 6 | — | $PC_L \leftarrow (SP), PC_H \leftarrow (SP + 1),$ $PC_S \leftarrow (SP + 2), PSW \leftarrow (SP + 3),$ $SP \leftarrow SP + 4$ | R | R | R |
| | RETB | — | 2 | 6 | — | $PC_L \leftarrow (SP), PC_H \leftarrow (SP + 1),$ $PC_S \leftarrow (SP + 2), PSW \leftarrow (SP + 3),$ $SP \leftarrow SP + 4$ | R | R | R |
| Stack manipulate | PUSH | PSW | 2 | 1 | — | $(SP - 1) \leftarrow PSW, (SP - 2) \leftarrow 00H,$ $SP \leftarrow SP - 2$ | | | |
| | | rp | 1 | 1 | — | $(SP - 1) \leftarrow rp_H, (SP - 2) \leftarrow rp_L,$ $SP \leftarrow SP - 2$ | | | |
| | POP | PSW | 2 | 3 | — | $PSW \leftarrow (SP + 1), SP \leftarrow SP + 2$ | R | R | R |
| | | rp | 1 | 1 | — | $rp_L \leftarrow (SP), rp_H \leftarrow (SP + 1), SP \leftarrow SP + 2$ | | | |
| | MOVW | SP, #word | 4 | 1 | — | $SP \leftarrow word$ | | | |
| | | SP, AX | 2 | 1 | — | $SP \leftarrow AX$ | | | |
| | | AX, SP | 2 | 1 | — | $AX \leftarrow SP$ | | | |
| | | HL, SP | 3 | 1 | — | $HL \leftarrow SP$ | | | |
| | | BC, SP | 3 | 1 | — | $BC \leftarrow SP$ | | | |
| | | DE, SP | 3 | 1 | — | $DE \leftarrow SP$ | | | |
| ADDW | SP, #byte | 2 | 1 | — | $SP \leftarrow SP + byte$ | | | | |
| SUBW | SP, #byte | 2 | 1 | — | $SP \leftarrow SP - byte$ | | | | |
| Unconditional branch | BR | AX | 2 | 3 | — | $PC \leftarrow CS, AX$ | | | |
| | | \$addr20 | 2 | 3 | — | $PC \leftarrow PC + 2 + jdisp8$ | | | |
| | | !\$addr20 | 3 | 3 | — | $PC \leftarrow PC + 3 + jdisp16$ | | | |
| | | laddr16 | 3 | 3 | — | $PC \leftarrow 0000, addr16$ | | | |
| | | !!addr20 | 4 | 3 | — | $PC \leftarrow addr20$ | | | |
| Conditional branch | BC | \$addr20 | 2 | 2/4 ^{Note 5} | — | $PC \leftarrow PC + 2 + jdisp8$ if CY = 1 | | | |
| | BNC | \$addr20 | 2 | 2/4 ^{Note 5} | — | $PC \leftarrow PC + 2 + jdisp8$ if CY = 0 | | | |
| | BZ | \$addr20 | 2 | 2/4 ^{Note 5} | — | $PC \leftarrow PC + 2 + jdisp8$ if Z = 1 | | | |
| | BNZ | \$addr20 | 2 | 2/4 ^{Note 5} | — | $PC \leftarrow PC + 2 + jdisp8$ if Z = 0 | | | |
| | BH | \$addr20 | 3 | 2/4 ^{Note 5} | — | $PC \leftarrow PC + 3 + jdisp8$ if $(Z \vee CY) = 0$ | | | |
| | BNH | \$addr20 | 3 | 2/4 ^{Note 5} | — | $PC \leftarrow PC + 3 + jdisp8$ if $(Z \vee CY) = 1$ | | | |
| | BT | saddr.bit, \$addr20 | 4 | 3/5 ^{Note 5} | — | $PC \leftarrow PC + 4 + jdisp8$ if (saddr).bit = 1 | | | |
| | | sfr.bit, \$addr20 | 4 | 3/5 ^{Note 5} | — | $PC \leftarrow PC + 4 + jdisp8$ if sfr.bit = 1 | | | |
| | | A.bit, \$addr20 | 3 | 3/5 ^{Note 5} | — | $PC \leftarrow PC + 3 + jdisp8$ if A.bit = 1 | | | |
| | | PSW.bit, \$addr20 | 4 | 3/5 ^{Note 5} | — | $PC \leftarrow PC + 4 + jdisp8$ if PSW.bit = 1 | | | |
| | | [HL].bit, \$addr20 | 3 | 3/5 ^{Note 5} | 6/7 | $PC \leftarrow PC + 3 + jdisp8$ if (HL).bit = 1 | | | |
| | | ES:[HL].bit, \$addr20 | 4 | 4/6 ^{Note 5} | 7/8 | $PC \leftarrow PC + 4 + jdisp8$ if (ES, HL).bit = 1 | | | |
| | BF | saddr.bit, \$addr20 | 4 | 3/5 ^{Note 5} | — | $PC \leftarrow PC + 4 + jdisp8$ if (saddr).bit = 0 | | | |
| | | sfr.bit, \$addr20 | 4 | 3/5 ^{Note 5} | — | $PC \leftarrow PC + 4 + jdisp8$ if sfr.bit = 0 | | | |
| | | A.bit, \$addr20 | 3 | 3/5 ^{Note 5} | — | $PC \leftarrow PC + 3 + jdisp8$ if A.bit = 0 | | | |
| PSW.bit, \$addr20 | | 4 | 3/5 ^{Note 5} | — | $PC \leftarrow PC + 4 + jdisp8$ if PSW.bit = 0 | | | | |
| [HL].bit, \$addr20 | | 3 | 3/5 ^{Note 5} | 6/7 | $PC \leftarrow PC + 3 + jdisp8$ if (HL).bit = 0 | | | | |
| ES:[HL].bit, \$addr20 | | 4 | 4/6 ^{Note 5} | 7/8 | $PC \leftarrow PC + 4 + jdisp8$ if (ES, HL).bit = 0 | | | | |

Table 22-5. Operation List (13/13)

| Instruction Group | Mnemonic | Operand | Bytes | Clock | | Operation | Flag | | |
|--------------------|-----------------------|-----------------------|-------|-----------------------|--------|---|------|----|----|
| | | | | Note 1 | Note 2 | | Z | AC | CY |
| Conditional branch | BTCLR | saddr.bit, \$addr20 | 4 | 3/5 ^{Note 5} | — | PC ← PC + 4 + jdisp8 if (saddr).bit = 1 then reset (saddr).bit | | | |
| | | sfr.bit, \$addr20 | 4 | 3/5 ^{Note 5} | — | PC ← PC + 4 + jdisp8 if sfr.bit = 1 then reset sfr.bit | | | |
| | | A.bit, \$addr20 | 3 | 3/5 ^{Note 5} | — | PC ← PC + 3 + jdisp8 if A.bit = 1 then reset A.bit | | | |
| | | PSW.bit, \$addr20 | 4 | 3/5 ^{Note 5} | — | PC ← PC + 4 + jdisp8 if PSW.bit = 1 then reset PSW.bit | x | x | x |
| | | [HL].bit, \$addr20 | 3 | 3/5 ^{Note 5} | — | PC ← PC + 3 + jdisp8 if (HL).bit = 1 then reset (HL).bit | | | |
| | | ES:[HL].bit, \$addr20 | 4 | 4/6 ^{Note 5} | — | PC ← PC + 4 + jdisp8 if (ES, HL).bit = 1 then reset (ES, HL).bit | | | |
| Conditional skip | SKC | — | 2 | 1 | — | Next instruction skip if CY = 1 | | | |
| | SKNC | — | 2 | 1 | — | Next instruction skip if CY = 0 | | | |
| | SKZ | — | 2 | 1 | — | Next instruction skip if Z = 1 | | | |
| | SKNZ | — | 2 | 1 | — | Next instruction skip if Z = 0 | | | |
| | SKH | — | 2 | 1 | — | Next instruction skip if (Z ∨ CY) = 0 | | | |
| | SKNH | — | 2 | 1 | — | Next instruction skip if (Z ∨ CY) = 1 | | | |
| CPU control | SEL ^{Note 6} | RBn | 2 | 1 | — | RBS[1:0] ← n | | | |
| | NOP | — | 1 | 1 | — | No Operation | | | |
| | EI | — | 3 | 4 | — | IE ← 1 (Enable Interrupt) | | | |
| | DI | — | 3 | 4 | — | IE ← 0 (Disable Interrupt) | | | |
| | HALT | — | 2 | 3 | — | Set HALT Mode | | | |
| | STOP | — | 2 | 3 | — | Set STOP Mode | | | |

Note 1. Number of CPU clocks (f_{CLK}) when the internal RAM area, SFR area, or extended SFR area is accessed, or when no data is accessed.

Note 2. Number of CPU clocks (f_{CLK}) when the code flash memory is accessed, or when the data flash memory is accessed by an 8-bit instruction.

Note 3. Except r = A

Note 4. Except rp = AX

Note 5. This indicates the number of clocks “when condition is not met/when condition is met”.

Note 6. n indicates the register bank number (n = 0 to 3).

Remark 1. These numbers of clock cycles apply when the program is in the internal ROM (flash memory) area. When the instruction is fetched from the internal RAM area, the number is, at most, the double of the number given here plus 3 further clock cycles.

Remark 2. cnt indicates the bit shift count.

CHAPTER 23 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+85^\circ\text{C}$)

- ★ This chapter describes the electrical specifications of A: Consumer applications ($T_A = -40$ to $+85^\circ\text{C}$), G: Industrial applications ($T_A = -40$ to $+105^\circ\text{C}$), and M: Industrial applications ($T_A = -40$ to $+125^\circ\text{C}$) when they are used in the range of $T_A = -40$ to $+85^\circ\text{C}$.

Caution 1. The RL78 microcontrollers have an on-chip debug function, which is provided for development and evaluation. Do not use the on-chip debug function in products designated for mass production, because the guaranteed number of rewritable times of the flash memory may be exceeded when this function is used, and product reliability therefore cannot be guaranteed. Renesas Electronics is not liable for problems occurring when the on-chip debug function is used.

Caution 2. The pins mounted depend on the product. Refer to 2.1 Port Function for the port functions and 2.2.1 Functions for each product for the other functions.

- ★ **Remark** There are differences in the high-speed on-chip oscillator clock accuracy between G: Industrial applications and M: Industrial applications, and A: Consumer applications.

| Classification | A: Consumer applications | G: Industrial applications | M: Industrial applications |
|--|---|--|--|
| High-speed on-chip oscillator clock accuracy | $\pm 2.0\%$ when $T_A = -40$ to $+85^\circ\text{C}$ | $\pm 1.5\%$ when $T_A = +85$ to $+105^\circ\text{C}$ $\pm 1.0\%$ when $T_A = -20$ to $+85^\circ\text{C}$ $\pm 1.5\%$ when $T_A = -40$ to -20°C | $\pm 1.5\%$ when $T_A = +85$ to $+125^\circ\text{C}$ $\pm 1.0\%$ when $T_A = -20$ to $+85^\circ\text{C}$ $\pm 1.5\%$ when $T_A = -40$ to -20°C |

23.1 Absolute Maximum Ratings

[$T_A = 25^\circ\text{C}$]

| Item | Symbol | Condition | Rating | Unit | |
|-------------------------------|-----------|-----------------------------|--|------------------|----|
| Supply voltage | V_{DD} | | -0.5 to +6.5 | V | |
| Input voltage | V_{I1} | | -0.3 to $V_{DD} + 0.3$ ^{Note 1} | V | |
| Output voltage | V_{O1} | | -0.3 to $V_{DD} + 0.3$ | V | |
| Output current, high | I_{OH1} | Per pin | -40 | mA | |
| | | Total of all pins -170mA | P20 to P23, P40, P41, P121, P122, P125 | -70 | mA |
| | | | P00 to P07 | -100 | mA |
| Output current, low | I_{OL1} | Per pin | 40 | mA | |
| | | Total of all pins 170mA | P20 to P23, P40, P41, P121, P122, P125 | 100 | mA |
| | | | P00 to P07 | 100 | mA |
| Operating ambient temperature | T_A | | -40 to +85 | $^\circ\text{C}$ | |
| Storage temperature | T_{stg} | | -65 to +150 | $^\circ\text{C}$ | |

Note 1. This must be no greater than 6.5 V.

Caution Product quality may suffer if the absolute maximum rating is exceeded even momentarily for any item. That is, the absolute maximum ratings are rated values at which the product is on the verge of suffering physical damage, and therefore the product must be used under conditions that ensure that the absolute maximum ratings are not exceeded.

Remark 1. The characteristics of functions multiplexed on a given pin are the same as those for the port pin unless otherwise specified.

Remark 2. The reference voltage is V_{SS} .

23.2 Oscillator Characteristics

23.2.1 X1 oscillator characteristics

[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Resonator | Condition | MIN. | TYP. | MAX. | Unit |
|--|---|---------------------------------|------|------|------|------|
| X1 clock oscillation frequency (f _X) ^{Note 1} | Ceramic resonator/ crystal resonator | 2.4 V ≤ V _{DD} ≤ 5.5 V | 1 | | 12 | MHz |

Note 1. Indicates only permissible oscillator frequency ranges. Refer to **23.4 AC Characteristics** for instruction execution time. For actual applications, request evaluation by the manufacturer of the oscillator circuit mounted on a board so you can use appropriate values.

Caution Since the CPU is started by the high-speed on-chip oscillator clock after release from the reset state, the user should use the oscillation stabilization time counter status register (OSTC) to check the X1 clock oscillation stabilization time. Specify the values for the oscillation stabilization time in the OSTC register and the oscillation stabilization time select register (OSTS) after having sufficiently evaluated the oscillation stabilization time with the resonator to be used.

Remark When using the X1 oscillator, refer to **5.4 System Clock Oscillator**.

23.2.2 On-chip oscillator characteristics

[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---|-----------------|-------------------------------|------|------|------|------|
| High-speed on-chip oscillator clock frequency ^{Note 1, Note 2} | f _{IH} | | 1 | | 16 | MHz |
| High-speed on-chip oscillator clock frequency accuracy | | T _A = -40 to +85°C | -2.0 | | +2.0 | % |
| Low-speed on-chip oscillator clock frequency | f _{IL} | | | 15 | | kHz |
| Low-speed on-chip oscillator clock frequency accuracy | | | -15 | | +15 | % |

Note 1. The high-speed on-chip oscillator frequency is selected by bits 0 to 2 of option byte (00C2H).

Note 2. The listed values only indicate the characteristics of the oscillators. Refer to **23.4 AC Characteristics** for instruction execution time.

23.3 DC Characteristics

23.3.1 Pin characteristics

[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

(1/2)

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|--|------------------|---|---------------------------------|--------|-------------------------|------|
| Output current, high Note 1 | I _{OH1} | Per pin for P00 to P07, P20 to P23, P40, P41, P121, P122, P125 | | | -10.0 ^{Note 2} | mA |
| | | Total of P20 to P23, P40, P41, P121, P122, P125 (when duty ≤ 70% ^{Note 3}) | 4.0 V ≤ V _{DD} ≤ 5.5 V | | -65.0 | mA |
| | | | 2.7 V ≤ V _{DD} < 4.0 V | | -14.0 | mA |
| | | | 2.4 V ≤ V _{DD} < 2.7 V | | -10.5 | mA |
| | | Total of P00 to P07 (when duty ≤ 70% ^{Note 3}) | 4.0 V ≤ V _{DD} ≤ 5.5 V | | -65.0 | mA |
| | | | 2.7 V ≤ V _{DD} < 4.0 V | | -12.0 | mA |
| | | | 2.4 V ≤ V _{DD} < 2.7 V | | -9.0 | mA |
| Total of all pins (when duty ≤ 70% ^{Note 3}) | | | | -105.0 | mA | |
| Output current, low Note 4 | I _{OL1} | Per pin for P00 to P07, P20 to P23, P40, P41, P121, P122, P125 | | | 20.0 ^{Note 2} | mA |
| | | Total of P20 to P23, P40, P41, P121, P122, P125 (when duty ≤ 70% ^{Note 3}) | 4.0 V ≤ V _{DD} ≤ 5.5 V | | 85.0 | mA |
| | | | 2.7 V ≤ V _{DD} < 4.0 V | | 21.0 | mA |
| | | | 2.4 V ≤ V _{DD} < 2.7 V | | 4.2 | mA |
| | | Total of P00 to P07 (when duty ≤ 70% ^{Note 3}) | 4.0 V ≤ V _{DD} ≤ 5.5 V | | 85.0 | mA |
| | | | 2.7 V ≤ V _{DD} < 4.0 V | | 18.0 | mA |
| | | | 2.4 V ≤ V _{DD} < 2.7 V | | 3.6 | mA |
| Total of all pins (when duty ≤ 70% ^{Note 3}) | | | | 145.0 | mA | |

Note 1. Device operation is guaranteed at the listed currents even if current is flowing from the V_{DD} pin to an output pin.

Note 2. The value for maximum total current must not be exceeded.

Note 3. The listed currents apply when the duty cycle is no greater than 70%. Use the following formula to calculate the output current when the duty cycle is greater than 70%, where n is the duty cycle.

- Total output current from the listed pins = (I_{OH} × 0.7)/(n × 0.01)
Example when n = 80% and I_{OH} = -10.0 mA
Total output current from the listed pins = (-10.0 × 0.7)/(80 × 0.01) ≅ -8.7 mA
- Total output current from the listed pins = (I_{OL} × 0.7)/(n × 0.01)
Example when n = 80% and I_{OL} = 10.0 mA
Total output current from the listed pins = (10.0 × 0.7)/(80 × 0.01) ≅ 8.7 mA

Note that the duty cycle has no effect on the current that is allowed to flow into a single pin. A current higher than the absolute maximum rating must not flow into a single pin.

Note 4. Device operation is guaranteed at the listed currents even if current is flowing from an output pin to the V_{SS} pin.

Caution P00, P01, P03 to P07, P22, and P41 do not output high level in N-ch open-drain mode.

Remark The characteristics of functions multiplexed on a given pin are the same as those for the port pin unless otherwise specified.

