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April 1, 2003

RENESAS

Renesas Technology Corp.

Hitachi SuperH™ RISC engine

SH7705

Hardware Manual

HITACHI

ADE-602-276

Rev. 1.0
11/29/02
Hitachi, Ltd.

Shaping intelligence
HITACHI SEMICONDUCTOR

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General Precautions on Handling of Product

1. Treatment of NC Pins

Note: Do not connect anything to the NC pins.
The NC (not connected) pins are either not connected to any of the internal circuitry or are used as test pins or to reduce noise. If something is connected to the NC pins, the operation of the LSI is not guaranteed.

2. Treatment of Unused Input Pins

Note: Fix all unused input pins to high or low level.
Generally, the input pins of CMOS products are high-impedance input pins. If unused pins are in their open states, intermediate levels are induced by noise in the vicinity, a pass-through current flows internally, and a malfunction may occur.

3. Processing before Initialization

Note: When power is first supplied, the product's state is undefined.
The states of internal circuits are undefined until full power is supplied throughout the chip and a low level is input on the reset pin. During the period where the states are undefined, the register settings and the output state of each pin are also undefined. Design your system so that it does not malfunction because of processing while it is in this undefined state. For those products which have a reset function, reset the LSI immediately after the power supply has been turned on.

4. Prohibition of Access to Undefined or Reserved Addresses

Note: Access to undefined or reserved addresses is prohibited.
The undefined or reserved addresses may be used to expand functions, or test registers may have been be allocated to these addresses. Do not access these registers; the system's operation is not guaranteed if they are accessed.

Configuration of This Manual

This manual comprises the following items:

1. General Precautions on Handling of Product
2. Configuration of This Manual
3. Preface
4. Contents
5. Overview
6. Description of Functional Modules
    - CPU and System-Control Modules
    - On-Chip Peripheral Modules

      The configuration of the functional description of each module differs according to the module. However, the generic style includes the following items:

    i) Feature
    ii) Input/Output Pin
    iii) Register Description
    iv) Operation
    v) Usage Note

When designing an application system that includes this LSI, take notes into account. Each section includes notes in relation to the descriptions given, and usage notes are given, as required, as the final part of each section.

7. List of Registers
8. Electrical Characteristics
9. Appendix
10. Index

Preface

The SH7705 single-chip RISC (Reduced Instruction Set Computer) microprocessor includes a Hitachi-original RISC CPU as its core, and the peripheral functions required to configure a system.

Target users: This manual was written for users who will be using the SH7705 Micro-Computer Unit (MCU) in the design of application systems. Users of this manual are expected to understand the fundamentals of electrical circuits, logical circuits, and microcomputers.

Objective: This manual was written to explain the hardware functions and electrical characteristics of the SH7705 MCU to the above users.
Refer to the SH-3/SH-3E/SH3-DSP Programming Manual for a detailed description of the instruction set.

Notes on reading this manual:

- Product names
  The following products are covered in this manual.

Product Classifications and Abbreviations

Basic Classification	Product Code
SH7705	HD6417705

- In order to understand the overall functions of the chip
  Read the manual according to the contents. This manual can be roughly categorized into parts on the CPU, system control functions, peripheral functions and electrical characteristics.
- In order to understand the details of the CPU's functions
  Read the SH-3/SH-3E/SH3-DSP Programming Manual.

Rules:	Register name:	The following notation is used for cases when the same or a similar function, e.g. serial communication, is implemented on more than one channel: XXX_N (XXX is the register name and N is the channel number)
	Bit order:	The MSB (most significant bit) is on the left and the LSB (least significant bit) is on the right.
	Number notation:	Binary is B'xxxx, hexadecimal is H'xxxx, decimal is xxxx
	Signal notation:	An overbar is added to a low-active signal: $\overline{\text{xxxx}}$

Related Manuals: The latest versions of all related manuals are available from our web site. Please ensure you have the latest versions of all documents you require. http://www.hitachisemiconductor.com/

SH7705 manuals:

Manual Title	ADE No.
SH7705 Hardware Manual	This manual
SH-3/SH-3E/SH3-DSP Programming Manual	ADE-602-096

Users manuals for development tools:

Manual Title	ADE No.
SH Series C/C++ Compiler, Assembler, Optimizing Linkage Editor User's Manual	ADE-702-246
SH Series Simulator/Debugger (for Windows) User's Manual	ADE-702-186
SH Series Simulator/Debugger (for UNIX) User's Manual	ADE-702-203
Hitachi Embedded Workshop User's Manual	ADE-702-201
SH Series Hitachi Embedded Workshop, Hitachi Debugging Interface Tutorial	ADE-702-230

Abbreviations

ADC	Analog to Digital Converter
ALU	Arithmetic Logic Unit
ASE	Adaptive System Evaluator
ASID	Address Space Identifier
AUD	Advanced User Debugger
BCD	Binary Coded Decimal
bps	bit per second
BSC	Bus State Controller
CCN	Cache Memory Controller
CMT	Compare Match Timer
CPG	Clock Pulse Generator
CPU	Central Processing Unit
DMAC	Direct Memory Access Controller
etu	Elementary Time Unit
FIFO	First-In First-Out
Hi-Z	High Impedance
H-UDI	HITACHI User Debugging Interface
INTC	Interrupt Controller
IrDA	Infrared Data Association
JTAG	Joint Test Action Group
LQFP	Low Profile QFP
LRU	Least Recently Used
LSB	Least Significant Bit
MMU	Memory Management Unit
MPX	Multiplex
MSB	Most Significant Bit
PC	Program Counter
PFC	Pin Function Controller
PLL	Phase Locked Loop
PWM	Pulse Width Modulation
RAM	Random Access Memory
RISC	Reduced Instruction Set Computer
ROM	Read Only Memory
RTC	Realtime Clock
SCIF	Serial Communication Interface with FIFO

SDRAM	Synchronous DRAM
TAP	Test Access Port
T.B.D	To Be Determined
TLB	Translation Lookaside Buffer
TMU	Timer Unit
TPU	Timer Pulse Unit
UART	Universal Asynchronous Receiver/Transmitter
UBC	User Break Controller
USB	Universal Serial Bus
WDT	Watchdog Timer

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Section 17 Infrared Data Association Module (IrDA)

Section 18 USB Function Module

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Appendix

Section 1 Overview

1.1 SH7705 Features

This LSI is a microprocessor that integrates a 32-bit RISC-type SuperH architecture CPU as its core, together with 32-kbyte cache memory as well as peripheral functions required for system configuration such as an interrupt controller.

High-speed data transfers can be formed by an on-chip direct memory access controller (DMAC), and an external memory access support function enables direct connection to different kinds of memory. This LSI also includes powerful peripheral functions that are essential to system configuration, such as USB (Function) functionality and a serial interface with a large FIFO.

A powerful built-in power-management function keeps power consumption low, even during high-speed operation. This LSI is ideal for use in electronic devices such as those for applications that require both high speeds and low power consumption.

The features of this LSI are listed in table 1.1.

Table 1.1 SH7705 Features

Item	Features
CPU	• Original Hitachi SuperH architecture • Compatible with SH-1, SH-2 and SH-3 at object code level • 32-bit internal data bus • General-registers Sixteen 32-bit general registers (eight 32-bit shadow registers) Five 32-bit control registers Four 32-bit system registers • RISC-type instruction set Instruction length: 16-bit fixed length and improved code efficiency Load/store architecture Delayed branch instructions Instruction set based on C language • Instruction execution time: one instruction/cycle for basic instructions • Logical address space: 4 Gbytes • Five-stage pipeline
Memory management unit (MMU)	• 4 Gbytes of address space, 256 address space identifiers (ASID: 8 bits) • Page unit sharing • Supports multiple page sizes: 1 kbyte or 4 kbytes • 128-entry, 4-way set associative TLB • Supports software selection of replacement method and random-replacement algorithms • Contents of TLB are directly accessible by address mapping
Cache memory	• 32-kbyte cache, mixture of instructions and data • 512 entries, 4-way set associative, 16-byte block length • Write-back, write-through, LRU replacement algorithm • 1-stage write-back buffer
Interrupt controller (INTC)	• Seven external interrupt pins (NMI, IRQ5 to IRQ0) • On-chip peripheral interrupt: Priority level is independently selected for each module

Item	Features
Bus state controller (BSC)	• Physical address space is divided into eight areas: area 0, areas 2 to 4; each a maximum of 64 Mbytes, and areas 5A, 5B, 6A, 6B; each a maximum of 32 Mbytes • The following features are settable for each area Bus size (8, 16, or 32 bits). The supported bus size differs for each area. Number of access wait cycles (Numbers of wait-state cycles during reading and writing are independently selectable for some areas.) Setting of idle wait cycles (for the same area or different area) Specifying the memory type to be connected to each area enables direct connection to SRAM, byte selection SRAM, SDRAM, and burst ROM. Some areas support address/data multiplex I/O (MPX). Outputs chip select signal ($\overline{CS0}$, $\overline{CS2}$ to $\overline{CS4}$, $\overline{CS5A}$/$\overline{B}$, $\overline{CS6A}$/$\overline{B}$) for corresponding area (Programs are used to select the $\overline{CS}$ assert/negate timing.) • SDRAM refresh function Supports auto-refresh and self-refresh modes • SDRAM burst access function Different SDRAM can be connected to area 2 or area 3 (size/latency) • Usable as either big or little endian machine
Direct memory access controller (DMAC)	• Four channels. Two of these channels support external requests. • Burst mode and cycle steal mode • Outputs transfer end signal in channel with DREQ (one channel) • Supports intermittent mode (supports 16 or 64 cycles)
Clock pulse generator (CPG)	• Clock mode: Input clock can be selected from external input (EXTAL or CKIO) or crystal resonator • Three types of clocks generated CPU clock: max. 133.34 MHz/100 MHz Bus clock: max. 66.67 MHz Peripheral clock: max. 33.34 MHz • Seven types of clock mode (selection of multiplication ratio of PLL1 and PLL2, and selection external clock or crystal resonator)
Watchdog timer (WDT)	• One-channel watchdog timer
Power-down mode	• Supports power-down mode Sleep mode Software standby mode and hardware standby mode Module standby mode

Item	Features
Timer unit (TMU)	• Three-channel auto-reload-type 32-bit timer • Input capture function (only channel 2) • Five types of counter input clocks can be selected (Pϕ/4, Pϕ/16, Pϕ/64, Pϕ/256, TCLK input)
Compare match timer (CMT)	• 16-bit counter • Four types of clocks can be selected (Pϕ/4, Pϕ/8, Pϕ/16, Pϕ/64)
16-bit timer pulse unit (TPU)	• Four PWM output (TO0, TO1, TO2, and TO3) • Supports PWM function
Realtime clock (RTC)	• Clock and calendar functions (BCD format) • 30-second adjust function • Alarm/periodic/carry interrupt • Automatic leap year adjustment
Serial communication interface (SCIF_0, SCIF_2)	• Clock synchronous/asynchronous mode • 64-byte transmit/receive FIFOs • High-speed UART • UART supports FIFO stop and FIFO trigger • Supports $\overline{RTS}/\overline{CTS}$ • Supports IrDA 1.0 (only channel 0)
USB function module (USB)	• Conforms to USB 1.1 • Supports modes with an on-chip and external USB transceiver • Supports control transfer (endpoint 0), bulk transfer (endpoint 1, 2), and interrupt transfer (endpoint 3) • The USB standard commands are supported, and class and bender commands are handled by firmware • On-chip FIFO buffer for endpoints (128 bytes/endpoint 1, 2) • Module input clock: 48 MHz
I/O port	• Bitwise selection of input/output for input/output port
A/D converter	• 10 bits ± 4 LSB, four channels • Input range: 0 to AVcc (max. 3.6 V)
User break controller (UBC)	• Address, data value, access type, and data size are available for setting as break conditions • Supports the sequential break function • Two break channels

Item	Features
Hitachi user debugging interface (H-UDI)	• Supports the E10A emulator • JTAG-standard pin assignment • Real-time branch trace (AUD)
Power-supply voltage	• I/O: 3.3 ± 0.3 V, internal: 1.5 ± 0.1 V

Product lineup

	Power Supply Voltage				
Product Name	**I/O**	**On-chip Modules**	**Operating Frequency**	**Product Code**	**Package**
SH7705	3.3 ± 0.3 V	1.5 ± 0.1 V	133 MHz	HD6417705F133	208-pin plastic LQFP (FP-208C)
			100 MHz	HD6417705F100	
			133 MHz	HD6417705BP133	208-pin TFBGA (TBP-208A)
			100 MHz	HD6417705BP100	

1.2 Block Diagram

Figure 1.1 shows an internal block diagram of the SH7705.

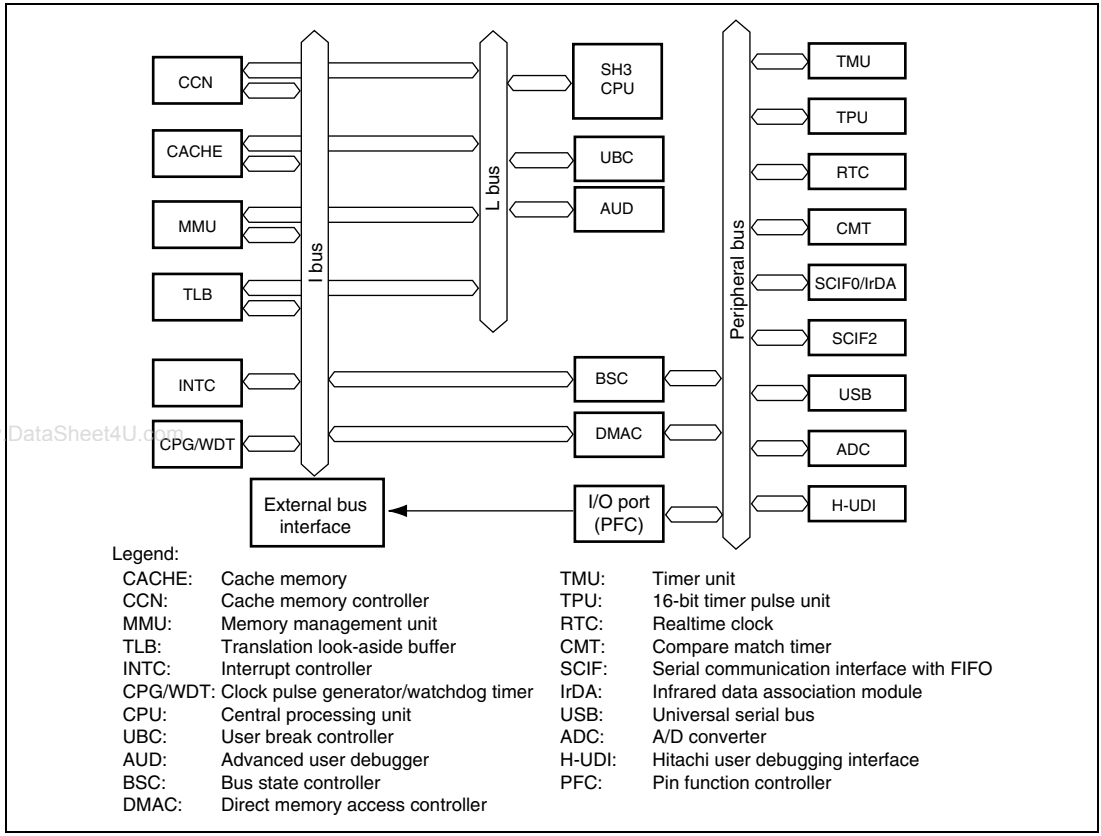
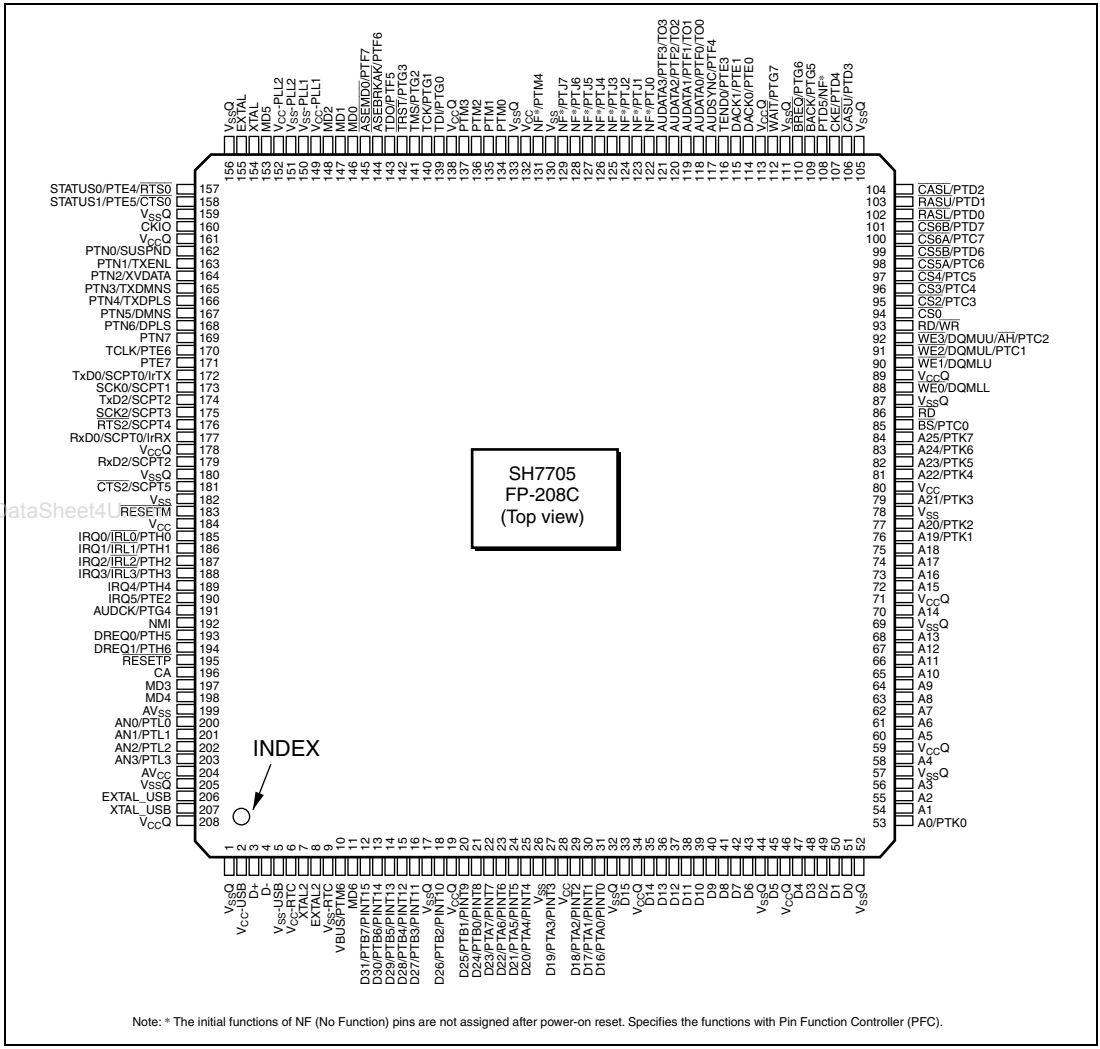


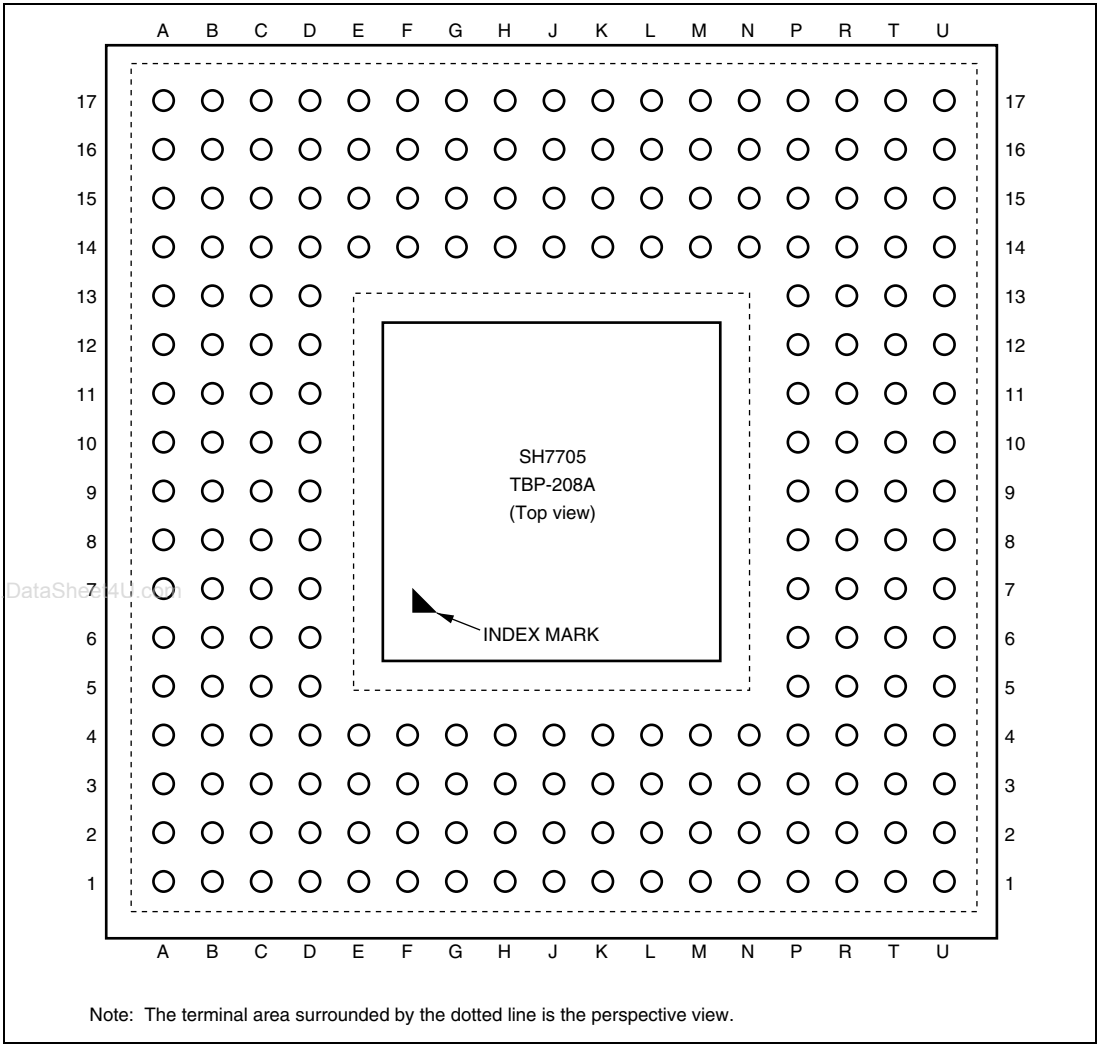
Figure 1.1 Block Diagram of SH7705

1.3 Pin Assignment



Note: * The initial functions of NF (No Function) pins are not assigned after power-on reset. Specifies the functions with Pin Function Controller (PFC).

Figure 1.2 Pin Assignment (FP-208C)



Note: The terminal area surrounded by the dotted line is the perspective view.

Figure 1.3 Pin Assignment (TBP-208A)

Table 1.2 Pin Functions

Pin No. FP-208C	Pin No. TBP-208A	Pin Name	I/O	Description
1	A1	VssQ	—	I/O power supply (0 V)
2	B1	Vcc-USB	—	USB power supply (3.3 V)
3	C3	D+	I/O	USB data line
4	C2	D-	I/O	USB data line
5	C1	Vss-USB	—	USB power supply (0 V)
6	D3	Vcc-RTC*[5]	—	RTC power supply (3.3 V)*[5]
7	D2	XTAL2	O	Crystal oscillator pin for on-chip RTC
8	D1	EXTAL2	I	Crystal oscillator pin for on-chip RTC
9	E4	Vss-RTC*[5]	—	RTC power supply (0 V)*[5]
10	E3	VBUS/PTM6	I / I/O	USB power supply detection / input/output port M
11	E2	MD6	I	connect to I/O power supply (0V)
12	E1	D31/PTB7/PINT15	I/O / I/O / I	Data bus / input/output port B / PINT interrupt
13	F4	D30/PTB6/PINT14	I/O / I/O / I	Data bus / input/output port B / PINT interrupt
14	F3	D29/PTB5/PINT13	I/O / I/O / I	Data bus / input/output port B / PINT interrupt
15	F2	D28/PTB4/PINT12	I/O / I/O / I	Data bus / input/output port B / PINT interrupt
16	F1	D27/PTB3/PINT11	I/O / I/O / I	Data bus / input/output port B / PINT interrupt
17	G4	VssQ	—	I/O power supply (0 V)
18	G3	D26/PTB2/PINT10	I/O / I/O / I	Data bus / input/output port B / PINT interrupt
19	G2	VccQ	—	I/O power supply (3.3 V)
20	G1	D25/PTB1/PINT9	I/O / I/O / I	Data bus / input/output port B / PINT interrupt
21	H4	D24/PTB0/PINT8	I/O / I/O / I	Data bus / input/output port B / PINT interrupt
22	H3	D23/PTA7/PINT7	I/O / I/O / I	Data bus / input/output port A / PINT interrupt
23	H2	D22/PTA6/PINT6	I/O / I/O / I	Data bus / input/output port A / PINT interrupt
24	H1	D21/PTA5/PINT5	I/O / I/O / I	Data bus / input/output port A / PINT interrupt
25	J4	D20/PTA4/PINT4	I/O / I/O / I	Data bus / input/output port A / PINT interrupt
26	J2	Vss	—	Internal power supply (0 V)
27	J1	D19/PTA3/PINT3	I/O / I/O / I	Data bus / input/output port A / PINT interrupt
28	J3	Vcc	—	Internal power supply (1.5 V)
29	K1	D18/PTA2/PINT2	I/O / I/O / I	Data bus / input/output port A / PINT interrupt
30	K2	D17/PTA1/PINT1	I/O / I/O / I	Data bus / input/output port A / PINT interrupt
31	K3	D16/PTA0/PINT0	I/O / I/O / I	Data bus / input/output port A / PINT interrupt

Pin No.				
FP-208C	TBP-208A	Pin Name	I/O	Description
32	K4	VssQ	—	I/O power supply (0 V)
33	L1	D15	I/O	Data bus
34	L2	VccQ	—	I/O power supply (3.3 V)
35	L3	D14	I/O	Data bus
36	L4	D13	I/O	Data bus
37	M1	D12	I/O	Data bus
38	M2	D11	I/O	Data bus
39	M3	D10	I/O	Data bus
40	M4	D9	I/O	Data bus
41	N1	D8	I/O	Data bus
42	N2	D7	I/O	Data bus
43	N3	D6	I/O	Data bus
44	N4	VssQ	—	I/O power supply (0 V)
45	P1	D5	I/O	Data bus
46	P2	VccQ	—	I/O power supply (3.3 V)
47	P3	D4	I/O	Data bus
48	R1	D3	I/O	Data bus
49	R2	D2	I/O	Data bus
50	P4	D1	I/O	Data bus
51	T1	D0	I/O	Data bus
52	T2	VssQ	—	I/O power supply (0 V)
53	U1	A0/PTK0	O / I/O	Address bus / input/output port K
54	U2	A1	O	Address bus
55	R3	A2	O	Address bus
56	T3	A3	O	Address bus
57	U3	VssQ	—	I/O power supply (0 V)
58	R4	A4	O	Address bus
59	T4	VccQ	—	I/O power supply (3.3 V)
60	U4	A5	O	Address bus
61	P5	A6	O	Address bus
62	R5	A7	O	Address bus
63	T5	A8	O	Address bus

Pin No.				
FP-208C	TBP-208A	Pin Name	I/O	Description
64	U5	A9	O	Address bus
65	P6	A10	O	Address bus
66	R6	A11	O	Address bus
67	T6	A12	O	Address bus
68	U6	A13	O	Address bus
69	P7	VssQ	—	I/O power supply (0 V)
70	R7	A14	O	Address bus
71	T7	VccQ	—	I/O power supply (3.3 V)
72	U7	A15	O	Address bus
73	P8	A16	O	Address bus
74	R8	A17	O	Address bus
75	T8	A18	O	Address bus
76	U8	A19/PTK1	O / I/O	Address bus / input/output port K
77	P9	A20/PTK2	O / I/O	Address bus / input/output port K
78	T9	Vss	—	Internal power supply (0 V)
79	U9	A21/PTK3	O / I/O	Address bus / input/output port K
80	R9	Vcc	—	Internal power supply (1.5 V)
81	U10	A22/PTK4	O / I/O	Address bus / input/output port K
82	T10	A23/PTK5	O / I/O	Address bus / input/output port K
83	R10	A24/PTK6	O / I/O	Address bus / input/output port K
84	P10	A25/PTK7	O / I/O	Address bus / input/output port K
85	U11	$\overline{BS}$/PTC0	O / I/O	Bus cycle start signal / input/output port C
86	T11	$\overline{RD}$	O	Read strobe
87	R11	VssQ	—	I/O power supply (0 V)
88	P11	$\overline{WE0}$/DQMLL	O / O	D7 to D0 select signal / DQM (SDRAM)
89	U12	VccQ	—	I/O power supply (3.3 V)
90	T12	$\overline{WE1}$/DQMLU	O / O	D15 to D8 select signal / DQM (SDRAM)
91	R12	$\overline{WE2}$/DQMUL/PTC1	O / O / I/O	D23 to D16 select signal / DQM (SDRAM) / input/output port C
92	P12	$\overline{WE3}$/DQMUU/$\overline{AH}$/PTC2	O / O / O / I/O	D31 to D24 select signal / DQM (SDRAM) / address hold / input/output port C
93	U13	RD/$\overline{WR}$	O	Read/write
94	T13	$\overline{CS0}$	O	Chip select 0

Pin No.				
FP-208C	TBP-208A	Pin Name	I/O	Description
95	R13	$\overline{CS2}$/PTC3	O / I/O	Chip select 2 / input/output port C
96	P13	$\overline{CS3}$/PTC4	O / I/O	Chip select 3 / input/output port C
97	U14	$\overline{CS4}$/PTC5	O / I/O	Chip select 4 / input/output port C
98	T14	$\overline{CS5A}$*[3]/PTC6	O / I/O	Chip select 5A / input/output port C
99	R14	$\overline{CS5B}$*[3]/PTD6	O / I/O	Chip select 5B / input/output port D
100	U15	$\overline{CS6A}$*[3]/PTC7	O / I/O	Chip select 6A / input/output port C
101	T15	$\overline{CS6B}$*[3]/PTD7	O / I/O	Chip select 6B / input/output port D
102	P14	$\overline{RASL}$/PTD0	O / I/O	Lower 32 Mbytes address RAS (SDRAM) / input/output port D
103	U16	$\overline{RASU}$*[3]/PTD1	O / I/O	Upper 32 Mbytes address RAS (SDRAM) / input/output port D
104	T16	$\overline{CASL}$/PTD2	O / I/O	Lower 32 Mbytes address CAS (SDRAM) / input/output port D
105	U17	VssQ	—	I/O power supply (0 V)
106	T17	$\overline{CASU}$*[3]/PTD3	O / I/O	Upper 32 Mbytes address CAS (SDRAM) / input/output port D
107	R15	CKE/PTD4	O / I/O	CK enable (SDRAM) / input/output port D
108	R16	PTD5/NF*[4]	I	Input port D / NF*[4]
109	R17	$\overline{BACK}$/PTG5	O / I/O	Bus acknowledge / input/output port G
110	P15	$\overline{BREQ}$/PTG6	I / I/O	Bus request / input/output port G
111	P16	VssQ	—	I/O power supply (0 V)
112	P17	$\overline{WAIT}$/PTG7	I / I/O	Hardware wait request / input/output port G
113	N14	VccQ	—	I/O power supply (3.3 V)
114	N15	DACK0/PTE0	O / I/O	DMA acknowledge 0 / input/output port E
115	N16	DACK1/PTE1	O / I/O	DMA acknowledge 1 / input/output port E
116	N17	TEND0/PTE3	O / I/O	DMA transfer end notification / input/output port E
117	M14	AUDSYNC/PTF4	O / I/O	AUD synchronous / input/output port F
118	M15	AUDATA0/PTF0/TO0	O / I/O / O	AUD data output / input/output port F / timer output
119	M16	AUDATA1/PTF1/TO1	O / I/O / O	AUD data output / input/output port F / timer output
120	M17	AUDATA2/PTF2/TO2	O / I/O / O	AUD data output / input/output port F / timer output

Pin No.				
FP-208C	TBP-208A	Pin Name	I/O	Description
121	L14	AUDATA3/PTF3/TO3	O / I/O / O	AUD data output / input/output port F / timer output
122	L15	NF*[4]/PTJ0	O	NF*[4]/output port J
123	L16	NF*[4]/PTJ1	O	NF*[4]/output port J
124	L17	NF*[4]/PTJ2	O	NF*[4]/output port J
125	K14	NF*[4]/PTJ3	O	NF*[4]/output port J
126	K15	NF*[4]/PTJ4	O	NF*[4]/output port J
127	K16	NF*[4]/PTJ5	O	NF*[4]/output port J
128	K17	NF*[4]/PTJ6	O	NF*[4]/output port J
129	J14	NF*[4]/PTJ7	O	NF*[4]/output port J
130	J16	Vss	—	Internal power supply (0 V)
131	J17	NF*[4]/PTM4	I	NF*[4]/ input port M
132	J15	Vcc	—	Internal power supply (1.5 V)
133	H17	VssQ	—	I/O power supply (0 V)
134	H16	PTM0	I/O	Input/output port M
135	H15	PTM1	I/O	Input/output port M
136	H14	PTM2	I/O	Input/output port M
137	G17	PTM3	I/O	Input/output port M
138	G16	VccQ	—	I/O power supply (3.3 V)
139	G15	TDI/PTG0	I / I/O	Test data input (H-UDI) / input/output port G
140	G14	TCK/PTG1	I / I/O	Test clock (H-UDI) / input/output port G
141	F17	TMS/PTG2	I / I/O	Test mode select (H-UDI) / input/output port G
142	F16	$\overline{\text{TRST}}$*[1]/PTG3	I / I/O	Test reset (H-UDI) / input/output port G
143	F15	TDO/PTF5	O / I/O	Test data output (H-UDI) / input/output port F
144	F14	$\overline{\text{ASEBRKAK}}$/PTF6	O / I/O	ASE break acknowledge (H-UDI) / input/output port F
145	E17	$\overline{\text{ASEMD0}}$*[2]/PTF7	I / I/O	ASE mode (H-UDI) / input/output port F
146	E16	MD0	I	Clock mode setting
147	E15	MD1	I	Clock mode setting
148	E14	MD2	I	Clock mode setting
149	D17	Vcc-PLL1	—	PLL1 power supply (1.5 V)
150	D16	Vss-PLL1	—	PLL1 power supply (0 V)

Pin No.				
FP-208C	TBP-208A	Pin Name	I/O	Description
151	D15	Vss-PLL2	—	PLL2 power supply (0 V)
152	C17	Vcc-PLL2	—	PLL2 power supply (1.5 V)
153	C16	MD5	I	Endian setting
154	D14	XTAL	O	Crystal oscillator pin
155	B17	EXTAL	I	External clock / crystal oscillator pin
156	B16	VssQ	—	I/O power supply (0 V)
157	A17	STATUS0/PTE4/ $\overline{\text{RTS0}}$	O / I/O / O	Processor status / input/output port E / SCIF0 transmit request
158	A16	STATUS1/PTE5/ $\overline{\text{CTS0}}$	O / I/O / I	Processor status / input/output port E / SCIF0 transmit clear
159	C15	VssQ	—	I/O power supply (0 V)
160	B15	CKIO	I/O	System clock input/output
161	A15	VccQ	—	I/O power supply (3.3 V)
162	C14	PTN0/SUSPND	I/O / O	input/output port N / USB suspend
163	B14	PTN1/TXENL	I/O / O	input/output port N / USB output enable
164	A14	PTN2/XVDATA	I/O / I	input/output port N / USB differential receive input
165	D13	PTN3/TXDMNS	I/O / O	input/output port N / USB D– transmit output
166	C13	PTN4/TXDPLS	I/O / O	input/output port N / USB D+ transmit output
167	B13	PTN5/DMNS	I/O / I	input/output port N / D– input from USB receiver
168	A13	PTN6/DPLS	I/O / I	input/output port N / D+ input from USB receiver
169	D12	PTN7	I/O	input/output port N
170	C12	TCLK/PTE6	I / I/O	TMU clock input / input/output port E
171	B12	PTE7	I/O	Input/output port E
172	A12	TxD0/SCPT0/IrTX	O / O / O	SCIF0 transmit data / SC port / IrDA TX port
173	D11	SCK0/SCPT1	I/O / I/O	SCIF0 clock / SC port
174	C11	TxD2/SCPT2	O / O	SCIF2 transmit data / SC port
175	B11	SCK2/SCPT3	I/O / I/O	SCIF2 clock / SC port
176	A11	$\overline{\text{RTS2}}$/SCPT4	O / I/O	SCIF2 transmit request / SC port
177	D10	RxD0/SCPT0/IrRX	I / I / I	SCIF0 receive data / SC port / IrDA RX port
178	C10	VccQ	—	I/O power supply (3.3 V)
179	B10	RxD2/SCPT2	I / I	SCIF2 receive data / SC port

Pin No. FP-208C	Pin No. TBP-208A	Pin Name	I/O	Description
180	A10	VssQ	—	I/O power supply (0 V)
181	D9	$\overline{\text{CTS2}}$/SCPT5	I / I/O	SCIF2 transmit clear / SC port
182	B9	Vss	—	I/O power supply (0 V)
183	A9	$\overline{\text{RESETM}}$	I	Manual reset request
184	C9	Vcc	—	Internal power supply (1.5 V)
185	A8	IRQ0/$\overline{\text{IRL0}}$/PTH0	I / I / I/O	External interrupt request / input/output port H
186	B8	IRQ1/$\overline{\text{IRL1}}$/PTH1	I / I / I/O	External interrupt request / input/output port H
187	C8	IRQ2/$\overline{\text{IRL2}}$/PTH2	I / I / I/O	External interrupt request / input/output port H
188	D8	IRQ3/$\overline{\text{IRL3}}$/PTH3	I / I / I/O	External interrupt request / input/output port H
189	A7	IRQ4/PTH4	I / I/O	External interrupt request / input/output port H
190	B7	IRQ5/PTE2	I / I/O	External interrupt request / input/output port E
191	C7	AUDCK/PTG4	O / I/O	AUD clock / input/output port G
192	D7	NMI	I	Nonmaskable interrupt request
193	A6	DREQ0/PTH5	I / I/O	DMA request / input/output port H
194	B6	DREQ1/PTH6	I / I/O	DMA request / input/output port H
195	C6	$\overline{\text{RESETP}}$	I	Power-on reset request
196	D6	CA	I	Hardware standby request
197	A5	MD3	I	Area 0 bus width setting
198	B5	MD4	I	Area 0 bus width setting
199	C5	AVss	—	Analog power supply (0 V)
200	D5	AN0/PTL0	I / I	A/D converter input / input port L
201	A4	AN1/PTL1	I / I	A/D converter input / input port L
202	B4	AN2/PTL2	I / I	A/D converter input / input port L
203	C4	AN3/PTL3	I / I	A/D converter input / input port L
204	A3	AVcc	—	Analog power supply (3.3 V)
205	B3	VssQ	—	I/O power supply (0 V)
206	D4	EXTAL_USB	I	USB clock
207	A2	XTAL_USB	O	USB clock
208	B2	VccQ	—	I/O power supply (3.3 V)

Notes: *1 The $\overline{\text{TRST}}$ pin must be driven low for a specified period when power supply is turned on regardless of whether the H-UDI function is used or not. As the same as the $\overline{\text{RESETP}}$ pin, the $\overline{\text{TRST}}$ pin should be driven low at the power-on set state and driven high after the power-on reset state is released.

*2 The input level of the $\overline{\text{ASEMD0}}$ pin must be high if the E10A emulator is not used. For details, refer to section 23.4.2, Reset Configuration.

*3 These pins are initialized to the general input port setting in which the pull-up MOS is off at a power-on reset. When these pins are connected to memory and so on, their levels must be fixed externally.

*4 The initial functions of NF (No Function) pins are not assigned after power-on reset. Specifies the functions with Pin Function Controller (PFC).

*5 In hardware standby mode, supply power to all power supply pins including the RTC power supply pins.

*6 The unused pins should be handled according to table A.1, I/O Port States in Each Processing State, in Appendix.

1.4 Pin Functions

Table 1.3 lists the pin functions.

Table 1.3 Pin Functions

Classification	Symbol	I/O	Name	Function
Power supply	Vcc	—	Power supply	Power supply for the internal modules and ports for the system. Connect all Vcc pins to the system power supply. There will be no operation if any pins are open.
	Vss	—	Ground	Ground pin. Connect all Vss pins to the system power supply (0 V). There will be no operation if any pins are open.
	VccQ	—	Power supply	Power supply for I/O pins. Connect all VccQ pins to the system power supply. There will be no operation if any pins are open.
	VssQ	—	Ground	Ground pin. Connect all VssQ pins to the system power supply (0 V). There will be no operation if any pins are open.
Clock	Vcc-PLL1	—	PLL1 power supply	Power supply for the on-chip PLL1 oscillator.
	Vss-PLL1	—	PLL1 ground	Ground pin for the on-chip PLL1 oscillator.
	Vcc-PLL2	—	PLL2 power supply	Power supply for the on-chip PLL2 oscillator.
	Vss-PLL2	—	PLL2 ground	Ground pin for the on-chip PLL2 oscillator.
	EXTAL	I	External clock	For connection to a crystal resonator. An external clock signal may also be input to the EXTAL pin.
	XTAL	O	Crystal	For connection to a crystal resonator.
	CKIO	I/O	System clock	Supplies the system clock to external devices.

Classification	Symbol	I/O	Name	Function
Operating mode control	MD6 to MD0	I	Mode set	Sets the operating mode. Do not change values on these pins during operation. MD2 to MD0 set the clock mode, MD3 and MD4 set the bus-width mode of area 0 and MD5 sets the endian. MD6 pin should be connected to VssQ.
System control	$\overline{\text{RESETP}}$	I	Power-on reset	When low, the system enters the power-on reset state.
	$\overline{\text{RESETM}}$	I	Manual reset	When low, the system enters the manual reset state.
	STATUS1, STATUS0	O	Status output	Indicates the operating state.
	$\overline{\text{BREQ}}$	I	Bus request	Low when an external device requests the release of the bus mastership.
	$\overline{\text{BACK}}$	O	Bus request acknowledge	Indicates that the bus mastership has been released to an external device. Reception of the $\overline{\text{BACK}}$ signal informs the device which has output the $\overline{\text{BREQ}}$ signal that it has acquired the bus.
	CA	I	Chip active	High in normal operation, and low in hardware standby mode.
Interrupts	NMI	I	Non-maskable interrupt	Non-maskable interrupt request pin. Fix to high level when not in use.
	IRQ5 to IRQ0	I	Interrupt requests 5 to 0	Maskable interrupt request pin. Selectable as level input or edge input. The rising edge or falling edge is selectable as the detection edge. The low level or high level is selectable as the detection level.
	$\overline{\text{IRL3}}$ to $\overline{\text{IRL0}}$	I	Interrupt requests 3 to 0	Maskable interrupt request pin. Input a coded interrupt level.
	PINT15 to PINT0	I	Interrupt requests 15 to 0	PINT interrupt request pin.
Address bus	A25 to A0	O	Address bus	Outputs addresses.
Data bus	D31 to D0	I/O	Data bus	32-bit bidirectional data bus.

Classification	Symbol	I/O	Name	Function
Bus control	$\overline{CS0}$, $\overline{CS2}$ to $\overline{CS4}$, $\overline{CS5A}$, $\overline{CS5B}$, $\overline{CS6A}$, $\overline{CS6B}$,	O	Chip select 0, 2 to 4, 5A, 5B, 6A, 6B	Chip-select signal for external memory or devices.
	$\overline{RD}$	O	Read	Indicates reading of data from external devices.
	RD/$\overline{WR}$	O	Read/write	Read/write signal.
	$\overline{BS}$	O	Bus start	Bus-cycle start.
	$\overline{WE3}$	O	Highest-byte write	Indicates that bits 31 to 24 of the data in the external memory or device are being written.
	$\overline{WE2}$	O	Second-highest-byte write	Indicates that bits 23 to 16 of the data in the external memory or device are being written.
	$\overline{WE1}$	O	Second-lowest-byte write	Indicates that bits 15 to 8 of the data in the external memory or device are being written.
	$\overline{WE0}$	O	Lowest-byte write	Indicates that bits 7 to 0 of the data in the external memory or device are being written.
	CKE	O	CK enable	Clock enable. (SDRAM)
	DQMUU	O	DQ mask UU	Selects D31 to D24. (SDRAM)
	DQMUL	O	DQ mask UL	Selects D23 to D16. (SDRAM)
	DQMLU	O	DQ mask LU	Selects D15 to D8. (SDRAM)
	DQMLL	O	DQ mask LL	Selects D7 to D0. (SDRAM)
	$\overline{RASU}$	O	Row address U	Specifies a row address. (SDRAM)
	$\overline{RASL}$	O	Row address L	Specifies a row address. (SDRAM)
	$\overline{CASU}$	O	Column address U	Specifies a column address. (SDRAM)
	$\overline{CASL}$	O	Column address L	Specifies a column address. (SDRAM)
	$\overline{AH}$	O	Address hold	Address hold signal.
	$\overline{WAIT}$	I	Wait	Inserts a wait cycle into the bus cycles during access to the external space.

Classification	Symbol	I/O	Name	Function
Direct memory access controller (DMAC)	DREQ0, DREQ1	I	DMA-transfer request	Input pin for external requests for DMA transfer.
	DACK0, DACK1	O	DMA-transfer strobe	Output strobe to external I/O, in response to external requests for DMA transfer.
	TEND0	O	DMA-transfer end	Transfer end output for DMAC channel 0.
Timer unit (TMU)	TCLK	I	Clock input	External clock input pin/input capture control input pin.
16-bit timer pulse unit (TPU)	TO3 to TO0	O	Timer output	Output compare/PWM output pin.
Serial communication interface with FIFO (SCIF0, SCIF2)	TxD0, TxD2	O	Transmit data	Transmit data pin.
	RxD0, RxD2	I	Receive data	Receive data pin.
	SCK0, SCK2	I/O	Serial clock	Clock input/output pin.
	$\overline{\text{RTS0}}$, $\overline{\text{RTS2}}$	O	Transmit request	Modem control pin.
	$\overline{\text{CTS0}}$, $\overline{\text{CTS2}}$	I	Transmit enable	Modem control pin.
IrDA	IrTX	O	IrDA TX port	IrDA transmit data output.
	IrRX	I	IrDA RX port	IrDA receive data input.
Realtime clock (RTC)	EXTAL2	I	RTC clock	RTC crystal oscillator pin. (32.768 kHz)
	XTAL2	O	RTC clock	RTC crystal oscillator pin. (32.768 kHz)
	Vcc-RTC	—	RTC power supply	Power supply pin for the RTC.
	Vss-RTC	—	RTC ground	Ground pin for the RTC.
A/D converter (ADC)	AN3 to AN0	I	Analog input pin	Analog input pin.
	AVcc	—	A/D analog power supply	Power supply for the A/D converter. When the A/D converter is not in use, connect this pin to the port power supply (VccQ).
	AVss	—	A/D analog ground	Ground pin for the A/D converter. Connect this pin to the system power supply (Vss).

Classification	Symbol	I/O	Name	Function
USB	EXTAL_USB	I	USB clock	USB clock input pin. (48-MHz input)
	XTAL_USB	O	USB clock	USB clock pin.
	XVDATA	I	Data input	Receive data input pin from the differential receiver.
	VBUS	I	USB power supply detection	USB-cable connection-monitor pin.
	TXDPLS	O	D+ output	D+ transmit output pin for the driver.
	TXDMNS	O	D– output	D– transmit output pin for the driver.
	DPLS	I	D+ input	D+ signal input pin from the receiver to the driver.
	DMNS	I	D– input	D– signal input pin from the receiver to the driver.
	TXENL	O	Output enable	Output enable pin for the driver.
	SUSPND	O	Suspend	Suspend-state output pin for the transceiver.
	Vcc-USB	—	USB analog power supply	USB power supply pin. When the USB is not in use, connect this pin to the port power supply (VccQ).
	Vss-USB	—	USB analog ground	USB ground pin. Connect this pin to the system power supply (Vss).
	D–	I/O	D– I/O	On-chip USB transceiver D–.
	D+	I/O	D+ I/O	On-chip USB transceiver D+.

Classification	Symbol	I/O	Name	Function
I/O port	PTA7 to PTA0	I/O	General purpose port	8-bit general-purpose I/O port pins.
	PTB7 to PTB0	I/O	General purpose port	8-bit general-purpose I/O port pins.
	PTC7 to PTC0	I/O	General purpose port	8-bit general-purpose I/O port pins.
	PTD7 to PTD0	I/O	General purpose port	8-bit general-purpose I/O port pins.
	PTE7 to PTE0	I/O	General purpose port	8-bit general-purpose I/O port pins.
	PTF7 to PTF0	I/O	General purpose port	8-bit general-purpose I/O port pins.
	PTG7 to PTG0	I/O	General purpose port	8-bit general-purpose I/O port pins.
	PTH6 to PTH0	I/O	General purpose port	7-bit general-purpose I/O port pins.
	PTJ7 to PTJ0	O	General purpose port	8-bit general-purpose output port pins.
	PTK7 to PTK0	I/O	General purpose port	8-bit general-purpose I/O port pins.
	PTL3 to PTL0	I	General purpose port	4-bit general-purpose input port pins.
	PTM6, PTM4 to PTM0	I/O	General purpose port	6-bit general-purpose I/O port pins.
	PTN7 to PTN0	I/O	General purpose port	8-bit general-purpose I/O port pins.
	SCPT5 to SCPT0	I/O	Serial port	6-bit serial port pins.

Classification	Symbol	I/O	Name	Function
Hitachi user debugging interface (H-UDI)	TCK	I	Test clock	Test-clock input pin.
	TMS	I	Test mode select	Inputs the test-mode select signal.
	TDI	I	Test data input	Serial input pin for instructions and data.
	TDO	O	Test data output	Serial output pin for instructions and data.
	$\overline{\text{TRST}}$	I	Test reset	Initial-signal input pin.
Advanced user debugger (AUD)	AUDATA3 to AUDATA0	O	AUD data	Destination-address output pin in branch-trace mode.
	AUDCK	O	AUD clock	Synchronous clock output pin in branch-trace mode.
	AUDSYNC	O	AUD synchronous signal	Data start-position acknowledge-signal output pin in branch-trace mode.
E10A interface	$\overline{\text{ASEBRKAK}}$	O	Break mode acknowledge	Indicates that the E10A emulator has entered its break mode. For the connection with the E10A, see the SH7705 E10A Emulator User's Manual (tentative title).
	$\overline{\text{ASEMD0}}$	I	ASE mode	Sets ASE mode.

Section 2 CPU

2.1 Processing States and Processing Modes

2.1.1 Processing States

This LSI supports four types of processing states: a reset state, an exception handling state, a program execution state, and a low-power consumption state, according to the CPU processing states.

Reset State: In the reset state, the CPU is reset. The LSI supports two types of resets: power-on reset and manual reset. For details on resets, refer to section 5, Exception Handling.

In power-on reset, the registers and internal statuses of all LSI on-chip modules are initialized. In manual reset, the register contents of a part of the LSI on-chip modules, such as the bus state controller (BSC), are retained. For details, refer to section 24, List of Registers. The CPU internal statuses and registers are initialized both in power-on reset and manual reset. After initialization, the program branches to address H'A0000000 to pass control to the reset processing program to be executed.

Exception Handling State: In the exception handling state, the CPU processing flow is changed temporarily by a general exception or interrupt exception processing. The program counter (PC) and status register (SR) are saved in the save program counter (SPC) and save status register (SSR), respectively. The program branches to an address obtained by adding a vector offset to the vector base register (VBR) and passes control to the exception processing program defined by the user to be executed. For details on reset, refer to section 5, Exception Handling.

Program Execution State: The CPU executes programs sequentially.

Low-Power Consumption State: The CPU stops operation to reduce power consumption. The low-power consumption state can be entered by executing the SLEEP instruction. For details on the low-power consumption state, refer to section 11, Power-Down Modes.

Figure 2.1 shows a status transition diagram.

2.1.2 Processing Modes

This LSI supports two processing modes: user mode and privileged mode. These processing modes can be determined by the processing mode bit (MD) of the status register (SR). If the MD bit is cleared to 0, the user mode is selected. If the MD bit is set to 1, the privileged mode is selected. The CPU enters the privileged mode by a transition to reset state or exception handling state. In the privileged mode, any registers and resources in address spaces can be accessed.

Clearing the MD bit of the SR to 0 puts the CPU in the user mode. In the user mode, some of the registers, including SR, and some of the address spaces cannot be accessed by the user program and system control instructions cannot be executed. This function effectively protects the system resources from the user program. To change the processing mode from user to privileged mode, a transition to exception handling state is required.*

Note: * To call a service routine used in privileged mode from user mode, the LSI supports an unconditional trap instruction (TRAPA). When a transition from user mode to privileged mode occurs, the contents of the SR and PC are saved. A program execution in user mode can be resumed by restoring the contents of the SR and PC. To return from an exception processing program, the LSI supports an RTE instruction.

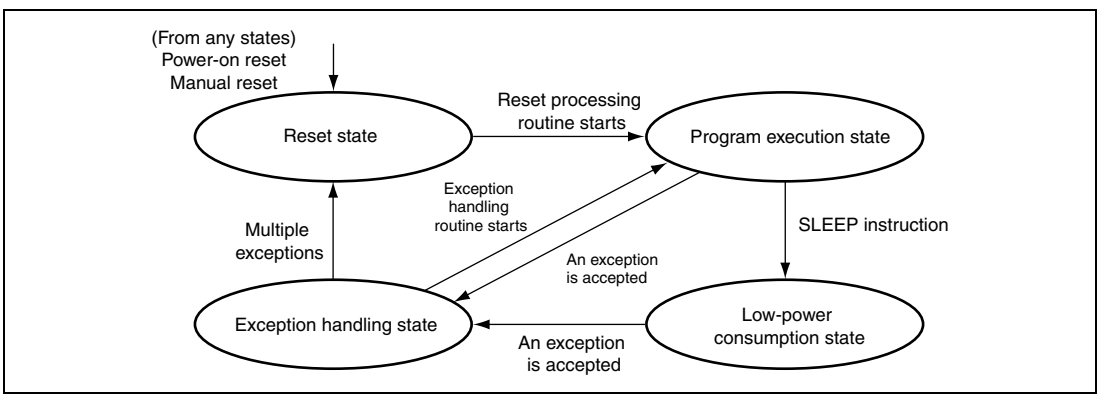


Figure 2.1 Processing State Transitions

2.2 Memory Map

2.2.1 Logical Address Space

The LSI supports 32-bit logical addresses and accesses system resources using the 4-Gbytes of logical address space. User programs and data are accessed from the logical address space. The logical address space is divided into several areas as shown in table 2.1.

P0/U0 Area: This area is called the P0 area when the CPU is in privileged mode and the U0 area when in user mode. For the P0 and U0 areas, access using the cache is enabled. The P0 and U0 areas are handled as address translatable areas.

If the cache is enabled, access to the P0 or U0 area is cached. If a P0 or U0 address is specified while the address translation unit is enabled, the P0 or U0 address is translated into a physical address based on translation information defined by the user.

If the CPU is in user mode, only the U0 area can be accessed. If P1, P2, P3, or P4 is accessed in user mode, a transition to an address error exception occurs.

P1 Area: The P1 area is defined as a cacheable but non-address translatable area. Normally, programs executed at high speed in privileged mode, such as exception processing handlers, which are at the core of the operating system (S), are assigned to the P1 area.

P2 Area: The P2 area is defined as a non-cacheable but non-address translatable area. A reset processing program to be called from the reset state is described at the start address (H'A0000000) of the P2 area. Normally, programs such as system initialization routines and OS initiation programs are assigned to the P2 area. To access a part of an on-chip module control register, its corresponding program should be assigned to the P2 area.

P3 Area: The P3 area is defined as a cacheable and address translatable area. This area is used if an address translation is required for a privileged program.

P4 Area: The P4 area is defined as a control area which is non-cacheable and non-address translatable. This area can be accessed only in privileged mode. A part of this LSI′s on-chip module control register is assigned to this area.

Table 2.1 Logical Address Space

Address Range	Name	Mode	Description
H'00000000 to H'7FFFFFFF	P0/U0	Privileged/user mode	2-Gbyte physical space, cacheable, address translatable In user mode, only this address space can be accessed.
H'80000000 to H'9FFFFFFF	P1	Privileged mode	0.5-Gbyte physical space, cacheable
H'A0000000 to H'BFFFFFFF	P2	Privileged mode	0.5-Gbyte physical space, non-cacheable
H'C0000000 to H'DFFFFFFF	P3	Privileged mode	0.5-Gbyte physical space, cacheable, address translatable
H'E0000000 to H'FFFFFFFF	P4	Privileged mode	0.5-Gbyte control space, non-cacheable

2.2.2 External Memory Space

The LSI uses 29 bits of the 32-bit logical address to access external memory. In this case, 0.5-Gbyte of external memory space can be accessed. The external memory space is managed in area units. Different types of memory can be connected to each area, as shown in figure 2.2. For details, please refer to section 7, Bus State Controller (BSC). In addition, area 1 in the external memory space is used as an on-chip I/O space where most of this LSI′s on-chip module control registers are mapped. *1

Normally, the upper three bits of the 32-bit logical address are masked and the lower 29 bits are used for external memory addresses.*2 For example, address H'00000100 in the P0 area, address H'80000100 in the P1 area, address H'A0000100 in the P2 area, and address H'C0000100 in the P3 area of the logical address space are mapped into address H'00000100 of area 0 in the external memory space. The P4 area in the logical address space is not mapped into the external memory address. If an address in the P4 area is accessed, an external memory cannot be accessed.

Notes: *1 To access an on-chip module control register mapped into area 1 in the external memory space, access the address from the P2 area which is not cached in the logical address space.

*2 If the address translation unit is enabled, arbitrary mapping in page units can be specified. For details, refer to section 3, Memory Management Unit (MMU).

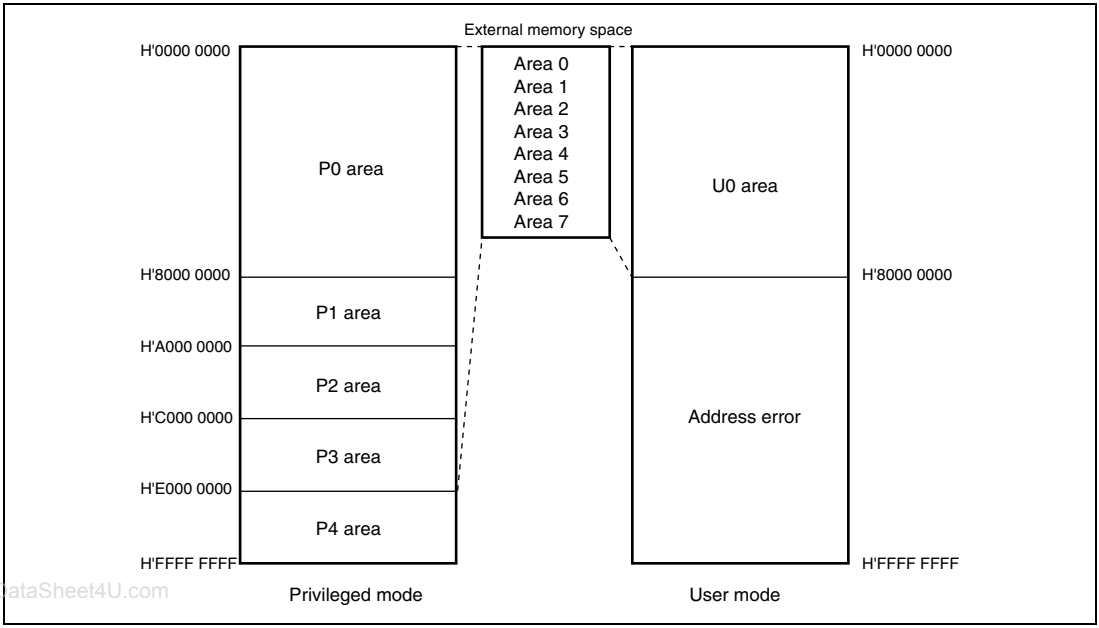


Figure 2.2 Logical Address to External Memory Space Mapping

2.3 Register Descriptions

This LSI provides thirty-three 32-bit registers: 24 general registers, five control registers, three system registers, and one program counter.

General Registers: This LSI incorporates 24 general registers: R0_BANK0 to R7_BANK0, R0_BANK1 to R7_BANK1 and R8 to R15. R0 to R7 are banked. The process mode and the register bank (RB) bit in the status register (SR) define which set of banked registers (R0_BANK0 to R7_BANK0 or R0_BANK1 to R7_BANK1) are accessed as general registers.

System Registers: This LSI incorporates the multiply and accumulate registers (MACH/MACL) and procedure register (PR) as system registers. These registers can be accessed regardless of the processing mode.

Program Counter: The program counter stores the value obtained by adding 4 to the current instruction address.

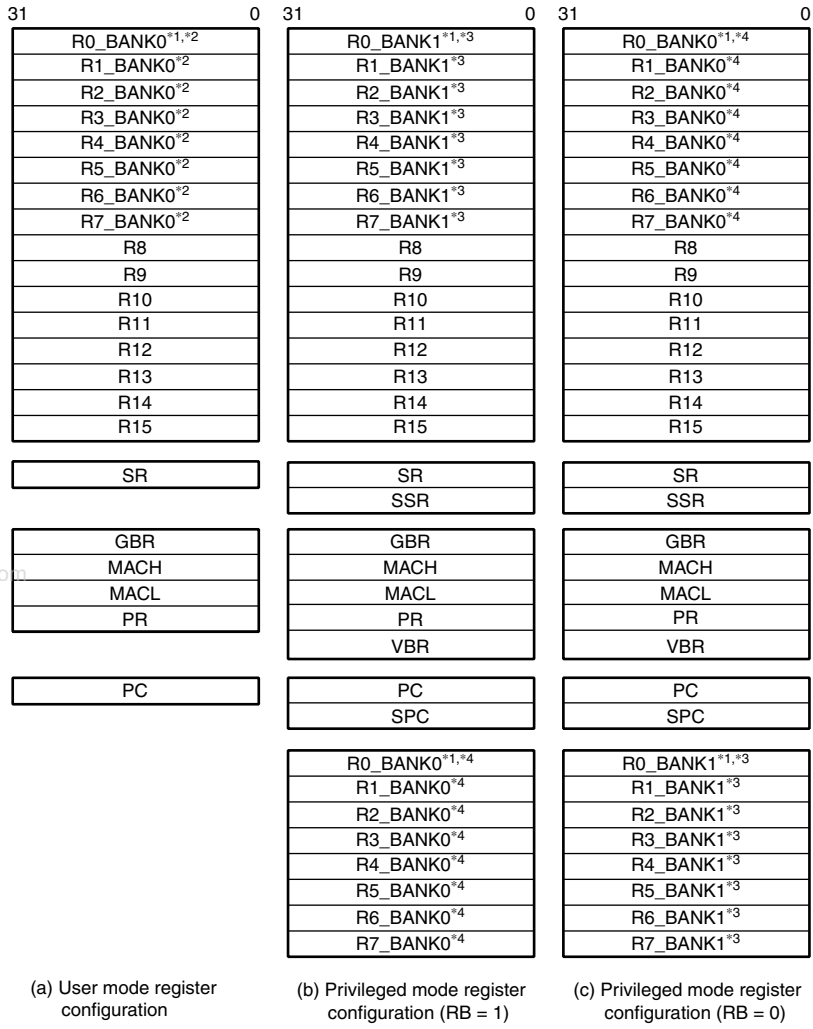
Control Registers: This LSI incorporates the status register (SR), global base register (GBR), save status register (SSR), save program counter (SPC), and vector base register as control register. Only the GBR can be accessed in user mode. Control registers other than the GBR can be accessed only in privileged mode.

Table 2.2 shows the register values after reset. Figure 2.3 shows the register configurations in each process mode.

Table 2.2 Register Initial Values

Register Type	Registers	Initial Values
General registers	R0_BANK0 to R7_BANK0, R0_BANK1 to R7_BANK1, R8 to R15	Undefined
System registers	MACH, MACL, PR	Undefined
Program counter	PC	H'A0000000
Control registers	SR	MD bit = 1, RB bit = 1, BL bit = 1, I3 to I0 bits = H'F (1111), reserved bits = all 0, other bits = undefined
	GBR, SSR, SPC	Undefined
	VBR	H'00000000

Note:* Initialized by a power-on or manual reset.



(a) User mode register configuration

(b) Privileged mode register configuration (RB = 1)

(c) Privileged mode register configuration (RB = 0)

Notes: *1 The R0 register is used as an index register in indexed register indirect addressing mode and indexed GBR indirect addressing mode.

*2 Bank register

*3 Bank register
Accessed as a general register when the RB bit is set to 1 in the SR register.
Accessed only by LDC/STC instructions when the RB bit is cleared to 0.

*4 Bank register
Accessed as a general register when the RB bit is cleared to 0 in the SR register.
Accessed only by LDC/STC instructions when the RB bit is set to 1.

Figure 2.3 Register Configuration in Each Processing Mode

2.3.1 General Registers

There are twenty-four 32-bit general registers: R0_BANK0 to R7_BANK0, R0_BANK1 to R7_BANK1, and R8 to R15. R0 to R7 are banked. The process mode and the register bank (RB) bit in the status register (SR) define which set of banked registers (R0_BANK0 to R7_BANK0 or R0_BANK1 to R7_BANK1) are accessed as general registers. R0 to R7 registers in the selected bank are accessed as R0 to R7. R0 to R7 in the non-selected bank is accessed as R0_BANK to R7_BANK by the control register load instruction (LDC) and control register store instruction (STC).

In user mode, bank 0 is selected regardless of he RB bit value. Sixteen registers: R0_BANK0 to R7_BANK0 and R8 to R15 are accessed as general registers R0 to R15. The R0_BANK1 to R7_BANK1 registers in bank 1 cannot be accessed.

In privileged mode that is entered by a transition to exception handling state, the RB bit is set to 1 to select bank 1. In privileged mode, sixteen registers: R0_BANK1 to R7_BANK1 and R8 to R15 are accessed as general registers R0 to R15. A bank is switched automatically when an exception handling state is entered, registers R0 to R7 need not be saved by the exception handling routine. The R0_BANK0 to R7_BANK0 registers in bank 0 can be accessed as R0_BANK to R7_BANK by the LDC and STC instructions.

In privileged mode, bank 0 can also be used as general registers by clearing the RB bit to 0. In this case, sixteen registers: R0_BANK0 to R7_BANK0 and R8 to R15 are accessed as general registers R0 to R15. The R0_BANK1 to R7_BANK1 registers in bank 1 can be accessed as R0_BANK to R7_BANK by the LDC and STC instructions.

The general registers R0 to R15 are used as equivalent registers for almost all instructions. In some instructions, the R0 register is automatically used or only the R0 register can be used as source or destination registers.

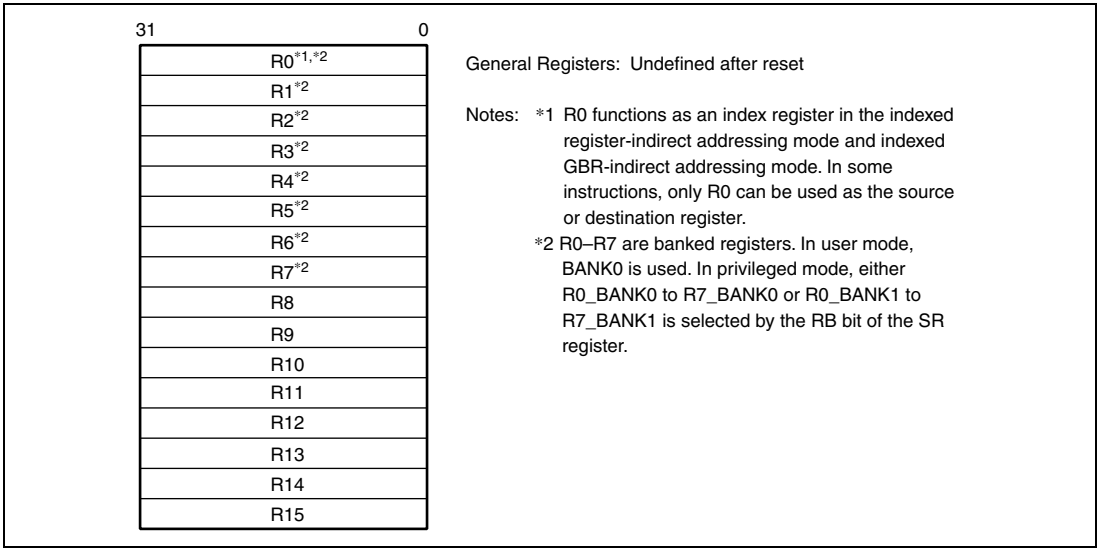


Figure 2.4 General Registers

2.3.2 System Registers

The system registers: multiply and accumulate registers (MACH/MACL) and procedure register (PR) as system registers can be accessed by the LDS and STS instructions.

Multiply and Accumulate Registers) (MACH/MACL: The multiply and accumulate registers (MACH/MACL) store the results of multiplication and accumulation instructions or multiplication instructions. The MACH/MACL registers also store addition values for the multiplication and accumulations. After reset, these registers are undefined. The MACH and MACL registers store upper 32 bits and lower 32 bits, respectively.

Procedure Register (PR): The procedure register (PR) stores the return address for a subroutine call using the BSR, BSRF, or JSR instruction. The return address stored in the PR register is restored to the program counter (PC) by the RTS (return from the subroutine) instruction. After reset, this register is undefined.

2.3.3 Program Counter

The program counter (PC) stores the value obtained by adding 4 to the current instruction address. There is no instruction to read the PC directly. Before an exception handling state is entered, the PC is saved in the save program counter (SPC). Before a subroutine call is executed, the PC is saved in the procedure register (PR). In addition, the PC can be used for PC relative addressing mode.

Figure 2.5 shows the system register and program counter configurations.

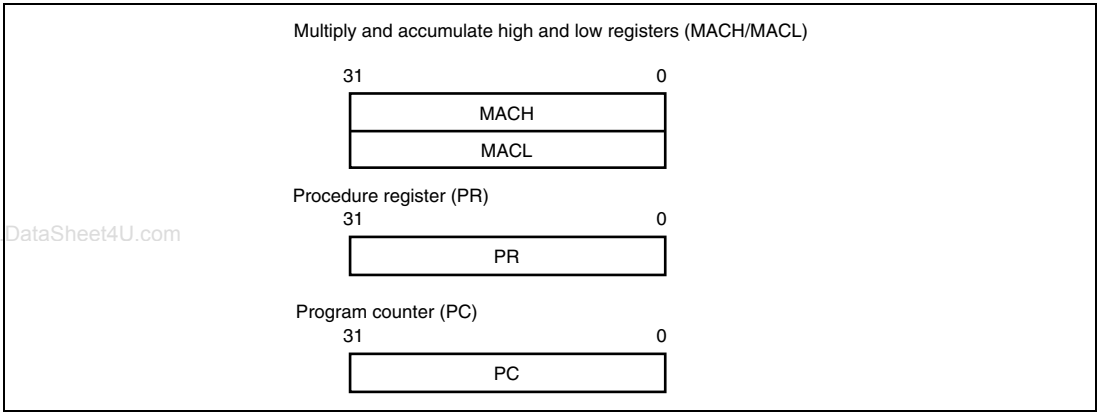


Figure 2.5 System Registers and Program Counter

2.3.4 Control Registers

The control registers (SR, GBR, SSR, SPC, and VBR) can be accessed by the LDC or STC instruction in privileged mode. The GBR register can be accessed in the user mode.

The control registers are described below.

Status Register (SR): The status register (SR) indicates the system status as shown below. The SR register can be accessed only in privileged mode.

Bit	Bit Name	Initial Value	R/W	Description
31	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
30	MD	1	R/W	Processing Mode Indicates the CPU processing mode. 0: User mode 1: Privileged mode The MD bit is set to 1 in reset or exception handling state.
29	RB	1	R/W	Register Bank The general registers R0 to R7 are banked registers. The RB bit selects a bank used in the privileged mode. 0: Selects bank 0 registers. In this case, R0_BANK0 to R7_BANK0 and R8 to R15 are used as general registers. R0_BANK1 to R7_BANK1 can be accessed by the LDC or STR instruction. 1: Selects bank 1 registers. In this case, R0_BANK1 to R7_BANK1 and R8 to R15 are used as general registers. R0_BANK0 to R7_BANK0 can be accessed by the LDC or STR instruction. The RB bit is set to 1 in reset or exception handling state.
28	BL	1	R/W	Block Specifies whether an exception, interrupt, or user break is enabled or not. 0: Enables an exception, interrupt, or user break. 1: Disables an exception, interrupt, or user break. The BL bit is set to 1 in reset or exception handling state.
27 to 10	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
9	M	—	R/W	M Bit
8	Q	—	R/W	Q Bit These bits are used by the DIV0S, DIV0U, and DIV1 instructions. These bits can be changed even in user mode by using the DIV0S, DIV0U, and DIV1 instructions. These bits are undefined at reset. These bits do not change in an exception handling state.
7 to 4	I3 to I0	All 1	R/W	Interrupt Mask Indicates the interrupt mask level. These bits do not change even if an interrupt occurs. At reset, these bits are initialized to B'1111. These bits are not affected in an exception handling state.
3, 2	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
1	S	—	R/W	Saturation Mode Specifies the saturation mode for multiply instructions or multiply and accumulate instructions. This bit can be specified by the SETS and CLRS instructions in user mode. At reset, this bit is undefined. This bit is not affected in an exception handling state.
0	T	—	R/W	T Bit Indicates true or false for compare instructions or carry or borrow occurrence for an operation instruction with carry or borrow. This bit can be specified by the SETT and CLRT instructions in user mode. At reset, this bit is undefined. This bit is not affected in an exception handling state.

Note: The M, Q, S, and T bits can be set/cleared by the user mode specific instructions. Other bits can be read or written in privileged mode.

Save Status Register (SSR): The save status register (SSR) can be accessed only in privileged mode. Before entering the exception, the contents of the SR register is stored in the SSR register. At reset, the SSR initial value is undefined.

Save Program Counter (SPC): The save program counter (SPC) can be accessed only in privileged mode. Before entering the exception, the contents of the PC are stored in the SPC. At reset, the SPC initial value is undefined.

Global Base Register (GBR): The global base register (GBR) is referenced as a base register in GBR indirect addressing mode. At reset, the GBR initial value is undefined.

Vector Base Register (VBR): The global base register (GBR) can be accessed only in privileged mode. If a transition from reset state to exception handling state occurs, this register is referenced as a base address. For details, refer to section 5, Exception Handling. At reset, the VBR is initialized as H'00000000.

Figure 2.6 shows the control register configuration.

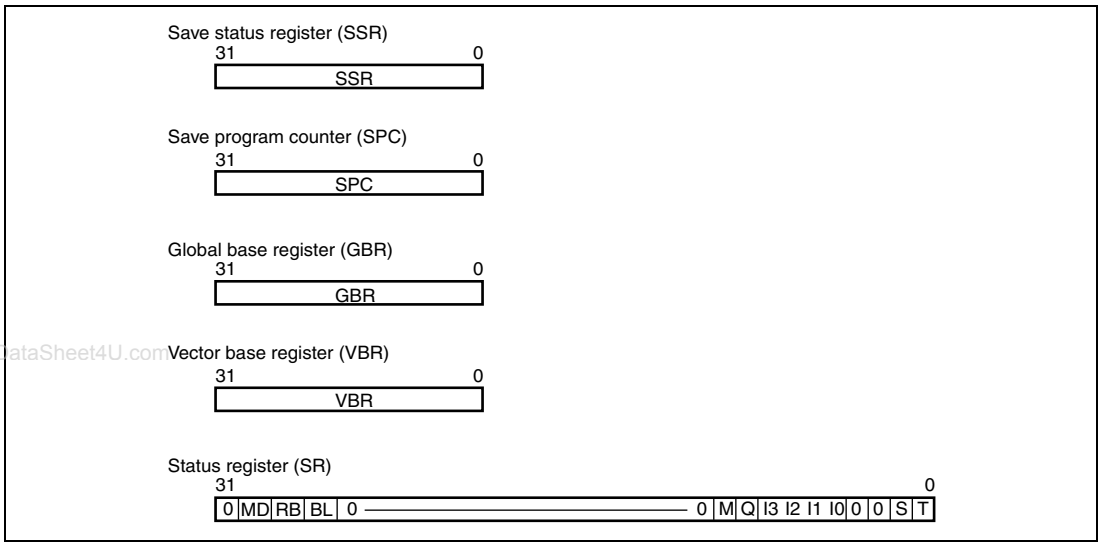
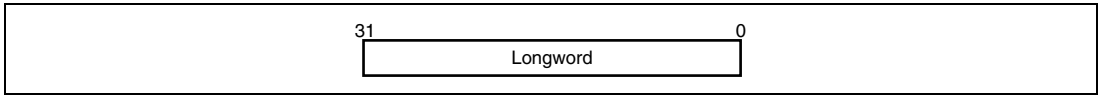


Figure 2.6 Control Register Configuration

2.4 Data Formats

2.4.1 Register Data Format

Register operands are always longwords (32 bits). When the memory operand is only a byte (8 bits) or a word (16 bits), it is sign-extended into a longword when loaded into a register.



2.4.2 Memory Data Formats

Memory data formats are classified into byte, word, and longword. Memory can be accessed in byte, word, and longword. When the memory operand is only a byte (8 bits) or a word (16 bits), it is sign-extended into a longword when loaded into a register.

An address error will occur if word data starting from an address other than 2n or longword data starting from an address other than 4n is accessed. In such cases, the data accessed cannot be guaranteed.

When a word or longword operand is accessed, the byte positions on the memory corresponding to the word or longword data on the register is determined to the specified endian mode (big endian or little endian).

Figure 2.7 shows a byte correspondence in big endian mode. In big endian mode, the MSB byte in the register corresponds to the lowest address in the memory, and the LSB the in the register corresponds to the highest address. For example, if the contents of the general register R0 is stored at an address indicated by the general register R1 in longword, the MSB byte of the R0 is stored at the address indicated by the R1 and the LSB byte of the R1 register is stored at the address indicated by the (R1 +3).

The on-chip device registers assigned to memory are accessed in big endian mode. Note that the available access size (byte, word, or long word) differs in each register.

Note: The CPU instruction codes of this LSI must be stored in word units. In big endian mode, the instruction code must be stored from upper byte to lower byte in this order from the word boundary of the memory.

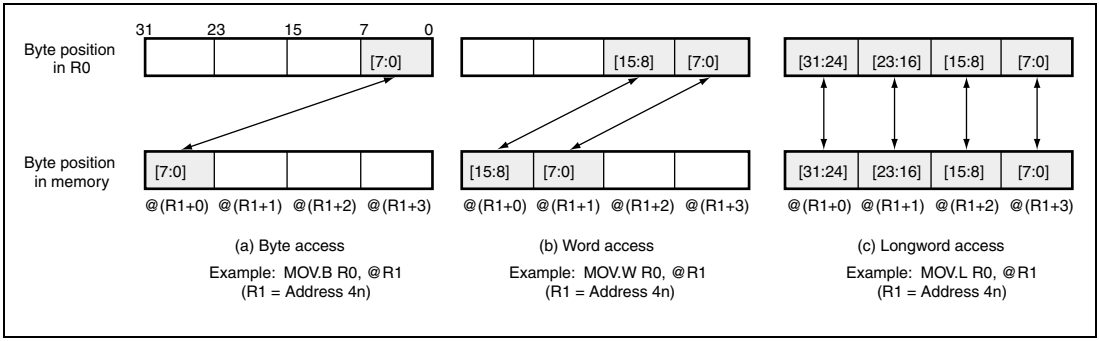


Figure 2.7 Data Format on Memory (Big Endian Mode)

The little endian mode can also be specified as data format. Either big-endian or little-endian mode can be selected according to the MD5 pin at reset. When MD5 is low at reset, the processor operates in big-endian mode. When MD5 is high at reset, the processor operates in little-endian mode. The endian mode cannot be modified dynamically.

In little endian mode, the MSB byte in the register corresponds to the highest address in the memory, and the LSB the in the register corresponds to the lowest address (figure 2.8). For example, if the contents of the general register R0 is stored at an address indicated by the general register R1 in longword, the MSB byte of the R0 is stored at the address indicated by the (R1+3) and the LSB byte of the R1 register is stored at the address indicated by the R1.

If the little endian mode is selected, the on-chip device registers assigned to memory are accessed in big endian mode. Note that the available access size (byte, word, or long word) differs in each register.

Note: The CPU instruction codes of this LSI must be stored in word units. In little endian mode, the instruction code must be stored from lower byte to upper byte in this order from the word boundary of the memory.

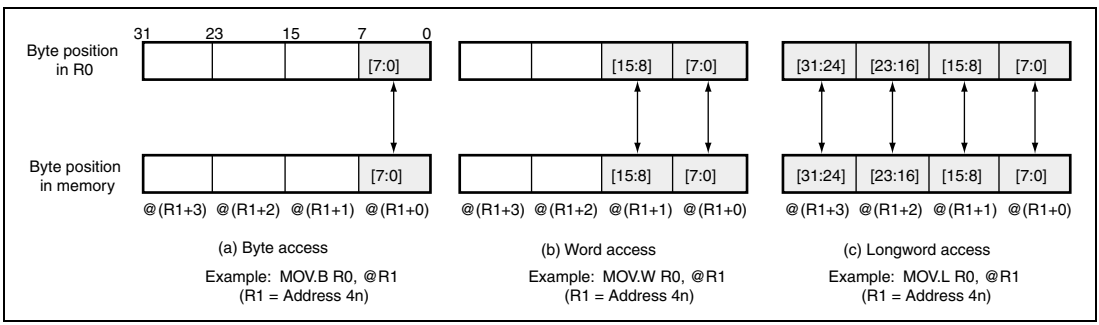


Figure 2.8 Data Format on Memory (Little Endian Mode)

2.5 Features of CPU Core Instructions

2.5.1 Instruction Execution Method

Instruction Length: All instructions have a fixed length of 16 bits and are executed in the sequential pipeline. In the sequential pipeline, almost all instructions can be executed in one cycle. All data items are handles in longword (32 bits). Memory can be accessed in byte, word, or longword. In this case, Memory byte or word data is sign-extended and operated on as longword data. Immediate data is sign-extended to longword size for arithmetic operations (MOV, ADD, and CMP/EQ instructions) or zero-extended to longword size for logical operations (TST, AND, OR, and XOR instructions).

Load/Store Architecture: Basic operations are executed between registers. In operations involving memory, data is first loaded into a register (load/store architecture). However, bit manipulation instructions such as AND are executed directly on memory.

Delayed Branching: Unconditional branch instructions are executed as delayed branches. With a delayed branch instruction, the branch is made after execution of the instruction (called the slot instruction) immediately following the delayed branch instruction. This minimizes disruption of the pipeline when a branch is made.