[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

(2/2)

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---------------------------------|-----------------------------|--|--|--|---------------------------------------|------|
| Input voltage, high | V _{IH1} | | 0.8 V _{DD} | | V _{DD} | V |
| Input voltage, low | V _{IL1} | | 0 | | 0.2 V _{DD} | V |
| Output voltage, high Note 1 | V _{OH1} | 4.0 V ≤ V _{DD} ≤ 5.5 V | I _{OH} = -10 mA | V _{DD} - 1.5 | | V |
| | | | I _{OH} = -3.0 mA | V _{DD} - 0.7 | | V |
| | | 2.7 V ≤ V _{DD} ≤ 5.5 V | I _{OH} = -2.0 mA | V _{DD} - 0.6 | | V |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | I _{OH} = -1.5 mA | V _{DD} - 0.5 | | V |
| Output voltage, low Note 2 | V _{OL1} | 4.0 V ≤ V _{DD} ≤ 5.5 V | I _{OL} = 20 mA | | 1.3 | V |
| | | | I _{OL} = 8.5 mA | | 0.7 | V |
| | | 2.7 V ≤ V _{DD} ≤ 5.5 V | I _{OL} = 3.0 mA | | 0.6 | V |
| | | | I _{OL} = 1.5 mA | | 0.4 | V |
| 2.4 V ≤ V _{DD} ≤ 5.5 V | I _{OL} = 0.6 mA | | 0.4 | V | | |
| | Input leakage current, high | I _{LIH1} | P00 to P07, P20 to P23, P40, P41, P125, P137 V _I = V _{DD} | | | 1 |
| I _{LIH2} | | | | P121, P122 (X1, X2, EXCLK) V _I = V _{DD} | In input port or external clock input | |
| | | In resonator connection | | | 10 | μA |
| Input leakage current, low | I _{LIL1} | P00 to P07, P20 to P23, P40, P41, P125, P137 V _I = V _{SS} | | | -1 | μA |
| | | | I _{LIL2} | P121, P122 (X1, X2, EXCLK) V _I = V _{SS} | In input port or external clock input | |
| | In resonator connection | | | | -10 | μA |
| On-chip pull-up resistance | R _U | V _I = V _{SS} | 10 | 20 | 100 | kΩ |

Note 1. The value under the condition which satisfies the high-level output current (I_{OH1}).

Note 2. The value under the condition which satisfies the low-level output current (I_{OL1}).

Caution The maximum value of V_{IH} of P00, P01, P03 to P07, P22, and P41 is V_{DD} even in N-ch open-drain mode. These pins do not output high level in N-ch open-drain mode.

Remark The characteristics of functions multiplexed on a given pin are the same as those for the port pin unless otherwise specified.

23.3.2 Supply current characteristics

[$T_A = -40$ to $+85^\circ\text{C}$, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit | | |
|----------------------------------|-----------------------------|----------------------|--|--|---------------------------------------|------|---------------|---------------|----|
| Supply current ^{Note 1} | I_{DD1} | Operating mode | Basic operation | $f_{IH} = 16\text{ MHz}$ ^{Note 4} | $V_{DD} = 3.0\text{ V}, 5.0\text{ V}$ | | 0.87 | | mA |
| | | | Normal operation | $f_{IH} = 16\text{ MHz}$ ^{Note 4} | $V_{DD} = 3.0\text{ V}, 5.0\text{ V}$ | | 1.86 | 2.47 | mA |
| | | | | $f_{IH} = 4\text{ MHz}$ ^{Note 4} | $V_{DD} = 3.0\text{ V}, 5.0\text{ V}$ | | 1.17 | 1.64 | mA |
| | | | | $f_{EX} = 16\text{ MHz}$ ^{Note 5, Note 6} | Square wave input | | 1.69 | 2.30 | mA |
| | | | | $f_X = 12\text{ MHz}$ ^{Note 5, Note 6} | Resonator connection | | 1.57 | 2.30 | mA |
| | | | | $f_{MX} = 4\text{ MHz}$ ^{Note 5, Note 6} | Square wave input | | 1.00 | 1.46 | mA |
| | | Resonator connection | | 1.05 | 1.53 | mA | | | |
| | I_{DD2} ^{Note 2} | HALT mode | $f_{IH} = 16\text{ MHz}$ ^{Note 4} | $V_{DD} = 3.0\text{ V}, 5.0\text{ V}$ | | 371 | 800 | μA | |
| | | | $f_{IH} = 4\text{ MHz}$ ^{Note 4} | $V_{DD} = 3.0\text{ V}, 5.0\text{ V}$ | | 334 | 630 | μA | |
| | | | $f_{EX} = 16\text{ MHz}$ ^{Note 5, Note 6} | Square wave input | | 207 | 636 | μA | |
| | | | $f_X = 12\text{ MHz}$ ^{Note 5, Note 6} | Resonator connection | | 309 | 894 | μA | |
| | | | $f_{MX} = 4\text{ MHz}$ ^{Note 5, Note 6} | Square wave input | | 156 | 452 | μA | |
| | | | | Resonator connection | | 207 | 599 | μA | |
| I_{DD3} ^{Note 3} | STOP mode | | $V_{DD} = 3.0\text{ V}$ | | 0.62 | 2.25 | μA | | |

Note 1. The listed currents are the total currents flowing into V_{DD} , including the input leakage currents flowing when the level of the input pin is fixed to V_{DD} or V_{SS} .
Regarding the values for main system clock operation, the TYP. value does not include the peripheral operating current. The MAX. value includes the peripheral operating current, but does not include those flowing into the A/D converter, comparator, I/O port, and on-chip pull-up/pull-down resistors.
Regarding the values for subsystem clock operation, the TYP. and MAX. values do not include the peripheral operating current. However, in HALT mode, the current flowing into the RTC is included.
Regarding the values in STOP mode, the TYP. and MAX. values do not include the peripheral operating current.

Note 2. When the HALT instruction is executed from the flash memory.

Note 3. The listed currents do not include the current flowing into the 12-bit interval timer and watchdog timer.

Note 4. When the high-speed subsystem clock is stopped.

Note 5. When the high-speed on-chip oscillator is stopped.

Note 6. 16-pin and 20-pin products only.

Remark 1. f_{IH} : High-speed on-chip oscillator clock frequency

Remark 2. f_{MX} : High-speed system clock frequency (X1 clock oscillation frequency or external main system clock frequency)

Remark 3. The temperature condition of the TYP. value is $T_A = 25^\circ\text{C}$.

Peripheral Functions

[$T_A = -40$ to $+85^\circ\text{C}$, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit | |
|--|--|--------------------------------|-------------------------|------|-------|---------------|---------------|
| Low-speed on-chip oscillator operating current | I_{FIL} ^{Note 1} | | | 0.30 | | μA | |
| 12-bit interval timer operating current | I_{TMKA} ^{Note 1, Note 2, Note 3} | | | 0.02 | | μA | |
| Watchdog timer operating current | I_{WDT} ^{Note 1, Note 4} | | | 0.02 | | μA | |
| A/D converter operating current | I_{ADC} ^{Note 1, Note 5} | In conversion at maximum speed | $V_{DD} = 5.0\text{ V}$ | | 1.30 | 1.90 | mA |
| | | | $V_{DD} = 3.0\text{ V}$ | | 0.50 | | mA |
| Comparator operating current | I_{CMP} ^{Note 1, Note 6} | In high-speed mode | $V_{DD} = 5.0\text{ V}$ | | 6.50 | | μA |
| | | In low-speed mode | $V_{DD} = 5.0\text{ V}$ | | 1.70 | | μA |
| Internal reference voltage operating current | I_{VREG} ^{Note 1} | | | 10 | | μA | |
| Self-programming operating current | I_{FSP} ^{Note 1, Note 7} | | | 2.0 | 12.20 | mA | |

Note 1. The current flowing into V_{DD} .

Note 2. When the high-speed on-chip oscillator and high-speed system clock are stopped.

Note 3. This current only flows into the 12-bit interval timer. It does not include the operating current of the low-speed on-chip oscillator. The supply current of the RL78 microcontrollers is the sum of I_{DD1} , I_{DD2} or I_{DD3} and I_{FIL} and I_{TMKA} when the 12-bit interval timer is in operation.

Note 4. This current only flows into the watchdog timer. It does not include the operating current of the low-speed on-chip oscillator. The supply current of the RL78 microcontrollers is the sum of I_{DD1} , I_{DD2} or I_{DD3} and I_{FIL} and I_{WDT} when the watchdog timer is in operation.

Note 5. This current only flows into the A/D converter. The supply current of the RL78 microcontrollers is the sum of I_{DD1} or I_{DD2} and I_{ADC} when the A/D converter is operating or in the HALT mode.

Note 6. This current only flows into a single comparator. The supply current of the RL78 microcontrollers is the sum of I_{DD1} , I_{DD2} or I_{DD3} and I_{CMP} when the comparator is in operation.

Note 7. This current only flows during self-programming.

Remark The temperature condition of the TYP. value is $T_A = 25^\circ\text{C}$.

23.4 AC Characteristics

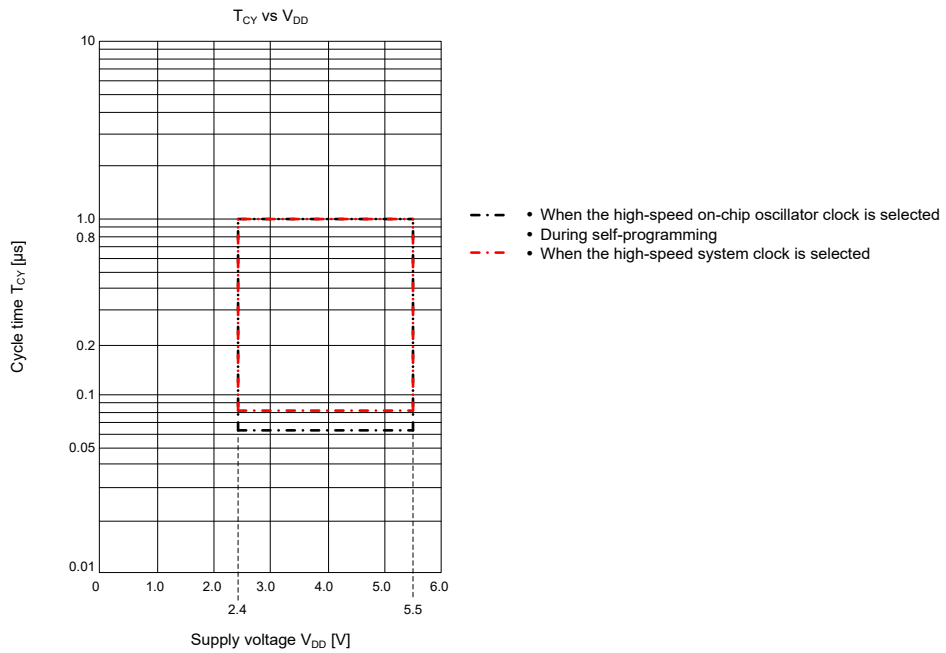
[$T_A = -40$ to $+85^\circ\text{C}$, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit | |
|---|-----------------------|---|--|----------------------|--------|------|---------------|---------------|
| Instruction cycle (minimum instruction execution time) | T_{CY} | When high-speed on-chip oscillator clock (f_{IH}) is selected | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | 0.0625 | | 1.0 | μs | |
| | | When high-speed system clock (f_{MX}) is selected | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | Square wave input | 0.0625 | | 1.0 | μs |
| | | | | Resonator connection | 0.0833 | | 1.0 | μs |
| | | In the self-programming mode | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | 0.0625 | | 1.0 | μs | |
| External system clock frequency | f_{EX} | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | | 1.0 | | 16 | MHz | |
| External system clock input high-level width, low-level width | t_{EXH} , t_{EXL} | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | | 30 | | | ns | |
| T100 to T107 input high-level width, low-level width | t_{TIH} , t_{TIL} | Noise filter is not used | | $1/f_{MCK} + 10$ | | | ns | |
| TO00 to TO07 output frequency | f_{TO} | $4.0\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | | | | 8 | MHz | |
| | | $2.7\text{ V} \leq V_{DD} < 4.0\text{ V}$ | | | | 5 | MHz | |
| | | $2.4\text{ V} \leq V_{DD} < 2.7\text{ V}$ | | | | 4 | MHz | |
| PCLBUZ0 output frequency | f_{PCL} | $4.0\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | | | | 10 | MHz | |
| | | $2.7\text{ V} \leq V_{DD} < 4.0\text{ V}$ | | | | 5 | MHz | |
| | | $2.4\text{ V} \leq V_{DD} < 2.7\text{ V}$ | | | | 4 | MHz | |
| RESET low-level width | t_{RSL} | | | 10 | | | μs | |

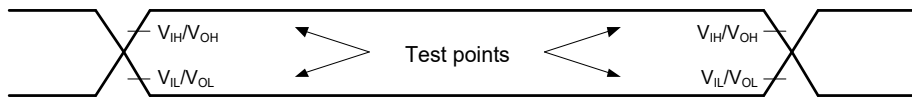
Remark f_{MCK} : Timer array unit operating clock frequency

(Operation clock to be set by timer clock select register 0 (TPS0) and the CKS0n1 bit of timer mode register 0n (TMR0n). n: Channel number (n = 0 to 7).)

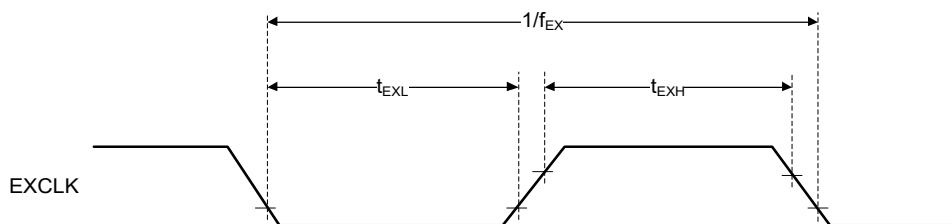
Minimum Instruction Execution Time during Main System Clock Operation



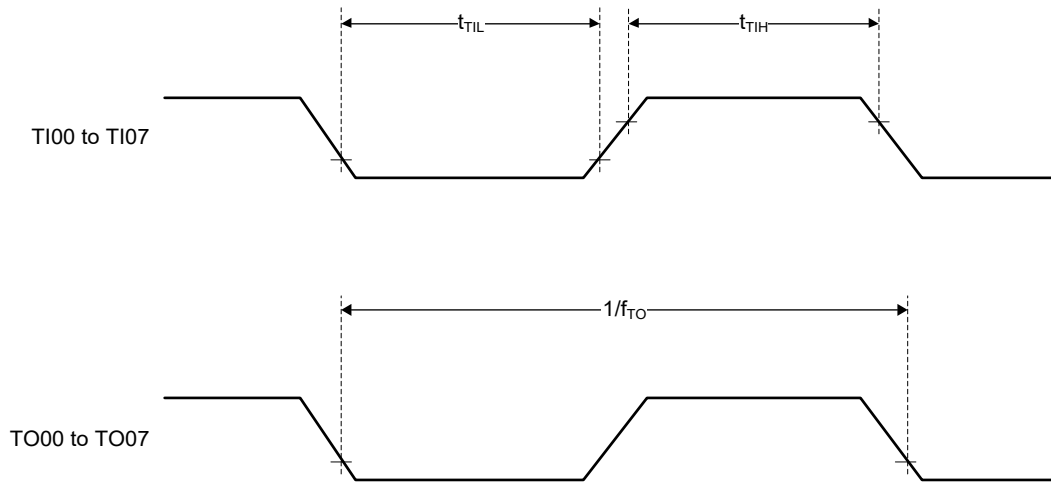
At AC Timing



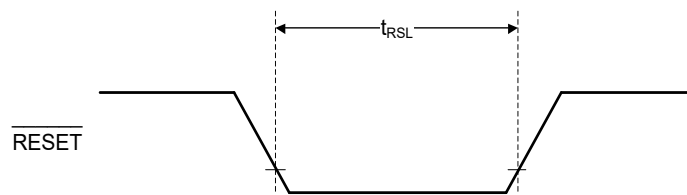
External System Clock Timing



TI/TO Timing

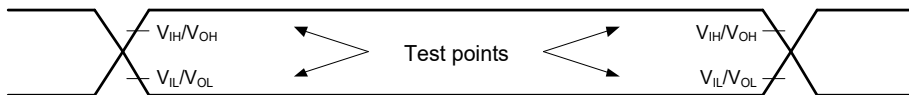


RESET Input Timing



23.5 Serial Interface Characteristics

AC Timing Test Points



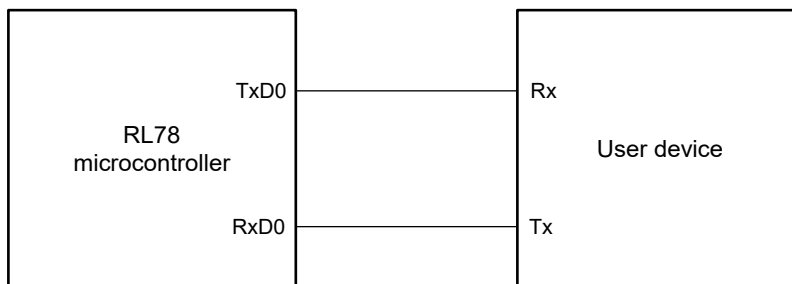
23.5.1 Serial array unit

(1) UART mode

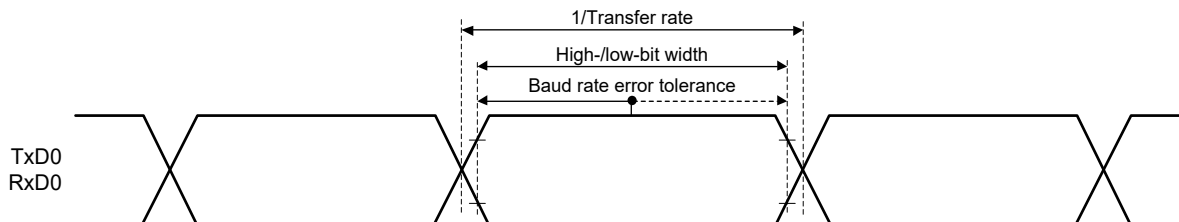
[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---------------|--------|--|------|------|---------------------|------|
| Transfer rate | | | | | f _{MCK} /6 | bps |
| | | Theoretical value of the maximum transfer rate f _{CLK} = f _{MCK} = 16 MHz | | | 2.6 | Mbps |

UART mode connection diagram



UART mode bit width (reference)



Remark f_{MCK}: Serial array unit operation clock frequency
 (Operation clock to be set by serial clock select register 0 (SPS0) and the CKS0n bit of serial mode register 0n (SMR0n). n: Channel number (n = 0, 1))

(2) Simplified SPI (CSI) mode (master mode, SCKp... internal clock output)**[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]**

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|--|-------------------------------------|---|---------------------------|------|------|------|
| SCKp cycle time | t _{KCY1} | t _{KCY1} ≥ 4/f _{CLK} 2.4 V ≤ V _{DD} ≤ 5.5 V | 250 | | | ns |
| SCKp high-/low-level width | t _{KH1} , t _{KL1} | 2.7 V ≤ V _{DD} ≤ 5.5 V | t _{KCY1} /2 - 18 | | | ns |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | t _{KCY1} /2 - 38 | | | ns |
| Slp setup time (to SCKp ↑) ^{Note 1} | t _{SIK1} | 2.7 V ≤ V _{DD} ≤ 5.5 V | 47 | | | ns |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | 75 | | | ns |
| Slp hold time (from SCKp ↑) ^{Note 1} | t _{KSH1} | | 19 | | | ns |
| Delay time from SCKp ↓ to SOp output ^{Note 2} | t _{KSO1} | C = 30 pF ^{Note 3} | | | 25 | ns |

Note 1. When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1. The Slp setup time becomes “to SCKp ↓” and the Slp hold time becomes “from SCKp ↓” when DAP0n = 0 and CKP0n = 1, or DAP0n = 1 and CKP0n = 0.