This LSI supports two types of conditional branch instructions: delayed branch instruction or normal branch instruction.

```
Example:  BRA     TARGET
          ADD     R1, R0        ; ADD is executed before branching to the TARGET
```

T Bit: The result of a comparison is indicated by the T bit in the status register (SR), and a conditional branch is performed according to whether the result is True or False. Processing speed has been improved by keeping the number of instructions that modify the T bit to a minimum.

```
Example:  ADD     #1, R0        ; The T bit cannot be modified by the ADD instruction
          CMP/EQ  #0, R0        ; The T bit is set to 1 if R0 is 0.
          BT      Target        ; Branch to TARGET if the T bit is set to 1 (R0=0).
```

Literal Constant: Byte literal constant is placed inside the instruction code as immediate data. Since the instruction length is fixed to 16 bits, word and longword literal constant is not placed inside the instruction code, but in a table in memory. The table in memory is referenced with a MOV instruction using PC-relative addressing mode with displacement.

```
Example:   MOV.W    @(disp, PC)
```

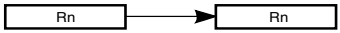
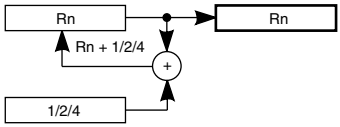
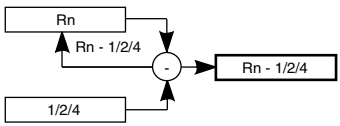
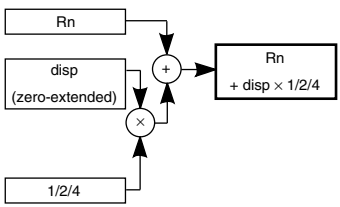
Absolute Addresses: When data is referenced by absolute address, the absolute address value is placed in a table in memory beforehand as well as word or longword literal constant. Using the method whereby immediate data is loaded when an instruction is executed, this value is transferred to a register and the data is referenced using register indirect addressing mode.

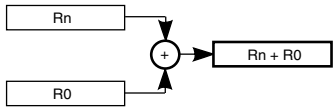
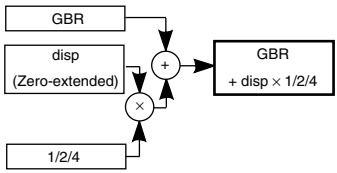
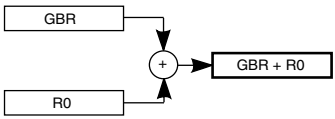
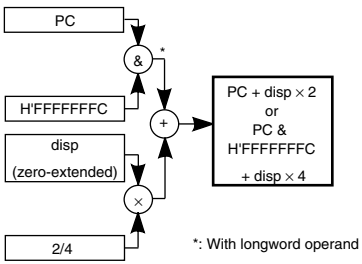
16-Bit/32-Bit Displacement: When data is referenced with a 16- or 32-bit displacement, the displacement value is placed in a table in memory beforehand. Using the method whereby word or longword immediate data is loaded when an instruction is executed, this value is transferred to a register and the data is referenced using indexed register indirect addressing mode.

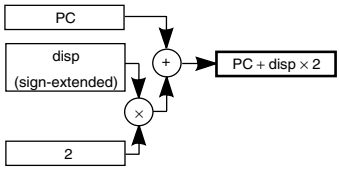
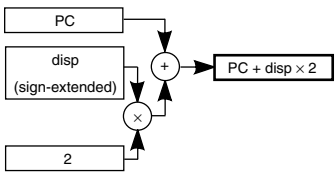
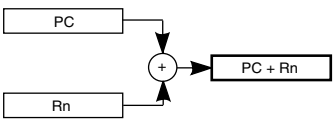
2.5.2 CPU Instruction Addressing Modes

The following table shows addressing modes and effective address calculation methods for instructions executed by the CPU core.

Table 2.3 Addressing Modes and Effective Addresses for CPU Instructions

Addressing Mode	Instruction Format	Effective Address Calculation Method	Calculation Formula
Register direct	Rn	Effective address is register Rn. (Operand is register Rn contents.)	—
Register indirect	@Rn	Effective address is register Rn contents. 	Rn
Register indirect with post-increment	@Rn+	Effective address is register Rn contents. A constant is added to Rn after instruction execution: 1 for a byte operand, 2 for a word operand, 4 for a longword operand. 	Rn After instruction execution Byte: Rn + 1 → Rn Word: Rn + 2 → Rn Longword: Rn + 4 → Rn
Register indirect with pre-decrement	@–Rn	Effective address is register Rn contents, decremented by a constant beforehand: 1 for a byte operand, 2 for a word operand, 4 for a longword operand. 	Byte: Rn – 1 → Rn Word: Rn – 2 → Rn Longword: Rn – 4 → Rn (Instruction executed with Rn after calculation)
Register indirect with displacement	@(disp:4, Rn)	Effective address is register Rn contents with 4-bit displacement disp added. After disp is zero-extended, it is multiplied by 1 (byte), 2 (word), or 4 (longword), according to the operand size. 	Byte: Rn + disp Word: Rn + disp × 2 Longword: Rn + disp × 4

Addressing Mode	Instruction Format	Effective Address Calculation Method	Calculation Formula
Indexed register indirect	@(R0, Rn)	Effective address is sum of register Rn and R0 contents. 	Rn + R0
GBR indirect with displacement	@(disp:8, GBR)	Effective address is register GBR contents with 8-bit displacement disp added. After disp is zero-extended, it is multiplied by 1 (byte), 2 (word), or 4 (longword), according to the operand size. 	Byte: GBR + disp Word: GBR + disp × 2 Longword: GBR + disp × 4
Indexed GBR indirect	@(R0, GBR)	Effective address is sum of register GBR and R0 contents. 	GBR + R0
PC-relative with displacement	@(disp:8, PC)	Effective address is PC with 8-bit displacement disp added. After disp is zero-extended, it is multiplied by 2 (word) or 4 (longword), according to the operand size. With a longword operand, the lower 2 bits of PC are masked. 	Word: PC + disp × 2 Longword: PC&H'FFFFFFFC + disp × 4

Addressing Mode	Instruction Format	Effective Address Calculation Method	Calculation Formula
PC-relative	disp:8	Effective address is PC with 8-bit displacement disp added after being sign-extended and multiplied by 2. 	PC + disp × 2
	disp:12	Effective address is PC with 12-bit displacement disp added after being sign-extended and multiplied by 2 	PC + disp × 2
	Rn	Effective address is sum of PC and Rn. 	PC + Rn
Immediate	#imm:8	8-bit immediate data imm of TST, AND, OR, or XOR instruction is zero-extended.	—
	#imm:8	8-bit immediate data imm of MOV, ADD, or CMP/EQ instruction is sign-extended.	—
	#imm:8	8-bit immediate data imm of TRAPA instruction is zero-extended and multiplied by 4.	—

Note: For addressing modes with displacement (disp) as shown below, the assembler description in this manual indicates the value before it is scaled (x 1, x2, or x4) according to the operand size to clarify the LSI operation. For details on assembler description, refer to the description rules in each assembler.

```
@ (disp:4, Rn)      ; Register indirect with displacement
@ (disp:8, Rn)      ; GBR indirect with displacement
@ (disp:8, PC)      ; PC relative with displacement
disp:8, disp        ; PC relative
```

2.5.3 CPU Instruction Formats

Table 2.4 shows the instruction formats, and the meaning of the source and destination operands, for instructions executed by the CPU core. The meaning of the operands depends on the instruction code. The following symbols are used in the table.

xxxx: Instruction code

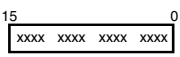
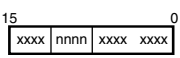
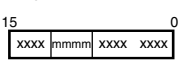
mmmm: Source register

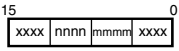
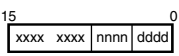
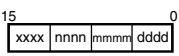
nnnn: Destination register

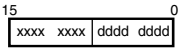
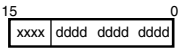
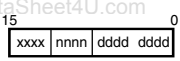
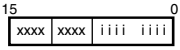
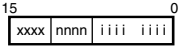
iiii: Immediate data

dddd: Displacement

Table 2.4 CPU Instruction Formats

Instruction Format	Source Operand	Destination Operand	Sample Instruction
0 type 	—	—	NOP
n type 	—	nnnn: register direct	MOVT Rn
	Control register or system register	nnnn: register direct	STS MACH,Rn
	Control register or system register	nnnn: pre-decrement register indirect	STC.L SR,@-Rn
m type 	mmmm: register direct	Control register or system register	LDC Rm,SR
	mmmm: post-increment register indirect	Control register or system register	LDC.L @Rm+,SR
	mmmm: register indirect	—	JMP @Rm
	PC-relative using Rm	—	BRAF Rm

Instruction Format	Source Operand	Destination Operand	Sample Instruction
nm type 	mmmm: register direct	nnnn: register direct	ADD Rm,Rn
	mmmm: register indirect	nnnn: register indirect	MOV.L Rm,@Rn
	mmmm: post-increment register indirect (multiply-and-accumulate operation) nnnn: * post-increment register indirect (multiply-and-accumulate operation)	MACH, MACL	MAC.W @Rm+,@Rn+
	mmmm: post-increment register indirect	nnnn: register direct	MOV.L @Rm+,Rn
	mmmm: register direct	nnnn: pre-decrement register indirect	MOV.L Rm,@-Rn
	mmmm: register direct	nnnn: indexed register indirect	MOV.L Rm,@(R0,Rn)
md type 	mmmmdddd: register indirect with displacement	R0 (register direct)	MOV.B @(disp,Rm),R0
nd4 type 	R0 (register direct)	nnnndddd: register indirect with displacement	MOV.B R0,@(disp,Rn)
nmd type 	mmmm: register direct	nnnndddd: register indirect with displacement	MOV.L Rm,@(disp,Rn)
	mmmmdddd: register indirect with displacement	nnnn: register direct	MOV.L @(disp,Rm),Rn

Instruction Format	Source Operand	Destination Operand	Sample Instruction
d type 	dddddddd: GBR indirect with displacement	R0 (register direct)	MOV.L @(disp,GBR),R0
	R0 (register direct)	dddddddd: GBR indirect with displacement	MOV.L R0,@(disp,GBR)
	dddddddd: PC-relative with displacement	R0 (register direct)	MOVA @(disp,PC),R0
	dddddddd: PC-relative	—	BF label
d12 type 	ddddddddddd: PC-relative	—	BRA label (label=disp+PC)
nd8 type 	dddddddd: PC-relative with displacement	nnnn: register direct	MOV.L @(disp,PC),Rn
i type 	iiiiiiii: immediate	Indexed GBR indirect	AND.B #imm,@(R0,GBR)
	iiiiiiii: immediate	R0 (register direct)	AND #imm,R0
	iiiiiiii: immediate	—	TRAPA #imm
ni type 	iiiiiiii: immediate	nnnn: register direct	ADD #imm,Rn

Note: * In multiply-and-accumulate instructions, nnnn is the source register.

2.6 Instruction Set

2.6.1 CPU Instruction Set Based on Functions

The CPU instruction set consists of 68 basic instruction types divided into six functional groups, as shown in table 2.5. Tables 2.6 to 2.11 show the instruction notation, machine code, execution time, and function.

Table 2.5 CPU Instruction Types

Type	Kinds of Instruction	Op Code	Function	Number of Instructions
Data transfer instructions	5	MOV	Data transfer Immediate data transfer Peripheral module data transfer Structure data transfer	39
		MOVA	Effective address transfer	
		MOVT	T bit transfer	
		SWAP	Upper/lower swap	
		XTRCT	Extraction of middle of linked registers	
Arithmetic operation instructions	21	ADD	Binary addition	33
		ADDC	Binary addition with carry	
		ADDV	Binary addition with overflow check	
		CMP/cond	Comparison	
		DIV1	Division	
		DIV0S	Signed division initialization	
		DIV0U	Unsigned division initialization	
		DMULS	Signed double-precision multiplication	
		DMULU	Unsigned double-precision multiplication	
		DT	Decrement and test	
		EXTS	Sign extension	
		EXTU	Zero extension	
		MAC	Multiply-and-accumulate, double-precision multiply-and-accumulate	
		MUL	Double-precision multiplication (32×32 bits)	

Type	Kinds of Instruction	Op Code	Function	Number of Instructions
Arithmetic operation instructions	21	MULS	Signed multiplication (16 × 16 bits)	33
		MULU	Unsigned multiplication (16 × 16 bits)	
		NEG	Sign inversion	
		NEGC	Sign inversion with borrow	
		SUB	Binary subtraction	
		SUBC	Binary subtraction with carry	
		SUBV	Binary subtraction with underflow	
Logic operation instructions	6	AND	Logical AND	14
		NOT	Bit inversion	
		OR	Logical OR	
		TAS	Memory test and bit setting	
		TST	Logical AND and T bit setting	
		XOR	Exclusive logical OR	
Shift instructions	12	ROTL	1-bit left shift	16
		ROTR	1-bit right shift	
		ROTCL	1-bit left shift with T bit	
		ROTCR	1-bit right shift with T bit	
		SHAL	Arithmetic 1-bit left shift	
		SHAR	Arithmetic 1-bit right shift	
		SHLL	Logical 1-bit left shift	
		SHLLn	Logical n-bit left shift	
		SHLR	Logical 1-bit right shift	
		SHLRn	Logical n-bit right shift	
		SHAD	Arithmetic dynamic shift	
		SHLD	Logical dynamic shift	

Type	Kinds of Instruction	Op Code	Function	Number of Instructions
Branch instructions	9	BF	Conditional branch, delayed conditional branch (T = 0)	11
		BT	Conditional branch, delayed conditional branch (T = 1)	
		BRA	Unconditional branch	
		BRAF	Unconditional branch	
		BSR	Branch to subroutine procedure	
		BSRF	Branch to subroutine procedure	
		JMP	Unconditional branch	
		JSR	Branch to subroutine procedure	
		RTS	Return from subroutine procedure	
System control instructions	15	CLRT	T bit clear	75
		CLRMAC	MAC register clear	
		CLRS	S bit clear	
		LDC	Load into control register	
		LDS	Load into system register	
		LDTLB	PTEH/PTEL load into TLB	
		NOP	No operation	
		PREF	Data prefetch to cache	
		RTE	Return from exception handling	
		SETS	S bit setting	
		SETT	T bit setting	
		SLEEP	Transition to power-down mode	
		STC	Store from control register	
		STS	Store from system register	
		TRAPA	Trap exception handling	
Total:	68			188

The instruction code, operation, and number of execution states of the CPU instructions are shown in the following tables, classified by instruction type, using the format shown below.

Instruction	Instruction Code	Operation	Privilege	Execution States	T Bit
Indicated by mnemonic.	Indicated in MSB ↔ LSB order.	Indicates summary of operation.	Indicates a privileged instruction.	Value when no wait states are inserted*1	Value of T bit after instruction is executed
Explanation of Symbols OP.Sz SRC, DEST OP: Operation code Sz: Size SRC: Source DEST: Destination Rm: Source register Rn: Destination register imm: Immediate data disp: Displacement	Explanation of Symbols mmmm: Source register nnnn: Destination register 0000: R0 0001: R1 ..... 1111: R15 iiii: Immediate data dddd: Displacement*2	Explanation of Symbols →, ←: Transfer direction (xx): Memory operand M/Q/T: Flag bits in SR &: Logical AND of each bit |: Logical OR of each bit ^: Exclusive logical OR of each bit ~: Logical NOT of each bit <<n: n-bit left shift >>n: n-bit right shift			Explanation of Symbols —: No change

Notes: 1. The table shows the minimum number of execution states. In practice, the number of instruction execution states will be increased in cases such as the following:
   a. When there is a conflict between an instruction fetch and a data access
   b. When the destination register of a load instruction (memory → register) is also used by the following instruction
2. Scaled (x1, x2, or x4) according to the instruction operand size, etc.

Table 2.6 Data Transfer Instructions

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
MOV	#imm,Rn	1110nnnniiiiiiii	Imm → Sign extension → Rn	–	1	–
MOV.W	@(disp,PC),Rn	1001nnnnddddddd	(disp x 2+PC)→Sign extension → Rn	–	1	–
MOV.L	@(disp,PC),Rn	1101nnnnddddddd	(disp x 4+PC)→Rn	–	1	–
MOV	Rm,Rn	0110nnnnmmmm0011	Rm→Rn	–	1	–
MOV.B	Rm,@Rn	0010nnnnmmmm0000	Rm→(Rn)	–	1	–
MOV.W	Rm,@Rn	0010nnnnmmmm0001	Rm→(Rn)	–	1	–
MOV.L	Rm,@Rn	0010nnnnmmmm0010	Rm→(Rn)	–	1	–
MOV.B	@Rm,Rn	0110nnnnmmmm0000	(Rm)→Sign extension→Rn	–	1	–
MOV.W	@Rm,Rn	0110nnnnmmmm0001	(Rm)→Sign extension→Rn	–	1	–
MOV.L	@Rm,Rn	0110nnnnmmmm0010	(Rm)→Rn	–	1	–
MOV.B	Rm,@–Rn	0010nnnnmmmm0100	Rn–1→Rn, Rm→(Rn)	–	1	–
MOV.W	Rm,@–Rn	0010nnnnmmmm0101	Rn–2→Rn, Rm→(Rn)	–	1	–
MOV.L	Rm,@–Rn	0010nnnnmmmm0110	Rn–4→Rn, Rm→(Rn)	–	1	–
MOV.B	@Rm+,Rn	0110nnnnmmmm0100	(Rm)→Sign extension→Rn, Rm+1→Rm	–	1	–
MOV.W	@Rm+,Rn	0110nnnnmmmm0101	(Rm)→Sign extension→Rn, Rm+2→Rm	–	1	–
MOV.L	@Rm+,Rn	0110nnnnmmmm0110	(Rm)→Rn, Rm+4→Rm	–	1	–
MOV.B	R0,@(disp,Rn)	10000000nnnndddd	R0→(disp+Rn)	–	1	–
MOV.W	R0,@(disp,Rn)	10000001nnnndddd	R0→(disp x 2+Rn)	–	1	–
MOV.L	Rm,@(disp,Rn)	0001nnnnmmmmdddd	Rm→(disp x 4+Rn)	–	1	–
MOV.B	@(disp,Rm),R0	10000100mmmmdddd	(disp+Rm)→Sign extension→R0	–	1	–
MOV.W	@(disp,Rm),R0	10000101mmmmdddd	(disp x 2+Rm)→Sign extension→R0	–	1	–
MOV.L	@(disp,Rm),Rn	0101nnnnmmmmdddd	(disp x 4+Rm)→Rn	–	1	–
MOV.B	Rm,@(R0,Rn)	0000nnnnmmmm0100	Rm→(R0+Rn)	–	1	–
MOV.W	Rm,@(R0,Rn)	0000nnnnmmmm0101	Rm→(R0+Rn)	–	1	–
MOV.L	Rm,@(R0,Rn)	0000nnnnmmmm0110	Rm→(R0+Rn)	–	1	–

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
MOV.B	@(R0,Rm),Rn	0000nnnnmmmm1100	(R0+Rm)→Sign extension→Rn	–	1	–
MOV.W	@(R0,Rm),Rn	0000nnnnmmmm1101	(R0+Rm)→Sign extension→Rn	–	1	–
MOV.L	@(R0,Rm),Rn	0000nnnnmmmm1110	(R0+Rm)→Rn	–	1	–
MOV.B	R0,@(disp,GBR)	11000000dddddddd	R0→(disp+GBR)	–	1	–
MOV.W	R0,@(disp,GBR)	11000001dddddddd	R0→(disp x 2+GBR)	–	1	–
MOV.L	R0,@(disp,GBR)	11000010dddddddd	R0→(disp x 4+GBR)	–	1	–
MOV.B	@(disp,GBR),R0	11000100dddddddd	(disp+GBR)→Sign extension→R0	–	1	–
MOV.W	@(disp,GBR),R0	11000101dddddddd	(disp x 2+GBR)→Sign extension→R0	–	1	–
MOV.L	@(disp,GBR),R0	11000110dddddddd	(disp x 4+GBR)→R0	–	1	–
MOVA	@(disp,PC),R0	11000111dddddddd	disp x 4+PC→R0	–	1	–
MOVT	Rn	0000nnnn00101001	T→Rn	–	1	–
SWAP.B	Rm,Rn	0110nnnnmmmm1000	Rm→Swap lowest two bytes→Rn	–	1	–
SWAP.W	Rm,Rn	0110nnnnmmmm1001	Rm→Swap two consecutive words→Rn	–	1	–
XTRCT	Rm,Rn	0010nnnnmmmm1101	Rm: Middle 32 bits of Rn →Rn	–	1	–

Table 2.7 Arithmetic Operation Instructions

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
ADD	Rm,Rn	0011nnnnmmmm1100	Rn+Rm→Rn	–	1	–
ADD	#imm,Rn	0111nnnniiiiiiii	Rn+imm→Rn	–	1	–
ADDC	Rm,Rn	0011nnnnmmmm1110	Rn+Rm+T→Rn, Carry→T	–	1	Carry
ADDV	Rm,Rn	0011nnnnmmmm1111	Rn+Rm→Rn, Overflow→T	–	1	Overflow
CMP/EQ	#imm,R0	10001000iiiiiiii	If R0 = imm, 1 → T	–	1	Comparison result
CMP/EQ	Rm,Rn	0011nnnnmmmm0000	If Rn = Rm, 1 → T	–	1	Comparison result
CMP/HS	Rm,Rn	0011nnnnmmmm0010	If Rn ≥ Rm with unsigned data, 1 → T	–	1	Comparison result
CMP/GE	Rm,Rn	0011nnnnmmmm0011	If Rn ≥ Rm with signed data, 1 → T	–	1	Comparison result
CMP/HI	Rm,Rn	0011nnnnmmmm0110	If Rn > Rm with unsigned data, 1 → T	–	1	Comparison result
CMP/GT	Rm,Rn	0011nnnnmmmm0111	If Rn > Rm with signed data, 1 → T	–	1	Comparison result
CMP/PL	Rn	0100nnnn00010101	If Rn ≥ 0, 1 → T	–	1	Comparison result
CMP/PZ	Rn	0100nnnn00010001	If Rn > 0, 1 → T	–	1	Comparison result
CMP/STR	Rm,Rn	0010nnnnmmmm1100	If Rn and Rm have an equivalent byte, 1 → T	–	1	Comparison result
DIV1	Rm,Rn	0011nnnnmmmm0100	Single-step division (Rn/Rm)	–	1	Calculation result
DIV0S	Rm,Rn	0010nnnnmmmm0111	MSB of Rn → Q, MSB of Rm → M, M ^ Q → T	–	1	Calculation result
DIV0U		0000000000011001	0 → M/Q/T	–	1	0
DMULS.L	Rm,Rn	0011nnnnmmmm1101	Signed operation of Rn × Rm → MACH, MACL 32 × 32 → 64 bits	–	2 (to 5)*	–
DMULU.L	Rm,Rn	0011nnnnmmmm0101	Unsigned operation of Rn × Rm → MACH, MACL 32 × 32 → 64 bits	–	2 (to 5)*	–
DT	Rn	0100nnnn00010000	Rn – 1 → Rn, if Rn = 0, 1 → T, else 0 → T	–	1	Comparison result

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
EXTS.B	Rm,Rn	0110nnnnmmmm1110	A byte in Rm is sign-extended → Rn	–	1	–
EXTS.W	Rm,Rn	0110nnnnmmmm1111	A word in Rm is sign-extended → Rn	–	1	–
EXTU.B	Rm,Rn	0110nnnnmmmm1100	A byte in Rm is zero-extended → Rn	–	1	–
EXTU.W	Rm,Rn	0110nnnnmmmm1101	A word in Rm is zero-extended → Rn	–	1	–
MAC.L	@Rm+, @Rn+	0000nnnnmmmm1111	Signed operation of (Rn) × (Rm) + MAC → MAC,Rn + 4 → Rn, Rm + 4 → Rm, 32 × 32 + 64 → 64 bits	–	2 (to 5)*	–
MAC.W	@Rm+, @Rn+	0100nnnnmmmm1111	Signed operation of (Rn) × (Rm) + MAC → MAC,Rn + 2 → Rn, Rm + 2 → Rm, 16 × 16 + 64 → 64 bits	–	2 (to 5)*	–
MUL.L	Rm,Rn	0000nnnnmmmm0111	Rn × Rm → MACL, 32 × 32 → 32 bits	–	2 (to 5)*	–
MULS.W	Rm,Rn	0010nnnnmmmm1111	Signed operation of Rn × Rm → MACL, 16 × 16 → 32 bits	–	1(to 3)*	–
MULU.W	Rm,Rn	0010nnnnmmmm1110	Unsigned operation of Rn × Rm → MACL, 16 × 16 → 32 bits	–	1(to 3)*	–
NEG	Rm,Rn	0110nnnnmmmm1011	0–Rm→Rn	–	1	–
NEGC	Rm,Rn	0110nnnnmmmm1010	0–Rm–T→Rn, Borrow→T	–	1	Borrow
SUB	Rm,Rn	0011nnnnmmmm1000	Rn–Rm→Rn	–	1	–
SUBC	Rm,Rn	0011nnnnmmmm1010	Rn–Rm–T→Rn, Borrow →T	–	1	Borrow
SUBV	Rm,Rn	0011nnnnmmmm1011	Rn–Rm→Rn, Underflow→T	–	1	Underflow

Note: * The number of execution cycles indicated within the parentheses ( ) are required when the operation result is read from the MACH/MACL register immediately after the instruction.

Table 2.8 Logic Operation Instructions

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
AND	Rm,Rn	0010nnnnmmmm1001	Rn & Rm → Rn	–	1	–
AND	#imm,R0	11001001iiiiiiii	R0 & imm → R0	–	1	–
AND.B	#imm,@(R0, GBR)	11001101iiiiiiii	(R0+GBR) & imm → (R0+GBR)	–	3	–
NOT	Rm,Rn	0110nnnnmmmm0111	~Rm → Rn	–	1	–
OR	Rm,Rn	0010nnnnmmmm1011	Rn | Rm → Rn	–	1	–
OR	#imm,R0	11001011iiiiiiii	R0 | imm → R0	–	1	–
OR.B	#imm,@(R0, GBR)	11001111iiiiiiii	(R0+GBR) | imm → (R0+GBR)	–	3	–
TAS.B	@Rn	0100nnnn00011011	If (Rn) is 0, 1 → T; 1 → MSB of (Rn)	–	4	Test result
TST	Rm,Rn	0010nnnnmmmm1000	Rn & Rm; if the result is 0, 1 → T	–	1	Test result
TST	#imm,R0	11001000iiiiiiii	R0 & imm; if the result is 0, 1 → T	–	1	Test result
TST.B	#imm,@(R0, GBR)	11001100iiiiiiii	(R0 + GBR) & imm; if the result is 0, 1 → T	–	3	Test result
XOR	Rm,Rn	0010nnnnmmmm1010	Rn ^ Rm → Rn	–	1	–
XOR	#imm,R0	11001010iiiiiiii	R0 ^ imm → R0	–	1	–
XOR.B	#imm,@(R0, GBR)	11001110iiiiiiii	(R0+GBR) ^ imm → (R0+GBR)	–	3	–

Table 2.9 Shift Instructions

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
ROTL	Rn	0100nnnn00000100	T←Rn←MSB	–	1	MSB
ROTR	Rn	0100nnnn00000101	LSB→Rn→T	–	1	LSB
ROTCL	Rn	0100nnnn00100100	T←Rn←T	–	1	MSB
ROTCR	Rn	0100nnnn00100101	T→Rn→T	–	1	LSB
SHAD	Rm, Rn	0100nnnnmmmm1100	Rn ≥ 0: Rn << Rm → Rn Rn < 0: Rn >> Rm → [MSB → Rn]	–	1	–
SHAL	Rn	0100nnnn00100000	T←Rn←0	–	1	MSB
SHAR	Rn	0100nnnn00100001	MSB→Rn→T	–	1	LSB
SHLD	Rm, Rn	0100nnnnmmmm1101	Rn ≥ 0: Rn << Rm → Rn Rn < 0: Rn >> Rm → [0 → Rn]	–	1	–
SHLL	Rn	0100nnnn00000000	T←Rn←0	–	1	MSB
SHLR	Rn	0100nnnn00000001	0→Rn→T	–	1	LSB
SHLL2	Rn	0100nnnn00001000	Rn<<2 → Rn	–	1	–
SHLR2	Rn	0100nnnn00001001	Rn>>2 → Rn	–	1	–
SHLL8	Rn	0100nnnn00011000	Rn<<8 → Rn	–	1	–
SHLR8	Rn	0100nnnn00011001	Rn>>8 → Rn	–	1	–
SHLL16	Rn	0100nnnn00101000	Rn<<16 → Rn	–	1	–
SHLR16	Rn	0100nnnn00101001	Rn>>16 → Rn	–	1	–

Table 2.10 Branch Instructions

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
BF	disp	10001011dddddddd	If T = 0, disp × 2 + PC → PC; if T = 1, nop	–	3/1*	–
BF/S	disp	10001111dddddddd	Delayed branch, if T = 0, disp × 2 + PC → PC; if T = 1, nop	–	2/1*	–
BT	disp	10001001dddddddd	If T = 1, disp × 2 + PC → PC; if T = 0, nop	–	3/1*	–
BT/S	disp	10001101dddddddd	Delayed branch, if T = 1, disp × 2 + PC → PC; if T = 0, nop	–	2/1*	–
BRA	disp	1010dddddddddddd	Delayed branch, disp × 2 + PC → PC	–	2	–
BRAF	Rm	0000mmmm00100011	Delayed branch,Rm + PC → PC	–	2	–
BSR	disp	1011dddddddddddd	Delayed branch, PC → PR, disp × 2 + PC → PC	–	2	–
BSRF	Rm	0000mmmm00000011	Delayed branch, PC → PR, Rm + PC → PC	–	2	–
JMP	@Rm	0100mmmm00101011	Delayed branch, Rm → PC	–	2	–
JSR	@Rm	0100mmmm00001011	Delayed branch, PC → PR, Rm → PC	–	2	–
RTS		0000000000001011	Delayed branch, PR → PC	–	2	–

Note: * One state when the branch is not executed.

Table 2.11 System Control Instructions

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
CLRMAC		0000000000101000	0→MACH,MACL	–	1	–
CLRS		0000000001001000	0→S	–	1	–
CLRT		0000000000001000	0→T	–	1	0
LDC	Rm,SR	0100mmmm00001110	Rm→SR	√	6	LSB
LDC	Rm,GBR	0100mmmm00011110	Rm→GBR	–	4	–
LDC	Rm,VBR	0100mmmm00101110	Rm→VBR	√	4	–
LDC	Rm,SSR	0100mmmm00111110	Rm→SSR	√	4	–
LDC	Rm,SPC	0100mmmm01001110	Rm→SPC	√	4	–
LDC	Rm,R0_BANK	0100mmmm10001110	Rm→R0_BANK	√	4	–
LDC	Rm,R1_BANK	0100mmmm10011110	Rm→R1_BANK	√	4	–
LDC	Rm,R2_BANK	0100mmmm10101110	Rm→R2_BANK	√	4	–
LDC	Rm,R3_BANK	0100mmmm10111110	Rm→R3_BANK	√	4	–
LDC	Rm,R4_BANK	0100mmmm11001110	Rm→R4_BANK	√	4	–
LDC	Rm,R5_BANK	0100mmmm11011110	Rm→R5_BANK	√	4	–
LDC	Rm,R6_BANK	0100mmmm11101110	Rm→R6_BANK	√	4	–
LDC	Rm,R7_BANK	0100mmmm11111110	Rm→R7_BANK	√	4	–
LDC.L	@Rm+,SR	0100mmmm00000111	(Rm)→SR, Rm+4→Rm	√	8	LSB
LDC.L	@Rm+,GBR	0100mmmm00010111	(Rm)→GBR, Rm+4→Rm	–	4	–
LDC.L	@Rm+,VBR	0100mmmm00100111	(Rm)→VBR, Rm+4→Rm	√	4	–
LDC.L	@Rm+,SSR	0100mmmm00110111	(Rm)→SSR, Rm+4→Rm	√	4	–
LDC.L	@Rm+,SPC	0100mmmm01000111	(Rm)→SPC, Rm+4→Rm	√	4	–
LDC.L	@Rm+, R0_BANK	0100mmmm10000111	(Rm)→R0_BANK, Rm+4→Rm	√	4	–
LDC.L	@Rm+, R1_BANK	0100mmmm10010111	(Rm)→R1_BANK, Rm+4→Rm	√	4	–
LDC.L	@Rm+, R2_BANK	0100mmmm10100111	(Rm)→R2_BANK, Rm+4→Rm	√	4	–
LDC.L	@Rm+, R3_BANK	0100mmmm10110111	(Rm)→R3_BANK, Rm+4→Rm	√	4	–
LDC.L	@Rm+, R4_BANK	0100mmmm11000111	(Rm)→R4_BANK, Rm+4→Rm	√	4	–
LDC.L	@Rm+, R5_BANK	0100mmmm11010111	(Rm)→R5_BANK, Rm+4→Rm	√	4	–

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
LDC.L	@Rm+, R6_BANK	0100mmmm11100111	(Rm)→R6_BANK, Rm+4→Rm	√	4	–
LDC.L	@Rm+, R7_BANK	0100mmmm11110111	(Rm)→R7_BANK, Rm+4→Rm	√	4	–
LDS	Rm,MACH	0100mmmm00001010	Rm→MACH	–	1	–
LDS	Rm,MACL	0100mmmm00011010	Rm→MACL	–	1	–
LDS	Rm,PR	0100mmmm00101010	Rm→PR	–	1	–
LDS.L	@Rm+,MACH	0100mmmm00000110	(Rm)→MACH, Rm+4→Rm	–	1	–
LDS.L	@Rm+,MACL	0100mmmm00010110	(Rm)→MACL, Rm+4→Rm	–	1	–
LDS.L	@Rm+,PR	0100mmmm00100110	(Rm)→PR, Rm+4→Rm	–	1	–
LDTLB		0000000000111000	PTEH/PTEL→TLB	√	1	–
NOP		0000000000001001	No operation	–	1	–
PREF	@Rm	0000mmmm10000011	(Rm) → cache	–	1	–
RTE		0000000000101011	Delayed branch, SSR → SR, SPC → PC	√	5	–
SETS		0000000001011000	1→S	–	1	–
SETT		0000000000011000	1→T	–	1	1
SLEEP		0000000000011011	Sleep	√	4*[1]	–
STC	SR,Rn	0000nnnn00000010	SR→Rn	√	1	–
STC	GBR,Rn	0000nnnn00010010	GBR→Rn	–	1	–
STC	VBR,Rn	0000nnnn00100010	VBR→Rn	√	1	–
STC	SSR, Rn	0000nnnn00110010	SSR→Rn	√	1	–
STC	SPC,Rn	0000nnnn01000010	SPC→Rn	√	1	–
STC	R0_BANK,Rn	0000nnnn10000010	R0_BANK→Rn	√	1	–
STC	R1_BANK,Rn	0000nnnn10010010	R1_BANK→Rn	√	1	–
STC	R2_BANK,Rn	0000nnnn10100010	R2_BANK→Rn	√	1	–
STC	R3_BANK,Rn	0000nnnn10110010	R3_BANK→Rn	√	1	–
STC	R4_BANK,Rn	0000nnnn11000010	R4_BANK→Rn	√	1	–
STC	R5_BANK,Rn	0000nnnn11010010	R5_BANK→Rn	√	1	–
STC	R6_BANK,Rn	0000nnnn11100010	R6_BANK→Rn	√	1	–
STC	R7_BANK,Rn	0000nnnn11110010	R7_BANK→Rn	√	1	–
STC.L	SR,@–Rn	0100nnnn00000011	Rn–4→Rn, SR→(Rn)	√	1	–
STC.L	GBR,@–Rn	0100nnnn00010011	Rn–4→Rn, GBR→(Rn)	–	1	–
STC.L	VBR,@–Rn	0100nnnn00100011	Rn–4→Rn, VBR→(Rn)	√	1	–

Instruction		Instruction Code	Operation	Privileged Mode	Cycles	T Bit
STC.L	SSR,@–Rn	0100nnnn00110011	Rn–4→Rn, SSR→(Rn)	√	1	–
STC.L	SPC,@–Rn	0100nnnn01000011	Rn–4→Rn, SPC→(Rn)	√	1	–
STC.L	R0_BANK,@–Rn	0100nnnn10000011	Rn–4→Rn, R0_BANK→(Rn)	√	1	–
STC.L	R1_BANK,@–Rn	0100nnnn10010011	Rn–4→Rn, R1_BANK→(Rn)	√	1	–
STC.L	R2_BANK,@–Rn	0100nnnn10100011	Rn–4→Rn, R2_BANK→(Rn)	√	1	–
STC.L	R3_BANK,@–Rn	0100nnnn10110011	Rn–4→Rn, R3_BANK→(Rn)	√	1	–
STC.L	R4_BANK,@–Rn	0100nnnn11000011	Rn–4→Rn, R4_BANK→(Rn)	√	1	–
STC.L	R5_BANK,@–Rn	0100nnnn11010011	Rn–4→Rn, R5_BANK→(Rn)	√	1	–
STC.L	R6_BANK,@–Rn	0100nnnn11100011	Rn–4→Rn, R6_BANK→(Rn)	√	1	–
STC.L	R7_BANK,@–Rn	0100nnnn11110011	Rn–4→Rn, R7_BANK→(Rn)	√	1	–
STS	MACH,Rn	0000nnnn00001010	MACH→Rn	–	1	–
STS	MACL,Rn	0000nnnn00011010	MACL→Rn	–	1	–
STS	PR,Rn	0000nnnn00101010	PR→Rn	–	1	–
STS.L	MACH,@–Rn	0100nnnn00000010	Rn–4→Rn, MACH→(Rn)	–	1	–
STS.L	MACL,@–Rn	0100nnnn00010010	Rn–4→Rn, MACL→(Rn)	–	1	–
STS.L	PR,@–Rn	0100nnnn00100010	Rn–4→Rn, PR→(Rn)	–	1	–
TRAPA	#imm	11000011iiiiiiii	Unconditional trap exception occurs*[3]	–	8	–

Notes: * Number of states before the chip enters the sleep state.

1. The table shows the minimum number of clocks required for execution. In practice, the number of execution cycles will be increased in the following conditions.
   a. If there is a conflict between an instruction fetch and a data access
   b. If the destination register of a load instruction (memory → register) is also used by the following instruction.
2. For addressing modes with displacement (disp) as shown below, the assembler description in this manual indicates the value before it is scaled (x 1, x2, or x4) according to the operand size to clarify the LSI operation. For details on assembler description, refer to the description rules in each assembler.
   @ (disp:4, Rn) ; Register indirect with displacement
   @ (disp:8, Rn) ; GBR indirect with displacement
   @ (disp:8, PC) ; PC relative with displacement
   disp:8, disp ; PC relative
3. For details, refer to section 5, Exception Handling.

2.6.2 Operation Code Map

Table 2.12 shows the operation code map.

Table 2.12 Operation Code Map

Instruction Code				Fx: 0000		Fx: 0001		Fx: 0010		Fx: 0011 to 1111	
MSB			LSB	MD: 00		MD: 01		MD: 10		MD: 11	
0000	Rn	Fx	0000								
0000	Rn	Fx	0001								
0000	Rn	00MD	0010	STC	SR, Rn	STC	GBR, Rn	STC	VBR, Rn	STC	SSR, Rn
0000	Rn	01MD	0010	STC	SPC, Rn						
0000	Rn	10MD	0010	STC	R0_BANK, Rn	STC	R1_BANK, Rn	STC	R2_BANK, Rn	STC	R3_BANK, Rn
0000	Rn	11MD	0010	STC	R4_BANK, Rn	STC	R5_BANK, Rn	STC	R6_BANK, Rn	STC	R7_BANK, Rn
0000	Rm	00MD	0011	BSRF	Rm			BRAF	Rm		
0000	Rm	10MD	0011	PREF	@Rm						
0000	Rn	Rm	01MD	MOV.B	Rm, @(R0, Rn)	MOV.W	Rm, @(R0, Rn)	MOV.L	Rm,@(R0, Rn)	MUL.L	Rm, Rn
0000	0000	00MD	1000	CLRT		SETT		CLRMAC		LDTLB	
0000	0000	01MD	1000	CLRS		SETS					
0000	0000	Fx	1001	NOP		DIV0U					
0000	0000	Fx	1010								
0000	0000	Fx	1011	RTS		SLEEP		RTE			
0000	Rn	Fx	1000								
0000	Rn	Fx	1001					MOVT	Rn		
0000	Rn	Fx	1010	STS	MACH, Rn	STS	MACL, Rn	STS	PR, Rn		
0000	Rn	Fx	1011								
0000	Rn	Rm	11MD	MOV. B	@(R0, Rm), Rn	MOV.W	@(R0, Rm), Rn	MOV.L	@(R0, Rm), Rn	MAC.L	@Rm+,@Rn+
0001	Rn	Rm	disp	MOV.L	Rm, @(disp:4, Rn)						
0010	Rn	Rm	00MD	MOV.B	Rm, @Rn	MOV.W	Rm, @Rn	MOV.L	Rm, @Rn		
0010	Rn	Rm	01MD	MOV.B	Rm, @–Rn	MOV.W	Rm, @–Rn	MOV.L	Rm, @–Rn	DIV0S	Rm, Rn
0010	Rn	Rm	10MD	TST	Rm, Rn	AND	Rm, Rn	XOR	Rm, Rn	OR	Rm, Rn
0010	Rn	Rm	11MD	CMP/STR	Rm, Rn	XTRCT	Rm, Rn	MULU.W	Rm, Rn	MULSW	Rm, Rn
0011	Rn	Rm	00MD	CMP/EQ	Rm, Rn			CMP/HS	Rm, Rn	CMP/GE	Rm, Rn

Instruction Code				Fx: 0000		Fx: 0001		Fx: 0010		Fx: 0011 to 1111	
MSB			LSB	MD: 00		MD: 01		MD: 10		MD: 11	
0011	Rn	Rm	01MD	DIV1	Rm, Rn	DMULU.L	Rm,Rn	CMP/HI	Rm, Rn	CMP/GT	Rm, Rn
0011	Rn	Rm	10MD	SUB	Rm, Rn			SUBC	Rm, Rn	SUBV	Rm, Rn
0011	Rn	Rm	11MD	ADD	Rm, Rn	DMULS.L	Rm,Rn	ADDC	Rm, Rn	ADDV	Rm, Rn
0100	Rn	Fx	0000	SHLL	Rn	DT	Rn	SHAL	Rn		
0100	Rn	Fx	0001	SHLR	Rn	CMP/PZ	Rn	SHAR	Rn		
0100	Rn	Fx	0010	STS.L	MACH, @–Rn	STS.L Rn	MACL, @–	STS.L Rn	PR, @–		
0100	Rn	00MD	0011	STC.L	SR, @–Rn	STC.L	GBR, @–Rn	STC.L	VBR, @–Rn	STC.L	SSR, @–Rn
0100	Rn	01MD	0011	STC.L	SPC, @–Rn						
0100	Rn	10MD	0011	STC.L R0_BANK, @–Rn		STC.L R1_BANK, @–Rn		STC.L R2_BANK, @–Rn		STC.L R3_BANK, @–Rn	
0100	Rn	11MD	0011	STC.L R4_BANK, @–Rn		STC.L R5_BANK, @–Rn		STC.L R6_BANK, @–Rn		STC.L R7_BANK, @–Rn	
0100	Rn	Fx	0100	ROTL	Rn			ROTCL	Rn		
0100	Rn	Fx	0101	ROTR	Rn	CMP/PL	Rn	ROTCR	Rn		
0100	Rm	Fx	0110	LDS.L @Rm+, MACH		LDS.L	@Rm+, MACL	LDS.L	@Rm+, PR		
0100	Rm	00MD	0111	LDC.L	@Rm+, SR	LDC.L	@Rm+, GBR	LDC.L	@Rm+, VBR	LDC.L	@Rm+, SSR
0100	Rm	01MD	0111	LDC.L SPC	@Rm+,						
0100	Rm	10MD	0111	LDC.L @Rm+, R0_BANK		LDC.L @Rm+, R1_BANK		LDC.L @Rm+, R2_BANK		LDC.L @Rm+, R3_BANK	
0100	Rm	11MD	0111	LDC.L @Rm+, R4_BANK		LDC.L @Rm+, R5_BANK		LDC.L @Rm+, R6_BANK		LDC.L @Rm+, R7_BANK	
0100	Rn	Fx	1000	SHLL2	Rn	SHLL8	Rn	SHLL16	Rn		
0100	Rn	Fx	1001	SHLR2	Rn	SHLR8	Rn	SHLR16	Rn		
0100	Rm	Fx	1010	LDS MACH	Rm,	LDS MACL	Rm,	LDS	Rm, PR		
0100	Rm/ Rn	Fx	1011	JSR	@Rm	TAS.B	@Rn	JMP	@Rm		

Instruction Code				Fx: 0000		Fx: 0001		Fx: 0010		Fx: 0011 to 1111	
MSB			LSB	MD: 00		MD: 01		MD: 10		MD: 11	
0100	Rn	Rm	1100	SHAD	Rm, Rn						
0100	Rn	Rm	1101	SHLD	Rm, Rn						
0100	Rm	00MD	1110	LDC	Rm, SR	LDC	Rm, GBR	LDC	Rm, VBR	LDC	Rm, SSR
0100	Rm	01MD	1110	LDC	Rm, SPC						
0100	Rm	10MD	1110	LDC	Rm, R0_BANK	LDC	Rm, R1_BANK	LDC	Rm, R2_BANK	LDC	Rm, R3_BANK
0100	Rm	11MD	1110	LDC	Rm, R4_BANK	LDC	Rm, R5_BANK	LDC	Rm, R6_BANK	LDC	Rm, R7_BANK
0100	Rn	Rm	1111	MAC.W	Rm+, Rn+						
0101	Rn	Rm	disp	MOV.L	(disp:4, Rm), Rn						
0110	Rn	Rm	00MD	MOV.B	@Rm, Rn	MOV.W	@Rm, Rn	MOV.L	@Rm, Rn	MOV	Rm, Rn
0110	Rn	Rm	01MD	MOV.B	@Rm+, Rn	MOV.W	@Rm+, Rn	MOV.L	@Rm+, Rn	NOT	Rm, Rn
0110	Rn	Rm	10MD	SWAP.B	Rm, Rn	SWAP.W	Rm, Rn	NEGC	Rm, Rn	NEG	Rm, Rn
0110	Rn	Rm	11MD	EXTU.B	Rm, Rn	EXTU.W	Rm, Rn	EXTS.B	Rm, Rn	EXTS.W	Rm, Rn
0111	Rn	imm		ADD	# imm : 8, Rn						
1000	00MD	Rn	disp	MOV. B R0, @(disp: 4, Rn)		MOV. W R0, @(disp: 4, Rn)					
1000	01MD	Rm	disp	MOV.B @(disp:4, Rm), R0		MOV.W @(disp: 4, Rm), R0					
1000	10MD	imm/disp		CMP/EQ	#imm:8, R0	BT	disp: 8			BF	disp: 8
1000	11MD	imm/disp				BT/S	disp: 8			BF/S	disp: 8
1001	Rn	disp		MOV.W	(disp : 8, PC), Rn						
1010	disp			BRA	disp: 12						
1011	disp			BSR	disp: 12						
1100	00MD	imm/disp		MOV.B R0, @(disp: 8, GBR)		MOV.W R0, @(disp: 8, GBR)		MOV.L R0, @(disp: 8, GBR)		TRAPA	#imm: 8
1100	01MD	disp		MOV.B @(disp: 8, GBR), R0		MOV.W @(disp: 8, GBR), R0		MOV.L @(disp: 8, GBR), R0		MOVA @(disp: 8, PC), R0	
1100	10MD	imm		TST	#imm: 8, R0	AND	#imm: 8, R0	XOR	#imm: 8, R0	OR	#imm: 8, R0
1100	11MD	imm		TST.B #imm: 8, @(R0, GBR)		AND.B #imm: 8, @(R0, GBR)		XOR.B #imm: 8, @(R0, GBR)		OR.B #imm: 8, @(R0, GBR)	
1101	Rn	disp		MOV.L	@(disp: 8, PC), Rn						
1110	Rn	imm		MOV	#imm:8, Rn						
1111	**********										

Note: For details, refer to the SH-3/SH-3H/SH3-DSP Programming Manual.

Section 3 Memory Management Unit (MMU)

This LSI has an on-chip memory management unit (MMU) that supports a virtual memory system. The on-chip translation look-aside buffer (TLB) caches information for user-created address translation tables located in external memory. It enables high-speed translation of virtual addresses into physical addresses. Address translation uses the paging system and supports two page sizes (1 kbyte or 4 kbytes). The access rights to virtual address space can be set for each of the privileged and user modes to provide memory protection.

3.1 Role of MMU

The MMU is a feature designed to make efficient use of physical memory. As shown in figure 3.1, if a process is smaller in size than the physical memory, the entire process can be mapped onto physical memory. However, if the process increases in size to the extent that it no longer fits into physical memory, it becomes necessary to partition the process and to map those parts requiring execution onto memory as occasion demands (figure 3.1 (1)). Having the process itself consider this mapping onto physical memory would impose a large burden on the process. To lighten this burden, the idea of virtual memory was born as a means of performing en bloc mapping onto physical memory (figure 3.1 (2)). In a virtual memory system, substantially more virtual memory than physical memory is provided, and the process is mapped onto this virtual memory. Thus a process only has to consider operation in virtual memory. Mapping from virtual memory to physical memory is handled by the MMU. The MMU is normally controlled by the operating system, switching physical memory to allow the virtual memory required by a process to be mapped onto physical memory in a smooth fashion. Switching of physical memory is performed via secondary storage, etc.

The virtual memory system that came into being in this way is particularly effective in a time-sharing system (TSS) in which a number of processes are running simultaneously (figure 3.1 (3)). If processes running in a TSS had to take mapping onto virtual memory into consideration while running, it would not be possible to increase efficiency. Virtual memory is thus used to reduce this load on the individual processes and so improve efficiency (figure 3.1 (4)). In the virtual memory system, virtual memory is allocated to each process. The task of the MMU is to perform efficient mapping of these virtual memory areas onto physical memory. It also has a memory protection feature that prevents one process from inadvertently accessing another process's physical memory.

When address translation from virtual memory to physical memory is performed using the MMU, it may occur that the relevant translation information is not recorded in the MMU, with the result that one process may inadvertently access the virtual memory allocated to another process. In this case, the MMU will generate an exception, change the physical memory mapping, and record the new address translation information.

Although the functions of the MMU could also be implemented by software alone, the need for translation to be performed by software each time a process accesses physical memory would

result in poor efficiency. For this reason, a buffer for address translation (translation look-aside buffer: TLB) is provided in hardware to hold frequently used address translation information. The TLB can be described as a cache for storing address translation information. Unlike cache memory, however, if address translation fails, that is, if an exception is generated, switching of address translation information is normally performed by software. This makes it possible for memory management to be performed flexibly by software.

The MMU has two methods of mapping from virtual memory to physical memory: a paging method using fixed-length address translation, and a segment method using variable-length address translation. With the paging method, the unit of translation is a fixed-size address space (usually of 1 to 64 kbytes) called a page.

In the following text, the address space in virtual memory is referred to as virtual address space, and address space in physical memory as physical memory space.

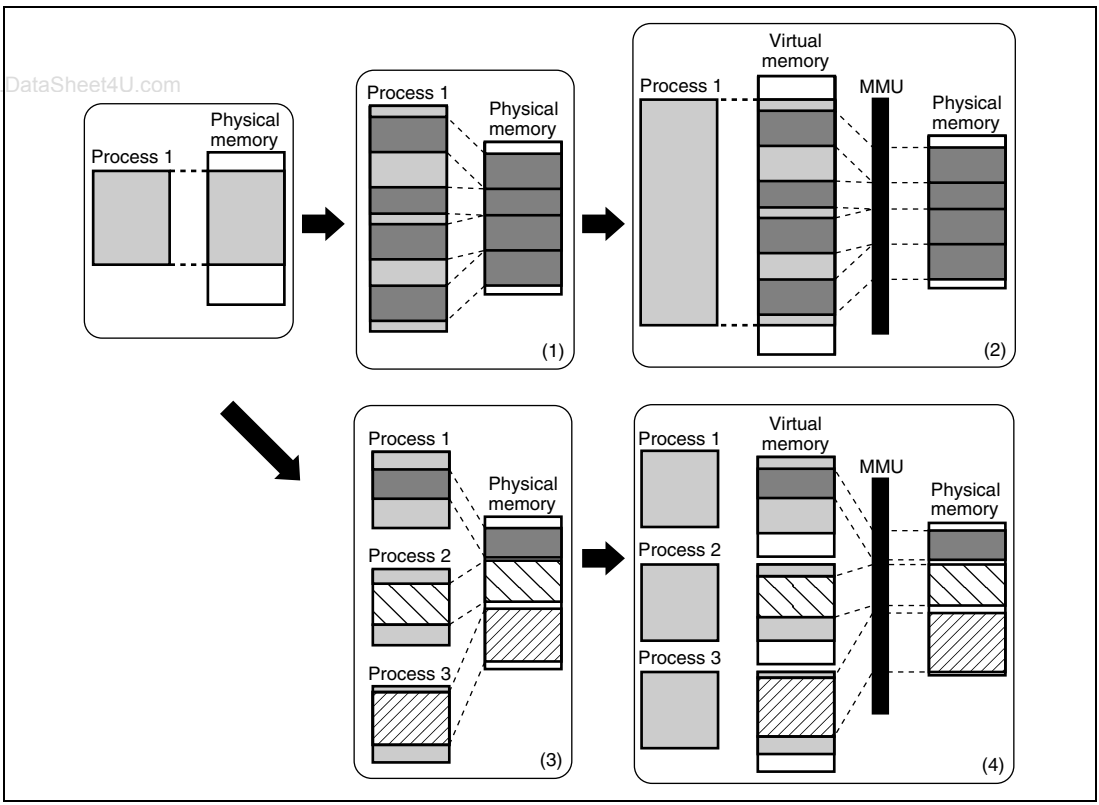


Figure 3.1 MMU Functions

3.1.1 MMU of This LSI

Virtual Address Space: This LSI supports a 32-bit virtual address space that enables access to a 4-Gbyte address space. As shown in figures 3.2 and 3.3, the virtual address space is divided into several areas. In privileged mode, a 4-Gbyte space comprising areas P0 to P4 is accessible. In user mode, a 2-Gbyte space of U0 area is accessible. Access to any area excluding the U0 area in user mode will result in an address error.

If the MMU is enabled by setting the AT bit of the MMUCR register to 1, P0, P3, and U0 areas can be used as any physical address area in 1- or 4-kbyte page units. By using an 8-bit address space identifier, P0, P2, and U0 areas can be increased to up to 256 areas. Mapping from virtual address to 29-bit physical address can be achieved by the TLB.

1. P0, P3, and U0 Areas

   The P0, P3, and U0 areas can be address translated by the TLB and can be accessed through the cache. If the MMU is enabled, these areas can be mapped to any physical address space in 1- or 4-kbyte page units via the TLB. If the CE bit in the cache control register (CCR1) is set to 1 and if the corresponding cache enable bit (C bit) of the TLB entry is set to 1, access via the cache is enabled. If the MMU is disabled, replacing the upper three bits of an address in these areas with 0s creates the address in the corresponding physical address space. If the CE bit of the CCR1 register is set to 1, access via the cache is enabled. When the cache is used, either the copy-back or write-through mode is selected for write access via the WT bit in CCR1.

   If these areas are mapped to the on-chip module control register area in area 1 in the physical address space via the TLB, the C bit of the corresponding page must be cleared to 0.

2. P1 Area

   The P1 area can be accessed via the cache and cannot be address-translated by the TLB. Whether the MMU is enabled or not, replacing the upper three bits of an address in these areas with 0s creates the address in the corresponding physical address space. Use of the cache is determined by the CE bit in the cache control register (CCR1). When the cache is used, either the copy-back or write-through mode is selected for write access by the CB bit in the CCR1 register.

3. P2 Area

   The P2 area cannot be accessed via the cache and cannot be address-translated by the TLB. Whether the MMU is enabled or not, replacing the upper three bits of an address in this area with 0s creates the address in the corresponding physical address space.

4. P4 Area

   The P4 area is mapped to the on-chip module control register of this LSI. This area cannot be accessed via the cache and cannot be address-translated by the TLB. Figure 3.4 shows the configuration of the P4 area.

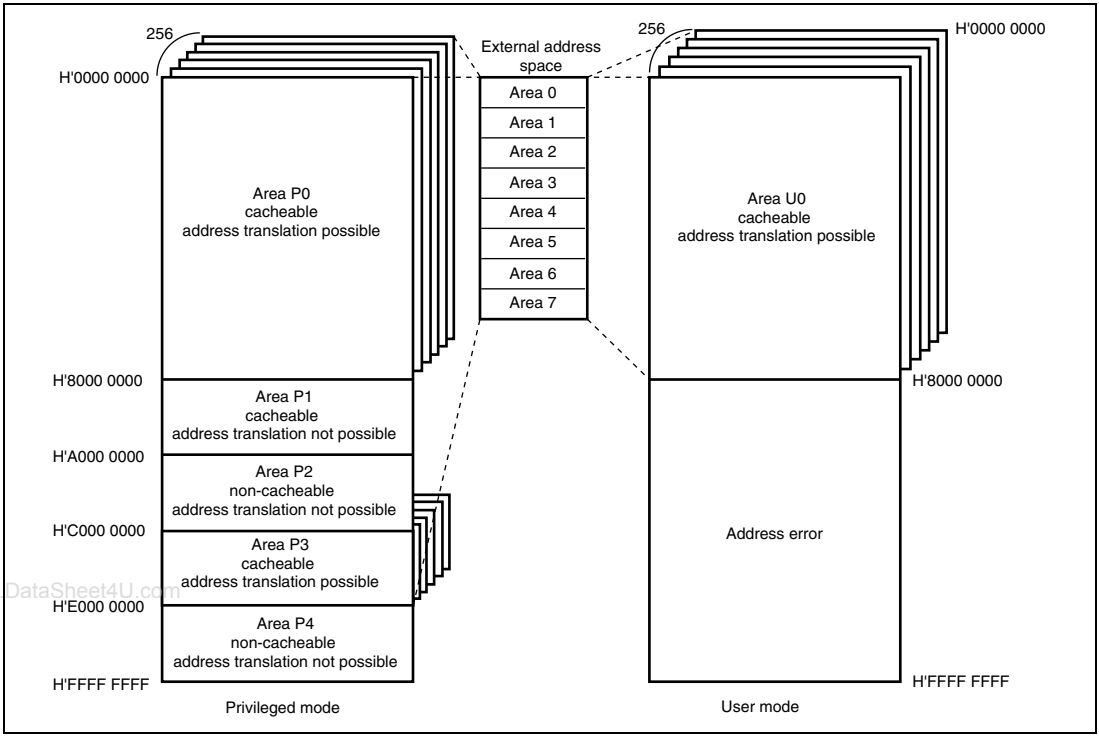


Figure 3.2 Virtual Address Space (MMUCR.AT = 1)

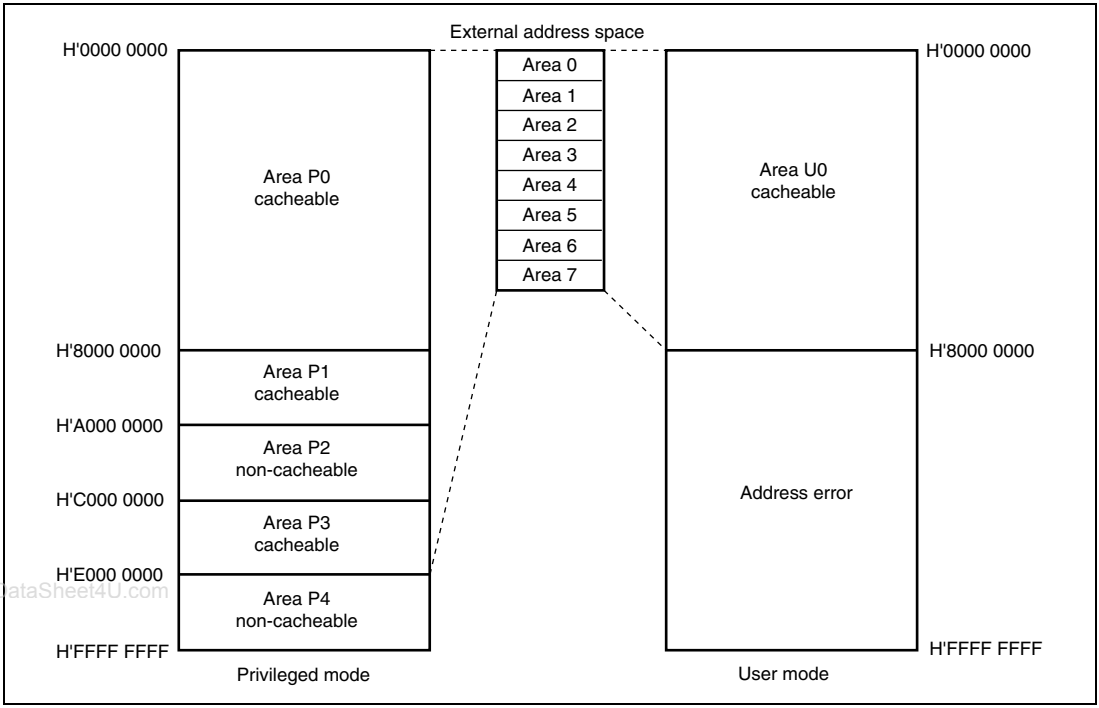


Figure 3.3 Virtual Address Space (MMUCR.AT = 0)

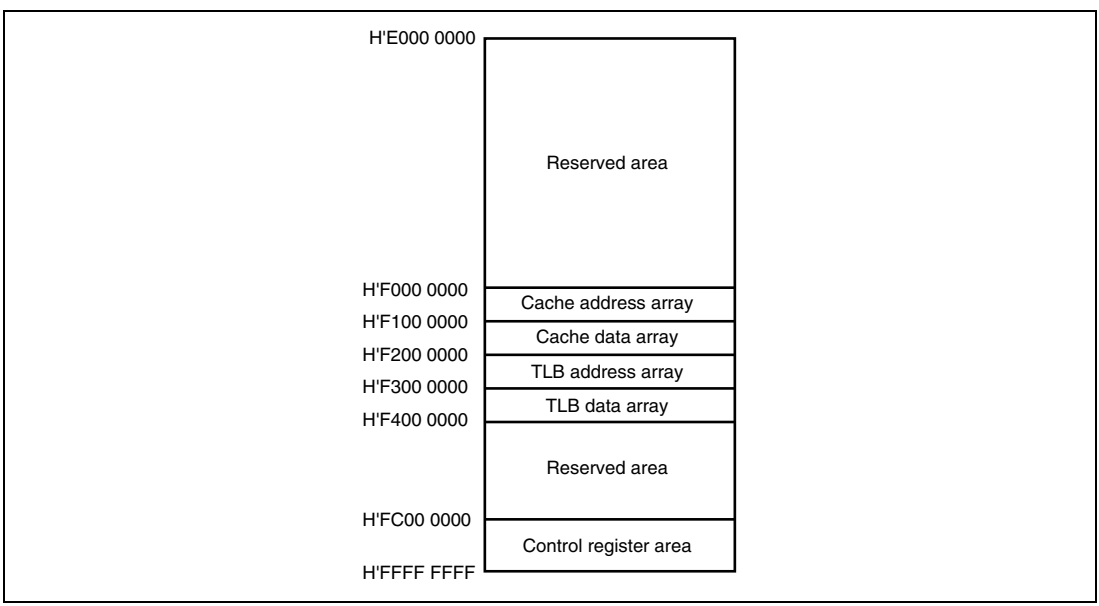


Figure 3.4 P4 Area

The area from H'F000 0000 to H'F0FF FFFF is for direct access to the cache address array. For more information, see section 4.4, Memory-Mapped Cache.

The area from H'F100 0000 to H'F1FF FFFF is for direct access to the cache data array. For more information, see section 4.4, Memory-Mapped Cache.

The area from H'F200 0000 to H'F2FF FFFF is for direct access to the TLB address array. For more information, see section 3.6, Memory-Mapped TLB.

The area from H'F300 0000 to H'F3FF FFFF is for direct access to the TLB data array. For more information, see section 3.6, Memory-Mapped TLB.

The area from H'FC00 0000 to H'FFFF FFFF is reserved for the on-chip module control registers. For more information, see section 24, List of Registers.

Physical Address Space: This LSI supports a 29-bit physical address space. As shown in figure 3.5, the physical address space is divided into eight areas. Area 1 is mapped to the on-chip module control register area. Area 7 is reserved.

For details on physical address space, refer to section 7, Bus State Controller (BSC).

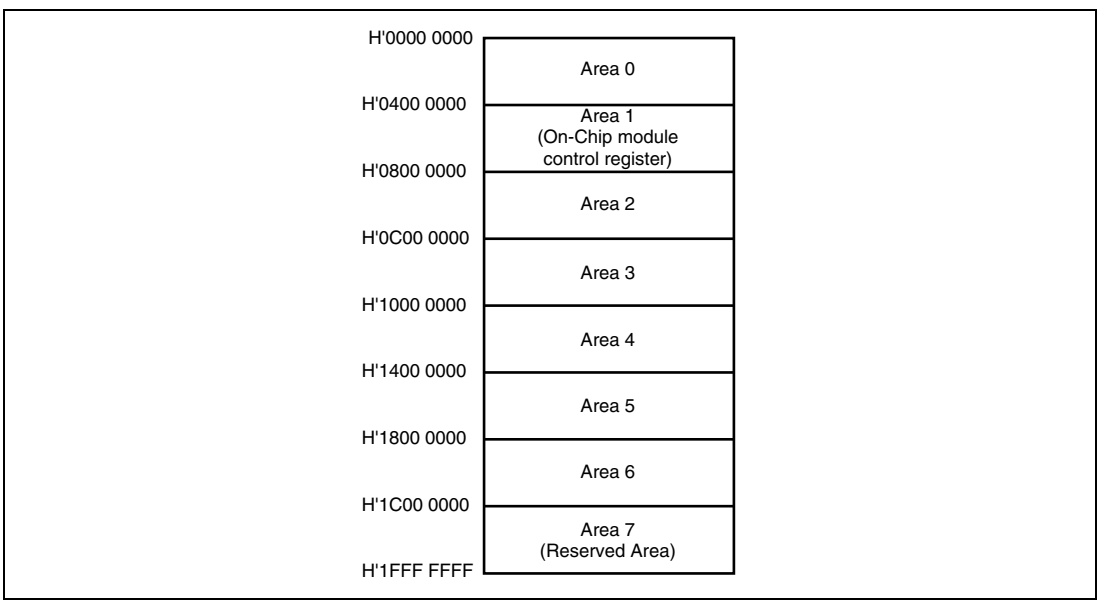


Figure 3.5 External Memory Space

Address Transition: When the MMU is enabled, the virtual address space is divided into units called pages. Physical addresses are translated in page units. Address translation tables in external memory hold information such as the physical address that corresponds to the virtual address and memory protection codes. When an access to area P1 or P2 occurs, there is no TLB access and the physical address is defined uniquely by hardware. If it belongs to area P0, P3 or U0, the TLB is searched by virtual address and, if that virtual address is registered in the TLB, the access hits the TLB. The corresponding physical address and the page control information are read from the TLB and the physical address is determined.

If the virtual address is not registered in the TLB, a TLB miss exception occurs and processing will shift to the TLB miss handler. In the TLB miss handler, the TLB address translation table in external memory is searched and the corresponding physical address and the page control information are registered in the TLB. After returning from the handler, the instruction that caused the TLB miss is re-executed. When the MMU is enabled, address translation information that results in a physical address space of H'20000000 to H'FFFFFFFF should not be registered in the TLB.

When the MMU is disabled, masking the upper three bits of the virtual address to 0s creates the address in the corresponding physical address space. Since this LSI supports 29-bit address space as physical address space, the upper three bits of the virtual address are ignored as shadow areas. For details, refer to section 7, Bus State Controller (BSC). For example, address H’00001000 in the P0 area, address H’80001000 in the P1 area, address H’A0001000 in the P2 area, and address H’C0001000 in the P3 area are all mapped to the same physical memory. If these addresses are accessed while the cache is enabled, the upper three bits are always cleared to 0 to guarantee the continuity of addresses stored in the address array of the cache.

Single Virtual Memory Mode and Multiple Virtual Memory Mode: There are two virtual memory modes: single virtual memory mode and multiple virtual memory mode. In single virtual memory mode, multiple processes run in parallel using the virtual address space exclusively and the physical address corresponding to a given virtual address is specified uniquely. In multiple virtual memory mode, multiple processes run in parallel sharing the virtual address space, so a given virtual address may be translated into different physical addresses depending on the process. By the value set to the MMU control register (MMUCR), either single or multiple virtual mode is selected.

In terms of operation, the only difference between single virtual memory mode and multiple virtual memory mode is in the TLB address comparison method (see section 3.3.3, TLB Address Comparison).

Address Space Identifier (ASID): In multiple virtual memory mode, the address space identifier (ASID) is used to differentiate between processes running in parallel and sharing virtual address space. The ASID is eight bits in length and can be set by software setting of the ASID of the currently running process in page table entry register high (PTEH) within the MMU. When the process is switched using the ASID, the TLB does not have to be purged.

In single virtual memory mode, the ASID is used to provide memory protection for processes running simultaneously and using the virtual address space exclusively (see section 3.3.3, TLB Address Comparison).

3.2 Register Descriptions

There are four registers for MMU processing. These are all on-chip module control registers, so they are located in address space area P4 and can only be accessed from privileged mode by specifying the address.

The MMU has the following registers. Refer to section 24, List of Registers, for the addresses and access size for these registers.

- Page table entry register high (PTEH)
- Page table entry register low (PTEL)
- Translation table base register (TTB)
- MMU control register (MMUCR)

3.2.1 Page Table Entry Register High (PTEH)

The page table entry register high (PTEH) register residing at address H'FFFFFFF0, which consists of a virtual page number (VPN) and ASID. The VPN set is the VPN of the virtual address at which the exception is generated in case of an MMU exception or address error exception. When the page size is 4 kbytes, the VPN is the upper 20 bits of the virtual address, but in this case the upper 22 bits of the virtual address are set. The VPN can also be modified by software. As the ASID, software sets the number of the currently executing process. The VPN and ASID are recorded in the TLB by the LDTLB instruction.

A program that modifies the ASID in PTEH should be allocated in the P1 or P2 areas.

Bit	Bit Name	Initial Value	R/W	Description
31 to 10	VPN	—	R/W	Number of Virtual Page
9, 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7 to 0	ASID	—	R/W	Address Space Identifier

3.2.2 Page Table Entry Register Low (PTEL)

The page table entry register low (PTEL) register residing at address H'FFFFFFF4, and used to store the physical page number and page management information to be recorded in the TLB by the LDTLB instruction. The contents of this register are only modified in response to a software command.

Bit	Bit Name	Initial Value	R/W	Description
31 to 29	—	All 0	R/W	Reserved These bits are always read as 0. The write value should always be 0.
28 to 10	PPN	—	R	Number of Physical Page
9	—	0	R/W	Page Management Information
8	V	—		For more details, see section 3.3, TLB Functions
7	—	0		
6, 5	PR	—		
4	SZ	—		
3	C	—		
2	D	—		
1	SH	—		
0	—	0		

3.2.3 Translation Table Base Register (TTB)

The translation table base register (TTB) residing at address H'FFFFFFF8, which points to the base address of the current page table. The hardware does not set any value in TTB automatically. TTB is available to software for general purposes. The initial value is undefined.

3.2.4 MMU Control Register (MMUCR)

The MMU control register (MMUCR) residing at address H'FFFFFFE0, which makes the MMU settings described in figure 3.3. Any program that modifies MMUCR should reside in the P1 or P2 area.

Bit	Bit Name	Initial Value	R/W	Description
31 to 9	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
8	SV	—	R/W	Single Virtual Memory Mode 0: Multiple virtual memory mode 1: Single virtual memory mode
7, 6	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
5, 4	RC	All 0	R/W	Random Counter A 2-bit random counter that is automatically updated by hardware according to the following rules in the event of an MMU exception. When a TLB miss exception occurs, all of TLB entry ways corresponding to the virtual address at which the exception occurred are checked. If all ways are valid, 1 is added to RC; if there is one or more invalid way, they are set by priority from way 0, in the order way 0, way 1, way 2, and way 3. In the event of an MMU exception other than a TLB miss exception, the way which caused the exception is set in RC.
3	—	0	R	Reserved These bits are always read as 0. The write value should always be 0.
2	TF	0	R/W	TLB Flush Write 1 to flush the TLB (clear all valid bits of the TLB to 0). When they are read, 0 is always returned.
1	IX	0	R/W	Index Mode 0: VPN bits 16 to 12 are used as the TLB index number. 1: The value obtained by EX-ORing ASID bits 4 to 0 in PTEH and VPN bits 16 to 12 is used as the TLB index number.
0	AT	0	R/W	Address Translation Enables/disables the MMU. 0: MMU disabled 1: MMU enabled

3.3 TLB Functions

3.3.1 Configuration of the TLB

The TLB caches address translation table information located in the external memory. The address translation table stores the logical page number and the corresponding physical number, the address space identifier, and the control information for the page, which is the unit of address translation. Figure 3.6 shows the overall TLB configuration. The TLB is 4-way set associative with 128 entries. There are 32 entries for each way. Figure 3.7 shows the configuration of virtual addresses and TLB entries.

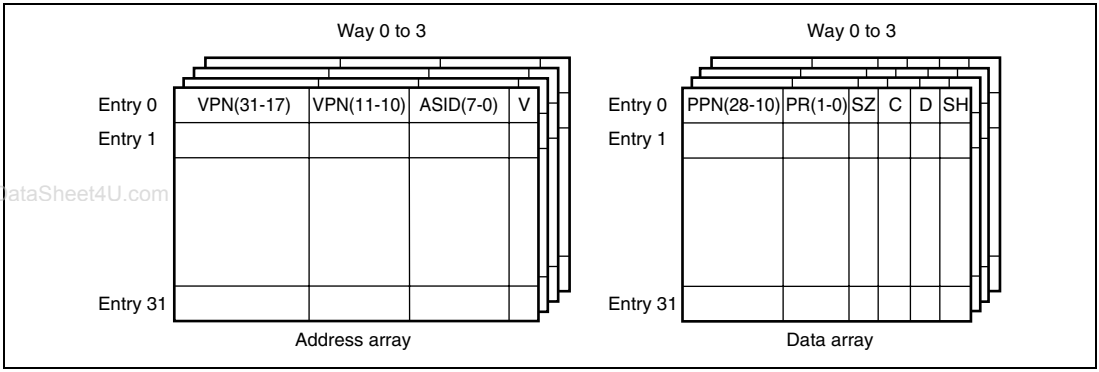
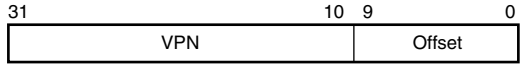
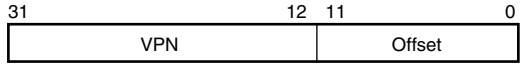


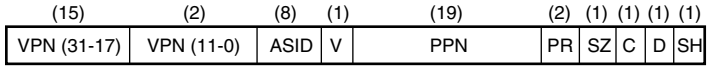
Figure 3.6 Overall Configuration of the TLB



Virtual address (1-kbyte page)



Virtual address (4-kbyte page)



TLB entry

Legend:

VPN: Virtual page number
Upper 22 bits of virtual address for a 1-kbyte page, or upper 20 bits of virtual address for a 4-kbyte page. Since VPN bits 16 to 12 are used as the index number, they are not stored in the TLB entry. Attention must be paid to the synonym problem (see section 3.4.4, Avoiding Synonym Problems).

ASID: Address space identifier
Indicates the process that can access a virtual page. In single virtual memory mode and user mode, or in multiple virtual memory mode, if the SH bit is 0, the address is compared with the ASID in PTEH when address comparison is performed.

SH: Share status bit
0: Page not shared between processes
1: Page shared between processes

SZ: Page-size bit
0: 1-kbyte page
1: 4-kbyte page

V: Valid bit
Indicates whether entry is valid.
0: Invalid
1: Valid
Cleared to 0 by a power-on reset. Not affected by a manual reset.

PPN: Physical page number
Upper 22 bits of physical address. PPN bits 11 to10 are not used in case of a 4-kbyte page.

PR: Protection key field
2-bit field encoded to define the access rights to the page.
00: Reading only is possible in privileged mode.
01: Reading/writing is possible in privileged mode.
10: Reading only is possible in privileged/user mode.
11: Reading/writing is possible in privileged/user mode.

C: Cacheable bit
Indicates whether the page is cacheable.
0: Non-cacheable
1: Cacheable

D: Dirty bit
Indicates whether the page has been written to.
0: Not written to
1: Written to

Figure 3.7 Virtual Address and TLB Structure

3.3.2 TLB Indexing

The TLB uses a 4-way set associative scheme, so entries must be selected by index. VPN bits 16 to 12 are used as the index number regardless of the page size. The index number can be generated in two different ways depending on the setting of the IX bit in MMUCR.

1. When IX = 0, VPN bits 16 to 12 alone are used as the index number
2. When IX = 1, VPN bits 16 to 12 are EX-ORed with ASID bits 4 to 0 to generate a 5-bit index number

The first method is used to prevent lowered TLB efficiency that results when multiple processes run simultaneously in the same virtual address space (multiple virtual memory) and a specific entry is selected by indexing of each process. In single virtual memory mode (MMUCR.SV = 1), IX bit should be set to 0. Figures 3.8 and 3.9 show the indexing schemes.

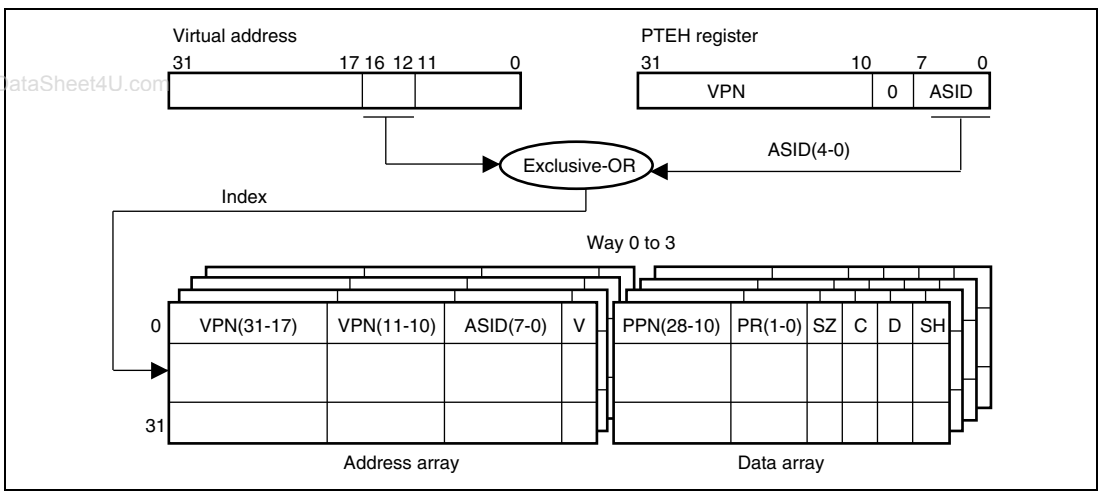


Figure 3.8 TLB Indexing (IX = 1)

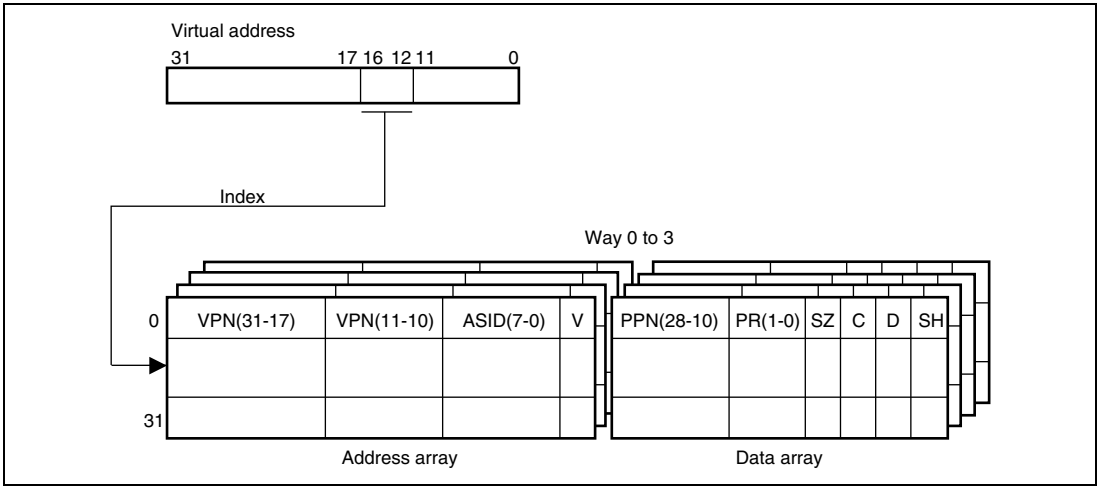


Figure 3.9 TLB Indexing (IX = 0)

3.3.3 TLB Address Comparison

The results of address comparison determine whether a specific virtual page number is registered in the TLB. The virtual page number of the virtual address that accesses external memory is compared to the virtual page number of the indexed TLB entry. The ASID within the PTEH is compared to the ASID of the indexed TLB entry. All four ways are searched simultaneously. If the compared values match, and the indexed TLB entry is valid (V bit = 1), the hit is registered.

It is necessary to have software ensure that TLB hits do not occur simultaneously in more than one way, as hardware operation is not guaranteed if this occurs. An example of setting which causes TLB hits to occur simultaneously in more than one way is described below. It is necessary to ensure that this kind of setting is not made by software.

1. If there are two identical TLB entries with the same VPN and a setting is made such that a TLB hit is made only by a process with ASID = H'FF when one is in the shared state (SH = 1) and the other in the non-shared state (SH = 0), then if the ASID in PTEH is set to H'FF, there is a possibility of simultaneous TLB hits in both these ways.
2. If several entries which have different ASID with the same VPN are registered in single virtual memory mode, there is the possibility of simultaneous TLB hits in more than one way when accessing the corresponding page in privileged mode. Several entries with the same VPN must not be registered in single virtual memory mode.
3. There is the possibility of simultaneous TLB hits in more than one way. These hits may occur depending on the contents of ASID in PTEH when a page to which SH is set 1 is registered in the TLB in index mode (MMUCR.IX = 1). Therefore a page to which SH is set 1 must not be registered in index mode. When memory is shared by several processings, different pages must be registered in each ASID.

The object compared varies depending on the page management information (SZ, SH) in the TLB entry. It also varies depending on whether the system supports multiple virtual memory or single virtual memory.

The page-size information determines whether VPN (11 to 10) is compared. VPN (11 to 10) is compared for 1-kbyte pages (SZ = 0) but not for 4-kbyte pages (SZ = 1).

The sharing information (SH) determines whether the PTEH.ASID and the ASID in the TLB entry are compared. ASIDs are compared when there is no sharing between processes (SH = 0) but not when there is sharing (SH = 1).

When single virtual memory is supported (MMUCR.SV = 1) and privileged mode is engaged (SR.MD = 1), all process resources can be accessed. This means that ASIDs are not compared when single virtual memory is supported and privileged mode is engaged. The objects of address comparison are shown in figure 3.10.