Note 2. When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1. The delay time to SOp output becomes “from SCKp ↓” when DAP0n = 0 and CKP0n = 1, or DAP0n = 1 and CKP0n = 0.

Note 3. C is the load capacitance of the SCKp and SOp output lines.

(3) Simplified SPI (CSI) mode (slave mode, SCKp... external clock input)**[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5V, V_{SS} = 0V]**

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|--|-------------------------------------|---------------------------------|------------------------------------|------|-------------------------|------|
| SCKp cycle time | t _{KCY2} | 2.7 V ≤ V _{DD} ≤ 5.5 V | 6/f _{MCK} | | | ns |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | 6/f _{MCK} and also 500 | | | ns |
| SCKp high-/low-level width | t _{KH2} , t _{KL2} | 2.4 V ≤ V _{DD} ≤ 5.5 V | t _{KCY2} /2 - 18 | | | ns |
| Slp setup time (to SCKp ↑) ^{Note 1} | t _{SIK2} | 2.7 V ≤ V _{DD} ≤ 5.5 V | 1/f _{MCK} + 20 | | | ns |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | 1/f _{MCK} + 30 | | | ns |
| Slp hold time (from SCKp ↑) ^{Note 1} | t _{KSI2} | 2.4 V ≤ V _{DD} ≤ 5.5 V | 1/f _{MCK} + 31 | | | ns |
| Delay time from SCKp ↓ to SOp output ^{Note 2} | t _{KSO2} | C = 30 pF ^{Note 3} | 2.7 V ≤ V _{DD} ≤ 5.5 V | | 2/f _{MCK} + 50 | ns |
| | | | 2.4 V ≤ V _{DD} ≤ 5.5 V | | 2/f _{MCK} + 75 | ns |

Note 1. When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1. The Slp setup time becomes “to SCKp ↓” and the Slp hold time becomes “from SCKp ↓” when DAP0n = 0 and CKP0n = 1, or DAP0n = 1 and CKP0n = 0.

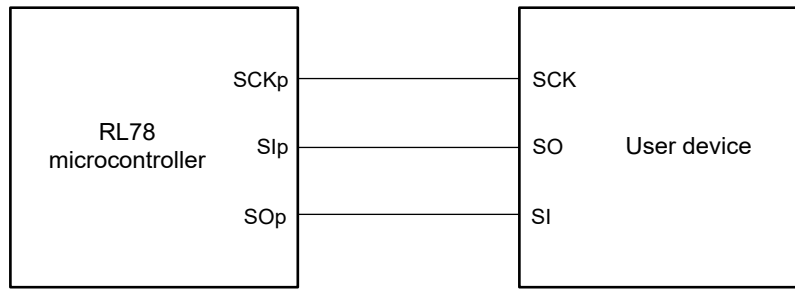
Note 2. When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1. The delay time to SOp output becomes “from SCKp ↓” when DAP0n = 0 and CKP0n = 1, or DAP0n = 1 and CKP0n = 0.

Note 3. C is the load capacitance of the SOp output lines.

Remark 1. p: CSI number (p = 00, 01), n: Channel number (n = 0, 1)

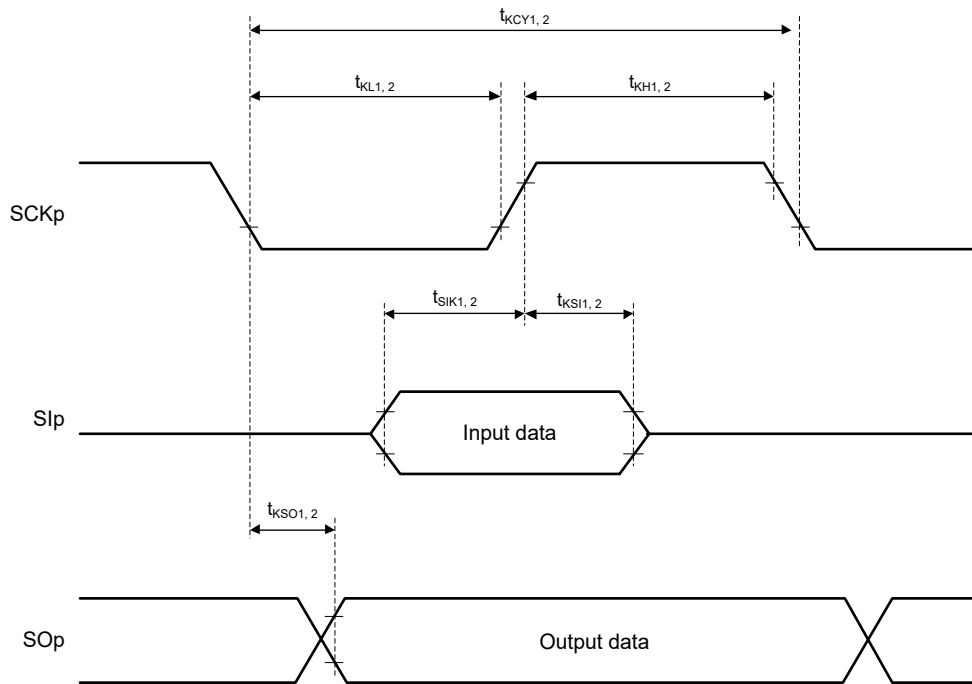
Remark 2. f_{MCK}: Serial array unit operation clock frequency
 (Operation clock to be set by serial clock select register 0 (SPS0) and the CKS0n bit of serial mode register 0n (SMR0n). n: Channel number (n = 0, 1))

Simplified SPI (CSI) mode connection diagram



Simplified SPI (CSI) mode serial transfer timing

(When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1)



Remark p: CSI number (p = 00, 01), n: Channel number (n = 0, 1)

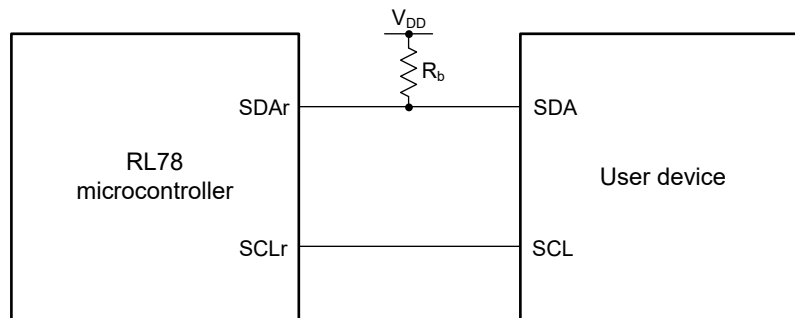
(4) Simplified I²C mode**[$T_A = -40$ to $+85^\circ\text{C}$, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]**

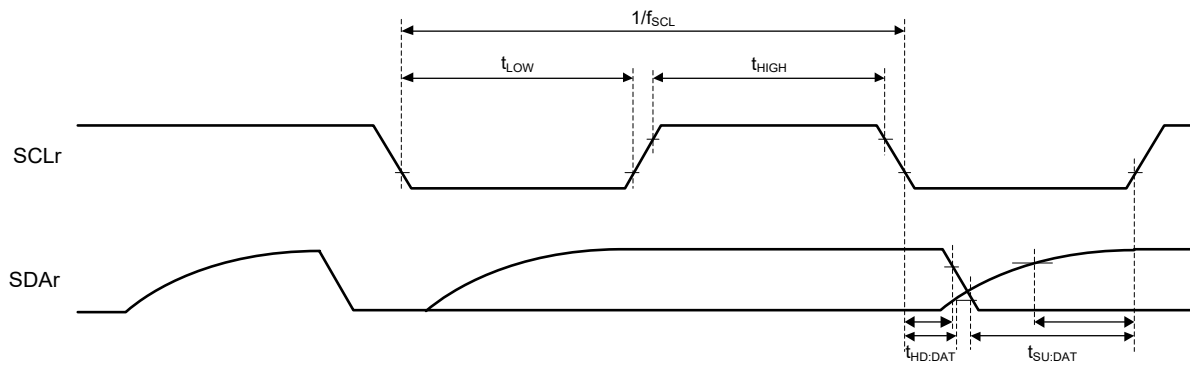
| Item | Symbol | Condition | MIN. | MAX. | Unit |
|-------------------------------|---------------------|--|--|-----------------------|------|
| SCLr clock frequency | f_{SCL} | $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | | 400 ^{Note 1} | kHz |
| Hold time when SCLr = "L" | t_{LOW} | $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | 1150 | | ns |
| Hold time when SCLr = "H" | t_{HIGH} | $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | 1150 | | ns |
| Data setup time (reception) | $t_{\text{SU:DAT}}$ | $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | $1/f_{\text{MCK}} + 145$ ^{Note 2} | | ns |
| Data hold time (transmission) | $t_{\text{HD:DAT}}$ | $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | 0 | 355 | ns |

Note 1. The value must also be no greater than $f_{\text{MCK}}/4$.

Note 2. Set f_{MCK} so that it will not exceed the hold time when SCLr = "L" or SCLr = "H".

Caution Select the N-ch open drain output (V_{DD} tolerance) mode for the SDAr pin by using port output mode register 0, 2, or 4 (POM0, 2, or 4).

Simplified I²C mode connection diagram

Simplified I²C mode serial transfer timing

- Remark 1.** $R_b[\Omega]$: Communication line (SDAr) pull-up resistance, $C_b[F]$: Communication line (SCLr, SDAr) load capacitance
- Remark 2.** r: IIC number (r = 00, 01)
- Remark 3.** f_{MCK} : Serial array unit operation clock frequency
(Operation clock to be set by serial clock select register 0 (SPS0) and the CKS0n bit of serial mode register 0n (SMR0n). n: Channel number (n = 0, 1))

23.5.2 Serial interface IICA

[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Symbol | Condition | Standard Mode | | Fast Mode | | Unit |
|---|---------------------|--|---------------|------|-----------|------|------|
| | | | MIN. | MAX. | MIN. | MAX. | |
| SCLA0 clock frequency | f _{SCL} | Fast mode: f _{CLK} ≥ 3.5 MHz | | | 0 | 400 | kHz |
| | | Standard mode: f _{CLK} ≥ 1 MHz | 0 | 100 | | | kHz |
| Setup time of restart condition | t _{SU:STA} | | 4.7 | | 0.6 | | μs |
| Hold time ^{Note 1} | t _{HD:STA} | | 4.0 | | 0.6 | | μs |
| Hold time when SCLA0 = "L" | t _{LOW} | | 4.7 | | 1.3 | | μs |
| Hold time when SCLA0 = "H" | t _{HIGH} | | 4.0 | | 0.6 | | μs |
| Data setup time (reception) | t _{SU:DAT} | | 250 | | 100 | | ns |
| Data hold time (transmission) ^{Note 2} | t _{HD:DAT} | | 0 | 3.45 | 0 | 0.9 | μs |
| Setup time of stop condition | t _{SU:STO} | | 4.0 | | 0.6 | | μs |
| Bus-free time | t _{BUF} | | 4.7 | | 1.3 | | μs |

Note 1. The first clock pulse is generated after this period when the start or restart condition is detected.

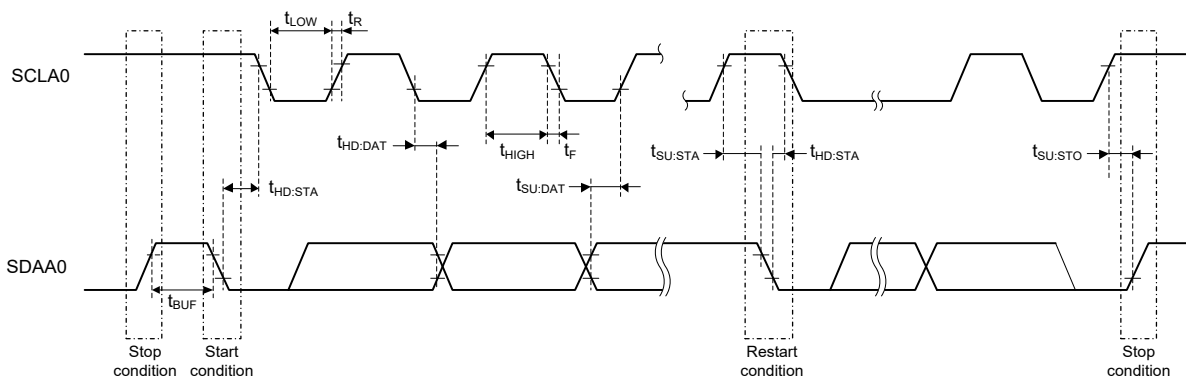
Note 2. The maximum value (MAX.) of t_{HD:DAT} applies to normal transfer and a wait is inserted at the ACK (acknowledge) timing.

Remark The maximum value of C_b (communication line capacitance) and the value of R_b (communication line pull-up resistance) at that time in each mode are as follows.

Standard mode: C_b = 400 pF, R_b = 2.7 kΩ

Fast mode: C_b = 200 pF, R_b = 1.7 kΩ

IICA serial transfer timing



23.6 Analog Characteristics

23.6.1 A/D converter characteristics

Targets: ANI0 to ANI10, internal reference voltage

[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit |
|--|-------------------|---|--|------|------|------------------------------------|------|
| Resolution | RES | | | 8 | | 10 | bit |
| Overall error ^{Note 1, Note 2, Note 3} | AINL | 10-bit resolution | V _{DD} = 5 V | | ±1.7 | ±3.1 | LSB |
| | | | V _{DD} = 3 V | | ±2.3 | ±4.5 | LSB |
| Conversion time | t _{CONV} | 10-bit resolution Targets: ANI0 to ANI10 | 2.7 V ≤ V _{DD} ≤ 5.5 V | 4.25 | | 17 | μs |
| | | | 2.4 V ≤ V _{DD} ≤ 5.5 V ^{Note 5} | 5.75 | | 23 | μs |
| | | 10-bit resolution Target: Internal reference voltage ^{Note 6} | 2.4 V ≤ V _{DD} ≤ 5.5 V | 5.75 | | 23 | μs |
| Zero-scale error ^{Note 1, Note 2, Note 3, Note 4} | E _{ZS} | 10-bit resolution | V _{DD} = 5 V | | | ±0.19 | %FSR |
| | | | V _{DD} = 3 V | | | ±0.39 | %FSR |
| Full-scale error ^{Note 1, Note 2, Note 3, Note 4} | E _{FS} | 10-bit resolution | V _{DD} = 5 V | | | ±0.29 | %FSR |
| | | | V _{DD} = 3 V | | | ±0.42 | %FSR |
| Integral linearity error ^{Note 1, Note 2, Note 3} | ILE | 10-bit resolution | V _{DD} = 5 V | | | ±1.8 | LSB |
| | | | V _{DD} = 3 V | | | ±1.7 | LSB |
| Differential linearity error ^{Note 1, Note 2, Note 3} | DLE | 10-bit resolution | V _{DD} = 5 V | | | ±1.4 | LSB |
| | | | V _{DD} = 3 V | | | ±1.5 | LSB |
| Analog input voltage | V _{AIN} | Targets: ANI0 to ANI10 | | 0 | | V _{DD} | V |
| | | Target: Internal reference voltage ^{Note 6} | | | | V _{REG} ^{Note 7} | V |

Note 1. The TYP. value is an average value at T_A = 25°C. The MAX. value is an average value ±3σ at normal distribution.

Note 2. These values are the results of characteristic evaluation and are not checked for shipment.

Note 3. A quantization error (±1/2 LSB) is not included.

Note 4. Expressed as a ratio (%FSR) relative to the full-scale value.

Note 5. Be sure to set the LV0 bit in A/D converter mode register 0 (ADM0) to 0 when conversion is done in the operating voltage range of 2.4 V ≤ V_{DD} < 2.7 V.

Note 6. Be sure to set the LV0 bit in A/D converter mode register 0 (ADM0) to 0 when the internal reference voltage is selected as the target for conversion.

Note 7. Refer to **23.6.3 Internal reference voltage characteristics**.

Caution 1. Arrange wiring and insert the capacitor so that no noise appears on the power supply/ground line.

Caution 2. Do not allow any pulses that rapidly change such as digital signals to be input/output to/from the pins adjacent to the conversion pin during A/D conversion.

Caution 3. Note that the internal reference voltage cannot be used as the reference voltage of the comparator when the internal reference voltage is selected as the target for A/D conversion.

23.6.2 Comparator characteristics

[$T_A = -40$ to $+85^\circ\text{C}$, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|-----------------------------------|------------|---|-----------------------------|------|----------------|---------------|
| Input voltage range | I_{VREF} | IVREFn pin input (CnVRF bit = 0) | 0 | | $V_{DD} - 1.4$ | V |
| | | Internal reference voltage (CnVRF bit = 1) ^{Note 1} | V_{REG} ^{Note 2} | | | V |
| | I_{VCMP} | IVCMPn pin input | -0.3 | | $V_{DD} + 0.3$ | V |
| Output delay | t_d | $V_{DD} = 3.0\text{ V}$, input slew rate $> 50\text{ mV}/\mu\text{s}$ | High-speed mode | | 0.5 | μs |
| | | | Low-speed mode | | 2.0 | μs |
| Operation stabilization wait time | t_{CMP} | | 100 | | | μs |

Note 1. When the internal reference voltage is selected as the reference voltage of the comparator, the internal reference voltage cannot be used as the target for A/D conversion.

Note 2. Refer to **23.6.3 Internal reference voltage characteristics**.

Remark n: Channel number (n = 0, 1)

23.6.3 Internal reference voltage characteristics

[$T_A = -40$ to $+85^\circ\text{C}$, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|-----------------------------------|-----------|--|------|-------|------|---------------|
| Internal reference voltage | V_{REG} | | 0.74 | 0.815 | 0.89 | V |
| Operation stabilization wait time | t_{AMP} | A/D converter is used (ADS register = 0DH) | 5 | | | μs |

Caution The internal reference voltage cannot be simultaneously used by the A/D converter and the comparator; only one of them must be selected.