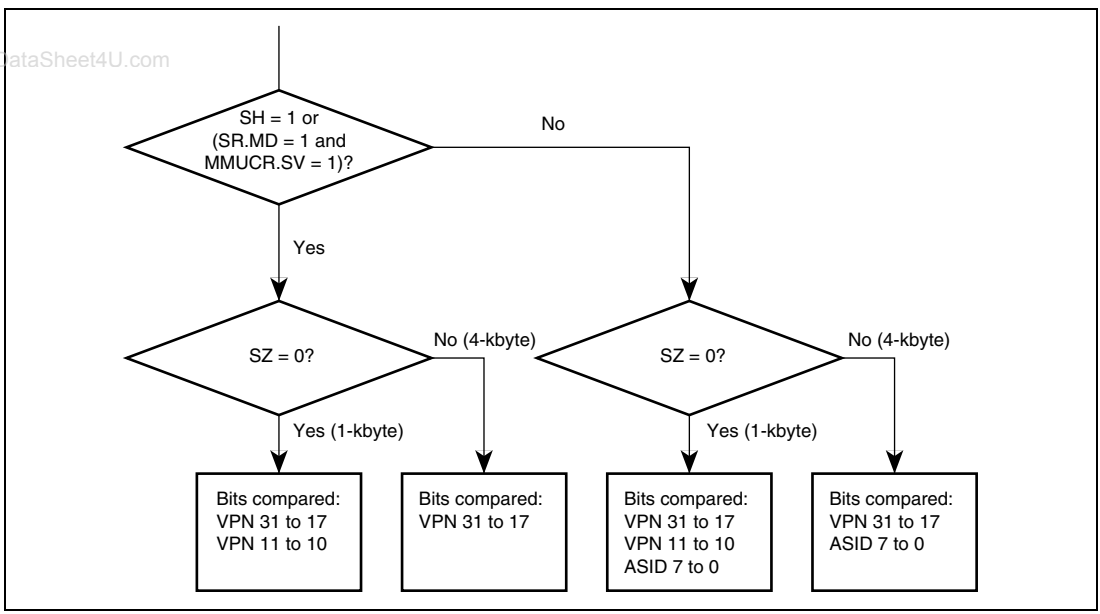


Figure 3.10 Objects of Address Comparison

3.3.4 Page Management Information

In addition to the SH and SZ bits, the page management information of TLB entries also includes D, C, and PR bits.

The D bit of a TLB entry indicates whether the page is dirty (i.e., has been written to). If the D bit is 0, an attempt to write to the page results in an initial page write exception. For physical page swapping between secondary memory and main memory, for example, pages are controlled so that a dirty page is paged out of main memory only after that page is written back to secondary memory. To record that there has been a write to a given page in the address translation table in memory, an initial page write exception is used.

The C bit in the entry indicates whether the referenced page resides in a cacheable or non-cacheable area of memory. When the on-chip module control registers in area 1 are mapped, set the C bit to 0. The PR field specifies the access rights for the page in privileged and user modes and is used to protect memory. Attempts at non-permitted accesses result in TLB protection violation exceptions.

Access states designated by the D, C, and PR bits are shown in table 3.1.

Table 3.1 Access States Designated by D, C, and PR Bits

		Privileged Mode		User Mode	
		Reading	**Writing**	**Reading**	**Writing**
D bit	0	Permitted	Initial page write exception	Permitted	Initial page write exception
	1	Permitted	Permitted	Permitted	Permitted
C bit	0	Permitted (no caching)	Permitted (no caching)	Permitted (no caching)	Permitted (no caching)
	1	Permitted (with caching)	Permitted (with caching)	Permitted (with caching)	Permitted (with caching)
PR bit	00	Permitted	TLB protection violation exception	TLB protection violation exception	TLB protection violation exception
	01	Permitted	Permitted	TLB protection violation exception	TLB protection violation exception
	10	Permitted	TLB protection violation exception	Permitted	TLB protection violation exception
	11	Permitted	Permitted	Permitted	Permitted

3.4 MMU Functions

3.4.1 MMU Hardware Management

There are two kinds of MMU hardware management as follows.

1. The MMU decodes the virtual address accessed by a process and performs address translation by controlling the TLB in accordance with the MMUCR settings.
2. In address translation, the MMU receives page management information from the TLB, and determines the MMU exception and whether the cache is to be accessed (using the C bit). For details of the determination method and the hardware processing, see section 3.5, MMU Exceptions.

3.4.2 MMU Software Management

There are three kinds of MMU software management, as follows.

1. MMU register setting

   MMUCR setting, in particular, should be performed in areas P1 and P2 for which address translation is not performed. Also, since SV and IX bit changes constitute address translation system changes, in this case, TLB flushing should be performed by simultaneously writing 1 to the TF bit also. Since MMU exceptions are not generated in the MMU disabled state with the AT bit cleared to 0, use in the disabled state must be avoided with software that does not use the MMU.
2. TLB entry recording, deletion, and reading

   TLB entry recording can be done in two ways by using the LDTLB instruction, or by writing directly to the memory-mapped TLB. For TLB entry deletion and reading, the memory allocation TLB can be accessed. See section 3.4.3, MMU Instruction (LDTLB), for details of the LDTLB instruction, and section 3.6, Memory-Mapped TLB, for details of the memory-mapped TLB.
3. MMU exception processing

   When an MMU exception is generated, it is handled on the basis of information set from the hardware side. See section 3.5, MMU Exceptions, for details.

When single virtual memory mode is used, it is possible to create a state in which physical memory access is enabled in the privileged mode only by clearing the share status bit (SH) to 0 to specify recording of all TLB entries. This strengthens inter-process memory protection, and enables special access levels to be created in the privileged mode only.

Recording a 1- or 4- kbyte page TLB entry may result in a synonym problem. See section 3.4.4, Avoiding Synonym Problems.

3.4.3 MMU Instruction (LDTLB)

The load TLB instruction (LDTLB) is used to record TLB entries. When the IX bit in MMUCR is 0, the LDTLB instruction changes the TLB entry in the way specified by the RC bit in MMUCR to the value specified by PTEH and PTEL, using VPN bits 16 to 12 specified in PTEH as the index number. When the IX bit in MMUCR is 1, the EX-OR of VPN bits 16 to 12 specified in PTEH and ASID bits 4 to 0 in PTEH are used as the index number.

Figure 3.11 shows the case where the IX bit in MMUCR is 0.

When an MMU exception occurs, the virtual page number of the virtual address that caused the exception is set in PTEH by hardware. The way is set in the RC bit of MMUCR for each exception according to the rules (see section 3.2.4, MMU Control Registers). Consequently, if the LDTLB instruction is issued after setting only PTEL in the MMU exception processing routine, TLB entry recording is possible. Any TLB entry can be updated by software rewriting of PTEH and the RC bits in MMUCR.

As the LDTLB instruction changes address translation information, there is a risk of destroying address translation information if this instruction is issued in the P0, U0, or P3 area. Make sure, therefore, that this instruction is issued in the P1 or P2 area. Also, an instruction associated with an access to the P0, U0, or P3 area (such as the RTE instruction) should be issued at least two instructions after the LDTLB instruction.

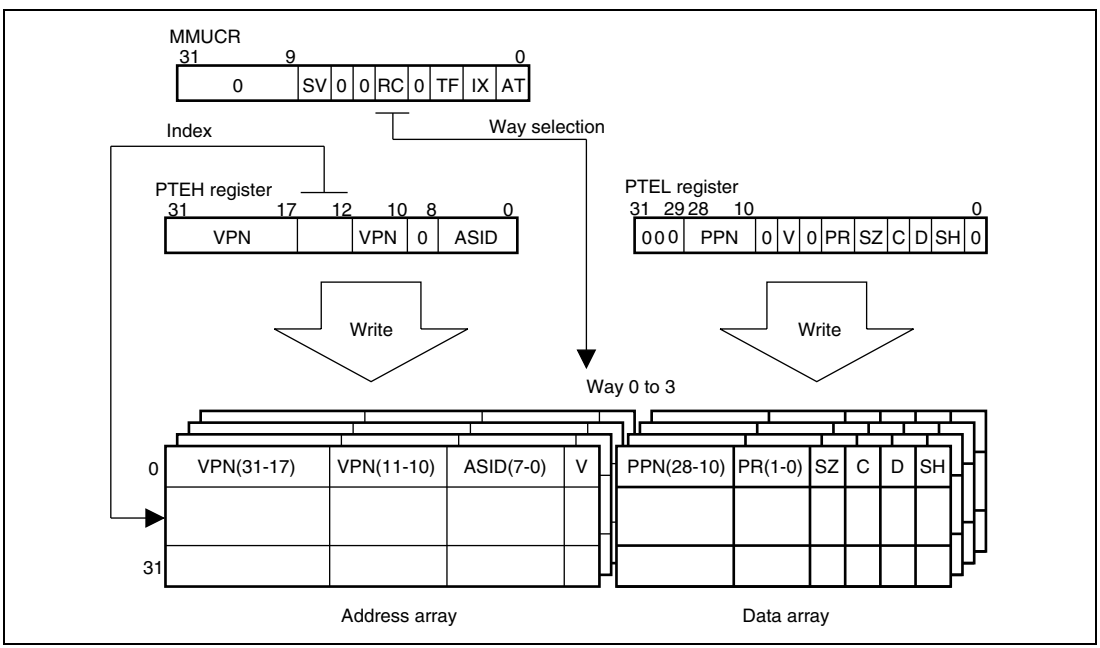


Figure 3.11 Operation of LDTLB Instruction

3.4.4 Avoiding Synonym Problems

When a 1- or 4-kbyte page is recorded in a TLB entry, a synonym problem may arise. If a number of virtual addresses are mapped onto a single physical address, the same physical address data will be recorded in a number of cache entries, and it will not be possible to guarantee data congruity. The reason that this problem occurs is explained below with reference to figure 3.12.

The relationship between bit n of the virtual address and cache size is shown in the following table. Note that no synonym problems occur in 4-kbyte page when the cache size is 16 kbytes.

Cache Size	Bit n in Virtual Address
16 kbytes	11
32 kbytes	12

To achieve high-speed operation of this LSI's cache, an index number is created using virtual address bits 12 to 4. When a 1-kbyte page is used, virtual address bits 12 to 10 is subject to address translation and when a 4-kbyte page is used, a virtual address bit 12 is subject to address translation. Therefore, the physical address bits 12 to 10 may not be the same as the virtual address bits 12 to 10.

For example, assume that, with 1-kbyte page TLB entries, TLB entries for which the following translation has been performed are recorded in two TLBs:

Virtual address 1 H'00000000 → physical address H'00000C00

Virtual address 2 H'00000C00 → physical address H'00000C00

Virtual address 1 is recorded in cache entry H'000, and virtual address 2 in cache entry H'0C0. Since two virtual addresses are recorded in different cache entries despite the fact that the physical addresses are the same, memory inconsistency will occur as soon as a write is performed to either virtual address.

Consequently, the following restrictions apply to the recording of address translation information in TLB entries.

1. When address translation information whereby a number of 1-kbyte page TLB entries are translated into the same physical address is recorded in the TLB, ensure that the VPN bits 12 to 10 are the same.
2. When address translation information whereby a number of 4-kbyte page TLB entries are translated into the same physical address is recorded in the TLB, ensure that the VPN bit 12 is the same.
3. Do not use the same physical addresses for address translation information of different page sizes.

The above restrictions apply only when performing accesses using the cache.

Note: When multiple items of address translation information use the same physical memory to provide for future SuperH RISC engine family expansion, ensure that the VPN bits 20 to 10 are the same.

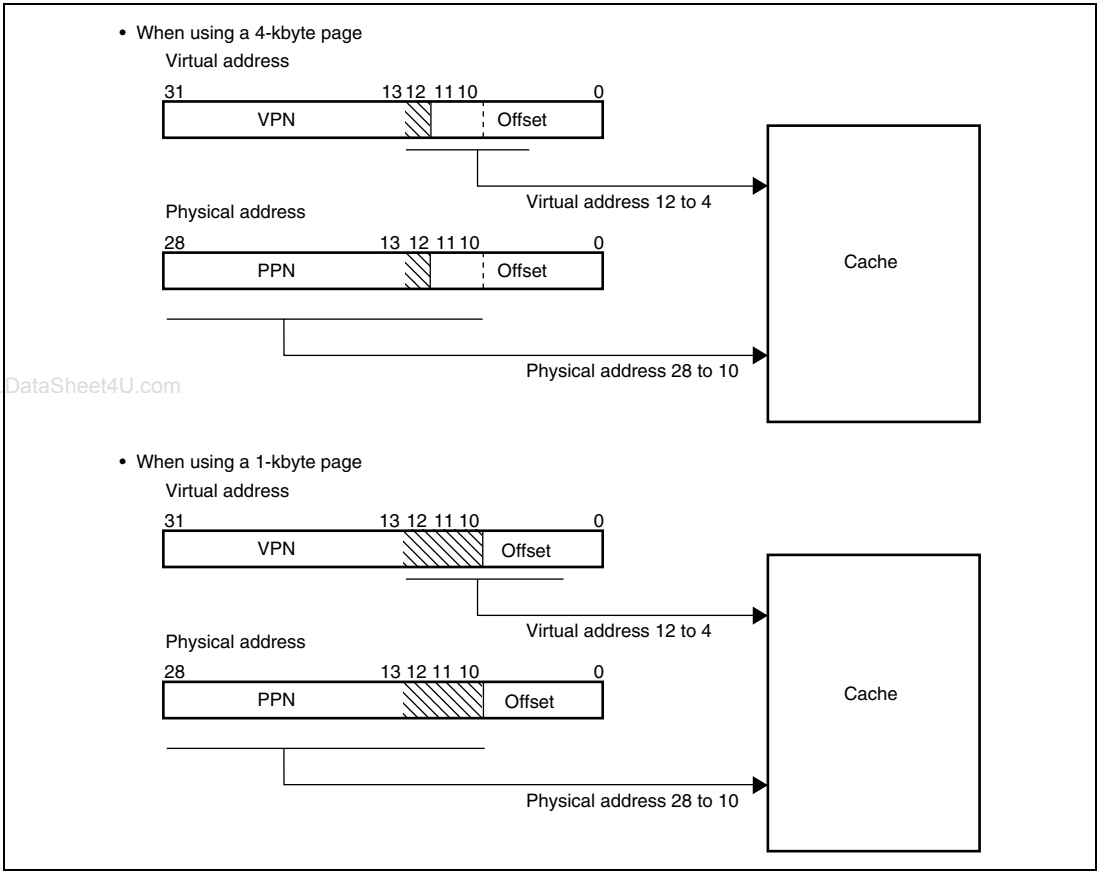


Figure 3.12 Synonym Problem (32-kbyte Cache)

3.5 MMU Exceptions

When the address translation unit of the MMU is enabled, occurrence of the MMU exception is checked following the CPU address error check. There are four MMU exceptions: TLB miss, TLB protection violation, TLB invalid, and initial page write, and these MMU exceptions are checked in this order.

3.5.1 TLB Miss Exception

A TLB miss results when the virtual address and the address array of the selected TLB entry are compared and no match is found. TLB miss exception processing includes both hardware and software operations.

Hardware Operations: In a TLB miss, this hardware executes a set of prescribed operations, as follows:

1. The VPN field of the virtual address causing the exception is written to the PTEH register.
2. The virtual address causing the exception is written to the TEA register.
3. Either exception code H'040 for a load access, or H'060 for a store access, is written to the EXPEVT register.
4. The PC value indicating the address of the instruction in which the exception occurred is written to the save program counter (SPC). If the exception occurred in a delay slot, the PC value indicating the address of the related delayed branch instruction is written to the SPC.
5. The contents of the status register (SR) at the time of the exception are written to the save status register (SSR).
6. The mode (MD) bit in SR is set to 1 to place the privileged mode.
7. The block (BL) bit in SR is set to 1 to mask any further exception requests.
8. The register bank (RB) bit in SR is set to 1.
9. The RC field in the MMU control register (MMUCR) is incremented by 1 when all entries indexed are valid. When some entries indexed are invalid, the smallest way number of them is set in RC.
10. Execution branches to the address obtained by adding the value of the VBR contents and H'00000400 to invoke the user-written TLB miss exception handler.

Software (TLB Miss Handler) Operations: The software searches the page tables in external memory and allocates the required page table entry. Upon retrieving the required page table entry, software must execute the following operations:

1. Write the value of the physical page number (PPN) field and the protection key (PR), page size (SZ), cacheable (C), dirty (D), share status (SH), and valid (V) bits of the page table entry recorded in the address translation table in the external memory into the PTEL register.

2. If using software for way selection for entry replacement, write the desired value to the RC field in MMUCR.
3. Issue the LDTLB instruction to load the contents of PTEH and PTEL into the TLB.
4. Issue the return from exception handler (RTE) instruction to terminate the handler routine and return to the instruction stream.

3.5.2 TLB Protection Violation Exception

A TLB protection violation exception results when the virtual address and the address array of the selected TLB entry are compared and a valid entry is found to match, but the type of access is not permitted by the access rights specified in the PR field. TLB protection violation exception processing includes both hardware and software operations.

Hardware Operations: In a TLB protection violation exception, this hardware executes a set of prescribed operations, as follows:

1. The VPN field of the virtual address causing the exception is written to the PTEH register.
2. The virtual address causing the exception is written to the TEA register.
3. Either exception code H'0A0 for a load access, or H'0C0 for a store access, is written to the EXPEVT register.
4. The PC value indicating the address of the instruction in which the exception occurred is written into SPC (if the exception occurred in a delay slot, the PC value indicating the address of the related delayed branch instruction is written into SPC).
5. The contents of SR at the time of the exception are written to SSR.
6. The MD bit in SR is set to 1 to place the privileged mode.
7. The BL bit in SR is set to 1 to mask any further exception requests.
8. The RB bit in SR is set to 1.
9. The way that generated the exception is set in the RC field in MMUCR.
10. Execution branches to the address obtained by adding the value of the VBR contents and H'00000100 to invoke the TLB protection violation exception handler.

Software (TLB Protection Violation Handler) Operations: Software resolves the TLB protection violation and issues the RTE (return from exception handler) instruction to terminate the handler and return to the instruction stream. Issue the RTE instruction after issuing two instructions from the LDTLB instruction.

3.5.3 TLB Invalid Exception

A TLB invalid exception results when the virtual address is compared to a selected TLB entry address array and a match is found but the entry is not valid (the V bit is 0). TLB invalid exception processing includes both hardware and software operations.

Hardware Operations: In a TLB invalid exception, this hardware executes a set of prescribed operations, as follows:

1. The VPN number of the virtual address causing the exception is written to the PTEH register.
2. The virtual address causing the exception is written to the TEA register.
3. Either exception code H'040 for a load access, or H'060 for a store access, is written to the EXPEVT register.
4. The PC value indicating the address of the instruction in which the exception occurred is written to the SPC. If the exception occurred in a delay slot, the PC value indicating the address of the delayed branch instruction is written to the SPC.
5. The contents of SR at the time of the exception are written into SSR.
6. The mode (MD) bit in SR is set to 1 to place the privileged mode.
7. The block (BL) bit in SR is set to 1 to mask any further exception requests.
8. The RB bit in SR is set to 1.
9. The way number causing the exception is written to RC in MMUCR.
10. Execution branches to the address obtained by adding the value of the VBR contents and H'00000100, and the TLB protection violation exception handler starts.

Software (TLB Invalid Exception Handler) Operations: The software searches the page tables in external memory and assigns the required page table entry. Upon retrieving the required page table entry, software must execute the following operations:

1. Write the values of the physical page number (PPN) field and the values of the protection key (PR), page size (SZ), cacheable (C), dirty (D), share status (SH), and valid (V) bits of the page table entry recorded in the external memory to the PTEL register.
2. If using software for way selection for entry replacement, write the desired value to the RC field in MMUCR.
3. Issue the LDTLB instruction to load the contents of PTEH and PTEL into the TLB.
4. Issue the RTE instruction to terminate the handler and return to the instruction stream. The RTE instruction should be issued after two LDTLB instructions.

3.5.4 Initial Page Write Exception

An initial page write exception results in a write access when the virtual address and the address array of the selected TLB entry are compared and a valid entry with the appropriate access rights is found to match, but the D (dirty) bit of the entry is 0 (the page has not been written to). Initial page write exception processing includes both hardware and software operations.

Hardware Operations: In an initial page write exception, this hardware executes a set of prescribed operations, as follows:

1. The VPN field of the virtual address causing the exception is written to the PTEH register.
2. The virtual address causing the exception is written to the TEA register.
3. Exception code H'080 is written to the EXPEVT register.
4. The PC value indicating the address of the instruction in which the exception occurred is written to the SPC. If the exception occurred in a delay slot, the PC value indicating the address of the related delayed branch instruction is written to the SPC.
5. The contents of SR at the time of the exception are written to SSR.
6. The MD bit in SR is set to 1 to place the privileged mode.
7. The BL bit in SR is set to 1 to mask any further exception requests.
8. The RB bit in SR is set to 1.
9. The way that caused the exception is set in the RC field in MMUCR.
10. Execution branches to the address obtained by adding the value of the VBR contents and H'00000100 to invoke the user-written initial page write exception handler.

Software (Initial Page Write Handler) Operations: The software must execute the following operations:

1. Retrieve the required page table entry from external memory.
2. Set the D bit of the page table entry in the external memory to 1.
3. Write the value of the PPN field and the PR, SZ, C, D, SH, and V bits of the page table entry in the external memory to the PTEL register.
4. If using software for way selection for entry replacement, write the desired value to the RC field in MMUCR.
5. Issue the LDTLB instruction to load the contents of PTEH and PTEL into the TLB.
6. Issue the RTE instruction to terminate the handler and return to the instruction stream. The RTE instruction must be issued after two LDTLB instructions.

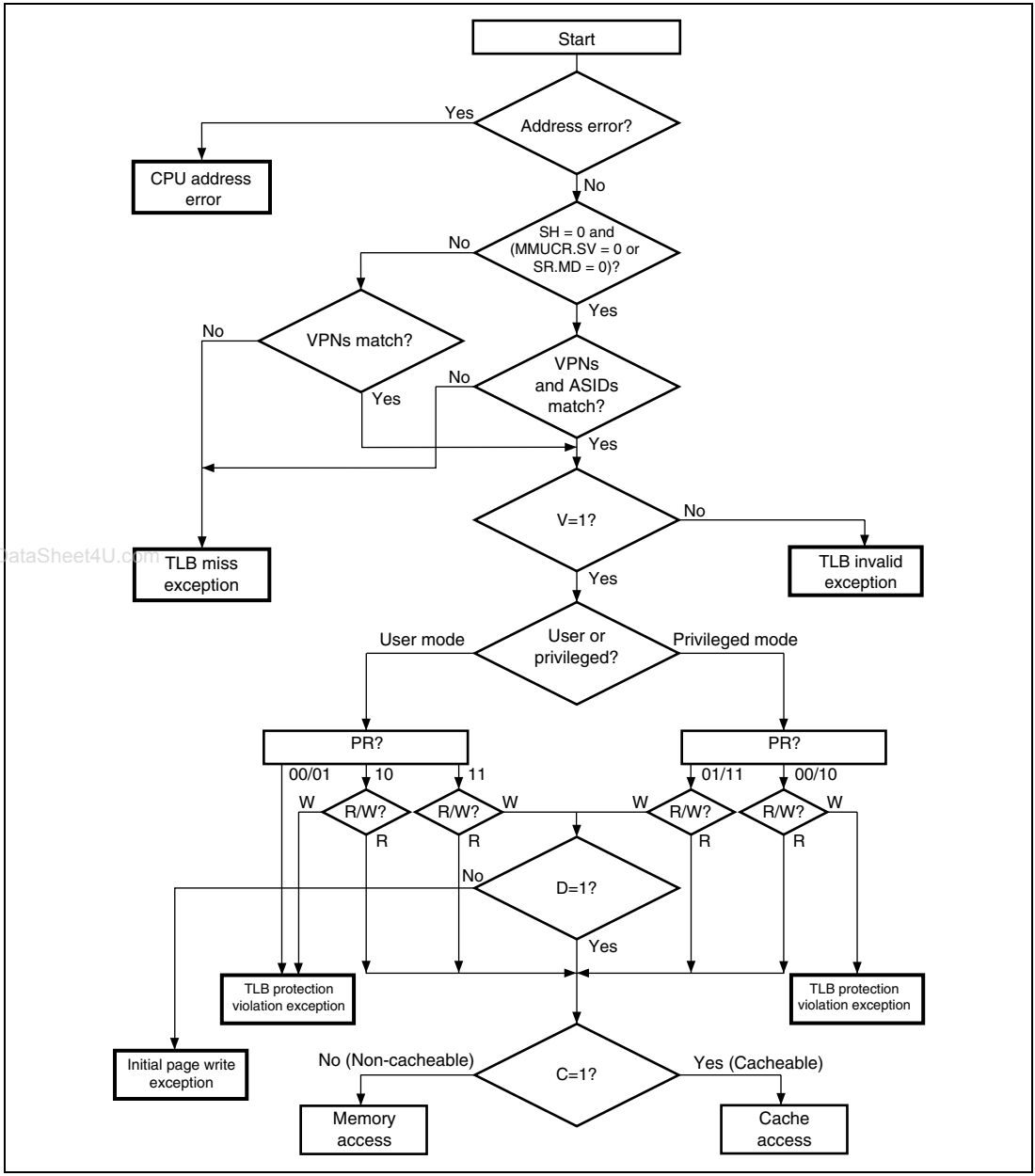


Figure 3.13 MMU Exception Generation Flowchart

3.6 Memory-Mapped TLB

In order for TLB operations to be managed by software, TLB contents can be read or written to in the privileged mode using the MOV instruction. The TLB is assigned to the P4 area in the virtual address space. The TLB address array (VPN, V bit, and ASID) is assigned to H'F2000000 to H'F2FFFFFF, and the data array (PPN, PR, SZ, C, D, and SH bits) to H'F3000000 to H'F3FFFFFF. The V bit in the address array can also be accessed from the data array. Only longword access is possible for both the address array and the data array. However, the instruction data cannot be fetched from both arrays.

3.6.1 Address Array

The address array is assigned to H'F2000000 to H'F2FFFFFF. To access an address array, the 32-bit address field (for read/write operations) and 32-bit data field (for write operations) must be specified. The address field specifies information for selecting the entry to be accessed; the data field specifies the VPN, V bit and ASID to be written to the address array (figure 3.14 (1)).

In the address field, specify the entry address for selecting the entry (bits 16 to 12), W for selecting the way (bits 9 to 8) and H'F2 to indicate address array access (bits 31 to 24). The IX bit in MMUCR indicates whether an EX-OR is taken of the entry address and ASID.

The following two operations can be used on the address array:

1. Address array read

   VPN, V, and ASID are read from the TLB entry corresponding to the entry address and way set in the address field.
2. TLB address array write

   The data specified in the data field are written to the TLB entry corresponding to the entry address and way set in the address field.

3.6.2 Data Array

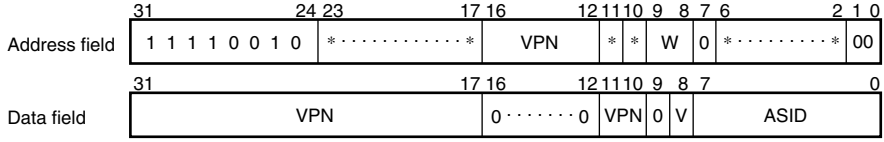
The data array is assigned to H'F3000000 to H'F3FFFFFF. To access a data array, the 32-bit address field (for read/write operations), and 32-bit data field (for write operations) must be specified. The address section specifies information for selecting the entry to be accessed; the data section specifies the longword data to be written to the data array (figure 3.14 (2)).

In the address section, specify the entry address for selecting the entry (bits 16 to 12), W for selecting the way (bits 9 to 8), and H'F3 to indicate data array access (bits 31 to 24). The IX bit in MMUCR indicates whether an EX-OR is taken of the entry address and ASID.

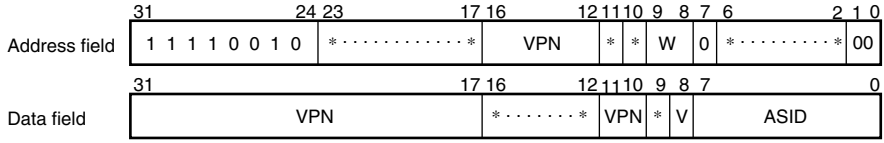
Both reading and writing use the longword of the data array specified by the entry address and way number. The access size of the data array is fixed at longword.

(1) TLB address array access

• Read access



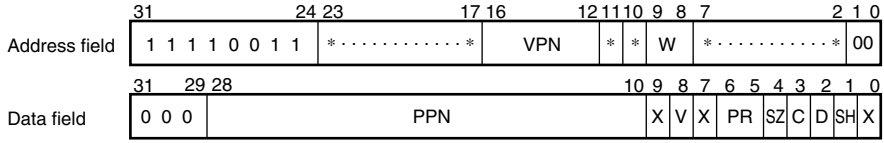
• Write access



VPN: Virtual page number
V: Valid bit
W: Way (00: Way 0, 01: Way 1, 10: Way 2, 11: Way 3)
ASID: Address space identifier
*: Don't care bit

(2) TLB data array access

• Read/write access



PPN: Physical page number
PR: Protection key field
C: Cacheable bit
SH: Share status bit
VPN: Virtual page number
X: 0 for read, don't care bit for write
W: Way (00: Way 0, 01: Way 1, 10: Way 2, 11: Way 3)
V: Valid bit
SZ: Page-size bit
D: Dirty bit
*: Don't care bit

Figure 3.14 Specifying Address and Data for Memory-Mapped TLB Access

3.6.3 Usage Examples

Invalidating Specific Entries: Specific TLB entries can be invalidated by writing 0 to the entry's V bit. R0 specifies the write data and R1 specifies the address.

```
; R0=H'1547 381C  R1=H'F201 3000
; MMUCR.IX=0
; the V bit of way 0 of the entry selected by the VPN(16–12)=B'1 0011
; index is cleared to0,achieving invalidation.
MOV.L  R0,@R1
```

Reading the Data of a Specific Entry: This example reads the data section of a specific TLB entry. The bit order indicated in the data field in figure 3.14 (2) is read. R0 specifies the address and the data section of a selected entry is read to R1.

```
; R0=H'F300 4300   VPN(16-12)=B'00100   Way 3
; MOV.L @R0,R1
```


3.7 Usage Note

The following operations should be performed in the P1 or P2 areas. In addition, when the P0, P3, or U0 areas are accessed consecutively (this access includes instruction fetching), the instruction code should be placed at least two instructions after the instruction that executes the following operations.

1. Modification of SR.MD or SR.BL
2. Execution of the LDTLB instruction
3. Write to the memory-mapped TLB
4. Modification of MMUCR
5. Modification of PTEH.ASID

Section 4 Cache

4.1 Features

- Capacity: 16 or 32 kbytes
- Structure: Instructions/data mixed, 4-way set associative
- Locking: Way 2 and way 3 are lockable
- Line size: 16 bytes
- Number of entries: 256 entries/way in 16-kbyte mode or 512 entries/way in 32-kbyte mode
- Write system: Write-back/write-through is selectable for spaces P0, P1, P3, and U0
  Group 1 (P0, P3, and U0 areas)
  Group 2 (P1 area)
- Replacement method: Least-recently used (LRU) algorithm

Note: After power-on reset or manual reset, initialized as 16-kbyte mode (256 entries/way).

4.1.1 Cache Structure

The cache mixes instructions and data and uses a 4-way set associative system. It is composed of four ways (banks), and each of which is divided into an address section and a data section. Note that the following sections will be described for the 32-kbyte mode as an example. For other cache size modes, change the number of entries and size/way according to table 4.1. Each of the address and data sections is divided into 512 entries. The entry data is called a line. Each line consists of 16 bytes (4 bytes × 4). The data capacity per way is 8 kbytes (16 bytes × 512 entries) in the cache as a whole (4 ways). The cache capacity is 32 kbytes as a whole. Figure 4.1 shows the cache structure.

Table 4.1 Number of Entries and Size/Way in Each Cache Size

Cache Size	Number of Entries	Size/Way
16 kbytes	256	4 kbytes
32 kbytes	512	8 kbytes

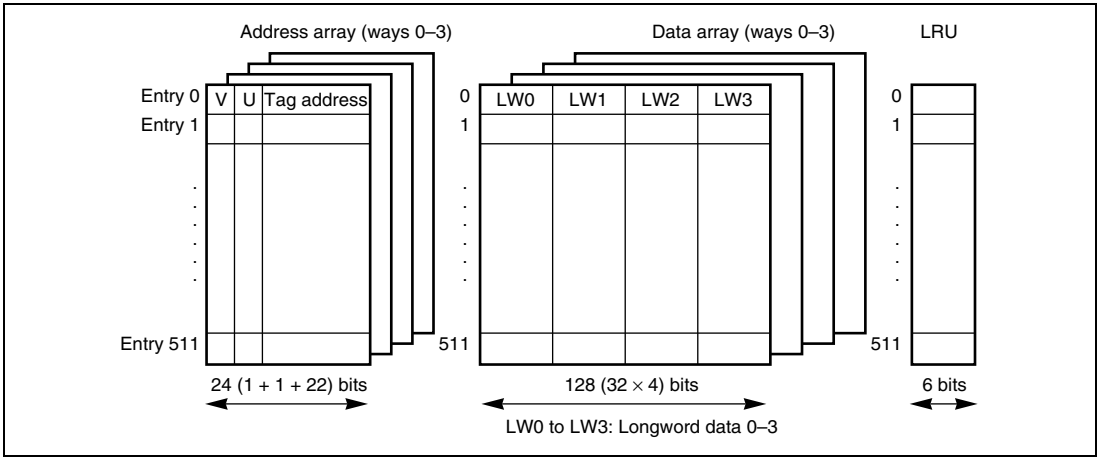


Figure 4.1 Cache Structure (32-kbyte Mode)

Address Array: The V bit indicates whether the entry data is valid. When the V bit is 1, data is valid; when 0, data is not valid. The U bit indicates whether the entry has been written to in write-back mode. When the U bit is 1, the entry has been written to; when 0, it has not. The tag address holds the physical address used in the external memory access. It is composed of 22 bits (address bits 31 to 10) used for comparison during cache searches.

In this LSI, the top three of 32 physical address bits are used as shadow bits (see section 7, Bus State Controller (BSC)), and therefore the top three bits of the tag address are cleared to 0.

The V and U bits are initialized to 0 by a power-on reset, but are not initialized by a manual reset. The tag address is not initialized by either a power-on or manual reset.

Data Array: Holds a 16-byte instruction or data. Entries are registered in the cache in line units (16 bytes). The data array is not initialized by a power-on or manual reset.

LRU: With the 4-way set associative system, up to four instructions or data with the same entry address can be registered in the cache. When an entry is registered, LRU shows which of the four ways it is recorded in. There are six LRU bits, controlled by hardware. A least-recently-used (LRU) algorithm is used to select the way.

Six LRU bits indicate the way to be replaced, when a cache miss occurs. Table 4.2 shows the relationship between the LRU bits and the way to be replaced when the cache locking mechanism is disabled. (For the relationship when the cache locking mechanism is enabled, refer to section 4.2.2, Cache Control Register 2.) If a bit pattern other than those listed in table 4.2 is set in the LRU bits by software, the cache will not function correctly. When modifying the LRU bits by software, set one of the patterns listed in table 4.2.

The LRU bits are initialized to 000000 by a power-on reset, but are not initialized by a manual reset.

Table 4.2 LRU and Way Replacement (when Cache Locking Mechanism is Disabled)

LRU (Bits 5 to 0)	Way to be Replaced
000000, 000100, 010100, 100000, 110000, 110100	3
000001, 000011, 001011, 100001, 101001, 101011	2
000110, 000111, 001111, 010110, 011110, 011111	1
111000, 111001, 111011, 111100, 111110, 111111	0

4.2 Register Descriptions

The cache has the following registers. For details on register addresses and register states during each process, refer to section 24, List of Registers.

- Cache control register 1 (CCR1)
- Cache control register 2 (CCR2)
- Cache control register 3 (CCR3)

4.2.1 Cache Control Register 1 (CCR1)

The cache is enabled or disabled using the CE bit in CCR1. CCR1 also has a CF bit (which invalidates all cache entries), and WT and CB bits (which select either write-through mode or write-back mode). Programs that change the contents of the CCR1 register should be placed in address space that is not cached.

Bit	Bit Name	Initial Value	R/W	Description
31 to 4	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
3	CF	0	R/W	Cache Flush Writing 1 flushes all cache entries (clears the V, U, and LRU bits of all cache entries to 0). This bit is always read as 0. Write-back to external memory is not performed when the cache is flushed.
2	CB	0	R/W	Write-Back Indicates the cache's operating mode for space P1. 0: Write-through mode 1: Write-back mode
1	WT	0	R/W	Write-Through Indicates the cache's operating mode for spaces P0, U0, and P3. 0: Write-back mode 1: Write-through mode
0	CE	0	R/W	Cache Enable Indicates whether the cache function is used. 0: The cache function is not used. 1: The cache function is used.

4.2.2 Cache Control Register 2 (CCR2)

The CCR2 register controls the cache locking mechanism in cache lock mode only. The CPU enters the cache lock mode when the lock enable bit (bit 16) in the cache control register 2 (CCR2) is set to 1. The cache locking mechanism is disabled in non-cache lock mode (DSP bit = 0).

When a prefetch instruction (PREF@Rn) is issued in cache lock mode and a cache miss occurs, the line of data pointed to by Rn will be loaded into the cache, according to the setting of bits 9 and 8 (W3LOAD, W3LOCK) and bits 1 and 0 (W2LOAD, W2LOCK in CCR2).

Table 4.3 shows the relationship between the settings of bits and the way that is to be replaced when the cache is missed by a prefetch instruction.

On the other hand, when the cache is hit by a prefetch instruction, new data is not loaded into the cache and the valid entry is held. For example, a prefetch instruction is issued while bits W3LOAD and W3LOCK are set to 1 and the line of data to which Rn points is already in way 0, the cache is hit and new data is not loaded into way 3.

In cache lock mode, bits W3LOCK and W2LOCK restrict the way that is to be replaced, when instructions other than the prefetch instruction are issued. Table 4.4 shows the relationship between the settings of bits in CCR2 and the way that is to be replaced when the cache is missed by instructions other than the prefetch instruction.

Programs that change the contents of the CCR2 register should be placed in address space that is not cached.

Bit	Bit Name	Initial Value	R/W	Description
31 to 17	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
16	LE	0	R/W	Lock Enable (LE) Controls cache lock mode. 0: Does not enter cache lock mode. 1: Enters cache lock mode.
15 to 10	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
9	W3LOAD	0	R/W	Way 3 Load (W3LOAD)
8	W3LOCK	0	R/W	Way 3 Lock (W3LOCK) When the cache is missed by a prefetch instruction while in cache lock mode and when bits W3LOAD and W3LOCK in CCR2 are set to 1, the data is always loaded into way 3. Under any other condition, the prefetched data is loaded into the way to which LRU points.
7 to 2	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
1	W2LOAD	0	R/W	Way 2 Load (W2LOAD)
0	W2LOCK	0	R/W	Way 2 Lock (W2LOCK) When the cache is missed by a prefetch instruction while in cache lock mode and when bits W2LOAD and W2LOCK in CCR2 are set to 1, the data is always loaded into way 2. Under any other condition, the prefetched data is loaded into the way to which LRU points.

Note: W2LOAD and W3LOAD should not be set to 1 at the same time.

Table 4.3 Way Replacement when a PREF Instruction Misses the Cache

DSP Bit	W3LOAD	W3LOCK	W2LOAD	W2LOCK	Way to be Replaced
0	*	*	*	*	Determined by LRU (table 4.2)
1	*	0	*	0	Determined by LRU (table 4.2)
1	*	0	0	1	Determined by LRU (table 4.5)
1	0	1	*	0	Determined by LRU (table 4.6)
1	0	1	0	1	Determined by LRU (table 4.7)
1	0	*	1	1	Way 2
1	1	1	0	*	Way 3

Note:* Don't care
W3LOAD and W2LOAD should not be set to 1 at the same time.

Table 4.4 Way Replacement when Instructions other than the PREF Instruction Miss the Cache

DSP Bit	W3LOAD	W3LOCK	W2LOAD	W2LOCK	Way to be Replaced
0	*	*	*	*	Determined by LRU (table 4.2)
1	*	0	*	0	Determined by LRU (table 4.2)
1	*	0	*	1	Determined by LRU (table 4.5)
1	*	1	*	0	Determined by LRU (table 4.6)
1	*	1	*	1	Determined by LRU (table 4.7)

Note:* Don't care
W3LOAD and W2LOAD should not be set to 1 at the same time.

Table 4.5 LRU and Way Replacement (when W2LOCK = 1 and W3LOCK = 0)

LRU (Bits 5 to 0)	Way to be Replaced
000000, 000001, 000100, 010100, 100000, 100001, 110000, 110100	3
000011, 000110, 000111, 001011, 001111, 010110, 011110, 011111	1
101001, 101011, 111000, 111001, 111011, 111100, 111110, 111111	0

Table 4.6 LRU and Way Replacement (when W2LOCK = 0 and W3LOCK = 1)

LRU (Bits 5 to 0)	Way to be Replaced
000000, 000001, 000011, 001011, 100000, 100001, 101001, 101011	2
000100, 000110, 000111, 001111, 010100, 010110, 011110, 011111	1
110000, 110100, 111000, 111001, 111011, 111100, 111110, 111111	0

Table 4.7 LRU and Way Replacement (when W2LOCK = 1 and W3LOCK = 1)

LRU (Bits 5 to 0)	Way to be Replaced
000000, 000001, 000011, 000100, 000110, 000111, 001011, 001111, 010100, 010110, 011110, 011111	1
100000, 100001, 101001, 101011, 110000, 110100, 111000, 111001, 111011, 111100, 111110, 111111	0

4.2.3 Cache Control Register 3 (CCR3)

The CCR3 register controls the cache size to be used. The cache size must be specified according to the LSI to be selected. If the specified cache size exceeds the size of cache incorporated in the LSI, correct operation cannot be guaranteed. Note that programs that change the contents of the CCR3 register should be placed in un-cached address space. In addition, note that all cache entries must be invalidated by setting the CF bit of the CCR1 to 1 before accessing the cache after the CCR3 is modified.

Bit	Bit Name	Initial Value	R/W	Description
31 to 24	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
23 to 16	CSIZE7 to CSIZE0	H'01	R/W	Cache Size Specify the cache size as shown below. 0000 0001: 16-kbyte cache 0000 0010: 32-kbyte cache Settings other than above are prohibited.
15 to 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

4.3 Operation

4.3.1 Searching the Cache

If the cache is enabled (the CE bit in CCR1 = 1), whenever instructions or data in spaces P0, P1, P3, and U0 are accessed the cache will be searched to see if the desired instruction or data is in the cache. Figure 4.2 illustrates the method by which the cache is searched. The cache is a physical cache and holds physical addresses in its address section. The following will be described for the 32-kbyte mode as an example.

Entries are selected using bits 12 to 4 of the address (virtual) of the access to memory and the tag address of that entry is read. The virtual address (bits 31 to 10) of the access to memory and the physical address (tag address) read from the address array are compared. The address comparison uses all four ways. When the comparison shows a match and the selected entry is valid (V = 1), a cache hit occurs. When the comparison does not show a match or the selected entry is not valid (V = 0), a cache miss occurs. Figure 4.2 shows a hit on way 1.

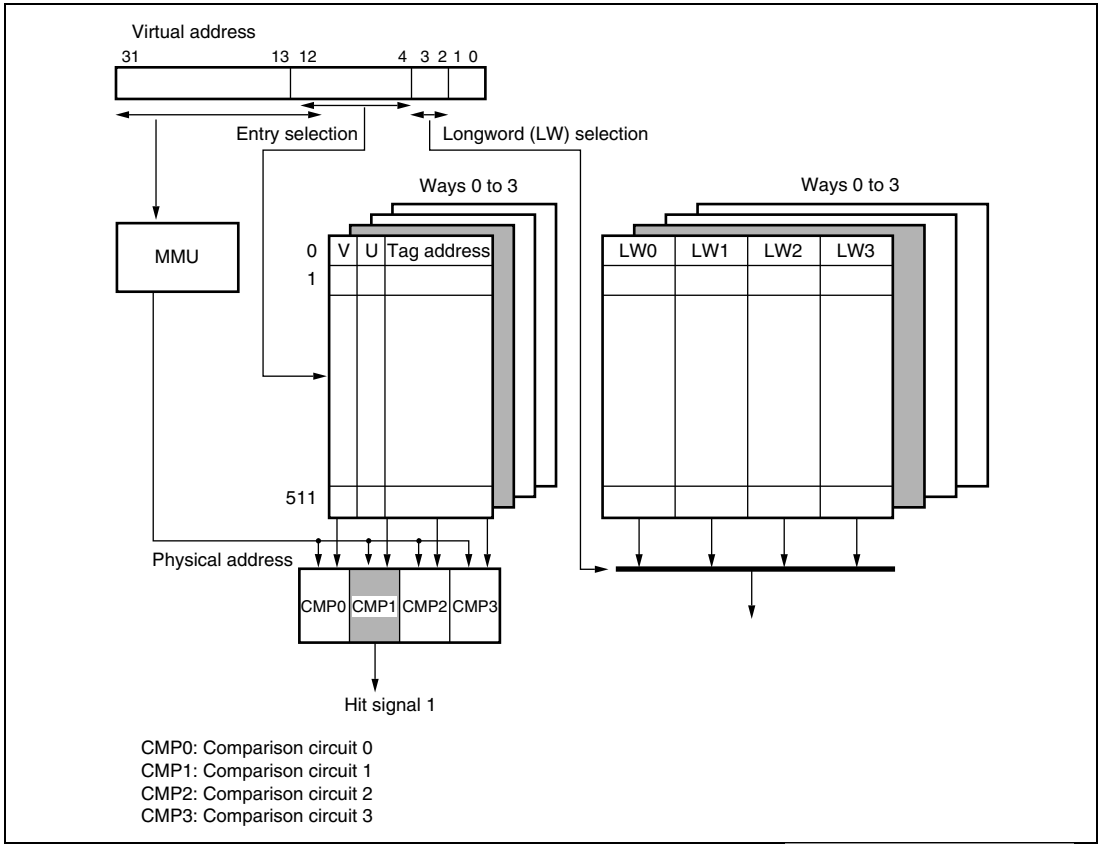


Figure 4.2 Cache Search Scheme

4.3.2 Read Access

Read Hit: In a read access, instructions and data are transferred from the cache to the CPU. The LRU is updated to indicate that the hit way is the most recently hit way.

Read Miss: An external bus cycle starts and the entry is updated. The way to be replaced is shown in table 4.3. Entries are updated in 16-byte units. When the desired instruction or data that caused the miss is loaded from external memory to the cache, the instruction or data is transferred to the CPU in parallel with being loaded to the cache. When it is loaded to the cache, the U bit is cleared to 0 and the V bit is set to 1 to indicate that the hit way is the most recently hit way. When the U bit for the entry which is to be replaced by entry updating in write-back mode is 1, the cache-update cycle starts after the entry is transferred to the write-back buffer. After the cache completes its update cycle, the write-back buffer writes the entry back to the memory. Transfer is in 16-byte units.

4.3.3 Prefetch Operation

Prefetch Hit: The LRU is updated to indicate that the hit way is the most recently hit way. The other contents of the cache are not changed. Instructions and data are not transferred from the cache to the CPU.

Prefetch Miss: Instructions and data are not transferred from the cache to the CPU. The way that is to be replaced is shown in table 4.2. The other operations are the same as those for a read miss.

4.3.4 Write Access

Write Hit: In a write access in write-back mode, the data is written to the cache and no external memory write cycle is issued. The U bit of the entry that has been written to is set to 1, and the LRU is updated to indicate that the hit way is the most recently hit way. In write-through mode, the data is written to the cache and an external memory write cycle is issued. The U bit of the entry that has been written to is not updated, and the LRU is updated to indicate that the hit way is the most recently hit way.

Write Miss: In write-back mode, an external write cycle starts when a write miss occurs, and the entry is updated. The way to be replaced is shown in table 4.3. When the U bit of the entry which is to be replaced by entry updating is 1, the cache-update cycle starts after the entry has been transferred to the write-back buffer. Data is written to the cache and the U bit and the V bit are set to 1. The LRU is updated to indicate that the replaced way is the most recently updated way. After the cache has completed its update cycle, the write-back buffer writes the entry back to the memory. Transfer is in 16-byte units. In write-through mode, no write to cache occurs in a write miss; the write is only to the external memory.

4.3.5 Write-Back Buffer

When the U bit of the entry to be replaced in write-back mode is 1, the entry must be written back to the external memory. To increase performance, the entry to be replaced is first transferred to the write-back buffer and fetching of new entries to the cache takes priority over writing back to the external memory. After the fetching of new entries to the cache completes, the write-back buffer writes the entry back to the external memory. During the write-back cycles, the cache can be accessed. The write-back buffer can hold one line of cache data (16 bytes) and its physical address. Figure 4.3 shows the configuration of the write-back buffer.

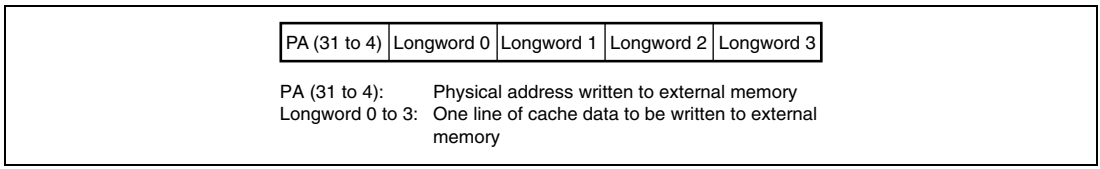


Figure 4.3 Write-Back Buffer Configuration

4.3.6 Coherency of Cache and External Memory

Use software to ensure coherency between the cache and the external memory. When memory shared by this LSI and another device is placed in an address space to which caching applies, use the memory-mapped cache to make the data invalid and written back, as required. Memory that is shared by this LSI's CPU and DMAC should also be handled in this way.

4.4 Memory-Mapped Cache

To allow software management of the cache, cache contents can be read and written by means of MOV instructions in privileged mode. The cache is mapped onto the P4 area in virtual address space. The address array is mapped onto addresses H'F0000000 to H'F0FFFFFF, and the data array onto addresses H'F1000000 to H'F1FFFFFF. Only longword can be used as the access size for the address array and data array, and instruction fetches cannot be performed.

4.4.1 Address Array

The address array is mapped onto H'F0000000 to H'F0FFFFFF. To access an address array, the 32-bit address field (for read/write accesses) and 32-bit data field (for write accesses) must be specified. The address field specifies information for selecting the entry to be accessed; the data field specifies the tag address, V bit, U bit, and LRU bits to be written to the address array.

In the address field, specify the entry address for selecting the entry, W for selecting the way, A for enabling or disabling the associative operation, and H'F0 for indicating address array access. As for W, 00 indicates way 0, 01 indicates way 1, 10 indicates way 2, and 11 indicates way 3).

In the data field, specify the tag address, LRU bits, U bit, and V bit. Figure 4.4 shows the address and data formats in 32-kbyte mode. The following three operations are available in the address array.

Address-Array Read: Read the tag address, LRU bits, U bit, and V bit for the entry that corresponds to the entry address and way specified by the address field of the read instruction. In reading, the associative operation is not performed, regardless of whether the associative bit (A bit) specified in the address is 1 or 0.

Address-Array Write (non-Associative Operation): Write the tag address, LRU bits, U bit, and V bit, specified by the data field of the write instruction, to the entry that corresponds to the entry address and way as specified by the address field of the write instruction. Ensure that the associative bit (A bit) in the address field is set to 0. When writing to a cache line for which the U bit = 1 and the V bit =1, write the contents of the cache line back to memory, then write the tag address, LRU bits, U bit, and V bit specified by the data field of the write instruction. Always clear the uppermost 3 bits (bits 31 to 29) of the tag address to 0. When 0 is written to the V bit, 0 must also be written to the U bit for that entry.

Address-Array Write (Associative Operation): When writing with the associative bit (A bit) of the address = 1, the addresses in the four ways for the entry specified by the address field of the write instruction are compared with the tag address that is specified by the data field of the write instruction. If the MMU is enabled in this case, a logical address specified by data is translated into a physical address via the TLB before comparison. Write the U bit and the V bit specified by the data field of the write instruction to the entry of the way that has a hit. However, the tag

address and LRU bits remain unchanged. When there is no way that receives a hit, nothing is written and there is no operation. This function is used to invalidate a specific entry in the cache. When the U bit of the entry that has received a hit is 1 at this point, writing back should be performed. However, when 0 is written to the V bit, 0 must also be written to the U bit of that entry.

4.4.2 Data Array

The data array is mapped onto H'F1000000 to H'F1FFFFFF. To access a data array, the 32-bit address field (for read/write accesses) and 32-bit data field (for write accesses) must be specified. The address field specifies information for selecting the entry to be accessed; the data field specifies the longword data to be written to the data array.

In the address field, specify the entry address for selecting the entry, L for indicating the longword position within the (16-byte) line, W for selecting the way, and H'F1 for indicating data array access. As for L, 00 indicates longword 0, 01 indicates longword 1, 10 indicates longword 2, and 11 indicates longword 3. As for W, 00 indicates way 0, 01 indicates way 1, 10 indicates way 2, and 11 indicates way 3).

Since access size of the data array is fixed at longword, bits 1 and 0 of the address field should be set to 00.

Figure 4.4 shows the address and data formats in 32-kbyte mode. For other cache size modes, change the entry address and w as shown in table 4.8.

The following two operations on the data array are available. The information in the address array is not affected by these operations.

Data-Array Read: Read the data specified by L of the address filed, from the entry that corresponds to the entry address and the way that is specified by the address filed.

Data-Array Write: Write the longword data specified by the data filed, to the position specified by L of the address field, in the entry that corresponds to the entry address and the way specified by the address field.

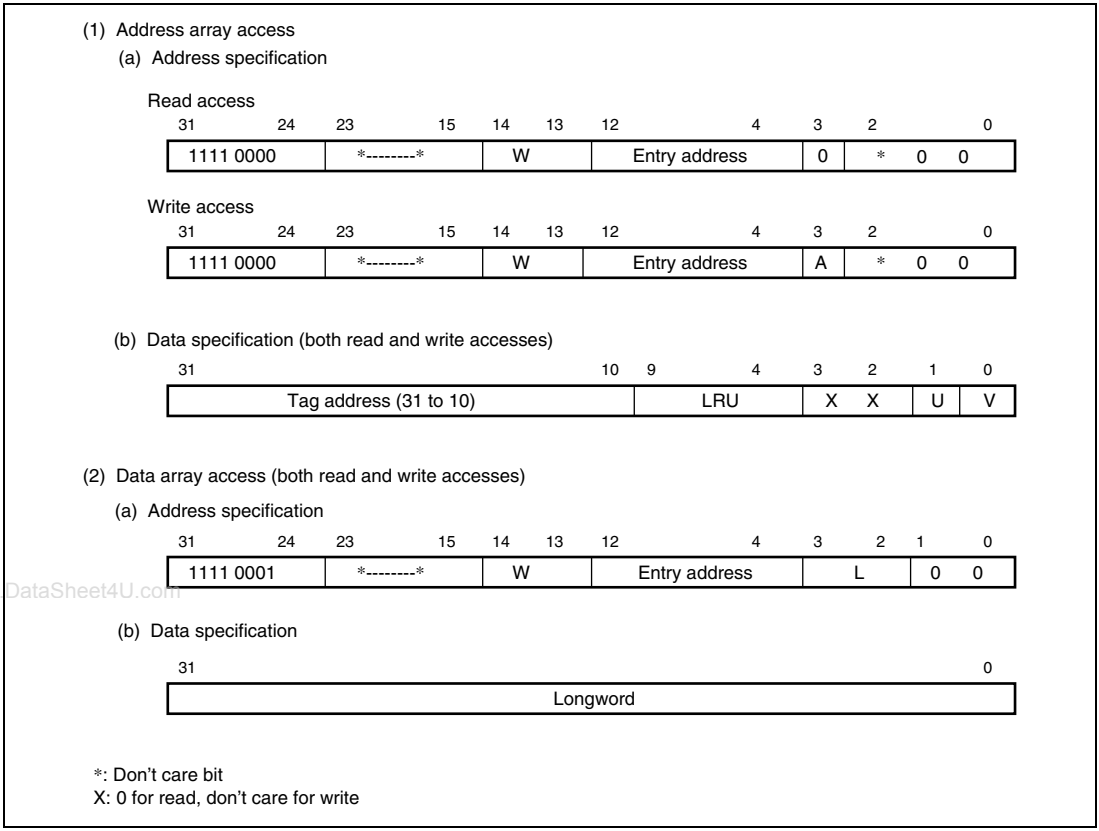


Figure 4.4 Specifying Address and Data for Memory-Mapped Cache Access (32-kbyte Mode)

Table 4.8 Address Format Based on Size of Cache to be Assigned to Memory

Cache Size	Entry Address Bits	W Bit
16 kbytes	11 to 4	13 to 12
32 kbytes	12 to 4	14 to 13

4.4.3 Usage Examples

Invalidating Specific Entries: Specific cache entries can be invalidated by writing 0 to the entry's V bit in the memory-mapped cache access. When the A bit is 1, the tag address specified by the write data is compared to the tag address within the cache selected by the entry address, and a match is found, the entry is written back if the entry's U bit is 1 and the V bit and U bit specified by the write data are written. If no match is found, there is no operation. In the example shown below, R0 specifies the write data and R1 specifies the address.

```
; R0=H'01100010; VPN=B'0000 0001 0001 0000 0000 00, U=0, V=0
; R1=H'F0000088; address array access, entry=B'00001000, A=1
;
MOV.L R0,@R1
```

Reading the Data of a Specific Entry: To read the data field of a specific entry is enabled by the memory-mapped cache access. The longword indicated in the data field of the data array in figure 4.4 is read into the register. In the example shown below, R0 specifies the address and R1 shows what is read.


```
; R0=H'F100 004C; data array access, entry=B'00000100
; Way = 0, longword address = 3
;
MOV.L @R0,R1 ; Longword 3 is read.
```

4.5 Usage Note

Do note execute the PREF instruction for the area that cannot be accessed using the cache (P2 and P4 areas).

Section 5 Exception Handling

Exception handling is separate from normal program processing, and is performed by a routine separate from the normal program. For example, if an attempt is made to execute an undefined instruction code or an instruction protected by the CPU processing mode, a control function may be required to return to the source program by executing the appropriate operation or to report an abnormality and carry out end processing. In addition, a function to control processing requested by LSI on-chip modules or an LSI external module to the CPU may also be required.

Transferring control to a user-defined exception processing routine and executing the process to support the above functions are called exception handling. This LSI has two types of exceptions: general exceptions and interrupts. The user can execute the required processing by assigning exception handling routines corresponding to the required exception processing and then return to the source program.

A reset input can terminate the normal program execution and pass control to the reset vector after register initialization. This reset operation can also be regarded as an exception handling. This section describes an overview of the exception handling operation. Here, general exceptions and interrupts are referred to as exception handling. For interrupts, this section describes only the process executed for interrupt requests. For details on how to generate an interrupt request, refer to section 6, Interrupt Controller (INTC).

5.1 Register Descriptions

There are five registers for exception handling. A register with an undefined initial value should be initialized by the software. Refer to section 24, List of Registers, for the addresses and access sizes of these registers.

- TRAPA exception register (TRA)
- Exception event register (EXPEVT)
- Interrupt event register (INTEVT)
- Interrupt event register 2 (INTEVT2)
- Exception address register (TEA)

Figure 5.1 shows the bit configuration of each register.

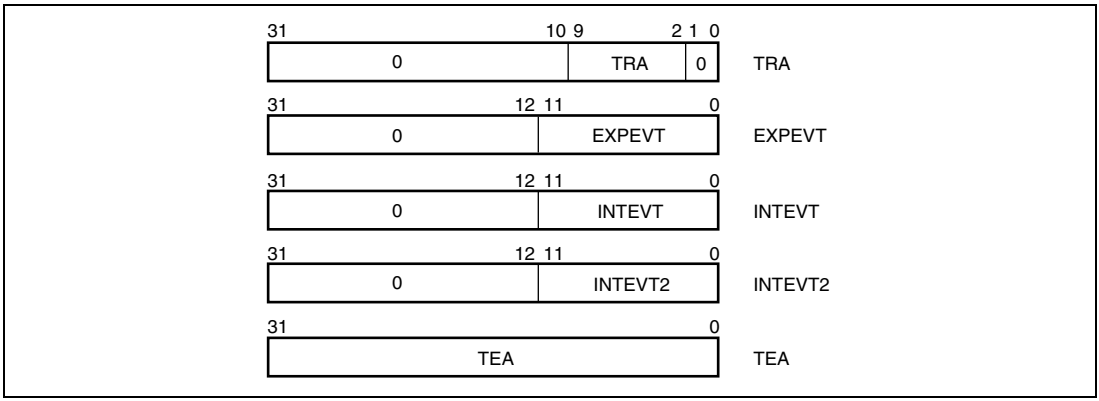


Figure 5.1 Register Bit Configuration

5.1.1 TRAPA Exception Register (TRA)

TRA is assigned to address H'FFFFFFD0 and consists of the 8-bit immediate data (imm) of the TRAPA instruction. TRA is automatically specified by the hardware when the TRAPA instruction is executed. Only bits 9 to 2 of the TRA can be re-written using the software.

Bit	Bit Name	Initial Value	R/W	Description
31 to 10	—	—	R	Reserved These bits are always read as 0. The write value should always be 0.
9 to 2	TRA	—	R/W	8-bit Immediate Data
1, 0	—	—	R	Reserved These bits are always read as 0. The write value should always be 0.

5.1.2 Exception Event Register (EXPEVT)

EXPEVT is assigned to address H'FFFFFFD4 and consists of a 12-bit exception code. Exception codes to be specified in EXPEVT are those for resets and general exceptions. These exception codes are automatically specified the hardware when an exception occurs. Only bits 11 to 0 of EXPEVT can be re-written using the software.

Bit	Bit Name	Initial Value	R/W	Description
31 to 12	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
11 to 0	EXPEVT	*	R/W	12-bit Exception Code

Note: Initialized to H'000 at power-on reset and H'020 at manual reset.

5.1.3 Interrupt Event Register (INTEVT)

INTEVT is assigned to address H'FFFFFFD8 and consists of a 12-bit exception code. Exception codes to be specified in INTEVT are those for interrupt requests. These exception codes are automatically specified by the hardware when an exception occurs. Only bits 11 to 0 of INTEVT can be re-written using the software.

Bit	Bit Name	Initial Value	R/W	Description
31 to 12	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
11 to 0	INTEVT	—	R/W	12-bit Exception Code

5.1.4 Interrupt Event Register 2 (INTEVT2)

INTEVT2 is assigned to address H'A4000000 and consists of a 12-bit exception code. Exception codes to be specified in INTEVT2 are those for interrupt requests. These exception codes are automatically specified by the hardware when an exception occurs. INTEVT2 cannot be modified using the software.

Bit	Bit Name	Initial Value	R/W	Description
31 to 12	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
11 to 0	INTEVT	—	R/W	12-bit Exception Code

Note: Initialized to H'000 at power-on reset and H'020 at manual reset.

5.1.5 Exception Address Register (TEA)

TEA is assigned to address H'FFFFFFFC and stores the logical address for an exception occurrence when an exception related to memory accesses occurs. TEA can be modified using the software.

Bit	Bit Name	Initial Value	R/W	Description
31 to 0	TEA	—	R/W	Logical address for exception occurrence

Note: Initialized to H'000 at power-on reset and H'020 at manual reset.

5.2 Exception Handling Function

5.2.1 Exception Handling Flow

In exception handling, the contents of the program counter (PC) and status register (SR) are saved in the saved program counter (SPC) and saved status register (SSR), respectively, and execution of the exception handler is invoked from a vector address. The return from exception handler (RTE) instruction is issued by the exception handler routine on completion of the routine, restoring the contents of PC and SR to return to the processor state at the point of interruption and the address where the exception occurred.

A basic exception handling sequence consists of the following operations. If an exception occurs and the CPU accepts it, operations 1 to 8 are executed.

1. The contents of PC is saved in SPC.
2. The contents of SR is saved in SSR.
3. The block (BL) bit in SR is set to 1, masking any subsequent exceptions.
4. The mode (MD) bit in SR is set to 1 to place the privileged mode.
5. The register bank (RB) bit in SR is set to 1.
6. An exception code identifying the exception event is written to bits 11 to 0 of the exception event (EXPEVT) or interrupt event (INTEVT or INTEVT2) register.
7. Instruction execution jumps to the designated exception vector address to invoke the handler routine.[*1]
8. If a TRAPA instruction is executed, an 8-bit immediate data specified by the TRAPA instruction is set to TRA. For an exception related to memory accesses, the logic address where the exception occurred is written to TEA.

The above operations from 1 to 8 are executed in sequence. During these operations, no other exceptions may be accepted unless multiple exception acceptance is enabled.

In an exception handling routine for a general exception, the appropriate exception handling must be executed based on an exception source determined by the EXPEVP. In an interrupt exception handling routine, the appropriate exception handling must be executed based on an exception source determined by the INTEVT or INTEVT2. After the exception handling routine has been completed, program execution can be resumed by executing an RTE instruction. The RTE instruction causes the following operations to be executed.

1. The contents of the SSR are restored into the SR to return to the processing state in effect before the exception handling took place.
2. A delay slot instruction of the RTE instruction is executed.*2
3. Control is passed to the address stored in the SPC.

The above operations from 1 to 3 are executed in sequence. During these operations, no other exceptions may be accepted. By changing the SPT and SSR before executing the RTE instruction, a status different from that in effect before the exception handling can also be specified.

Notes: 1. The MMU registers are also modified if an MMU exception occurs.
2. For details on the CPU processing mode in which RTE delay slot instructions are executed, please refer to section 5.4, Usage Notes.

5.2.2 Exception Vector Addresses

A vector address for general exceptions is determined by adding a vector offset to a vector base address. The vector offset for general exceptions other than the TLB error exception is H'00000100. The vector offset for interrupts is H'00000600. The vector base address is loaded into the vector base register (VBR) using the software. The vector base address should reside in the P1 or P2 fixed physical address space.

5.2.3 Exception Codes

The exception codes are written to bits 11 to 0 of the EXPEVT register (for reset or general exceptions) or the INTEVT2 register (for interrupt requests) to identify each specific exception event. See section 6, Interrupt Controller (INTC), for details of the exception codes for interrupt requests. Table 5.1 lists exception codes for resets and general exceptions.

5.2.4 Exception Request and BL Bit (Multiple Exception Prevention)

The BL bit in SR is set to 1 when a reset or exception is accepted. While the BL bit is set to 1, acceptance of general exceptions is restricted as described below, making it possible to effectively prevent multiple exceptions from being accepted.

If the BL bit is set to 1, an interrupt request is not accepted and is retained. The interrupt request is accepted when the BL bit is cleared to 0. If the CPU is in low power consumption mode, an interrupt is accepted even if the BL bit is set to 1 and the CPU returns from the low power consumption mode.

A DMA error is not accepted and is retained if the BL bit is set to 1 and accepted when the BL bit is cleared to 0. User break requests generated while the BL bit is set are ignored and are not retained. Accordingly, user breaks are not accepted even if the BL bit is cleared to 0.

If a general exception other than a DMA address error or user break occurs while the BL bit is set to 1, the CPU enters a state similar to that in effect immediately after a reset, and passes control to the reset vector (H'A0000000) (multiple exception). In this case, unlike a normal reset, modules other than the CPU are not initialized, the contents of EXPEVT, SPC, and SSR are undefined, and this status is not detected by an external device.

To enable acceptance of multiple exceptions, the contents of SPC and SSR must be saved while the BL bit is set to 1 after an exception has been accepted, and then the BL bit must be cleared to 0. Before restoring the SPC and SSR, the BL bit must be set to 1.

5.2.5 Exception Source Acceptance Timing and Priority

Exception Request of Instruction Synchronous Type and Instruction Asynchronous Type: Resets and interrupts are requested asynchronously regardless of the program flow. In general exceptions, a DMA address error and a user break under the specific condition are also requested asynchronously. The user cannot expect on which instruction an exception is requested. For general exceptions other than a DMA address error and a user break under a specific condition, each general exception corresponds to a specific instruction.

Re-execution Type and Processing-completion Type Exceptions: All exceptions are classified into two types: a re-execution type and a processing-completion type. If a re-execution type exception is accepted, the current instruction executed when the exception is accepted is terminated and the instruction address is saved to the SPC. After returning from the exception processing, program execution resumes from the instruction where the exception was accepted. In a processing-completion type exception, the current instruction executed when the exception is accepted is completed, the next instruction address is saved to the SPC, and then the exception processing is executed.

During a delayed branch instruction and delay slot, the following operations are executed. A re-execution type exception detected in a delay slot is accepted before executing the delayed branch instruction. A processing-completion type exception detected in a delayed branch instruction or a delay slot is accepted when the delayed branch instruction has been executed. In this case, the acceptance of delayed branch instruction or a delay slot precedes the execution of the branch destination instruction. In the above description, a delay slot indicates an instruction following an unconditional delayed branch instruction or an instruction following a conditional delayed branch instruction whose branch condition is satisfied. If a branch does not occur in a conditional delayed branch, the normal processing is executed.

Acceptance Priority and Test Priority: Acceptance priorities are determined for all exception requests. The priority of resets, general exceptions, and interrupts are determined in this order: a reset is always accepted regardless of the CPU status. Interrupts are accepted only when resets or general exceptions are not requested.

If multiple general exceptions occur simultaneously in the same instruction, the priority is determined as follows.

1. A processing-completion type exception generated at the previous instruction*
2. A user break before instruction execution (re-execution type)
3. An exception related to an instruction fetch (CPU address error and MMU related exceptions: re-execution type)

4. An exception caused by an instruction decode (General illegal instruction exceptions and slot illegal instruction exceptions: re-execution type, unconditional trap: processing-completion type)
5. An exception related to data access (CPU address error and MMU related exceptions: re-execution type)
6. Unconditional trap (processing-completion type)
7. A user break other than one before instruction execution (processing-completion type)
8. DMA address error (processing-completion type)

Note:* If a processing-completion type exception is accepted at an instruction, exception processing starts before the next instruction is executed. This exception processing executed before an exception generated at the next instruction is detected.

Only one exception is accepted at a time. Accepting multiple exceptions sequentially results in all exception requests being processed.

Table 5.1 Exception Event Vectors

Exception Type	Current Instruction	Exception Event	Priority*[1]	Exception Order	Process at BL=1	Vector Code	Vector Offset
Reset	Aborted	Power-on reset	1	1	Reset	H'A00	—
		Manual reset	1	2	Reset	H'020	—
General exception events	Re-executed	User break(before instruction execution)	2	0	Ignored	H'1E0	H'00000100
		CPU address error (instruction access)	2	1	Reset	H'0E0	H'00000100
		TLB miss *[4] (instruction access)	2	1-1	Reset	H'040	H'00000400
		TLB invalid *[4] (instruction access)	2	1-2	Reset	H'040	H'00000100
		TLB protection violation *[4] (instruction access)	2	1-4	Reset	H'0A0	H'00000100
		Illegal general instruction exception	2	2	Reset	H'180	H'00000100
		Illegal slot instruction exception	2	2	Reset	H'1A0	H'00000100
		CPU address error (data access)	2	3	Reset	H'0E0/ H'100	H'00000100
		TLB miss *[4] (data access)	2	3-1	Reset	H'040/ H'060	H'00000400

Exception Type	Current Instruction	Exception Event	Priority*1	Exception Order	Process at BL=1	Vector Code	Vector Offset
General exception events	Re-executed	TLB invalid *4 (data access)	2	3-2	Reset	H'040/ H'060	H'00000100
		TLB protection violation *4 (data access)	2	3-3	Reset	H'0A0/ H'0C0	H'00000100
		Initial page write *4 (data access)	2	3-4	Reset	H'080	H'00000100
	Completed	Unconditional trap (TRAPA instruction)	2	4	Reset	H'160	H'00000100
		User breakpoint (After instruction execution, address)	2	5	Ignored	H'1E0	H'00000100
General interrupt requests	Completed	User breakpoint (Data break, I-BUS break)	2	5	Ignored	H'1E0	H'00000100
		DMA address error	2	6	Retained	H'5C0	H'00000100
Interrupt requests	Completed	Interrupt requests	3	—*2	Retained	—*3	H'00000600

Notes: *1 Priorities are indicated from high to low, 1 being the highest and 3 the lowest.
A reset has the highest priority. An interrupt is accepted only when general exceptions are not requested.

*2 For details on priorities in multiple interrupt sources, refer to section 6, Interrupt Controller (INTC).

*3 If an interrupt is accepted, the interrupt source register (EXPEVT) is not changed. The interrupt source code is specified in interrupt source register 2 (EXPEVT2). For details, refer to section 6, Interrupt Controller (INTC).

*4 These exception codes are valid when the MMU is used.

5.3 Individual Exception Operations

This section describes the conditions for specific exception handling and the processor operations for resets and general exceptions. For interrupts, refer to section 6, Interrupt Controller (INTC).

5.3.1 Resets

Power-On Reset:

- Conditions

  Power-on reset is request
- Operations

  Set EXPEVT to H'000, initialize the CPU and on-chip peripheral modules, and branch to the reset vector H'A0000000. For details, refer to the register descriptions in the relevant sections.

Manual Reset:

- Conditions

  Manual reset is request
- Operations

  Set EXPEVT to H'020, initialize the CPU and on-chip peripheral modules, and branch to the reset vector H'A0000000. For details, refer to the register descriptions in the relevant sections.

5.3.2 General Exceptions

CPU address error:

- Conditions
  - Instruction is fetched from odd address (4n + 1, 4n + 3)
  - Word data is accessed from addresses other than word boundaries (4n + 1, 4n + 3)
  - Longword is accessed from addresses other than longword boundaries (4n + 1, 4n + 2, 4n + 3)
  - The area ranging from H'80000000 to H'FFFFFFFF in logical space is accessed in user mode
- Types

  Instruction synchronous, re-execution type
- Save address

  Instruction fetch: An instruction address to be fetched when an exception occurred

  Data access: An instruction address where an exception occurs (a delayed branch instruction address if an instruction is assigned to a delay slot)

- Exception code

  An exception occurred during read: H'0E0

  An exception occurred during write: H'1E0
- Remarks

  The logical address (32 bits) that caused the exception is set in TEA.

Illegal general instruction exception:

- Conditions
  - When undefined code not in a delay slot is decoded

    Delayed branch instructions: JMP, JSR, BRA, BRAF, BSR, BSRF, RTS, RTE, BT/S, BF/S

Note: For details on undefined code, refer to section 2.6.2, Operation Code Map. When an undefined code other than H′F000 to H′FFFF is decoded, operation cannot be guaranteed.

  - When a privileged instruction not in a delay slot is decoded in user mode

    Privileged instructions: LDC, STC, RTE, LDTLB, SLEEP; instructions that access GBR with LDC/STC are not privileged instructions.

- Types

  Instruction synchronous, re-execution type
- Save address

  An instruction address where an exception occurs
- Exception code

  H'180
- Remarks

  None

Illegal slot instruction:

- Conditions
  - When undefined code in a delay slot is decoded

    Delayed branch instructions: JMP, JSR, BRA, BRAF, BSR, BSRF, RTS, RTE, BT/S, BF/S
  - When a privileged instruction in a delay slot is decoded in user mode

    Privileged instructions: LDC, STC, RTE, LDTLB, SLEEP; instructions that access GBR with LDC/STC are not privileged instructions.
  - When an instruction that rewrites PC in a delay slot is decoded

    Instructions that rewrite PC: JMP, JSR, BRA, BRAF, BSR, BSRF, RTS, RTE, BT, BF, BT/S, BF/S, TRAPA, LDC Rm, SR, LDC.L @Rm+, SR
- Types

  Instruction synchronous, re-execution type

- Save address
  A delayed branch instruction address
- Exception code
  H’1A0
- Remarks
  None

Unconditional trap:

- Conditions
  TRAPA instruction executed
- Types
  Instruction synchronous, processing-completion type
- Save address
  An address of an instruction following TRAPA
- Exception code
  H’160
- Remarks
  The exception is a processing-completion type, so PC of the instruction after the TRAPA instruction is saved to SPC. The 8-bit immediate value in the TRAPA instruction is quadrupled and set in TRA[9:2].

User break point trap:

- Conditions
  When a break condition set in the user break controller is satisfied
- Types
  Break (L bus) before instruction execution: Instruction synchronous, re-execution type
  Operand break (L bus): Instruction synchronous, processing-completion type
  Data break (L bus): Instruction asynchronous, processing-completion type
  I bus break: Instruction asynchronous, processing-completion type
- Save address
  Re-execution type: An address of the instruction where a break occurs (a delayed branch instruction address if an instruction is assigned to a delay slot)
  Processing-completion type: An address of the instruction following the instruction where a break occurs (a delayed branch instruction address if an instruction is assigned to a delay slot)
- Exception code
  H’1E0

- Remarks

  For details on user break controller, refer to section 22, User Break Controller (UBC).

DMA address error:

- Conditions
  - Word data accessed from addresses other than word boundaries (4n + 1, 4n + 3)
  - Longword accessed from addresses other than longword boundaries (4n + 1, 4n + 2, 4n + 3)
- Types

  Instruction asynchronous, processing-completion type
- Save address

  An address of the instruction following the instruction where a break occurs (a delayed branch instruction destination address if an instruction is assigned to a delay slot)
- Exception code

  H'5C0

- Remarks

  An exception occurs when a DMA transfer is executed while an illegal instruction address described above is specified in the DMAC. Since the DMA transfer is performed asynchronously with the CPU instruction operation, an exception is also requested asynchronously with the instruction execution. For details on DMAC, refer to section 8, Direct Memory Access Controller (DMAC).

5.3.3 General Exceptions (MMU Exceptions)

When the address translation unit of the memory management unit (MMU) is valid, MMU exceptions are checked after a CPU address error has been checked. Four types of MMU exceptions are defined: TLP error exception, TLP invalid exception, TLB protection exception, and initial page write exception. These exceptions are checked in this order.

A vector offset for a TLB error exception is defined as H'00000400 to simplify exception source determination. For details on MMU exception operations, refer to section 3, Memory Management Unit (MMU).

TLB miss exception:

- Conditions

  Comparison of TLB addresses shows no address match.
- Types

  Instruction synchronous, re-execution type

- Save address

  Instruction fetch: An instruction address to be fetched when an exception occurred

  Data access: An instruction address where an exception occurs (a delayed branch instruction address if an instruction is assigned to a delay slot)
- Exception code

  An exception occurred during read: H’040

  An exception occurred during write: H’060
- Remarks

  The logical address (32 bits) that caused the exception is set in TEA and the MMU registers are updated. The vector address of the TLB miss exception is VBR + H'0400. To speed up TLB miss processing, the offset differs from other exceptions.

TLB invalid exception:

- Conditions

  Comparison of TLB addresses shows address match but V = 0.

- Types

  Instruction synchronous, re-execution type
- Save address

  Instruction fetch: An instruction address to be fetched when an exception occurred

  Data access: An instruction address where an exception occurs (a delayed branch instruction address if an instruction is assigned to a delay slot)
- Exception code

  An exception occurred during read: H’040

  An exception occurred during write: H’060
- Remarks

  The logical address (32 bits) that caused the exception is set in TEA and the MMU registers are updated.

TLB protection exception:

- Conditions

  When a hit access violates the TLB protection information (PR bits)
- Types

  Instruction synchronous, re-execution type
- Save address

  Instruction fetch: An instruction address to be fetched when an exception occurred

  Data access: An instruction address where an exception occurs (a delayed branch instruction address if an instruction is assigned to a delay slot)

- Exception code

  An exception occurred during read: H'0A0

  An exception occurred during write: H'0C0
- Remarks

  The logical address (32 bits) that caused the exception is set in TEA and the MMU registers are updated.

Initial page write exception:

- Conditions

  A hit occurred to the TLB for a store access, but D = 0.
- Types

  Instruction synchronous, re-execution type
- Save address

  Instruction fetch: An instruction address to be fetched when an exception occurred

  Data access: An instruction address where an exception occurs (a delayed branch instruction address if an instruction is assigned to a delay slot)
- Exception code

  H'080
- Remarks

  The logical address (32 bits) that caused the exception is set in TEA and the MMU registers are updated.

5.4 Usage Notes

1. An instruction assigned at a delay slot of the RTE instruction is executed after the contents of the SSR is restored into the SR. An acceptance of an exception related to instruction access is determined according to the SR before restore. An acceptance of other exceptions is determined by the SR after restore, processing mode, and BL bit value. A processing-completion type exception is accepted before an instruction at the RTE branch destination address is executed. However, note that the correct operation cannot be guaranteed if a re-execution type exception occurs.
2. In an instruction assigned at a delay slot of the RTE instruction, a user break cannot be accepted.
3. If the MD and BL bits of the SR register are changed by the LDC instruction, an exception is accepted according to the changed SR value from the next instruction.* A processing-completion type exception is accepted before the next instruction is executed. An interrupt and DMA address error in re-execution type exceptions are accepted before the next instruction is executed.

Note:* If an LDC instruction is executed for the SR, the following instructions are re-fetched and an instruction fetch exception is accepted according to the modified SR value.

Section 6 Interrupt Controller (INTC)

The interrupt controller (INTC) ascertains the priority of interrupt sources and controls interrupt requests to the CPU. The INTC registers set the order of priority of each interrupt, allowing the user to process interrupt requests according to the user-set priority.

6.1 Features

- 16 levels of interrupt priority can be set

  By setting the interrupt priority registers, the priorities of on-chip peripheral modules, and IRQ interrupts can be selected from 16 levels for individual request sources.
- NMI noise canceller function

  An NMI input-level bit indicates the NMI pin state. By reading this bit in the interrupt exception service routine, the pin state can be checked, enabling it to be used as a noise canceller.
- IRQ interrupts can be set

  Detection of low level, high level, rising edge, or falling edge

Figure 6.1 shows a block diagram of the INTC.

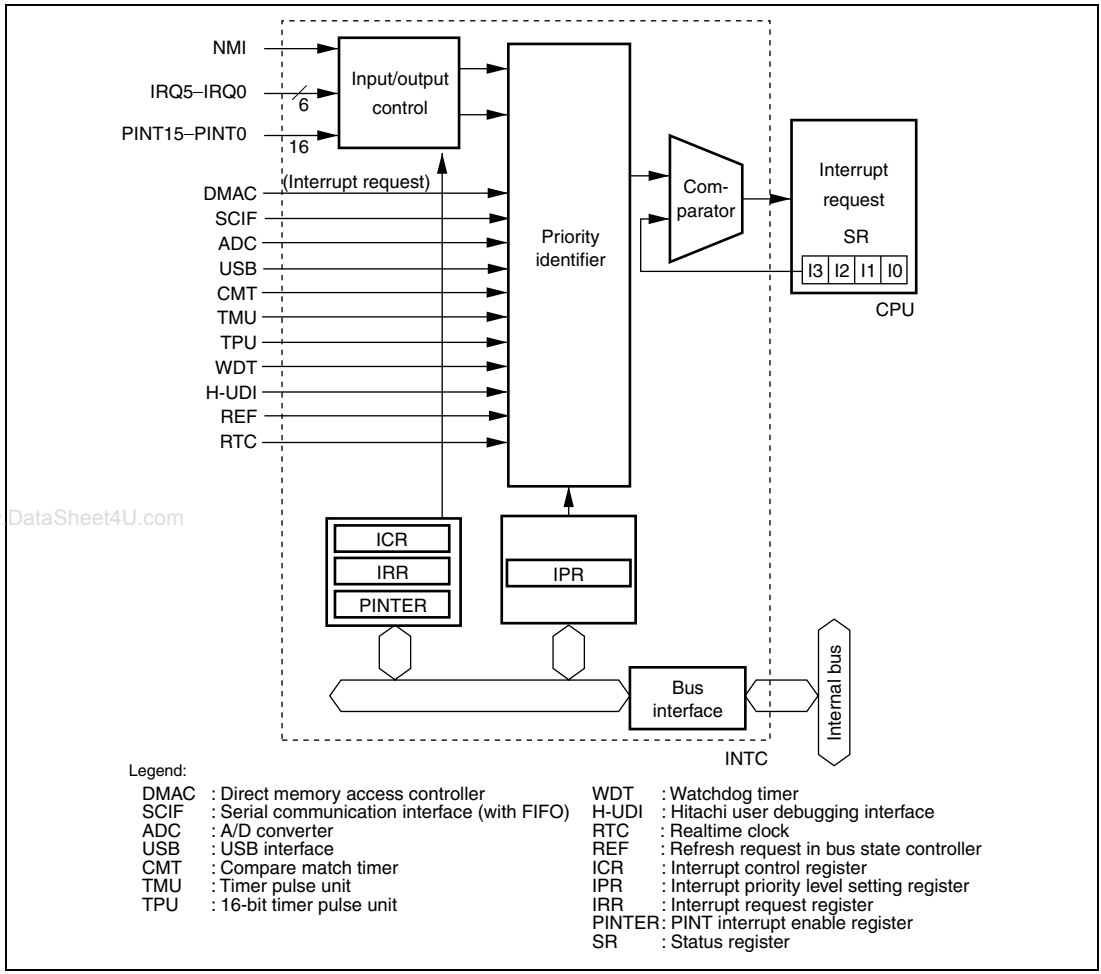


Figure 6.1 Block Diagram of INTC

6.2 Input/Output Pins

Table 6.1 shows the INTC pin configuration.

Table 6.1 Pin Configuration

Name	Abbreviation	I/O	Description
Nonmaskable interrupt input pin	NMI	Input	Input of interrupt request signal, not maskable by the interrupt mask bits in SR
Interrupt input pins	IRQ5 to IRQ0, $\overline{\text{IRL3}}$ to $\overline{\text{IRL0}}$	Input	Input of interrupt request signals
Port interrupt input pins	PINT15 to PINT0	Input	Input of port interrupt signals

Note: $\overline{\text{IRL3}}$ to $\overline{\text{IRL0}}$ are multiplexed with IRQ3 to IRQ0; they cannot be used together with IRQ3 to IRQ0 at the same time.

6.3 Register Descriptions

The INTC has the following registers. For details on register addresses and register states during each processing, refer to section 24, List of Registers.

- Interrupt control register 0 (ICR0)
- Interrupt control register 1 (ICR1)
- Interrupt control register 2 (ICR2)
- PINT interrupt enable register (PINTER)
- Interrupt priority level setting register A (IPRA)
- Interrupt priority level setting register B (IPRB)
- Interrupt priority level setting register C (IPRC)
- Interrupt priority level setting register D (IPRD)
- Interrupt priority level setting register E (IPRE)
- Interrupt priority level setting register F (IPRF)
- Interrupt priority level setting register G (IPRG)
- Interrupt priority level setting register H (IPRH)
- Interrupt request register 0 (IRR0)
- Interrupt request register 1 (IRR1)
- Interrupt request register 2 (IRR2)

6.3.1 Interrupt Priority Level Setting Registers A to H (IPRA to IPRH)

IPRA to IPRH are 16-bit readable/writable registers in which priority levels from 0 to 15 are set for on-chip peripheral module, and IRQ and PINT interrupts.

Bit	Bit Name	Initial Value	R/W	Description
15 to 0	IPR15 to IPR0	All 0	R/W	These bits set the priority level for each interrupt source in 4-bit units. For details, see table 6.2, Interrupt Sources and IPRA to IPRH.

Table 6.2 Interrupt Sources and IPRA to IPRH

Register	Bits 15 to 12	Bits 11 to 8	Bits 7 to 4	Bits 3 to 0
IPRA	TMU0	TMU1	TMU2	RTC
IPRB	WDT	REF	Reserved*	Reserved*
IPRC	IRQ3	IRQ2	IRQ1	IRQ0
IPRD	PINT0 to PINT7	PINT8 to PINT15	IRQ5	IRQ4
IPRE	DMAC	SCIF0	SCIF2	ADC
IPRF	Reserved*	Reserved*	USB	Reserved*
IPRG	TPU0	TPU1	Reserved*	Reserved*
IPRH	TPU2	TPU3	Reserved*	Reserved*

Note: * Always read as 0. The write value should always be 0.

As shown in table 6.2, on-chip peripheral module, or IRQ or PINT interrupts are assigned to four 4-bit groups in each register. These 4-bit groups (bits 15 to 12, bits 11 to 8, bits 7 to 4, and bits 3 to 0) are set with values from H'0 (0000) to H'F (1111). Setting H'0 means priority level 0 (masking is requested); H'F means priority level 15 (the highest level).

6.3.2 Interrupt Control Register 0 (ICR0)

ICR0 is a register that sets the input signal detection mode of external interrupt input pin NMI, and indicates the input signal level at the NMI pin.

Bit	Bit Name	Initial Value	R/W	Description
15	NMIL	0/1*	R	NMI Input Level Sets the level of the signal input at the NMI pin. This bit can be read from to determine the NMI pin level. This bit cannot be modified. 0: NMI input level is low 1: NMI input level is high
14 to 9	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
8	NMIE	0	R/W	NMI Edge Select Selects whether the falling or rising edge of the interrupt request signal at the NMI pin is detected. 0: Interrupt request is detected on falling edge of NMI input 1: Interrupt request is detected on rising edge of NMI input
7 to 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Note: * When NMI input is high, 0 when NMI input is low.

6.3.3 Interrupt Control Register 1 (ICR1)

ICR1 is a 16-bit register that specifies the detection mode for external interrupt input pins IRQ0 to IRQ5 individually: rising edge, falling edge, high level, or low level.

Bit	Bit Name	Initial Value	R/W	Description
15	MAI	0	R/W	Mask All Interrupts When set to 1, masks all interrupt requests when a low level is being input to the NMI pin. Masks NMI interrupts in standby mode. 0: All interrupt requests are not masked when a low level is being input to the NMI pin 1: All interrupt requests are masked when a low level is being input to the NMI pin
14	IRQLVL	1	R/W	Interrupt Request Level Detect Selects whether the IRQ3 to IRQ0 pins are enabled or disabled to be used as four independent interrupt pins. This bit does not affect the IRQ4 and IRQ5 pins. 0: Used as four independent interrupt request pins IRQ3 to IRQ0 1: Used as encoded 15-level interrupt pins as $\overline{\text{IRL3}}$ to $\overline{\text{IRL0}}$
13	BLMSK	0	R/W	BL Bit Mask Specifies whether NMI interrupts are masked when the BL bit of the SR register is 1. 0: NMI interrupts are masked when the BL bit is 1 1: NMI interrupts are accepted regardless of the BL bit setting
12	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
11 to 0	IRQ51S to IRQ00S	All 0	R/W	IRQn Sense Select Select whether the interrupt signals to the IRQ5 to IRQ0 pins are detected at the falling edge, at the rising edge, at low level, or at high level.

Bit 2n+1	Bit 2n	
IRQn1S	IRQn0S	
0	0	An interrupt request is detected at IRQn input falling edge
0	1	An interrupt request is detected at IRQn input rising edge
1	0	An interrupt request is detected at IRQn input low level
1	1	An interrupt request is detected at IRQn input high level

[Legend] n = 0 to 5

6.3.4 Interrupt Control Register 2 (ICR2)

ICR2 is a 16-bit register that specifies the detection mode for external interrupt input pins PINT15 to PINT0.

Bit	Bit Name	Initial Value	R/W	Description
15 to 0	PINT15S to PINT0S	All 0	R/W	PINT15 to PINT0 Sense Select Select whether interrupt request signals to PINT15 to PINT0 are detected at low levels or high levels. PINTnS 0: Interrupt requests are detected at low level input to the PINT pins 1: Interrupt requests are detected at high level input to the PINT pins [Legend] n = 0 to 15

6.3.5 PINT Interrupt Enable Register (PINTER)

PINTER is a 16-bit register that enables interrupt requests input to external interrupt input pins PINT0 to PINT15.

When all or some of these pins, PINT0 to PINT15 are not used as an interrupt input, a bit corresponding to a pin unused as an interrupt request should be cleared to 0.

Bit	Bit Name	Initial Value	R/W	Description
15 to 0	PINT15E to PINT0E	All 0	R/W	PINT15 to PINT0 Interrupt Enable Select whether the interrupt requests input to the PINT15 to PINT0 pins is enabled. PINTnE 0: Disables PINT input interrupt requests 1: Enables PINT input interrupt requests [Legend] n = 0 to 15

6.3.6 Interrupt Request Register 0 (IRR0)

IRR0 is an 8-bit register that indicates interrupt requests from external input pins IRQ0 to IRQ5 and PINT0 to PINT15.

Bit	Bit Name	Initial Value	R/W	Description
7	PINT0R	0	R	PINT0 to PINT7 Interrupt Request Indicates whether interrupt requests are input to PINT0 to PINT7 pins. 0: Interrupt requests are not input to PINT0 to PINT7 pins 1: Interrupt requests are input to PINT0 to PINT7 pins
6	PINT1R	0	R	PINT8 to PINT15 Interrupt Request Indicates whether interrupt requests are input to PINT8 to PINT15 pins. 0: Interrupt requests are not input to PINT8 to PINT15 pins 1: Interrupt requests are input to PINT8 to PINT15 pins
5 to 0	IRQ5R to IRQ0R	All 0	R/W	IRQn Interrupt Request Indicates whether there is interrupt request input to the IRQn pin. When edge-detection mode is set for IRQn, an interrupt request is cleared by writing 0 to the IRQnR bit after reading IRQnR = 1. When level-detection mode is set for IRQn, these bits indicate whether an interrupt request is input. The interrupt request is set/cleared by only 1/0 input to the IRQn pin. IRQnR 0: No interrupt request input to IRQn pin 1: Interrupt request input to IRQn pin [Legend] n = 0 to 5

6.3.7 Interrupt Request Register 1 (IRR1)

IRR1 is an 8-bit register that indicates whether DMAC or SCIF0 interrupt requests are generated.

Bit	Bit Name	Initial Value	R/W	Description
7	TXI0R	0	R	TXI0 Interrupt Request Indicates whether a TXI0 (SCIF0) interrupt request is generated. 0: A TXI0 interrupt request is not generated 1: A TXI0 interrupt request is generated
6	—	0	R	Reserved This bit is always read as 0.
5	RXI0R	0	R	RXI0 Interrupt Request Indicates whether an RXI0 (SCIF0) interrupt request is generated. 0: An RXI0 interrupt request is not generated 1: An RXI0 interrupt request is generated
4	ERI0R	0	R	ERI0 Interrupt Request Indicates whether an ERI0 (SCIF0) interrupt request is generated. 0: An ERI0 interrupt request is not generated 1: An ERI0 interrupt request is generated
3	DEI3R	0	R	DEI3 Interrupt Request Indicates whether a DEI3 (DMAC) interrupt request is generated. 0: A DEI3 interrupt request is not generated 1: A DEI3 interrupt request is generated
2	DEI2R	0	R	DEI2 Interrupt Request Indicates whether a DEI2 (DMAC) interrupt request is generated. 0: A DEI2 interrupt request is not generated 1: A DEI2 interrupt request is generated
1	DEI1R	0	R	DEI1 Interrupt Request Indicates whether a DEI1 (DMAC) interrupt request is generated. 0: A DEI1 interrupt request is not generated 1: A DEI1 interrupt request is generated

Bit	Bit Name	Initial Value	R/W	Description
0	DEI0R	0	R	DEI0 Interrupt Request Indicates whether a DEI0 (DMAC) interrupt request is generated. 0: A DEI0 interrupt request is not generated 1: A DEI0 interrupt request is generated

6.3.8 Interrupt Request Register 2 (IRR2)

IRR2 is an 8-bit register that indicates whether SCIF2 or ADC interrupt requests are generated.

Bit	Bit Name	Initial Value	R/W	Description
7 to 5	—	All 0	R	Reserved These bits are always read as 0.
4	ADIR	0	R	ADI Interrupt Request Indicates whether an ADI (ADC) interrupt request is generated. 0: An ADI interrupt request is not generated 1: An ADI interrupt request is generated
3	TXI2R	0	R	TXI2 Interrupt Request Indicates whether a TXI2 (SCIF2) interrupt request is generated. 0: A TXI2 interrupt request is not generated 1: A TXI2 interrupt request is generated
2	—	0	R	Reserved This bit is always read as 0.
1	RXI2R	0	R	RXI2 Interrupt Request Indicates whether an RXI2 (SCIF2) interrupt request is generated. 0: An RXI2 interrupt request is not generated 1: An RXI2 interrupt request is generated
0	ERI2R	0	R	ERI2 Interrupt Request Indicates whether an ERI2 (SCIF2) interrupt request is generated. 0: An ERI2 interrupt request is not generated 1: An ERI2 interrupt request is generated

6.4 Interrupt Sources

There are five types of interrupt sources: NMI, IRQ, IRL, PINT, and on-chip peripheral modules. Each interrupt has a priority level (0 to 16), with 1 the lowest and 16 the highest. Priority level 0 masks an interrupt, so the interrupt request is ignored.

6.4.1 NMI Interrupt

The NMI interrupt has the highest priority level of 16. When the BLMSK bit in the interrupt control register 1 (ICR1) is 1 or the BL bit in the status register (SR) is 0, NMI interrupt is accepted. NMI interrupt is edge-detected. In sleep or standby mode, the interrupt is accepted regardless of the BL setting. The NMI edge select bit (NMIE) in the interrupt control register 0 (ICR0) is used to select either rising or falling edge detection.

When using edge-input detection for NMI interrupt, a pulse width of at least two Pϕ cycles (peripheral clock) is necessary. NMI interrupt exception handling does not affect the interrupt mask level bits (I3 to I0) in the status register (SR). When the MAI bit in ICR1 is 1, NMI interrupt is not accepted.

It is possible to wake the chip up from sleep mode or standby mode with an NMI interrupt.

6.4.2 IRQ Interrupts

IRQ interrupts are input by level or edge from pins IRQ0 to IRQ5. The priority level can be set by interrupt priority registers C and D (IPRC and IPRD) in a range from 0 to 15.

When using edge-sensing for IRQ interrupts, clear the interrupt source by having software read 1 from the corresponding bit in IRR0, then write 0 to the bit.

When ICR1 is rewritten, IRQ interrupts may be mistakenly detected, depending on the IRQ pin states. To prevent this, rewrite the register while interrupts are masked, then release the mask after clearing the illegal interrupt by writing 0 to interrupt request register 0 (IRR0).

Edge input interrupt detection requires input of a pulse width of more than two cycles on a P clock basis.

When using level-sensing for IRQ interrupts, the pin levels must be retained until the CPU samples the pins. Therefore, the interrupt source must be cleared by the interrupt handler.

The interrupt mask bits (I3 to I0) in the status register (SR) are not affected by IRQ interrupt handling. IRQ interrupts can wake the chip up from the standby state when the relevant interrupt level is higher than I3 to I0 in SR (but only when the RTC is used, the clock for the RTC is used to wake the chip up from the standby state).

6.4.3 IRL Interrupts

IRL interrupts are input by level at pins $\overline{IRL3}$ to $\overline{IRL0}$. The priority level is the higher of those indicated by pins $\overline{IRL3}$ to $\overline{IRL0}$. An $\overline{IRL3}$ to $\overline{IRL0}$ value of 0 (0000) indicates the highest-level interrupt request (interrupt priority level 15). A value of 15 (1111) indicates no interrupt request (interrupt priority level 0). Figure 6.2 shows an examples of an IRL interrupt connection. Table 6.3 shows $\overline{IRL}$ pin and interrupt levels.

A noise-cancellation feature is built in, and the IRL interrupt is not detected unless the levels sampled at every peripheral clock remain unchanged for two consecutive cycles, so that no transient level on the $\overline{IRL}$ pin change is detected. In standby mode, as the peripheral clock is stopped, noise cancellation is performed using the clock for the RTC instead. Therefore when the RTC is not used, recovery from standby mode by means of IRL interrupts cannot be performed in standby mode.

The priority level of the IRL interrupt must not be lowered unless the interrupt is accepted and the interrupt processing starts. However, the priority level can be changed to a higher one.

The interrupt mask bits (I3 to I0) in the status register (SR) are not affected by $\overline{IRL}$ interrupt processing.

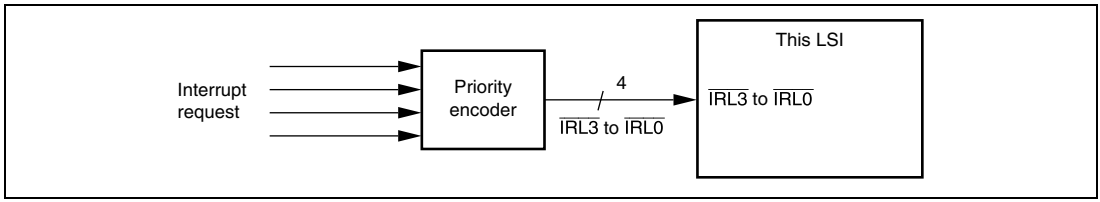


Figure 6.2 Example of IRL Interrupt Connection

Table 6.3 $\overline{IRL3}$ to $\overline{IRL0}$ Pins and Interrupt Levels

$\overline{IRL3}$	$\overline{IRL2}$	$\overline{IRL1}$	$\overline{IRL0}$	Interrupt Priority Level	Interrupt Request
0	0	0	0	15	Level 15 interrupt request
0	0	0	1	14	Level 14 interrupt request
0	0	1	0	13	Level 13 interrupt request
0	0	1	1	12	Level 12 interrupt request
0	1	0	0	11	Level 11 interrupt request
0	1	0	1	10	Level 10 interrupt request
0	1	1	0	9	Level 9 interrupt request
0	1	1	1	8	Level 8 interrupt request
1	0	0	0	7	Level 7 interrupt request
1	0	0	1	6	Level 6 interrupt request
1	0	1	0	5	Level 5 interrupt request
1	0	1	1	4	Level 4 interrupt request
1	1	0	0	3	Level 3 interrupt request
1	1	0	1	2	Level 2 interrupt request
1	1	1	0	1	Level 1 interrupt request
1	1	1	1	0	No interrupt request

6.4.4 PINT Interrupt

PINT interrupts are input from pins PINT0 to PINT15 with a level. The priority level can be set by the interrupt priority level setting register D (IPRD) in a range from levels 0 to 15, in the unit of PINT0 to PINT7 or PINT8 to PINT15. The PINT interrupt level should be held until the interrupt is accepted and interrupt handling is started.

The interrupt mask bits (I3 to I0) in the status register (SR) are not affected by PINT interrupt processing. PINT interrupts can wake the chip up from the standby state when the relevant interrupt level is higher than I3 to I0 in SR (but only when the RTC is used, the clock for the RTC is used to wake the chip up from the standby state).

6.4.5 On-Chip Peripheral Module Interrupts

On-chip peripheral module interrupts are generated by the following 10 modules:

- Direct memory access controller (DMAC)
- Serial communication interfaces (SCIF0 and SCIF2)
- A/D converter (ADC)
- USB interface (USB)

- Timer unit (TMU)
- 16-bit timer pulse unit (TPU)
- Watchdog timer (WDT)
- Bus state controller (BSC)
- Hitachi user-debugging interface (H-UDI)
- Realtime clock (RTC)

Not every interrupt source is assigned a different interrupt vector. Sources are reflected in the interrupt event registers (INTEVT and INTEVT2). It is easy to identify sources by using the value of INTEVT or INTEVT2 as a branch offset.

A priority level (from 0 to 15) can be set for each module except H-UDI by writing to the interrupt priority level setting registers A to H (IPRA to IPRH). The priority level of the H-UDI interrupt is 15 (fixed).

The interrupt mask bits (I3 to I0) in the status register are not affected by on-chip peripheral module interrupt handling.

6.4.6 Interrupt Exception Handling and Priority

There are five types of interrupt sources: NMI, IRQ, IRL, PINT, and on-chip peripheral modules. The priority of each interrupt source is set within priority levels 0 to 16; level 16 is the highest and level 1 is the lowest. When the priority is set to level 0, that interrupt is masked and the interrupt request is ignored.

Tables 6.4 and 6.5 list the codes for the interrupt source and the interrupt event registers (INTEVT and INTEVT2) and the order of interrupt priority.

Each interrupt source is assigned a unique code by INTEVT and INTEVT2. The start address of the interrupt service routine is common for each interrupt source. This is why, for instance, the value of INTEVT2 is used as an offset at the start of the interrupt service routine and branched to in order to identify the interrupt source.

IRQ and PINT interrupts, and on-chip peripheral module interrupt priorities can be set freely between 0 and 15 for each module by setting the interrupt priority level setting registers. A reset assigns priority level 0 to IRQ, PINT, and on-chip peripheral module interrupts.

If the same priority level is assigned to two or more interrupt sources and interrupts from those sources occur simultaneously, their priority order is the default priority order indicated at the right in tables 6.4 and 6.5.

Table 6.4 Interrupt Exception Handling Sources and Priority (IRQ Mode)

Interrupt Source		Interrupt Code*[1]	Interrupt Priority (Initial Value)	IPR (Bit Numbers)	Priority within IPR Setting Unit	Default Priority
NMI		H'1C0*[2]	16	—	—	High
H-UDI		H'5E0*[2]	15	—	—	
IRQ	IRQ0	H'600*[3]	0 to 15 (0)	IPRC (3 to 0)	—	
	IRQ1	H'620*[3]	0 to 15 (0)	IPRC (7 to 4)	—	
	IRQ2	H'640*[3]	0 to 15 (0)	IPRC (11 to 8)	—	
	IRQ3	H'660*[3]	0 to 15 (0)	IPRC (15 to 12)	—	
	IRQ4	H'680*[3]	0 to 15 (0)	IPRD (3 to 0)	—	
	IRQ5	H'6A0*[3]	0 to 15 (0)	IPRD (7 to 4)	—	
PINT	PINT0 to PINT7	H'700*[3]	0 to 15 (0)	IPRD (15 to 12)	—	
	PINT8 to PINT15	H'720*[3]	0 to 15 (0)	IPRD (11 to 8)	—	
DMAC	DEI0	H'800*[3]	0 to 15 (0)	IPRE (15 to 12)	High	
	DEI1	H'820*[3]				
	DEI2	H'840*[3]				
	DEI3	H'860*[3]			Low	
SCIF0	ERI0	H'880*[3]	0 to 15 (0)	IPRE (11 to 8)	High	
	RXI0	H'8A0*[3]				
	TXI0	H'8E0*[3]			Low	
SCIF2	ERI2	H'900*[3]	0 to 15 (0)	IPRE (7 to 4)	High	
	RXI2	H'920*[3]				
	TXI2	H'960*[3]			Low	
ADC	ADI	H'980*[3]	0 to 15 (0)	IPRE (3 to 0)	—	
USB	USI0	H'A20*[3]	0 to 15 (0)	IPRF (7 to 4)	High	
	USI1	H'A40*[3]			Low	
TPU0	TPI0	H'C00*[3]	0 to 15 (0)	IPRG (15 to 12)	—	
TPU1	TPI1	H'C20*[3]	0 to 15 (0)	IPRG (11 to 8)	—	
TPU2	TPI2	H'C80*[3]	0 to 15 (0)	IPRH (15 to 12)	—	
TPU3	TPI3	H'CA0*[3]	0 to 15 (0)	IPRH (11 to 8)	—	Low

Interrupt Source		Interrupt Code*[1]	Interrupt Priority (Initial Value)	IPR (Bit Numbers)	Priority within IPR Setting Unit	Default Priority
TMU0	TUNI0	H'400*[2]	0 to 15 (0)	IPRA (15 to 12)	—	High
TMU1	TUNI1	H'420*[2]	0 to 15 (0)	IPRA (11 to 8)	—	
TMU2	TUNI2	H'440*[2]	0 to 15 (0)	IPRA (8 to 4)	High	
	TICPI2	H'460*[2]			Low	
RTC	ATI	H'480*[2]	0 to 15 (0)	IPRA (3 to 0)	High	
	PRI	H'4A0*[2]				
	CUI	H'4C0*[2]			Low	
WDT	ITI	H'560*[2]	0 to 15 (0)	IPRB (15 to 12)	—	
REF	RCMI	H'580*[2]	0 to 15 (0)	IPRB (11 to 8)	—	Low

Notes: 1. The INTEVT2 code.

2. The same code as INTEVT2 is set in INTEVT.

3. The code indicating an interrupt level (H'200 to H'3C0 shown in table 6.6) is set in INTEVT.

Table 6.5 Interrupt Exception Handling Sources and Priority (IRL Mode)

Interrupt Source		Interrupt Code*[1]	Interrupt Priority (Initial Value)	IPR (Bit Numbers)	Priority within IPR Setting Unit	Default Priority
NMI		H'1C0*[2]	16	—	—	High
H-UDI		H'5E0*[2]	15	—	—	
IRL	$\overline{IRL}$(3:0) = 0000	H'200*[3]	15	—	—	
	$\overline{IRL}$(3:0) = 0001	H'220*[3]	14	—	—	
	$\overline{IRL}$(3:0) = 0010	H'240*[3]	13	—	—	
	$\overline{IRL}$(3:0) = 0011	H'260*[3]	12	—	—	
	$\overline{IRL}$(3:0) = 0100	H'280*[3]	11	—	—	
	$\overline{IRL}$(3:0) = 0101	H'2A0*[3]	10	—	—	
	$\overline{IRL}$(3:0) = 0110	H'2C0*[3]	9	—	—	
	$\overline{IRL}$(3:0) = 0111	H'2E0*[3]	8	—	—	
	$\overline{IRL}$(3:0) = 1000	H'300*[3]	7	—	—	
	$\overline{IRL}$(3:0) = 1001	H'320*[3]	6	—	—	
	$\overline{IRL}$(3:0) = 1010	H'340*[3]	5	—	—	
	$\overline{IRL}$(3:0) = 1011	H'360*[3]	4	—	—	
	$\overline{IRL}$(3:0) = 1100	H'380*[3]	3	—	—	
	$\overline{IRL}$(3:0) = 1101	H'3A0*[3]	2	—	—	
	$\overline{IRL}$(3:0) = 1110	H'3C0*[3]	1	—	—	
IRQ	IRQ4	H'680*[3]	0 to 15 (0)	IPRD (3 to 0)	—	
	IRQ5	H'6A0*[3]	0 to 15 (0)	IPRD (7 to 4)	—	
PINT	PINT0 to PINT 7	H'700*[3]	0 to 15 (0)	IPRD (15 to 12)	—	
	PINT8 to PINT 15	H'720*[3]	0 to 15 (0)	IPRD (11 to 8)	—	
DMAC	DEI0	H'800*[3]	0 to 15 (0)	IPRE (15 to 12)	High	
	DEI1	H'820*[3]				
	DEI2	H'840*[3]				
	DEI3	H'860*[3]			Low	
SCIF0	ERI0	H'880*[3]	0 to 15 (0)	IPRE (11 to 8)	High	
	RXI0	H'8A0*[3]				
	TXI0	H'8E0*[3]			Low	Low

Interrupt Source		Interrupt Code*[1]	Interrupt Priority (Initial Value)	IPR (Bit Numbers)	Priority within IPR Setting Unit	Default Priority
SCIF2	ERI2	H'900*[3]	0 to 15 (0)	IPRE (7 to 4)	High	High
	RXI2	H'920*[3]			↕	
	TXI2	H'960*[3]			Low	
ADC	ADI	H'980*[3]	0 to 15 (0)	IPRE (3 to 0)	—	
USB	USI0	H'A20*[3]	0 to 15 (0)	IPRF (7 to 4)	High	
	USI1	H'A40*[3]			Low	
TPU0	TPI0	H'C00*[3]	0 to 15 (0)	IPRG (15 to 12)	—	
TPU1	TPI1	H'C20*[3]	0 to 15 (0)	IPRG (11 to 8)	—	
TPU2	TPI2	H'C80*[3]	0 to 15 (0)	IPRH (15 to 12)	—	
TPU3	TPI3	H'CA0*[3]	0 to 15 (0)	IPRH (11 to 8)	—	
TMU0	TUNI0	H'400*[2]	0 to 15 (0)	IPRA (15 to 12)	—	
TMU1	TUNI1	H'420*[2]	0 to 15 (0)	IPRA (11 to 8)	—	
TMU2	TUNI2	H'440*[2]	0 to 15 (0)	IPRA (7 to 4)	High	
	TICPI2	H'460*[2]			Low	
RTC	ATI	H'480*[2]	0 to 15 (0)	IPRA (3 to 0)	High	
	PRI	H'4A0*[2]			↕	
	CUI	H'4C0*[2]			Low	
WDT	ITI	H'560*[2]	0 to 15 (0)	IPRB (15 to 12)	—	
REF	RCMI	H'580*[2]	0 to 15 (0)	IPRB (11 to 8)	—	Low

Notes: 1. The INTEVT2 code.
2. The same code as INTEVT2 is set in INTEVT.
3. The code indicating an interrupt level (H'200 to H'3C0 shown in table 6.6) is set in INTEVT.

Table 6.6 Interrupt Level and INTEVT Code

Interrupt level	INTEVT Code
15	H'200
14	H'220
13	H'240
12	H'260
11	H'280
10	H'2A0
9	H'2C0
8	H'2E0
7	H'300
6	H'320
5	H'340
4	H'360
3	H'380
2	H'3A0
1	H'3C0

6.5 Operation

6.5.1 Interrupt Sequence

The sequence of interrupt operations is described below. Figure 6.3 is a flowchart of the operations.

1. The interrupt request sources send interrupt request signals to the interrupt controller.
2. The interrupt controller selects the highest-priority interrupt from the interrupt requests sent, following the priority levels set in the interrupt priority level setting registers A to H (IPRA to IPRH). Lower priority interrupts are held pending. If two of these interrupts have the same priority level or if multiple interrupts occur within a single module, the interrupt with the highest priority is selected, according to tables 6.4 and 6.5, Interrupt Exception Handling Sources and Priority.
3. The priority level of the interrupt selected by the interrupt controller is compared with the interrupt mask bits (I3 to I0) in the status register (SR) of the CPU. If the request priority level is higher than the level in bits I3 to I0, the interrupt controller accepts the interrupt and sends an interrupt request signal to the CPU.

4. Detection timing: The INTC operates, and notifies the CPU of interrupt requests, in synchronization with the peripheral clock (Pϕ). The CPU receives an interrupt at a break in instructions.
5. The interrupt source code is set in the interrupt event registers (INTEVT and INTEVT2).
6. The status register (SR) and program counter (PC) are saved to SSR and SPC, respectively.
7. The block bit (BL), mode bit (MD), and register bank bit (RB) in SR are set to 1.
8. The CPU jumps to the start address of the interrupt handler (the sum of the value set in the vector base register (VBR) and H'00000600). This jump is not a delayed branch. The interrupt handler may branch with INTEVT or INTEVT2 value as its offset in order to identify the interrupt source. This enables it to branch to the handling routine for the individual interrupt source.

Notes: 1. The interrupt mask bits (I3 to I0) in the status register (SR) are not changed by acceptance of an interrupt in this LSI.
2. The interrupt source flag should be cleared in the interrupt handler. To ensure that an interrupt request that should have been cleared is not inadvertently accepted again, read the interrupt source flag after it has been cleared, and then execute an RTE instruction.

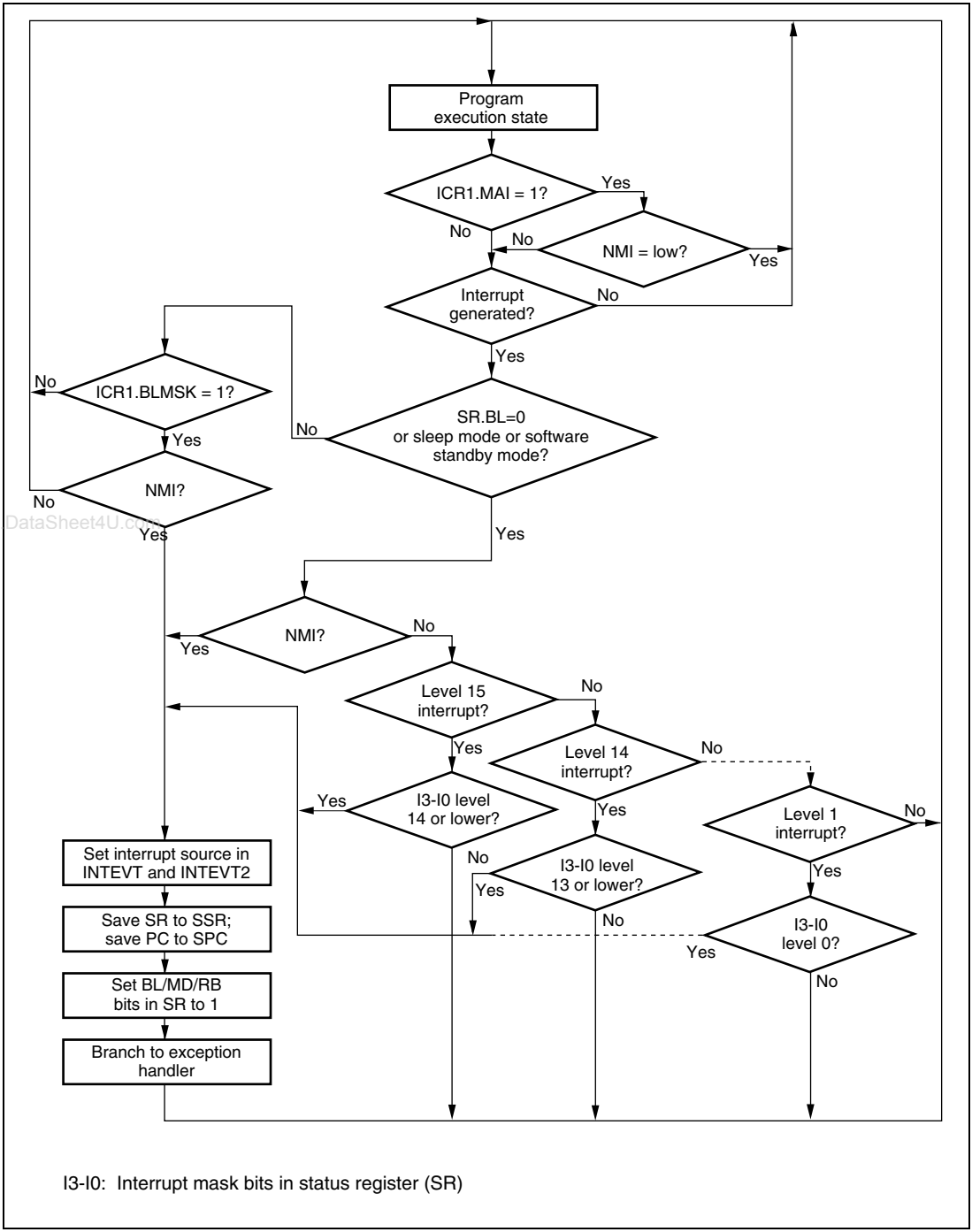


Figure 6.3 Interrupt Operation Flowchart

6.5.2 Multiple Interrupts

When handling multiple interrupts, an interrupt handler should include the following procedures:

1. Branch to a specific interrupt handler corresponding to a code set in INTEVT or INTEVT2. The code in INTEVT or INTEVT2 can be used as an offset for branching to the specific handler.
2. Clear the interrupt source in each specific handler.
3. Save SSR and SPC to memory.
4. Clear the BL bit in SR, and set the accepted interrupt level in the interrupt mask bits in SR.
5. Handle the interrupt.
6. Execute the RTE instruction.

When these procedures are followed in order, an interrupt of higher priority than the one being handled can be accepted after clearing BL in step 4. Figure 6.3 shows a sample interrupt operation flowchart.

6.6 Usage Note

The interrupt accept timing in this LSI is not acknowledged externally. Thus, keep the following note in mind when designing the system.

- Level interrupt

  The level interrupt request should be held until the CPU accepts it. The level interrupt request needs to be cleared (released) within the specific interrupt handler. If the level interrupt request is not held, the operation may branch to the interrupt handling routine when the value in INTEVT/2 becomes H′000.

  When the standby state is cancelled, if the level interrupt request is not held, the operation will go back to the standby state again in the middle of WDT counting. When canceling the standby state again in such a condition by asserting the level interrupt request, the settling time for the PLL or crystal oscillator is not secured enough and the operation may not recover from the standby state correctly.
- Interrupt flag update

  When an interrupt is acceptable and the generation of an interrupt request is enabled, updating or clearing the interrupt flag may branch the operation to the interrupt handling routine when the value in INTEVT2 becomes H′000.

Section 7 Bus State Controller (BSC)

7.1 Overview

The bus state controller (BSC) outputs control signals for various types of memory that is connected to the external address space and external devices. BSC functions enable this LSI to connect directly with SRAM, SDRAM, and other memory storage devices, and external devices.

7.1.1 Features

The BSC has the following features:

- Physical address space is divided into eight areas
  - A maximum 32 or 64 Mbytes for each of the eight areas, CS0, CS2 to CS4, CS5A, CS5B, CS6A and CS6B, totally 384 Mbytes.
  - Can specify the normal space interface, byte-selection SRAM interface, burst ROM, address/data multiplex I/O (MPX), or SDRAM for each address space.
  - Can select the data bus width (8, 16, or 32 bits) for each address space.
  - Controls the insertion of the wait state for each address space.
  - Controls the insertion of the wait state for each read access and write access.
  - Can set the independent idling cycle in the continuous access for five cases: read-write (in same space/different space), read-read (in same space/different space), the first cycle is a write access.
- Normal space interface
  - Supports the interface that can directly connect to the SRAM.
- Burst ROM interface
  - High-speed access to the ROM, such as flash memory, that has the page mode function.
- Address/data multiplex I/O (MPX) interface
  - Can directly connect to a peripheral LSI that needs an address/data multiplexing.
- SDRAM interface
  - Can set the SDRAM up to 2 areas.
  - Multiplex output for row address/column address.
  - Efficient access by single read/single write.
  - High-speed access by the bank-active mode.
  - Supports an auto-refresh and self-refresh.

- Bus arbitration
  - — Shares all of the resources with other CPU and outputs the bus enable after receiving the bus request from external devices.

7.1.2 Block Diagram

BSC functional block diagram is shown in figure 7.1.

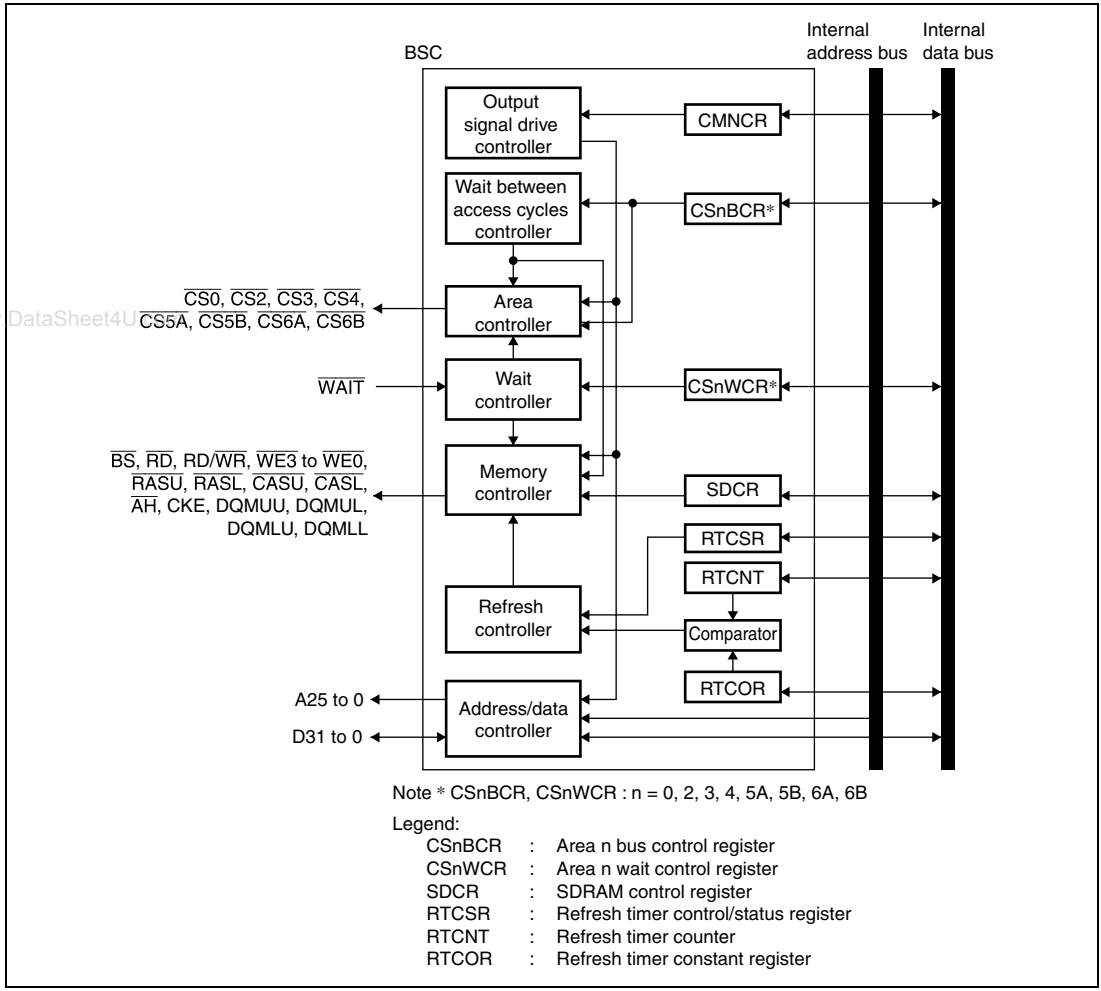


Figure 7.1 BSC Functional Block Diagram

7.2 Pin Configuration

Table 7.1 Pin Configuration

Name	I/O	Function
A25 to A0	O	Address bus
D31 to D0	I/O	Data bus
$\overline{BS}$	O	Bus cycle start Asserted when a normal space, byte-selection SRAM, burst ROM, or address/data multiplex I/O is accessed. Asserted by the same timing as $\overline{CAS}$ in SDRAM access.
$\overline{CS0}$, $\overline{CS2}$ to $\overline{CS4}$, $\overline{CS5A}$, $\overline{CS5B}$, $\overline{CS6A}$, $\overline{CS6B}$	O	Chip select
RD/$\overline{WR}$	O	Read/write Connects to $\overline{WE}$ pins when SDRAM or byte-selection SRAM is connected.
$\overline{RD}$	O	Read
$\overline{WE3}$, DQMUU	O	Indicates that D31 to D24 are being written to when a normal space is set. Selects D31 to D24 when a byte-selection SRAM space is set. Selects D31 to D24 when an SDRAM space is set.
$\overline{WE2}$, DQMUL	O	Indicates that D23 to D16 are being written to when a normal space is set. Selects D23 to D16 when a byte-selection SRAM space is set. Selects D23 to D16 when an SDRAM space is set.
$\overline{WE1}$, DQMLU	O	Indicates that D15 to D8 are being written to when a normal space and address/data multiplex I/O space are set. Selects D15 to D8 when a byte-selection SRAM space is set. Selects D15 to D8 when an SDRAM space is set.
$\overline{WE0}$, DQMLL	O	Indicates that D7 to D0 are being written to when a normal space and address/data multiplex I/O space are set. Selects D7 to D0 when a byte-selection SRAM space is set. Selects D7 to D0 when an SDRAM space is set.
$\overline{RASU}$ $\overline{RASL}$	O	Connects to $\overline{RAS}$ pin when SDRAM is connected.
$\overline{CASU}$ $\overline{CASL}$	O	Connects to $\overline{CAS}$ pin when SDRAM is connected.

Name	I/O	Function
CKE	O	Connects to CKE pin when SDRAM is connected.
$\overline{AH}$	O	Holds the address in address/data multiplex I/O mode.
$\overline{WAIT}$	I	External wait input
$\overline{BREQ}$	I	Bus request input
$\overline{BACK}$	O	Bus acknowledge output
MD3, MD4	I	Area 0 bus width (8/16/32 bits)
MD5	I	Specifies endian 0: Big endian 1: Little endian

7.3 Area Overview

In the architecture of this LSI, both logical spaces and physical spaces have 32-bit address spaces. The cache access method is shown by the upper 3 bits. For details see section 4, Cache. The remaining 29 bits are used for division of the space into eight areas. The BSC performs control for this 29-bit space.

As listed in table 7.2, this LSI can be connected directly to eight areas of memory, and it outputs chip select signals ($\overline{CS0}$, $\overline{CS2}$ to $\overline{CS4}$, $\overline{CS5A}$, $\overline{CS5B}$, $\overline{CS6A}$, and $\overline{CS6B}$) for each of them. $\overline{CS0}$ is asserted during area 0 access; $\overline{CS5B}$ is asserted during area 5B access. When an SDRAM is connected to area 2 or area 3, $\overline{RASU}$, $\overline{RASL}$, $\overline{CASU}$, $\overline{CASL}$, DQMUU, DQMUL, DQMLU, and DQMLL are asserted.

7.3.1 Address Map

The external address space has a capacity of 384 Mbytes and is used by dividing 8 partial spaces. The kind of memory to be connected and the data bus width are specified in each partial space. The address map for the external address space is listed below.

Table 7.2 Physical Address Space Map

Area	Memory to be Connected	Physical Address		Capacity	Access Size
Area 0	Normal memory*[1], Burst ROM	H′00000000	to H′03FFFFFF	64 Mbytes	8, 16, 32*[2]
		H′00000000 +H′20000000×n	to H′03FFFFFF +H′20000000×n	Shadow	(n: 1 to 6)

Area	Memory to be Connected	Physical Address		Capacity	Access Size
Area 1	Internal I/O register*7	H′04000000	to H′07FFFFFF		
		H′04000000 +H′20000000×n	to H′07FFFFFF +H′20000000×n		(n:1 to 6)
Area 2	Normal memory*1, Synchronous DRAM	H′08000000	to H′0BFFFFFF	64 Mbytes	8, 16, 32*3, *5
		H′08000000 +H′20000000×n	to H′0BFFFFFF +H′20000000×n	Shadow	(n:1 to 6)
Area 3	Normal memory*1, Synchronous DRAM	H′0C000000	to H′0FFFFFFF	64 Mbytes	8, 16, 32*3, *5
		H′0C000000 +H′20000000×n	to H′0FFFFFFF +H′20000000×n	Shadow	(n: 1 to 6)
Area 4	Normal memory*1, Burst ROM, Byte-selection SRAM	H′10000000	to H′13FFFFFF	64 Mbytes	8, 16, 32*3
		H′10000000 +H′20000000×n	to H′13FFFFFF +H′20000000×n	Shadow	(n: 1 to 6)
Area 5A	Normal memory*1	H′14000000	to H′15FFFFFF	32 Mbytes	8, 16, 32*3
		H′14000000 +H′20000000×n	to H′15FFFFFF +H′20000000×n	Shadow	(n: 1 to 6)
Area 5B	Normal memory*1, Address/data multiplex I/O (MPX), Byte-selection SRAM	H′16000000	to H′17FFFFFF	32 Mbytes	8, 16*3, *4
		H′16000000 +H′20000000×n	to H′17FFFFFF +H′20000000×n	Shadow	(n: 1 to 6)
Area 6A	Normal memory*1	H′18000000	to H′19FFFFFF	32 Mbytes	8, 16*3
		H′18000000 +H′20000000×n	to H′19FFFFFF +H′20000000×n	Shadow	(n: 1 to 6)
Area 6B	Normal memory*1	H′1A000000	to H′1BFFFFFF	32 Mbytes	8, 16*3
		H′1A000000 +H′20000000×n	to H′1BFFFFFF +H′20000000×n	Shadow	(n: 1 to 6)
Area 7*6	Reserved area	H′1C000000 +H′20000000×n	to H′1FFFFFFF +H′20000000×n		(n: 0 to 7)

Notes: *1 Memory that has an interface such as SRAM or ROM.

*2 Memory bus width is specified by an external pin.

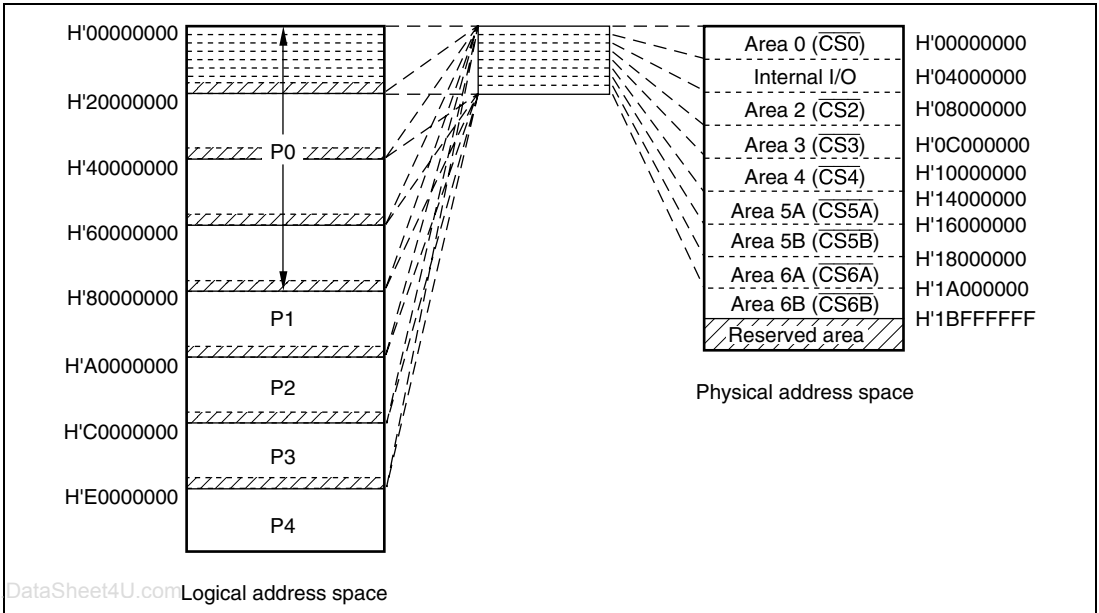
*3 Memory bus width is specified by a register.

*4 With the address/data multiplex I/O (MPX) interface, the bus width must be 16 bits.

*5 With the SDRAM, the bus width must be 16 bits or 32 bits.

*6 Do not access the reserved area. If the reserved area is accessed, the operation cannot be guaranteed.

*7 When the addresses of the on-chip module control registers (internal I/O registers) in area 1 are not translated by the MMU, set the top three bits of the logical addresses to 101 to allocate in the P2 space.



Note: For logical address spaces P0 and P3, when the memory management unit (MMU) is on, it can optionally generate a physical address for the logical address. This figure can be applied when MMU is off and when the MMU is on and each physical address for the logical address is equal except for higher three bits. When translating a logical address to a physical address, refer to table 7.2, Address Space Map.

Figure 7.2 Address Space

7.3.2 Memory Bus Width

The memory bus width in this LSI can be set for each area. In area 0, external pins can be used to select byte (8 bits), word (16 bits), or longword (32 bits) on power-on reset. The correspondence between the external pins (MD3, MD4) and memory size is listed in the table below.

Table 7.3 Correspondence between External Pins (MD3 and MD4) and Memory Size

MD4	MD3	Memory Size
0	0	Setting prohibited.
	1	8 bits
1	0	16 bits
	1	32 bits

For areas other than area 0, byte, word, and longword may be chosen for the bus width using CSnBCR that can be set in each area. The bus width that can be set differs according to a connected interface. For more details, see the CSn Bus Control Register.

When port A or B is used, set the bus width of all areas to 8-bit or 16-bit.

For details see section 7.4.2, CSn Space Bus Control Register (CSnBCR).

7.3.3 Shadow Space

Areas 0, 2 to 4, 5A, 5B, 6A, and 6B are decoded by physical addresses A28 to A26, which correspond to areas 000 to 110. Address bits 31 to 29 are ignored. This means that the range of area 0 addresses, for example, is H'00000000 to H'03FFFFFF, and its corresponding shadow space is the address space obtained by adding to it H'20000000 × n (n = 1 to 6) in areas P1 to P3.

The address range for area 7 is H'1C000000 to H'1FFFFFFF. The address space H'1C000000 + H'20000000 × n to H'1FFFFFFF + H'20000000 × n (n = 0 to 7) corresponding to the area 7 shadow space is reserved, so do not use it.

Area P4 (H'E0000000 to H'EFFFFFFF) is the I/O area where on-chip registers are allocated. This area has no shadow space.

7.4 Register Descriptions

The BSC has the following registers. Refer to section 24, List of Registers for the details of the addresses of these registers and the state of registers in each operating mode.

Do not access spaces other than CS0 until the termination of the setting the memory interface.

- Common control register (CMNCR)
- Bus control register for CS0 space (CS0BCR)
- Bus control register for CS2 space (CS2BCR)
- Bus control register for CS3 space (CS3BCR)
- Bus control register for CS4 space (CS4BCR)
- Bus control register for CS5A space (CS5ABCR)
- Bus control register for CS5B space (CS5BBCR)
- Bus control register for CS6A space (CS6ABCR)
- Bus control register for CS6B space (CS6BBCR)
- Wait control register for CS0 space (CS0WCR)
- Wait control register for CS2 space (CS2WCR)
- Wait control register for CS3 space (CS3WCR)
- Wait control register for CS4 space (CS4WCR)
- Wait control register for CS5A space (CS5AWCR)
- Wait control register for CS5B space (CS5BWCR)
- Wait control register for CS6A space (CS6AWCR)

- Wait control register for CS6B space (CS6BWCR)
- SDRAM control register (SDCR)
- Refresh timer control/status register (RTCSR)*1
- Refresh timer counter (RTCNT)*1
- Refresh time constant register (RTCOR)*1
- SDRAM mode register for CS2 space (SDMR2)*2
- SDRAM mode register for CS3 space (SDMR3)*2

Notes: *1 This register only accepts 32-bit writing to prevent incorrect writing. In this case, the upper 16 bits of the data must be H'A55A, otherwise writing cannot be performed. When reading, the upper 16 bits are read as H'0000.

*2 The contents of this register are stored in SDRAM. When this register space is accessed, the corresponding register in SDRAM is written to. For details, refer to section 7.8.10, Power-On Sequence.

7.4.1 Common Control Register (CMNCR)

CMNCR is a 32-bit register that controls the common items for each area. Do not access external memory other than area 0 until the CMNCR register initialization is complete.

Bit	Bit Name	Initial Value	R/W	Description
31 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7	DMAIW1	0	R/W	Wait states between access cycles when DMA single address transfer is performed. Specify the number of idle cycles to be inserted after an access to an external device with DACK when DMA single address transfer is performed. The method of inserting idle cycles depends on the contents of DMAIWA. 00: No idle cycle inserted 01: 1 idle cycle inserted 10: 2 idle cycles inserted 11: 4 idle cycled inserted
6	DMAIW0	0	R/W	

Bit	Bit Name	Initial Value	R/W	Description
5	DMAIWA	0	R/W	Method of inserting wait states between access cycles when DMA single address transfer is performed. Specifies the method of inserting the idle cycles specified by the DMAIW1 and DMAIW0 bits. Clearing this bit will make this LSI insert the idle cycles when another device, which includes this LSI, drives the data bus after an external device with DACK drove it. Setting this bit will make this LSI insert the idle cycles even when the continuous accesses to an external device with DACK are performed.
4	—	1	R	Reserved This bit is always read as 1. The write value should always be 1.
3	ENDIAN	0/1*	R	Endian Flag Samples the external pin for specifying endian on power-on reset (MD5). All address spaces are defined by this bit. This is a read-only bit. 0: The external pin for specifying endian (MD5) was low level on power-on reset. This LSI is being operated as big endian. 1: The external pin for specifying endian (MD5) was high level on power-on reset. This LSI is being operated as little endian.
2	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
1	HIZMEM	0	R/W	High-Z Memory Control Specifies the pin state in software standby mode for A25 to A0, $\overline{BS}$, $\overline{CS}$, RD/$\overline{WR}$, $\overline{WE}$, and $\overline{RD}$. 0: High impedance in software standby mode. 1: Driven in software standby mode
0	HIZCNT	0	R/W	High-Z Control Specifies the state in software standby mode and bus released for $\overline{RASU}$, $\overline{RASL}$, $\overline{CASU}$, and $\overline{CASL}$. 0: High impedance in software standby mode and bus released for $\overline{RASU}$, $\overline{RASL}$, $\overline{CASU}$, and $\overline{CASL}$. 1: Driven in standby mode and bus released for $\overline{RASU}$, $\overline{RASL}$, $\overline{CASU}$, and $\overline{CASL}$.

Note: * The external pin for specifying endian (MD5) is sampled on power-on reset. When big endian is specified, this bit is read as 0 and when little endian is specified, this bit is read as 1.

7.4.2 CSn Space Bus Control Register (CSnBCR) (n = 0, 2, 3, 4, 5A, 5B, 6A, 6B)

CSnBCR is a 32-bit readable/writable register that specifies the function of each area, the number of idle cycles between bus cycles, and the bus-width.

Do not access external memory other than area 0 until CSnBCR register initialization is completed.

Bit	Bit Name	Initial Value	R/W	Description
31, 30	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
29	IWW1	1	R/W	Idle Cycles between Write-read Cycles and Write-write Cycles
28	IWW0	1	R/W	These bits specify the number of idle cycles to be inserted after the access to a memory that is connected to the space. The target access cycles are the write-read cycle and write-write cycle. 00: No idle cycle inserted 01: 1 idle cycle inserted 10: 2 idle cycles inserted 11: 4 idle cycles inserted
27	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
26	IWRWD1	1	R/W	Idle Cycles for Another Space Read-write
25	IWRWD2	1	R/W	Specify the number of idle cycles to be inserted after the access to a memory that is connected to the space. The target access cycle is a read-write one in which continuous accesses switch between different spaces. 00: Setting prohibited 01: 2 idle cycles inserted 10: 3 idle cycles inserted 11: 5 idle cycles inserted

Bit	Bit Name	Initial Value	R/W	Description
24	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
23	IWRWS1	1	R/W	Idle Cycles for Read-write in the Same Space
22	IWRWS0	1	R/W	Specify the number of idle cycles to be inserted after the access to a memory that is connected to the space. The target cycle is a read-write cycle of which continuous accesses are for the same space. 00: Setting prohibited. 01: 2 idle cycles inserted 10: 3 idle cycles inserted 11: 5 idle cycles inserted
21	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
20	IWRRD1	1	R/W	Idle Cycles for Read-read in Another Space
19	IWRRD0	1	R/W	Specify the number of idle cycles to be inserted after the access to a memory that is connected to the space. The target cycle is a read-read cycle of which continuous accesses switch between different space. 00: 1 idle cycle inserted 01: 2 idle cycles inserted 10: 3 idle cycles inserted 11: 5 idle cycles inserted
18	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
17	IWRRS1	1	R/W	Idle Cycles for Read-read in the Same Space
16	IWRRS0	1	R/W	Specify the number of idle cycles to be inserted after the access to a memory that is connected to the space. The target cycle is a read-read cycle of which continuous accesses are for the same space. 00: No idle cycle inserted 01: 1 idle cycle inserted 10: 2 idle cycles inserted 11: 4 idle cycles inserted

Bit	Bit Name	Initial Value	R/W	Description
15	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
14	TYPE2	0	R/W	Memory Type
13	TYPE1	0	R/W	Specify the type of memory connected to a space.
12	TYPE0	0	R/W	000: Normal space 001: Burst ROM 010: Address/data multiplex I/O (MPX) 011: Byte-selection SRAM 100: SDRAM 101: Setting prohibited. 110: Setting prohibited. 111: Setting prohibited. Note: SDRAM can be specified only in area 2 and area 3. Burst ROM can be specified only in area 0 and area 4. Address/data multiplex I/O (MPX) can be specified only in area 5B. Byte-selection SRAM can be specified only in area 4 and area 5B.
11	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
10	BSZ1	1	R/W	Data Bus Size
9	BSZ0	1	R/W	Specify the data bus sizes of spaces. The data bus sizes of areas 2, 3, 4 and 5A are shown below. 00: Setting prohibited. 01: 8-bit size 10: 16-bit size 11: 32-bit size The data bus sizes of areas 5B, 6A, and 6B are shown below. 00: Setting prohibited. 01: 8-bit size 10: 16-bit size 11: Setting Prohibited

Bit	Bit Name	Initial Value	R/W	Description
8 to 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Notes: 1. When the CS5B space is specified as address/data multiplex I/O (MPX), specify the bus size to 16 bits.
2. The data bus size of the CS0 space is specified by an external input pin. The value of BSZ[1:0] bits in CS0BCR are invalid.
3. When both the CS2 and CS3 spaces are specified as the SDRAM space, specify the same bus size for the CS2 and CS3 spaces.
4. When the CS2 or CS3 space is specified as the SDRAM space, specify the bus width to 16 bits or 32 bits.
5. The initial values of the bus size assignment for areas 5B, 6A, and 6B after power-on reset is specified to prohibited setting. Therefore, specify the 8- or 16-bit size before accessing these areas.
6. When port A or B is used, specify the bus size of all areas to 8 bits or 16 bits.

When the memory type is specified to an area other than the areas that can be specified, the operation of this LSI is not guaranteed.

7.4.3 CSn Space Wait Control Register (CSnWCR) (n = 0, 2, 3, 4, 5A, 5B, 6A, 6B)

CSnWCR is a 32-bit readable/writable register that specifies various wait cycles for memory accesses. The bit configuration of this register varies as shown below according to the memory type (TYPE 2, TYPE 1, or TYPE 0) specified by the CSn space bus control register (CSnBCR). Specify the CSnWCR register before accessing the target area. Specify CSnBCR register first, then specify the CSnWCR register.

CS0WCR, CS6AWCR, CS6BWCR

Bit	Bit Name	Initial Value	R/W	Description
31 to 13	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
12	SW1	0	R/W	Number of Delay Cycles from Address, $\overline{CSn}$ Assertion to $\overline{RD}$, $\overline{WEn}$ Assertion Specify the number of delay cycles from address and $\overline{CSn}$ assertion to $\overline{RD}$ and $\overline{WEn}$ assertion. 00: 0.5 cycles 01: 1.5 cycles 10: 2.5 cycles 11: 3.5 cycles
11	SW0	0	R/W	
10	WR3	1	R/W	Number of Access Wait Cycles Specify the number of cycles that are necessary for read/write access. 0000: 0 cycle 0001: 1 cycle 0010: 2 cycles 0011: 3 cycles 0100: 4 cycles 0101: 5 cycles 0110: 6 cycles 0111: 8 cycles 1000: 10 cycles 1001: 12 cycles 1010: 14 cycles 1011: 18 cycles 1100: 24 cycles 1101: Setting prohibited. 1110: Setting prohibited. 1111: Setting prohibited.
9	WR2	0	R/W	
8	WR1	1	R/W	
7	WR0	0	R/W	

Bit	Bit Name	Initial Value	R/W	Description
6	WM	0	R/W	External Wait Mask Specification Specifies whether or not the external wait input is valid. The specification by this bit is valid even when the number of access wait cycle is 0. 0: External wait is valid 1: External wait is ignored
5 to 2	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
1	HW1	0	R/W	Delay Cycles from RD, $\overline{WEn}$ negation to Address, $\overline{CSn}$ negation Specify the number of delay cycles from RD and $\overline{WEn}$ negation to address and $\overline{CSn}$ negation. 00: 0.5 cycles 01: 1.5 cycles 10: 2.5 cycles 11: 3.5 cycles
0	HW0	0	R/W	

Bit	Bit Name	Initial Value	R/W	Description
31 to 11	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
10	WR3	1	R/W	Number of Access Wait Cycles
9	WR2	0	R/W	Specify the number of cycles that are necessary for read/write access.
8	WR1	1	R/W	
7	WR0	0	R/W	0000: 0 cycle 0001: 1 cycle 0010: 2 cycles 0011: 3 cycles 0100: 4 cycles 0101: 5 cycles 0110: 6 cycles 0111: 8 cycles 1000: 10 cycles 1001: 12 cycles 1010: 14 cycles 1011: 18 cycles 1100: 24 cycles 1101: Setting prohibited. 1110: Setting prohibited. 1111: Setting prohibited.
6	WM	0	R/W	External Wait Mask Specification Specify whether or not the external wait input is valid. The specification by this bit is valid even when the number of access wait cycle is 0. 0: External wait is valid 1: External wait is ignored
5 to 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
31 to 19	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
18	WW2	0	R/W	Number of Write Access Wait Cycles
17	WW1	0	R/W	Specify the number of cycles that are necessary for write access.
16	WW0	0	R/W	000: The same cycles as WR3 to WR0 setting (read access wait) 001: 0 cycle 010: 1 cycles 011: 2 cycles 100: 3 cycles 101: 4 cycles 110: 5 cycles 111: 6 cycles
15 to 13	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
12	SW1	0	R/W	Number of Delay Cycles from Address, $\overline{CSn}$ Assertion to $\overline{RD}$, $\overline{WEn}$ Assertion
11	SW0	0	R/W	Specify the number of delay cycles from address and $\overline{CSn}$ assertion to $\overline{RD}$ and $\overline{WEn}$ assertion. 00: 0.5 cycles 01: 1.5 cycles 10: 2.5 cycles 11: 3.5 cycles

Bit	Bit Name	Initial Value	R/W	Description
10	WR3	1	R/W	Number of Access Wait Cycles
9	WR2	0	R/W	Specify the number of cycles that are necessary for read/write access.
8	WR1	1	R/W	
7	WR0	0	R/W	0000: 0 cycle
				0001: 1 cycle
				0010: 2 cycles
				0011: 3 cycles
				0100: 4 cycles
				0101: 5 cycles
				0110: 6 cycles
				0111: 8 cycles
				1000: 10 cycles
				1001: 12 cycles
				1010: 14 cycles
				1011: 18 cycles
				1100: 24 cycles
				1101: Setting prohibited.
				1110: Setting prohibited.
				1111: Setting prohibited.
6	WM	0	R/W	External Wait Mask Specification
				Specifies whether or not the external wait input is valid. The specification by this bit is valid even when the number of access wait cycle is 0.
				0: External wait is valid
				1: External wait is ignored
5 to 2	—	All 0	R	Reserved
				These bits are always read as 0. The write value should always be 0.
1	HW1	0	R/W	Delay Cycles from RD, $\overline{WEn}$ negation to Address, $\overline{CSn}$ negation
0	HW0	0	R/W	Specify the number of delay cycles from RD and $\overline{WEn}$ negation to address and $\overline{CSn}$ negation.
				00: 0.5 cycles
				01: 1.5 cycles
				10: 2.5 cycles
				11: 3.5 cycles

Bit	Bit Name	Initial Value	R/W	Description
31 to 21	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
20	MPXW	0	R/W	MPX Interface Address Wait Specifies the wait to be inserted between address cycles for address/data multiplex I/O. This specification is valid only when area 5B is specified to address/data multiplex I/O. 0: No wait 1: 1 cycle wait inserted
19	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
18	WW2	0	R/W	Number of Write Access Wait Cycles
17	WW1	0	R/W	Specify the number of cycles that are necessary for write access.
16	WW0	0	R/W	000: The same cycles as WR3 to WR0 setting (read access wait) 001: 0 cycle 010: 1 cycles 011: 2 cycles 100: 3 cycles 101: 4 cycles 110: 5 cycles 111: 6 cycles
15 to 13	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
12	SW1	0	R/W	Number of Delay Cycles from Address, $\overline{CSn}$ Assertion to $\overline{RD}$, $\overline{WEn}$ Assertion
11	SW0	0	R/W	Specify the number of delay cycles from address and $\overline{CSn}$ assertion to $\overline{RD}$ and $\overline{WEn}$ assertion. 00: 0.5 cycles 01: 1.5 cycles 10: 2.5 cycles 11: 3.5 cycles

Bit	Bit Name	Initial Value	R/W	Description
10	WR3	1	R/W	Number of Access Wait Cycles
9	WR2	0	R/W	Specify the number of cycles that are necessary for read/write access.
8	WR1	1	R/W	
7	WR0	0	R/W	0000: 0 cycle
				0001: 1 cycle
				0010: 2 cycles
				0011: 3 cycles
				0100: 4 cycles
				0101: 5 cycles
				0110: 6 cycles
				0111: 8 cycles
				1000: 10 cycles
				1001: 12 cycles
				1010: 14 cycles
				1011: 18 cycles
				1100: 24 cycles
				1101: Setting prohibited.
				1110: Setting prohibited.
				1111: Setting prohibited.
6	WM	0	R/W	External Wait Mask Specification
				Specify whether or not the external wait input is valid. The specification by this bit is valid even when the number of access wait cycle is 0.
				0: External wait is valid
				1: External wait is ignored
5 to 2	—	All 0	R	Reserved
				These bits are always read as 0. The write value should always be 0.
1	HW1	0	R/W	Delay Cycles from RD, $\overline{WEn}$ negation to Address, $\overline{CSn}$ negation
0	HW0	0	R/W	Specify the number of delay cycles from RD and $\overline{WEn}$ negation to address and $\overline{CSn}$ negation.
				00: 0.5 cycles
				01: 1.5 cycles
				10: 2.5 cycles
				11: 3.5 cycles

CS0WCR

Bit	Bit Name	Initial Value	R/W	Description
31 to 18	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
17	BW1	0	R/W	Number of Burst Wait Cycles
16	BW0	0	R/W	Specify the number of wait cycles to be inserted between the second or later access cycles in burst access. 00: 0 cycle 01: 1 cycle 10: 2 cycles 11: 3 cycles
15 to 11	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
10	W3	1	R/W	Number of Access Wait Cycles
9	W2	0	R/W	Specify the number of wait cycles to be inserted in the first read/write access cycle.
8	W1	1	R/W	
7	W0	0	R/W	0000: 0 cycle 0001: 1 cycle 0010: 2 cycles 0011: 3 cycles 0100: 4 cycles 0101: 5 cycles 0110: 6 cycles 0111: 8 cycles 1000: 10 cycles 1001: 12 cycles 1010: 14 cycles 1011: 18 cycles 1100: 24 cycles 1101: Setting prohibited. 1110: Setting prohibited. 1111: Setting prohibited.

Bit	Bit Name	Initial Value	R/W	Description
6	WM	0	R/W	External Wait Mask Specification Specify whether or not the external wait input is valid. The specification by this bit is valid even when the number of access wait cycle is 0. 0: External wait is valid 1: External wait is ignored
5 to 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

CS4WCR

Bit	Bit Name	Initial Value	R/W	Description
31 to 18	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
17	BW1	0	R/W	Number of Burst Wait Cycles
16	BW0	0	R/W	Specify the number of wait cycles to be inserted between the second or later access cycles in burst access. 00: 0 cycle 01: 1 cycle 10: 2 cycles 11: 3 cycles
15 to 13	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
12	SW1	0	R/W	Number of Delay Cycles from Address, $\overline{CSn}$ Assertion to $\overline{RD}$, $\overline{WEn}$ Assertion
11	SW0	0	R/W	Specify the number of delay cycles from address and $\overline{CSn}$ assertion to $\overline{RD}$ and $\overline{WEn}$ assertion. 00: 0.5 cycles 01: 1.5 cycles 10: 2.5 cycles 11: 3.5 cycles

Bit	Bit Name	Initial Value	R/W	Description
10	W3	1	R/W	Number of Access Wait Cycles
9	W2	0	R/W	Specify the number of wait cycles to be inserted in the first read/write access cycle.
8	W1	1	R/W	
7	W0	0	R/W	0000: 0 cycle
				0001: 1 cycle
				0010: 2 cycles
				0011: 3 cycles
				0100: 4 cycles
				0101: 5 cycles
				0110: 6 cycles
				0111: 8 cycles
				1000: 10 cycles
				1001: 12 cycles
				1010: 14 cycles
				1011: 18 cycles
				1100: 24 cycles
				1101: Setting prohibited.
				1110: Setting prohibited.
				1111: Setting prohibited.
6	WM	0	R/W	External Wait Mask Specification
				Specifies whether or not the external wait input is valid. The specification by this bit is valid even when the number of access wait cycle is 0.
				0: External wait is valid
				1: External wait is ignored
5 to 2	—	All 0	R	Reserved
				These bits are always read as 0. The write value should always be 0.
1	HW1	0	R/W	Delay Cycles from $\overline{RD}$, $\overline{WEn}$ negation to Address, $\overline{CSn}$ negation
0	HW0	0	R/W	Specify the number of delay cycles from $\overline{RD}$ and $\overline{WEn}$ negation to address and $\overline{CSn}$ negation.
				00: 0.5 cycles
				01: 1.5 cycles
				10: 2.5 cycles
				11: 3.5 cycles

CS2WCR

Bit	Bit Name	Initial Value	R/W	Description
31 to 11	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
10	—	1	R	Reserved This bit is always read as 1. The write value should always be 1.
9	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
8	A2CL1	1	R/W	CAS Latency for Area 2
7	A2CL0	0	R/W	Specify the CAS latency for area 2. 00: Setting prohibited. 01: 2 cycles 10: 3 cycles 11: Setting prohibited.
6 to 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
31 to 15	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
14	TRP1	0	R/W	Number of Cycles from Auto-precharge/PRE Command to ACTV Command Specify the number of minimum cycles from the start of auto-precharge or issuing of PRE command to the issuing of ACTV command for the same bank. The setting for areas 2 and 3 is common. 00: 1 cycle 01: 2 cycles 10: 3 cycles 11: 4 cycles
13	TRP0	0	R/W	
12	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
11	TRCD1	0	R/W	Number of Cycles from ACTV Command to READ(A)/WRIT(A) Command Specify the number of minimum cycles from issuing ACTV command to issuing READ(A)/WRIT(A) command. The setting for areas 2 and 3 is common. 00: 1 cycle 01: 2 cycles 10: 3 cycles 11: 4 cycles
10	TRCD0	1	R/W	
9	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
8	A3CL1	1	R/W	CAS Latency for Area 3 Specify the CAS latency for area 3. 00: Setting prohibited. 01: 2 cycles 10: 3 cycles 11: Setting prohibited.
7	A3CL0	0	R/W	

Bit	Bit Name	Initial Value	R/W	Description
6, 5	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
4	TRWL1	0	R/W	Number of Cycles from WRITA/WRIT Command to Auto-precharge/PRE Command Specifies the number of cycles from issuing WRITA/WRIT command to the start of auto-precharge or to issuing PRE command. The setting for areas 2 and 3 is common. 00: 0 cycle 01: 1 cycle 10: 2 cycles 11: Setting prohibited
3	TRWL0	0	R/W	
2	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
1	TRC1	0	R/W	Number of Cycles from REF Command/Self-refresh Release to ACTV Command Specify the number of cycles from issuing the REF command or releasing self-refresh to issuing the ACTV command. The setting for areas 2 and 3 is common. 00: 3 cycles 01: 4 cycles 10: 6 cycles 11: 9 cycles
0	TRC0	0	R/W	

Note: * Specify area 3 as SDRAM when only one area is connected with SDRAM. In this case, specify area 2 as normal space.

7.4.4 SDRAM Control Register (SDCR)

SDCR specifies the method to refresh and access SDRAM, and the types of SDRAMs to be connected.

The bits other than RFSH and RMODE should be written in the initialization after a power-on reset and should not be modified after the initialization. When modifying these bits RFSH and RMODE, do not change the values of other bits and write the previous values. Do not access area 2 or 3 until the SDCR register setting is complete when using synchronous DRAM.

Bit	Bit Name	Initial Value	R/W	Description
31 to 21	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
20	A2ROW1	0	R/W	Number of Bits of Row Address for Area 2
19	A2ROW0	0	R/W	Specifies the number of bits of row address for area 2. 00: 11 bits 01: 12 bits 10: 13 bits 11: Setting prohibited
18	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
17	A2COL1	0	R/W	Number of Bits of Column Address for Area 2
16	A2COL0	0	R/W	Specifies the number of bits of column address for area 2. 00: 8 bits 01: 9 bits 10: 10 bits 11: Setting prohibited
15 to 13	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
12	SLOW	0	R/W	Low-Frequency Mode Specifies the output timing of command, address, and write data for SDRAM and the latch timing of read data from SDRAM. Setting this bit makes the hold time for command, address, write and read data extended. This mode is suitable for SDRAM with low-frequency clock. 0: Command, address, and write data for SDRAM is output at the rising edge of CKIO. Read data from SDRAM is latched at the rising edge of CKIO. 1: Command, address, and write data for SDRAM is output at the falling edge of CKIO. Read data from SDRAM is latched at the falling edge of CKIO.

Bit	Bit Name	Initial Value	R/W	Description
11	RFSH	0	R/W	Refresh Control Specifies whether or not the refresh operation of the SDRAM is performed. 0: No refresh 1: Refresh
10	RMODE	0	R/W	Refresh Control Specifies whether to perform auto-refresh or self-refresh when the RFSH bit is 1. When the RFSH bit is 1 and this bit is 1, self-refresh starts immediately. When the RFSH bit is 1 and this bit is 0, auto-refresh starts according to the contents that are set in registers RTCSR, RTCNT, and RTCOR. 0: Auto-refresh is performed 1: Self-refresh is performed
9	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
8	BACTV	0	R/W	Bank Active Mode Specifies to access whether in auto-precharge mode (using READA and WRITA commands) or in bank active mode (using READ and WRIT commands). 0: Auto-precharge mode (using READA and WRITA commands) 1: Bank active mode (using READ and WRIT commands) Note: Bank active mode can be used only when either the upper or lower bits of the CS3 space are used. When both the CS2 and CS3 spaces are set to SDRAM, specify the auto-precharge mode.
7 to 5	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
4	A3ROW1	0	R/W	Number of Bits of Row Address for Area 3
3	A3ROW0	0	R/W	Specifies the number of bits of the row address for area 3. 00: 11 bits 01: 12 bits 10: 13 bits 11: Setting prohibited

Bit	Bit Name	Initial Value	R/W	Description
2	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
1	A3COL1	0	R/W	Number of Bits of Column Address for Area 3
0	A3COL0	0	R/W	Specifies the number of bits of the column address for area 3. 00: 8 bits 01: 9 bits 10: 10 bits 11: Setting prohibited

7.4.5 Refresh Timer Control/Status Register (RTCSR)

RTCSR specifies various items about refresh for SDRAM.

This register only accepts 32-bit writing to prevent incorrect writing. In this case, the upper 16 bits of the data must be H'A55A, otherwise writing cannot be performed. When reading, the upper 16 bits are read as H'0000.

RTCSR

Bit	Bit Name	Initial Value	R/W	Description
31 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7	CMF	0	R/W	Compare Match Flag 0: Clearing condition When 0 is written in CMF after reading out RTCSR during CMF = 1. 1: Setting condition When the condition RTCNT = RTCOR is satisfied.
6	CMIE	0	R/W	CMF Interrupt Enable 0: CMF interrupt request is disabled. 1: CMF interrupt request is enabled.

Bit	Bit Name	Initial Value	R/W	Description
5	CKS2	0	R/W	Clock Select
4	CKS1	0	R/W	Select the clock input to count-up the refresh timer counter (RTCNT).
3	CKS0	0	R/W	000: Stop the counting-up 001: Bϕ/4 010: Bϕ/16 011: Bϕ/64 100: Bϕ/256 101: Bϕ/1024 110: Bϕ/2048 111: Bϕ/4096
2	RRC2	0	R/W	Refresh Count
1	RRC1	0	R/W	Specify the number of continuous refresh cycles, when the refresh request occurs after the coincidence of the values of the refresh timer counter (RTCNT) and the refresh time constant register (RTCOR). These bits can make the period of occurrence of refresh long.
0	RRC0	0	R/W	000: Once 001: Twice 010: 4 times 011: 6 times 100: 8 times 101: Setting prohibited. 110: Setting prohibited. 111: Setting prohibited.

7.4.6 Refresh Timer Counter (RTCNT)

RTCNT is an 8-bit counter that counts up using the clock selected by bits CKS2 to CKS0 in RTCSR.

This register only accepts 32-bit writing to prevent incorrect writing. In this case, the upper 16 bits of the data must be H'A55A, otherwise writing cannot be performed. When reading, the upper 16 bits are read as H'0000.

When RTCNT matches RTCOR, RTCNT is cleared to 0. The value in RTCNT returns to 0 after counting up to 255.

Bit	Bit Name	Initial Value	R/W	Description
31 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7 to 0	—	All 0	R/W	8-Bit Counter

7.4.7 Refresh Time Constant Register (RTCOR)

RTCOR is an 8-bit register. When RTCOR matches RTCNT, the CMF bit in RTCSR is set to 1 and RTCNT is cleared to 0.

This register only accepts 32-bit writing to prevent incorrect writing. In this case, the upper 16 bits of the data must be H'A55A, otherwise writing cannot be performed. When reading, the upper 16 bits are read as H'0000.

When the RFSH bit in SDCR is 1, a memory refresh request is issued by this matching signal. This request is maintained until the refresh operation is performed. If the request is not processed when the next matching occurs, the previous request is ignored.

When the CMIE bit in RTCSR is 1, an interrupt request is issued by this matching signal. This request signal is output until the CMF bit in RTCSR is cleared. Clearing the CMF bit only affects the interrupt and does not affect the refresh request. Accordingly, the refresh requests and interval timer interrupts can be used together. For example, the number of refresh requests can be counted by using interrupts while the refresh is performed.

This register only accepts 32-bit writing to prevent incorrect writing. In this case, the upper 16 bits of the data must be H'A55A, otherwise writing cannot be performed. When reading, the upper 16 bits are read as H'0000.

Bit	Bit Name	Initial Value	R/W	Description
31 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7 to 0	—	All 0	R/W	Maximum Counter Value (eight bits)

7.4.8 Reset Wait Counter (RWTCNT)

RWTCNT is a 16-bit register. The lower seven bits of this register (bits 6 to 0) are valid as a counter and the upper nine bits (bits 15 to 7) are reserved. This counter starts to count-up by synchronizing the CKIO after a power-on reset is released. This counter stops when the value reaches to H′007F. The access to an external bus has to wait when the counter is operating. This counter is provided to minimize the time from releasing a reset for flash memory to the first access. This counter cannot be read or written into.

7.5 Endian/Access Size and Data Alignment

This LSI supports big endian, in which the 0 address is the most significant byte (MSByte) in the byte data and little endian, in which the 0 address is the least significant byte (LSByte) in the byte data. Endian is specified on power-on reset by the external pin (MD5). When MD5 pin is low level on power-on reset, the endian will become big endian and when MD5 pin is high level on power-on reset, the endian will become little endian. Three data bus widths are available for normal memory (byte, word, and longword). Word and longword are available for SDRAM. Data bus width for address/data multiplex I/O (MPX) should be 16 bits. Data alignment is performed in accordance with the data bus width of the device and endian. This also means that when longword data is read from a byte-width device, the read operation must be done four times. In this LSI, data alignment and conversion of data length is performed automatically between the respective interfaces.

Tables 7.4 to 7.9 show the relationship between endian, device data width, and access unit.