23.6.4 SPOR circuit characteristics

[$T_A = -40$ to $+85^\circ\text{C}$, $V_{SS} = 0$ V]

| Item | | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---------------------------------------|----------------------------|-------------|----------------------|------|------|------|---------------|
| Detection voltage | Power supply voltage level | V_{SPOR0} | Power supply rising | 4.08 | 4.28 | 4.45 | V |
| | | V_{SPDR0} | Power supply falling | 4.00 | 4.20 | 4.37 | V |
| | | V_{SPOR1} | Power supply rising | 2.76 | 2.90 | 3.02 | V |
| | | V_{SPDR1} | Power supply falling | 2.70 | 2.84 | 2.96 | V |
| | | V_{SPOR2} | Power supply rising | 2.44 | 2.57 | 2.68 | V |
| | | V_{SPDR2} | Power supply falling | 2.40 | 2.52 | 2.62 | V |
| | | V_{SPOR3} | Power supply rising | | 2.16 | | V |
| | | V_{SPDR3} | Power supply falling | | 2.11 | | V |
| Minimum pulse width ^{Note 1} | | T_{SPW} | | 300 | | | μs |

Note 1. Time required for the reset operation by the SPOR circuit when V_{DD} falls below V_{SPDR} .

Caution Make sure to keep the internal reset state by the SPOR or an external reset until the power supply voltage (V_{DD}) reaches the operating voltage range shown in 23.4 AC Characteristics.

23.6.5 Power supply voltage rising slope characteristics

[$T_A = -40$ to $+85^\circ\text{C}$, $V_{SS} = 0$ V]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|-----------------------------------|-----------|-----------|------|------|------|------|
| Power supply voltage rising slope | S_{VDD} | | | | 54 | V/ms |

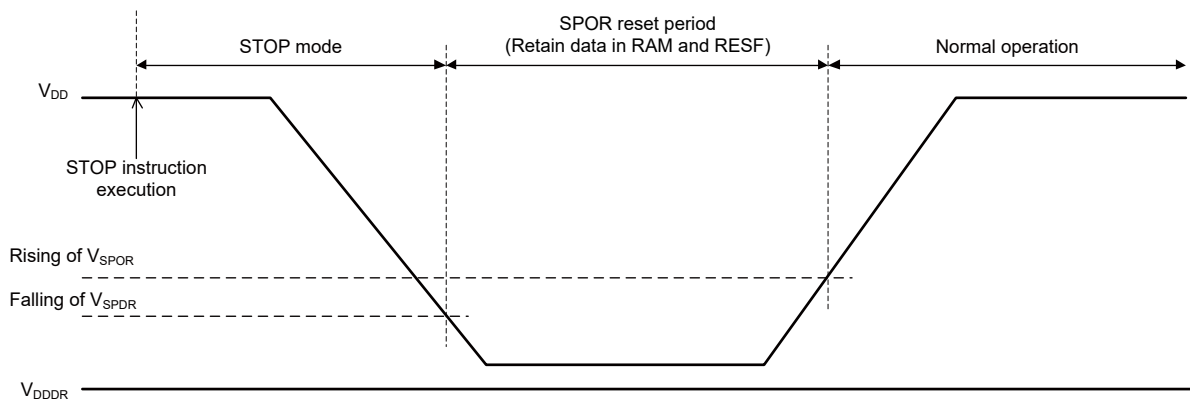
Caution Make sure to keep the internal reset state by the SPOR or an external reset until the power supply voltage (V_{DD}) reaches the operating voltage range shown in 23.4 AC Characteristics.

23.7 RAM Data Retention Characteristics

[T_A = -40 to +85°C, V_{SS} = 0 V]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|-------------------------------------|-------------------|-----------|------|------|------|------|
| Data retention power supply voltage | V _{DDDR} | | 1.9 | | 5.5 | V |

Caution Data in RAM is retained until the power supply voltage falls below the MIN. value of the data retention power supply voltage (V_{DDDR}). Note that data in the RESF register might not be cleared even if the power supply voltage falls below the MIN. value of the data retention power supply voltage (V_{DDDR}).



23.8 Flash Memory Programming Characteristics

[$T_A = -40$ to $+85^\circ\text{C}$, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit |
|---|------------|-----------------------|---------------------------|---------|-----------|------|-------|
| Number of code flash rewrites Note 1, Note 2 | C_{erwr} | Retained for 20 years | $T_A = +85^\circ\text{C}$ | 1000 | | | Times |
| Number of data flash rewrites Note 1, Note 2 | | Retained for 1 year | $T_A = +25^\circ\text{C}$ | | 1,000,000 | | Times |
| | | Retained for 5 years | $T_A = +85^\circ\text{C}$ | 100,000 | | | Times |
| | | Retained for 20 years | $T_A = +85^\circ\text{C}$ | 10,000 | | | Times |

Note 1. 1 erase + 1 write after the erase is regarded as 1 rewrite. The retaining years are until next rewrite after the rewrite.

Note 2. These are the characteristics of the flash memory and the results obtained from reliability testing by Renesas Electronics.

Code flash/data flash self-programming time

[$T_A = -40$ to $+85^\circ\text{C}$, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | $f_{CLK} = 1\text{ MHz}$ | | | $f_{CLK} = 16\text{ MHz}$ | | | Unit |
|----------------------|-----------|--------------------------|------|-------|---------------------------|------|-------|---------------|
| | | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. | |
| Writing (4 bytes) | t_{P4} | | 104 | 905 | | 53.8 | 504.9 | μs |
| Block erasure (1 KB) | t_{E1K} | | 7.9 | 262.3 | | 5.5 | 214.1 | ms |

Caution The listed values do not include the time until the operations of the flash memory start following execution of an instruction by software.

23.9 Dedicated Flash Memory Programmer Communication (UART)

[$T_A = -40$ to $+85^\circ\text{C}$, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

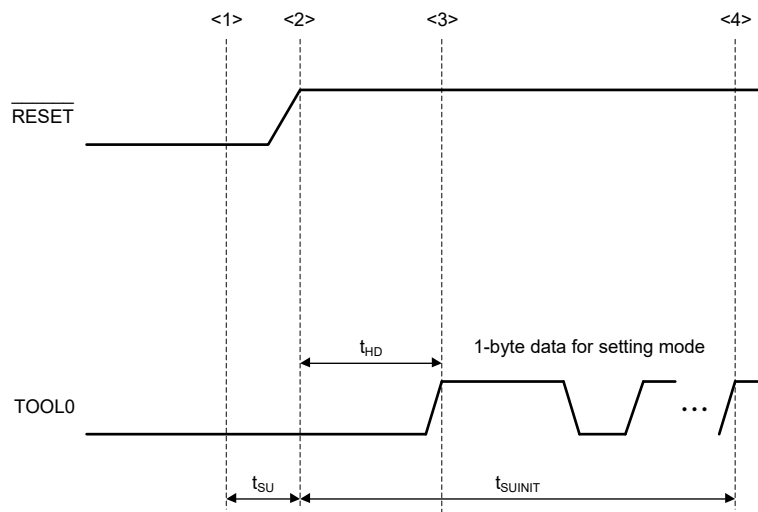
| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---------------|--------|-----------|------|---------|------|------|
| Transfer rate | | | | 115,200 | | bps |

Remark The transfer rate during flash memory programming is fixed to 115,200 bps.

23.10 Timing of Entry to Flash Memory Programming Mode

[T_A = -40 to +85°C, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---|---------------------|--|------|------|------|------|
| Time to complete the communication for the initial setting after the external reset is released | t _{SUINIT} | The SPOR reset must be released before the external reset is released. | | | 100 | ms |
| Time to release the external reset after the TOOL0 pin is set to the low level | t _{SU} | The SPOR reset must be released before the external reset is released. | 10 | | | μs |
| Time to hold the TOOL0 pin at the low level after the external reset is released | t _{HD} | The SPOR reset must be released before the external reset is released. | 1 | | | ms |



- <1> The low level is input to the TOOL0 pin.
- <2> The external reset is released (the SPOR reset must have been released before that).
- <3> The TOOL0 pin is released from the low level.
- <4> Setting of entry to the flash memory programming mode by UART reception is completed.

Remark t_{SUINIT}: During this period, the communications for the initial setting must be completed within 100 ms after release from the reset.

t_{SU}: Time to release the external reset after the TOOL0 pin is set to the low level

t_{HD}: Time to hold the TOOL0 pin at the low level after the external reset is released

CHAPTER 24 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+105^\circ\text{C}$, $T_A = -40$ to $+125^\circ\text{C}$)

This chapter describes the electrical specifications of the following target products.

Target product G: Industrial applications $T_A = -40$ to $+105^\circ\text{C}$

Target product M: Industrial applications $T_A = -40$ to $+125^\circ\text{C}$

Caution 1. The RL78 microcontrollers have an on-chip debug function, which is provided for development and evaluation. Do not use the on-chip debug function in products designated for mass production, because the guaranteed number of rewritable times of the flash memory may be exceeded when this function is used, and product reliability therefore cannot be guaranteed. Renesas Electronics is not liable for problems occurring when the on-chip debug function is used.

Caution 2. The pins mounted depend on the product. Refer to 2.1 Port Function for the port functions and 2.2.1 Functions for each product for the other functions.

★ **Remark** When the products are used in the range of $T_A = -40$ to $+85^\circ\text{C}$, refer to **CHAPTER 23 Electrical Specifications ($T_A = -40$ to $+85^\circ\text{C}$)**. However, there are differences in the high-speed on-chip oscillator clock accuracy between G: Industrial applications and M: Industrial applications, and A: Consumer applications.

| Classification | A: Consumer applications | G: Industrial applications | M: Industrial applications |
|--|---|--|--|
| High-speed on-chip oscillator clock accuracy | $\pm 2.0\%$ when $T_A = -40$ to $+85^\circ\text{C}$ | $\pm 1.5\%$ when $T_A = +85$ to $+105^\circ\text{C}$ $\pm 1.0\%$ when $T_A = -20$ to $+85^\circ\text{C}$ $\pm 1.5\%$ when $T_A = -40$ to -20°C | $\pm 1.5\%$ when $T_A = +85$ to $+125^\circ\text{C}$ $\pm 1.0\%$ when $T_A = -20$ to $+85^\circ\text{C}$ $\pm 1.5\%$ when $T_A = -40$ to -20°C |

24.1 Absolute Maximum Ratings

[$T_A = 25^\circ\text{C}$]

| Item | Symbol | Condition | Rating | Unit | |
|-------------------------------|-----------|-----------------------------|--|------------------|----|
| Supply voltage | V_{DD} | | -0.5 to +6.5 | V | |
| Input voltage | V_{I1} | | -0.3 to $V_{DD} + 0.3$ ^{Note 1} | V | |
| Output voltage | V_{O1} | | -0.3 to $V_{DD} + 0.3$ | V | |
| Output current, high | I_{OH1} | Per pin | -40 | mA | |
| | | Total of all pins -170mA | P20 to P23, P40, P41, P121, P122, P125 | -70 | mA |
| | | | P00 to P07 | -100 | mA |
| Output current, low | I_{OL1} | Per pin | 40 | mA | |
| | | Total of all pins 170mA | P20 to P23, P40, P41, P121, P122, P125 | 100 | mA |
| | | | P00 to P07 | 100 | mA |
| Operating ambient temperature | T_A | G products | -40 to +105 | $^\circ\text{C}$ | |
| | | M products | -40 to +125 | $^\circ\text{C}$ | |
| Storage temperature | T_{stg} | | -65 to +150 | $^\circ\text{C}$ | |

Note 1. This must be no greater than 6.5 V.

Caution Product quality may suffer if the absolute maximum rating is exceeded even momentarily for any item. That is, the absolute maximum ratings are rated values at which the product is on the verge of suffering physical damage, and therefore the product must be used under conditions that ensure that the absolute maximum ratings are not exceeded.

Remark 1. The characteristics of functions multiplexed on a given pin are the same as those for the port pin unless otherwise specified.

Remark 2. The reference voltage is V_{SS} .

24.2 Oscillator Characteristics

24.2.1 X1 oscillator characteristics

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Resonator | Condition | MIN. | TYP. | MAX. | Unit |
|--|---|--|------|------|------|------|
| X1 clock oscillation frequency (f_x) ^{Note 1} | Ceramic resonator/ crystal resonator | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | 1 | | 12 | MHz |

Note 1. Indicates only permissible oscillator frequency ranges. Refer to **24.4 AC Characteristics** for instruction execution time. For actual applications, request evaluation by the manufacturer of the oscillator circuit mounted on a board so you can use appropriate values.

Caution Since the CPU is started by the high-speed on-chip oscillator clock after release from the reset state, the user should use the oscillation stabilization time counter status register (OSTC) to check the X1 clock oscillation stabilization time. Specify the values for the oscillation stabilization time in the OSTC register and the oscillation stabilization time select register (OSTS) after having sufficiently evaluated the oscillation stabilization time with the resonator to be used.

Remark When using the X1 oscillator, refer to **5.4 System Clock Oscillator**.

24.2.2 On-chip oscillator characteristics

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---|----------|-------------------------------------|------|------|------|------|
| High-speed on-chip oscillator clock frequency ^{Note 1, Note 2} | f_{IH} | | 1 | | 16 | MHz |
| High-speed on-chip oscillator clock frequency accuracy | | $T_A = +85$ to $+125^\circ\text{C}$ | -1.5 | | +1.5 | % |
| | | $T_A = -20$ to $+85^\circ\text{C}$ | -1.0 | | +1.0 | % |
| | | $T_A = -40$ to -20°C | -1.5 | | +1.5 | % |
| Low-speed on-chip oscillator clock frequency | f_{IL} | | | 15 | | kHz |
| Low-speed on-chip oscillator clock frequency accuracy | | | -15 | | +15 | % |

Note 1. The high-speed on-chip oscillator frequency is selected by bits 0 to 2 of option byte (00C2H).

Note 2. The listed values only indicate the characteristics of the oscillators. Refer to **24.4 AC Characteristics** for instruction execution time.

24.3 DC Characteristics

24.3.1 Pin characteristics

[T_A = -40 to +105°C: G products, T_A = -40 to +125°C: M products, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

(1/2)

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit | |
|--|------------------|--|---------------------------------|--------------------------------|------------------------|------|----|
| Output current, high ^{Note 1} | I _{OH1} | Per pin for P00 to P07, P20 to P23, P40, P41, P121, P122, P125 | | | -3.0 ^{Note 2} | mA | |
| | | Total of P20 to P23, P40, P41, P121, P122, P125 (when duty ≤ 70% ^{Note 3}) | 4.0 V ≤ V _{DD} ≤ 5.5 V | | -25.0 | mA | |
| | | | 2.4 V ≤ V _{DD} < 4.0 V | | -7.0 | mA | |
| | | Total of P00 to P07 (when duty ≤ 70% ^{Note 3}) | 4.0 V ≤ V _{DD} ≤ 5.5 V | | -24.0 | mA | |
| | | | 2.4 V ≤ V _{DD} < 4.0 V | | -6.0 | mA | |
| Total of all pins (when duty ≤ 70% ^{Note 3}) | | | | -40.0 | mA | | |
| Output current, low ^{Note 4} | I _{OL1} | Per pin for P00 to P07, P20 to P23, P40, P41, P121, P122, P125 | | | 8.5 ^{Note 2} | mA | |
| | | Total of P20 to P23, P40, P41, P121, P122, P125 (when duty ≤ 70% ^{Note 3}) | 4.0 V ≤ V _{DD} ≤ 5.5 V | T _A = -40 to +105°C | | 50.0 | mA |
| | | | | T _A = -40 to +125°C | | 40.0 | mA |
| | | | 2.7 V ≤ V _{DD} < 4.0 V | | | 10.5 | mA |
| | | | 2.4 V ≤ V _{DD} < 2.7 V | | | 4.2 | mA |
| | | Total of P00 to P07 (when duty ≤ 70% ^{Note 3}) | 4.0 V ≤ V _{DD} ≤ 5.5 V | T _A = -40 to +105°C | | 50.0 | mA |
| | | | | T _A = -40 to +125°C | | 40.0 | mA |
| | | | 2.7 V ≤ V _{DD} < 4.0 V | | | 9.0 | mA |
| | | | 2.4 V ≤ V _{DD} < 2.7 V | | | 3.6 | mA |
| | | Total of all pins (when duty ≤ 70% ^{Note 3}) | | T _A = -40 to +105°C | | 80.0 | mA |
| | | | | T _A = -40 to +125°C | | 60.0 | mA |

Note 1. Device operation is guaranteed at the listed currents even if current is flowing from the V_{DD} pin to an output pin.

Note 2. The value for maximum total current must not be exceeded.

Note 3. The listed currents apply when the duty cycle is no greater than 70%. Use the following formula to calculate the output current when the duty cycle is greater than 70%, where n is the duty cycle.

- Total output current from the listed pins = (I_{OH} × 0.7)/(n × 0.01)
Example when n = 80% and I_{OH} = -10.0 mA
Total output current from the listed pins = (-10.0 × 0.7)/(80 × 0.01) ≅ -8.7 mA
- Total output current from the listed pins = (I_{OL} × 0.7)/(n × 0.01)
Example when n = 80% and I_{OL} = 10.0 mA
Total output current from the listed pins = (10.0 × 0.7)/(80 × 0.01) ≅ 8.7 mA

Note that the duty cycle has no effect on the current that is allowed to flow into a single pin. A current higher than the absolute maximum rating must not flow into a single pin.

Note 4. Device operation is guaranteed at the listed currents even if current is flowing from an output pin to the V_{SS} pin.

Caution P00, P01, P03 to P07, P22, and P41 do not output high level in N-ch open-drain mode.

Remark The characteristics of functions multiplexed on a given pin are the same as those for the port pin unless otherwise specified.

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

(2/2)

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit |
|--------------------------------|-------------------------|--|---------------------------------------|----------------|------|---------------|------------------|
| Input voltage, high | V_{IH1} | | | $0.8 V_{DD}$ | | V_{DD} | V |
| Input voltage, low | V_{IL1} | | | 0 | | $0.2 V_{DD}$ | V |
| Output voltage, high Note 1 | V_{OH1} | $4.0\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | $I_{OH} = -3.0\text{ mA}$ | $V_{DD} - 0.7$ | | | V |
| | | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | $I_{OH} = -1.0\text{ mA}$ | $V_{DD} - 0.5$ | | | V |
| Output voltage, low Note 2 | V_{OL1} | $4.0\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | $I_{OL} = 8.5\text{ mA}$ | | | 0.7 | V |
| | | $2.7\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | $I_{OL} = 1.5\text{ mA}$ | | | 0.5 | V |
| | | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | $I_{OL} = 0.6\text{ mA}$ | | | 0.4 | V |
| Input leakage current, high | I_{LH1} | P00 to P07, P20 to P23, P40, P41, P125, P137 $V_i = V_{DD}$ | | | | 1 | μA |
| | | P121, P122 (X1, X2, EXCLK) $V_i = V_{DD}$ | In input port or external clock input | | | 1 | μA |
| | In resonator connection | | | | 10 | μA | |
| Input leakage current, low | I_{LH1} | P00 to P07, P20 to P23, P40, P41, P125, P137 $V_i = V_{SS}$ | | | | -1 | μA |
| | | P121, P122 (X1, X2, EXCLK) $V_i = V_{SS}$ | In input port or external clock input | | | -1 | μA |
| | In resonator connection | | | | -10 | μA | |
| On-chip pull-up resistance | R_U | $V_i = V_{SS}$ | | 10 | 20 | 100 | $\text{k}\Omega$ |

Note 1. The value under the condition which satisfies the high-level output current (I_{OH1}).