Table 7.4 32-Bit External Device/Big Endian Access and Data Alignment

	Data Bus				Strobe Signals			
Operation	**D31 to D24**	**D23 to D16**	**D15 to D8**	**D7 to D0**	**$\overline{WE3}$, DQMUU**	**$\overline{WE2}$, DQMUL**	**$\overline{WE1}$, DQMLU**	**$\overline{WE0}$, DQMLL**
Byte access at 0	Data 7 to Data 0	—	—	—	Assert	—	—	—
Byte access at 1	—	Data 7 to Data 0	—	—	—	Assert	—	—
Byte access at 2	—	—	Data 7 to Data 0	—	—	—	Assert	—
Byte access at 3	—	—	—	Data 7 to Data 0	—	—	—	Assert
Word access at 0	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert	—	—
Word access at 2	—	—	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert
Longword access at 0	Data 31 to Data 24	Data 23 to Data 16	Data 15 to Data 8	Data 7 to Data 0	Assert	Assert	Assert	Assert

Table 7.5 16-Bit External Device/Big Endian Access and Data Alignment

Operation		Data Bus				Strobe Signals			
		D31 to D24	D23 to D16	D15 to D8	D7 to D0	$\overline{WE3}$, DQMUU	$\overline{WE2}$, DQMUL	$\overline{WE1}$, DQMLU	$\overline{WE0}$, DQMLL
Byte access at 0		—	—	Data 7 to Data 0	—	—	—	Assert	—
Byte access at 1		—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 2		—	—	Data 7 to Data 0	—	—	—	Assert	—
Byte access at 3		—	—	—	Data 7 to Data 0	—	—	—	Assert
Word access at 0		—	—	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert
Word access at 2		—	—	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert
Longword access at 0	1st time at 0	—	—	Data 31 to Data 24	Data 23 to Data 16	—	—	Assert	Assert
	2nd time at 2	—	—	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert

Table 7.6 8-Bit External Device/Big Endian Access and Data Alignment

Operation		Data Bus				Strobe Signals			
		D31 to D24	D23 to D16	D15 to D8	D7 to D0	$\overline{WE3}$, DQMUU	$\overline{WE2}$, DQMUL	$\overline{WE1}$, DQMLU	$\overline{WE0}$, DQMLL
Byte access at 0		—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 1		—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 2		—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 3		—	—	—	Data 7 to Data 0	—	—	—	Assert
Word access at 0	1st time at 0	—	—	—	Data 15 to Data 8	—	—	—	Assert
	2nd time at 1	—	—	—	Data 7 to Data 0	—	—	—	Assert
Word access at 2	1st time at 2	—	—	—	Data 15 to Data 8	—	—	—	Assert
	2nd time at 3	—	—	—	Data 7 to Data 0	—	—	—	Assert
Longword access at 0	1st time at 0	—	—	—	Data 31 to Data 24	—	—	—	Assert
	2nd time at 1	—	—	—	Data 23 to Data 16	—	—	—	Assert
	3rd time at 2	—	—	—	Data 15 to Data 8	—	—	—	Assert
	4th time at 3	—	—	—	Data 7 to Data 0	—	—	—	Assert

Table 7.7 32-Bit External Device/Little Endian Access and Data Alignment

	Data Bus				Strobe Signals			
Operation	**D31 to D24**	**D23 to D16**	**D15 to D8**	**D7 to D0**	**$\overline{WE3}$, DQMUU**	**$\overline{WE2}$, DQMUL**	**$\overline{WE1}$, DQMLU**	**$\overline{WE0}$, DQMLL**
Byte access at 0	—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 1	—	—	Data 7 to Data 0	—	—	—	Assert	—
Byte access at 2	—	Data 7 to Data 0	—	—	—	Assert	—	—
Byte access at 3	Data 7 to Data 0	—	—	—	Assert	—	—	—
Word access at 0	—	—	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert
Word access at 2	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert	—	—
Longword access at 0	Data 31 to Data 24	Data 23 to Data 16	Data 15 to Data 8	Data 7 to Data 0	Assert	Assert	Assert	Assert

Table 7.8 16-Bit External Device/Little Endian Access and Data Alignment

Operation		Data Bus				Strobe Signals			
		D31 to D24	D23 to D16	D15 to D8	D7 to D0	$\overline{WE3}$, DQMUU	$\overline{WE2}$, DQMUL	$\overline{WE1}$, DQMLU	$\overline{WE0}$, DQMLL
Byte access at 0		—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 1		—	—	Data 7 to Data 0	—	—	—	Assert	—
Byte access at 2		—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 3		—	—	Data7 to Data 0	—	—	—	Assert	—
Word access at 0		—	—	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert
Word access at 2		—	—	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert
Longword access at 0	1st time at 0	—	—	Data 15 to Data 8	Data 7 to Data 0	—	—	Assert	Assert
	2nd time at 1	—	—	Data 31 to Data 24	Data 23 to Data 16	—	—	Assert	Assert

Table 7.9 8-Bit External Device/Little Endian Access and Data Alignment

Operation		Data Bus				Strobe Signals			
		D31 to D24	D23 to D16	D15 to D8	D7 to D0	$\overline{WE3}$, DQMUU	$\overline{WE2}$, DQMUL	$\overline{WE1}$, DQMLU	$\overline{WE0}$, DQMLL
Byte access at 0		—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 1		—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 2		—	—	—	Data 7 to Data 0	—	—	—	Assert
Byte access at 3		—	—	—	Data 7 to Data 0	—	—	—	Assert
Word access at 0	1st time at 0	—	—	—	Data 7 to Data 0	—	—	—	Assert
	2nd time at 1	—	—	—	Data 15 to Data 8	—	—	—	Assert
Word access at 2	1st time at 2	—	—	—	Data 7 to Data 0	—	—	—	Assert
	2nd time at 3	—	—	—	Data 15 to Data 8	—	—	—	Assert
Longword access at 0	1st time at 0	—	—	—	Data 7 to Data 0	—	—	—	Assert
	2nd time at 1	—	—	—	Data 15 to Data 8	—	—	—	Assert
	3rd time at 2	—	—	—	Data 23 to Data 16	—	—	—	Assert
	4th time at 3	—	—	—	Data 31 to Data 24	—	—	—	Assert

7.6 Normal Space Interface

7.6.1 Basic Timing

For access to a normal space, this LSI uses strobe signal output in consideration of the fact that mainly static RAM will be directly connected. When using SRAM with a byte-selection pin, see section 7.10, Byte-Selection SRAM Interface. Figures 7.3 and 7.4 show the basic timings of normal space accesses. A no-wait normal access is completed in two cycles. The $\overline{BS}$ signal is asserted for one cycle to indicate the start of a bus cycle.

There is no access size specification when reading. The correct access start address is output in the least significant bit of the address, but since there is no access size specification, 32 bits are always read in case of a 32-bit device, and 16 bits in case of a 16-bit device. When writing, only the $\overline{WEn}$ signal for the byte to be written is asserted.

Read/write for cache fill or writeback follows the selected bus width and transfers a total of 16 bytes continuously. The bus is not released during this transfer. For cache misses that occur during byte or word operand accesses or branching to odd word boundaries, the fill is always performed by longword accesses on the chip-external interface. Write-through-area write access and non-cacheable read/write access are based on the actual address size.

It is necessary to output the read out data by using $\overline{RD}$ when a buffer is established in the data bus. The RD/$\overline{WR}$ signal is in a read state (high output) when an access is not performed. Therefore, care must be taken about the collision of output in controlling the external data buffer.

When the WM bit in CSnWCR is cleared to 0, a Tnop cycle is inserted to evaluate an external wait. When the WM bit in CSnWCR is set to 1, an external wait is ignored and no Tnop cycle is inserted.

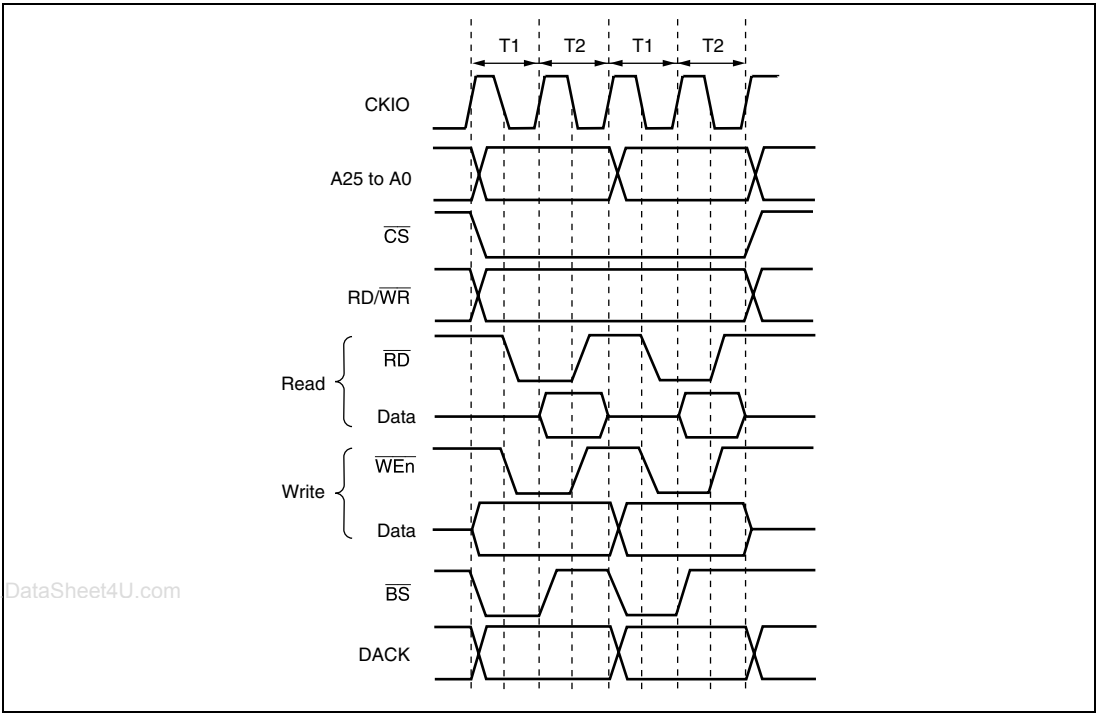


Figure 7.3 Continuous Access for Normal Space (No Wait, WM Bit in CSnWCR = 1, 16-Bit Bus Width, Longword Access, No Wait State between Cycles)

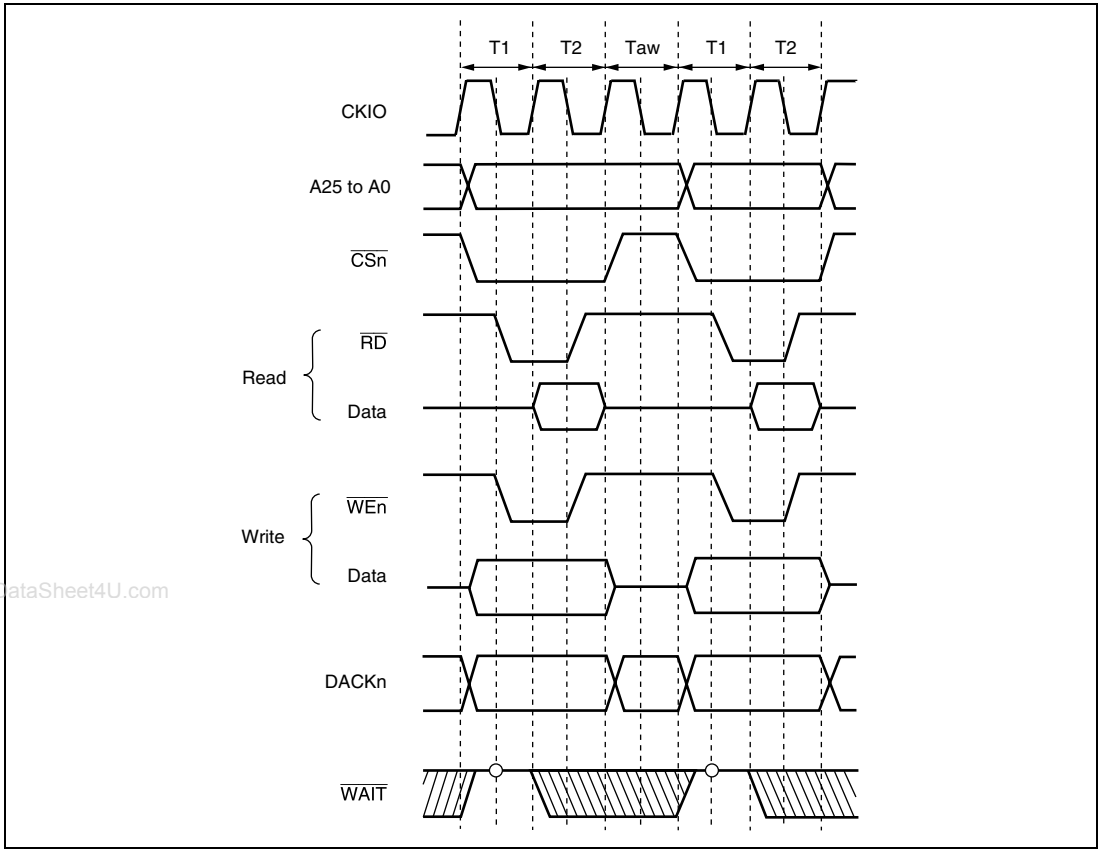


Figure 7.4 Continuous Access for Normal Space (No Wait, One Wait State between Cycles)

Figures 7.5 to 7.7 show examples of connection to 32-bit, 16-bit, and 8-bit data-width SRAM, respectively.

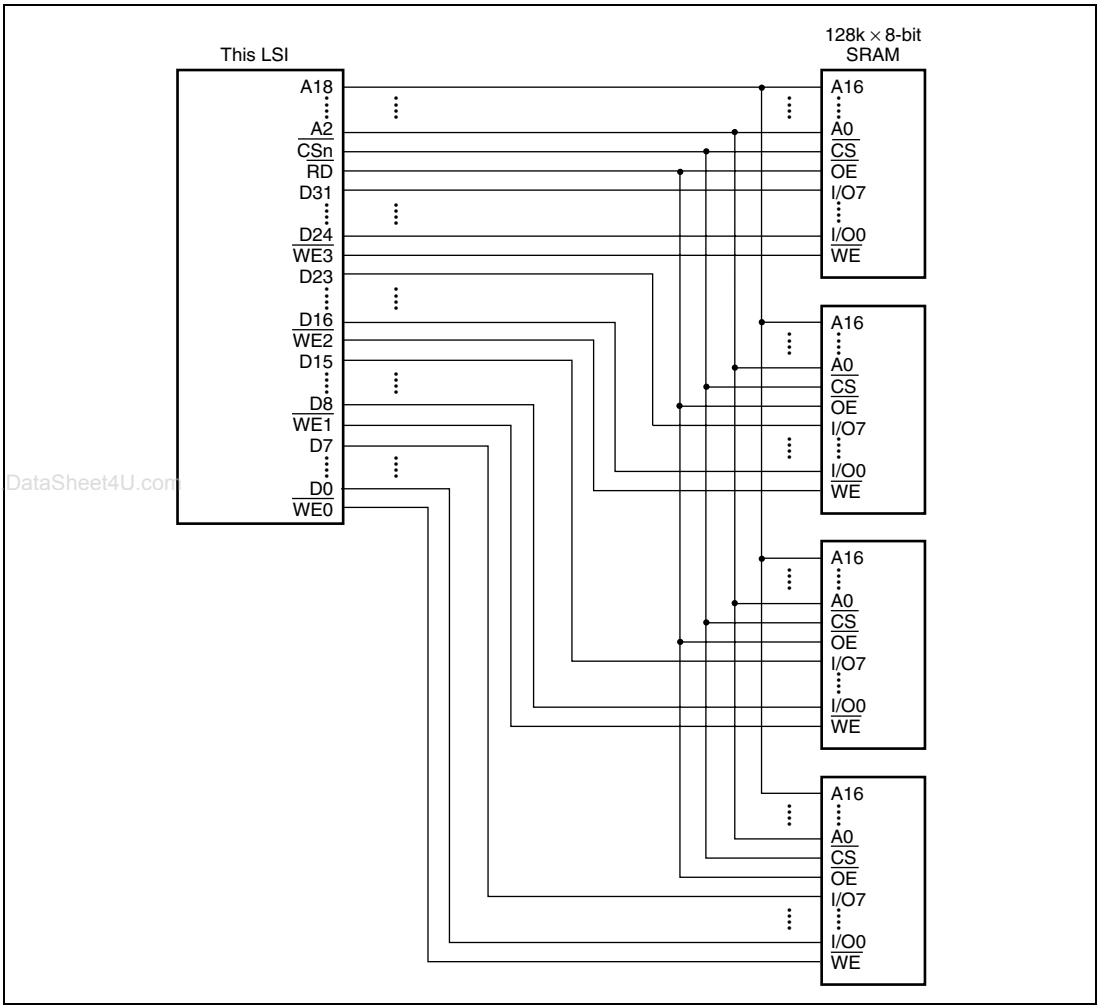


Figure 7.5 Example of 32-Bit Data-Width SRAM Connection

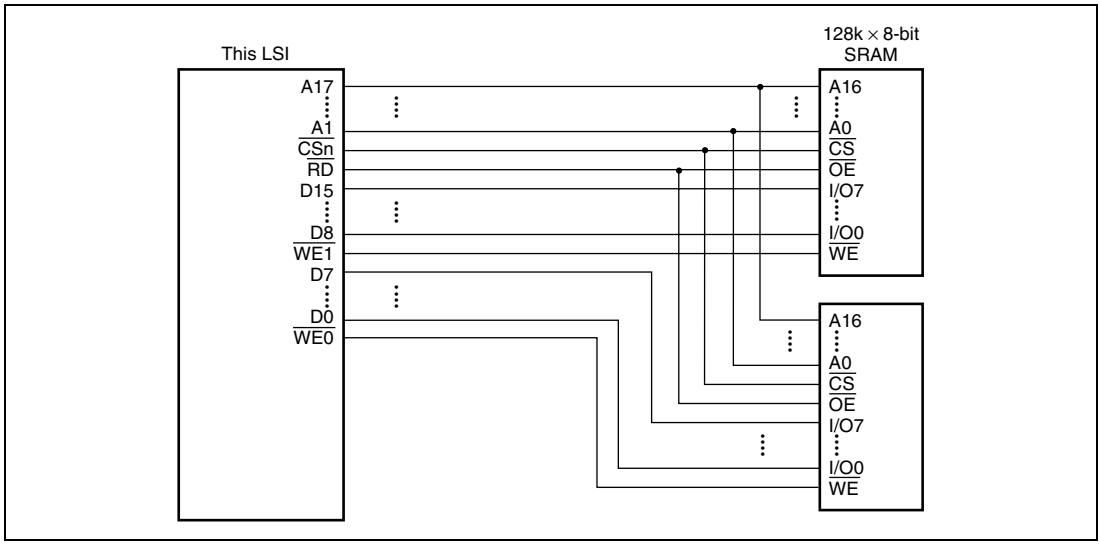


Figure 7.6 Example of 16-Bit Data-Width SRAM Connection

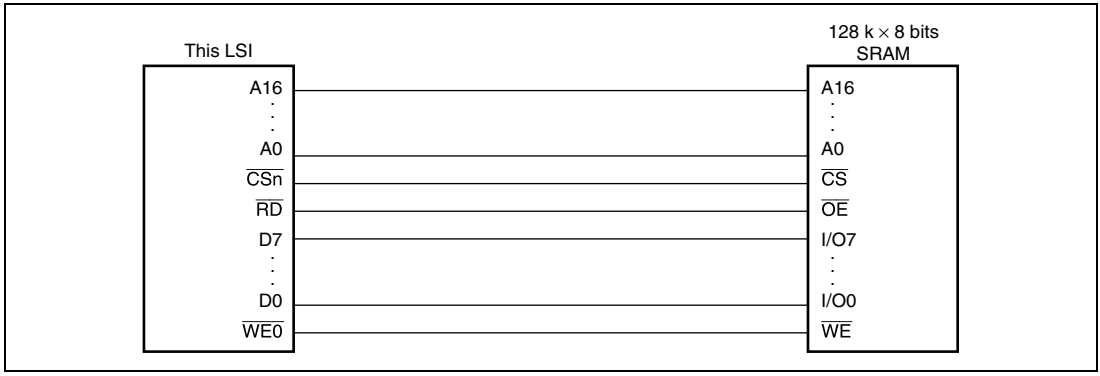
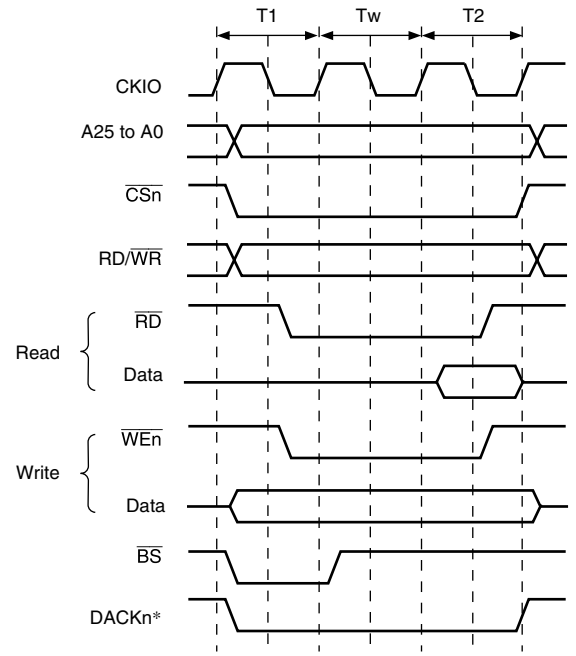


Figure 7.7 Example of 8-Bit Data-Width SRAM Connection

7.6.2 Access Wait Control

Wait cycle insertion on a normal space access can be controlled by the settings of bits WR3 to WR0 in CSnWCR. It is possible for areas 4, 5A, and 5B to insert wait cycles independently in read access and in write access. The areas other than 4, 5A, and 5B have common access wait for read cycle and write cycle. The specified number of Tw cycles is inserted as wait cycles in a normal space access shown in figure 7.8.



Note: * The waveform for DACKn is when active low is specified.

Figure 7.8 Wait Timing for Normal Space Access (Software Wait Only)

When the WM bit in CSnWCR is cleared to 0, the external wait input $\overline{\text{WAIT}}$ signal is also sampled. $\overline{\text{WAIT}}$ pin sampling is shown in figure 7.9. A 2-cycle wait is specified as a software wait. The $\overline{\text{WAIT}}$ signal is sampled on the falling edge of CKIO at the transition from the T1 or Tw cycle to the T2 cycle.

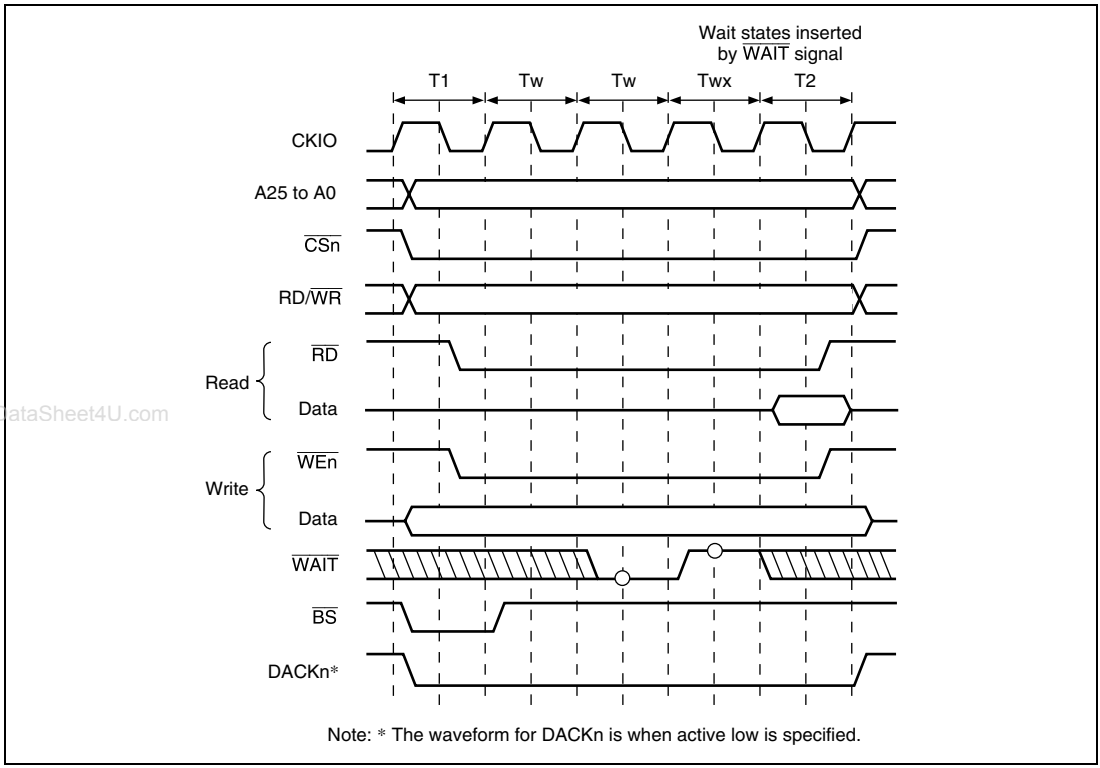
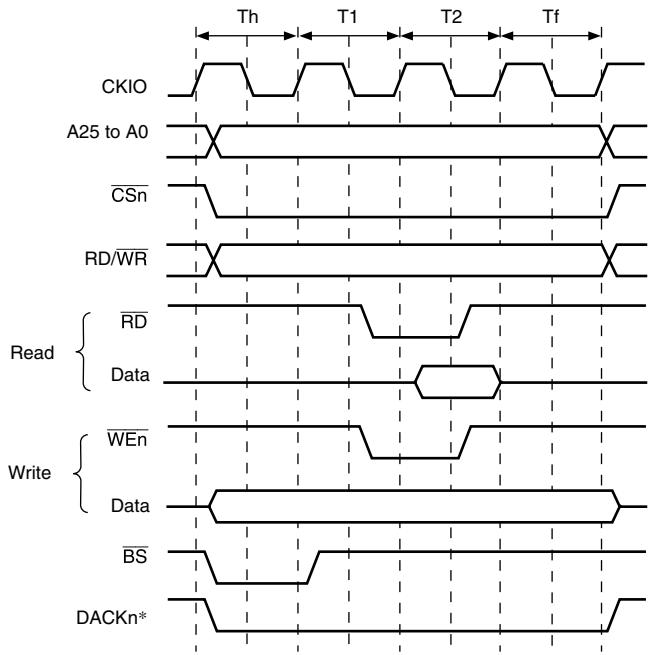


Figure 7.9 Wait State Timing for Normal Space Access (Wait State Insertion by $\overline{\text{WAIT}}$ Signal)

7.6.3 $\overline{\text{CSn}}$ Assert Period Expansion

The number of cycles from $\overline{\text{CSn}}$ assertion to $\overline{\text{RD}}$, $\overline{\text{WEn}}$ assertion can be specified by setting bits SW1 and SW0 in CSnWCR. The number of cycles from $\overline{\text{RD}}$, $\overline{\text{WEn}}$ negation to $\overline{\text{CSn}}$ negation can be specified by setting bits HW1 and HW0. Therefore, a flexible interface to an external device can be obtained. Figure 7.10 shows an example. A Th cycle and a Tf cycle are added before and after an ordinary cycle, respectively. In these cycles, $\overline{\text{RD}}$ and $\overline{\text{WEn}}$ are not asserted, while other signals are asserted. The data output is prolonged to the Tf cycle, and this prolongation is useful for devices with slow writing operations.



Note: * The waveform for DACKn is when active low is specified.

Figure 7.10 $\overline{\text{CSn}}$ Assert Period Expansion

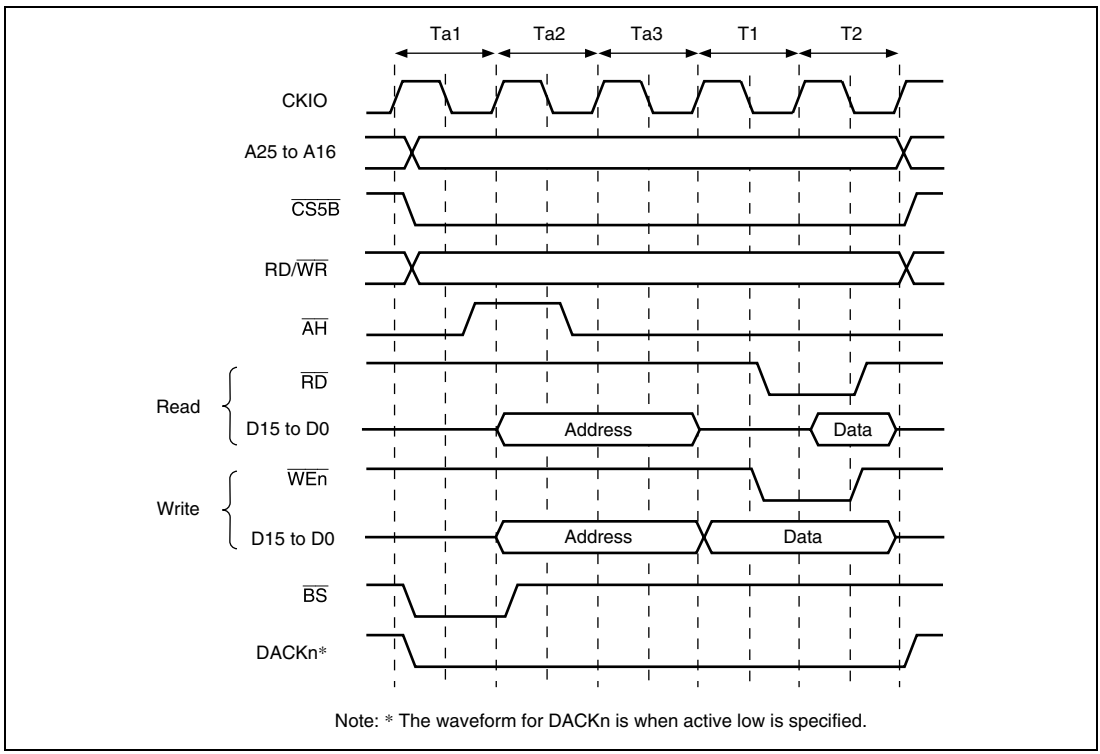
7.7 Address/Data Multiplex I/O Interface

The address/data multiplex (MPX) I/O interface can be selected by setting bits TYPE2 to TYPE0 to 010 in CS5BBCR. Do not set this value to the bits in CSnBCR other than those in area 5B, otherwise the operation of the LSI is not guaranteed. Access timing for the MPX space is shown below. In the MPX space, $\overline{CS5B}$, $\overline{AH}$, $\overline{RD}$, and $\overline{WEn}$ signals control the accessing. The basic access for the MPX space consists of 2 cycles of address output followed by an access to a normal space.

The address output is performed from cycle Ta2 to cycle Ta3. Because cycle Ta1 has a high-impedance state, collisions of addresses and data can be avoided without inserting idle cycles, even in continuous accesses. Address output is increased to 3 cycles by setting the MPXW bit to 1 in CS5BWCR. The RD/$\overline{WR}$ signal is output at the same time as the $\overline{CSn}$ signal; it is high in the read cycle and low in the write cycle.

The data cycle is the same as that in a normal space access.

Timing charts are shown in figures 7.11, 7.12, and 7.13.



Note: * The waveform for DACKn is when active low is specified.

Figure 7.11 Access Timing for MPX Space (Address Cycle No Wait, Data Cycle No Wait)

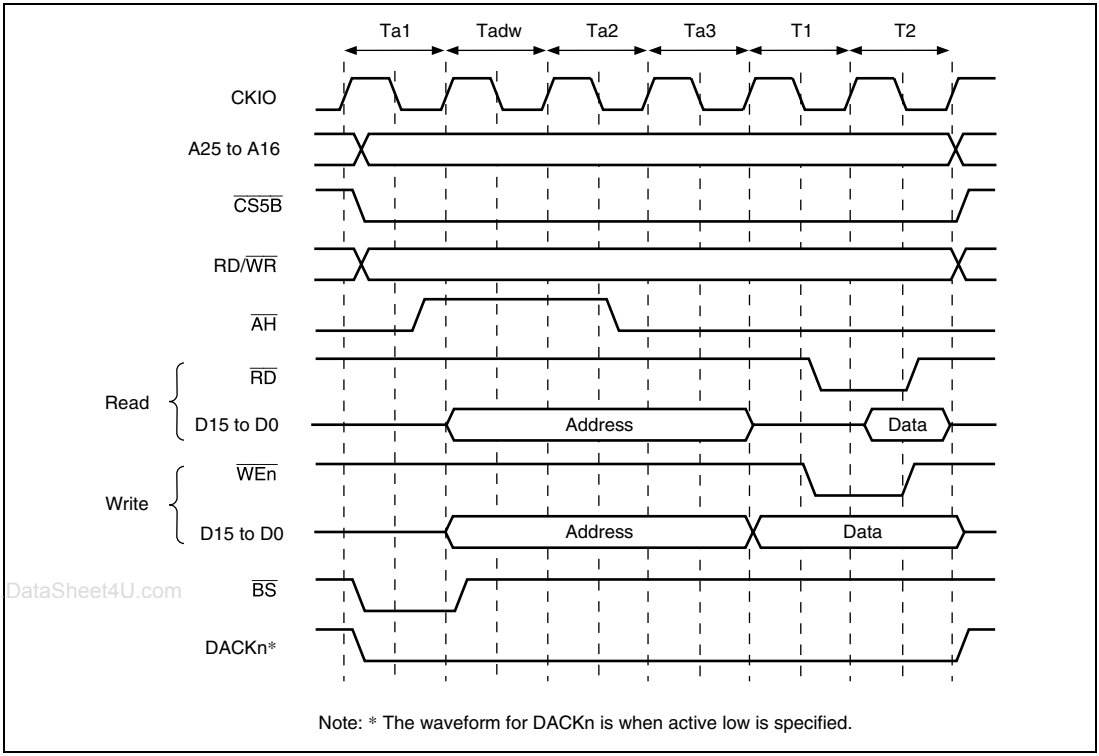


Figure 7.12 Access Timing for MPX Space (Address Cycle Wait 1, Data Cycle No Wait)

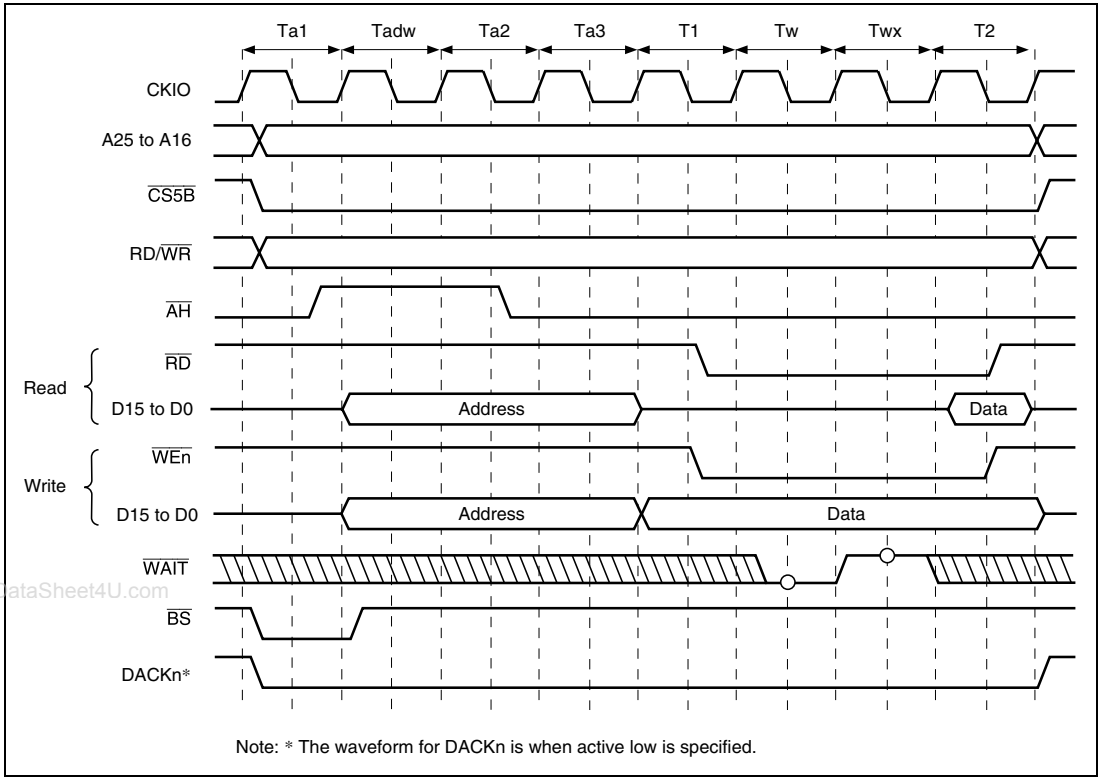


Figure 7.13 Access Timing for MPX Space
(Address Cycle Access Wait 1, Data Cycle Wait 1, External Wait 1)

7.8 SDRAM Interface

7.8.1 SDRAM Direct Connection

Since synchronous DRAM can be selected by the $\overline{CS}$ signal, physical space areas 2 and 3 can be connected using $\overline{RAS}$ and other control signals in common. If the TYPE[2:0] bits in CSnBCR (n = 2 or 3) are set to 100, the synchronous DRAM interface can be selected. Do not set this value to CSnBCR unless n = 2 or 3, otherwise the operation of this LSI is not guaranteed.

The SDRAM that can be connected to this LSI is a product that has 11/12/13 bits of row address, 8/9/10 bits of column address, 4 or less banks, and uses the A10 pin for setting precharge mode in read and write command cycles. The control signals for direct connection of SDRAM are $\overline{RASU}$, $\overline{RASL}$, $\overline{CASU}$, $\overline{CASL}$, RD/$\overline{WR}$, DQMUU, DQMUL, DQMLU, DQMLL, CKE, $\overline{CS2}$, and $\overline{CS3}$. All the signals other than $\overline{CS2}$ and $\overline{CS3}$ are common to all areas, and signals other than CKE are valid when $\overline{CS2}$ or $\overline{CS3}$ is asserted. SDRAM can be connected to up to 2 spaces. The data bus width of the area that is connected to SDRAM can be set to 32 or 16 bits.

Burst read/single write (burst length 1) and burst read/burst write (burst length 1) are supported as the SDRAM operating mode.

Commands for SDRAM can be specified by $\overline{RASU}$, $\overline{RASL}$, $\overline{CASU}$, $\overline{CASL}$, RD/WR, and specific address signals. These commands are shown below.

- NOP
- Auto-refresh (REF)
- Self-refresh (SELF)
- All banks pre-charge (PALL)
- Specified bank pre-charge (PRE)
- Bank active (ACTV)
- Read (READ)
- Read with pre-charge (READA)
- Write (WRIT)
- Write with pre-charge (WRITA)
- Write mode register (MRS)

The byte to be accessed is specified by DQMUU, DQMUL, DQMLU, and DQMLL. For the relationship between DQMxx and the byte to be accessed, refer to section 7.5, Endian/Access Size and Data Alignment.

Figures 7.14 and 7.15 show examples of the connection of SDRAM with the LSI.

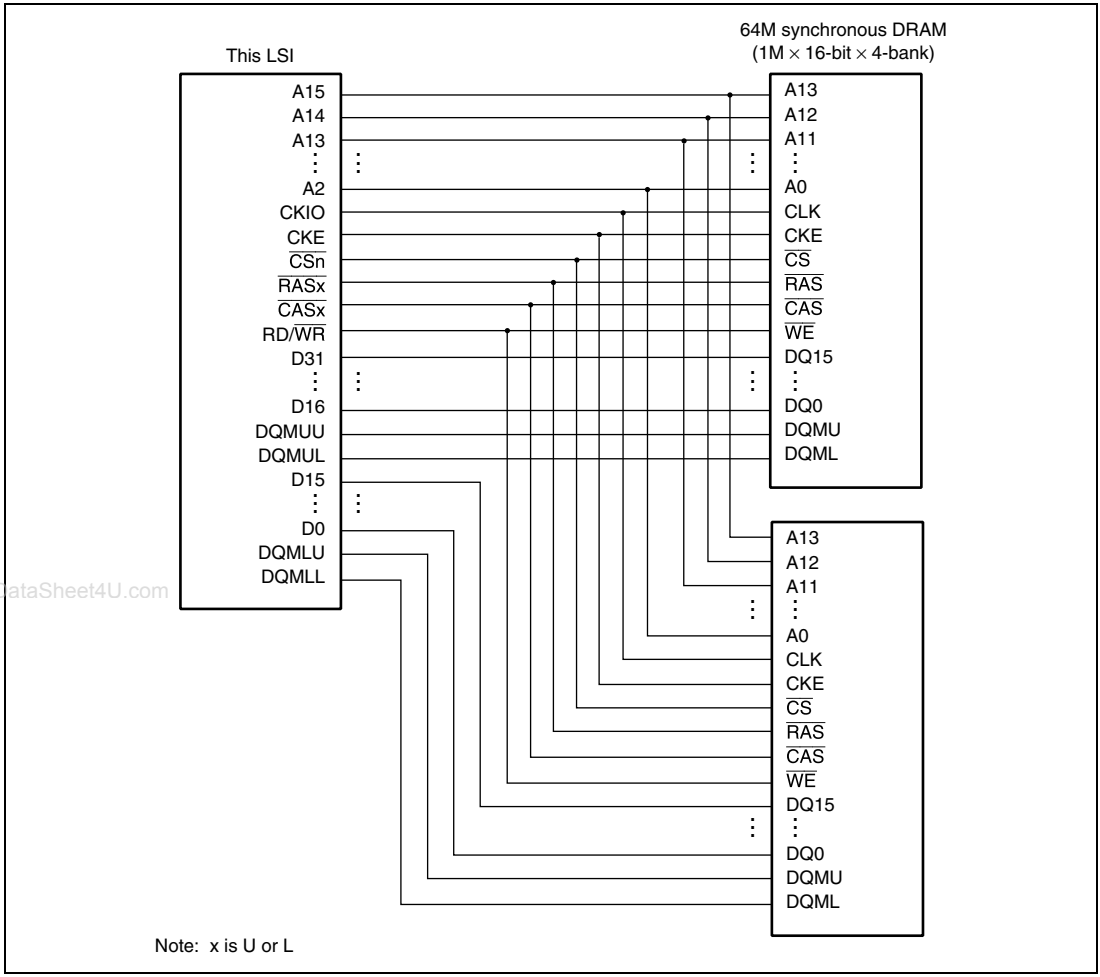


Figure 7.14 Example of 64-MBit Synchronous DRAM Connection (32-Bit Data Bus)

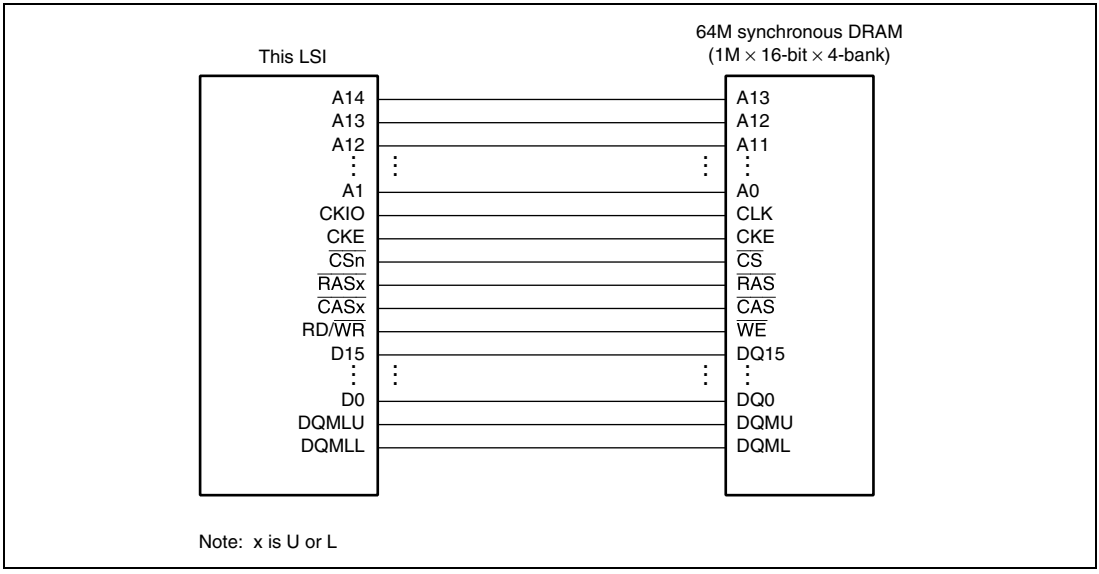


Figure 7.15 Example of 64-MBit Synchronous DRAM (16-Bit Data Bus)

7.8.2 Address Multiplexing

An address multiplexing is specified so that SDRAM can be connected without external multiplexing circuitry according to the setting of bits BSZ[1:0] in CSnBCR, AxROW[1:0] and AxCOL[1:0] in SDCR. Tables 7.10 to 7.15 show the relationship between the settings of bits BSZ[1:0], AxROW[1:0], and AxCOL[1:0] and the bits output at the address pins. Do not specify those bits in the manner other than this table, otherwise the operation of this LSI is not guaranteed. A25 to A18 are not multiplexed and the original values of address are always output at these pins.

When the data bus width is 16 bits (BSZ[1:0] = 10), A0 of SDRAM specifies a word address. Therefore, connect this A0 pin of SDRAM to the A1 pin of the LSI; the A1 pin of SDRAM to the A2 pin of the LSI, and so on. When the data bus width is 32 bits (BSZ[1:0] = 11), the A0 pin of SDRAM specifies a longword address. Therefore, connect this A0 pin of SDRAM to the A2 pin of the LSI; the A1 pin of SDRAM to the A3 pin of the LSI, and so on.

Table 7.10 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (1)-1

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
11 (32 bits)	**00 (11 bits)**	**00 (8 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A25	A17		Unused
A16	A24	A16		
A15	A23	A15		
A14	A22*2	A22*2	A12 (BA1)	Specifies bank
A13	A21*2	A21*2	A11 (BA0)	
A12	A20	L/H*1	A10/AP	Specifies address/precharge
A11	A19	A11	A9	Address
A10	A18	A10	A8	
A9	A17	A9	A7	
A8	A16	A8	A6	
A7	A15	A7	A5	
A6	A14	A6	A4	
A5	A13	A5	A3	
A4	A12	A4	A2	
A3	A11	A3	A1	
A2	A10	A2	A0	
A1	A9	A1		Unused
A0	A8	A0		
Example of connected memory				
64-Mbit product (512 kwords x 32 bits x 4 banks, column 8 bits product): 1 device				
16-Mbit product (512 kwords x 16 bits x 2 banks, column 8 bits product): 2 devices				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

Table 7.10 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (1)-2

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
11 (32 bits)	**01 (12 bits)**	**00 (8 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A25	A17		Unused
A16	A24	A16		
A15	A23*2	A23*2	A13 (BA1)	Specifies bank
A14	A22*2	A22*2	A12 (BA0)	
A13	A21	A13	A11	Address
A12	A20	L/H*1	A10/AP	Specifies address/precharge
A11	A19	A11	A9	Address
A10	A18	A10	A8	
A9	A17	A9	A7	
A8	A16	A8	A6	
A7	A15	A7	A5	
A6	A14	A6	A4	
A5	A13	A5	A3	
A4	A12	A4	A2	
A3	A11	A3	A1	
A2	A10	A2	A0	
A1	A9	A1		Unused
A0	A8	A0		
Example of connected memory				
128-Mbit product (1 Mword x 32 bits x 4 banks, column 8 bits product): 1 device				
64-Mbit product (1 Mword x 16 bits x 4 banks, column 8 bits product): 2 devices				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

Table 7.11 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (2)-1

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
11 (32 bits)	**01 (12 bits)**	**01 (9 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A26	A17		Unused
A16	A25	A16		
A15	A24*2	A24*2	A13 (BA1)	Specifies bank
A14	A23*2	A23*2	A12 (BA0)	
A13	A22	A13	A11	Address
A12	A21	L/H*1	A10/AP	Specifies address/precharge
A11	A20	A11	A9	Address
A10	A19	A10	A8	
A9	A18	A9	A7	
A8	A17	A8	A6	
A7	A16	A7	A5	
A6	A15	A6	A4	
A5	A14	A5	A3	
A4	A13	A4	A2	
A3	A12	A3	A1	
A2	A11	A2	A0	
A1	A10	A1		Unused
A0	A9	A0		
Example of connected memory				
256-Mbit product (2 Mwords x 32 bits x 4 banks, column 9 bits product): 1 device				
128-Mbit product (2 Mwords x 16 bits x 4 banks, column 9 bits product): 2 devices				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

*3 Only the $\overline{\text{RASL}}$ pin is asserted because the A25 pin specified the bank address. $\overline{\text{RASU}}$ is not asserted.

Table 7.11 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (2)-2

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
11 (32 bits)	**01 (12 bits)**	**10 (10 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A27	A17		Unused
A16	A26	A16		
A15	A25*[2]	A25*[2]*[3]	A13 (BA1)	Specifies bank
A14	A24*[2]	A24*[2]	A12 (BA0)	
A13	A23	A13	A11	Address
A12	A22	L/H*[1]	A10/AP	Specifies address/precharge
A11	A21	A11	A9	Address
A10	A20	A10	A8	
A9	A19	A9	A7	
A8	A18	A8	A6	
A7	A17	A7	A5	
A6	A16	A6	A4	
A5	A15	A5	A3	
A4	A14	A4	A2	
A3	A13	A3	A1	
A2	A12	A2	A0	
A1	A11	A1		Unused
A0	A10	A0		
Example of connected memory				
512-Mbit product (4 Mwords x 32 bits x 4 banks, column 10 bits product): 1 device				
256-Mbit product (4 Mwords x 16 bits x 4 banks, column 10 bits product): 2 devices				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

*3 Only the $\overline{\text{RASL}}$ pin is asserted because the A25 pin specified the bank address. $\overline{\text{RASU}}$ is not asserted.

Table 7.12 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (3)

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
11 (32 bits)	**10 (13 bits)**	**01 (9 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A26	A17		Unused
A16	A25*2*3	A25*2*3	A14 (BA1)	Specifies bank
A15	A24*2	A24*2	A13 (BA0)	
A14	A23	A14	A12	Address
A13	A22	A13	A11	
A12	A21	L/H*1	A10/AP	Specifies address/precharge
A11	A20	A11	A9	Address
A10	A19	A10	A8	
A9	A18	A9	A7	
A8	A17	A8	A6	
A7	A16	A7	A5	
A6	A15	A6	A4	
A5	A14	A5	A3	
A4	A13	A4	A2	
A3	A12	A3	A1	
A2	A11	A2	A0	
A1	A10	A1		Unused
A0	A9	A0		
Example of connected memory				
512-Mbit product (4 Mwords x 32 bits x 4 banks, column 9 bits product): 1 device				
256-Mbit product (4 Mwords x 16 bits x 4 banks, column 9 bits product): 2 devices				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

*3 Only the $\overline{\text{RASL}}$ pin is asserted because the A25 pin specified the bank address. $\overline{\text{RASU}}$ is not asserted.

Table 7.13 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (4)-1

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
10 (16 bits)	**00 (11 bits)**	**00 (8 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A25	A17		Unused
A16	A24	A16		
A15	A23	A15		
A14	A22	A14		
A13	A21*2	A21*2	A12 (BA1)	Specifies bank
A12	A20*2	A20*2	A11 (BA0)	
A11	A19	L/H*1	A10/AP	Specifies address/precharge
A10	A18	A10	A9	Address
A9	A17	A9	A8	
A8	A16	A8	A7	
A7	A15	A7	A6	
A6	A14	A6	A5	
A5	A13	A5	A4	
A4	A12	A4	A3	
A3	A11	A3	A2	
A2	A10	A2	A1	
A1	A9	A1	A0	
A0	A8	A0		Unused
Example of connected memory				
16-Mbit product (512 kwords x 16 bits x 2 banks, column 8 bits product): 1 device				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

Table 7.13 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (4)-2

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
10 (16 bits)	**01 (12 bits)**	**00 (8 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A25	A17		Unused
A16	A24	A16		
A15	A23	A15		
A14	A22*2	A22*2	A13 (BA1)	Specifies bank
A13	A21*2	A21*2	A12 (BA0)	Address
A12	A20	A12	A11	
A11	A19	L/H*1	A10/AP	Specifies address/precharge
A10	A18	A10	A9	Address
A9	A17	A9	A8	
A8	A16	A8	A7	
A7	A15	A7	A6	
A6	A14	A6	A5	
A5	A13	A5	A4	
A4	A12	A4	A3	
A3	A11	A3	A2	
A2	A10	A2	A1	
A1	A9	A1	A0	
A0	A8	A0		Unused
Example of connected memory				
64-Mbit product (1 Mword x 16 bits x 4 banks, column 8 bits product): 1 device				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

Table 7.14 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (5)-1

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
10 (16 bits)	**01 (12 bits)**	**01 (9 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A26	A17		Unused
A16	A25	A16		
A15	A24	A15		
A14	A23*2	A23*2	A13 (BA1)	Specifies bank
A13	A22*2	A22*2	A12 (BA0)	
A12	A21	A12	A11	Address
A11	A20	L/H*1	A10/AP	Specifies address/precharge
A10	A19	A10	A9	Address
A9	A18	A9	A8	
A8	A17	A8	A7	
A7	A16	A7	A6	
A6	A15	A6	A5	
A5	A14	A5	A4	
A4	A13	A4	A3	
A3	A12	A3	A2	
A2	A11	A2	A1	
A1	A10	A1	A0	
A0	A9	A0		Unused
Example of connected memory				
128-Mbit product (2 Mwords x 16 bits x 4 banks, column 9 bits product): 1 device				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

Table 7.14 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (5)-2

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
10 (16 bits)	**01 (12 bits)**	**10 (10 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A27	A17		Unused
A16	A26	A16		
A15	A25	A15		
A14	A24*2	A24*2	A13 (BA1)	Specifies bank
A13	A23*2	A23*2	A12 (BA0)	
A12	A22	A12	A11	Address
A11	A21	L/H*1	A10/AP	Specifies address/precharge
A10	A20	A10	A9	Address
A9	A19	A9	A8	
A8	A18	A8	A7	
A7	A17	A7	A6	
A6	A16	A6	A5	
A5	A15	A5	A4	
A4	A14	A4	A3	
A3	A13	A3	A2	
A2	A12	A2	A1	
A1	A11	A1	A0	
A0	A10	A0		Unused
Example of connected memory				
256-Mbit product (4 Mwords x 16 bits x 4 banks, column 10 bits product): 1 device				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

Table 7.15 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (6)-1

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
10 (16 bits)	**10 (13 bits)**	**01 (9 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A26	A17		Unused
A16	A25	A16		
A15	A24*2	A24*2	A14 (BA1)	Specifies bank
A14	A23*2	A23*2	A13 (BA0)	
A13	A22	A13	A12	Address
A12	A21	A12	A11	
A11	A20	L/H*1	A10/AP	Specifies address/precharge
A10	A19	A10	A9	Address
A9	A18	A9	A8	
A8	A17	A8	A7	
A7	A16	A7	A6	
A6	A15	A6	A5	
A5	A14	A5	A4	
A4	A13	A4	A3	
A3	A12	A3	A2	
A2	A11	A2	A1	
A1	A10	A1	A0	
A0	A9	A0		Unused
Example of connected memory				
256-Mbit product (4 Mwords x 16 bits x 4 banks, column 9 bits product): 1 device				

Notes: *1 L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2 Bank address specification

*3 Only the $\overline{\text{RASL}}$ pin is asserted because the A25 pin specified the bank address. $\overline{\text{RASU}}$ is not asserted.

Table 7.15 Relationship between A2/3BSZ[1:0], A2/3ROW[1:0], and Address Multiplex Output (6)-2

Setting				
A2/3 BSZ[1:0]	**A2/3 ROW[1:0]**	**A2/3 COL[1:0]**		
10 (16 bits)	**10 (13 bits)**	**10 (10 bits)**		
Output Pin of This LSI	**Row Address Output Cycle**	**Column Address Output Cycle**	**Synchronous DRAM Pin**	**Function**
A17	A27	A17		Unused
A16	A26	A16		
A15	A25*2*3	A25*2*3	A14 (BA1)	Specifies bank
A14	A24*2	A24*2	A13 (BA0)	
A13	A23	A13	A12	Address
A12	A22	A12	A11	
A11	A21	L/H*1	A10/AP	Specifies address/precharge
A10	A20	A10	A9	Address
A9	A19	A9	A8	
A8	A18	A8	A7	
A7	A17	A7	A6	
A6	A16	A6	A5	
A5	A15	A5	A4	
A4	A14	A4	A3	
A3	A13	A3	A2	
A2	A12	A2	A1	
A1	A11	A1	A0	
A0	A10	A0		Unused
Example of connected memory				
512-Mbit product (8 Mwords x 16 bits x 4 banks, column 10 bits product): 1 device				

Notes: *1. L/H is a bit used in the command specification; it is fixed at L or H according to the access mode.

*2. Bank address specification

*3. Only the $\overline{\text{RASL}}$ pin is asserted because the A25 pin specified the bank address. $\overline{\text{RASU}}$ is not asserted.

7.8.3 Burst Read

A burst read occurs in the following cases in this LSI.

- 16-byte transfer in cache miss.
- 16-byte transfer in DMAC (access to non-cacheable region)
- Access size in reading is larger than data bus width.

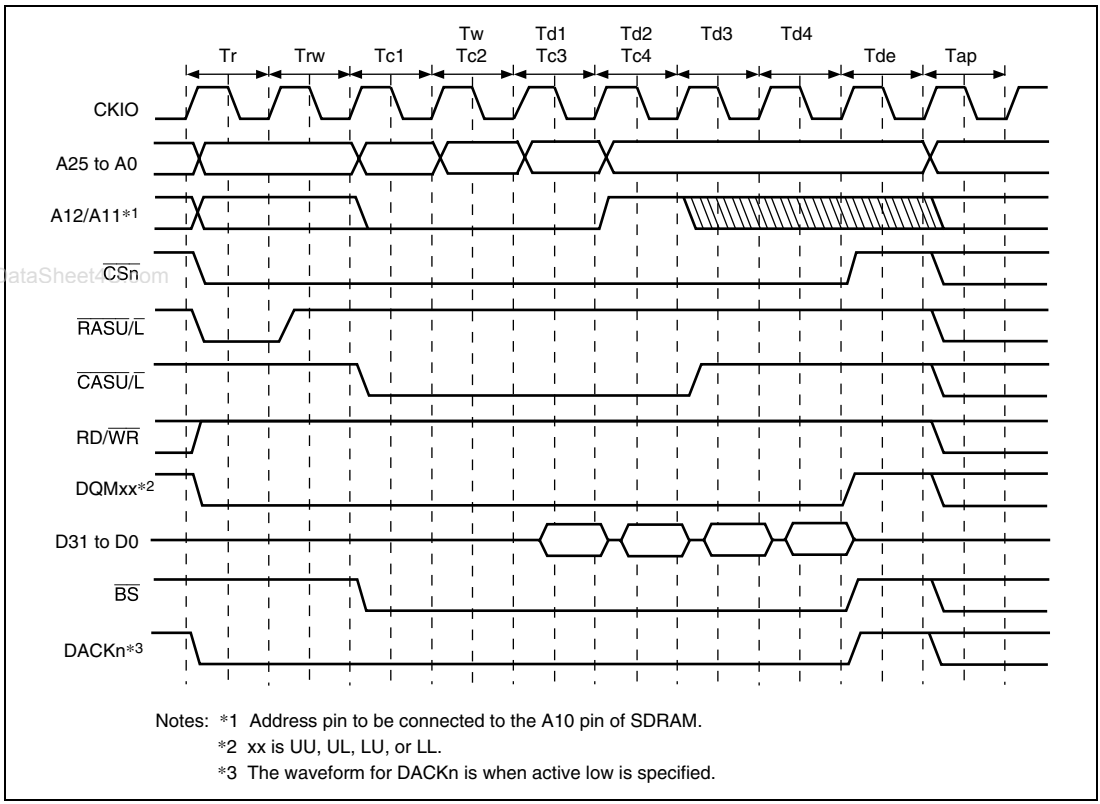
This LSI always accesses the SDRAM with burst length 1. For example, read access of burst length 1 is performed consecutively 4 times to read 16-byte continuous data from the SDRAM that is connected to a 32-bit data bus.

Table 7.16 shows the relationship between the access size and the number of bursts.

Table 7.16 Relationship between Access Size and Number of Bursts

Bus Width	Access Size	Number of Bursts
16 bits	8 bits	1
	16 bits	1
	32 bits	2
	16 bits	8
32 bits	8 bits	1
	16 bits	1
	32 bits	1
	16 bits	4

Figure 7.16 shows a timing chart in burst read. In burst read, an ACTV command is output in the Tr cycle, the READ command is issued in the Tc1, Tc2, and Tc3 cycles, the READA command is issued in the Tc4 cycle, and the read data is received at the rising edge of the external clock (CKIO) in the Td1 to Td4 cycles. The Tap cycle is used to wait for the completion of an auto-precharge induced by the READ command in the SDRAM. In the Tap cycle, a new command will not be issued to the same bank. However, access to another CS space or another bank in the same SDRAM space is enabled. The number of Tap cycles is specified by the TRP[1:0] bits of the CS3WCR register.



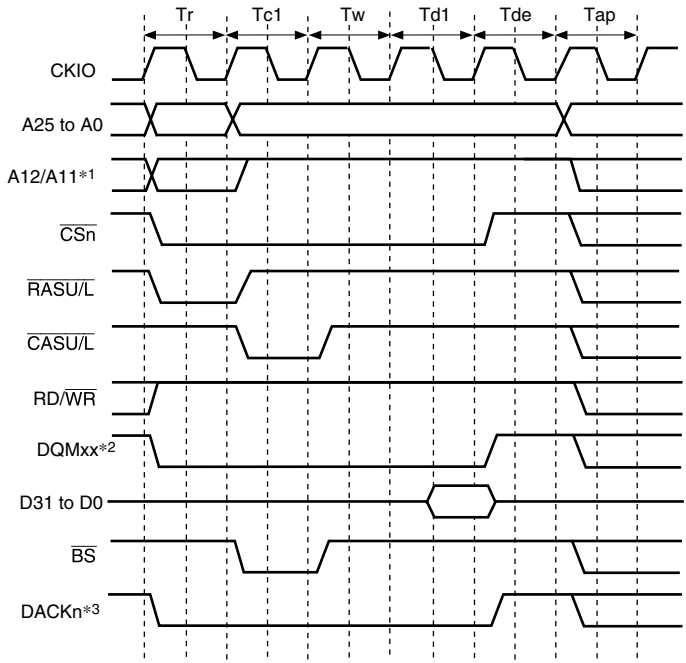
Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.16 Synchronous DRAM Burst Read Wait Specification Timing (Auto Pre-charge)

7.8.4 Single Read

A read access ends in one cycle when data exists in non-cacheable region and the data bus width is larger than or equal to access size. As the burst length is set to 1 in synchronous DRAM burst read/single write mode, only the required data is output. Consequently, no unnecessary bus cycles are generated even when a cache-through area is accessed.

Figure 7.17 shows the basic timing chart for single read.



Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL
*3 The waveform for DACKn is when active low is specified.

Figure 7.17 Basic Timing for Single Read (Auto Pre-charge)

7.8.5 Burst Write

A burst write occurs in the following cases in this LSI.

- Copyback of the cache
- 16-byte transfer in DMAC (access to non-cacheable region)
- Access size in writing is larger than data bus width.

This LSI always accesses SDRAM with burst length 1. For example, write access of burst length 1 is performed continuously 4 times to write 16-byte continuous data to the SDRAM that is connected to a 32-bit data bus.

The relationship between the access size and the number of bursts is shown in table 7.16.

Figure 7.18 shows a timing chart for burst writes. In burst write, an ACTV command is output in the Tr cycle, the WRIT command is issued in the Tc1, Tc2, and Tc3 cycles, and the WRITA command is issued to execute an auto-precharge in the Tc4 cycle. In the write cycle, the write data is output simultaneously with the write command. After the write command with the auto-precharge is output, the Trw1 cycle that waits for the auto-precharge initiation is followed by the Tap cycle that waits for completion of the auto-precharge induced by the WRITA command in the SDRAM. In the Tap cycle, a new command will not be issued to the same bank. However, access to another CS space or another bank in the same SDRAM space is enabled. The number of Trw1 cycles is specified by the TRWL[1:0] bits of the CS3WCR register. The number of Tap cycles is specified by the TRP[1:0] bits of the CS3WCR register.

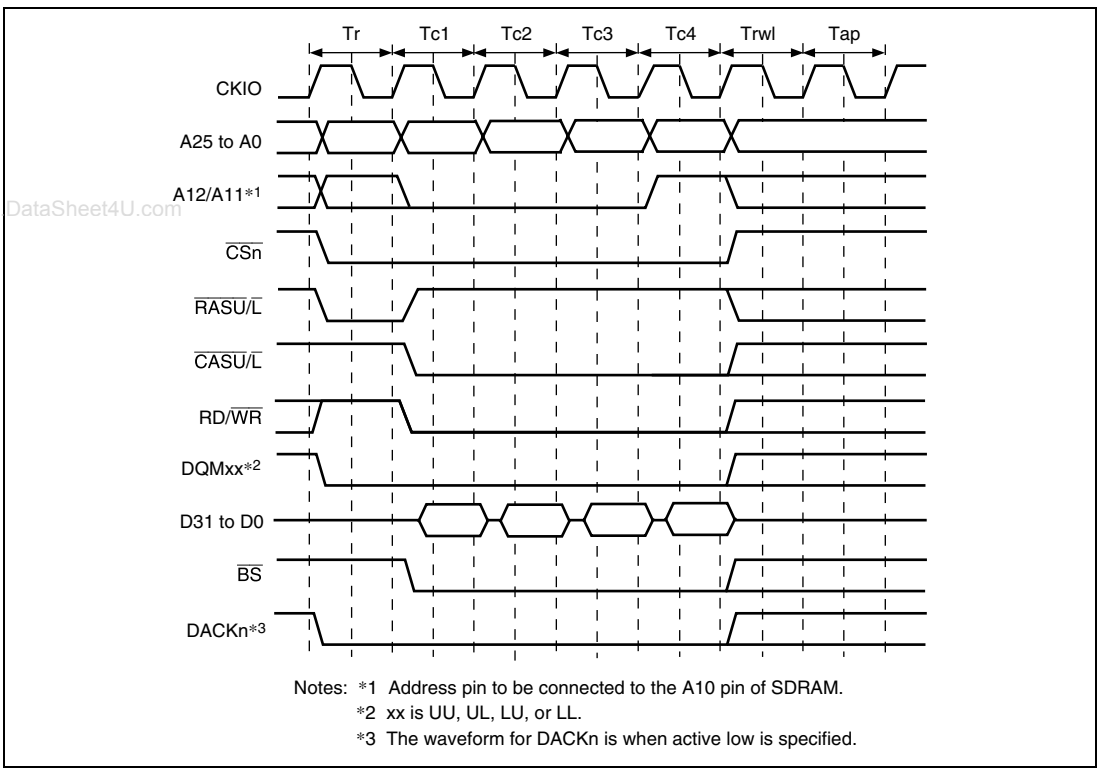
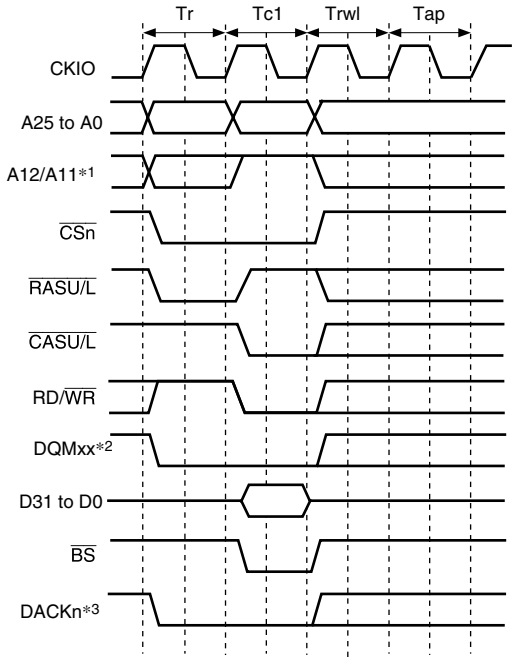


Figure 7.18 Basic Timing for Synchronous DRAM Burst Write (Auto Pre-charge)

7.8.6 Single Write

A write access ends in one cycle when data is written in non-cacheable region and the data bus width is larger than or equal to access size. This is called single write. Figure 7.19 shows the basic timing chart for single write.



Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.19 Basic Timing for Single Write (Auto Pre-charge)

7.8.7 Bank Active

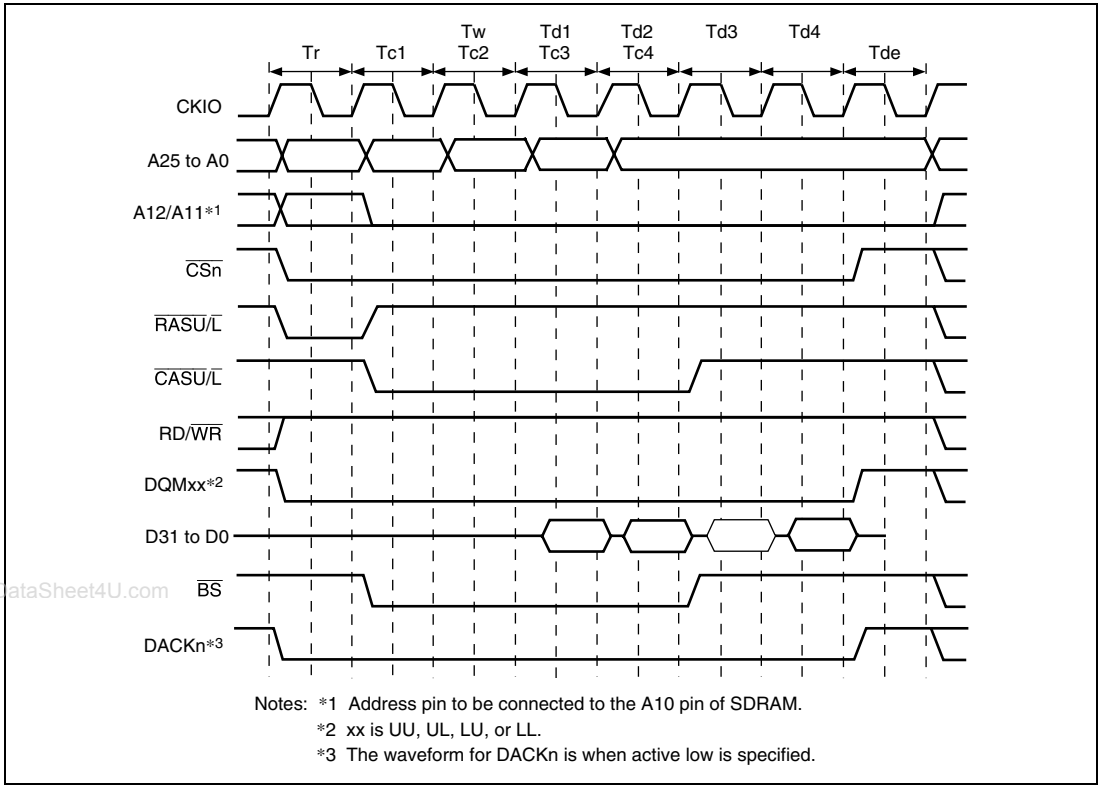
The synchronous DRAM bank function is used to support high-speed accesses to the same row address. When the BACTV bit in SDCR is 1, accesses are performed using commands (READ, WRIT) without auto-precharge. This function is called bank-active function. This function is valid only for either the upper or lower bits of area 3. When area 3 is set to bank-active mode, area 2 should be set to normal space or byte-selection SRAM. When areas 2 and 3 are both set to SDRAM or both the upper and lower bits of area 3 are connected to SDRAM, auto pre-charge mode must be set. In this case, precharging is not performed when the access ends. When accessing the same row address in the same bank, it is possible to issue the READ or WRIT command immediately, without issuing an ACTV command. As synchronous DRAM is internally divided into several banks, it is possible to activate one row address in each bank. If the next access is to a different row address, a PRE command is first issued to precharge the relevant bank, then when precharging is completed, the access is performed by issuing an ACTV command followed by a READ or WRIT command. If this is followed by an access to a different row address, the access time will be longer because of the precharging performed after the access request is issued.

In a write, when auto-precharge is performed, a command cannot be issued for a period of Trwl + Tpc cycles after issuance of the WRITA command. When bank active mode is used, READ or WRIT commands can be issued successively if the row address is the same. The number of cycles can thus be reduced by Trwl + Tpc cycles for each write.

There is a limit on t_{RAS}, the time for placing each bank in the active state. If there is no guarantee that there will not be a cache hit and another row address will be accessed within the period in which this value is maintained by program execution, it is necessary to set auto-refresh and set the refresh cycle to no more than the maximum value of t_{RAS}.

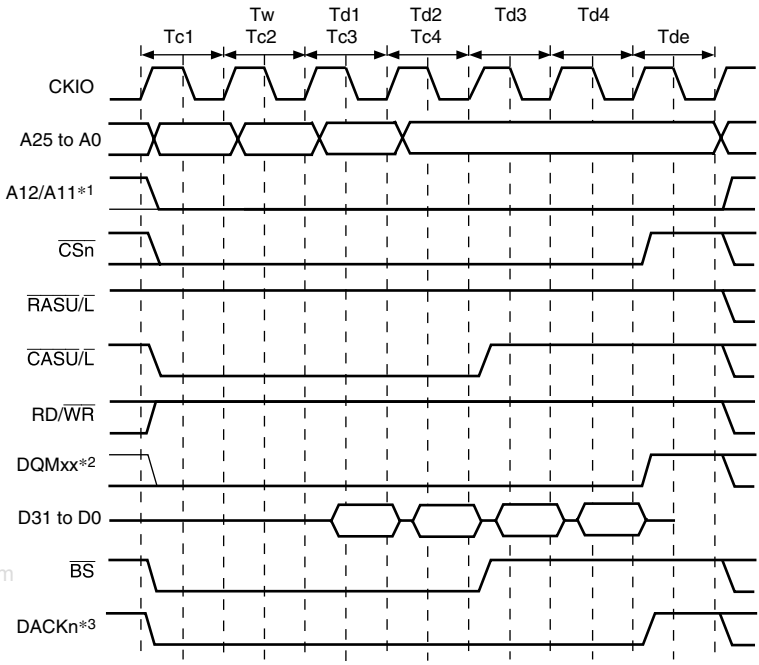
A burst read cycle without auto-precharge is shown in figure 7.20, a burst read cycle for the same row address in figure 7.21, and a burst read cycle for different row addresses in figure 7.22. Similarly, a burst write cycle without auto-precharge is shown in figure 7.23, a single write cycle for the same row address in figure 7.24, and a single write cycle for different row addresses in figure 7.25.

When bank active mode is set, if only accesses to the respective banks in the area 3 space are considered, as long as accesses to the same row address continue, the operation starts with the cycle in figure 7.20 or 7.23, followed by repetition of the cycle in figure 7.21 or 7.24. An access to a different area during this time has no effect. If there is an access to a different row address in the bank active state, after this is detected the bus cycle in figure 7.22 or 7.25 is executed instead of that in figure 7.21 or 7.24. In bank active mode, too, all banks become inactive after a refresh cycle or after the bus is released as the result of bus arbitration.



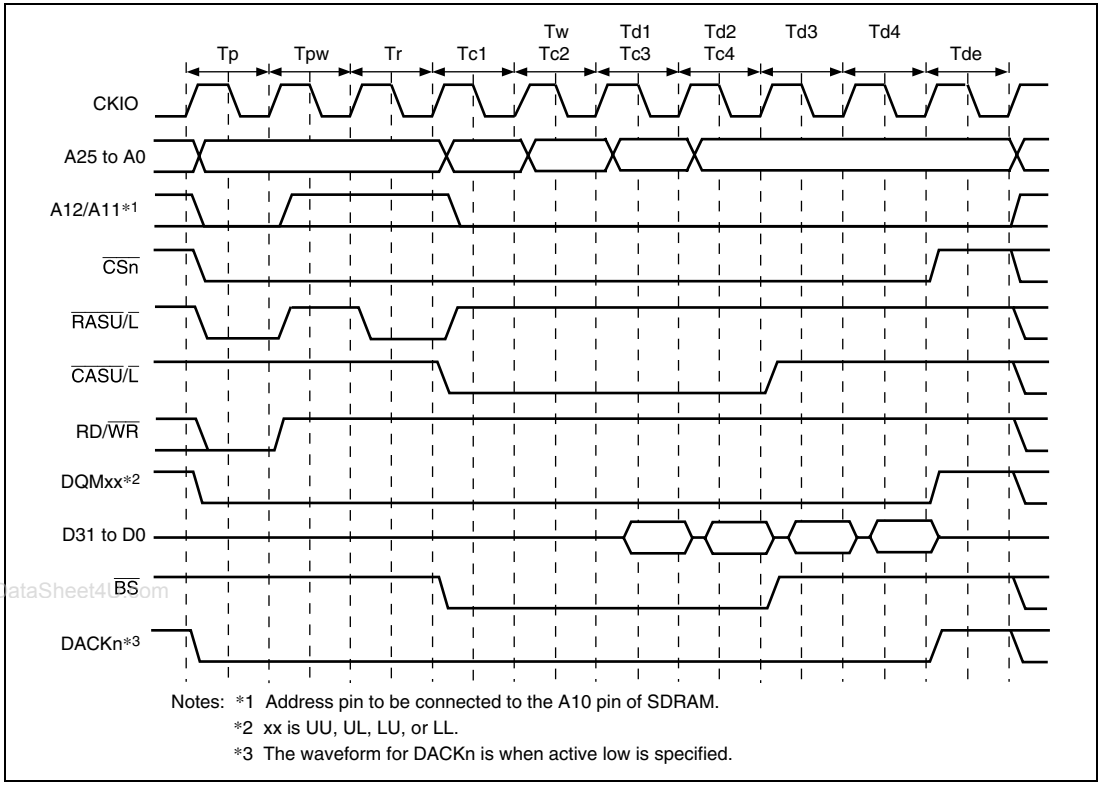
Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.20 Burst Read Timing (No Auto Precharge)



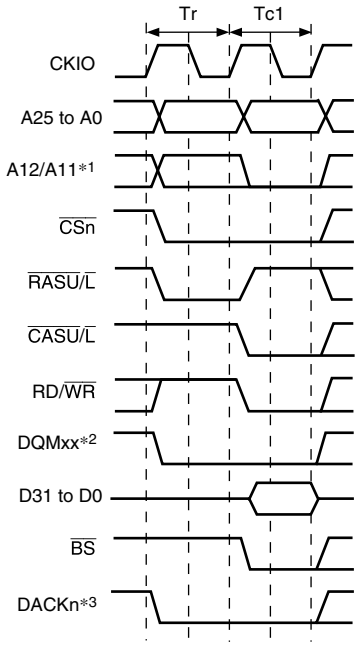
Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.21 Burst Read Timing (Bank Active, Same Row Address)



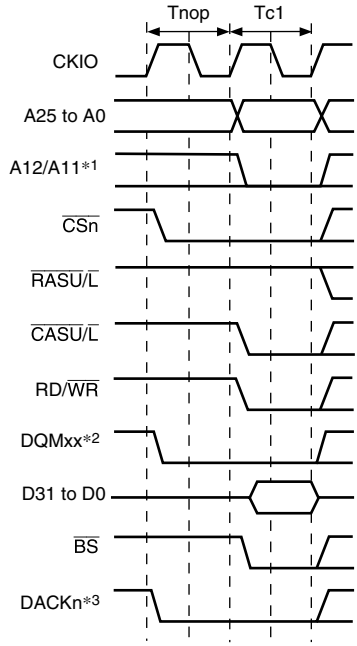
Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.22 Burst Read Timing (Bank Active, Different Row Addresses)



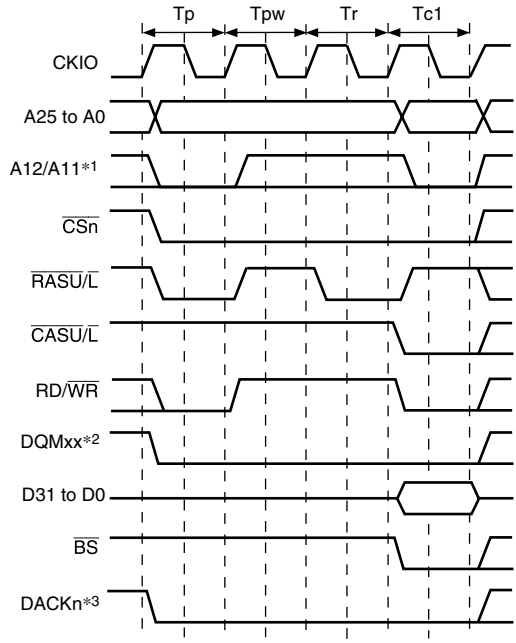
Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.23 Single Write Timing (No Auto Precharge)



Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.24 Single Write Timing (Bank Active, Same Row Address)



Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.25 Single Write Timing (Bank Active, Different Row Addresses)

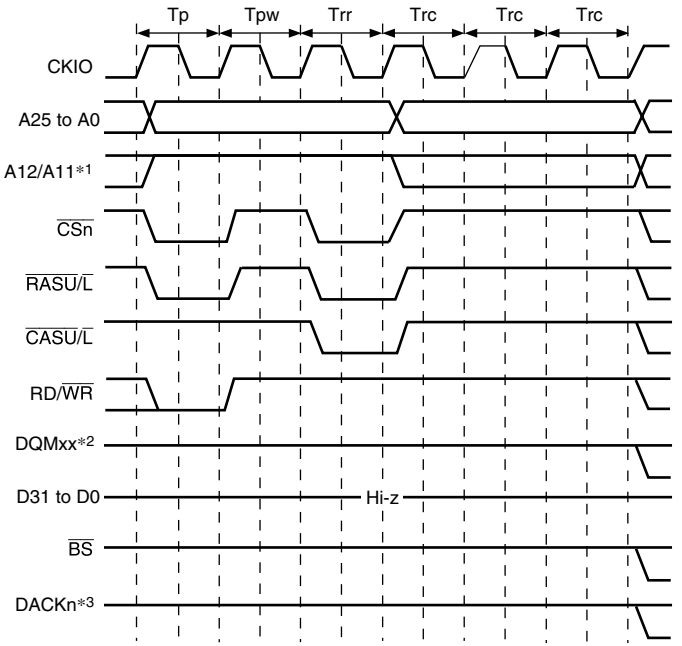
7.8.8 Refreshing

This LSI has a function for controlling synchronous DRAM refreshing. Auto-refreshing can be performed by clearing the RMODE bit to 0 and setting the RFSH bit to 1 in SDCR. A continuous refreshing can be performed by setting the RRC[2:0] bits in RTCSR. If synchronous DRAM is not accessed for a long period, self-refresh mode, in which the power consumption for data retention is low, can be activated by setting both the RMODE bit and the RFSH bit to 1.

1. Auto-refreshing

   Refreshing is performed for the number of times specified by bits RRC[2:0] in RTCSR at intervals determined by the input clock selected by bits CKS[2:0] in RTCSR, and the value set in RTCOR. The value of these bits should be set so as to satisfy the refresh interval stipulation for the synchronous DRAM used. First make the settings for RTCOR, RTCNT, and the RMODE and RFSH bits in SDCR, then make bits CKS[2:0] and RRC[2:0] settings in RTCSR. When the clock is selected by bits CKS[2:0], RTCNT starts counting up from the value at that time. The RTCNT value is constantly compared with the RTCOR value, and if the two values are the same, a refresh request is generated and auto-refresh is performed for the number of times specified by bits RRC[2:0]. At the same time, RTCNT is cleared to zero and the count-up is restarted. Figure 7.26 shows the auto-refresh cycle timing.

   After starting, the auto refreshing, PALL command is issued in the Tp cycle to make all the banks to pre-charged state from active state when some bank is being pre-charged. Then REF command is issued in the Trr cycle after inserting idle cycles of which number is specified by the TRP[1:0] bits in CSnWCR. A new command is not issued for the duration of the number of cycles specified by the TRC[1:0] bits in CSnWCR after the Trr cycle. The TRC[1:0] bits must be set so as to satisfy the SDRAM refreshing cycle time stipulation (t_{RC}). A NOP cycle is inserted between the Tp cycle and Trr cycle when the setting value of the TRP[1:0] bits in CSnWCR is longer than or equal to 2 cycles.



Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.26 Auto-Refresh Timing

2. Self-refreshing

Self-refresh mode in which the refresh timing and refresh addresses are generated within the synchronous DRAM. Self-refreshing is activated by setting both the RMODE bit and the RFSH bit in SDCR to 1. After starting the self-refreshing, PALL command is issued in Tp cycle after the completion of the pre-charging bank. A SELF command is then issued after inserting idle cycles of which number is specified by the TRP[1:0] bits in CSnWSR. Synchronous DRAM cannot be accessed while in the self-refresh state. Self-refresh mode is cleared by clearing the RMODE bit to 0. After self-refresh mode has been cleared, command issuance is disabled for the number of cycles specified by the TRC[1:0] bits in CSnWCR. Self-refresh timing is shown in figure 7.27. Settings must be made so that self-refresh clearing and data retention are performed correctly, and auto-refreshing is performed at the correct intervals. When self-refreshing is activated from the state in which auto-refreshing is set, auto-refreshing is restarted if the RFSH bit is set to 1 and the RMODE bit is cleared to 0 when self-refresh mode is cleared. If the transition from clearing of self-refresh mode to the start of auto-refreshing takes time, this time should be taken into consideration when setting the initial value of RTCNT. Making the RTCNT value 1 less than the RTCOR value will enable refreshing to be started immediately.