Note 2. The value under the condition which satisfies the low-level output current (I_{OL1}).

Caution The maximum value of V_{IH} of P00, P01, P03 to P07, P22, and P41 is V_{DD} even in N-ch open-drain mode. These pins do not output high level in N-ch open-drain mode.

Remark The characteristics of functions multiplexed on a given pin are the same as those for the port pin unless otherwise specified.

24.3.2 Supply current characteristics

[T_A = -40 to +105°C: G products, T_A = -40 to +125°C: M products, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit | | |
|------------------------------------|------------------------------------|--|-------------------------|--|--------------------------------|------|------|------|----|
| Supply current ^{Note 1} | I _{DD1} | Operating mode | Basic operation | f _{IH} = 16 MHz ^{Note 4} | V _{DD} = 3.0 V, 5.0 V | | 0.87 | mA | |
| | | | Normal operation | f _{IH} = 16 MHz ^{Note 4} | V _{DD} = 3.0 V, 5.0 V | | 1.86 | 2.49 | mA |
| | | f _{IH} = 4 MHz ^{Note 4} | | V _{DD} = 3.0 V, 5.0 V | | 1.17 | 1.65 | mA | |
| | | f _{EX} = 16 MHz ^{Note 5, Note 6} | | Square wave input | | 1.69 | 2.32 | mA | |
| | | f _X = 12 MHz ^{Note 5, Note 6} | | Resonator connection | | 1.57 | 2.32 | mA | |
| | | f _{MX} = 4 MHz ^{Note 5, Note 6} | Square wave input | | 1.00 | 1.47 | mA | | |
| | | | Resonator connection | | 1.05 | 1.55 | mA | | |
| | I _{DD2} ^{Note 2} | HALT mode | | f _{IH} = 16 MHz ^{Note 4} | V _{DD} = 3.0 V, 5.0 V | | 371 | 811 | μA |
| | | | | f _{IH} = 4 MHz ^{Note 4} | V _{DD} = 3.0 V, 5.0 V | | 334 | 637 | μA |
| | | | | f _{EX} = 16 MHz ^{Note 5, Note 6} | Square wave input | | 207 | 647 | μA |
| | | | | f _X = 12 MHz ^{Note 5, Note 6} | Resonator connection | | 309 | 909 | μA |
| | | | | f _{MX} = 4 MHz ^{Note 5, Note 6} | Square wave input | | 156 | 459 | μA |
| | | | | | Resonator connection | | 207 | 609 | μA |
| I _{DD3} ^{Note 3} | STOP mode | | V _{DD} = 3.0 V | T _A = +105°C | | 0.62 | 3.71 | μA | |
| | | | | T _A = +125°C | | 0.62 | 7.44 | μA | |

Note 1. The listed currents are the total currents flowing into V_{DD}, including the input leakage currents flowing when the level of the input pin is fixed to V_{DD} or V_{SS}.
Regarding the values for main system clock operation, the TYP. value does not include the peripheral operating current. The MAX. value includes the peripheral operating current, but does not include those flowing into the A/D converter, comparator, I/O port, and on-chip pull-up/pull-down resistors.
Regarding the values for subsystem clock operation, the TYP. and MAX. values do not include the peripheral operating current. However, in HALT mode, the current flowing into the RTC is included.
Regarding the values in STOP mode, the TYP. and MAX. values do not include the peripheral operating current.

Note 2. When the HALT instruction is executed from the flash memory.

Note 3. The listed currents do not include the current flowing into the 12-bit interval timer and watchdog timer.

Note 4. When the high-speed subsystem clock is stopped.

Note 5. When the high-speed on-chip oscillator is stopped.

Note 6. 16-pin and 20-pin products only.

Remark 1. f_{IH}: High-speed on-chip oscillator clock frequency

Remark 2. f_{MX}: High-speed system clock frequency (X1 clock oscillation frequency or external main system clock frequency)

Remark 3. The temperature condition of the TYP. value is T_A = 25°C.

Peripheral Functions

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit |
|--|--|--------------------------------|-------------------------|------|------|-------|---------------|
| Low-speed on-chip oscillator operating current | I_{FIL} ^{Note 1} | | | | 0.30 | | μA |
| 12-bit interval timer operating current | I_{TMKA} ^{Note 1, Note 2, Note 3} | | | | 0.02 | | μA |
| Watchdog timer operating current | I_{WDT} ^{Note 1, Note 4} | | | | 0.02 | | μA |
| A/D converter operating current | I_{ADC} ^{Note 1, Note 5} | In conversion at maximum speed | $V_{DD} = 5.0\text{ V}$ | | 1.30 | 1.90 | mA |
| | | | $V_{DD} = 3.0\text{ V}$ | | 0.50 | | mA |
| Comparator operating current | I_{CMP} ^{Note 1, Note 6} | In high-speed mode | $V_{DD} = 5.0\text{ V}$ | | 6.50 | | μA |
| | | In low-speed mode | $V_{DD} = 5.0\text{ V}$ | | 1.70 | | μA |
| Internal reference voltage operating current | I_{VREG} ^{Note 1} | | | | 10 | | μA |
| Self-programming operating current | I_{FSP} ^{Note 1, Note 7} | | | | 2.0 | 12.20 | mA |

Note 1. The current flowing into V_{DD} .

Note 2. When the high-speed on-chip oscillator and high-speed system clock are stopped.

Note 3. This current only flows into the 12-bit interval timer. It does not include the operating current of the low-speed on-chip oscillator. The supply current of the RL78 microcontrollers is the sum of I_{DD1} , I_{DD2} or I_{DD3} and I_{FIL} and I_{TMKA} when the 12-bit interval timer is in operation.

Note 4. This current only flows into the watchdog timer. It does not include the operating current of the low-speed on-chip oscillator. The supply current of the RL78 microcontrollers is the sum of I_{DD1} , I_{DD2} or I_{DD3} and I_{FIL} and I_{WDT} when the watchdog timer is in operation.

Note 5. This current only flows into the A/D converter. The supply current of the RL78 microcontrollers is the sum of I_{DD1} or I_{DD2} and I_{ADC} when the A/D converter is operating or in the HALT mode.

Note 6. This current only flows into a single comparator. The supply current of the RL78 microcontrollers is the sum of I_{DD1} , I_{DD2} or I_{DD3} and I_{CMP} when the comparator is in operation.

Note 7. This current only flows during self-programming.

Remark The temperature condition of the TYP. value is $T_A = 25^\circ\text{C}$.

24.4 AC Characteristics

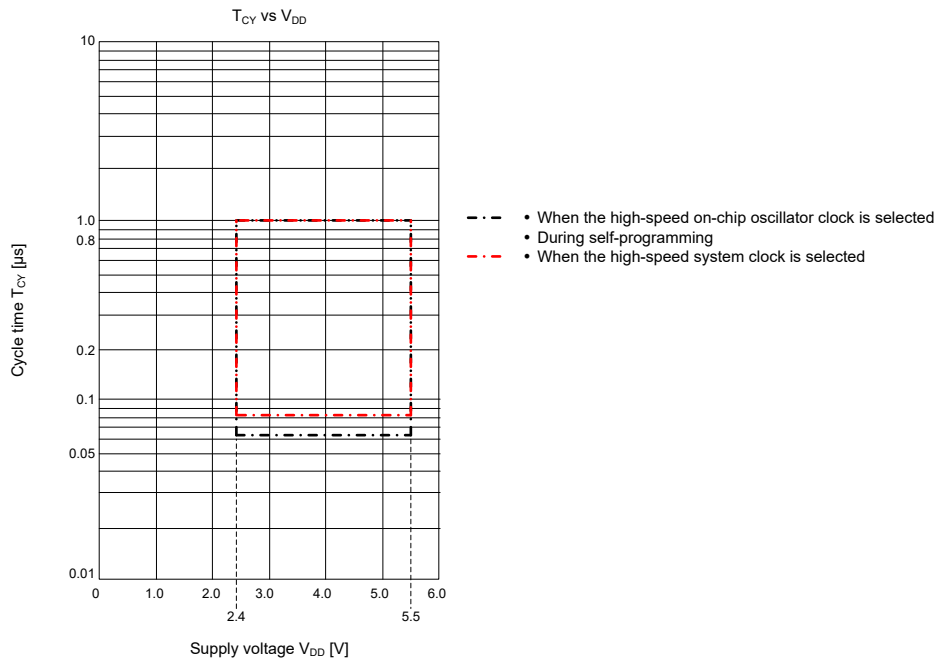
[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit | |
|---|-----------------------|---|--|----------------------|--------|------|---------------|---------------|
| Instruction cycle (minimum instruction execution time) | T_{CY} | When high-speed on-chip oscillator clock (f_{IH}) is selected | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | 0.0625 | | 1.0 | μs | |
| | | When high-speed system clock (f_{MX}) is selected | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | Square wave input | 0.0625 | | 1.0 | μs |
| | | | | Resonator connection | 0.0833 | | 1.0 | μs |
| | | In the self-programming mode | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | 0.0625 | | 1.0 | μs | |
| External system clock frequency | f_{EX} | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | | 1.0 | | 16 | MHz | |
| External system clock input high-level width, low-level width | t_{EXH} , t_{EXL} | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | | 30 | | | ns | |
| T100 to T107 input high-level width, low-level width | t_{TIH} , t_{TIL} | Noise filter is not used | | $1/f_{MCK} + 10$ | | | ns | |
| TO00 to TO07 output frequency | f_{TO} | $4.0\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | | | | 8 | MHz | |
| | | $2.7\text{ V} \leq V_{DD} < 4.0\text{ V}$ | | | | 5 | MHz | |
| | | $2.4\text{ V} \leq V_{DD} < 2.7\text{ V}$ | | | | 4 | MHz | |
| PCLBUZ0 output frequency | f_{PCL} | $4.0\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | | | | 10 | MHz | |
| | | $2.7\text{ V} \leq V_{DD} < 4.0\text{ V}$ | | | | 5 | MHz | |
| | | $2.4\text{ V} \leq V_{DD} < 2.7\text{ V}$ | | | | 4 | MHz | |
| RESET low-level width | t_{RSL} | | | 10 | | | μs | |

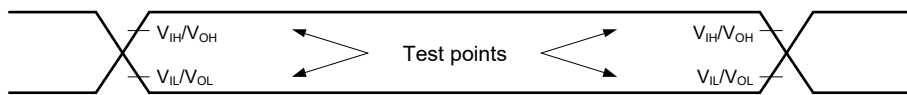
Remark f_{MCK} : Timer array unit operating clock frequency

(Operation clock to be set by timer clock select register 0 (TPS0) and the CKS0n1 bit of timer mode register 0n (TMR0n). n: Channel number (n = 0 to 7).)

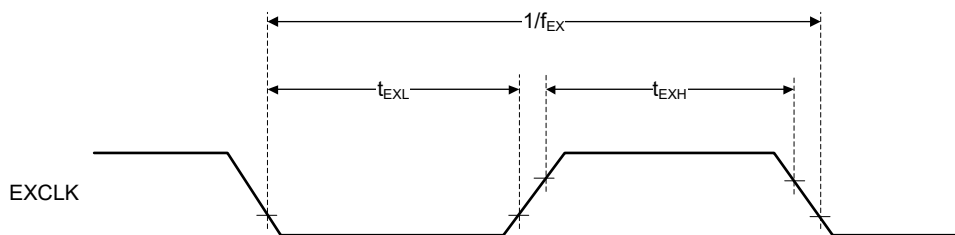
Minimum Instruction Execution Time during Main System Clock Operation



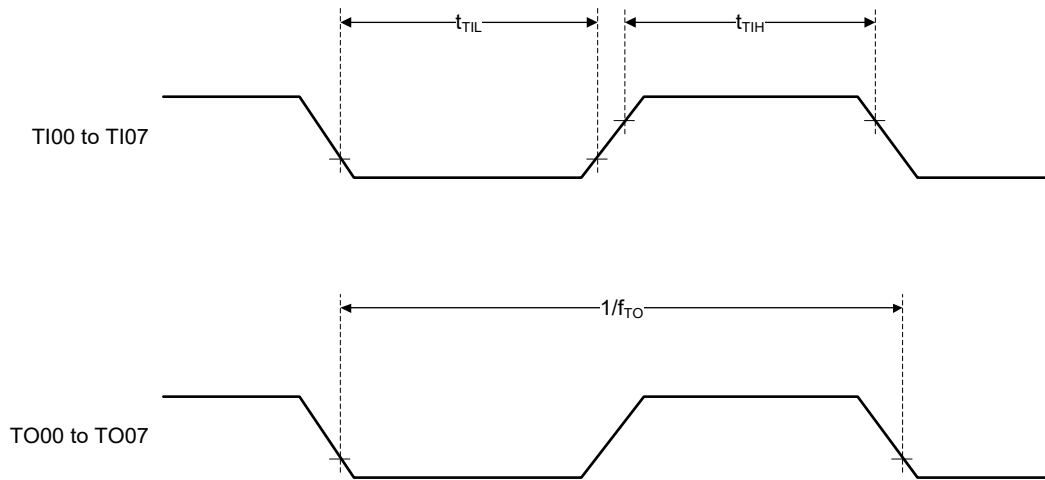
At AC Timing



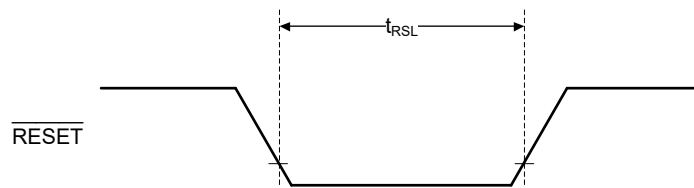
External System Clock Timing



TI/TO Timing

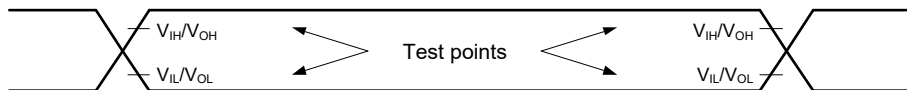


$\overline{\text{RESET}}$ Input Timing



24.5 Serial Interface Characteristics

AC Timing Test Points



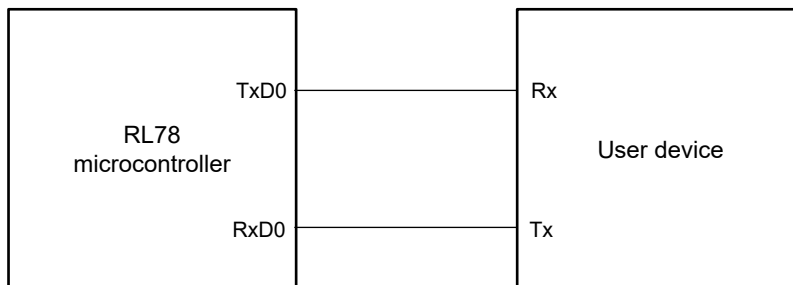
24.5.1 Serial array unit

(1) UART mode

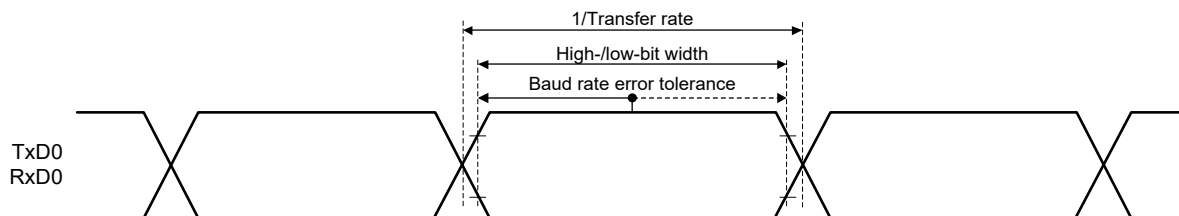
[T_A = -40 to +105°C: G products, T_A = -40 to +125°C: M products, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---------------|--------|--|------|------|----------------------|------|
| Transfer rate | | | | | f _{MCK} /12 | bps |
| | | Theoretical value of the maximum transfer rate f _{CLK} = f _{MCK} = 16 MHz | | | 1.3 | Mbps |

UART mode connection diagram



UART mode bit width (reference)



Remark f_{MCK}: Serial array unit operation clock frequency
 (Operation clock to be set by serial clock select register 0 (SPS0) and the CKS0n bit of serial mode register 0n (SMR0n). n: Channel number (n = 0, 1))

(2) Simplified SPI (CSI) mode (master mode, SCKp... internal clock output)**[T_A = -40 to +105°C: G products, T_A = -40 to +125°C: M products, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]**

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit | |
|--|-------------------------------------|--|---------------------------------|---------------------------|------|------|----|
| SCKp cycle time | t _{KCY1} | t _{KCY1} ≥ 4/f _{CLK} | 2.7 V ≤ V _{DD} ≤ 5.5 V | 250 | | | ns |
| | | | 2.4 V ≤ V _{DD} ≤ 5.5 V | 500 | | | ns |
| SCKp high-/low-level width | t _{KH1} , t _{KL1} | 2.7 V ≤ V _{DD} ≤ 5.5 V | | t _{KCY1} /2 - 36 | | | ns |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | | t _{KCY1} /2 - 76 | | | ns |
| Slp setup time (to SCKp ↑) ^{Note 1} | t _{SIK1} | 2.7 V ≤ V _{DD} ≤ 5.5 V | | 66 | | | ns |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | | 113 | | | ns |
| Slp hold time (from SCKp ↑) ^{Note 1} | t _{KSI1} | | | 38 | | | ns |
| Delay time from SCKp ↓ to SOp output ^{Note 2} | t _{KSO1} | C = 30 pF ^{Note 3} | | | 66 | | ns |

Note 1. When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1. The Slp setup time becomes “to SCKp ↓” and the Slp hold time becomes “from SCKp ↓” when DAP0n = 0 and CKP0n = 1, or DAP0n = 1 and CKP0n = 0.

Note 2. When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1. The delay time to SOp output becomes “from SCKp ↓” when DAP0n = 0 and CKP0n = 1, or DAP0n = 1 and CKP0n = 0.

Note 3. C is the load capacitance of the SCKp and SOp output lines.