After self-refreshing has been set, the self-refresh state continues even if the chip standby state is entered using the LSI standby function, and is maintained even after recovery from standby mode other than through a power-on reset. In case of a power-on reset, the bus state controller's registers are initialized, and therefore the self-refresh state is cleared.

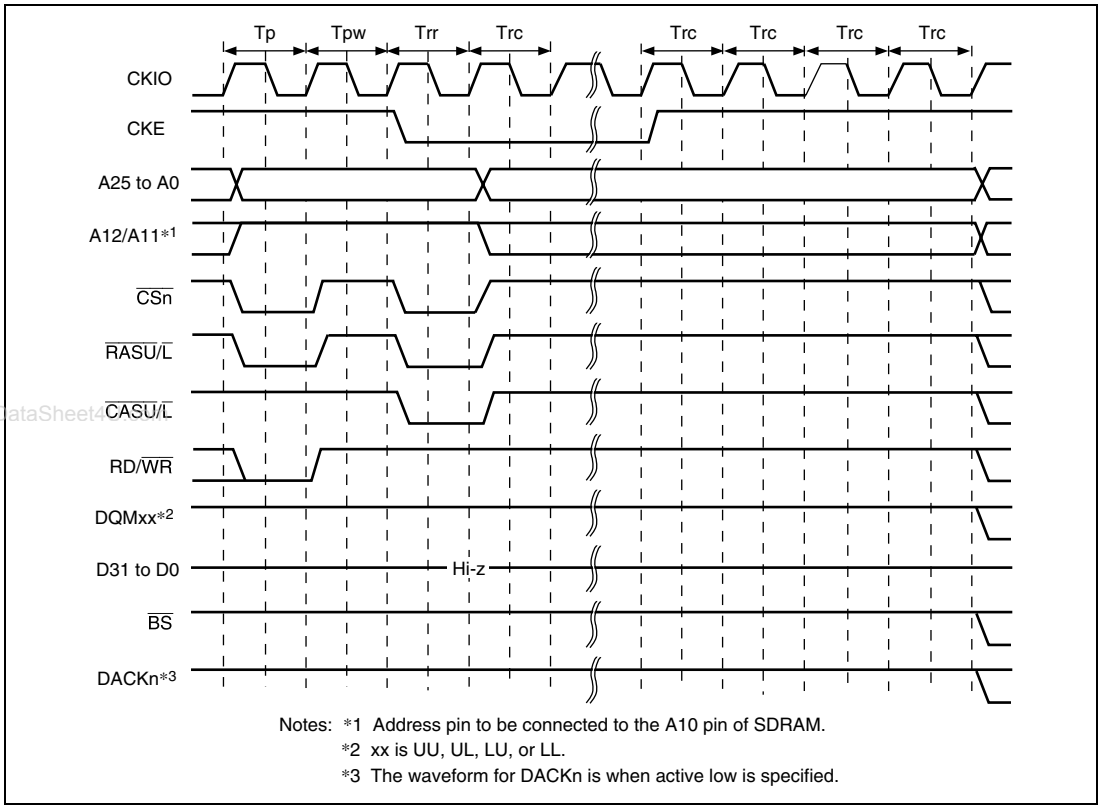


Figure 7.27 Self-Refresh Timing

3. Relationship between refresh requests and bus cycle

   If a refresh request is generated during a bus cycle, refresh waits for the bus cycle to be completed. If a refresh request is generated while the bus is released by the bus arbitration function, refresh waits for the bus mastership to be obtained.

   If a new refresh request is generated while refresh is waiting, the first refresh request is canceled. To perform refresh correctly, the bus cycle and the bus-owned period must be shorter than the refresh interval.

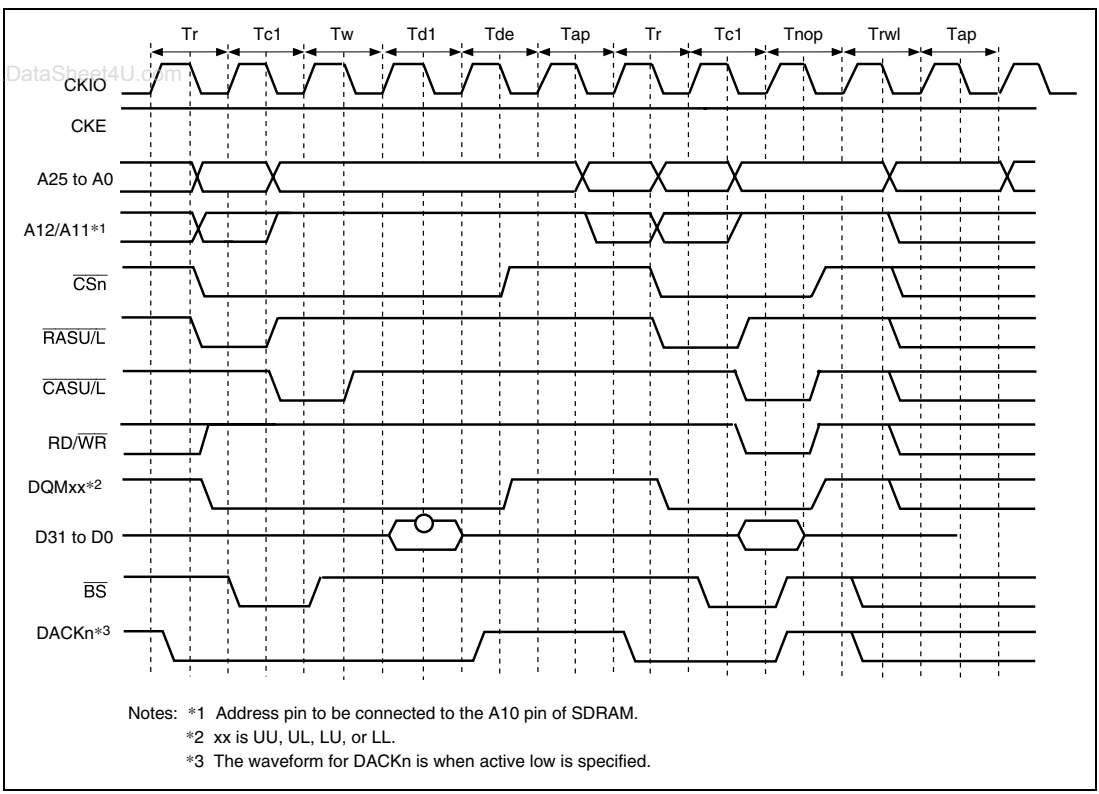
   If a bus request is issued during self-refreshing, the bus is not released until the refresh is completed.

7.8.9 Low-Frequency Mode

When the SLOW bit in SDCR is set to 1, output of commands, addresses, and write data, and fetch of read data are performed at a timing suitable for operating SDRAM at a low frequency.

Figure 7.28 shows the access timing in low-frequency mode. In this mode, commands, addresses, and write data are output in synchronization with the falling edge of CKIO, which is half a cycle delayed than the normal timing. Read data is fetched at the rising edge of CKIO, which is half a cycle faster than the normal timing. This timing allows the hold time of commands, addresses, write data, and read data to be extended.

If SDRAM is operated at a high frequency with the SLOW bit set to 1, the setup time of commands, addresses, write data, and read data are not guaranteed. Take the operating frequency and timing design into consideration when making the SLOW bit setting.



Notes: *1 Address pin to be connected to the A10 pin of SDRAM.
*2 xx is UU, UL, LU, or LL.
*3 The waveform for DACKn is when active low is specified.

Figure 7.28 Low-Frequency Mode Access Timing

7.8.10 Power-On Sequence

In order to use synchronous DRAM, mode setting must first be performed after powering on. To perform synchronous DRAM initialization correctly, the bus state controller registers must first be set, followed by a write to the synchronous DRAM mode register. In synchronous DRAM mode register setting, the address signal value at that time is latched by a combination of the $\overline{CSn}$, $\overline{RAS}$, $\overline{CAS}$, and RD/$\overline{WR}$ signals. If the value to be set is X, the bus state controller provides for value X to be written to the synchronous DRAM mode register by performing a write to address H'A4FD4000 + X for area 2 synchronous DRAM, and to address H'A4FD5000 + X for area 3 synchronous DRAM. In this operation the data is ignored, but the mode write is performed as a byte-size access. To set burst read/single write, CAS latency 2 to 3, wrap type = sequential, and burst length 1 supported by the LSI, arbitrary data is written in a byte-size access to the addresses shown in table 7.17. In this time 0 is output at the external address pins of A12 or later.

Table 7.17 Access Address in SDRAM Mode Register Write

(1) Setting for Area 2 (SDMR2)

Burst read/single write (burst length 1):

Data Bus Width	CAS Latency	Access Address	External Address Pin
16 bits	2	H′A4FD4440	H′0000440
	3	H′A4FD4460	H′0000460
32 bits	2	H′A4FD4880	H′0000880
	3	H′A4FD48C0	H′00008C0

Burst read/burst write (burst length 1):

Data Bus Width	CAS Latency	Access Address	External Address Pin
16 bits	2	H′A4FD4040	H′0000040
	3	H′A4FD4060	H′0000060
32 bits	2	H′A4FD4080	H′0000080
	3	H′A4FD40C0	H′00000C0

(2) Setting for Area 3 (SDMR3)

Burst read/single write (burst length 1):

Data Bus Width	CAS Latency	Access Address	External Address Pin
16 bits	2	H′A4FD5440	H′0000440
	3	H′A4FD5460	H′0000460
32 bits	2	H′A4FD5880	H′0000880
	3	H′A4FD58C0	H′00008C0

Burst read/burst write (burst length 1):

Data Bus Width	CAS Latency	Access Address	External Address Pin
16 bits	2	H′A4FD5040	H′0000040
	3	H′A4FD5060	H′0000060
32 bits	2	H′A4FD5080	H′0000080
	3	H′A4FD50C0	H′00000C0

Mode register setting timing is shown in figure 7.29. A PALL command (all bank pre-charge command) is firstly issued. A REF command (auto refresh command) is then issued 8 times. An MRS command (mode register write command) is finally issued. Idle cycles, of which number is specified by the TRP[1:0] bits in CSnWCR, are inserted between the PALL and the first REF. Idle cycles, of which number is specified by the TRC[1:0] bits in CSnWCR, are inserted between REF and REF, and between the 8th REF and MRS. Idle cycles, of which number is one or more, are inserted between the MRS and a command to be issued next.

It is necessary to keep idle time of certain cycles for SDRAM before issuing PALL command after power-on. Refer the manual of the SDRAM for the idle time to be needed. When the pulse width of the reset signal is longer then the idle time, mode register setting can be started immediately after the reset, but care should be taken when the pulse width of the reset signal is shorter than the idle time.

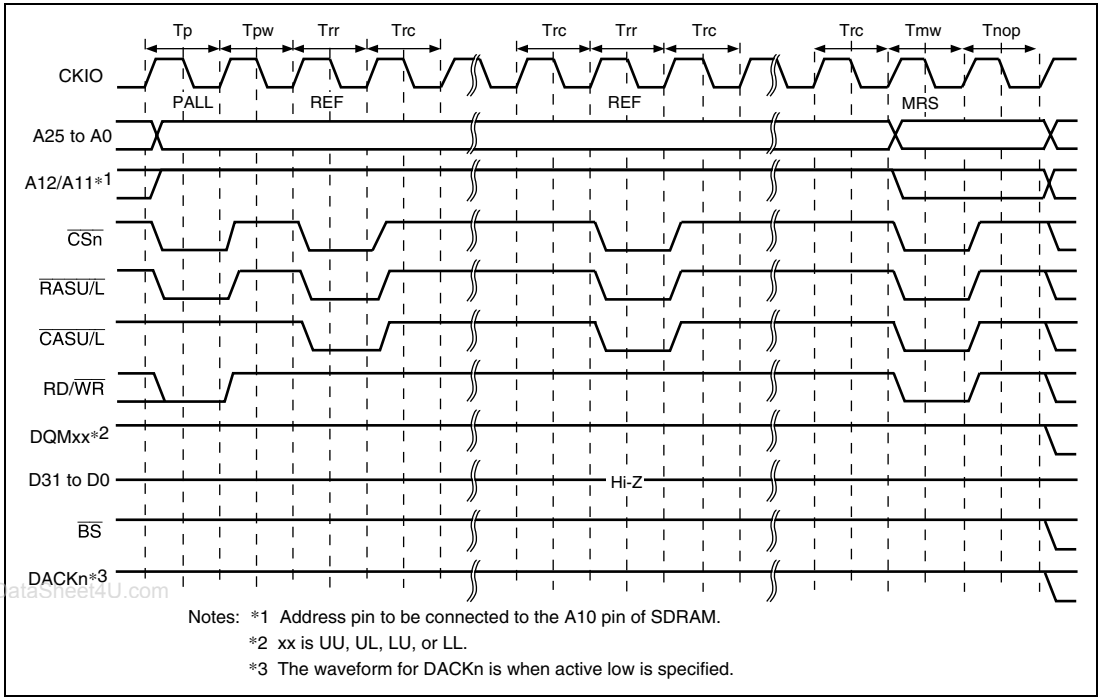


Figure 7.29 Synchronous DRAM Mode Write Timing (Based on JEDEC)

7.9 Burst ROM Interface

The burst ROM interface is provided to access ROM that has the page mode function, such as flash memory, in high speed. Basically the access to the ROM is performed in the same way as for normal space. When the first cycle is terminated, however, negation of the $\overline{RD}$ signal is not executed. The accesses after the 2nd access are performed by exchanging only the address. In the accesses after the 2nd access, the address is changed at the falling edge of CKIO.

The number of wait cycles specified by the W[3:0] bits in CSnWCR are inserted for the first access cycle. The number of wait cycles specified by the BW[1:0] bits in CSnWCR are inserted for the second and subsequent access cycles.

In the access to the burst ROM, the $\overline{BS}$ signal is asserted only to the first access cycle. An external wait input is valid only to the first access cycle. In the single access or write access that do not perform the burst operation in the burst ROM interface, access timing is same as a normal space. Table 7.18 lists a relationship between bus width, access size, and the number of bursts. Figure 7.30 shows a timing chart.

Table 7.18 Relationship between Bus Width, Access Size, and Number of Bursts

Bus Width	Access Size	Number of Bursts
8 bits	8 bits	1
	16 bits	2
	32 bits	4
	16 bytes	16
16 bits	8 bits	1
	16 bits	1
	32 bits	2
	16 bytes	8

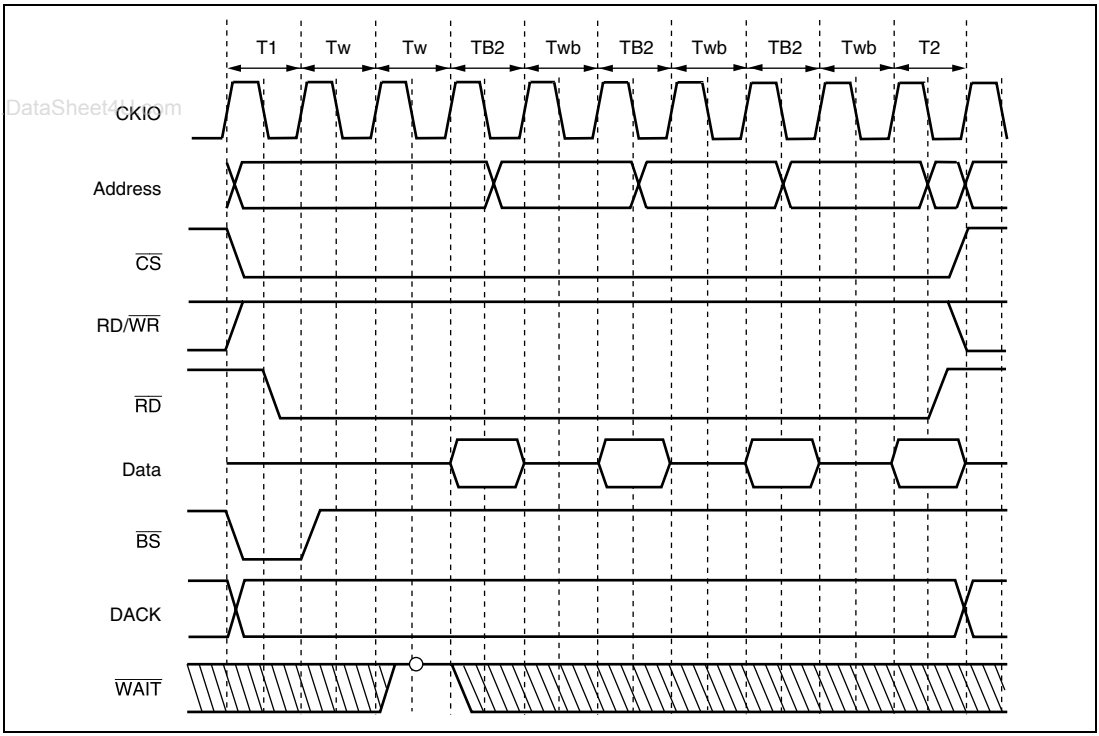
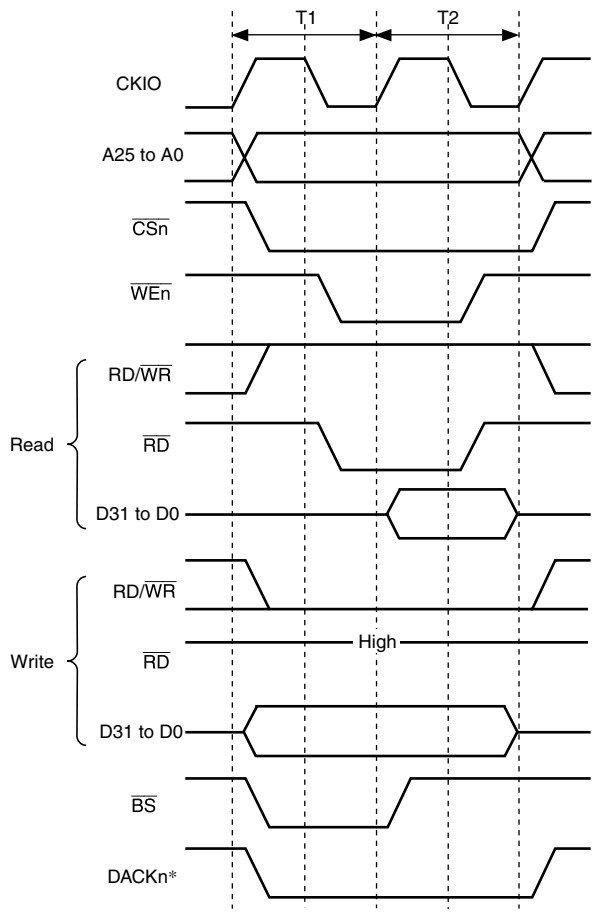


Figure 7.30 Burst ROM Access (bus width 8 bits, access size 32 bits (number of burst 4), access wait for the 1st time 2, access wait for 2nd time and after 1)

7.10 Byte-Selection SRAM Interface

The byte-selection SRAM interface is for outputting the byte-selection signal ($\overline{WEn}$) in both read and write bus cycles. This interface has 16-bit data pins and accesses SRAM that has an upper byte-selection pin and a lower byte-selection pin, such as UB and LB. The write access timing is the same as that for the normal space interface. The read access timing differs from that for the normal space interface in the $\overline{WEn}$ timing, and a byte-selection signal is output from the $\overline{WEn}$ pin. The basic access timing is shown in figure 7.31.

Note that in a write cycle, data is written in accordance with the byte-selection pin ($\overline{WEn}$) timing. Check the data sheet of the memory to be used for the actual timing.



Note: * The waveform for DACKn is when active low is specified.

Figure 7.31 Byte-Selection SRAM Basic Access Timing

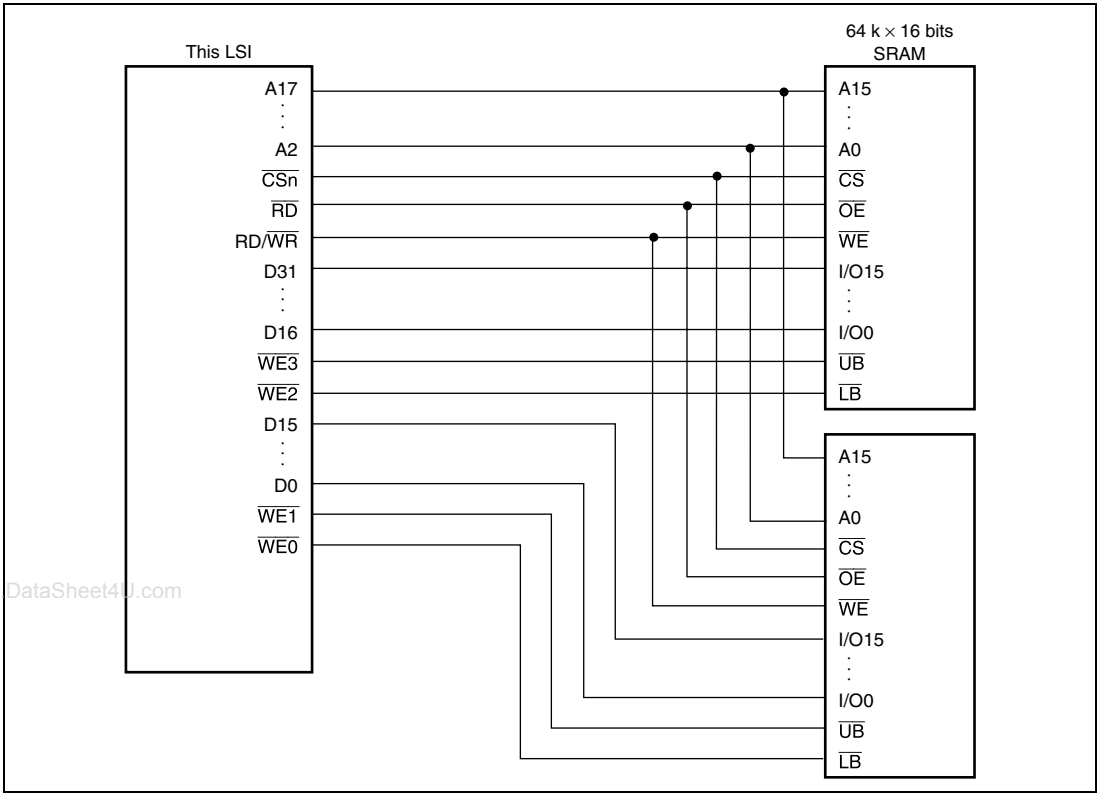


Figure 7.32 Example of Connection with 32-Bit Data-Width Byte-Selection SRAM

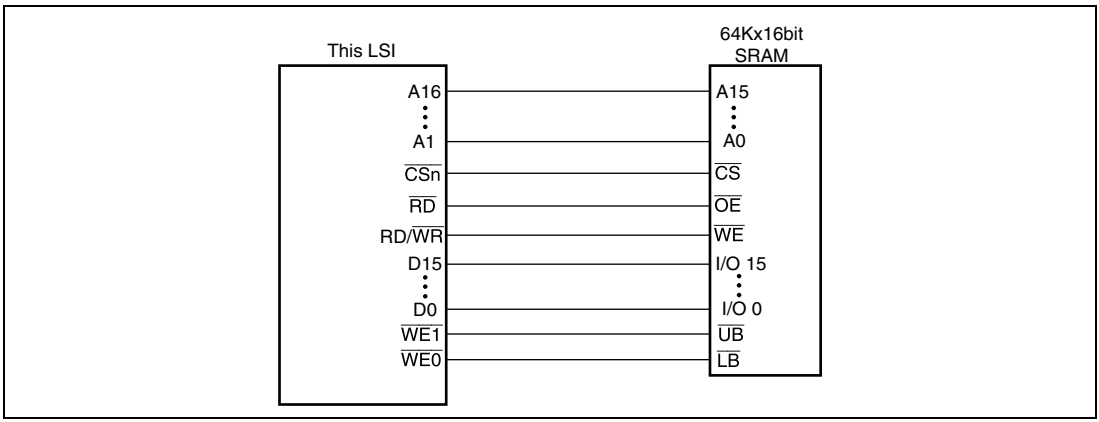


Figure 7.33 Example of Connection with 16-Bit Data-Width Byte-Selection SRAM

7.11 Wait between Access Cycles

As the operating frequency of LSIs becomes higher, the off-operation of the data buffer often collides with the next data access when the read operation from devices with slow access speed is completed. As a result of these collisions, the reliability of the device is low and malfunctions may occur. A function that avoids data collisions by inserting wait cycles between continuous access cycles has been newly added.

The number of wait cycles between access cycles can be set by bits IWW[1:0], IWRWD[1:0], IWRWS[1:0], IWRRD[1:0], and IWRRS[1:0] in CSnBCR, and bits DMAIW[1:0] and DMAIWA in CMNCR. The conditions for setting the wait cycles between access cycles (idle cycles) are shown below.

1. Continuous accesses are write-read or write-write
2. Continuous accesses are read-write for different spaces
3. Continuous accesses are read-write for the same space
4. Continuous accesses are read-read for different spaces
5. Continuous accesses are read-read for the same space
6. Data output from an external device caused by DMA single transfer is followed by data output from another device that includes this LSI (DMAIWA = 0)
7. Data output from an external device caused by DMA single transfer is followed by any type of access (DMAIWA = 1)

7.12 Bus Arbitration

This LSI supports bus arbitration. This LSI has bus mastership in the normal state and releases bus mastership after receiving a bus request from another device.

To prevent device malfunction while the bus mastership is transferred between master and slave, the LSI negates all of the bus control signals before bus release. When the bus mastership is received, all of the bus control signals are first negated and then driven appropriately. In this case, output buffer conflicts can be prevented because the master and slave drive the same signals with the same values. In addition, to prevent noise while the bus control signal is in the high-impedance state, pull-up resistors must be connected to these control signals.

Bus mastership is transferred at the boundary of bus cycles. Namely, bus mastership is released immediately after receiving a bus request when a bus cycle is not being performed. The release of bus mastership is delayed until the bus cycle is complete when a bus cycle is in progress. Even when from outside the LSI it looks like a bus cycle is not being performed, a bus cycle may be performing internally, started by inserting wait cycles between access cycles. Therefore, it cannot be immediately determined whether or not bus mastership has been released by looking at the $\overline{\text{CSn}}$ signal or other bus control signals. The states that do not allow bus mastership release are shown below.

1. 16-byte transition because of a cache miss
2. During copyback operation for the cache
3. Between the read and write cycles of a TAS instruction
4. Multiple bus cycles generated when data bus width is smaller than the access size (For example, between bus cycles when longword access is made to memory with a data bus width of 8 bits.)
5. 16-byte transfer by the DMAC

If self-refresh mode is specified for the SDRAM, the master device cannot release the bus. If the master clock stops because a transition is underway to standby mode or the frequency is changed, or if this LSI is being reset, the master device cannot release the bus. To prevent the slave from issuing bus requests in such a case, the slave must be put into the sleep state so that no slave access cycles are generated.

The refresh request and bus request are accepted during the DMA burst transfer.

Bus mastership is maintained until a new bus request is received. Bus mastership is released immediately after the completion of the bus cycle in progress when an external bus request ($\overline{\text{BREQ}}$) is asserted (low level) and a bus acknowledge signal ($\overline{\text{BACK}}$) is asserted (low level). Bus use is resumed when a negation (high level) of $\overline{\text{BREQ}}$, which shows that the slave has released the bus, has been received.

SDRAM issues all bank pre-charge commands (PALLs) when active banks exist and releases the bus after completion of a PALL command.

The bus release sequence is as follows. The address bus and data bus are placed in a high-impedance state synchronized with the rising edge of CKIO. The bus mastership enable signal is asserted 0.5 cycles after the above timing, synchronized with the falling edge of CKIO. Bus control signals ($\overline{\text{BS}}$, $\overline{\text{CSn}}$, $\overline{\text{RASU}}$, $\overline{\text{RASL}}$, $\overline{\text{CASU}}$, $\overline{\text{CASL}}$, DQMxx, $\overline{\text{WEn}}$, $\overline{\text{RD}}$, and RD/$\overline{\text{WR}}$) are made to the high-impedance states at the subsequent rising edge of CKIO. Bus request signals are sampled at the falling edge of CKIO. The sequence for re-claiming bus mastership from a slave is described below. After detecting the negation of $\overline{\text{BREQ}}$ at the falling edge of CKIO, the bus enable signal is negated at the subsequent falling edge of the clock. The address and data signals are driven at the subsequent rising edge of CKIO. Figure 7.34 shows the bus arbitration timing.

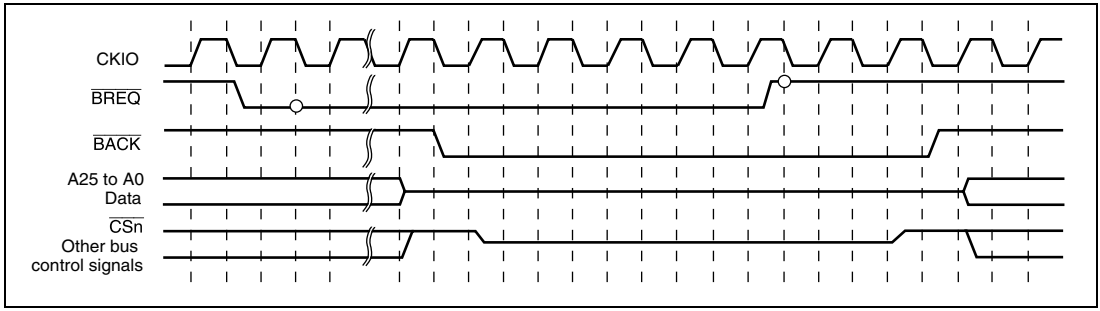


Figure 7.34 Bus Arbitration

In an original slave device designed by the user, multiple bus accesses are generated continuously to reduce the overhead caused by bus arbitration. In this case, to execute SDRAM refresh correctly, the slave device must be designed to release the bus mastership within the refresh interval time.

The bus release by the $\overline{\text{BREQ}}$ and $\overline{\text{BACK}}$ signal handshaking requires some overhead. If the slave has many tasks, multiple bus cycles should be executed in a bus mastership acquisition. Reducing the cycles required for master to slave bus mastership transitions streamlines the system design.

7.13 Others

Reset: The bus state controller (BSC) can be initialized completely only at power-on reset. At power-on reset, all signals are negated and output buffers are turned off regardless of the bus cycle state. All control registers are initialized.

In standby, sleep, and manual reset, control registers of the bus state controller are not initialized. At manual reset, the current bus cycle being executed is completed and then the access wait state is entered. If a 16-byte transfer is performed by a cache or if another LSI on-chip bus master module is executed when a manual reset occurs, the current access is cancelled in longword units because the access request is cancelled by the bus master at manual reset. If a manual reset is requested during cache fill operations, the contents of the cache cannot be guaranteed. Since the RTCNT continues counting up during manual reset signal assertion, a refresh request occurs to initiate the refresh cycle.

On-Chip Peripheral Module Access: To access an on-chip module register, two or more peripheral module clock (Pϕ) cycles are required. Care must be taken in system design.

Section 8 Direct Memory Access Controller (DMAC)

This LSI includes the direct memory access controller (DMAC). The DMAC can be used in place of the CPU to perform high-speed transfers between external devices with DACK (transfer request acknowledge signal), external memory, memory-mapped external devices, and on-chip peripheral modules.

8.1 Features

- Four channels (two channels can receive an external request)
- 4-Gbyte physical address space
- Data transfer unit: Byte, word (2 bytes), longword (4 bytes), and 16 bytes (longword × 4)
- Maximum transfer count: 16777216 transfers
- Address mode: Dual address mode or single address mode can be selected.
- Transfer requests: External request, on-chip peripheral module request, or auto request can be selected.

  The following modules can issue an on-chip peripheral module request.

  SCIF0, SCIF2, CMT, USB, and A/D converter
- Bus modes: Cycle steal mode (normal mode and intermittent mode 16/64) or burst mode can be selected.
- Selectable channel priority levels:

  The channel priority levels are selectable between fixed mode and round-robin mode.
- Interrupt request: An interrupt request can be generated to the CPU after transfers end.
- External request detection: Low-/high-level or rising/falling edge detection of DREQ input can be selected.
- Transfer request acknowledge signal: Active levels for DACK can be set independently.
- Transfer end signal: Active level for TEND can be set. TEND is output at the same timing as DACK in the last DMA transfer. (Only channel 0)

Figure 8.1 shows the block diagram of the DMAC.

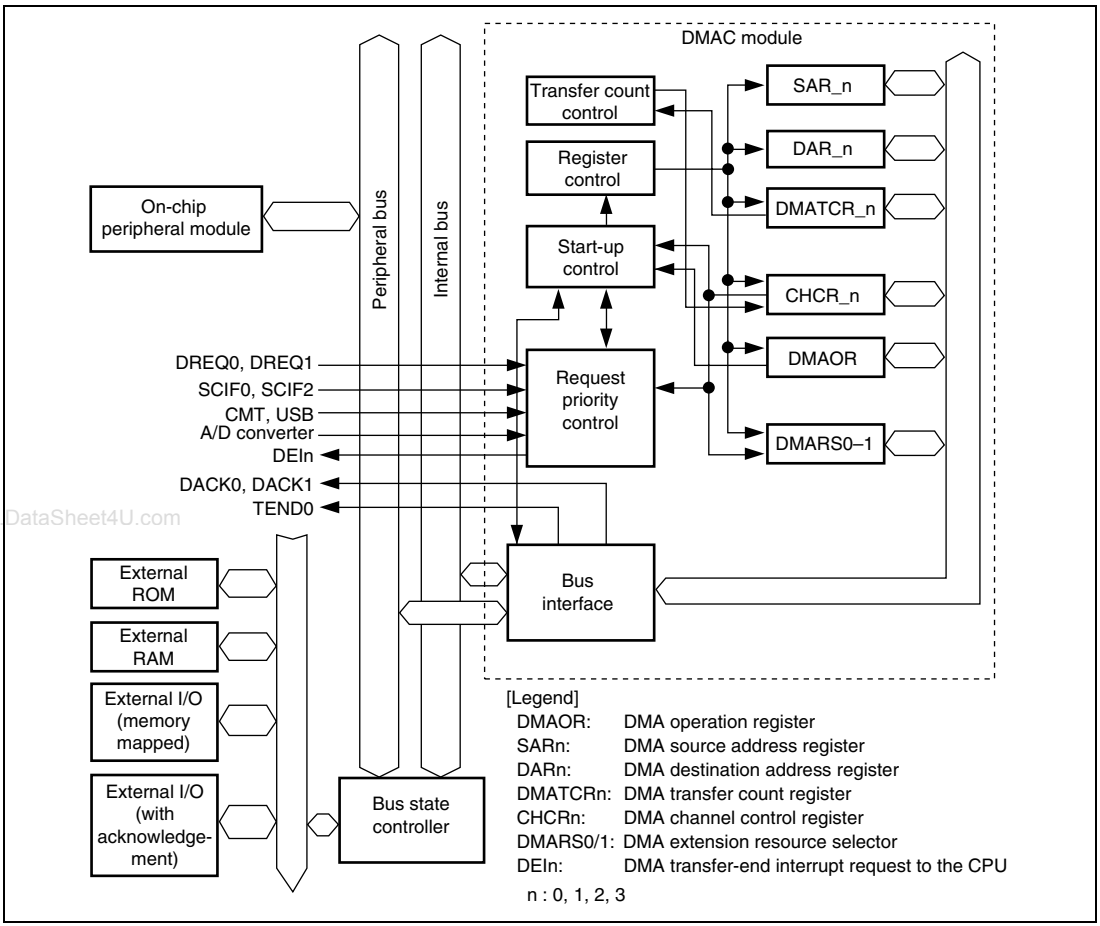


Figure 8.1 Block Diagram of DMAC

8.2 Input/Output Pins

The external pins for the DMAC are described below.

Table 8.1 lists the configuration of the pins that are connected to external bus. The DMAC has pins for 2 channels (channels 0 and 1) for external bus use. Channel 0 has the DMA transfer end signal.

Table 8.1 Pin Configuration

Channel	Name	Symbol	I/O	Function
0	DMA transfer request	DREQ0	I	DMA transfer request input from external device to channel 0
	DMA transfer request acknowledge	DACK0	O	DMA transfer request acknowledge output from channel 0 to external device
	DMA transfer end	TEND0	O	Transfer end output in channel 0
1	DMA transfer request	DREQ1	I	DMA transfer request input from external device to channel 1
	DMA transfer request acknowledge	DACK1	O	DMA transfer request acknowledge output from channel 1 to external device

8.3 Register Descriptions

The DMAC has the following registers. See section 24, List of Registers, for the addresses of these registers and the states of them in each processing state. The SAR for channel 0 is expressed such as SAR_0.

1. Channel 0

- DMA source address register_0 (SAR_0)
- DMA destination address register_0 (DAR_0)
- DMA transfer count register_0 (DMATCR_0)
- DMA channel control register_0 (CHCR_0)

2. Channel 1

- DMA source address register_1 (SAR_1)
- DMA destination address register_1 (DAR_1)
- DMA transfer count register_1 (DMATCR_1)
- DMA channel control register _1 (CHCR_1)

3. Channel 2
- DMA source address register_2 (SAR_2)
- DMA destination address register_2 (DAR_2)
- DMA transfer count register_2 (DMATCR_2)
- DMA channel control register_2 (CHCR_2)

4. Channel 3
- DMA source address register_3 (SAR_3)
- DMA destination address register_3 (DAR_3)
- DMA transfer count register_3 (DMATCR_3)
- DMA channel control register_3 (CHCR_3)

5. Common
- DMA operation register (DMAOR)
- DMA extended resource selector 0 (DMARS0)
- DMA extended resource selector 1 (DMARS1)

8.3.1 DMA Source Address Registers (SAR)

SAR are 32-bit readable/writable registers that specify the source address of a DMA transfer. During a DMA transfer, these registers indicate the next source address. When the data of an external device with DACK is transferred in single address mode, SAR is ignored.

To transfer data in 16 bits or in 32 bits, specify the address with 16-bit or 32-bit address boundary. When transferring data in 16-byte units, a 16-byte boundary must be set for the source address value. The initial value is undefined. The SAR retains the current value in software standby or module standby mode.

8.3.2 DMA Destination Address Registers (DAR)

DAR are 32-bit readable/writable registers that specify the destination address of a DMA transfer. During a DMA transfer, these registers indicate the next destination address. When the data of an external device with DACK is transferred in single address mode, DAR is ignored.

To transfer data in 16 bits or in 32 bits, specify the address with 16-bit or 32-bit address boundary. When transferring data in 16-byte units, a 16-byte boundary must be set for the source address value. The initial value is undefined. The DAR retains the current value in software standby or module standby mode.

8.3.3 DMA Transfer Count Registers (DMATCR)

DMATCR are 32-bit readable/writable registers that specify the DMA transfer count. The number of transfers is 1 when the setting is H'00000001, 16777215 when H'00FFFFFF is set, and 16777216 (the maximum) when H'00000000 is set. During a DMA transfer, these registers indicate the remaining transfer count.

The upper 8 bits of DMATCR are always read as 0. The write value should always be 0. To transfer data in 16 bytes, one 16-byte transfer (128 bits) counts one. The initial value is undefined. The DMATCR retains the current value in software standby or module standby mode.

8.3.4 DMA Channel Control Registers (CHCR)

CHCR are 32-bit readable/writable registers that control the DMA transfer mode.

Bit	Bit Name	Initial Value	R/W	Descriptions
31 to 24	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
23	DO	0	R/W	DMA Overrun Selects whether DREQ is detected by overrun 0 or by overrun 1. This bit is valid only in CHCR_0 and CHCR_1. This bit is always read as 0 in CHCR_2 and CHCR_3. The write value should always be 0. 0: Detects DREQ by overrun 0 1: Detects DREQ by overrun 1
22	TL	0	R/W	Transfer End Level Selects whether the TEND signal output is high active or low active. This bit is valid only in CHCR_0. There are no TEND pins in CHCR_1 to CHCR_3. Therefore this setting is invalid. This bit is always read as 0. The write value should always be 0. 0: Low-active output of TEND 1: High-active output of TEND
21 to 18	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Descriptions
17	AM	0	R/W	Acknowledge Mode Selects whether DACK is output in data read cycle or in data write cycle in dual address mode. In single address mode, DACK is always output regardless of the specification by this bit. This bit is valid only in CHCR_0 and CHCR_1. This bit is always read as 0 in CHCR_2 and CHCR_3. The write value should always be 0. 0: DACK output in read cycle (Dual address mode) 1: DACK output in write cycle (Dual address mode)
16	AL	0	R/W	Acknowledge Level Specifies the DACK signal output is high active or low active. This bit is valid only in CHCR_0 and CHCR_1. This bit is always read as 0 in CHCR_2 and CHCR_3. The write value should always be 0. 0: Low-active output of DACK 1: High-active output of DACK
15	DM1	0	R/W	Destination Address Mode
14	DM0	0	R/W	Specify whether the DMA destination address is incremented, decremented, or left fixed. (In single address mode, the DM1 and DM0 bits are ignored when data is transferred to an external device with DACK.) 00: Fixed destination address 01: Destination address is incremented (+1 in byte-size transfer, +2 in word-size transfer, +4 in longword-size transfer, +16 in 16-byte transfer) 10: Destination address is decremented (–1 in byte-size transfer, –2 in word-size transfer, –4 in longword-size transfer, setting prohibited in 16-byte transfer) 11: Setting prohibited

Bit	Bit Name	Initial Value	R/W	Descriptions
13	SM1	0	R/W	Source Address Mode
12	SM0	0	R/W	Specifies whether the DMA source address is incremented, decremented, or left fixed. (In single address mode, the SM1 and SM0 bits are ignored when data is transferred from an external device with DACK.) 00: Fixed source address 01: Source address is incremented (+1 in byte-size transfer, +2 in word-size transfer, +4 in longword-size transfer, +16 in 16-byte transfer) 10: Source address is decremented (–1 in byte-size transfer, –2 in word-size transfer, –4 in longword-size transfer, setting prohibited in 16-byte transfer) 11: Setting prohibited
11	RS3	0	R/W	Resource Select
10	RS2	0	R/W	Specifies which transfer requests will be sent to the DMAC. The changing of transfer request source should be done in the state that the DMA enable bit (DE) is set to 0. 0000: External request, dual address mode 0001: Setting prohibited 0010: External request/single address mode External address space → external device with DACK 0011: External request/single address mode External device with DACK → external address space 0100: Auto request 0101: Setting prohibited 0110: Setting prohibited 0111: Setting prohibited 1000: DMA extended resource selector specification 1001: Setting prohibited 1010: Setting prohibited 1011: Setting prohibited 1100: Setting prohibited 1101: Setting prohibited 1110: Peripheral module request, A/D converter 1111: Peripheral module request, CMT Note: External request specification is valid only in CHCR_0 and CHCR_1. None of the external request specification can be set in channels CHCR_2 and CHCR_3.
9	RS1	0	R/W	
8	RS0	0	R/W	

Bit	Bit Name	Initial Value	R/W	Descriptions
7	DL	0	R/W	DREQ Level and DREQ Edge Select
6	DS	0	R/W	Select the detection method of the DREQ pin input and the detection level. These bits are valid only in CHCR_0 and CHCR_1. These bits are always read as 0 in CHCR_2 and CHCR_3. The write value should always be 0. In channels 0 and 1, also, if the transfer request source is specified as an on-chip peripheral module or if an auto-request is specified, these bits are invalid. 00: DREQ detected in low level 01: DREQ detected at falling edge 10: DREQ detected in high level 11: DREQ detected at rising edge
5	TB	0	R/W	Transfer Bus Mode Specifies the bus mode when DMA transfers data. 0: Cycle steal mode 1: Burst mode
4	TS1	0	R/W	Transfer Size
3	TS0	0	R/W	Specify the size of data to be transferred. Select the size of data to be transferred when the source or destination is an on-chip peripheral module register of which transfer size is specified. 00: Byte size 01: Word size (two bytes) 10: Longword size (four bytes) 11: 16-byte unit (four longword transfers)
2	IE	0	R/W	Interrupt Enable Specifies whether or not an interrupt request is generated to the CPU at the end of the DMA transfer. Setting this bit to 1 generates an interrupt request (DEI) to the CPU when the TE bit is set to 1. 0: Interrupt request disabled 1: Interrupt request enabled

Bit	Bit Name	Initial Value	R/W	Descriptions
1	TE	0	R/(W)*	Transfer End Flag Indicates that the DMA transfer ends. The TE bit is set to 1 when data transfer ends when DMATCR becomes to 0. The TE bit is not set to 1 in the following cases. • DMA transfer ends due to an NMI interrupt or DMA address error before DMATCR becomes to 0. • DMA transfer is ended by clearing the DE bit and the DME bit in the DMA operation register (DMAOR). This bit can only be cleared by writing 0 after reading 1. Even if the DE bit is set to 1 while this bit is set to 1, transfer is not enabled. 0: During the DMA transfer or DMA transfer has been aborted [Clearing conditions] • Writing 0 after reading TE = 1 • Power-on reset • Manual reset 1: Data transfer ends by the specified count (DMATCR = 0)
0	DE	0	R/W	DMA Enable Enables or disables the DMA transfer. In auto request mode, DMA transfer starts by setting the DE bit and DME bit in DMAOR to 1. In this time, all of the bits TE, NMIF in DMAOR, and AE must be 0. In an external request or peripheral module request, DMA transfer starts if DMA transfer request is generated by the devices or peripheral modules after setting the bits DE and DME to 1. In this case, however, all of the bits TE, NMIF, and AE must be 0 an in the case of auto request mode. Clearing the DE bit to 0 can terminate the DMA transfer. 0: DMA transfer disabled 1: DMA transfer enabled

Note: * Only 0 can be written for clearing the flags.

8.3.5 DMA Operation Register (DMAOR)

DMAOR is a 16-bit readable/writable register that specifies the priority level of channels at the DMA transfer. This register shows the DMA transfer status.

Bit	Bit Name	Initial Value	R/W	Description
15, 14	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
13	CMS1	0	R/W	Cycle Steal Mode Select
12	CMS0	0	R/W	Select either normal mode or intermittent mode in cycle steal mode. It is necessary that all channels' bus modes are set to cycle steal mode to make valid intermittent mode. 00: Normal mode 01: Setting prohibited 10: Intermittent mode 16 Executes one DMA transfer in each of 16 clocks of an external bus clock. 11: Intermittent mode 64 Executes one DMA transfer in each of 64 clocks of an external bus clock.
11, 10	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
9	PR1	0	R/W	Priority Mode
8	PR0	0	R/W	Select the priority level between channels when there are transfer requests for multiple channels simultaneously. 00: CH0 > CH1 > CH2 > CH3 01: CH0 > CH2 > CH3 > CH1 10: Setting prohibited 11: Round-robin mode
7 to 3	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
2	AE	0	R/(W)*	Address Error Flag Indicates that an address error occurred by the DMAC. If this bit is set, DMA transfer is not enabled even if the DE bit in CHCR and the DME bit in DMAOR are set to 1. This bit can only be cleared by writing 0 after reading 1. 0: No DMAC address error [Clearing conditions] • Writing 0 after reading AE = 1 • Power-on reset • Manual reset 1: DMAC address error. DMA transfer disabled. [Setting condition] DMAC address error occurrence
1	NMIF	0	R/(W)*	NMI Flag Indicates that an NMI interrupt occurred. If this bit is set, DMA transfer is not enabled even if the DE bit in CHCR and the DME bit in DMAOR are set to 1. This bit can only be cleared by writing 0 after reading 1. When the NMI is input, the DMA transfer in progress can be done in one transfer unit. When the DMAC is not in operation, the NMIF bit is set to 1 even if the NMI interrupt was input. 0: No NMI interrupt [Clearing conditions] • Writing 0 after reading NMIF = 1 • Power-on reset • Manual reset 1: NMI input. DMA transfer disabled. [Setting condition] NMI interrupt occurrence
0	DME	0	R/W	DMA Master Enable Enables or disables DMA transfers on all channels. If the DME bit and the DE bit in CHCR are set to 1, DMA transfers are enabled. In this time, all of the bits TE in CHCR, NMIF in DMAOR, and AE must be 0. If this bit is cleared during transfer, transfers in all the channels can be terminated. 0: Disable DMA transfers on all channels 1: Enable DMA transfers on all channels

Note: * Only 0 can be written for clearing the flags.

8.3.6 DMA Extended Resource Selectors 0, 1 (DMARS0, DMARS1)

DMARS is a 16-bit readable/writable register that specifies the DMA transfer request sources from peripheral modules in each channel. DMARS0 specifies for channels 0 and 1, DMARS1 for channels 2 and 3. This register can set the transfer request of SCIF0, SCIF2 and USB.

When MID/RID other than the values listed in table 8.2 is set, the operation of this LSI is not guaranteed. The transfer request from DMARS is valid only when the resource select bits (RS3 to RS0) has been set to B'1000 for CHCR_0 to CHCR_3. Otherwise, even if DMARS has been set, transfer request source is not accepted.

- DMARS0

Bit	Bit Name	Initial Value	R/W	Description
15	C1MID5	0	R/W	Transfer request source module ID5 to ID0 for DMA channel 1 (MID) See table 8.2.
14	C1MID4	0	R/W	
13	C1MID3	0	R/W	
12	C1MID2	0	R/W	
11	C1MID1	0	R/W	
10	C1MID0	0	R/W	
9	C1RID1	0	R/W	Transfer request resource register ID1 to ID0 for DMA channel 1 (RID) See table 8.2.
8	C1RID0	0	R/W	
7	C0MID5	0	R/W	Transfer request source module ID5 to ID0 for DMA channel 0 (MID) See table 8.2
6	C0MID4	0	R/W	
5	C0MID3	0	R/W	
4	C0MID2	0	R/W	
3	C0MID1	0	R/W	
2	C0MID0	0	R/W	
1	C0RID1	0	R/W	Transfer request resource register ID1 to ID0 for DMA channel 0 (RID) See table 8.2.
0	C0RID0	0	R/W	

- DMARS1

Bit	Bit Name	Initial Value	R/W	Description
15 to 10	C3MID5 to C3MID0	All 0	R/W	Transfer request resource module ID5 to ID0 for DMA channel 3 (MID) See table 8.2.
9	C3RID1	0	R/W	Transfer request resource register ID1 and ID0 for DMA channel 3 (RID)
8	C3RID0	0	R/W	See table 8.2.
7 to 2	C2MID5 to C2MID0	All 0	R/W	Transfer request resource module ID5 to ID0 for DMA channel 2 (MID) See table 8.2.
1	C2RID1	0	R/W	Transfer request resource register ID1 and ID0 for DMA channel 2 (RID)
0	C2RID0	0	R/W	See table 8.2.

Table 8.2 Transfer Request Sources

Peripheral Module	Setting Value for One Channel (MID + RID)	MID	RID	Function
SCIF0	H'21	B'001000	B'01	Transmit
	H'22		B'10	Receive
SCIF2	H'29	B'001010	B'01	Transmit
	H'2A		B'10	Receive
USB	H'73	B'011100	B'11	Transmit
	H'70		B'00	Receive

8.4 Operation

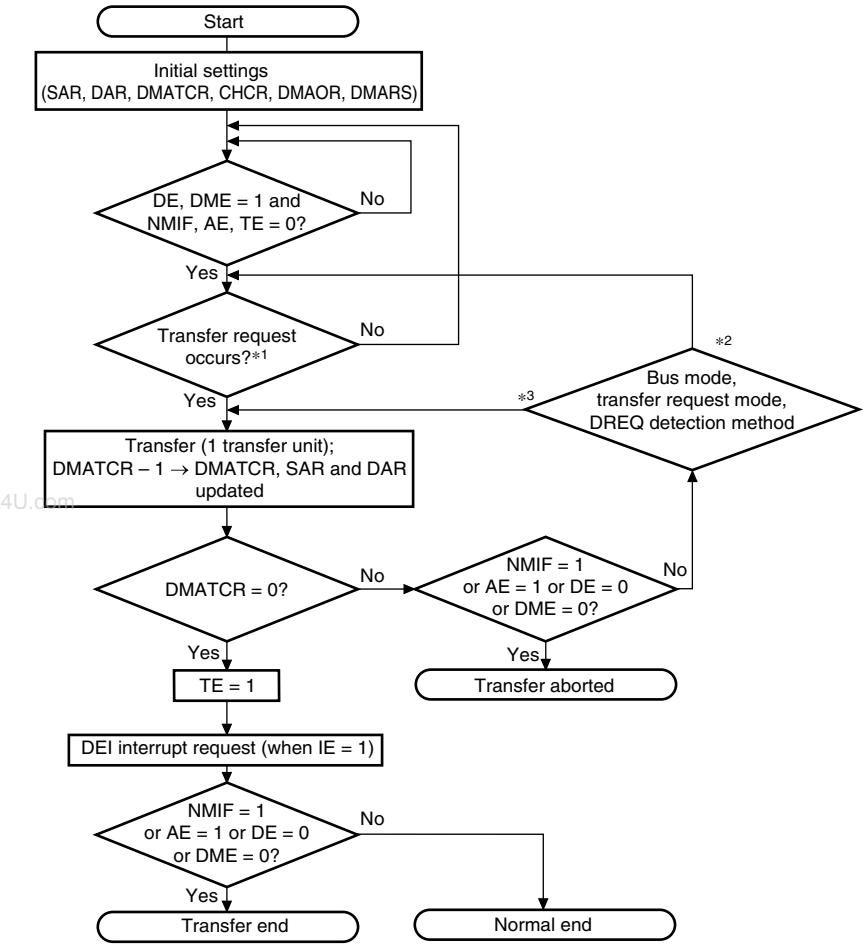
When there is a DMA transfer request, the DMAC starts the transfer according to the predetermined channel priority order; when the transfer end conditions are satisfied, it ends the transfer. Transfers can be requested in three modes: auto request, external request, and on-chip peripheral module request. In bus mode, burst mode or cycle steal mode can be selected.

8.4.1 Transfer Flow

After the DMA source address registers (SAR), DMA destination address registers (DAR), DMA transfer count registers (DMATCR), DMA channel control registers (CHCR), DMA operation register (DMAOR), and DMA extended resource selector (DMARS) are set, the DMAC transfers data according to the following procedure:

1. Checks to see if transfer is enabled (DE = 1, DME = 1, TE = 0, AE = 0, NMIF = 0)
2. When a transfer request is generated and transfer is enabled, the DMAC transfers 1 transfer unit of data (depending on the TS0 and TS1 settings). For an auto request, the transfer begins automatically when the DE bit and DME bit are set to 1. The DMATCR value will be decremented for each transfer. The actual transfer flows vary by address mode and bus mode.
3. When the specified number of transfer have been completed (when DMATCR reaches 0), the transfer ends normally. If the IE bit in CHCR is set to 1 at this time, a DEI interrupt is sent to the CPU.
4. When an address error or an NMI interrupt is generated, the transfer is aborted. Transfers are also aborted when the DE bit in CHCR or the DME bit in DMAOR are cleared to 0.

Figure 8.2 is a flowchart of this procedure.



Notes: *1 In auto-request mode, transfer begins when NMIF, AE, and TE bits are 0 and the DE and DME bits are set to 1.
*2 DREQ = level detection in burst mode (external request) or cycle-steal mode.
*3 DREQ = edge detection in burst mode (external request), or auto-request mode in burst mode.

Figure 8.2 DMAC Transfer Flowchart

8.4.2 DMA Transfer Requests

DMA transfer requests are basically generated in either the data transfer source or destination, but they can also be generated by external devices and on-chip peripheral modules that are neither the source nor the destination. Transfers can be requested in three modes: auto request, external request, and on-chip peripheral module request. The request mode is selected in the RS3 to RS0 bits in the DMA channel control register (CHCR), and DMARS0 and DMARS1.

Auto-Request Mode: When there is no transfer request signal from an external source, as in a memory-to-memory transfer or a transfer between memory and an on-chip peripheral module unable to request a transfer, auto-request mode allows the DMAC to automatically generate a transfer request signal internally. When the DE bit in CHCR and the DME bit in DMAOR are set to 1, the transfer begins so long as the AE and NMIF bits in DMAOR are 0.

External Request Mode: In this mode a transfer is performed at the request signals (DREQ0 and DREQ1) of an external device. This mode is valid only in channels 0 and 1. Choose one of the modes shown in table 8.3 according to the application system. When this mode is selected, if the DMA transfer is enabled (DE = 1, DME = 1, TE = 0, AE = 0, NMIF = 0), a transfer is performed upon a request at the DREQ input.

Table 8.3 Selecting External Request Modes with RS Bits

RS3	RS2	RS1	RS0	Address Mode	Source	Destination
0	0	0	0	Dual address mode	Any	Any
		1	0	Single address mode	External memory, memory-mapped external device	External device with DACK
			1		External device with DACK	External memory, memory-mapped external device

Choose to detect DREQ by either the edge or level of the signal input with the DL bit and DS bit of CHCR_0 and CHCR_1 as shown in table 8.4. The source of the transfer request does not have to be the data transfer source or destination.

Table 8.4 Selecting External Request Detection with DL, DS Bits

CHCR_0 or CHCR_1		
DL	**DS**	**Detection of External Request**
0	0	Low level detection
	1	Falling edge detection
1	0	High level detection
	1	Rising edge detection

When DREQ is accepted, the DREQ pin becomes request accept disabled state. After issuing acknowledge signal DACK for the accepted DREQ, the DREQ pin again becomes request accept enabled state.

When DREQ is used for level detection, there are the following two cases depending on the timing to detect the next DREQ after outputting DACK. A case wherein transfer is aborted after the same number of transfers has been performed as requests (overrun 0) and wherein another transfer is aborted after transfers have been performed for (the number of requests plus 1) times (overrun 1). The DO bit in CHCR selects overrun 0 or overrun 1.

Table 8.5 Selecting External Request Detection with DO Bit

CHCR_0 or CHCR_1	
DO	**External Request**
0	Overrun 0
1	Overrun 1

On-Chip Peripheral Module Request Mode: In this mode a transfer is performed at the transfer request signal of an on-chip peripheral module. Transfer request signals comprise the transmit data empty transfer request and receive data full transfer request from the SCIF0 and SCIF2 set by DMARS0/1, the compare-match timer transfer request from the CMT, and transfer requests from the USB.

When this mode is selected, if the DMA transfer is enabled (DE = 1, DME = 1, TE = 0, AE = 0, NMIF = 0), a transfer is performed upon the input of a transfer request signal.

When a transmit data empty transfer request of the SCIF is set as the transfer request, the transfer destination must be the SCIF's transmit data register. Likewise, when receive data full transfer request of the SCIF is set as the transfer request, the transfer source must be the SCIF's receive data register. These conditions also apply to the USB. Any address can be specified for data source and destination, when transfer request is generated by the CMT.

Table 8.6 Selecting On-Chip Peripheral Module Request Modes with RS3 to RS0 Bits

RS3	RS2	RS1	RS0	DMA Transfer Request Source	DMA Transfer Request Signal	Source	Destination	Bus Mode
1	1	1	0	ADC	AD-conversion end request	ADDR	Any	Cycle steal
1	1	1	1	CMT	Compare-match transfer request	Any	Any	Burst/ cycle steal

Table 8.7 Selecting On-Chip Peripheral Module Request Modes with RS3 to RS0 Bits

CHCR	DMARS		DMA Transfer Request	DMA Transfer			Bus
RS[3:0]	MID	RID	Source	Request Signal	Source	Destination	Mode
1000	001000	01	SCIF0 transmitter	TXI0 (transmit FIFO data empty)	Any	SCFTDR_0	Cycle steal
		10	SCIF0 receiver	RXI0 (receive FIFO data full)	SCFRDR_0	Any	Cycle steal
	001010	01	SCIF2 transmitter	TXI2 (transmit FIFO data empty)	Any	SCFTDR_2	Cycle steal
		10	SCIF2 receiver	RXI2 (receive FIFO data full)	SCFRDR_2	Any	Cycle steal
	011100	11	USB transmitter	EP2 FIFO empty transfer request	Any	EPDR2	Cycle steal
		00	USB receiver	EP1 FIFO full transfer request	EPDR1	Any	Cycle steal

8.4.3 Channel Priority

When the DMAC receives simultaneous transfer requests on two or more channels, it selects a channel according to a predetermined priority order. Two modes (fixed mode and round-robin mode) are selected by bits PR1 and PR0 in the DMA operation register (DMAOR).

Fixed Mode: In these modes, the priority levels among the channels remain fixed. There are two kinds of fixed modes as follows:

CH0 > CH1 > CH2 > CH3
CH0 > CH2 > CH3 > CH1

These are selected by the PR1 and the PR0 bits in the DMA operation register (DMAOR).

Round-Robin Mode: Each time one byte, word, longword, or 16-byte is transferred on one channel, the priority order is rotated. The channel on which the transfer was just finished rotates to the bottom of the priority order. The round-robin mode operation is shown in figure 8.3. The priority of round-robin mode is CH0 > CH1 > CH2 > CH3 immediately after a reset.

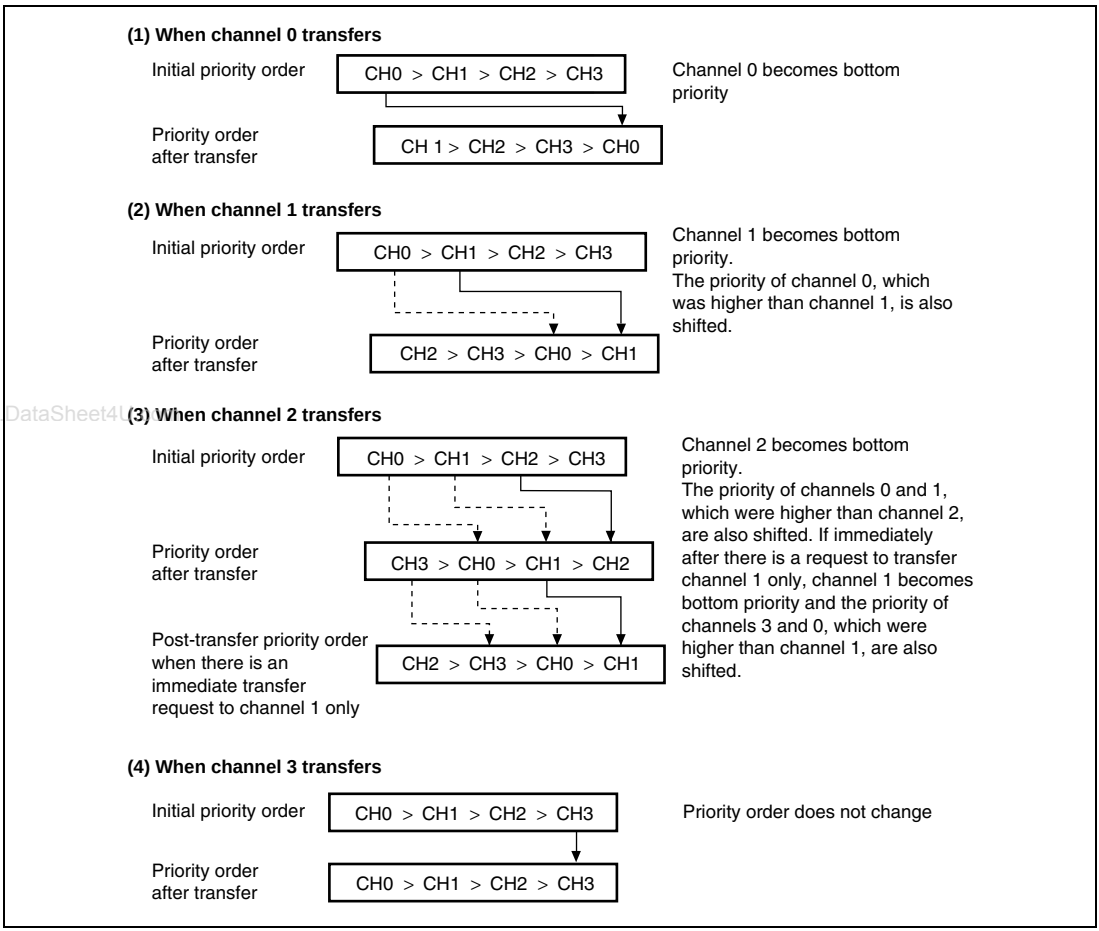


Figure 8.3 Round-Robin Mode

Figure 8.4 shows how the priority order changes when channel 0 and channel 3 transfers are requested simultaneously and a channel 1 transfer is requested during the channel 0 transfer. The DMAC operates as follows:

1. Transfer requests are generated simultaneously to channels 0 and 3.
2. Channel 0 has a higher priority, so the channel 0 transfer begins first (channel 3 waits for transfer).
3. A channel 1 transfer request occurs during the channel 0 transfer (channels 1 and 3 are both waiting)
4. When the channel 0 transfer ends, channel 0 becomes lowest priority.
5. At this point, channel 1 has a higher priority than channel 3, so the channel 1 transfer begins (channel 3 waits for transfer).
6. When the channel 1 transfer ends, channel 1 becomes lowest priority.
7. The channel 3 transfer begins.
8. When the channel 3 transfer ends, channels 3 and 2 shift downward in priority so that channel 3 becomes the lowest priority.

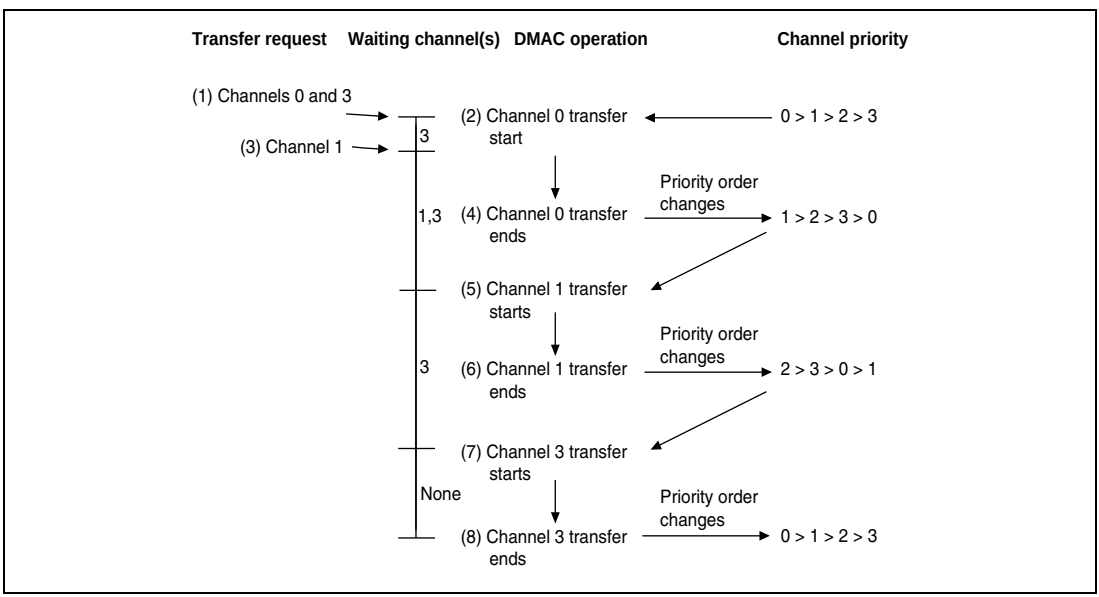


Figure 8.4 Channel Priority in Round-Robin Mode

8.4.4 DMA Transfer Types

DMA transfer has two types; single address mode transfer and dual address mode transfer. They depend on the number of bus cycles of access to source and destination. A data transfer timing depends on the bus mode, which has cycle steal mode and burst mode. The DMAC supports the transfers shown in table 8.8.

Table 8.8 Supported DMA Transfers

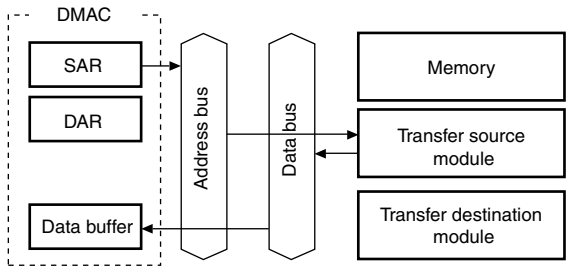
	Destination			
Source	**External Device with DACK**	**External Memory**	**Memory-Mapped External Device**	**On-Chip Peripheral Module**
External device with DACK	Not available	Dual, single	Dual, single	Not available
External memory	Dual, single	Dual	Dual	Dual
Memory-mapped external device	Dual, single	Dual	Dual	Dual
On-chip peripheral module	Not available	Dual	Dual	Dual

Notes: 1. Dual: Dual address mode
2. Single: Single address mode
3. A 16-byte transfer is available only for the registers to which longword-size access is enabled in the on-chip peripheral modules.

- Dual Address Mode

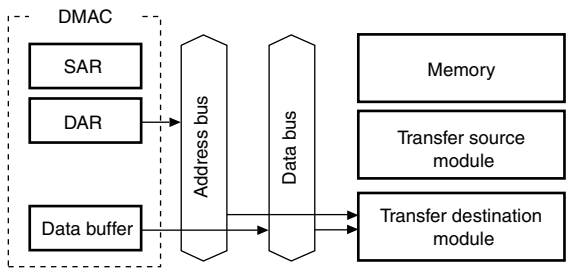
  In dual address mode, both the transfer source and destination are accessed by an address. The source and destination can be located externally or internally.

  DMA transfer requires two bus cycles because data is read from the transfer source in a data read cycle and written to the transfer destination in a data write cycle. At this time, transfer data is temporarily stored in the DMAC. In the transfer between external memories as shown in figure 8.5, data is read to the DMAC from one external memory in a data read cycle, and then that data is written to the other external memory in a write cycle.



The SAR value is an address, data is read from the transfer source module, and the data is temporarily stored in the DMAC.

First bus cycle



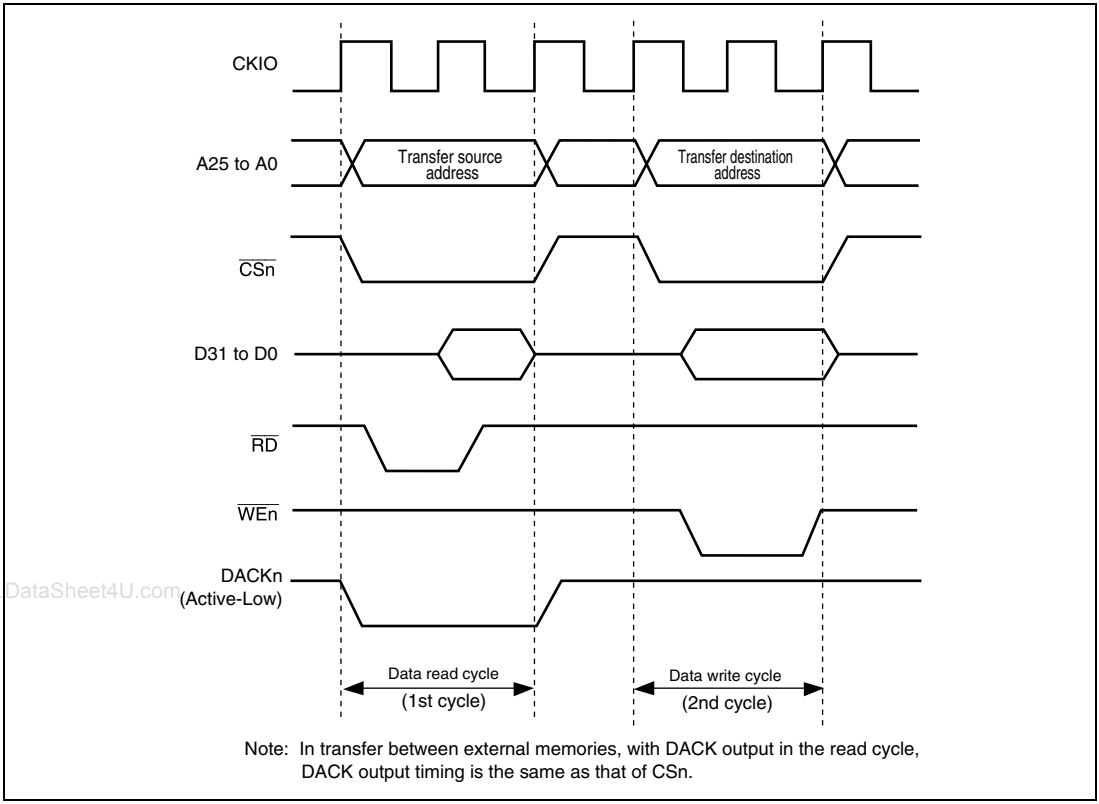
The DAR value is an address and the value stored in the data buffer in the DMAC is written to the transfer destination module.

Second bus cycle

Figure 8.5 Data Flow of Dual Address Mode

Auto request, external request, and on-chip peripheral module request are available for the transfer request. DACK can be output in read cycle or write cycle in dual address mode. Channel control register (CHCR) can specify whether the DACK is output in read cycle or write cycle.

Figure 8.6 shows an example of DMA transfer timing in dual address mode.



Note: In transfer between external memories, with DACK output in the read cycle, DACK output timing is the same as that of CSn.

Figure 8.6 Example of DMA Transfer Timing in Dual Mode (source: ordinary memory, destination: ordinary memory)

- Single Address Mode

  In single address mode, either the transfer source or transfer destination peripheral device is accessed (selected) by means of the DACK signal, and the other device is accessed by address. In this mode, the DMAC performs one DMA transfer in one bus cycle, accessing one of the external devices by outputting the DACK transfer request acknowledge signal to it, and at the same time outputting an address to the other device involved in the transfer. For example, in the case of transfer between external memory and an external device with DACK shown in figure 8.7, when the external device outputs data to the data bus, that data is written to the external memory in the same bus cycle.

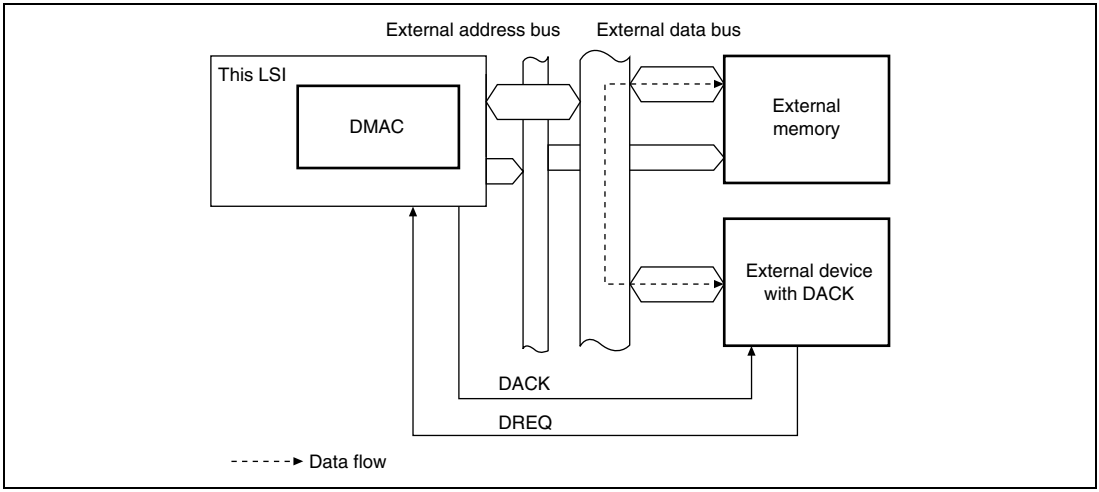


Figure 8.7 Data Flow in Single Address Mode

Two kinds of transfer are possible in single address mode: (1) transfer between an external device with DACK and a memory-mapped external device, and (2) transfer between an external device with DACK and external memory. In both cases, only the external request signal (DREQ) is used for transfer requests.

Figures 8.8 shows example of DMA transfer timing in single address mode.

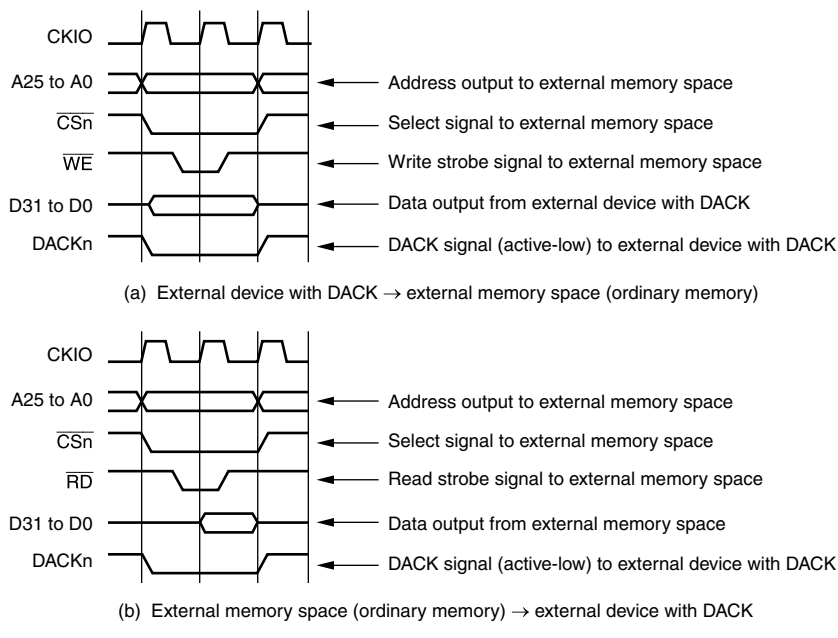


Figure 8.8 Example of DMA Transfer Timing in Single Address Mode

Bus Modes: There are two bus modes: cycle steal and burst. Select the mode in the TB bits of channel control register (CHCR).

a. Cycle-Steal Mode

- Normal mode

  In the normal mode of cycle-steal, the bus right is given to another bus master after a one-transfer-unit (byte, word, long-word, or 16 bytes unit) DMA transfer. When another transfer request occurs, the bus rights are obtained from the other bus master and a transfer is performed for one transfer unit. When that transfer ends, the bus right is passed to the other bus master. This is repeated until the transfer end conditions are satisfied.

  In cycle-steal mode, transfer areas are not affected regardless of settings of the transfer request source, transfer source, and transfer destination. Figure 8.9 shows an example of DMA transfer timing in cycle steal mode. Transfer conditions shown in the figure are:

  — Dual address mode

  — DREQ low level detection

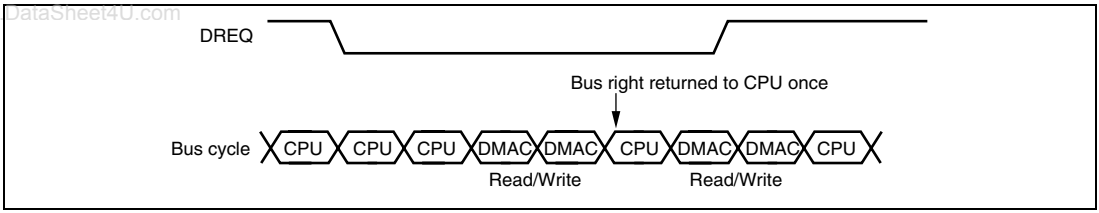


Figure 8.9 DMA Transfer Example in Cycle-Steal Normal Mode (dual address, DREQ low level detection)

- Intermittent Mode 16 and Intermittent Mode 64

  In intermittent mode of cycle steal, DMAC returns the bus right to other bus master whenever a unit of transfer (byte, word, longword, or 16 bytes) is complete. If the next transfer request occurs after that, DMAC gets the bus right from other bus master after waiting for 16 or 64 clocks in Bϕ count. DMAC then transfers data of one unit and returns the bus right to other bus master. These operations are repeated until the transfer end condition is satisfied. It is thus possible to make lower the ratio of bus occupation by DMA transfer than the normal mode of cycle steal.

  When DMAC gets again the bus right, DMA transfer can be postponed in case of entry updating due to cache miss.

  This intermittent mode can be used for all transfer section; transfer requester, source, and destination. The bus modes, however, must be cycle steal mode in all channels.

Figure 8.10 shows an example of DMA transfer timing in cycle steal intermittent mode. Transfer conditions shown in the figure are:

— Dual address mode

— DREQ low level detection

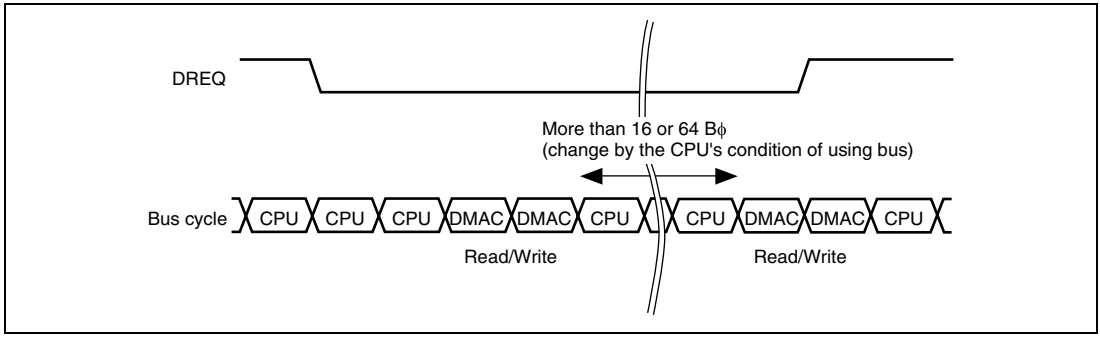


Figure 8.10 Example of DMA Transfer in Cycle Steal Intermittent Mode (dual address, DREQ low level detection)

b. Burst Mode

Once the bus right is obtained, the transfer is performed continuously until the transfer end condition is satisfied. In external request mode with low level detection of the DREQ pin, however, when the DREQ pin is driven high, the bus passes to the other bus master after the DMAC transfer request that has already been accepted ends, even if the transfer end conditions have not been satisfied.

Burst mode cannot be used for other than the CMT when the on-chip peripheral module is the transfer request source. Figure 8.11 shows DMA transfer timing in burst mode.

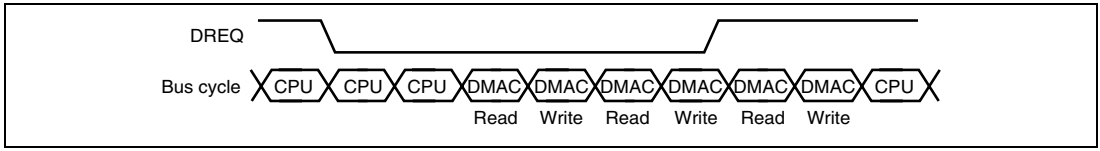


Figure 8.11 DMA Transfer Example in Burst Mode (dual address, DREQ low level detection)

Relationship between Request Modes and Bus Modes by DMA Transfer Category: Table 8.9 shows the relationship between request modes and bus modes by DMA transfer category.

Table 8.9 Relationship of Request Modes and Bus Modes by DMA Transfer Category

Address Mode	Transfer Category	Request Mode	Bus Mode	Transfer Size (bits)	Usable Channels
Dual	External device with DACK and external memory	External	B/C	8/16/32/128	0, 1
	External device with DACK and memory-mapped external device	External	B/C	8/16/32/128	0, 1
	External memory and external memory	All*[1]	B/C	8/16/32/128	0 to 3*[5]
	External memory and memory-mapped external device	All*[1]	B/C	8/16/32/128	0 to 3*[5]
	Memory-mapped external device and memory-mapped external device	All*[1]	B/C	8/16/32/128	0 to 3*[5]
	External memory and on-chip peripheral module	All*[2]	B/C*[3]	8/16/32/128*[4]	0 to 3*[5]
	Memory-mapped external device and on-chip peripheral module	All*[2]	B/C*[3]	8/16/32/128*[4]	0 to 3*[5]
	On-chip peripheral module and on-chip peripheral module	All*[2]	B/C*[3]	8/16/32/128*[4]	0 to 3*[5]
Single	External device with DACK and external memory	External	B/C	8/16/32	0, 1
	External device with DACK and memory-mapped external device	External	B/C	8/16/32	0, 1

B: Burst, C: Cycle steal

Notes: 1. External requests, auto requests, and on-chip peripheral module requests are all available. In the case of on-chip peripheral module requests, however, the CMT is only available.
2. External requests, auto requests, and on-chip peripheral module requests are all available. However, with the exception of the CMT, the module must be designated as the transfer request source or the transfer destination.
3. Only cycle steal except for the CMT as the transfer source.
4. Access size permitted for the on-chip peripheral module register functioning as the transfer source or transfer destination.
5. If the transfer request is an external request, channels 0 and 1 are only available.