(3) Simplified SPI (CSI) mode (slave mode, SCKp... external clock input)**[T_A = -40 to +105°C: G products, T_A = -40 to +125°C: M products, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]**

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit | |
|--|-------------------------------------|---------------------------------|---------------------------------|-----------------------------------|------|--------------------------|----|
| SCKp cycle time | t _{KCY2} | 2.7 V ≤ V _{DD} ≤ 5.5 V | | 12/f _{MCK} | | | ns |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | | 12/f _{MCK} and also 1000 | | | ns |
| SCKp high-/low-level width | t _{KH2} , t _{KL2} | 2.7 V ≤ V _{DD} ≤ 5.5 V | | t _{KCY2} /2 - 16 | | | ns |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | | t _{KCY2} /2 - 36 | | | ns |
| Slp setup time (to SCKp ↑) ^{Note 1} | t _{SIK2} | 2.7 V ≤ V _{DD} ≤ 5.5 V | | 1/f _{MCK} + 40 | | | ns |
| | | 2.4 V ≤ V _{DD} ≤ 5.5 V | | 1/f _{MCK} + 60 | | | ns |
| Slp hold time (from SCKp ↑) ^{Note 1} | t _{KSI2} | 2.4 V ≤ V _{DD} ≤ 5.5 V | | 1/f _{MCK} + 62 | | | ns |
| Delay time from SCKp ↓ to SOp output ^{Note 2} | t _{KSO2} | C = 30 pF ^{Note 3} | 2.7 V ≤ V _{DD} ≤ 5.5 V | | | 2/f _{MCK} + 66 | ns |
| | | | 2.4 V ≤ V _{DD} ≤ 5.5 V | | | 2/f _{MCK} + 113 | ns |

Note 1. When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1. The Slp setup time becomes “to SCKp ↓” and the Slp hold time becomes “from SCKp ↓” when DAP0n = 0 and CKP0n = 1, or DAP0n = 1 and CKP0n = 0.

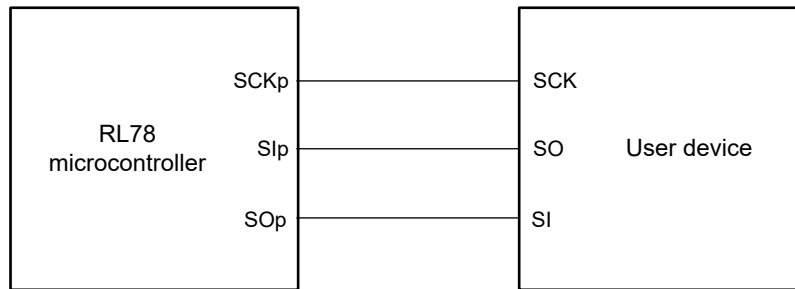
Note 2. When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1. The delay time to SOp output becomes “from SCKp ↓” when DAP0n = 0 and CKP0n = 1, or DAP0n = 1 and CKP0n = 0.

Note 3. C is the load capacitance of the SOp output lines.

Remark 1. p: CSI number (p = 00, 01), n: Channel number (n = 0, 1)

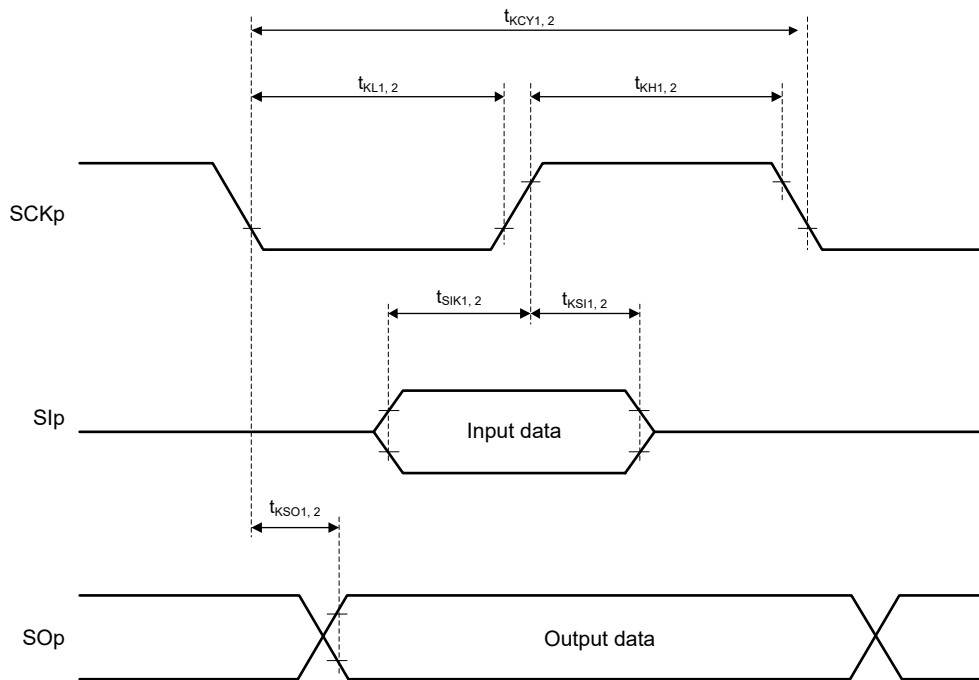
Remark 2. f_{MCK}: Serial array unit operation clock frequency
 (Operation clock to be set by serial clock select register 0 (SPS0) and the CKS0n bit of serial mode register 0n (SMR0n). n: Channel number (n = 0, 1))

Simplified SPI (CSI) mode connection diagram



Simplified SPI (CSI) mode serial transfer timing

(When DAP0n = 0 and CKP0n = 0, or DAP0n = 1 and CKP0n = 1)



Remark p: CSI number (p = 00, 01), n: Channel number (n = 0, 1)

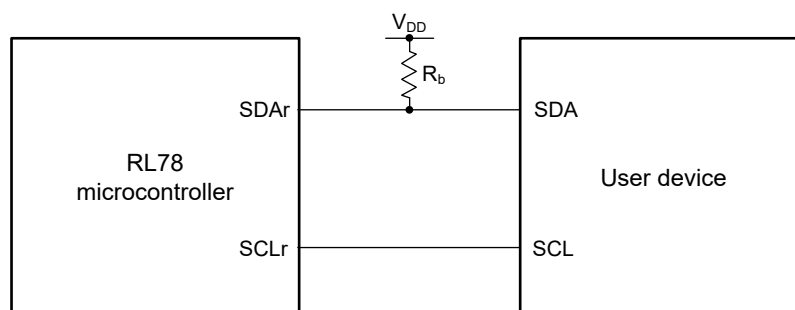
(4) Simplified I²C mode**[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]**

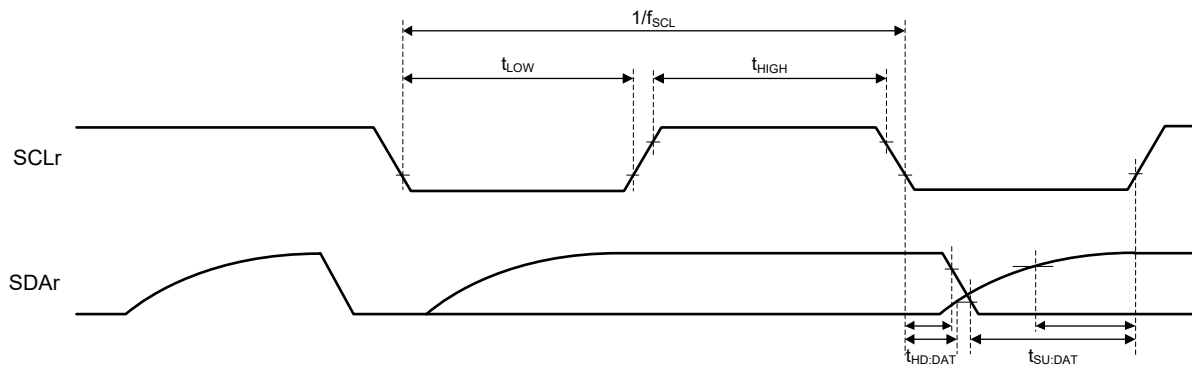
| Item | Symbol | Condition | MIN. | MAX. | Unit |
|-------------------------------|---------------------|--|--|-----------------------|------|
| SCLr clock frequency | f_{SCL} | $2.7\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | | 400 ^{Note 1} | kHz |
| | | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | | 100 ^{Note 1} | kHz |
| Hold time when SCLr = "L" | t_{LOW} | $2.7\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | 1200 | | ns |
| | | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | 4600 | | ns |
| Hold time when SCLr = "H" | t_{HIGH} | $2.7\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | 1200 | | ns |
| | | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | 4600 | | ns |
| Data setup time (reception) | $t_{\text{SU:DAT}}$ | $2.7\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | $1/f_{\text{MCK}} + 220$ ^{Note 2} | | ns |
| | | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | $1/f_{\text{MCK}} + 580$ ^{Note 2} | | ns |
| Data hold time (transmission) | $t_{\text{HD:DAT}}$ | $2.7\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | 0 | 770 | ns |
| | | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ $C_b = 100\text{ pF}$, $R_b = 3\text{ k}\Omega$ | 0 | 1420 | ns |

Note 1. The value must also be no greater than $f_{\text{MCK}}/4$.

Note 2. Set f_{MCK} so that it will not exceed the hold time when SCLr = "L" or SCLr = "H".

Caution Select the N-ch open drain output (V_{DD} tolerance) mode for the SDAr pin by using port output mode register 0, 2, or 4 (POM0, 2, or 4).

Simplified I²C mode connection diagram

Simplified I²C mode serial transfer timing

- Remark 1.** $R_b[\Omega]$: Communication line (SDAr) pull-up resistance, $C_b[F]$: Communication line (SCLr, SDAr) load capacitance
- Remark 2.** r: IIC number (r = 00, 01)
- Remark 3.** f_{MCK} : Serial array unit operation clock frequency
(Operation clock to be set by serial clock select register 0 (SPS0) and the CKS0n bit of serial mode register 0n (SMR0n). n: Channel number (n = 0, 1))

24.5.2 Serial interface IICA

[T_A = -40 to +105°C: G products, T_A = -40 to +125°C: M products, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Symbol | Condition | Standard Mode | | Fast Mode | | Unit |
|---|---------------------|--|---------------|------|-----------|------|------|
| | | | MIN. | MAX. | MIN. | MAX. | |
| SCLA0 clock frequency | f _{SCL} | Fast mode: f _{CLK} ≥ 3.5 MHz | | | 0 | 400 | kHz |
| | | Standard mode: f _{CLK} ≥ 1 MHz | 0 | 100 | | | kHz |
| Setup time of restart condition | t _{SU:STA} | | 4.7 | | 0.6 | | μs |
| Hold time ^{Note 1} | t _{HD:STA} | | 4.0 | | 0.6 | | μs |
| Hold time when SCLA0 = "L" | t _{LOW} | | 4.7 | | 1.3 | | μs |
| Hold time when SCLA0 = "H" | t _{HIGH} | | 4.0 | | 0.6 | | μs |
| Data setup time (reception) | t _{SU:DAT} | | 250 | | 100 | | ns |
| Data hold time (transmission) ^{Note 2} | t _{HD:DAT} | | 0 | 3.45 | 0 | 0.9 | μs |
| Setup time of stop condition | t _{SU:STO} | | 4.0 | | 0.6 | | μs |
| Bus-free time | t _{BUF} | | 4.7 | | 1.3 | | μs |

Note 1. The first clock pulse is generated after this period when the start or restart condition is detected.

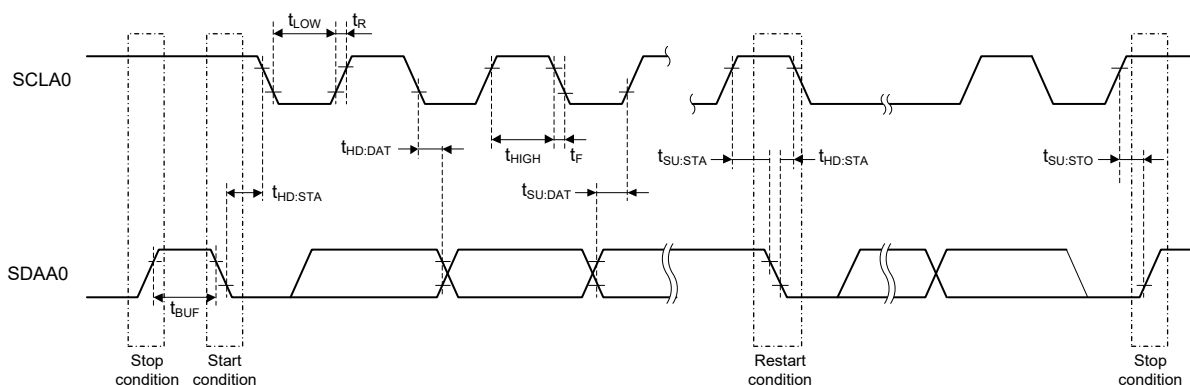
Note 2. The maximum value (MAX.) of t_{HD:DAT} applies to normal transfer and a wait is inserted at the ACK (acknowledge) timing.

Remark The maximum value of C_b (communication line capacitance) and the value of R_b (communication line pull-up resistance) at that time in each mode are as follows.

Standard mode: C_b = 400 pF, R_b = 2.7 kΩ

Fast mode: C_b = 200 pF, R_b = 1.7 kΩ

IICA serial transfer timing



24.6 Analog Characteristics

24.6.1 A/D converter characteristics

Targets: ANI0 to ANI10, internal reference voltage

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit |
|--|-------------------|---|---|------------------------------------|-----------|------------|---------------|
| Resolution | RES | | | 8 | | 10 | bit |
| Overall error ^{Note 1, Note 2, Note 3} | AINL | 10-bit resolution | $V_{DD} = 5\text{ V}$ | | ± 1.7 | ± 3.1 | LSB |
| | | | $V_{DD} = 3\text{ V}$ | | ± 2.3 | ± 4.5 | LSB |
| Conversion time | t_{CONV} | 10-bit resolution Targets: ANI0 to ANI10 | $2.7\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | 4.25 | | 17 | μs |
| | | | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ ^{Note 5} | 5.75 | | 23 | μs |
| | | 10-bit resolution Target: Internal reference voltage ^{Note 6} | $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$ | 5.75 | | 23 | μs |
| Zero-scale error ^{Note 1, Note 2, Note 3, Note 4} | E_{ZS} | 10-bit resolution | $V_{DD} = 5\text{ V}$ | | | ± 0.19 | %FSR |
| | | | $V_{DD} = 3\text{ V}$ | | | ± 0.39 | %FSR |
| Full-scale error ^{Note 1, Note 2, Note 3, Note 4} | E_{FS} | 10-bit resolution | $V_{DD} = 5\text{ V}$ | | | ± 0.29 | %FSR |
| | | | $V_{DD} = 3\text{ V}$ | | | ± 0.42 | %FSR |
| Integral linearity error ^{Note 1, Note 2, Note 3} | ILE | 10-bit resolution | $V_{DD} = 5\text{ V}$ | | | ± 1.8 | LSB |
| | | | $V_{DD} = 3\text{ V}$ | | | ± 1.7 | LSB |
| Differential linearity error ^{Note 1, Note 2, Note 3} | DLE | 10-bit resolution | $V_{DD} = 5\text{ V}$ | | | ± 1.4 | LSB |
| | | | $V_{DD} = 3\text{ V}$ | | | ± 1.5 | LSB |
| Analog input voltage | V_{AIN} | Targets: ANI0 to ANI10 | | 0 | | V_{DD} | V |
| | | Target: Internal reference voltage ^{Note 6} | | V_{REG} ^{Note 7} | | | V |

Note 1. The TYP. value is an average value at $T_A = 25^\circ\text{C}$. The MAX. value is an average value $\pm 3\sigma$ at normal distribution.

Note 2. These values are the results of characteristic evaluation and are not checked for shipment.

Note 3. A quantization error ($\pm 1/2$ LSB) is not included.

Note 4. Expressed as a ratio (%FSR) relative to the full-scale value.

Note 5. Be sure to set the LV0 bit in A/D converter mode register 0 (ADM0) to 0 when conversion is done in the operating voltage range of $2.4\text{ V} \leq V_{DD} < 2.7\text{ V}$.

Note 6. Be sure to set the LV0 bit in A/D converter mode register 0 (ADM0) to 0 when the internal reference voltage is selected as the target for conversion.

Note 7. Refer to **24.6.3 Internal reference voltage characteristics**.

Caution 1. Arrange wiring and insert the capacitor so that no noise appears on the power supply/ground line.

Caution 2. Do not allow any pulses that rapidly change such as digital signals to be input/output to/from the pins adjacent to the conversion pin during A/D conversion.

Caution 3. Note that the internal reference voltage cannot be used as the reference voltage of the comparator when the internal reference voltage is selected as the target for A/D conversion.

24.6.2 Comparator characteristics

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|-----------------------------------|------------|---|-----------------------------|------|----------------|---------------|
| Input voltage range | I_{VREF} | IVREFn pin input (CnVRF bit = 0) | 0 | | $V_{DD} - 1.4$ | V |
| | | Internal reference voltage (CnVRF bit = 1) ^{Note 1} | V_{REG} ^{Note 2} | | | V |
| | I_{VCMP} | IVCMPn pin input | -0.3 | | $V_{DD} + 0.3$ | V |
| Output delay | t_d | $V_{DD} = 3.0\text{ V}$, input slew rate $> 50\text{ mV}/\mu\text{s}$ | High-speed mode | | 0.5 | μs |
| | | | Low-speed mode | | 2.0 | μs |
| Operation stabilization wait time | t_{CMP} | | 100 | | | μs |

Note 1. When the internal reference voltage is selected as the reference voltage of the comparator, the internal reference voltage cannot be used as the target for A/D conversion.

Note 2. Refer to **24.6.3 Internal reference voltage characteristics**.

Remark n: Channel number (n = 0, 1)

24.6.3 Internal reference voltage characteristics

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|-----------------------------------|-----------|--|------|-------|------|---------------|
| Internal reference voltage | V_{REG} | | 0.74 | 0.815 | 0.89 | V |
| Operation stabilization wait time | t_{AMP} | A/D converter is used (ADS register = 0DH) | 5 | | | μs |

Caution The internal reference voltage cannot be simultaneously used by the A/D converter and the comparator; only one of them must be selected.

24.6.4 SPOR circuit characteristics

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $V_{SS} = 0$ V]

| Item | | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---------------------------------------|----------------------------|-------------|----------------------|------|------|------|---------------|
| Detection voltage | Power supply voltage level | V_{SPOR0} | Power supply rising | 4.08 | 4.28 | 4.45 | V |
| | | V_{SPDR0} | Power supply falling | 4.00 | 4.20 | 4.37 | V |
| | | V_{SPOR1} | Power supply rising | 2.76 | 2.90 | 3.02 | V |
| | | V_{SPDR1} | Power supply falling | 2.70 | 2.84 | 2.96 | V |
| | | V_{SPOR2} | Power supply rising | 2.44 | 2.57 | 2.68 | V |
| | | V_{SPDR2} | Power supply falling | 2.40 | 2.52 | 2.62 | V |
| | | V_{SPOR3} | Power supply rising | | 2.16 | | V |
| | | V_{SPDR3} | Power supply falling | | 2.11 | | V |
| Minimum pulse width ^{Note 1} | | T_{SPW} | | 300 | | | μs |

Note 1. Time required for the reset operation by the SPOR circuit when V_{DD} falls below V_{SPDR} .

Caution Make sure to keep the internal reset state by the SPOR or an external reset until the power supply voltage (V_{DD}) reaches the operating voltage range shown in 24.4 AC Characteristics.

24.6.5 Power supply voltage rising slope characteristics

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $V_{SS} = 0$ V]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|-----------------------------------|-----------|-----------|------|------|------|------|
| Power supply voltage rising slope | S_{VDD} | | | | 54 | V/ms |

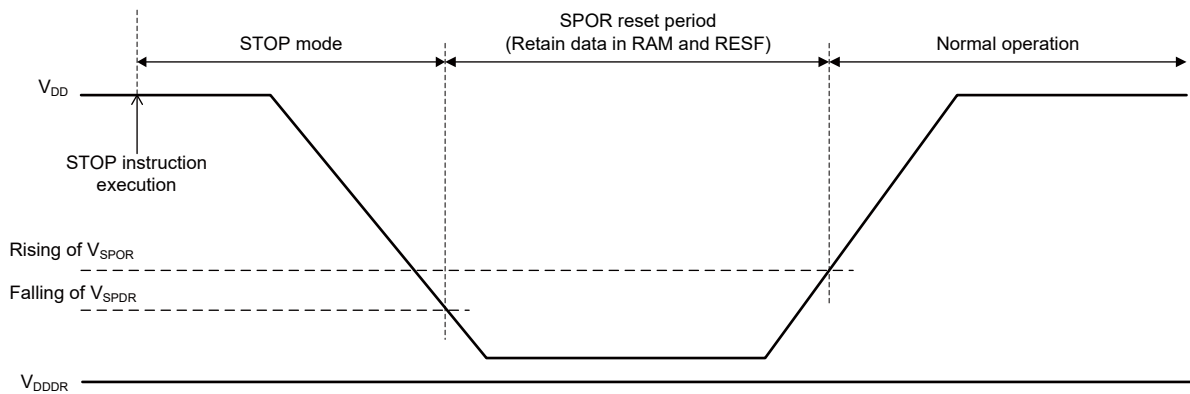
Caution Make sure to keep the internal reset state by the SPOR or an external reset until the power supply voltage (V_{DD}) reaches the operating voltage range shown in 24.4 AC Characteristics.

24.7 RAM Data Retention Characteristics

[T_A = -40 to +105°C: G products, T_A = -40 to +125°C: M products, V_{SS} = 0 V]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|-------------------------------------|-------------------|-----------|------|------|------|------|
| Data retention power supply voltage | V _{DDDR} | | 1.9 | | 5.5 | V |

Caution Data in RAM is retained until the power supply voltage falls below the MIN. value of the data retention power supply voltage (V_{DDDR}). Note that data in the RESF register might not be cleared even if the power supply voltage falls below the MIN. value of the data retention power supply voltage (V_{DDDR}).



24.8 Flash Memory Programming Characteristics

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | Condition | | MIN. | TYP. | MAX. | Unit |
|---|------------|-----------------------|---|---------|-----------|------|-------|
| Number of code flash rewrites Note 1, Note 2 | C_{erwr} | Retained for 20 years | $T_A = +85^\circ\text{C}$ ^{Note 3} | 1000 | | | Times |
| Number of data flash rewrites Note 1, Note 2 | | Retained for 1 year | $T_A = +25^\circ\text{C}$ | | 1,000,000 | | Times |
| | | Retained for 5 years | $T_A = +85^\circ\text{C}$ ^{Note 3} | 100,000 | | | Times |
| | | Retained for 20 years | $T_A = +85^\circ\text{C}$ ^{Note 3} | 10,000 | | | Times |

Note 1. 1 erase + 1 write after the erase is regarded as 1 rewrite. The retaining years are until next rewrite after the rewrite.

Note 2. These are the characteristics of the flash memory and the results obtained from reliability testing by Renesas Electronics.

Note 3. This temperature is the average value at which data are retained.

Code flash/data flash self-programming time

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

| Item | Symbol | $f_{CLK} = 1\text{ MHz}$ | | | $f_{CLK} = 16\text{ MHz}$ | | | Unit |
|----------------------|-----------|--------------------------|------|-------|---------------------------|------|-------|---------------|
| | | MIN. | TYP. | MAX. | MIN. | TYP. | MAX. | |
| Writing (4 bytes) | t_{P4} | | 104 | 905 | | 53.8 | 504.9 | μs |
| Block erasure (1 KB) | t_{E1K} | | 7.9 | 262.3 | | 5.5 | 214.1 | ms |

Caution The listed values do not include the time until the operations of the flash memory start following execution of an instruction by software.

24.9 Dedicated Flash Memory Programmer Communication (UART)

[$T_A = -40$ to $+105^\circ\text{C}$: G products, $T_A = -40$ to $+125^\circ\text{C}$: M products, $2.4\text{ V} \leq V_{DD} \leq 5.5\text{ V}$, $V_{SS} = 0\text{ V}$]

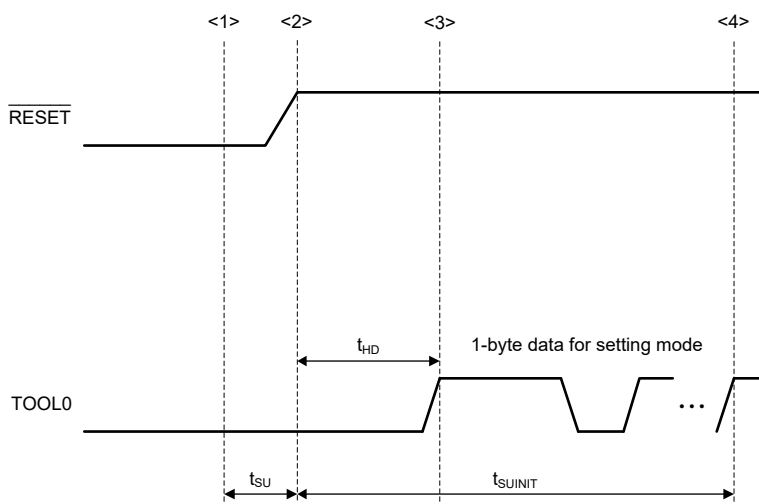
| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---------------|--------|-----------|------|---------|------|------|
| Transfer rate | | | | 115,200 | | bps |

Remark The transfer rate during flash memory programming is fixed to 115,200 bps.

24.10 Timing of Entry to Flash Memory Programming Mode

[T_A = -40 to +105°C: G products, T_A = -40 to +125°C: M products, 2.4 V ≤ V_{DD} ≤ 5.5 V, V_{SS} = 0 V]

| Item | Symbol | Condition | MIN. | TYP. | MAX. | Unit |
|---|---------------------|--|------|------|------|------|
| Time to complete the communication for the initial setting after the external reset is released | t _{SUINIT} | The SPOR reset must be released before the external reset is released. | | | 100 | ms |
| Time to release the external reset after the TOOL0 pin is set to the low level | t _{SU} | The SPOR reset must be released before the external reset is released. | 10 | | | μs |
| Time to hold the TOOL0 pin at the low level after the external reset is released | t _{HD} | The SPOR reset must be released before the external reset is released. | 1 | | | ms |



- <1> The low level is input to the TOOL0 pin.
- <2> The external reset is released (the SPOR reset must have been released before that).
- <3> The TOOL0 pin is released from the low level.
- <4> Setting of entry to the flash memory programming mode by UART reception is completed.

Remark t_{SUINIT}: During this period, the communications for the initial setting must be completed within 100 ms after release from the reset.

t_{SU}: Time to release the external reset after the TOOL0 pin is set to the low level

t_{HD}: Time to hold the TOOL0 pin at the low level after the external reset is released

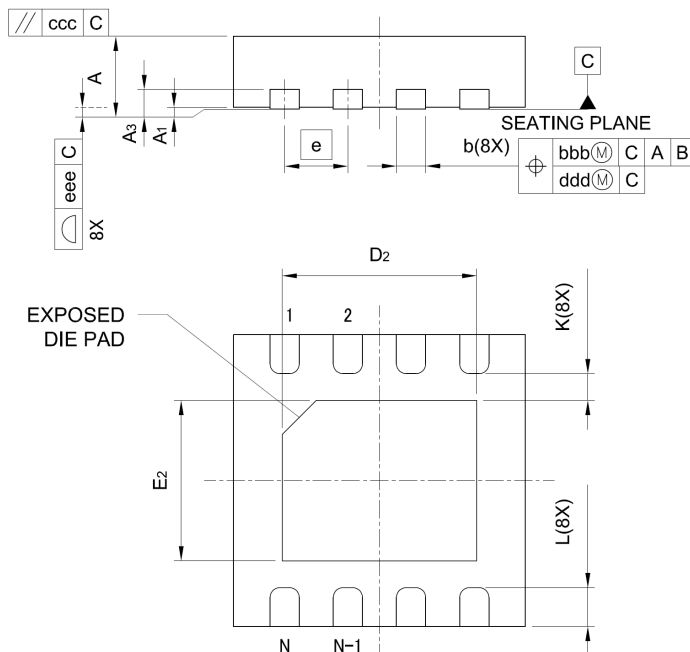
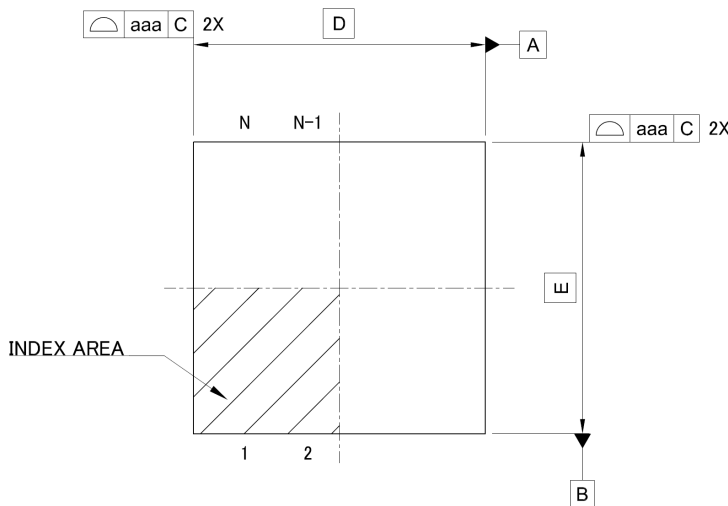
CHAPTER 25 PACKAGE DRAWINGS

25.1 8-pin products

R5F12008MNS, R5F12008GNS, R5F12008ANS

R5F12007MNS, R5F12007GNS, R5F12007ANS

| | | |
|--------------------|--------------|---------------|
| JEITA Package code | RENESAS code | MASS(TYP.)[g] |
| P-HWSON8-3x3-0.65 | PWSN0008JG-A | 0.02 |



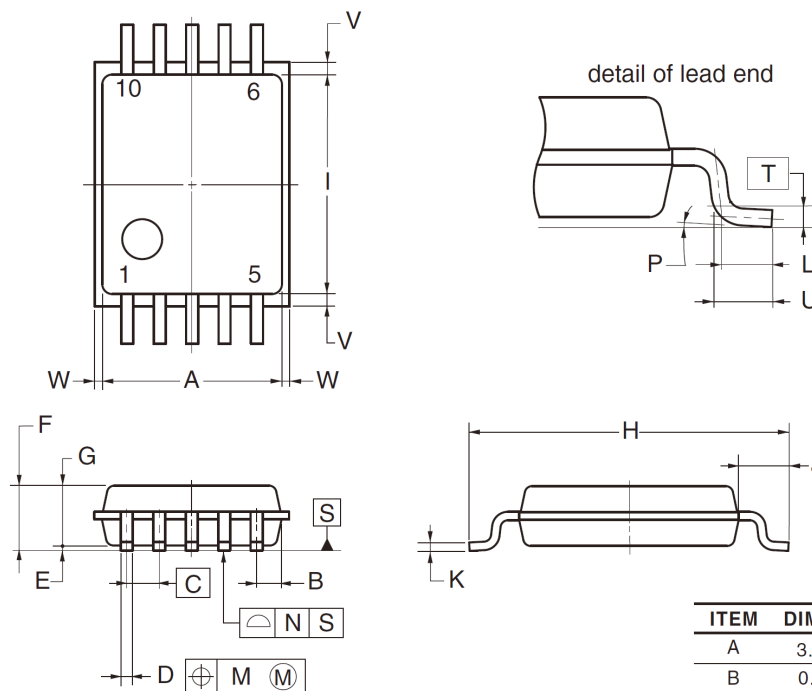
| Reference Symbol | Dimension in Millimeters | | |
|------------------|--------------------------|------|------|
| | Min. | Nom. | Max. |
| A | — | — | 0.80 |
| A ₁ | 0.00 | — | 0.05 |
| A ₃ | 0.203 REF. | | |
| b | 0.25 | 0.30 | 0.35 |
| D | 3.00 | | |
| E | 3.00 | | |
| e | 0.65 | | |
| N | 8 | | |
| L | 0.35 | 0.40 | 0.45 |
| K | 0.20 | — | — |
| D ₂ | 1.95 | 2.00 | 2.05 |
| E ₂ | 1.60 | 1.65 | 1.70 |
| aaa | — | — | 0.15 |
| bbb | — | — | 0.10 |
| ccc | — | — | 0.10 |
| ddd | — | — | 0.05 |
| eee | — | — | 0.08 |

25.2 10-pin products

R5F12018MSP, R5F12018GSP, R5F12018ASP

R5F12017MSP, R5F12017GSP, R5F12017ASP

| | | | |
|------------------------|--------------|----------------|-----------------|
| JEITA Package Code | RENESAS Code | Previous Code | MASS (TYP.) [g] |
| P-LSSOP10-4.4x3.6-0.65 | PLSP0010JA-A | P10MA-65-CAC-2 | 0.05 |



(UNIT:mm)

| ITEM | DIMENSIONS |
|------|--|
| A | 3.60±0.10 |
| B | 0.50 |
| C | 0.65 (T.P.) |
| D | 0.24±0.08 |
| E | 0.10±0.05 |
| F | 1.45 MAX. |
| G | 1.20±0.10 |
| H | 6.40±0.20 |
| I | 4.40±0.10 |
| J | 1.00±0.20 |
| K | 0.17 ^{+0.08} _{-0.07} |
| L | 0.50 |
| M | 0.13 |
| N | 0.10 |
| P | 3° ^{+5°} _{-3°} |
| T | 0.25 (T.P.) |
| U | 0.60±0.15 |
| V | 0.25 MAX. |
| W | 0.15 MAX. |

NOTE

Each lead centerline is located within 0.13 mm of its true position (T.P.) at maximum material condition.

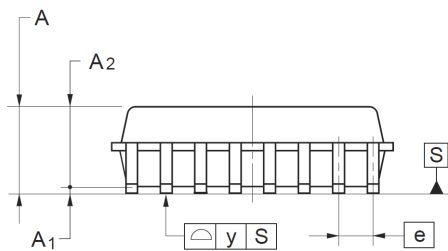
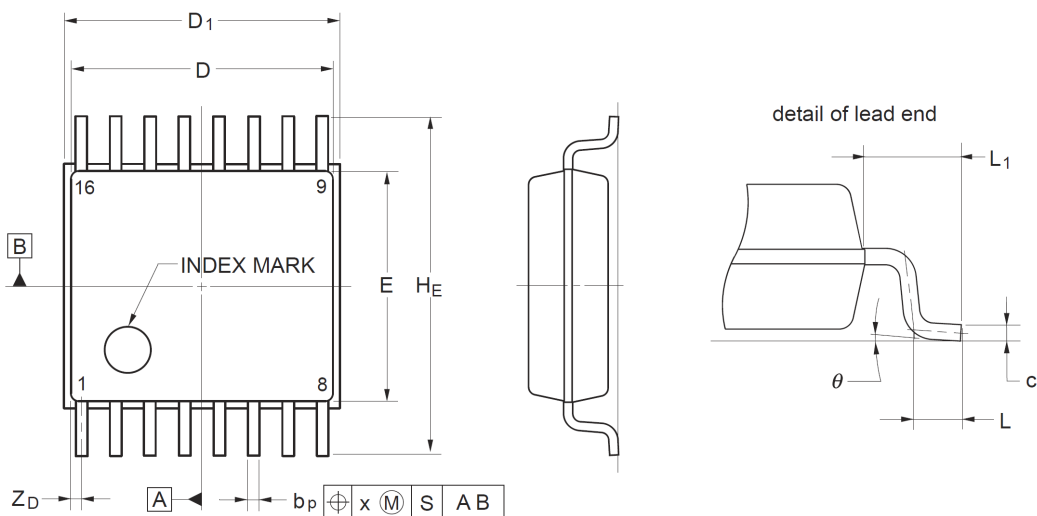
25.3 16-pin products

R5F12048MSP, R5F12048GSP, R5F12048ASP

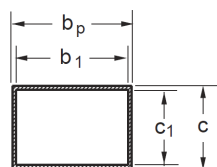
R5F12047MSP, R5F12047GSP, R5F12047ASP

| JEITA Package Code | RENESAS Code | Previous Code | MASS (Typ) [g] |
|---------------------|--------------|----------------|----------------|
| P-SSOP16-4.4x5-0.65 | PRSP0016JC-B | P16MA-65-FAB-1 | 0.08 |