Bus Mode and Channel Priority Order: When a given channel 1 is transferring in burst mode and there is a transfer request to a channel 0 with a higher priority, the transfer of channel 0 will begin immediately.

At this time, if the priority is set in fixed mode (CH0 > CH1), the channel 1 transfer will continue when the channel 0 transfer has completely finished, even if channel 0 is operating in cycle steal mode or in burst mode.

If the priority is set in round-robin mode, channel 1 will begin operating again after channel 0 completes the transfer of one transfer unit, even if channel 0 is in cycle steal mode or in burst mode. The bus will then switch between the two in the order channel 1, channel 0, channel 1, channel 0.

Even if the priority is set in fixed mode or in round-robin mode, it will not give the bus to the CPU since channel 1 is in burst mode. This example is illustrated in figure 8.12.

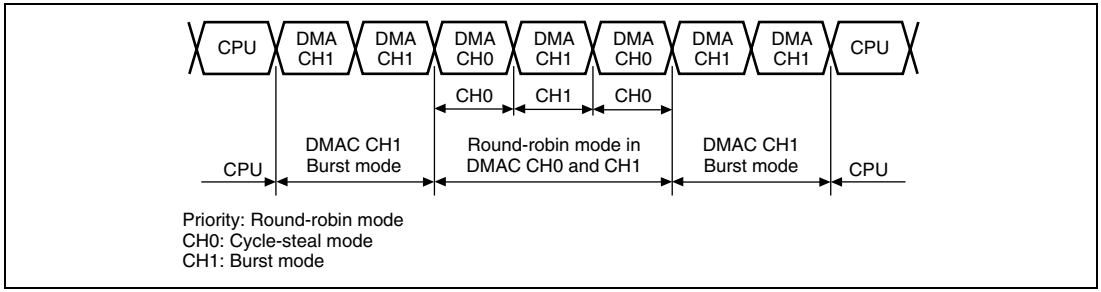


Figure 8.12 Bus State when Multiple Channels are Operating

8.4.5 Number of Bus Cycle States and DREQ Pin Sampling Timing

Number of Bus Cycle States: When the DMAC is the bus master, the number of bus cycle states is controlled by the bus state controller (BSC) in the same way as when the CPU is the bus master. For details, see section 7, Bus State Controller (BSC).

DREQ Pin Sampling Timing:

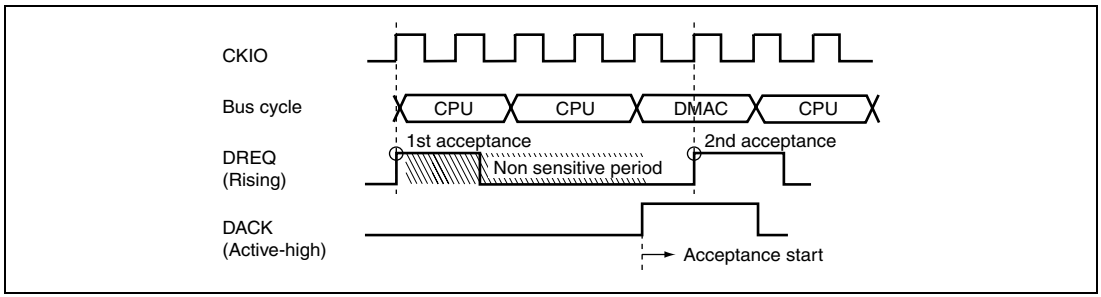


Figure 8.13 Example of DREQ Input Detection in Cycle Steal Mode Edge Detection

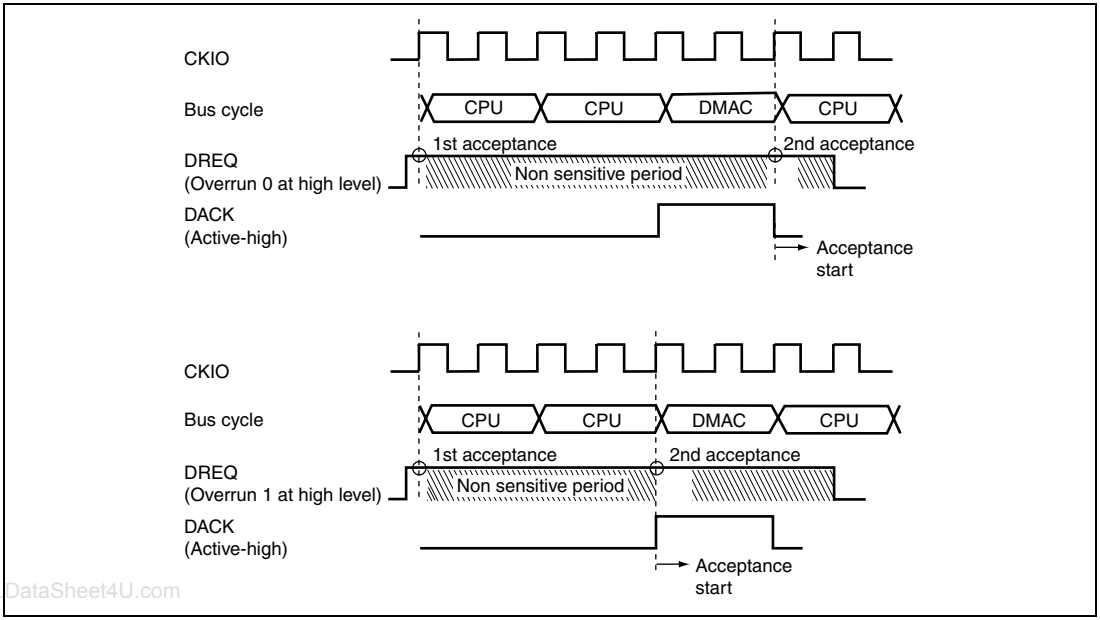


Figure 8.14 Example of DREQ Input Detection in Cycle Steal Mode Level Detection

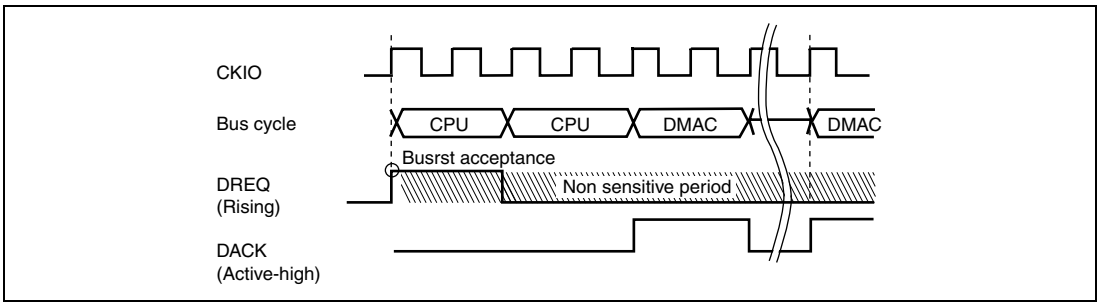


Figure 8.15 Example of DREQ Input Detection in Burst Mode Edge Detection

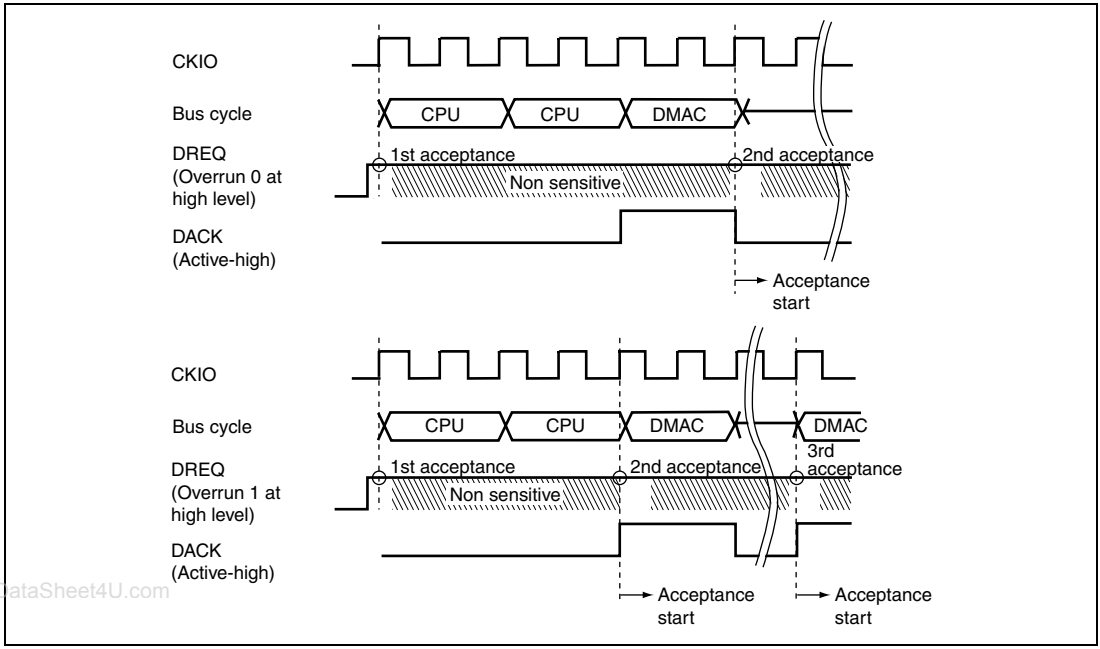


Figure 8.16 Example of DREQ Input Detection in Burst Mode Level Detection

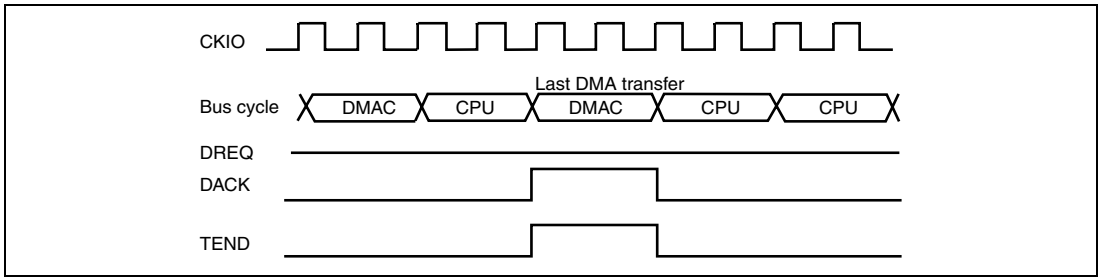
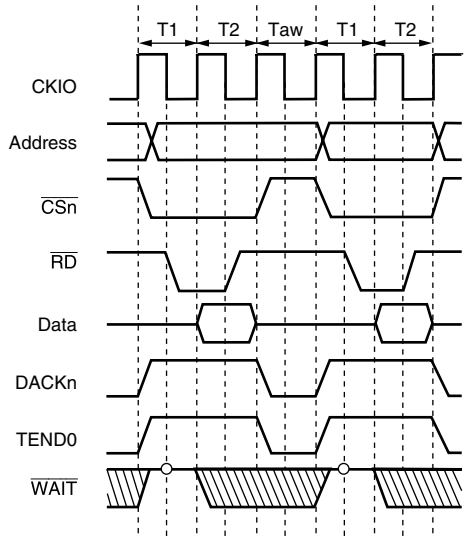


Figure 8.17 Example of DMA Transfer End Signal (in cycle steal level detection)



Note: TEND0 is asserted during the last transfer unit of DMA transfer. When the transfer unit is divided into several bus cycles and CS is negated between bus cycles, TEND0 is also divided.

Figure 8.18 BSC Ordinary Memory Access (no wait, idle cycle 1, longword access to 16-bit device)

Section 9 Clock Pulse Generator (CPG)

This LSI has a clock pulse generator (CPG) that generates an internal clock (Iϕ), a peripheral clock (Pϕ), and a bus clock (Bϕ). The CPG consists of oscillators, PLL circuits, and divider circuits.

9.1 Features

- Seven clock modes

  Selection of seven clock modes depending on the frequency ranges and crystal oscillation or external clock input.
- Three clocks generated independently

  An internal clock for the CPU and cache (Iϕ); a peripheral clock (Pϕ) for the peripheral modules; a bus clock (Bϕ = CKIO) for the external bus interface.
- Frequency change function

  Internal and peripheral clock frequencies can be changed independently using the phase-locked loop (PLL) circuit and divider circuit within the CPG. Frequencies are changed by software using the frequency control register (FRQCR) settings.
- Power-down mode control

  The clock can be stopped for sleep mode and software standby mode and specific modules can be stopped using the module standby function.

A block diagram of the CPG is shown in figure 9.1.

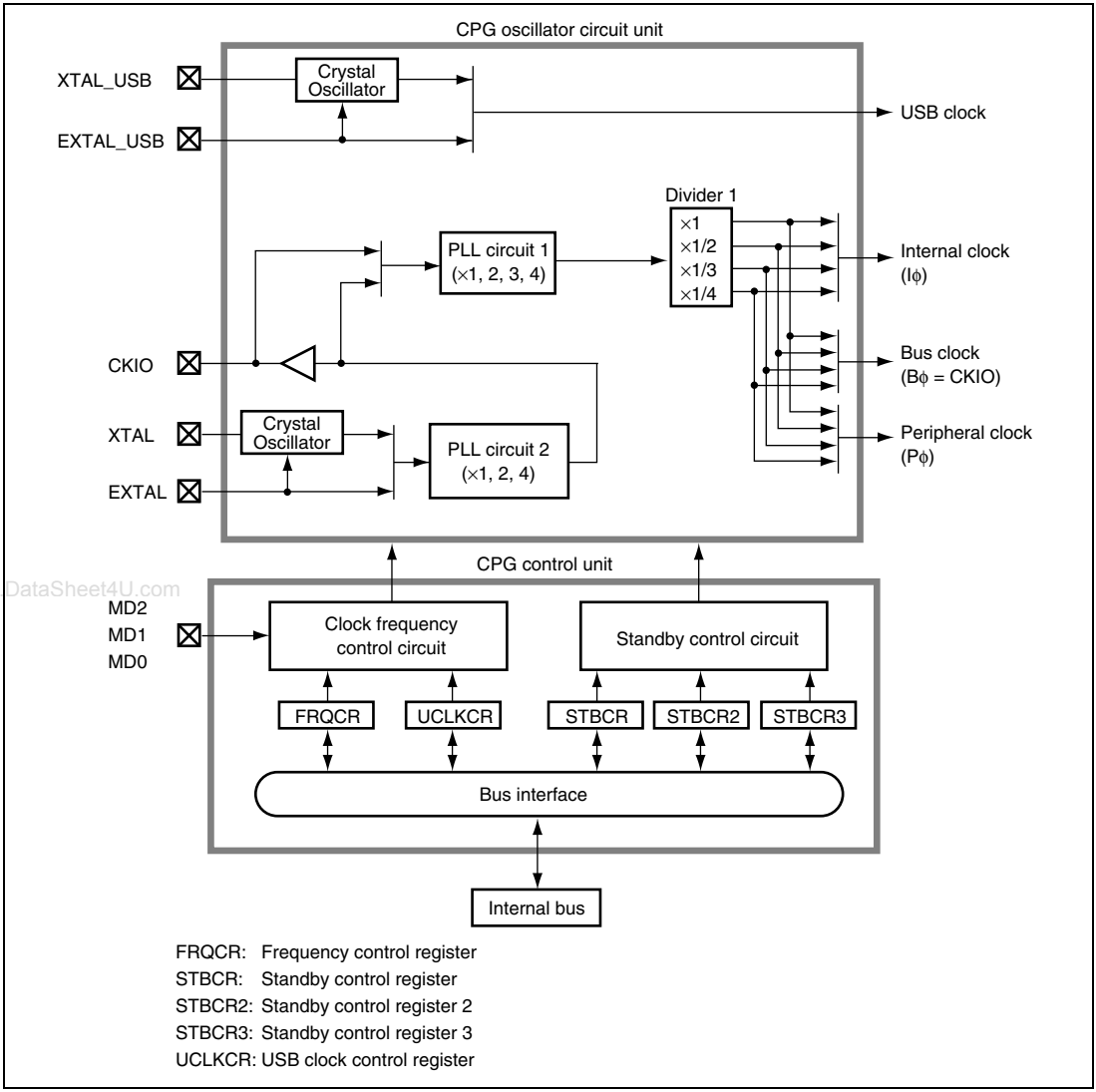


Figure 9.1 Block Diagram of Clock Pulse Generator

The clock pulse generator blocks function as follows:

1. PLL Circuit 1

   PLL circuit 1 doubles, triples, quadruples, or leaves unchanged the input clock frequency from the CKIO pin or PLL circuit 2. The multiplication rate is set by the frequency control register. When this is done, the phase of the rising edge of the internal clock is controlled so that it will synchronize with the phase of the rising edge of the CKIO pin.

2. PLL Circuit 2

   PLL circuit 2 leaves unchanged, doubles, or quadruples the input clock frequency coming from the crystal oscillator or EXTAL pin. The multiplication ratio is fixed by the clock-operating mode. The clock-operating mode is set by pins MD0, MD1, and MD2. For more details on clock operating modes, refer to table 9.2.

3. Crystal Oscillator

   This oscillator circuit is used when a crystal resonator is connected to the XTAL and EXTAL pins. This crystal oscillator operates according to the clock operating mode setting.

4. Divider 1

   Divider 1 generates a clock at the operating frequency used by the internal or peripheral clock. The operating frequency can be 1, 1/2, 1/3, or 1/4 times the output frequency of PLL circuit 1, as long as it stays at or above the clock frequency of the CKIO pin. The division ratio is set in the frequency control register.

5. Clock Frequency Control Circuit

   The clock frequency control circuit controls the clock frequency using the MD0, MD1, and MD2 pins and the frequency control register.

6. Standby Control Circuit

   The standby control circuit controls the state of the on-chip oscillator and other modules during clock switching and software/standby modes.

7. Frequency Control Register

   The frequency control register has control bits assigned for the following functions: clock output/non-output from the CKIO pin, the frequency multiplication ratio of PLL circuit 1, and the frequency division ratio of the internal clock and the peripheral clock.

8. Standby Control Register

   The standby control register has bits for controlling the power-down modes. See section 11, Power-Down Modes, for more information.

9. USB Clock Control Register

   The source clock generating the USB clock is set in the USB clock control register.

9.2 Input/Output Pins

Table 9.1 lists the CPG pins and their functions.

Table 9.1 Clock Pulse Generator Pins and Functions

Pin Name	Symbol	I/O	Description
Mode control pins	MD0	I	Set the clock-operating mode.
	MD1	I	Set the clock-operating mode.
	MD2	I	Set the clock-operating mode.
Crystal oscillator pins for system clock (clock input pins)	XTAL	O	Connects a crystal resonator.
	EXTAL	I	Connects a crystal resonator. Also used to input an external clock.
Clock I/O pin	CKIO	I/O	Inputs or outputs an external clock.
Crystal oscillator pins for USB (clock input pins)	XTAL_USB	O	Connects a crystal resonator for the USB.
	EXTAL_USB	I	Connects a crystal resonator for the USB. Also used to input an external clock.

Note: The values of the mode control pins are sampled only in a power-on reset. This can prevent the erroneous operation of the LSI.

9.3 Clock Operating Modes

Table 9.2 shows the relationship between the mode control pins (MD2 to MD0) combinations and the clock operating modes. Table 9.3 shows the usable frequency ranges in the clock operating modes and the frequency range of the input clock.

Table 9.2 Clock Operating Modes

	Pin Values			Clock I/O				
Mode	MD2	MD1	MD0	Source	Output	PLL2 On/Off	PLL1 On/Off	CKIO Frequency
0	0	0	0	EXTAL	CKIO	ON (× 1)	ON (× 1, 2, 3, 4)	(EXTAL)
1	0	0	1	EXTAL	CKIO	ON (× 4)	ON (× 1, 2, 3, 4)	(EXTAL) × 4
2	0	1	0	Crystal resonator	CKIO	ON (× 4)	ON (× 1, 2, 3, 4)	(Crystal) × 4
4	1	0	0	Crystal resonator	CKIO	ON (× 1)	ON (× 1, 2, 3, 4)	(Crystal)
5	1	0	1	EXTAL	CKIO	ON (× 2)	ON (× 1, 2, 3, 4)	(EXTAL) × 2
6	1	1	0	Crystal resonator	CKIO	ON (× 2)	ON (× 1, 2, 3, 4)	(Crystal) × 2
7	1	1	1	CKIO	—	OFF	ON (× 1, 2, 3, 4)	(CKIO)

Mode 0: An external clock is input from the EXTAL pin and executes waveform shaping by PLL circuit 2 before being supplied inside this LSI.

Mode 1: An external clock is input from the EXTAL pin and its frequency is multiplied by 4 by PLL circuit 2 before being supplied inside this LSI, allowing a low-frequency external clock to be used.

Mode 2: The on-chip crystal oscillator operates, with the oscillation frequency being multiplied by 4 by PLL circuit 2 before being supplied inside this LSI, allowing a low-frequency external clock to be used.

Mode 4: The on-chip crystal oscillator operates and executes waveform shaping by PLL circuit 2 before being supplied inside this LSI.

Mode 5: An external clock is input from the EXTAL pin and its frequency is multiplied by 2 by PLL circuit 2 before being supplied inside this LSI, allowing a low-frequency external clock to be used.

Mode 6: The on-chip crystal oscillator operates, with the oscillation frequency being multiplied by 2 by PLL circuit 2 before being supplied inside this LSI, allowing a low crystal frequency to be used.

Mode 7: In this mode, the CKIO pin is an input, an external clock is input to this pin, and executes waveform shaping, and also frequency multiplication according to the setting, by PLL circuit 1 before being supplied to this LSI. As PLL circuit 1 compensates for fluctuations in the CKIO pin load, this mode is suitable for connection of synchronous DRAM.

Table 9.3 Possible Combination of Clock Modes and FRQCR Values

Clock Mode	FRQCR*[1]	PLL1	PLL2	Clock Rate*[2] (I:B:P)	Input Clock/Crystal Resonator Frequency Range	CKIO Frequency Range
0	H'1000	ON (× 1)	ON (× 1)	1:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1001	ON (× 1)	ON (× 1)	1:1:1/2	20.00 MHz to 66.67 MHz	20.00 MHz to 66.67 MHz
	H'1003	ON (× 1)	ON (× 1)	1:1:1/4	20.00 MHz to 66.67 MHz	20.00 MHz to 66.67 MHz
	H'1101	ON (× 2)	ON (× 1)	2:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1103	ON (× 2)	ON (× 1)	2:1:1/2	20.00 MHz to 66.67 MHz	20.00 MHz to 66.67 MHz
	H'1111	ON (× 2)	ON (× 1)	1:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1113	ON (× 2)	ON (× 1)	1:1:1/2	20.00 MHz to 66.67 MHz	20.00 MHz to 66.67 MHz
	H'1202	ON (× 3)	ON (× 1)	3:1:1	26.70 MHz to 33.34 MHz	26.70 MHz to 33.34 MHz
	H'1222	ON (× 3)	ON (× 1)	1:1:1	26.70 MHz to 33.34 MHz	26.70 MHz to 33.34 MHz
	H'1303	ON (× 4)	ON (× 1)	4:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1313	ON (× 4)	ON (× 1)	2:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1333	ON (× 4)	ON (× 1)	1:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
1, 2	H'1001	ON (× 1)	ON (× 4)	4:4:2	10.00 MHz to 16.67 MHz	40.00 MHz to 66.67 MHz
	H'1003	ON (× 1)	ON (× 4)	4:4:1	10.00 MHz to 16.67 MHz	40.00 MHz to 66.67 MHz
	H'1103	ON (× 2)	ON (× 4)	8:4:2	10.00 MHz to 16.67 MHz	40.00 MHz to 66.67 MHz
	H'1113	ON (× 2)	ON (× 4)	4:4:2	10.00 MHz to 16.67 MHz	40.00 MHz to 66.67 MHz
4	H'1000	ON (× 1)	ON (× 1)	1:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1001	ON (× 1)	ON (× 1)	1:1:1/2	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1003	ON (× 1)	ON (× 1)	1:1:1/4	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1101	ON (× 2)	ON (× 1)	2:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1103	ON (× 2)	ON (× 1)	2:1:1/2	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1111	ON (× 2)	ON (× 1)	1:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1113	ON (× 2)	ON (× 1)	1:1:1/2	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1202	ON (× 3)	ON (× 1)	3:1:1	26.70 MHz to 33.34 MHz	26.70 MHz to 33.34 MHz
	H'1222	ON (× 3)	ON (× 1)	1:1:1	26.70 MHz to 33.34 MHz	26.70 MHz to 33.34 MHz
	H'1303	ON (× 4)	ON (× 1)	4:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1313	ON (× 4)	ON (× 1)	2:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1333	ON (× 4)	ON (× 1)	1:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz

Clock Mode	FRQCR*[1]	PLL1	PLL2	Clock Rate*[2] (I:B:P)	Input Clock / Crystal Resonator Frequency Range	CKIO Frequency Range
5	H'1000	ON (× 1)	ON (× 2)	2:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz
	H'1001	ON (× 1)	ON (× 2)	2:2:1	10.00 MHz to 33.34 MHz	20.00 MHz to 66.67 MHz
	H'1003	ON (× 1)	ON (× 2)	2:2:1/2	10.00 MHz to 33.34 MHz	20.00 MHz to 66.67 MHz
	H'1101	ON (× 2)	ON (× 2)	4:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.33 MHz
	H'1103	ON (× 2)	ON (× 2)	4:2:1	10.00 MHz to 33.34 MHz	20.00 MHz to 66.67 MHz
	H'1111	ON (× 2)	ON (× 2)	2:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz
	H'1113	ON (× 2)	ON (× 2)	2:2:1	10.00 MHz to 33.34 MHz	20.00 MHz to 66.67 MHz
	H'1202	ON (× 3)	ON (× 2)	6:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz
	H'1222	ON (× 3)	ON (× 2)	2:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz
	H'1303	ON (× 4)	ON (× 2)	8:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.33 MHz
	H'1313	ON (× 4)	ON (× 2)	4:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.33 MHz
	H'1333	ON (× 4)	ON (× 2)	2:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz
6	H'1000	ON (× 1)	ON (× 2)	2:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz
	H'1001	ON (× 1)	ON (× 2)	2:2:1	10.00 MHz to 33.34 MHz	20.00 MHz to 66.67 MHz
	H'1003	ON (× 1)	ON (× 2)	2:2:1/2	10.00 MHz to 33.34 MHz	20.00 MHz to 66.67 MHz
	H'1101	ON (× 2)	ON (× 2)	4:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.33 MHz
	H'1103	ON (× 2)	ON (× 2)	4:2:1	10.00 MHz to 33.34 MHz	20.00 MHz to 66.67 MHz
	H'1111	ON (× 2)	ON (× 2)	2:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz
	H'1113	ON (× 2)	ON (× 2)	2:2:1	10.00 MHz to 33.34 MHz	20.00 MHz to 66.67 MHz
	H'1202	ON (× 3)	ON (× 2)	6:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz
	H'1222	ON (× 3)	ON (× 2)	2:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz
	H'1303	ON (× 4)	ON (× 2)	8:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.33 MHz
	H'1313	ON (× 4)	ON (× 2)	4:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.33 MHz
	H'1333	ON (× 4)	ON (× 2)	2:2:2	10.00 MHz to 16.67 MHz	20.00 MHz to 33.34 MHz

Clock Mode	FRQCR*[1]	PLL1	PLL2	Clock Rate*[2] (I:B:P)	Input Clock / Crystal Resonator Frequency Range	CKIO Frequency Range
7	H'1000	ON (× 1)	OFF	1:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1001	ON (× 1)	OFF	1:1:1/2	20.00 MHz to 66.67 MHz	20.00 MHz to 66.67 MHz
	H'1003	ON (× 1)	OFF	1:1:1/4	20.00 MHz to 66.67 MHz	20.00 MHz to 66.67 MHz
	H'1101	ON (× 2)	OFF	2:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1103	ON (× 2)	OFF	2:1:1/2	20.00 MHz to 66.67 MHz	20.00 MHz to 66.67 MHz
	H'1111	ON (× 2)	OFF	1:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1113	ON (× 2)	OFF	1:1:1/2	20.00 MHz to 66.67 MHz	20.00 MHz to 66.67 MHz
	H'1202	ON (× 3)	OFF	3:1:1	26.70 MHz to 33.34 MHz	26.70 MHz to 33.34 MHz
	H'1222	ON (× 3)	OFF	1:1:1	26.70 MHz to 33.34 MHz	26.70 MHz to 33.34 MHz
	H'1303	ON (× 4)	OFF	4:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1313	ON (× 4)	OFF	2:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz
	H'1333	ON (× 4)	OFF	1:1:1	20.00 MHz to 33.34 MHz	20.00 MHz to 33.34 MHz

Notes: *1 This LSI cannot operate in an FRQCR value other than that listed in table 9.3.
*2 Taking input clock frequency ratio as 1.

Cautions:

1. The input to divider 1 is the output of the PLL circuit 1.
2. The frequency of the internal clock (Iϕ) is:
   - The product of the frequency of the CKIO pin, the frequency multiplication ratio of PLL circuit 1, and the division ratio of divider 1.
   - Do not set the internal clock frequency lower than the CKIO pin frequency.
3. The frequency of the peripheral clock (Pϕ) is:
   - The product of the frequency of the CKIO pin, the frequency multiplication ratio of PLL circuit 1, and the division ratio of divider 1.
   - The peripheral clock frequency should not be set higher than the frequency of the CKIO pin, higher than 33.34 MHz, or lower than 13 MHz when the USB is used.
4. ×1, ×2, ×3, or ×4 can be used as the multiplication ratio of PLL circuit 1. ×1, ×1/2, ×1/3, or ×1/4 can be selected as the division ratios of divider 1. Set the rate in the frequency control register.
5. The output frequency of PLL circuit 1 is the product of the CKIO frequency and the multiplication ratio of PLL circuit 1. Use the output frequency under 133.34 MHz.

9.4 Register Descriptions

The CPG has the following registers. Refer to section 24, List of Registers, for the addresses of the registers and the state of each register in each processor state.

- Frequency control register (FRQCR)
- USB clock control register (UCLKCR)

9.4.1 Frequency Control Register (FRQCR)

The frequency control register (FRQCR) is a 16-bit readable/writable register used to specify whether a clock is output from the CKIO pin, the on/off state of PLL circuit 1, PLL standby, the frequency multiplication ratio of PLL circuit 1, and the frequency division ratio of the internal clock and the peripheral clock. Only word access can be used on FRQCR. As for the combination of the clock rate, refer to table 9.3, Possible Combination of Clock Modes and FRQCR Values. The combinations listed in table 9.3 should only be set on FRQCR.

Bit	Bit Name	Initial Value	R/W	Description
15 to 13	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
12	CKOEN	1	R/W	Clock Output Enable Specifies to output a clock from the CKIO pin or to fix the CKIO pin low when software standby is canceled (after an interrupt before STATUS1 becomes low and STATUS0 becomes low). The CKIO pin is fixed low during STATUS1 = low and STATUS0 = high, when the CKOEN bit is cleared to 0. Therefore, the malfunction of an external circuit because of an unstable CKIO clock in releasing software standby mode can be prevented. In clock operating mode 7, the CKIO pin is in the input state regardless of this bit. 0: Fixes the CKIO pin low in software standby mode. 1: Outputs a clock from the CKIO pin.
11, 10	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
9	STC1	0	R/W	Frequency Multiplication Ratio
8	STC0	0	R/W	00: × 1 time
				01: × 2 times
				10: × 3 times
				11: × 4 times
7, 6	—	All 0	R	Reserved
				These bits are always read as 0. The write value should always be 0.
5	IFC1	0	R/W	Internal Clock Frequency Division Ratio
4	IFC0	0	R/W	Specify the frequency division ratio of the internal clock with respect to the output frequency of PLL circuit 1.
				00: × 1 time
				01: × 1/2 time
				10: × 1/3 time
				11: × 1/4 time
3, 2	—	All 0	R	Reserved
				These bits are always read as 0. The write value should always be 0.
1	PFC1	1	R/W	Peripheral Clock Frequency Division Ratio
0	PFC0	1	R/W	Specify the frequency division ratio of the peripheral clock with respect to the output frequency of PLL circuit 1.
				00: × 1 time
				01: × 1/2 time
				10: × 1/3 time
				11: × 1/4 time

9.4.2 USB Clock Frequency Control Register (UCLKCR)

UCLKCR is an 8-bit readable/writable register.

Word-size access is used to write to this register. This writing should be performed with H'A5 in the upper byte and the write data in the lower byte.

Bit	Bit Name	Initial Value	R/W	Description
7	USSCS1	1	R/W	Source Clock Selection Bit
6	USSCS0	1	R/W	These bits select the source clock. 00: Clock stopped 01: Setting prohibited 10: Setting prohibited 11: External input clock
5	USBEN	1	R/W	USB On-chip Oscillator Enable This bit controls the operation of the USB on-chip oscillator. 0: USB on-chip oscillator stopped 1: USB on-chip oscillator operates
4 to 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

9.4.3 Usage Notes

Note the following when using the USB. If these are used incorrectly, the correct clocks may not be generated, causing faulty operation of the USB.

1. UCLKCR is used only for generation of the USB clocks. When the USB is not used, it is recommended that UCLKCR be cleared to H'00 to halt the clock.
2. Halt the USB before changing the values of UCLKCR. Halt the USB by stopping the clock supply using the USB module stop bits in STBCR3.
3. UCLKCR is initialized only by a power-on reset. In a manual reset, they retain their current set values.
4. Use the USB module with Pϕ > 13 MHz. Otherwise, the operation of this LSI is not guaranteed.

9.5 Changing Frequency

The frequency of the internal clock and peripheral clock can be changed either by changing the multiplication rate of PLL circuit 1 or by changing the division rates of divider 1. All of these are controlled by software through the frequency control register. The methods are described below.

9.5.1 Changing Multiplication Rate

A PLL settling time is required when the multiplication rate of PLL circuit 1 is changed. The on-chip WDT counts the settling time.

1. In the initial state, the multiplication rate of PLL circuit 1 is 1.
2. Set a value that will become the specified oscillation settling time in the WDT and stop the WDT. The following must be set:
   WTCSR.TME = 0: WDT stops
   WTCSR.CKS[2:0]: Division ratio of WDT count clock
   WTCNT: Initial counter value
3. Set the desired value in the STC[1:0] bits. The division ratio can also be set in the IFC[1:0] bits and PFC[1:0] bits.
4. The processor pauses internally and the WDT starts incrementing. The internal and peripheral clocks both stop and the WDT is supplied with the clock. The clock will continue to be output at the CKIO pin.
5. Supply of the clock that has been set begins at WDT count overflow, and the processor begins operating again. The WDT stops after it overflows.

9.5.2 Changing Division Ratio

The WDT will not count unless the multiplication rate is changed simultaneously.

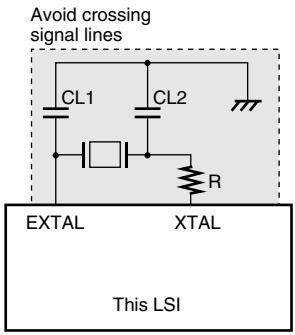
1. In the initial state, IFC[1:0] = 00 and PFC[1:0] = 11.
2. Set the IFC[1:0], PFC[1:0] bits to the new division ratio. The values that can be set are limited by the clock mode and the multiplication rate of PLL circuit 1. Note that if the wrong value is set, the processor will malfunction.
3. The clock is immediately supplied at the new division ratio.

9.5.3 Modification of Clock Operating Mode

The values of the mode control pins (MD2 to MD0) that define a clock-operating mode are reflected at power-on reset.

9.6 Usage Notes

When Using an External Crystal Resonator: Place the crystal resonator, capacitors CL1 and CL2, and damping resistance R as close as possible to the EXTAL and XTAL pins. To prevent induction from interfering with correct oscillation, use a common grounding point for the capacitors connected to the resonator, and do not locate a wiring pattern near these components.



Note: The values for CL1, CL2, and damping resistance should be determined after consultation with the crystal resonator manufacturer.

Figure 9.2 Points for Attention when Using Crystal Resonator

Decoupling Capacitors: As far as possible, insert a laminated ceramic capacitor of 0.1 to 1 µF as a passive capacitor for each $V_{SS}/V_{SS}Q$ and $V_{CC}/V_{CC}Q$ pair. Mount the passive capacitors as close as possible to the chip's power supply pins, and use components with a frequency characteristic suitable for the chip's operating frequency, as well as a suitable capacitance value.

Digital system $V_{SS}/V_{SS}Q$ and $V_{CC}/V_{CC}Q$ pairs: 2-5, 17-19, 26-28, 32-34, 44-46, 57-59, 69-71, 78-80, 87-89, 111-113, 130-132, 133-138, 159-161, 178-180, 182-184, 199-204

On-chip oscillator $V_{SS}/V_{SS}Q$ and $V_{CC}/V_{CC}Q$ pairs: 6-9, 149-150, 151-152, 205-208

When Using a PLL Oscillator Circuit: Keep the wiring from the PLL V_{CC} and PLL V_{SS} connection pattern to the power supply pins short, and make the pattern width wide, to minimize the inductance value.

In clock mode 7, connect the EXTAL pin to $V_{CC}Q$ (3.3-V power) with pull-up resistor, and leave the XTAL pin open.

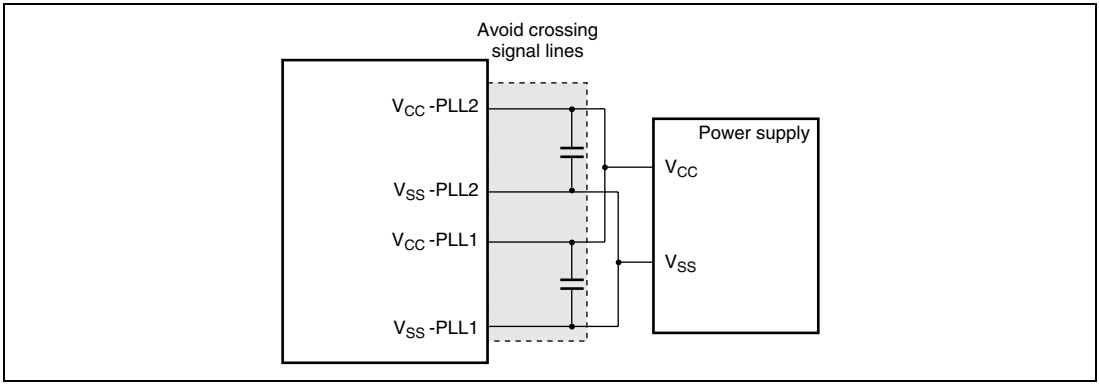


Figure 9.3 Points for Attention when Using PLL Oscillator Circuit

Notes on Wiring Power Supply Pins: To avoid crossing signal lines, wire V_{CC}–PLL1, V_{CC}–PLL2, V_{SS}–PLL1, and V_{SS}–PLL2 as three patterns from the power supply source on the board so that they are independent of digital V_{CC} and V_{SS}.

Section 10 Watchdog Timer (WDT)

This LSI includes the watchdog timer (WDT) and can be reset by the overflow of the counter when the value of the counter has not been updated because of an erroneous system operation.

The WDT is a single-channel timer that uses a peripheral clock as an input and counts the clock settling time when clearing software standby mode and temporary standbys, such as frequency changes. It can also be used as a conventional watchdog timer or an interval timer.

10.1 Features

- Can be used to ensure the clock settling time
  Use the WDT to clear software standby mode and the temporary standbys which occur when the clock frequency is changed.
- Can switch between watchdog timer mode and interval timer mode.
- Generates internal resets in watchdog timer mode
  Internal resets occur after counter overflow.
  Power-on reset and manual reset are available.
- Interrupt generation in interval timer mode
  An interval timer interrupt is generated when the counter overflows.
- Choice of eight counter input clocks
  Eight clocks (×1 to ×1/4096) that are obtained by dividing the peripheral clock can be selected.

Figures 10.1 shows a block diagram of the WDT.

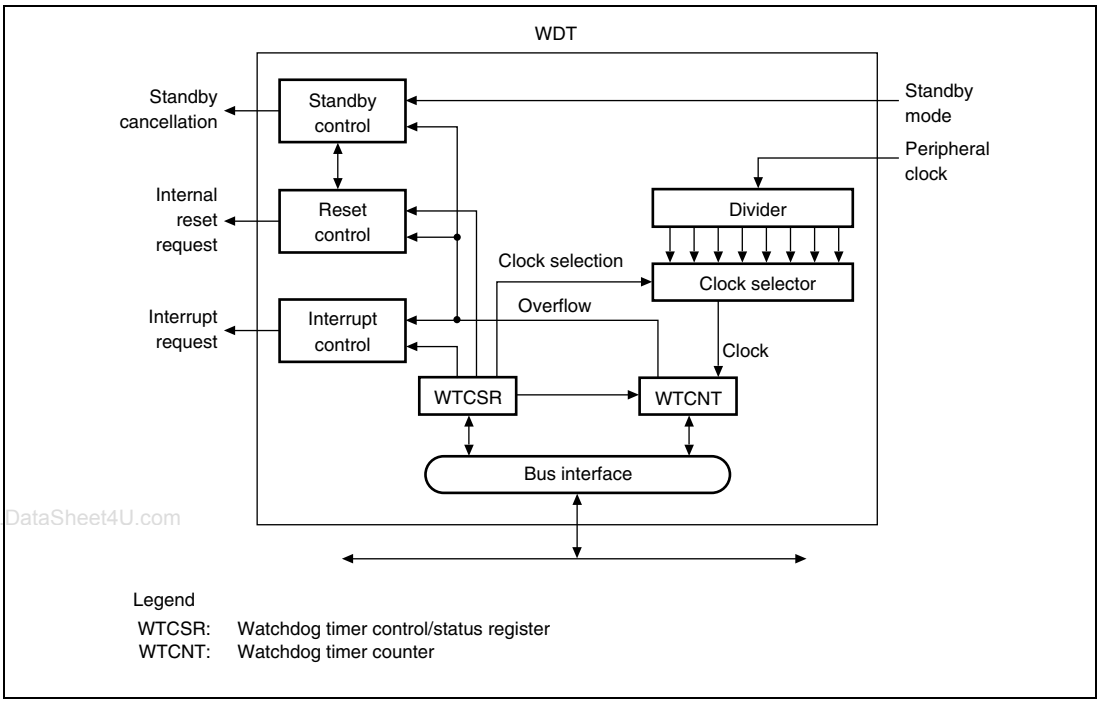


Figure 10.1 Block Diagram of WDT

10.2 Register Descriptions

The WDT has the following two registers. Refer to section 24, List of Registers for the details of the addresses of these registers and the state of registers in each operating mode.

- Watchdog timer counter (WTCNT)
- Watchdog timer control/status register (WTCSR)

10.2.1 Watchdog Timer Counter (WTCNT)

The watchdog timer counter (WTCNT) is an 8-bit readable/writable register that increments on the selected clock. When an overflow occurs, it generates a reset in watchdog timer mode and an interrupt in interval timer mode. The WTCNT counter is not initialized by an internal reset due to the WDT overflow. The WTCNT counter is initialized to H'00 only by a power-on reset using the $\overline{\text{RESETP}}$ pin.

Use a word access to write to the WTCNT counter, with H'5A in the upper byte. Use a byte access to read WTCNT.

Note: WTCNT differs from other registers in that it is more difficult to write to. See section 10.2.3, Notes on Register Access, for details.

10.2.2 Watchdog Timer Control/Status Register (WTCSR)

The watchdog timer control/status register (WTCSR) is an 8-bit readable/writable register composed of bits to select the clock used for the count, overflow flags, and enable bits.

WTCSR holds its value in an internal reset due to the WDT overflow. WTCSR is initialized to H'00 only by a power-on reset using the $\overline{\text{RESETP}}$ pin.

When used to count the clock settling time for canceling a software standby, it retains its value after counter overflow. Use a word access to write to the WTCSR counter, with H'A5 in the upper byte. Use a byte access to read WTCSR.

Note: WTCSR differs from other registers in that it is more difficult to write to. See section 10.2.3, Notes on Register Access, for details.

Bit	Bit Name	Initial Value	R/W	Description
7	TME	0	R/W	Timer Enable Starts and stops timer operation. Clear this bit to 0 when using the WDT in software standby mode or when changing the clock frequency. 0: Timer disabled: Count-up stops and WTCNT value is retained 1: Timer enabled
6	WT/$\overline{IT}$	0	R/W	Timer Mode Select Selects whether to use the WDT as a watchdog timer or an interval timer. 0: Use as interval timer 1: Use as watchdog timer Note: If WT/$\overline{IT}$ is modified when the WDT is running, the up-count may not be performed correctly.
5	RSTS	0	R/W	Reset Select Selects the type of reset when WTCNT overflows in watchdog timer mode. In interval timer mode, this setting is ignored. 0: Power-on reset 1: Manual reset
4	WOVF	0	R/W	Watchdog Timer Overflow Indicates that WTCNT has overflowed in watchdog timer mode. This bit is not set in interval timer mode. 0: No overflow 1: WTCNT has overflowed in watchdog timer mode
3	IOVF	0	R/W	Interval Timer Overflow Indicates that WTCNT has overflowed in interval timer mode. This bit is not set in watchdog timer mode. 0: No overflow 1: WTCNT has overflowed in interval timer mode

Bit	Bit Name	Initial Value	R/W	Description
2	CKS2	0	R/W	Clock Select 2 to 0
1	CKS1	0	R/W	These bits select the clock to be used for the WTCNT count from the eight types obtainable by dividing the peripheral clock. The overflow period that is shown inside the parenthesis in the table is the value when the peripheral clock (Pϕ) is 15 MHz.
0	CKS0	0	R/W	

000	Pϕ	(17 μs)
001	Pϕ/4	(68 μs)
010	Pϕ/16	(273 μs)
011	Pϕ/32	(546 μs)
100	Pϕ/64	(1.09 ms)
101	Pϕ/256	(4.36 ms)
110	Pϕ/1024	(17.48 ms)
111	Pϕ/4096	(69.91 ms)

Note: If bits CKS2 to CKS0 are modified when the WDT is running, the up-count may not be performed correctly. Ensure that these bits are modified only when the WDT is not running.

10.2.3 Notes on Register Access

The watchdog timer counter (WTCNT) and watchdog timer control/status register (WTCSR) are more difficult to write to than other registers. The procedure for writing to these registers is given below.

- These registers must be written by a word transfer instruction. They cannot be written by a byte or longword transfer instruction.

When writing to WTCNT, set the upper byte to H'5A and transfer the lower byte as the write data, as shown in figure 10.2. When writing to WTCSR, set the upper byte to H'A5 and transfer the lower byte as the write data. This transfer procedure writes the lower byte data to WTCNT or WTCSR.

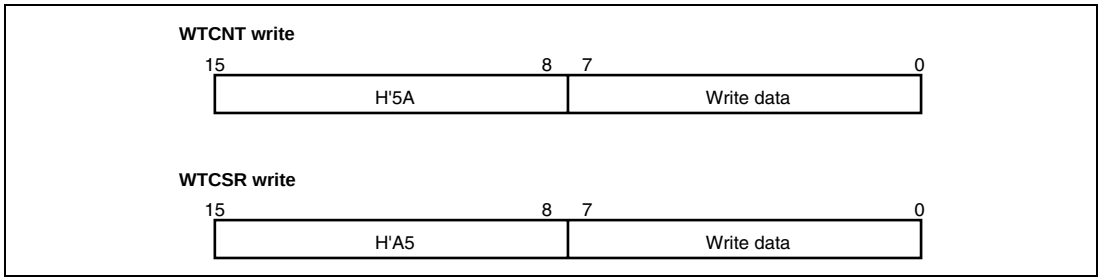


Figure 10.2 Writing to WTCNT and WTCSR

10.3 Operation

10.3.1 Canceling Software Standbys

The WDT is used to cancel software standby mode with an interrupt such as an NMI. The procedure when using an NMI interrupt is described below. (The WDT does not run when resets are used for canceling, so keep the $\overline{\text{RESETP}}$ or $\overline{\text{RESETM}}$ pin low until the clock stabilizes.)

1. Before transitioning to software standby mode, always clear the TME bit in WTCSR to 0. When the TME bit is 1, an erroneous reset or interval timer interrupt may be generated when the count overflows.
2. Set the type of count clock used in the CKS2 to CKS0 bits in WTCSR and the initial values for the counter in the WTCNT counter. These values should ensure that the time till count overflow is longer than the clock oscillation settling time.
3. Move to software standby mode by executing a SLEEP instruction, after that clock stops.
4. The WDT starts counting by detecting the edge change of the NMI signal.
5. When the WDT count overflows, the CPG starts supplying the clock and the processor resumes operation. The WOVF flag in WTCSR is not set.
6. Since the WDT continues counting from H'00, clear the STBY bit in the STBCR register to 0 in the interrupt processing program and this will stop the WDT. When the STBY bit remains 1, the LSI again enters the software standby mode when the WDT has counted up to H'80. This software standby mode can be canceled by power-on resets.

10.3.2 Changing Frequency

To change the frequency used by the PLL, use the WDT. When changing the frequency only by switching the divider, do not use the WDT.

1. Before changing the frequency, always clear the TME bit in WTCSR to 0. When the TME bit is 1, an erroneous reset or interval timer interrupt may be generated when the count overflows.
2. Set the type of count clock used in the CKS2 to CKS0 bits of WTCSR and the initial values for the counter in the WTCNT counter. These values should ensure that the time till count overflow is longer than the clock oscillation settling time. The divided clock set by CKS2 to CKS0 bits in WTCSR will be used for the base clock of Pϕ after the frequency is changed.
3. When the frequency control register (FRQCR) is written, the processor stops temporarily. The WDT starts counting.
4. When the WDT count overflows, the CPG resumes supplying the clock and the processor resumes operation. The WOVF flag in WTCSR is not set.
5. The counter stops at the values H'00.
6. Before changing WTCNT after the execution of the frequency change instruction, always confirm that the value of WTCNT is H'00 by reading WTCNT.

10.3.3 Using Watchdog Timer Mode

1. Set the WT/$\overline{IT}$ bit in WTCSR to 1, set the reset type in the RSTS bit, set the type of count clock in the CKS2 to CKS0 bits, and set the initial value of the counter in the WTCNT counter.
2. Set the TME bit in WTCSR to 1 to start the count in watchdog timer mode.
3. While operating in watchdog timer mode, rewrite the counter periodically to H'00 to prevent the counter from overflowing.
4. When the counter overflows, the WDT sets the WOVF flag in WTCSR to 1 and generates the reset signal specified by the RSTS bit. The counter then resumes counting.

10.3.4 Using Interval Timer Mode

When operating in interval timer mode, interval timer interrupts are generated at every overflow of the counter. This enables interrupts to be generated at set periods.

1. Clear the WT/$\overline{IT}$ bit in WTCSR to 0, set the type of count clock in the CKS2 to CKS0 bits, and set the initial value of the counter in the WTCNT counter.
2. Set the TME bit in WTCSR to 1 to start the count in interval timer mode.
3. When the counter overflows, the WDT sets the IOVF flag in WTCSR to 1 and an interval timer interrupt request is sent to the INTC. The counter then resumes counting.

Section 11 Power-Down Modes

This LSI has four types of the power-down modes: sleep mode, software standby mode, module standby function, and hardware standby mode.

11.1 Features

This LSI has the following power-down modes and function:

1. Sleep mode
2. Software standby mode
3. Module standby function (Cache, TLB, UBC, DMAC, H-UDI, and on-chip peripheral module)
4. Hardware standby mode

Table 11.1 shows the transition conditions for entering the modes from the program execution state, as well as the CPU and peripheral module states in each mode and the procedures for canceling each mode.

Table 11.1 States of Power-Down Modes

Mode	Transition Conditions	State						
		CPG	CPU	CPU Register	On-Chip Peripheral Modules	Pins	External Memory	Canceling Condition
Sleep mode	Execute SLEEP instruction with STBY bit cleared to 0 in STBCR	Run	Halt	Held	Run	*3	Refresh	1. Interrupt 2. Reset
Software standby mode	Execute SLEEP instruction with STBY bit set to 1 in STBCR	Halt	Halt	Held	Halt*1	*3	Self-refresh	1. Interrupt 2. Reset
Module standby function	Set MSTP bit of STBCR, STBCR2, and STBCR3 to 1	Run	Run	Held	Specified module halts	*2	Refresh	1. Clear MSTP bit to 0 2. Power-on reset
Hardware standby mode	Drive CA pin low	Halt	Halt	Held	Halt*1	*4	—	Power-on reset

Notes: *1 The RTC still runs if the START bit in RCR2 is set to 1 (see section 15, Realtime Clock (RTC)).

*2 Depends on the on-chip peripheral module.

*3 Refer to table A.1, I/O Port States in Each Processing State, in Appendix.

*4 Hi-Z except EXTAL, XTAL, EXTAL2, XTAL2, EXTAL_USB, XTAL_USB, STATUS1, and STATUS0.

11.2 Input/Output Pins

Table 11.2 lists the pins used for the power-down modes.

Table 11.2 Pin Configuration

Pin Name	Symbol	I/O	Description
Processing state	STATUS1, STATUS0	O	Operating state of the processor. HH: Reset HL: Sleep mode LH: Standby mode LL: Normal operation Note: H means high level, and L means low level.
Power-on reset	$\overline{\text{RESETP}}$	I	Reset input signal. Power-on reset occurs at low-level.
Manual reset	$\overline{\text{RESETM}}$	I	Reset input signal. Manual reset occurs at low-level.
Hardware standby	CA	I	Normal operation at high-level and hardware standby mode is entered at low-level.

11.3 Register Descriptions

There are following five registers used for the power-down modes. Refer to section 24, List of Registers, for the details of the addresses of these registers and the state of registers in each operating mode.

- Standby control register (STBCR)
- Standby control register 2 (STBCR2)
- Standby control register 3 (STBCR3)

11.3.1 Standby Control Register (STBCR)

STBCR is an 8-bit readable/writable register that specifies the state of the power-down mode.

Bit	Bit Name	Initial Value	R/W	Description
7	STBY	0	R/W	Standby Specifies transition to software standby mode. 0: Executing SLEEP instruction puts chip into sleep mode 1: Executing SLEEP instruction puts chip into software standby mode
6, 5	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
4	STBXTL	0	R/W	Standby Crystal Specifies stop/start of the crystal oscillator in standby mode. 0: Crystal oscillator stops in standby mode. 1: Crystal oscillator continues operation in standby mode.
3	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
2	MSTP2	0	R/W	Module Stop 2 Specifies halting the clock supply to the TMU when the MSTP2 bit has been set to 1. 0: TMU runs 1: Clock supply to TMU halted
1	MSTP1	0	R/W	Module Stop 1 Specifies halting the clock supply to the RTC when the MSTP1 bit has been set to 1. 0: RTC runs 1: Clock supply to RTC halted
0	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.

11.3.2 Standby Control Register 2 (STBCR2)

STBCR2 is an 8-bit readable/writable register that controls the operation of modules in the power-down mode.

Bit	Bit Name	Initial Value	R/W	Description
7	MSTP10	0	R/W	Module Stop Bit 10 When the MSTP10 bit is set to 1, the clock supply to the H-UDI is halted. 0: H-UDI runs 1: Clock supply to H-UDI is halted
6	MSTP9	0	R/W	Module Stop Bit 9 When the MSTP9 bit is set to 1, the clock supply to the UBC is halted. 0: UBC runs 1: Clock supply to UBC is halted
5	MSTP8	0	R/W	Module Stop Bit 8 When the MSTP8 bit is set to 1, the clock supply to the DMAC is halted. 0: DMAC runs 1: Clock supply to DMAC is halted
4	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
3	MSTP6	0	R/W	Module Stop Bit 6 When the MSTP6 bit is set to 1, the clock supply to the TLB is halted. 0: TLB runs 1: Clock supply to TLB is halted
2	MSTP5	0	R/W	Module Stop Bit 5 When the MSTP5 bit is set to 1, the clock supply to cache memory is halted. 0: Cache memory runs 1: Clock supply to cache memory is halted

Bit	Bit Name	Initial Value	R/W	Description
1, 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

11.3.3 Standby Control Register 3 (STBCR3)

STBCR3 is an 8-bit readable/writable register that controls the operation of modules in the power-down mode.

Bit	Bit Name	Initial Value	R/W	Description
7	MSTP37	0	R/W	Module Stop Bit 37 When the MSTP37 bit is set to 1, the clock supply to the USB is halted. 0: USB runs 1: Clock supply to USB is halted
6	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
5	MSTP35	0	R/W	Module Stop Bit 35 When the MSTP35 bit is set to 1, the clock supply to the CMT is halted. 0: CMT runs 1: Clock supply to CMT is halted
4	MSTP34	0	R/W	Module Stop Bit 34 When the MSTP34 bit is set to 1, the clock supply to the TPU is halted. 0: TPU runs 1: Clock supply to TPU is halted
3	MSTP33	0	R/W	Module Stop Bit 33 When the MSTP33 bit is set to 1, the clock supply to the ADC is halted. 0: ADC runs 1: Clock supply to ADC is halted

Bit	Bit Name	Initial Value	R/W	Description
2	MSTP32	0	R/W	Module Stop Bit 32 When the MSTP32 bit is set to 1, the clock supply to the IrDA is halted. 0: IrDA runs 1: Clock supply to IrDA is halted
1	MSTP31	0	R/W	Module Stop Bit 31 When the MSTP31 bit is set to 1, the clock supply to the SCIF2 is halted. 0: SCIF2 runs 1: Clock supply to SCIF2 is halted
0	MSTP30	0	R/W	Module Stop Bit 30 When the MSTP30 bit is set to 1, the clock supply to the SCIF0 is halted. 0: SCIF0 runs 1: Clock supply to SCIF0 is halted

11.4 Sleep Mode

11.4.1 Transition to Sleep Mode

Executing the SLEEP instruction when the STBY bit in STBCR is 0 causes a transition from the program execution state to sleep mode. Although the CPU halts immediately after executing the SLEEP instruction, the contents of its internal registers remain unchanged. The on-chip peripheral modules continue to run in sleep mode and the clock continues to be output to the CKIO pin.

In sleep mode, the STATUS1 pin is set high and the STATUS0 pin low.

11.4.2 Canceling Sleep Mode

Sleep mode is canceled by an interrupt (NMI, IRQ, IRL, PINT, and on-chip peripheral module) or reset. Interrupts are accepted in sleep mode even when the BL bit in SR is 1. If necessary, save SPC and SSR to the stack before executing the SLEEP instruction.

Canceling with an Interrupt: When an NMI, IRQ, IRL, PINT, or on-chip peripheral module interrupt occurs, sleep mode is canceled and interrupt exception processing is executed. A code indicating the interrupt source is set in INTEVT and INTEVT2.

Canceling with a Reset: Sleep mode is canceled by a power-on reset or a manual reset.

11.5 Software Standby Mode

11.5.1 Transition to Software Standby Mode

The LSI switches from a program execution state to software standby mode by executing the SLEEP instruction when the STBY bit is 1 in STBCR. In software standby mode, not only the CPU but also the clock and on-chip peripheral modules halt. The clock output from the CKIO pin also halts.

The contents of the CPU and cache registers remain unchanged. Some registers of on-chip peripheral modules are, however, initialized. For more details on the states of on-chip peripheral modules registers in software standby mode, refer to section 24.3, Register States in Each Operating Mode.

The procedure for moving to software standby mode is as follows:

1. Clear the TME bit in the WDT's timer control register (WTCSR) to 0 to stop the WDT.
2. Clear the WDT's timer counter (WTCNT) to 0 and set the CKS2 to CKS0 bits in WTCSR to appropriate values to secure the specified oscillation settling time.
3. After the STBY bit in STBCR is set to 1, a SLEEP instruction is executed.
4. Software standby mode is entered and the clocks within the LSI are halted. The STATUS1 pin output goes low and the STATUS0 pin output goes high.

11.5.2 Canceling Software Standby Mode

Software standby mode is canceled by an interrupt (NMI, IRQ, IRL, PINT, or RTC) or a reset.

Canceling with an Interrupt: The on-chip WDT can be used for hot starts. When the chip detects an NMI, IRQ*[1], IRL*[1], PINT*[1], or RTC*[1] interrupt, the clock will be supplied to the entire chip and software standby mode canceled after the time set in the WDT's timer control/status register has elapsed. The STATUS1 and STATUS0 pins both go low. Interrupt exception handling then begins and a code indicating the interrupt source is set in INTEVT and INTEVT2. After branching to the interrupt handling routine occurs, clear the STBY bit in STBCR. WTCNT stops automatically. If the STBY bit is not cleared, WTCNT continues operation and transits to software standby mode*[2] when it reaches H'80. This function prevents data from being broken in case of a voltage rise when the power supply is unstable. At this time, a manual reset is not accepted until the STBY bit is cleared to 0.

Interrupts are accepted in software standby mode even when the BL bit in SR is 1. If necessary, save SPC and SSR to the stack before executing the SLEEP instruction.

Immediately after an interrupt is detected, the phase of the clock output of the CKIO pin may be unstable, until software standby mode is cancelled.

Notes: 1. Only when the RTC is being used can standby mode be canceled using IRQ, IRL, PINT, or RTC.

2. Use a power-on reset to cancel software standby mode.

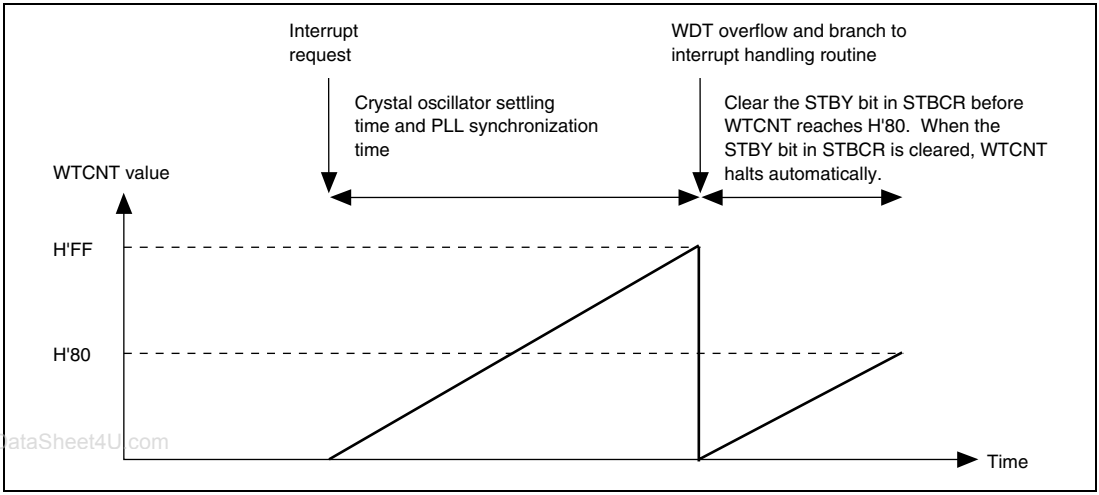


Figure 11.1 Canceling Standby Mode with STBY bit in STBCR

Canceling with a Reset: Software standby mode is canceled by a reset (power-on or manual). Keep the $\overline{\text{RESETP}}$ or $\overline{\text{RESETM}}$ pins low until the clock oscillation settles. The internal clock will continue to be output to the CKIO pin.

11.6 Module Standby Function

11.6.1 Transition to Module Standby Function

Setting the standby control register MSTP bits to 1 halts the supply of clocks to the corresponding on-chip peripheral modules. This function can be used to reduce the power consumption in normal mode. Before making a transition to module standby state, be sure to disable the relevant module.

In module standby state, the functions of the external pins of the on-chip peripheral modules change depending on the on-chip peripheral module and port settings. With a few exceptions, all registers hold their values prior to halt.

11.6.2 Canceling Module Standby Function

The module standby function can be canceled by clearing the MSTP bits to 0 or by a power-on reset.

When canceling the module standby function by clearing the corresponding MSTP bit, be sure to read the relevant MSTP bit to confirm that it has been cleared to 0.

11.7 Hardware Standby Mode

11.7.1 Transition to Hardware Standby Mode

The LSI enters hardware standby mode by driving the CA pin low. In hardware standby mode, as the same as software standby mode entered by executing the SLEEP instruction, all modules halt except ones operated by the RTC clock. Even in hardware standby mode, supply power to all power supply pins including the RTC power supply pins.

As differing from software standby mode, an interrupt or manual reset cannot be accepted in hardware standby mode.

When the CA pin is driven low, the LSI enters hardware standby mode in the following procedure depending on the state of CPG.

During software standby mode: The LSI enters the hardware standby state with the clock halted. An interrupt or manual reset cannot be accepted.

During WDT operation for canceling software standby mode by an interrupt: The CPU restarts the operation after software standby mode is canceled. Then, the LSI enters hardware standby mode.

During sleep mode: The CPU restarts the operation after sleep mode is canceled. Then, the LSI enters hardware standby mode.

In hardware standby mode, the CA pin must be held low.

11.7.2 Canceling Hardware Standby Mode

The hardware standby function can be canceled only by the power-on reset.

When the CA pin is driven high while the $\overline{\text{RESETP}}$ pin is low, the clock starts oscillating. Make sure to hold the $\overline{\text{RESETP}}$ pin low until the oscillation stabilizes. Then, drive the $\overline{\text{RESETP}}$ pin high to start the power-on resetting by the CPU.

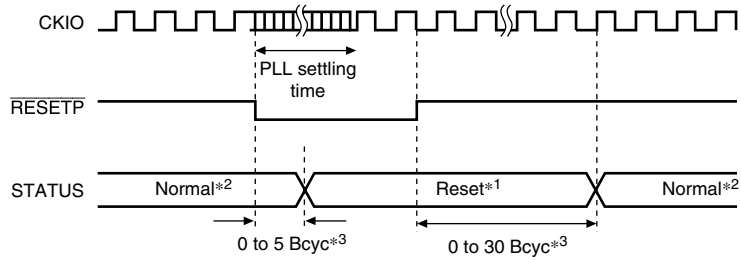
The operation is not guaranteed when an interrupt or manual reset is input.

11.8 Timing of STATUS Pin Changes

The timing of the STATUS0 and STATUS1 pin changes is shown in figures 11.2 to 11.9.

In Case of A Reset:

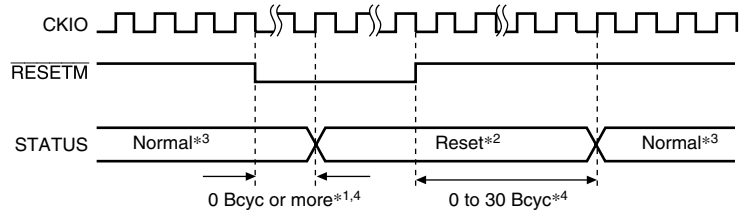
a. Power-on reset



Notes: *1. Reset: HH (STATUS1 high, STATUS0 high)
*2. Normal: LL (STATUS1 low, STATUS0 low)
*3. Bcyc: Bus clock cycle

Figure 11.2 Power-On Reset STATUS Output

b. Manual reset



Notes: *1 During manual reset, STATUS becomes HH (reset) and the internal reset begins after waiting for the executing bus cycle to end.
*2 Reset: HH (STATUS1 high, STATUS0 high)
*3 Normal: LL (STATUS1 low, STATUS0 low)
*4 Bcyc: Bus clock cycle

Figure 11.3 Manual Reset STATUS Output

In Case of Canceling Software Standby:

a. Canceling software standby by interrupt

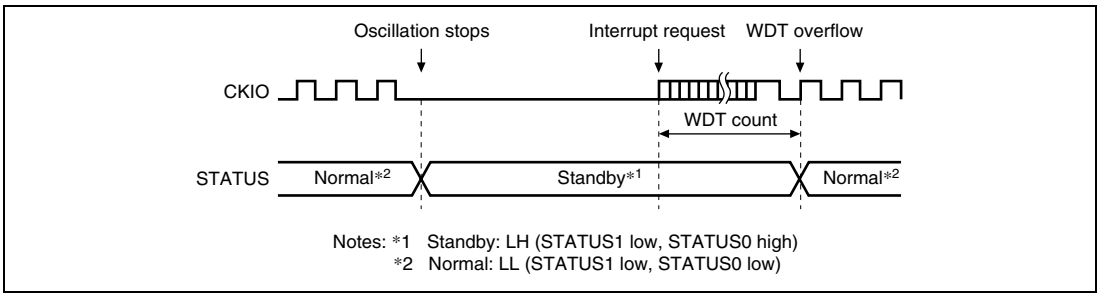


Figure 11.4 Canceling Software Standby by Interrupt STATUS Output

b. Canceling software standby by power-on reset

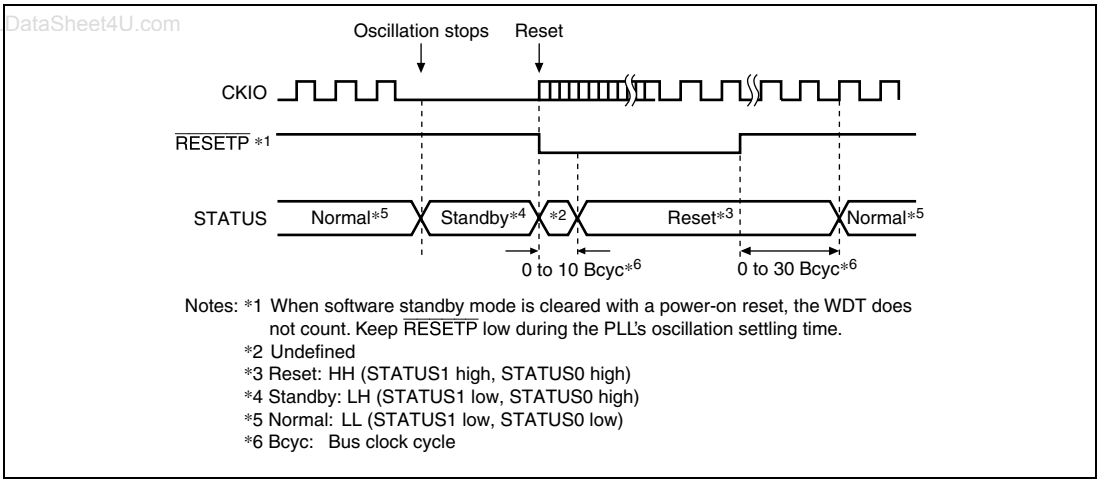
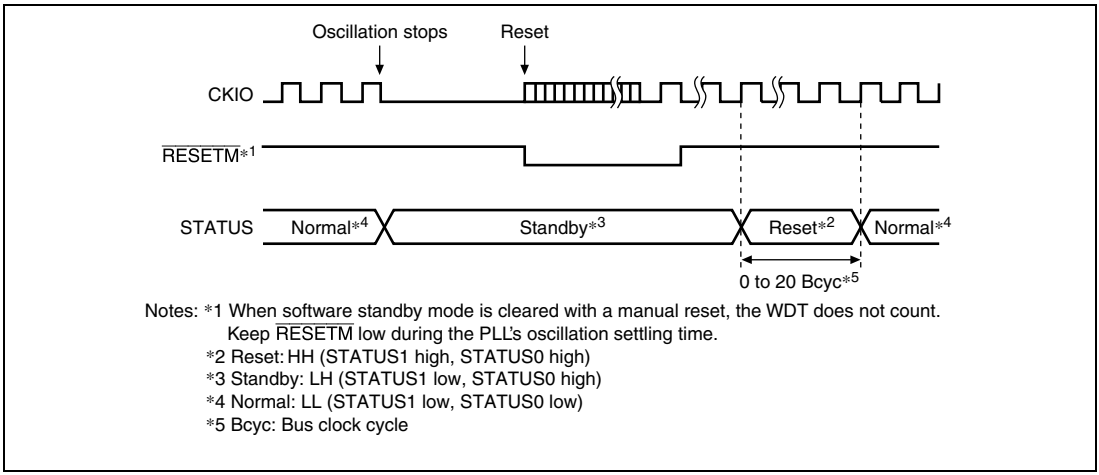


Figure 11.5 Canceling Software Standby by Power-On Reset STATUS Output

c. Canceling software standby by manual reset

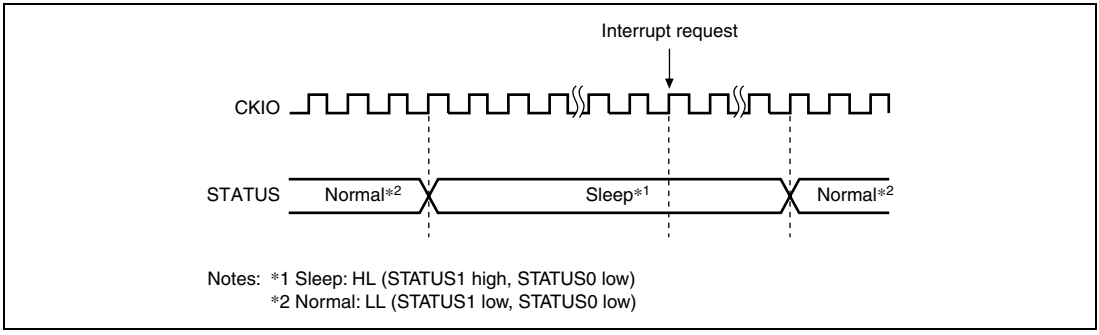


Notes: *1 When software standby mode is cleared with a manual reset, the WDT does not count. Keep RESETM low during the PLL's oscillation settling time.
*2 Reset: HH (STATUS1 high, STATUS0 high)
*3 Standby: LH (STATUS1 low, STATUS0 high)
*4 Normal: LL (STATUS1 low, STATUS0 low)
*5 Bcyc: Bus clock cycle

Figure 11.6 Canceling Software Standby by Manual Reset STATUS Output

In Case of Canceling Sleep:

a. Canceling sleep to interrupt



Notes: *1 Sleep: HL (STATUS1 high, STATUS0 low)
*2 Normal: LL (STATUS1 low, STATUS0 low)

Figure 11.7 Canceling Sleep by Interrupt STATUS Output

b. Canceling sleep by power-on reset

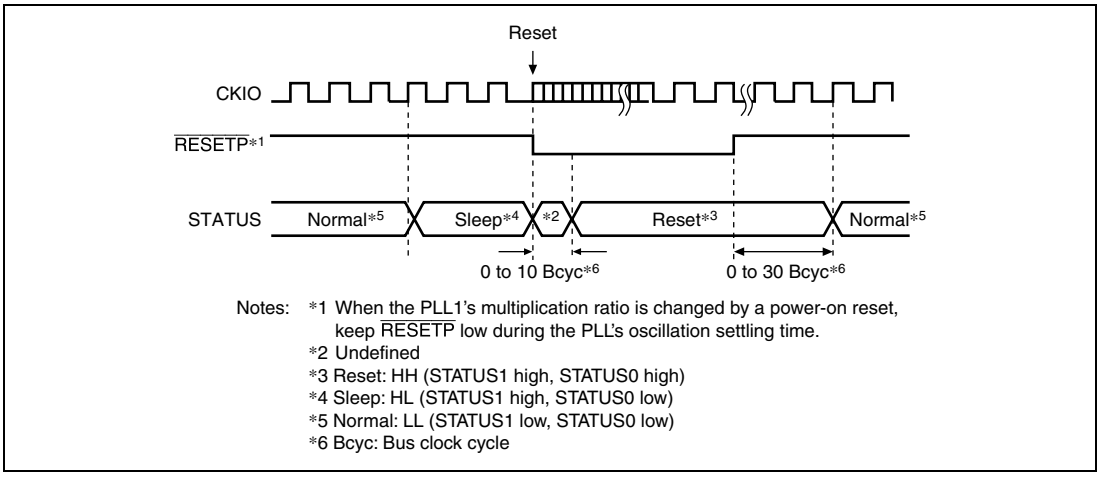


Figure 11.8 Canceling Sleep by Power-On Reset STATUS Output

c. Canceling sleep by manual reset

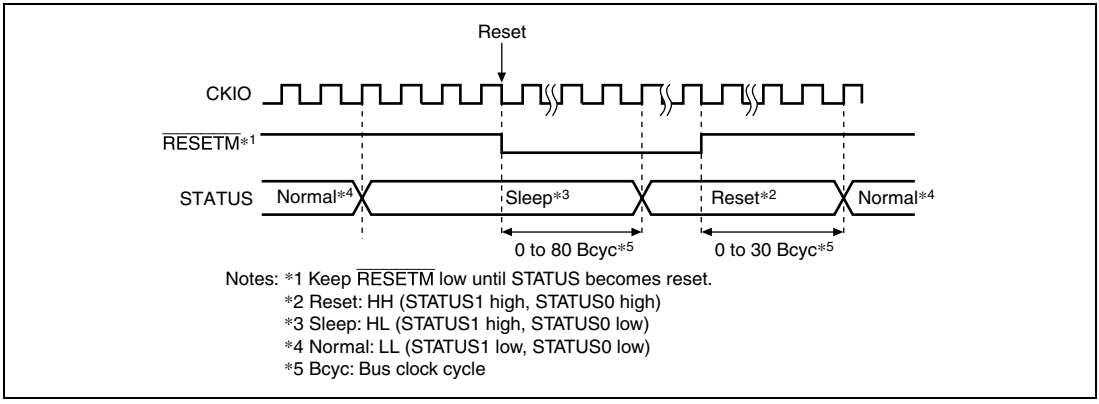


Figure 11.9 Canceling Sleep by Manual Reset STATUS Output

In Case of Hardware Standby:

Figures 11.10 and 11.11 show examples of pin timing in hardware standby mode.

The CA pin is sampled using EXTAL2 (32.768 kHz), and a hardware standby request is only detected when the pin is low for two consecutive clock cycles.

The CA pin must be held low while the chip is in hardware standby mode.

Clock oscillation starts when the CA pin is driven high after the RESETP pin is driven low.

a. Normal operation to hardware standby

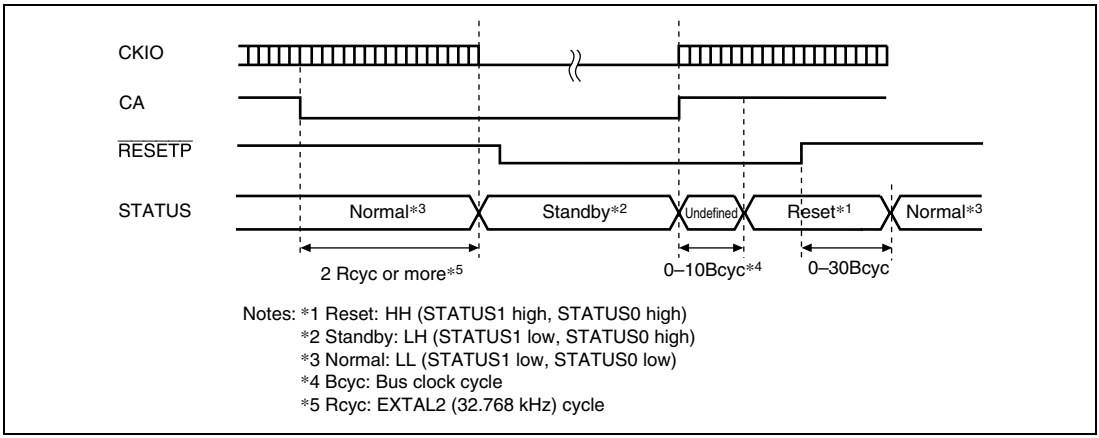


Figure 11.10 Hardware Standby Mode
(When CA Goes Low in Normal Operation)

b. Canceling software standby (during WDT operation) to hardware standby

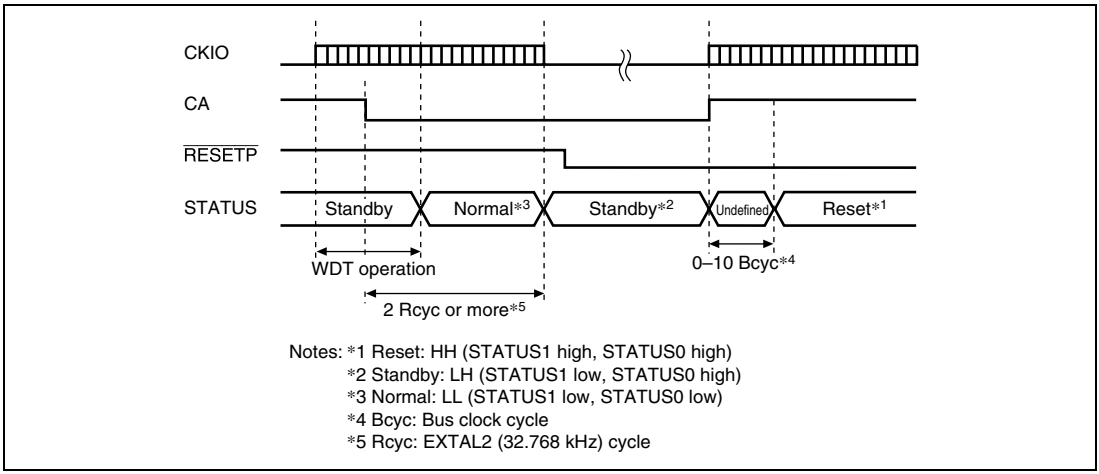


Figure 11.11 Hardware Standby Mode Timing
(When CA Goes Low during WDT Operation while Standby Mode is Canceled)

Section 12 Timer Unit (TMU)

This LSI includes a three-channel 32-bit timer unit (TMU).

12.1 Features

- Each channel is provided with an auto-reload 32-bit down counter
- All channels are provided with 32-bit constant registers and 32-bit down counters for an auto-reload function that can be read or written to at any time
- All channels generate interrupt requests when the 32-bit down counter underflows (H'00000000 → H'FFFFFFFF)
- Only channel 2 is provided with an input capture function
- Allows selection among five counter input clocks: External clock (TCLK), Pϕ/4, Pϕ/16, Pϕ/64, and Pϕ/256

Figure 12.1 shows a block diagram of the TMU.