Unit: mm



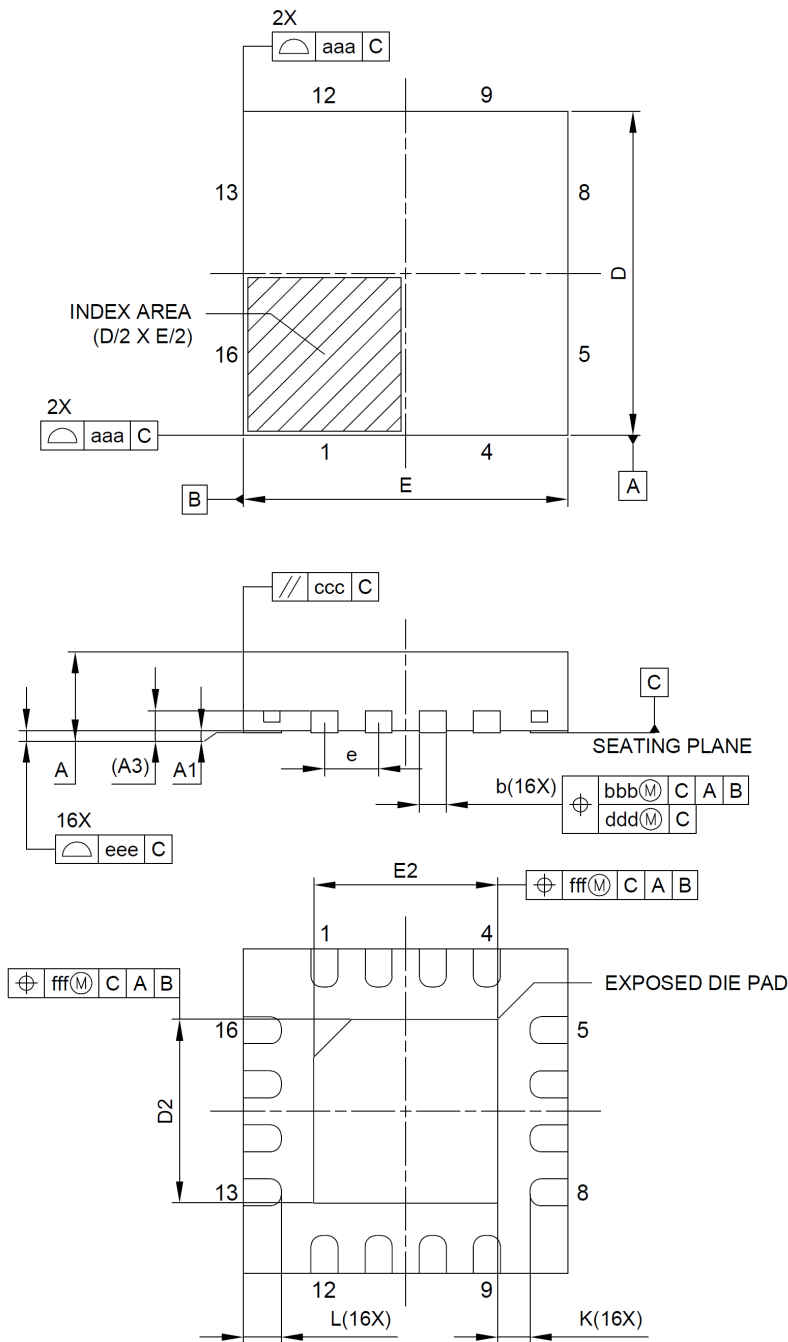
Terminal cross section



| Reference Symbol | Dimensions in millimeters | | |
|------------------|---------------------------|-------|-------|
| | Min | Nom | Max |
| D | 4.85 | 5.00 | 5.15 |
| D ₁ | 5.05 | 5.20 | 5.35 |
| E | 4.20 | 4.40 | 4.60 |
| A ₂ | — | 1.50 | — |
| A ₁ | 0.075 | 0.125 | 0.175 |
| A | — | — | 1.725 |
| b _p | 0.17 | 0.24 | 0.32 |
| b ₁ | — | 0.22 | — |
| c | 0.14 | 0.17 | 0.20 |
| c ₁ | — | 0.15 | — |
| θ | 0° | — | 8° |
| H _E | 6.20 | 6.40 | 6.60 |
| e | — | 0.65 | — |
| x | — | — | 0.13 |
| y | — | — | 0.10 |
| Z _D | — | 0.225 | — |
| L | 0.35 | 0.50 | 0.65 |
| L ₁ | — | 1.00 | — |

R5F12048MNA, R5F12048GNA, R5F12048ANA
 R5F12047MNA, R5F12047GNA, R5F12047ANA

| | | |
|---------------------|--------------|---------------|
| JEITA Package code | RENESAS code | MASS(TYP.)[g] |
| P-HWQFN016-3x3-0.50 | PWQN0016KD-A | 0.02 |



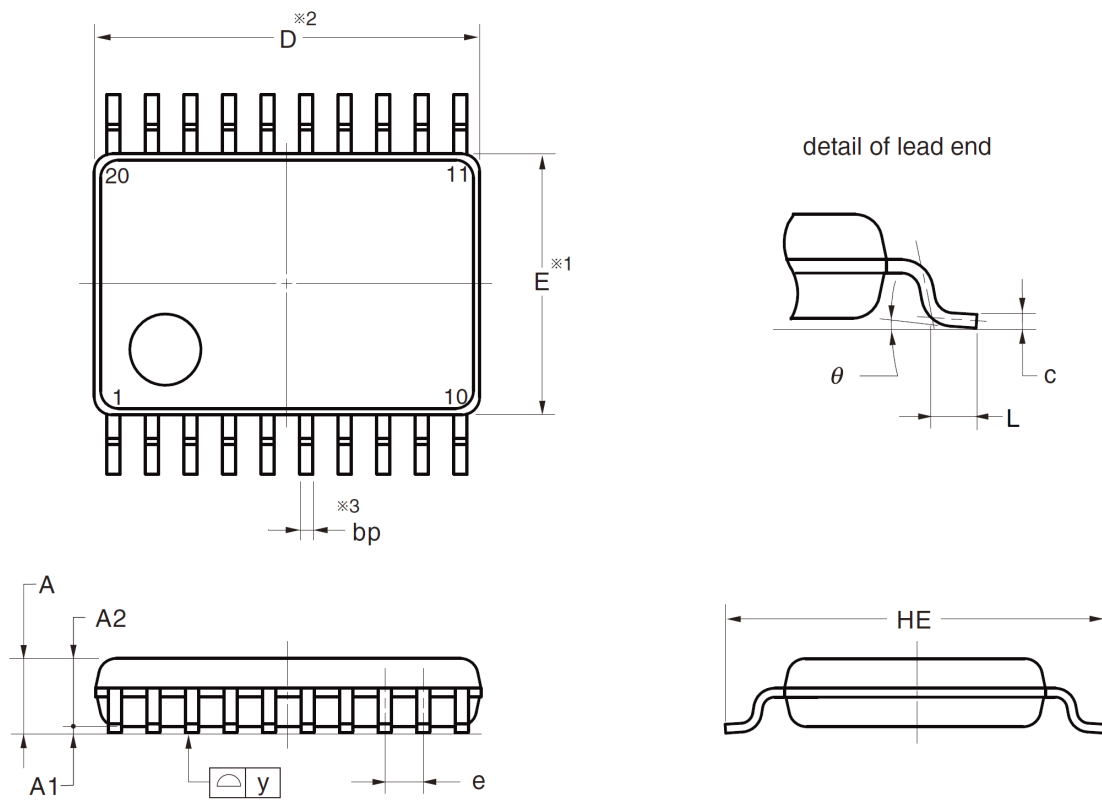
| Reference Symbol | Dimension in Millimeters | | |
|------------------|--------------------------|------|------|
| | Min. | Nom. | Max. |
| A | — | — | 0.80 |
| A1 | 0.00 | 0.02 | 0.05 |
| A3 | 0.203 REF. | | |
| b | 0.20 | 0.25 | 0.30 |
| D | 3.00 BSC | | |
| E | 3.00 BSC | | |
| e | 0.50 BSC | | |
| L | 0.30 | 0.35 | 0.40 |
| K | 0.20 | — | — |
| D2 | 1.65 | 1.70 | 1.75 |
| E2 | 1.65 | 1.70 | 1.75 |
| aaa | 0.15 | | |
| bbb | 0.10 | | |
| ccc | 0.10 | | |
| ddd | 0.05 | | |
| eee | 0.08 | | |
| fff | 0.10 | | |

25.4 20-pin products

R5F12068MSP, R5F12068GSP, R5F12068ASP

R5F12067MSP, R5F12067GSP, R5F12067ASP

| | | | |
|------------------------|--------------|----------------|-----------------|
| JEITA Package Code | RENESAS Code | Previous Code | MASS (TYP.) [g] |
| P-LSSOP20-4.4x6.5-0.65 | PLSP0020JB-A | P20MA-65-NAA-1 | 0.1 |



NOTE

- 1. Dimensions “※1” and “※2” do not include mold flash.
- 2. Dimension “※3” does not include trim offset.

(UNIT:mm)

| ITEM | DIMENSIONS |
|------|--|
| D | 6.50±0.10 |
| E | 4.40±0.10 |
| HE | 6.40±0.20 |
| A | 1.45 MAX. |
| A1 | 0.10±0.10 |
| A2 | 1.15 |
| e | 0.65±0.12 |
| bp | 0.22 ^{+0.10} _{-0.05} |
| c | 0.15 ^{+0.05} _{-0.02} |
| L | 0.50±0.20 |
| y | 0.10 |
| θ | 0° to 10° |

APPENDIX A REVISION HISTORY

A.1 Major Revisions in This Edition

| Page | Description | Classification |
|--|---|----------------|
| CHAPTER 1 OUTLINE | | |
| p.20 | 1.1 Features: Features of the high-speed on-chip oscillator, modified | (a) |
| p.22 | Figure 1-1. Part Number, Memory Size, and Package of RL78/G15: ROM number, added. Packaging Specifications, modified | (d) |
| p.23 | Table 1-1. List of Ordering Part Numbers: Packaging Specifications, modified | (d) |
| p.28 | 1.3.3 16-pin products: Remark 3, added | (c) |
| CHAPTER 20 ON-CHIP DEBUG FUNCTION | | |
| p.687 | Figure 20-3. Memory Spaces Where Debug Monitor Programs Are Allocated: The area of 4 bytes in the internal RAM, modified | (a) |
| CHAPTER 23 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+85^\circ\text{C}$) | | |
| p.709 | CHAPTER 23 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+85^\circ\text{C}$): The description, modified. Remark, added | (c) |
| CHAPTER 24 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+105^\circ\text{C}$, $T_A = -40$ to $+125^\circ\text{C}$) | | |
| p.731 | CHAPTER 24 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+105^\circ\text{C}$, $T_A = -40$ to $+125^\circ\text{C}$): Remark, added | (c) |

Remark "Classification" in the above table classifies revisions as follows.

- (a): Error correction, (b): Addition/change of specifications, (c): Addition/change of description or note,
- (d): Addition/change of package, part number, or management division,
- (e): Addition/change of related documents

A.2 Revision History of Preceding Editions

Here is the revision history of the preceding editions. Chapter indicates the chapter of each edition.

(1/5)

| Edition | Description | Chapter |
|--|--|---|
| Rev.1.00 | Figure 1-1. Part Number, Memory Size, and Package of RL78/G15: Packaging specifications, modified | CHAPTER 1 OUTLINE |
| | Table 1-1. List of Ordering Part Numbers: The ordering part number was changed to list the product name and the packaging specifications in respective columns. RENESAS Code, added. | |
| | ● 8-pin plastic WDFN (3 × 3 mm, 0.65-mm pitch): Pin name, modified for pin 2, 5. Pin name order, changed for pin 1, 5 to 7. | |
| | Table 1-2. Multiplexed Functions of 8-pin Products, added | |
| | ● 10-pin plastic LSSOP (4.4 × 3.6 mm, 0.65-mm pitch): Pin name, modified for pin 2, 7. Pin name order, changed | |
| | Table 1-3. Multiplexed Functions of 10-pin Products, added | |
| | ● 16-pin plastic SSOP (4.4 × 5.0 mm, 0.65-mm pitch): Pin name, modified for pin 3, 6. Pin name order, changed for pin 2, 9 to 16. | |
| | ● 16-pin plastic HWQFN (3 × 3 mm, 0.5-mm pitch): Pin name, modified for pin 1. Pin name order, changed for pin 7 to 14, 16. | |
| | Table 1-4. Multiplexed Functions of 16-pin Products, added | |
| | ● 20-pin plastic LSSOP (4.4 × 6.5 mm, 0.65-mm pitch): Pin name, modified for pin 5. Pin name order, changed for pin 3, 4, 11 to 20. | |
| | Table 1-5. Multiplexed Functions of 20-pin Products, added | |
| 1.6 Outline of Functions: High-speed system clock for 16-pin and 20-pin in the table, modified | | |
| 2.2.2 Pins for each product (pins other than port pins): VCOUT0 and VCOUT1 in the table, modified | CHAPTER 3 CPU ARCHITECTURE | |
| Figure 3-1. Memory Map (R5F120x8 (x = 0, 1, 4, 6)): Note 1, deleted (Numbering change: Note 2. → Note 1.) | | |
| Figure 3-2. Memory Map (R5F120x7 (x = 0, 1, 4, 6)): Note 1, deleted (Numbering change: Note 2. → Note 1.) | | |
| Table 3-5. SFR List (1/2): R/W for the comparator filter control register, modified | | |
| Table 3-6. Extended SFR (2nd SFR) List (1/4): High-speed on-chip oscillator frequency select register, added | | |
| Table 3-6. Extended SFR (2nd SFR) List (1/4): R/W for the flash sequencer status register L, modified | | |
| Table 3-6. Extended SFR (2nd SFR) List (1/4): R/W for the flash sequence status register H, modified | | |
| Table 3-6. Extended SFR (2nd SFR) List (2/4): 16-bit manipulable bit range, enabled for the serial output level register 0 | | |
| Table 3-6. Extended SFR (2nd SFR) List (4/4): Timer clock select register 1, deleted | | |
| Table 3-6. Extended SFR (2nd SFR) List (4/4): Flash memory CRC operation result register, deleted | | |
| Table 3-6. Extended SFR (2nd SFR) List (4/4): Note 2, added | | Figure 3-38. Illegal Memory Access Detection Space: Notes (Note 1, Note 2), deleted |

(2/5)

| Edition | Description | Chapter |
|----------|--|------------------------------|
| Rev.1.00 | 4.5.1 Basic concept when using alternate function: The description, modified | CHAPTER 4 PORT FUNCTIONS |
| | Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (3/10): POMp setting for (TxD0) and TxD0, modified | |
| | Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function (4/10): POMp setting for (TxD0), modified | |
| | 5.3 Registers Controlling Clock Generator, 1) 8-pin and 10-pin products: High-speed on-chip oscillator trimming register (HIOTRM), added | CHAPTER 5 CLOCK GENERATOR |
| | Figure 5-2. Format of Clock Operation Mode Control Register (CMC): The description of setting 1 of the AMPH bit, modified | |
| | Table 5-2. Conditions Before Clock Oscillation Is Stopped and Flag Settings: The table title, modified | |
| | 5.3.5 Oscillation stabilization time select register (OSTS): The description, modified | |
| | Figure 5-12. Examples of Incorrect Resonator Connection (2/2): The figure in (g) Signals are fetched, modified | |
| | Independent channel operation function: Note 1, modified | |
| | 6.1.1 Independent channel operation function, 1) Interval timer to 6) Measurement of high-/low-level width of input signal: Remark 1 and Remark 2, added | |
| | 6.1.1 Independent channel operation function, 4) Divider function (channels 0 and 3 only): Channel 3, added. The channel number, changed to index (n). | |
| | Figure 6-20. Format of Input Switch Control Register (ISC): RXD0 → RxD0, modified | |
| | 6.8.3 Operation as frequency divider (channels 0 and 3 only): Channel 3, added. The channel number, changed to index (n). Remark, added. | |
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| | 23.3.2 Supply current characteristics: f _{MX} = 16 MHz in the table, changed to f _{EX} = 16 MHz, f _X = 12 MHz. The TYP. and MAX. values, modified. | |
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| | 23.4 AC Characteristics: The conditions when selecting the high-speed system clock (f _{MX}) and the MIN. values in the table, modified | |
| | 23.5.2 Serial interface IICA: The unit in the table, modified | |
| | 23.6.3 Internal reference voltage characteristics: The ADS register value in the table, modified | |
| | 23.8 Flash Memory Programming Characteristics: The T _A value, changed | |
| | 23.9 Dedicated Flash Memory Programmer Communication (UART): The T _A value, changed | |
| | CHAPTER 24 ELECTRICAL SPECIFICATIONS (T _A = -40 to +105°C, T _A = -40 to +125°C) (Target): Caution 3, added | |
| | 24.2.2 On-chip oscillator characteristics: Note 3, added | |
| | 24.3.2 Supply current characteristics: f _{MX} = 16 MHz in the table, changed to f _{EX} = 16 MHz, f _X = 12 MHz. The TYP. and MAX. values, modified | |
| | 24.3.2 Supply current characteristics Peripheral Functions: The MAX. value of the A/D converter operating current in the table, modified. The TYP. and MAX. values for the self-programming operating current, modified. | |
| | 24.4 AC Characteristics: The conditions when selecting the high-speed system clock (f _{MX}) and the MIN. values in the table, modified | |
| 24.5.2 Serial interface IICA: The unit in the table, modified | | |
| 24.6.3 Internal reference voltage characteristics: The MIN. and MAX. values of the internal reference voltage in the table, modified. The ADS register value, modified. | | |
| 25.1 8-pin products: The description, added | CHAPTER 25 PACKAGE DRAWINGS | |
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| | 3.1 Overview: The section, added | CHAPTER 3 CPU ARCHITECTURE |
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| | Table 4-7. Setting Examples of Registers and Output Latches When Using Pin Function: Alternate Function Output (SAU Output Function), modified | |

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| | Figure 13-31. Example of Master to Slave Communications: WTIM0, modified | |
| | Figure 13-32. Example of Slave to Master Communications: WTIM0, modified | |
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| | 19.2 Writing to Flash Memory by Using External Device (that Incorporates UART): The description, modified | CHAPTER 19 FLASH MEMORY |
| | Figure 19-4. Communication with External Device: The signal name of the external device, modified | |
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| | Figure 20-3. Memory Spaces Where Debug Monitor Programs Are Allocated: The address value of internal RASM, deleted. Note 3, modified. | |
| | CHAPTER 23 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+85^\circ\text{C}$): The section title, modified. Caution 3, deleted. | CHAPTER 23 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+85^\circ\text{C}$) |
| | 23.2.2 On-chip oscillator characteristics: Note 3, deleted | |
| | 23.3.2 Supply current characteristics: Note 1, modified | |
| | 23.8 Flash Memory Programming Characteristics: The condition was added to the code flash/data flash self-programming time | |
| | 23.10 Timing of Entry to Flash Memory Programming Mode: The condition, added | |
| | CHAPTER 24 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+105^\circ\text{C}$, $T_A = -40$ to $+125^\circ\text{C}$): The section title, modified. Caution 3, deleted. | CHAPTER 24 ELECTRICAL SPECIFICATIONS ($T_A = -40$ to $+105^\circ\text{C}$, $T_A = -40$ to $+125^\circ\text{C}$) |
| | 24.2.2 On-chip oscillator characteristics: The TYP. and MAX. values of high-speed on-chip oscillator clock frequency accuracy ($T_A = +85$ to $+125^\circ\text{C}$), modified. Note 3, deleted. | |
| | 24.3.2 Supply current characteristics: Note 1, modified | |
| | 24.8 Flash Memory Programming Characteristics: The condition in the table, modified. Note 3, added. The condition was added to the code flash/data flash self-programming time. | |
| | 24.10 Timing of Entry to Flash Memory Programming Mode: The condition, added | |
| 25.1 8-pin products: The description, deleted. The package drawing, added. | CHAPTER 25 PACKAGE DRAWINGS | |

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