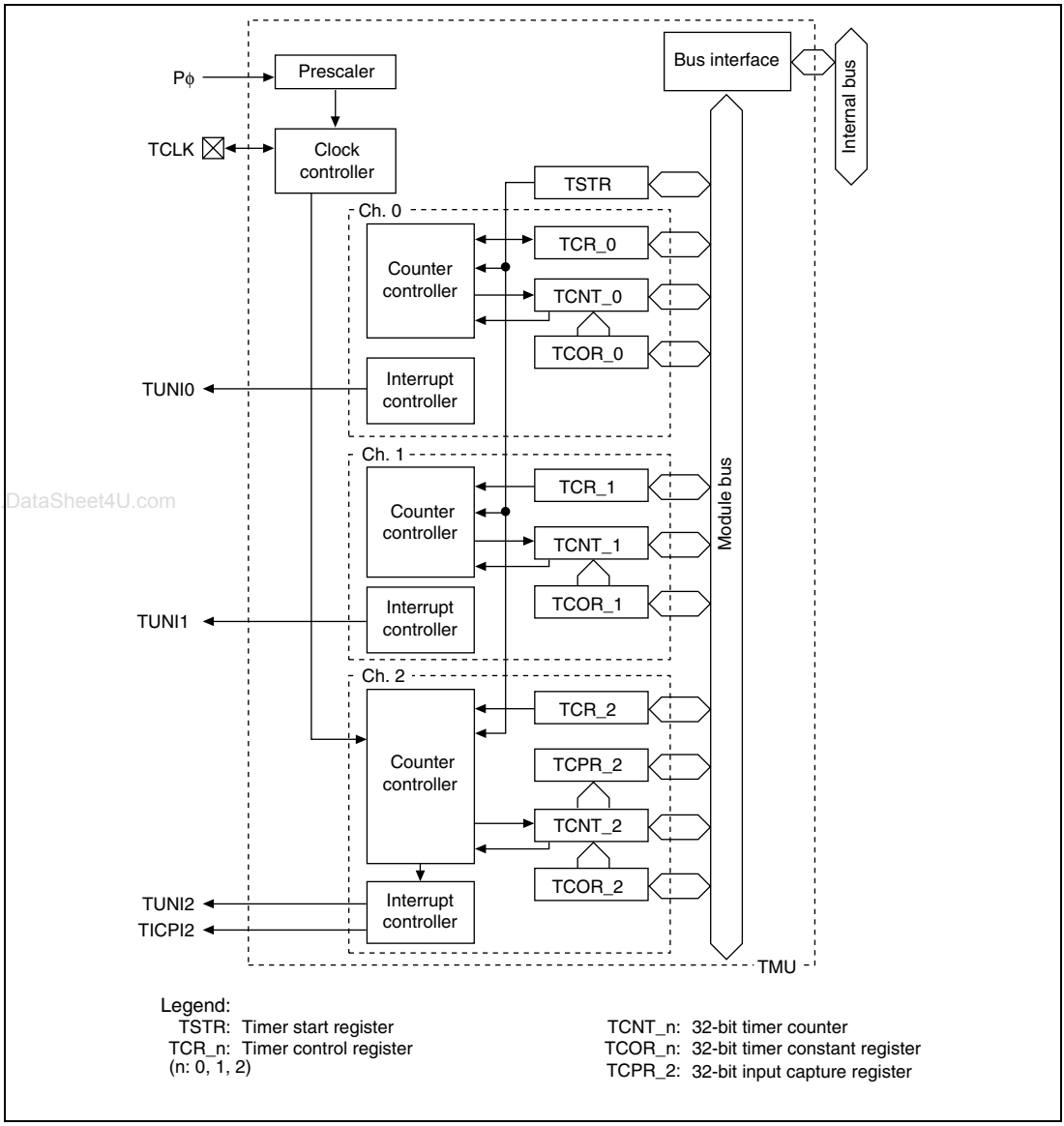


Figure 12.1 TMU Block Diagram

12.2 Input/Output Pin

Table 12.1 shows the pin configuration of the TMU.

Table 12.1 Pin Configuration

Name	Abbreviation	I/O	Description
Clock input	TCLK	I	External clock input pin/input capture control input pin

12.3 Register Descriptions

The TMU has the following registers. Refer to section 24, List of Registers, for more details of the addresses of these registers and state of these registers in each processing state. For the register name for each channel, TCOR for channel 0 is noted as TCOR_0.

1. Common

- Timer start register (TSTR)

2. Channel 0

- Timer constant register_0 (TCOR_0)
- Timer counter_0 (TCNT_0)
- Timer control register_0 (TCR_0)

3. Channel 1

- Timer constant register_1 (TCOR_1)
- Timer counter_1 (TCNT_1)
- Timer control register_1 (TCR_1)

4. Channel 2

- Timer constant register_2 (TCOR_2)
- Timer counter_2 (TCNT_2)
- Timer control register_2 (TCR_2)
- Input capture register_2 (TCPR_2)

12.3.1 Timer Start Register (TSTR)

TSTR is an 8-bit readable/writable register that selects whether to run or halt the timer counters (TCNT).

TSTR is initialized by satisfying the initialization conditions shown in section 24, List of Registers, changing the multiplication ratio of PLL1, or setting the MSTP2 bit in STBCR to 1.

Bit	Bit Name	Initial Value	R/W	Description
7 to 3	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
2	STR2	0	R/W	Counter Start 2 Selects whether to run or halt timer counter 2 (TCNT_2). 0: TCNT_2 count halted 1: TCNT_2 counts
1	STR1	0	R/W	Counter Start 1 Selects whether to run or halt timer counter 1 (TCNT_1). 0: TCNT_1 count halted 1: TCNT_1 counts
0	STR0	0	R/W	Counter Start 0 Selects whether to run or halt timer counter 0 (TCNT_0). 0: TCNT_0 count halted 1: TCNT_0 counts

12.3.2 Timer Control Registers (TCR)

TCR are 16-bit readable/writable registers that control the timer counters (TCNT) and interrupts.

TCR control the issuance of interrupts when the flag indicating timer counter (TCNT) underflow has been set to 1, and also carry out counter clock selection. When the external clock has been selected, they also select its edge.

Only TCR_2 controls the input capture function and the issuance of interrupts during input capture.

TCR_0 and TCR_1:

Bit	Bit Name	Initial Value	R/W	Description
15 to 9	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
8	UNF	0	R/(W)*	Underflow Flag Status flag that indicates occurrence of a TCNT underflow. 0: TCNT has not underflowed [Clearing condition] 0 is written to UNF 1: TCNT has underflowed [Setting condition] TCNT underflows
7, 6	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
5	UNIE	0	R/W	Underflow Interrupt Control Controls enabling of interrupt generation when the status flag (UNF) indicating TCNT underflow has been set to 1. 0: Interrupt due to UNF (TUNI) is disabled 1: Interrupt due to UNF (TUNI) is enabled

Bit	Bit Name	Initial Value	R/W	Description
4	CKEG1	0	R/W	Clock Edge
3	CKEG0	0	R/W	Select an input edge of the external clock when the external clock is selected. 00: Count on rising edge 01: Count on falling edge 1X: Count on both rising and falling edges Note: X: Don't care
2	TPSC2	0	R/W	Timer Prescaler
1	TPSC1	0	R/W	Select the TCNT count clock.
0	TPSC0	0	R/W	000: Count on Pϕ/4 001: Count on Pϕ/16 010: Count on Pϕ/64 011: Count on Pϕ/256 100: Setting prohibited 101: Count on TCLK pin input 110: Setting prohibited 111: Setting prohibited

Note: * Only 0 can be written for clearing the flags. If 1 is written to this bit, the prior value is retained.

TCR_2:

Bit	Bit Name	Initial Value	R/W	Description
15 to 10	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
9	ICPF	0	R/(W)*	Input Capture Interrupt Flag A function of channel 2 only: the flag is set when input capture is requested via the TCLK pin. 0: No input capture request has been issued. [Clearing condition] 0 is written to ICPF 1: Input capture has been requested via the TCLK pin. [Setting condition] When an input capture is requested via the TCLK pin
8	UNF	0	R/(W)*	Underflow Flag Status flag that indicates occurrence of a TCNT_2 underflow. 0: TCNT_2 has not underflowed [Clearing condition] 0 is written to UNF 1: TCNT_2 has underflowed [Setting condition] TCNT_2 underflows

Bit	Bit Name	Initial Value	R/W	Description
7	ICPE1	0	R/W	Input Capture Control
6	ICPE0	0	R/W	A function of channel 2 only: determines whether the input capture function can be used, and when used, whether or not to enable interrupts. Use the CKEG1 and CKEG0 bits to designate use of either the rising or falling edge of the TCLK pin to set the value of TCNT_2 in TCPR_2. 00: Input capture function is not used. 01: Setting prohibited 10: Input capture function is used. Interrupt due to ICPF (TICPI2) are not enabled. 11: Input capture function is used. Interrupt due to ICPF (TICPI2) are enabled.
5	UNIE	0	R/W	Underflow Interrupt Control Controls enabling of interrupt generation when the status flag (UNF) indicating TCNT_2 underflow has been set to 1. 0: Interrupt due to UNF (TUNI2) is not enabled. 1: Interrupt due to UNF (TUNI2) is enabled.
4	CKEG1	0	R/W	Clock Edge
3	CKEG0	0	R/W	Select an input edge of the external clock when the external clock is selected, or when the input capture function is used. 00: Count/capture register set on rising edge 01: Count/capture register set on falling edge 1X: Count/capture register set on both rising and falling edge Note: X: Don't care.

Bit	Bit Name	Initial Value	R/W	Description
2	TPSC2	0	R/W	Timer Prescaler
1	TPSC1	0	R/W	Select the TCNT_2 count clock.
0	TPSC0	0	R/W	000: Count on Pϕ/4
				001: Count on Pϕ/16
				010: Count on Pϕ/64
				011: Count on Pϕ/256
				100: Setting prohibited
				101: Count on TCLK pin input
				110: Setting prohibited
				111: Setting prohibited

Note: * Only 0 can be written for clearing the flags. If 1 is written to this bit, the prior value is retained.

12.3.3 Timer Constant Registers (TCOR)

TCOR set the value to be set in TCNT when TCNT underflows.

TCOR are 32-bit readable/writable registers. Their initial value is H'FFFFFFFF.

12.3.4 Timer Counters (TCNT)

TCNT counts down upon input of a clock. The clock input is selected using the TPSC2 to TPSC0 bits in the timer control register (TCR).

When a TCNT countdown results in an underflow (H'00000000 → H'FFFFFFFF), the underflow flag (UNF) in the timer control register (TCR) of the relevant channel is set. The TCOR value is simultaneously set in TCNT itself and the countdown continues from that value.

Initial value of TCNT is H'FFFFFFFF.

12.3.5 Input Capture Register_2 (TCPR_2)

TCPR_2 is a read-only 32-bit register used for the input capture function built only into timer 2. The TCPR_2 setting conditions due to the TCLK pin are controlled by the input capture function bits (ICPE1/ICPE0 and CKEG1/CKEG0) in TCR_2. When a TCPR_2 setting indication due to the TCLK pin occurs, the value of TCNT_2 is copied into TCPR_2.

Initial value of TCPR_2 is undefined.

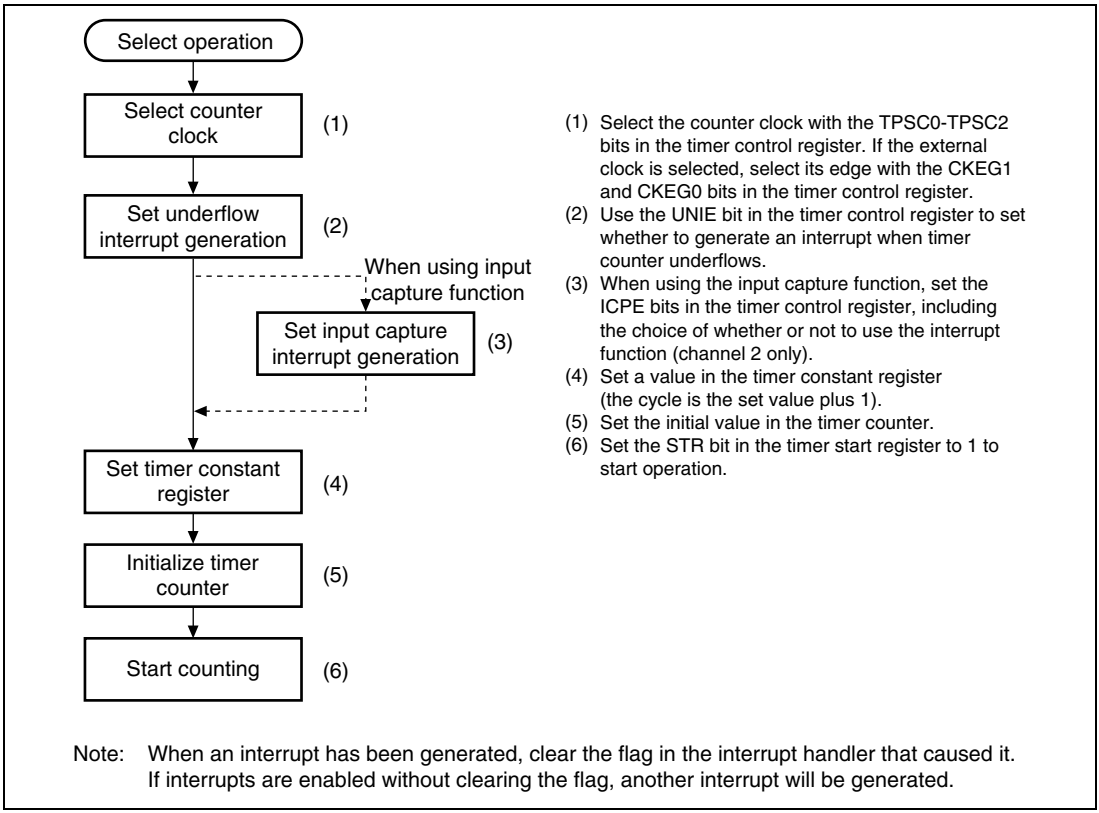
12.4 Operation

Each of the three channels has a 32-bit timer counter (TCNT) and a 32-bit timer constant register (TCOR). The TCNT counts down. The auto-reload function enables synchronized counting and counting by external events. Channel 2 has an input capture function.

12.4.1 Counter Operation

When the STR0 to STR2 bits in the timer start register (TSTR) are set to 1, the corresponding timer counter (TCNT) starts counting. When a TCNT underflows, the UNF flag of the corresponding timer control register (TCR) is set. At this time, if the UNIE bit in TCR is 1, an interrupt request is sent to the CPU. Also at this time, the value is copied from TCOR to TCNT and the down-count operation is continued.

Count Operation Setting Procedure: An example of the procedure for setting the count operation is shown in figure 12.2.



Note: When an interrupt has been generated, clear the flag in the interrupt handler that caused it. If interrupts are enabled without clearing the flag, another interrupt will be generated.

Figure 12.2 Setting Count Operation

Auto-Reload Count Operation: Figure 12.3 shows the TCNT auto-reload operation.

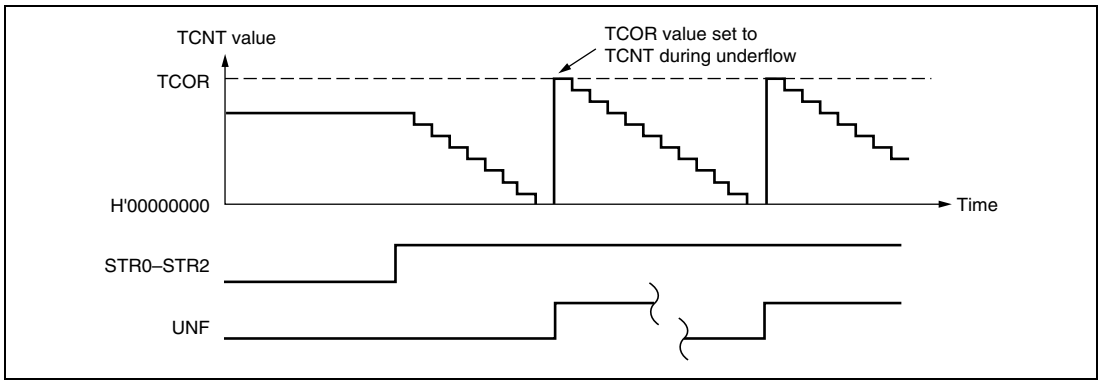


Figure 12.3 Auto-Reload Count Operation

TCNT Count Timing:

1. Internal Clock Operation: Set the TPSC2 to TPSC0 bits in TCR to select whether one of the four internal clocks created by dividing the peripheral module clock is used (Pϕ/4, Pϕ/16, Pϕ/64, Pϕ/256). Figure 12.4 shows the timing.

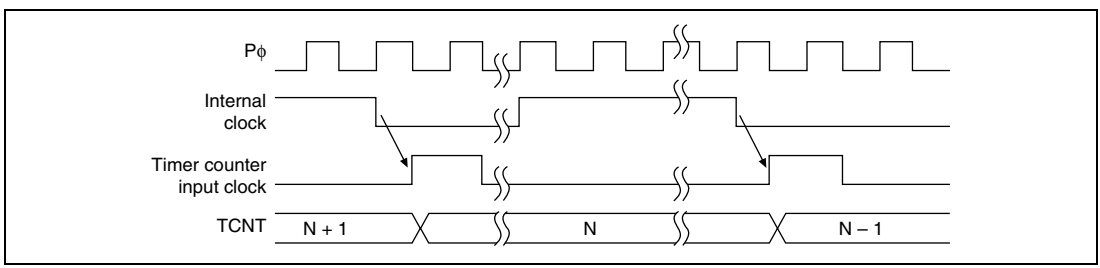


Figure 12.4 Count Timing when Internal Clock is Operating

2. External Clock Operation: Set the TPSC2 to TPSC0 bits in TCR to select the external clock (TCLK) as the timer clock. Use the CKEG1 and CKEG0 bits in TCR to select the detection edge. Rise, fall or both may be selected. The pulse width of the external clock must be at least 2 peripheral module clock cycles (Pϕ) for single edges or 3 peripheral module clock cycles (Pϕ) for both edges. A shorter pulse width will result in incorrect operation. Figure 12.5 shows the timing for both-edge detection.

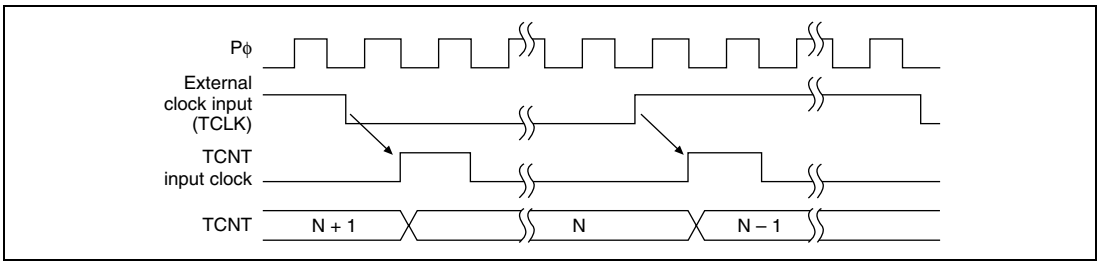


Figure 12.5 Count Timing when External Clock is Operating (Both Edges Detected)

12.4.2 Input Capture Function

Channel 2 has an input capture function. When using the input capture function, set the timer operation clock to internal clock with the TPSC2 to TPSC0 bits in TCR_2. Also, specifies use of the input capture function and whether to generate interrupts on using it with the ICPE1 to ICPE0 bits in TCR_2, and specifies the use of either the rising or falling edge of the TCLK pin to set the TCNT_2 value into TCPR_2 with the CKEG1 to CKEG0 bits in TCR_2. The input capture function cannot be used in standby mode.

Figure 12.6 shows the timing at the rising edge of the TCLK pin input.

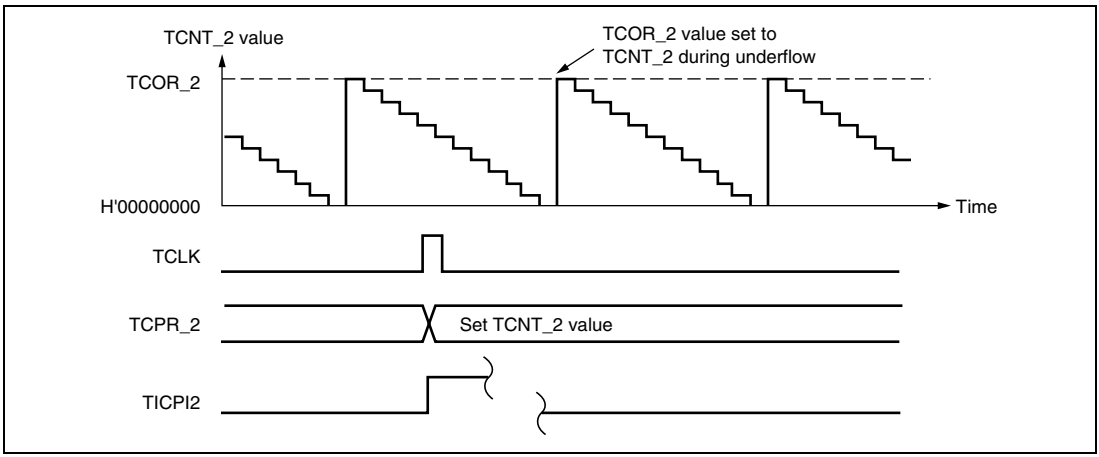


Figure 12.6 Operation Timing when Using Input Capture Function (Using TCLK Rising Edge)

12.5 Interrupts

There are two sources of TMU interrupts: underflow interrupts (TUNI) and interrupts when using the input capture function (TICPI2).

12.5.1 Status Flag Set Timing

The UNF bit is set to 1 when the TCNT underflows. Figure 12.7 shows the timing.

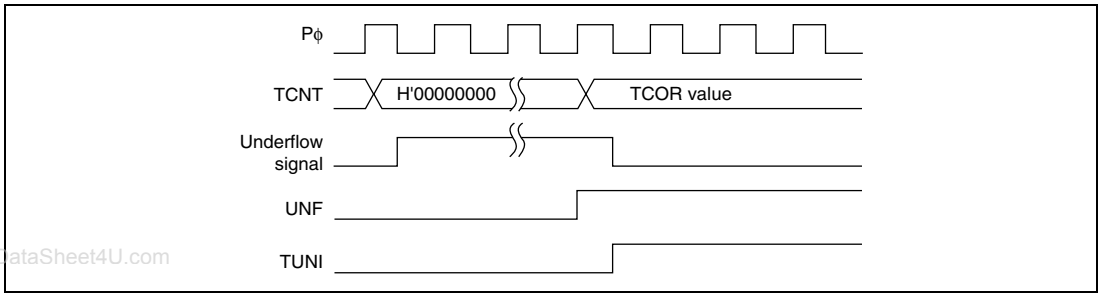


Figure 12.7 UNF Set Timing

12.5.2 Status Flag Clear Timing

The status flag can be cleared by writing 0 from the CPU. Figure 12.8 shows the timing.

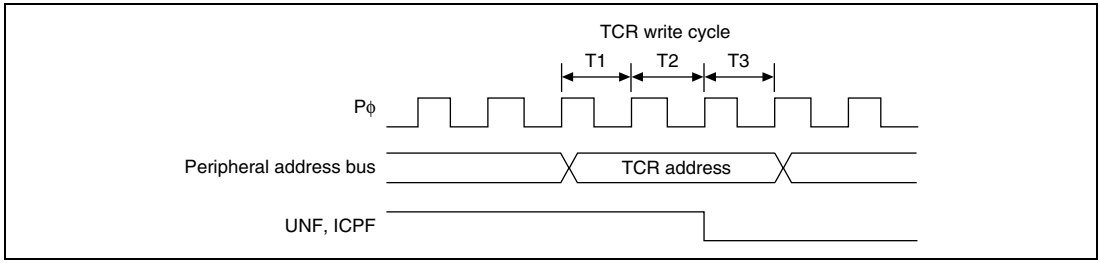


Figure 12.8 Status Flag Clear Timing

12.5.3 Interrupt Sources and Priorities

The TMU generates underflow interrupts for each channel. When the interrupt request flag and interrupt enable bit are both set to 1, the relevant interrupt is requested. Codes are set in the interrupt event register (INTEVT and INTEVT2) for these interrupts and interrupt processing must be executed according to the codes.

The relative priorities of channels can be changed using the interrupt controller. For details, see section 5, Exception Handling, and section 6, Interrupt Controller (INTC).

Table 12.2 lists TMU interrupt sources.

Table 12.2 TMU Interrupt Sources

Channel	Interrupt Source	Description	Priority
0	TUNI0	Underflow interrupt 0	High
1	TUNI1	Underflow interrupt 1	
2	TUNI2	Underflow interrupt 2	
	TICPI2	Input capture interrupt 2	Low

12.6 Usage Notes

12.6.1 Writing to Registers

Synchronization processing is not performed for timer counting during register writes. When writing to registers, always clear the appropriate start bits for the channel (STR2 to STR0) in the timer start register (TSTR) to halt timer counting.

12.6.2 Reading Registers

Synchronization processing is performed for timer counting during register reads. When timer counting and register read processing are performed simultaneously, the register value before TCNT counting down is read.

Section 13 Compare Match Timer (CMT)

The DMAC has an on-chip compare match timer (CMT) to generate a DMA transfer request. The CMT has 16-bit counter.

Figure 13.1 shows a CMT block diagram.

13.1 Features

- Four types of counter input clock can be selected.
  One of four internal clocks (Pϕ/4, Pϕ/8, Pϕ/16, Pϕ/64) can be selected.
- Generates a DMA transfer request when compare match occurs. (The CPU interrupt is not supported.)
- When the CMT is not used, the operation can be halted by stopping the clock supply to the CMT so that the power consumption can be reduced.

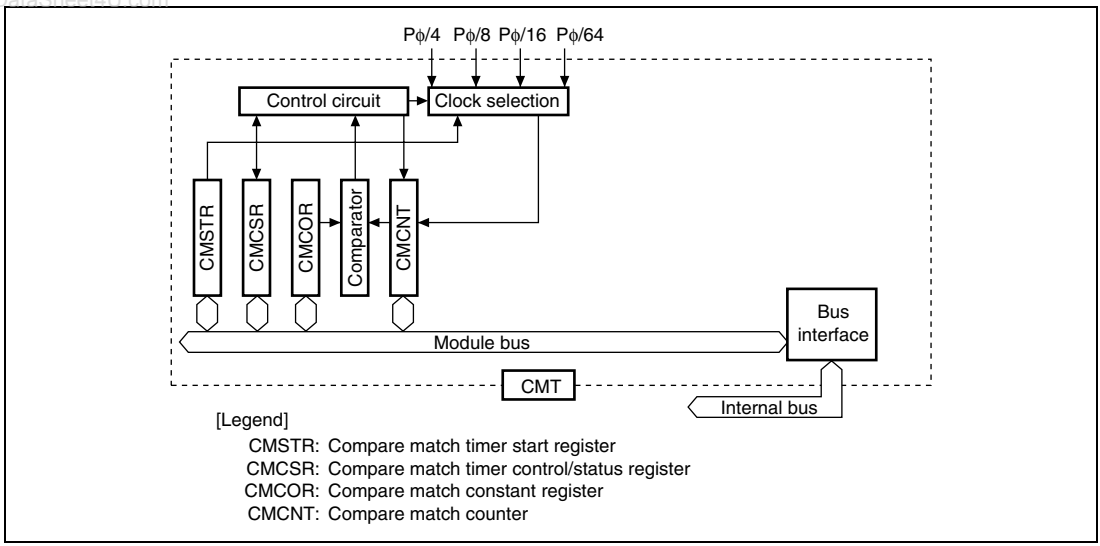


Figure 13.1 CMT Block Diagram

13.2 Register Descriptions

The CMT has the following registers. Refer to section 24, List of Registers, for more detail of the addresses and access size.

- Compare match timer start register (CMSTR)
- Compare match timer control/status register (CMCSR)
- Compare match counter (CMCNT)
- Compare match constant register (CMCOR)

13.2.1 Compare Match Timer Start Register (CMSTR)

CMSTR is a 16-bit register that selects whether to operate or halt the counter (CMCNT).

Bit	Bit Name	Initial Value	R/W	Description
15 to 1	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
0	STR	0	R/W	Count Start Selects whether to operate or halt the compare match counter. 0: CMCNT count operation halted 1: CMCNT count operation

13.2.2 Compare Match Timer Control/Status Register (CMCSR)

CMCSR is a 16-bit register that indicates the occurrence of compare matches, and sets the enable/disable of DMA transfer requests and the clock used for incrementation.

Bit	Bit Name	Initial Value	R/W	Description
15 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7	CMF	0	R/(W)*	Compare Match Flag Indicates whether CMCNT and CMCOR values have matched or not. 0: CMCNT and CMCOR values have not matched [Clearing condition] Write 0 to CMF after reading CMF = 1 1: CMCNT and CMCOR values have matched
6, 5	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
4	CMR	0	R/W	Compare Match Request 0: Disables a DMA transfer request 1: Enables a DMA transfer request
3, 2	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
1	CKS1	0	R/W	Clock Select
0	CKS0	0	R/W	Select the clock input to CMCNT from among the four internal clocks obtained by dividing the peripheral clock (Pϕ). When the STR bit in CMSTR is set to 1, CMCNT begins incrementing with the clock selected by the CKS1 and CKS0 bits. 00: P ϕ/4 01: P ϕ/8 10: P ϕ/16 11: P ϕ/64

Note: *Only 0 can be written for clearing the flags.

13.2.3 Compare Match Counter (CMCNT)

CMCNT is a 16-bit register used as an up-counter.

When an internal clock is selected with the CKS1 and CKS0 bits in CMCSR and the STR bit in CMSTR is set to 1, CMCNT begins incrementing with the selected clock. When the CMCNT value matches that of CMCOR, CMCNT is cleared to H'0000 and the CMF flag in CMCSR is set to 1.

The initial value of CMCNT is H'0000.

13.2.4 Compare Match Constant Register (CMCOR)

CMCOR is a 16-bit register that sets the compare match period with CMCNT.

The initial value of CMCOR is H'FFFF.

13.3 Operation

13.3.1 Period Count Operation

When an internal clock is selected with the CKS1 and CKS0 bits in CMCSR and the STR bit in CMSTR is set to 1, CMCNT begins incrementing with the selected clock. When the CMCNT value matches that of CMCOR, CMCNT is cleared to H'0000 and the CMF flag in CMCSR is set to 1. CMCNT begins counting up again from H'0000.

Figure 13.2 shows the compare match counter operation.

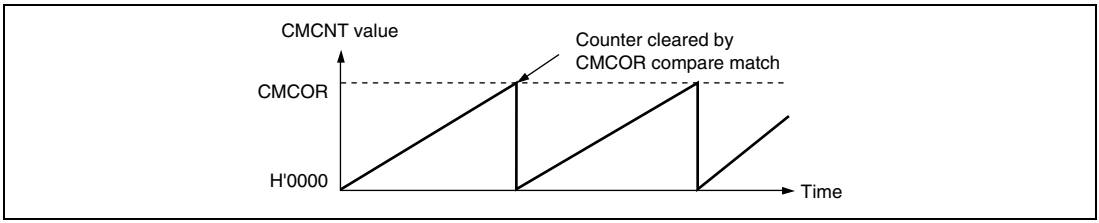


Figure 13.2 Counter Operation

13.3.2 CMCNT Count Timing

One of four clocks (Pϕ/4, Pϕ/8, Pϕ/16, Pϕ/64) obtained by dividing the peripheral clock (Pϕ) can be selected by the CKS1 and CKS0 bits in CMCSR. Figure 13.3 shows the timing.

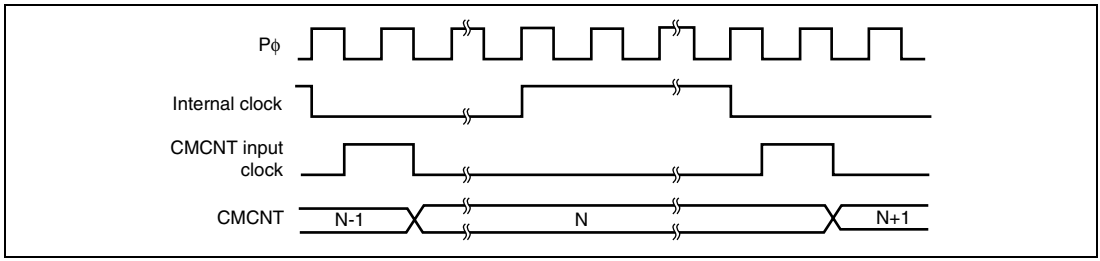


Figure 13.3 Count Timing

13.3.3 Compare Match Flag Set Timing

The CMF bit in CMCSR is set to 1 by the compare match signal generated when CMCOR and CMCNT match. The compare match signal is generated upon the final state of the match (timing at which the CMCNT matching count value is updated to H'0000). Consequently, after CMCOR and CMCNT match, a compare match signal will not be generated until a CMCNT clock is input. Figure 13.4 shows the CMF bit set timing.

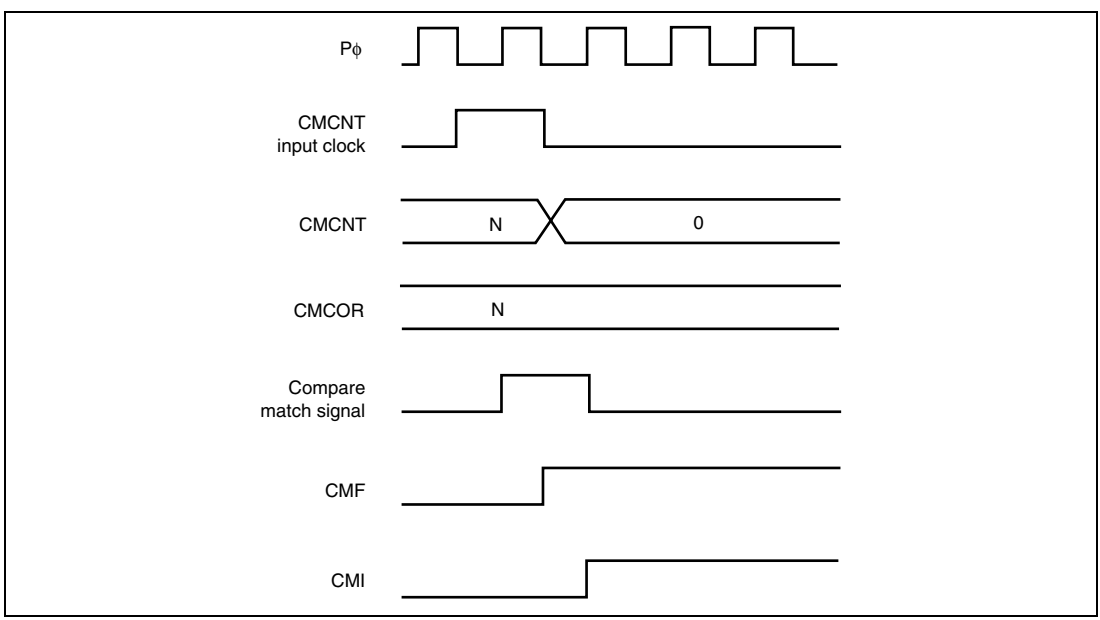


Figure 13.4 CMF Set Timing

Section 14 16-Bit Timer Pulse Unit (TPU)

This LSI has an on-chip 16-bit timer pulse unit (TPU) that comprises four 16-bit timer channels.

14.1 Features

- Maximum 4-pulse output

  A total of 16 timer general registers (TGRA to TGRD × 4 ch.) are provided (four each for channels). TGRA can be set as an output compare register.

  TGRB, TGRC, and TGRD for each channel can also be used as timer counter clearing registers. TGRC and TGRD can also be used as buffer registers.
- Selection of four counter input clocks for channels 0 to 3
- The following operations can be set for each channel:

  Waveform output at compare match: Selection of 0, 1, or toggle output

  Counter clear operation: Counter clearing possible by compare match

  PWM mode: Any PWM output duty cycle can be set

  Maximum of 4-phase PWM output possible
- Buffer operation settable for each channel

  Automatic rewriting of output compare register possible
- An interrupt request for each channel

  Compare match and overflow interrupt requests can be enabled or disabled for each source independently

Table 14.1 lists the functions of the TPU.

Table 14.1 TPU Functions

Item		Channel 0	Channel 1	Channel 2	Channel 3
Count clock		Pϕ/1 Pϕ/4 Pϕ/16 Pϕ/64	Pϕ/1 Pϕ/4 Pϕ/16 Pϕ/64	Pϕ/1 Pϕ/4 Pϕ/16 Pϕ/64	Pϕ/1 Pϕ/4 Pϕ/16 Pϕ/64
General registers		TGR0A TGR0B	TGR1A TGR1B	TGR2A TGR2B	TGR3A TGR3B
General registers/ buffer registers		TGR0C TGR0D	TGR1C TGR1D	TGR2C TGR2D	TGR3C TGR3D
Output pins		TO0	TO1	TO2	TO3
Counter clear function		TGR compare match	TGR compare match	TGR compare match	TGR compare match
Compare match output	0 output	◯	◯	◯	◯
	1 output	◯	◯	◯	◯
	Toggle output	◯	◯	◯	◯
PWM mode		◯	◯	◯	◯
Buffer operation		◯	◯	◯	◯
Interrupt sources		5 sources • Compare match • Overflow	5 sources • Compare match • Overflow	5 sources • Compare match • Overflow	5 sources • Compare match • Overflow

Legend

◯: Possible

—: Not possible

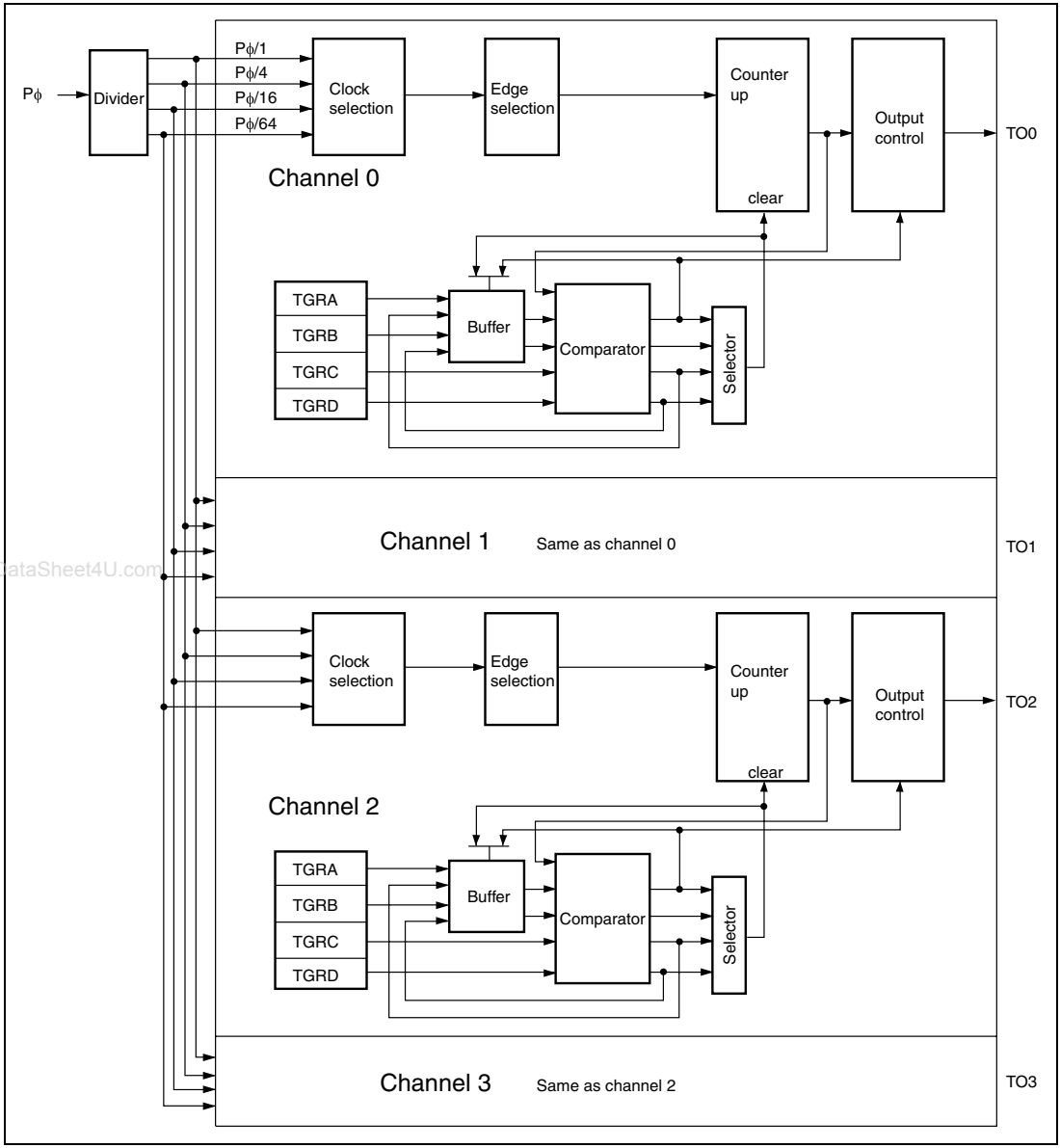


Figure 14.1 Block Diagram of TPU

14.2 Input/Output Pins

Table 14.2 shows the pin configuration of the TPU.

Table 14.2 Pin Configuration

Channel	Name	Symbol	I/O	Function
0	Output compare match 0	TO0	O	TGR0A output compare output/PWM output pin
1	Output compare match 1	TO1	O	TGR1A output compare output/PWM output pin
2	Output compare match 2	TO2	O	TGR2A output compare output/PWM output pin
3	Output compare match 3	TO3	O	TGR3A output compare output/PWM output pin

14.3 Register Descriptions

The TPU has the following registers. Refer to section 24, List of Registers, for more details of the addresses of these registers and state of these registers in each processing state. For the register name for each channel, TCR for channel 0 is noted as TCR_0.

1. Channel 0
- Timer control register_0 (TCR_0)
- Timer mode register_0 (TMDR_0)
- Timer I/O control register_0 (TIOR_0)
- Timer interrupt enable register_0 (TIER_0)
- Timer status register_0 (TSR_0)
- Timer counter_0 (TCNT_0)
- Timer general register A_0 (TGRA_0)
- Timer general register B_0 (TGRB_0)
- Timer general register C_0 (TGRC_0)
- Timer general register D_0 (TGRD_0)

2. Channel 1
- Timer control register_1 (TCR_1)
- Timer mode register_1 (TMDR_1)
- Timer I/O control register_1 (TIOR_1)
- Timer interrupt enable register_1 (TIER_1)
- Timer status register_1 (TSR_1)

- Timer counter_1 (TCNT_1)
- Timer general register A_1 (TGRA_1)
- Timer general register B_1 (TGRB_1)
- Timer general register C_1 (TGRC_1)
- Timer general register D_1 (TGRD_1)

3. Channel 2
- Timer control register_2 (TCR_2)
- Timer mode register_2 (TMDR_2)
- Timer I/O control register_2 (TIOR_2)
- Timer interrupt enable register_2 (TIER_2)
- Timer status register 2 (TSR_2)
- Timer counter_2 (TCNT_2)
- Timer general register A_2 (TGRA_2)
- Timer general register B_2 (TGRB_2)
- Timer general register C_2 (TGRC_2)
- Timer general register D_2 (TGRD_2)

4. Channel 3
- Timer control register_3 (TCR_3)
- Timer mode register_3 (TMDR_3)
- Timer I/O control register_3 (TIOR_3)
- Timer interrupt enable register_3 (TIER_3)
- Timer status register_3 (TSR_3)
- Timer counter_3 (TCNT_3)
- Timer general register A_3 (TGRA_3)
- Timer general register B_3 (TGRB_3)
- Timer general register C_3 (TGRC_3)
- Timer general register D_3 (TGRD_3)

5. Common
- Timer start register (TSTR)

14.3.1 Timer Control Registers (TCR)

TCR are 16-bit registers that control the TCNT channels.

TCR register settings should be made only when TCNT operation is stopped.

Bit	Bit Name	Initial Value	R/W	Description
15 to 8	—	All 0	R	Reserved These bits are always read as 0 and cannot be modified.
7	CCLR2	0	R/W	Counter Clear
6	CCLR1	0	R/W	Select the TCNT clearing source.
5	CCLR0	0	R/W	000: TCNT clearing disabled 001: TCNT cleared by TGRA compare match 010: TCNT cleared by TGRB compare match 011: Setting prohibited 100: TCNT clearing disabled 101: TCNT cleared by TGRC compare match 110: TCNT cleared by TGRD compare match 111: Setting prohibited
4	CKEG1	0	R/W	Clock Edge
3	CKEG0	0	R/W	Select the input clock edge. When the internal clock is counted using both edges, the input clock period is halved (e.g. Pϕ/4 both edges = Pϕ/2 rising edge). 00: Count at rising edge 01: Count at falling edge 1X: Count at both edges* [Legend] X: Don't care Note: * Internal-clock edge selection is valid when the input clock is Pϕ/4 or slower. If the input clock is Pϕ/1, this operation is not performed.
2	TPSC2	0	R/W	Timer Prescaler
1	TPSC1	0	R/W	Select the TCNT count clock. The clock source can be selected independently for each channel. Table 14.3 shows the clock sources that can be set for each channel. For more information on count clock selection, see table 14.4, TPSC2 to TPSC0 (1) to (4).
0	TPSC0	0	R/W	

Table 14.3 TPU Clock Sources

	Internal Clock			
Channel	**Pϕ/1**	**Pϕ/4**	**Pϕ/16**	**Pϕ/64**
0	○	○	○	○
1	○	○	○	○
2	○	○	○	○
3	○	○	○	○

[Legend]

○ : Setting

Blank: No setting

Table 14.4 TPSC2 to TPSC0 (1)

Channel	**Bit 2 TPSC2**	**Bit 1 TPSC1**	**Bit 0 TPSC0**	**Description**
0	0	0	0	Internal clock: counts on Pϕ/1
			1	Internal clock: counts on Pϕ/4
		1	0	Internal clock: counts on Pϕ/16
			1	Internal clock: counts on Pϕ/64
	1	X	X	Setting prohibited

Note: X: Don't care

Table 14.4 TPSC2 to TPSC0 (2)

Channel	**Bit 2 TPSC2**	**Bit 1 TPSC1**	**Bit 0 TPSC0**	**Description**
1	0	0	0	Internal clock: counts on Pϕ/1
			1	Internal clock: counts on Pϕ/4
		1	0	Internal clock: counts on Pϕ/16
			1	Internal clock: counts on Pϕ/64
	1	X	X	Setting prohibited

Note: X: Don't care

Table 14.4 TPSC2 to TPSC0 (3)

Channel	Bit 2 TPSC2	Bit 1 TPSC1	Bit 0 TPSC0	Description
2	0	0	0	Internal clock: counts on Pϕ/1
			1	Internal clock: counts on Pϕ/4
		1	0	Internal clock: counts on Pϕ/16
			1	Internal clock: counts on Pϕ/64
	1	X	X	Setting prohibited

Note: X: Don't care

Table 14.4 TPSC2 to TPSC0 (4)

Channel	Bit 2 TPSC2	Bit 1 TPSC1	Bit 0 TPSC0	Description
3	0	0	0	Internal clock: counts on Pϕ/1
			1	Internal clock: counts on Pϕ/4
		1	0	Internal clock: counts on Pϕ/16
			1	Internal clock: counts on Pϕ/64
	1	X	X	Setting prohibited

Note: X: Don't care

14.3.2 Timer Mode Registers (TMDR)

TMDR are 16-bit readable/writable registers that are used to set the operating mode for each channel.

TMDR register settings should be made only when TCNT operation is stopped.

Bit	Bit Name	Initial Value	R/W	Description
15 to 7	—	All 0	R	Reserved These bits are always read as 0 and cannot be modified.
6	BFWT	0	R/W	Buffer Write Timing Specifies TGRA and TGRB update timing when TGRC and TGRD are used as a compare match buffer. When TGRC and TGRD are not used as a compare match buffer register, this bit is ignored. 0: TGRA and TGRB are rewritten at compare match of each register. 1: TGRA and TGRB are rewritten in counter clearing.
5	BFB	0	R/W	Buffer Operation B Specifies whether TGRB is to operate in the normal way, or TGRB and TGRD are to be used together for buffer operation. 0: TGRB operates normally 1: TGRB and TGRD used together for buffer operation
4	BFA	0	R/W	Buffer Operation A Specifies whether TGRA is to operate in the normal way, or TGRA and TGRC are to be used together for buffer operation. 0: TGRA operates normally 1: TGRA and TGRC used together for buffer operation
3	—	0	R	Reserved This bit is always read as 0 and cannot be modified.
2	MD2	0	R/W	Timer Operating Mode Set the timer-operating mode. 000: Normal operation 001: Setting prohibited 010: PWM mode 011: Setting prohibited 1XX: Setting prohibited Note: X: Don't care
1	MD1	0	R/W	
0	MD0	0	R/W	

14.3.3 Timer I/O Control Registers (TIOR)

TIOR are 16-bit registers that control the TO pin.

TIOR register settings should be made only when TCNT operation is stopped.

Care is required since TIOR is affected by the TMDR setting.

Bit	Bit Name	Initial Value	R/W	Description
15 to 3	—	All 0	R	Reserved These bits are always read as 0 and cannot be modified.
2	IOA2	0	R/W	I/O Control
1	IOA1	0	R/W	Bits IOA2 to IOA0 specify the functions of TGRA and the TO pin. For details, refer to table 14.5, IOA2 to IOA0.
0	IOA0	0	R/W	

Table 14.5 IOA2 to IOA0

Channel	Bit 2 IOA2	Bit 1 IOA1	Bit 0 IOA0	Description	
0 to 3	0	0	0	Always 0 output	
			1	Initial output is 0 output for TO pin	0 output at TGRA compare match*
		1	0		1 output at TGRA compare match
			1		Toggle output at TGRA compare match*
	1	0	0	Always 1 output	
			1	Initial output is 1 output for TO pin	0 output at TGRA compare match
		1	0		1 output at TGRA compare match*
			1		Toggle output at TGRA compare match*

Note: * This setting is invalid in PWM mode.

14.3.4 Timer Interrupt Enable Registers (TIER)

TIER are 16-bit registers that control enabling or disabling of interrupt requests for each channel.

Bit	Bit Name	Initial Value	R/W	Description
15 to 5	—	All 0	R	Reserved These bits are always read as 0 and cannot be modified.
4	TCIEV	0	R/W	Overflow Interrupt Enable Enables or disables interrupt requests by the TCFV bit when the TCFV bit in TSR is set to 1 (TCNT overflow). 0: Interrupt requests by TCFV disabled 1: Interrupt requests by TCFV enabled
3	TGIED	0	R/W	TGR Interrupt Enable D Enables or disables interrupt requests by the TGFD bit when the TGFD bit in TSR is set to 1 (TCNT and TGRD compare match). 0: Interrupt requests by TGFD disabled 1: Interrupt requests by TGFD enabled
2	TGIEC	0	R/W	TGR Interrupt Enable C Enables or disables interrupt requests by the TGFC bit when the TGFC bit in TSR is set to 1 (TCNT and TGRC compare match). 0: Interrupt requests by TGFC disabled 1: Interrupt requests by TGFC enabled
1	TGIEB	0	R/W	TGR Interrupt Enable B Enables or disables interrupt requests by the TGFB bit when the TGFB bit in TSR is set to 1 (TCNT and TGRB compare match). 0: Interrupt requests by TGFB disabled 1: Interrupt requests by TGFB enabled
0	TGIEA	0	R/W	TGR Interrupt Enable A Enables or disables interrupt requests by the TGFA bit when the TGFA bit in TSR is set to 1 (TCNT and TGRA compare match). 0: Interrupt requests by TGFA disabled 1: Interrupt requests by TGFA enabled

14.3.5 Timer Status Registers (TSR)

TSR are 16-bit registers that indicate the status of each channel.

Bit	Bit Name	Initial Value	R/W	Description
15 to 5	—	All 0	R	Reserved These bits are always read as 0 and cannot be modified.
4	TCFV	0	R/(W)*	Overflow Flag Status flag that indicates that TCNT overflow has occurred. [Clearing condition] When 0 is written to TCFV after reading TCFV = 1 [Setting condition] When the TCNT value overflows (changes from H'FFFF to H'0000)
3	TGFD	0	R/(W)*	Output Compare Flag D Status flag that indicates the occurrence of TGRD compare match. [Clearing condition] When 0 is written to TGFD after reading TGFD = 1 [Setting condition] When TCNT = TGRD
2	TGFC	0	R/(W)*	Output Compare Flag C Status flag that indicates the occurrence of TGRC compare match. [Clearing condition] When 0 is written to TGFC after reading TGFC = 1 [Setting condition] When TCNT = TGRC
1	TGFB	0	R/(W)*	Output Compare Flag B Status flag that indicates the occurrence of TGRB compare match. [Clearing condition] When 0 is written to TGFB after reading TGFB = 1 [Setting condition] When TCNT = TGRB

Bit	Bit Name	Initial Value	R/W	Description
0	TGFA	0	R/(W)*	Output Compare Flag A Status flag that indicates the occurrence of TGRA compare match. [Clearing condition] When 0 is written to TGFA after reading TGFA = 1 [Setting condition] When TCNT = TGRA

Note: * Only 0 can be written for clearing the flags.

14.3.6 Timer Counters (TCNT)

TCNT are 16-bit counters.

The initial value of TCNT is H'0000.

14.3.7 Timer General Registers (TGR)

TGR are 16-bit registers.

TGRC and TGRD can also be designated for operation as buffer registers*. The initial value of TGR is H'FFFF.

Note: *TGR buffer register combinations are TGRA—TGRC and TGRB—TGRD.

14.3.8 Timer Start Register (TSTR)

TSTR is a 16-bit readable/writable register that selects TCNT operation/stoppage for channels 0 to 3.

Bit	Bit Name	Initial Value	R/W	Description
15 to 4	—	All 0	R	Reserved These bits are always read as 0 and cannot be modified.
3	CST3	0	R/W	Counter Start
2	CST2	0	R/W	Select operation or stoppage for TCNT.
1	CST1	0	R/W	0: TCNTn count operation is stopped
0	CST0	0	R/W	1: TCNTn performs count operation [Legend] n = 3 to 0

14.4 Operation

14.4.1 Overview

Operation in each mode is outlined below.

Normal Operation: Each channel has a TCNT and TGR register. TCNT performs up-counting, and is also capable of free-running operation and periodic counting.

Buffer Operation: When a compare match occurs, the value in the buffer register for the relevant channel is transferred to TGR. For update timing from a buffer register, rewriting on compare match occurrence or on counter clearing can be selected.

PWM Mode: In this mode, a PWM waveform is output. The output level can be set by means of TIOR. A PWM waveform with a duty cycle of between 0% and 100% can be output, according to the setting of each TGR register.

14.4.2 Basic Functions

Counter Operation: When one of bits CST0 to CST3 is set to 1 in TSTR, the TCNT counter for the corresponding channel starts counting. TCNT can operate as a free-running counter, periodic counter, and so on.

- Example of count operation setting procedure
  Figure 14.2 shows an example of the count operation setting procedure.

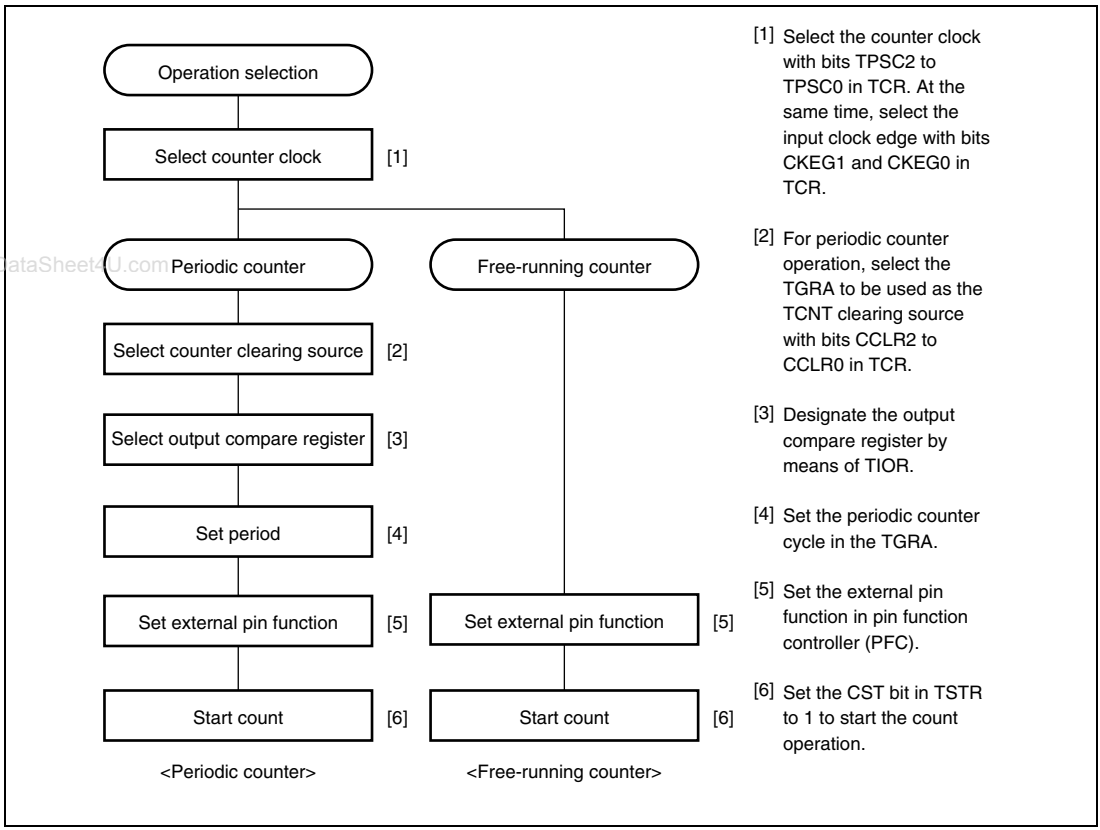


Figure 14.2 Example of Counter Operation Setting Procedure

- Free-running count operation and periodic count operation

  Immediately after a reset, the TPU's TCNT counters are all designated as free-running counters. When the relevant bit in TSTR is set to 1 the corresponding TCNT counter starts up-count operation as a free-running counter. When TCNT overflows (from H'FFFF to H'0000), the TCFV bit in TSR is set to 1. After overflow, TCNT starts counting up again from H'0000.

  Figure 14.3 illustrates free-running counter operation.

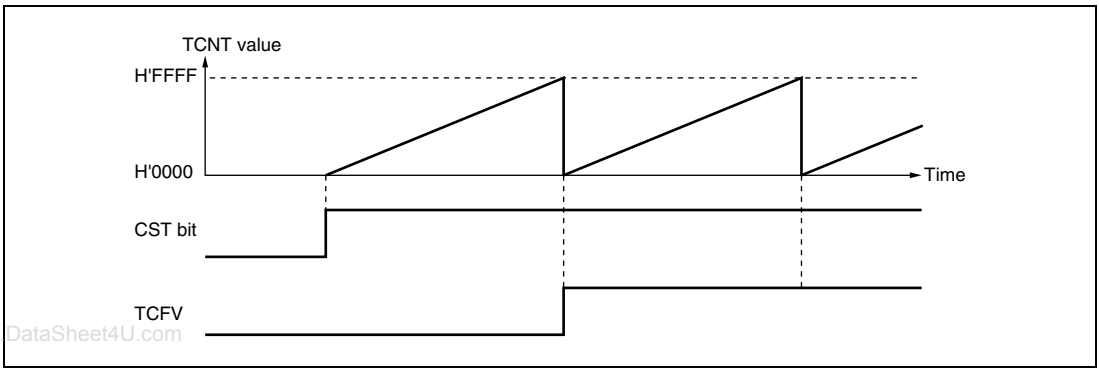


Figure 14.3 Free-Running Counter Operation

When compare match is selected as the TCNT clearing source, the TCNT counter for the relevant channel performs periodic count operation. The TGR register for setting the period is designated as an output compare register, and counter clearing by compare match is selected by means of bits CCLR2 to CCLR0 in TCR. After the settings have been made, TCNT starts up-count operation as a periodic counter when the corresponding bit in TSTR is set to 1. When the count value matches the value in TGR, the TGF bit in TSR is set to 1 and TCNT is cleared to H'0000.

After a compare match, TCNT starts counting up again from H'0000.

Figure 14.4 illustrates periodic counter operation.

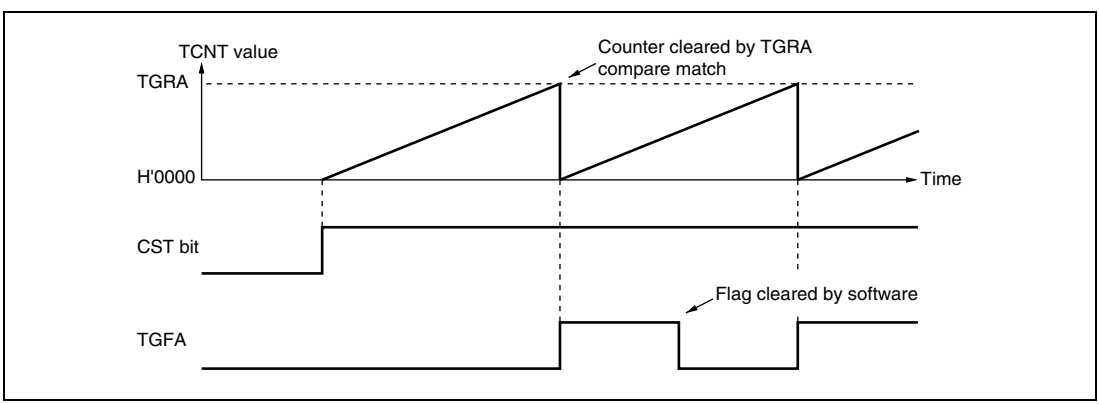


Figure 14.4 Periodic Counter Operation

Waveform Output by Compare Match: The TPU can perform 0, 1, or toggle output from the corresponding output pin (TO pin) using TGRA compare match.

- Example of setting procedure for waveform output by compare match

  Figure 14.5 shows an example of the setting procedure for waveform output by compare match

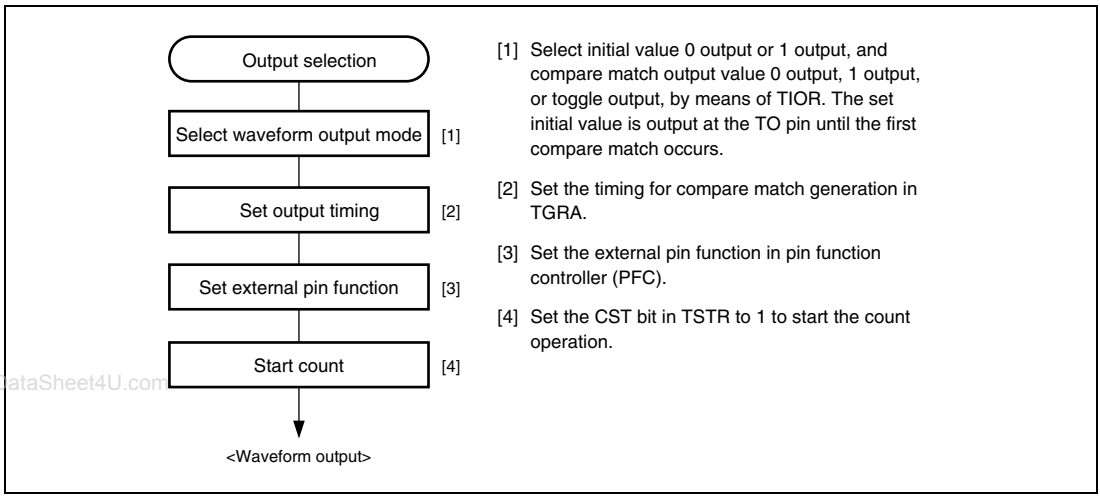


Figure 14.5 Example of Setting Procedure for Waveform Output by Compare Match

- Examples of waveform output operation

  Figure 14.6 shows an example of 0 output/1 output.

  In this example TCNT has been designated as a free-running counter, and settings have been made so that 1 is output by compare match A, and 0 is output by compare match B. When the set level and the pin level coincide, the pin level does not change.

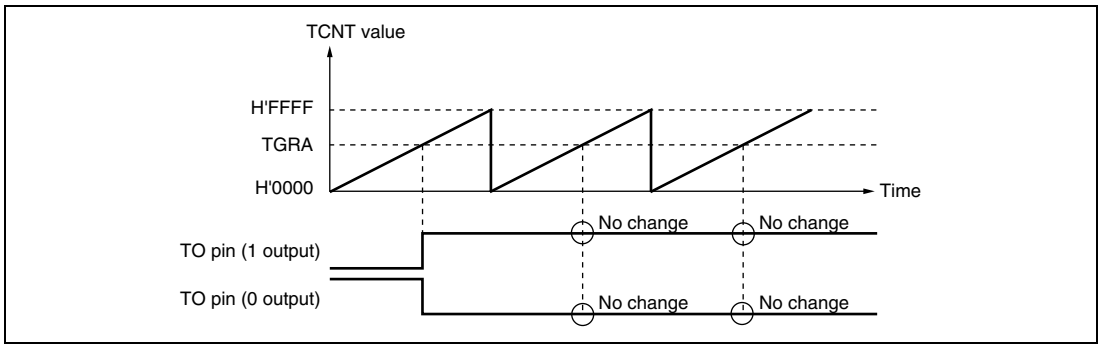


Figure 14.6 Example of 0 Output/1 Output Operation

Figure 14.7 shows an example of toggle output.

In this example TCNT has been designated as a periodic counter (with counter clearing performed by compare match B), and settings have been made so that output is toggled by compare match A.

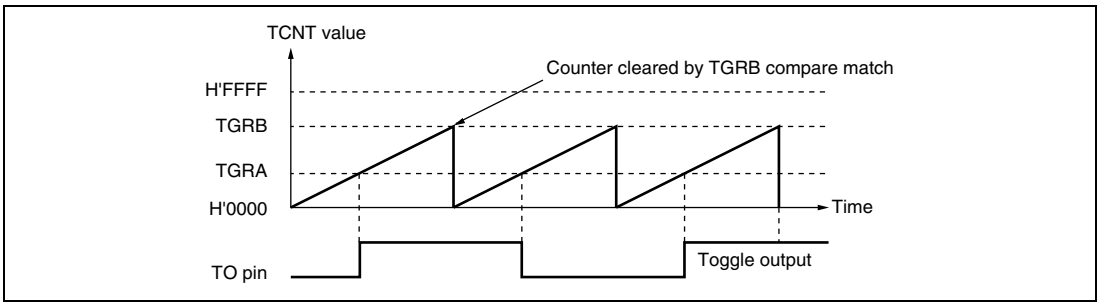


Figure 14.7 Example of Toggle Output Operation

14.4.3 Buffer Operation

Buffer operation, enables TGRC and TGRD to be used as buffer registers.

Table 14.6 shows the register combinations used in buffer operation.

Table 14.6 Register Combinations in Buffer Operation

Timer General Register	Buffer Register
TGRA	TGRC
TGRB	TGRD

When a compare match occurs, the value in the buffer register for the corresponding channel is transferred to the timer general register. For update timing from a buffer register, rewriting on compare match occurrence or on counter cleaning can be selected.

This operation is illustrated in figure 14.8.

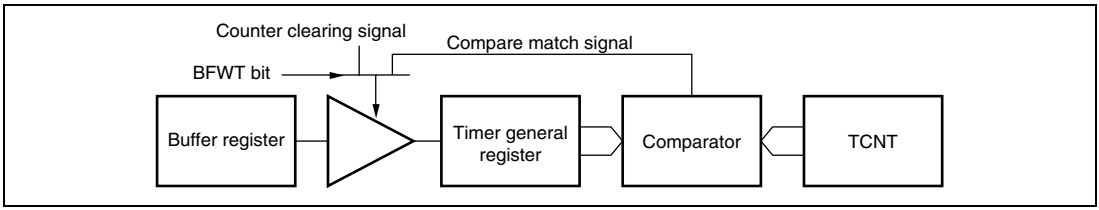
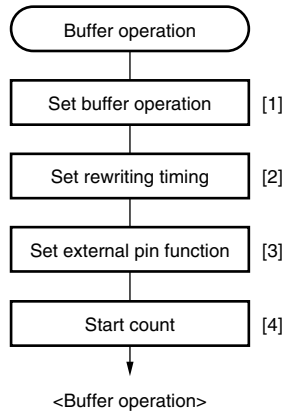


Figure 14.8 Compare Match Buffer Operation

Example of Buffer Operation Setting Procedure: Figure 14.9 shows an example of the buffer operation setting procedure.



[1] Designate TGR for buffer operation with bits BFA and BFB in TMDR.

[2] Set rewriting timing from the buffer register with bit BFWT in TMDR.

[3] Set the external pin function in pin function controller (PFC).

[4] Set the CST bit in TSTR to 1 to start the count operation.

Figure 14.9 Example of Buffer Operation Setting Procedure

Example of Buffer Operation

Figure 14.10 shows an operation example in which PWM mode has been designated for channel 0, and buffer operation has been designated for TGRA and TGRC. The settings used in this example are TCNT clearing by compare match B, 1 output at compare match A, and 0 output at counter clearing. Rewriting timing from the buffer register is set at counter clearing.

As buffer operation has been set, when compare match A occurs the output changes. When counter clearing occurs by TGRB, the output changes and the value in buffer register TGRC is simultaneously transferred to timer general register TGRA. This operation is repeated each time compare match A occurs.

For details of PWM modes, see section 14.4.4, PWM Modes.

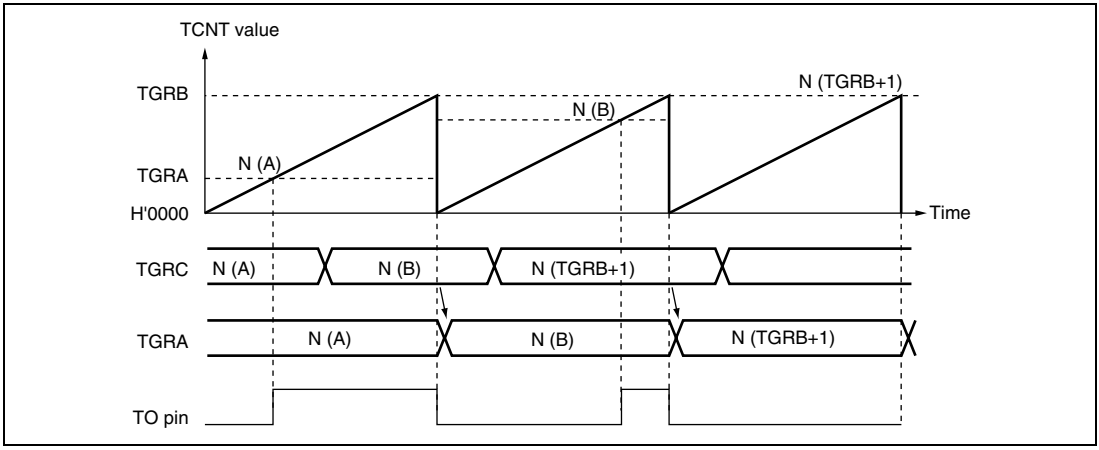


Figure 14.10 Example of Buffer Operation

14.4.4 PWM Modes

In PWM mode, PWM waveforms are output from the output pins. 0 or 1 output can be selected as the output level in response to compare match of each TGRA.

Designating TGRB compare match as the counter-clearing source enables the period to be set in that register. All channels can be designated for PWM mode independently.

PWM output is generated from the TO pin using TGRB as the period register and TGRA as duty cycle registers. The output specified in TIOR is performed by means of compare matches. Upon counter clearing by a period register compare match, the output value of each pin is the initial value set in TIOR. Set TIOR so that the initial output and an output value by compare match are different. If the same levels or toggle outputs are selected, operation is disabled.

Conditions of duty cycle 0% and 100% are shown below.

- Duty cycle 0%: The set value of the period register (TGRB) is TGRA + 1 for the duty register (TGRA).
- Duty cycle 100%: The set value of the duty register (TGRA) is 0.

In PWM mode, a maximum 4-phase PWM output is possible.

Example of PWM Mode Setting Procedure: Figure 14.11 shows an example of the PWM mode setting procedure.

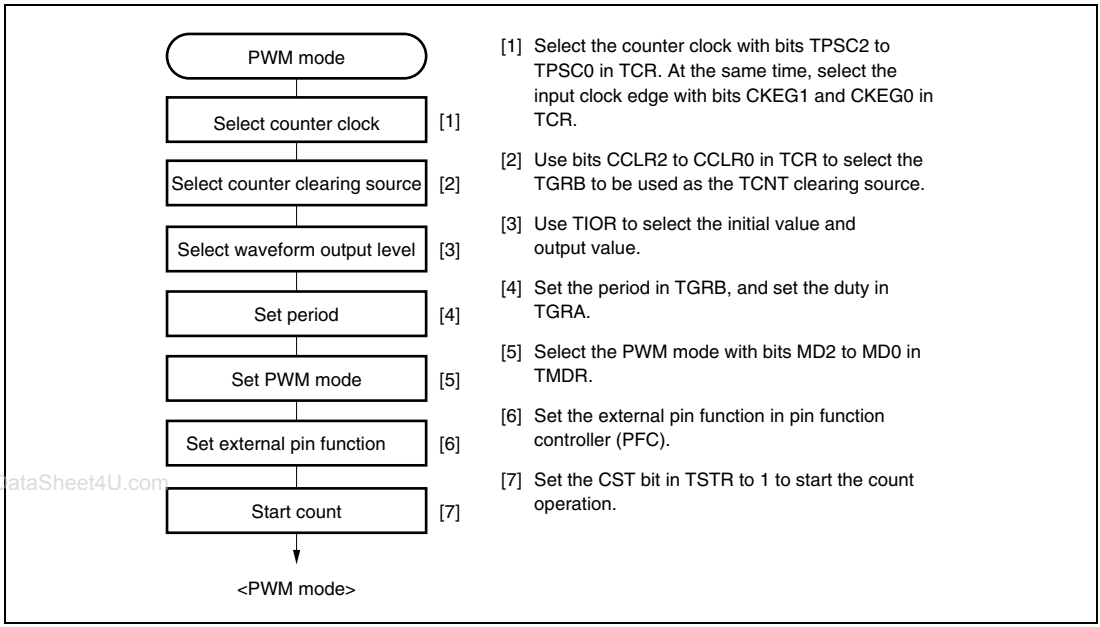


Figure 14.11 Example of PWM Mode Setting Procedure

Examples of PWM Mode Operation: Figure 14.12 shows an example of PWM mode operation.

In this example, TGRB compare match is set as the TCNT clearing source, 0 is set as the initial output value of the TO pin by TGRA, and 1 is set as the output value by TGRA compare match.

In this case, the value set in TGRB is used as the period, and the value set in TGRA as the duty.

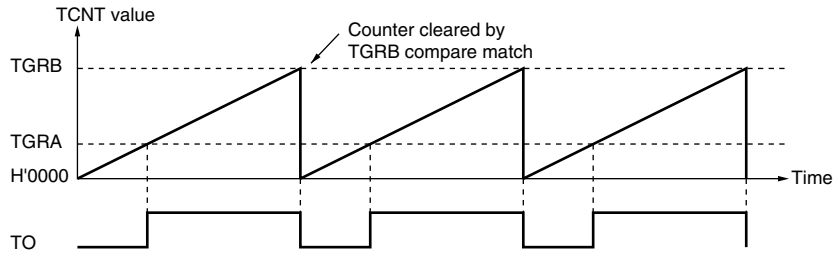


Figure 14.12 Example of PWM Mode Operation (1)

Figure 14.13 shows examples of PWM waveform output with 0% duty and 100% duty in PWM mode.

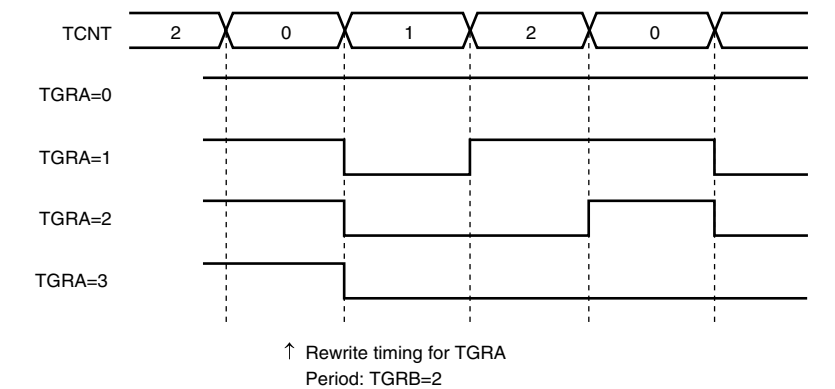


Figure 14.13 Examples of PWM Mode Operation (2)

Section 15 Realtime Clock (RTC)

This LSI has a realtime clock (RTC) with its own 32.768 kHz crystal oscillator. A block diagram of the RTC is shown in figure 15.1.

15.1 Features

The RTC has the following features:

- Clock and calendar functions (BCD format): seconds, minutes, hours, date, day of the week, month, and year
- 1-Hz to 64-Hz timer (binary format)
- Start/stop function
- 30-second adjust function
- Alarm interrupt: frame comparison of seconds, minutes, hours, date, day of the week, month, and year can be used as conditions for the alarm interrupt
- Periodic interrupts: the interrupt cycle may be 1/256 second, 1/64 second, 1/16 second, 1/4 second, 1/2 second, 1 second, or 2 seconds
- Carry interrupt: a carry interrupt indicates when a carry occurs during a counter read
- Automatic leap year adjustment

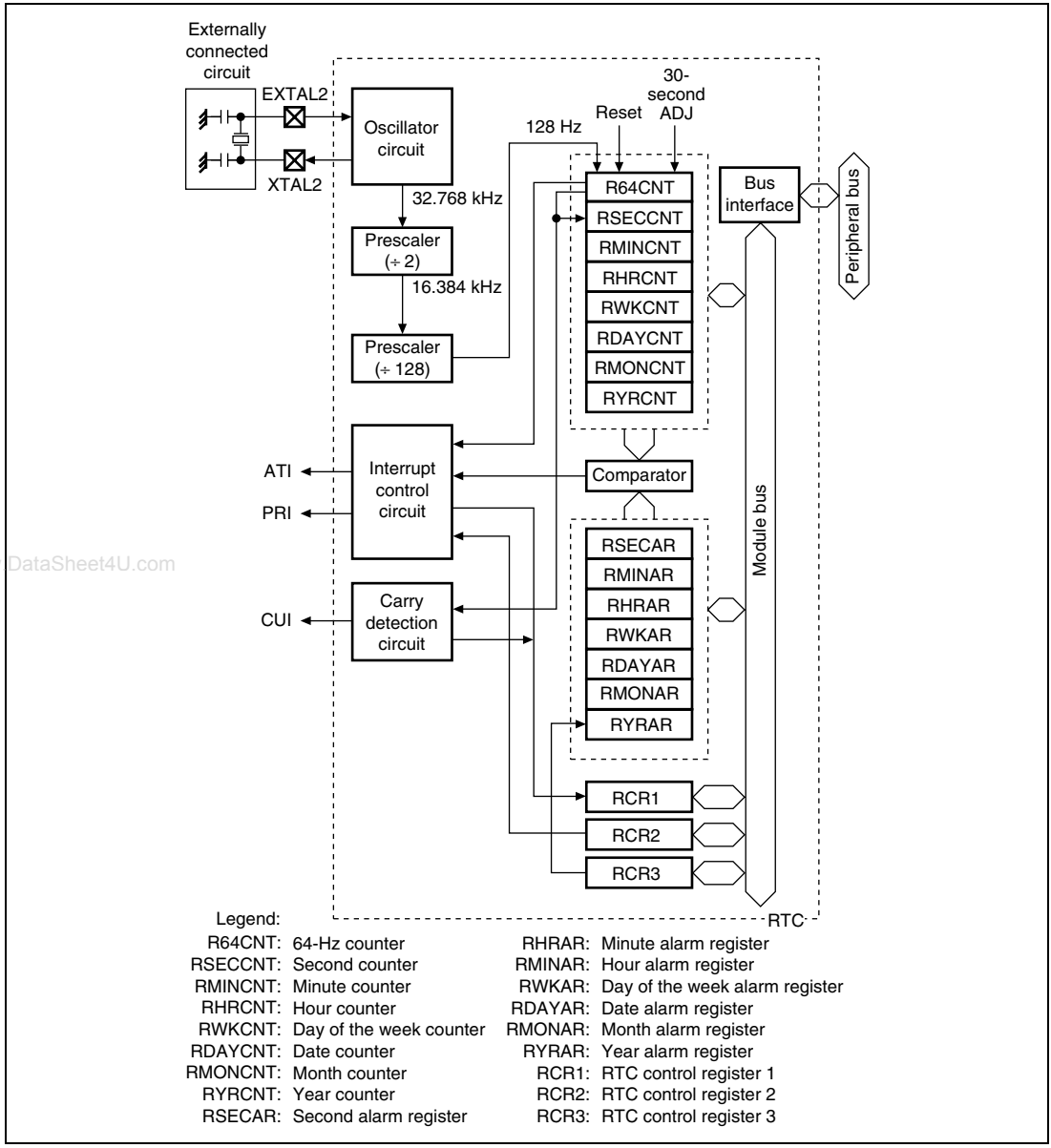


Figure 15.1 RTC Block Diagram

15.2 Input/Output Pins

Table 15.1 shows the RTC pin configuration.

Table 15.1 Pin Configuration

Pin	Abbreviation	I/O	Function
Crystal oscillator for RTC	EXTAL2	I	Connects crystal to RTC oscillator*
Crystal oscillator for RTC	XTAL2	O	Connects crystal to RTC oscillator*
Power-supply for RTC	V_{CC}-RTC	—	Power-supply pin for RTC
GND for RTC	V_{SS}-RTC	—	GND pin for RTC

Note: * Pull up (VccQ (3.3 V power)) EXTAL2 and leave XTAL2 open, when the RTC is not used.

15.3 Register Descriptions

The RTC has the following registers. Refer to section 24, List of Registers, for more detail of the address and access size.

- 64-Hz counter (R64CNT)
- Second counter (RSECCNT)
- Minute counter (RMINCNT)
- Hour counter (RHRCNT)
- Day of week counter (RWKCNT)
- Date counter (RDAYCNT)
- Month counter (RMONCNT)
- Year counter (RYRCNT)
- Second alarm register (RSECAR)
- Minute alarm register (RMINAR)
- Hour alarm register (RHRAR)
- Day of week alarm register (RWKAR)
- Date alarm register (RDAYAR)
- Month alarm register (RMONAR)
- Year alarm register (RYRAR)
- RTC control register 1 (RCR1)
- RTC control register 2 (RCR2)
- RTC control register 3 (RCR3)

15.3.1 64-Hz Counter (R64CNT)

The 64-Hz counter (R64CNT) is an 8-bit read-only register that indicates the state of the divider circuit between 64 Hz and 1 Hz.

R64CNT is reset to H'00 by setting the RESET bit in RCR2 or the ADJ bit in RCR2 to 1.

R64CNT is not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	—	0	R	Reserved This bit is always read as 0.
6 to 0	—	—	R	64-Hz Counter Each bit (bits 6 to 0) indicates the state of the RTC divider circuit between 64 Hz and 1 Hz. Bit Frequency 6: 1 Hz 5: 2 Hz 4: 4 Hz 3: 8 Hz 2: 16 Hz 1: 32 Hz 0: 64 Hz

15.3.2 Second Counter (RSECCNT)

The second counter (RSECCNT) is an 8-bit readable/writable register used for setting/counting in the BCD-coded second section. The count operation is performed by a carry for each second of the 64-Hz counter.

The range of second that can be set is 00 to 59 (decimal). Errant operation will result if any other value is set. Carry out write processing after stopping the count operation with the START bit in RCR2.

RSECCNT is not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
6 to 4	—	—	R/W	10-unit of the second counter in the BCD-code. The range that can be set is 0 to 5 (decimal).
3 to 0	—	—	R/W	1-unit of the second counter in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.3 Minute Counter (RMINCNT)

The minute counter (RMINCNT) is an 8-bit readable/writable register used for setting/counting in the BCD-coded minute section. The count operation is performed by a carry for each minute of the second counter.

The range of minute that can be set is 00 to 59 (decimal). Errant operation will result if any other value is set. Carry out write processing after stopping the count operation with the START bit in RCR2.

RMINCNT is not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
6 to 4	—	—	R/W	10-unit of the minute counter in the BCD-code. The range that can be set is 0 to 5 (decimal).
3 to 0	—	—	R/W	1-unit of the minute counter in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.4 Hour Counter (RHRCNT)

The hour counter (RHRCNT) is an 8-bit readable/writable register used for setting/counting in the BCD-coded hour section. The count operation is performed by a carry for each 1 hour of the minute counter.

The range of hour that can be set is 00 to 23 (decimal). Errant operation will result if any other value is set. Carry out write processing after stopping the count operation with the START bit in RCR2.

RHRCNT is not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7, 6	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
5, 4	—	—	R/W	10-unit of the hour counter in the BCD-code. The range that can be set is 0 to 2 (decimal).
3 to 0	—	—	R/W	1-unit of the hour counter in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.5 Day of Week Counter (RWKCNT)

The day of week counter (RWKCNT) is an 8-bit readable/writable register used for setting/counting in the day of week section. The count operation is performed by a carry for each day of the date counter.

The range for day of the week that can be set is 0 to 6 (decimal). Errant operation will result if any other value is set. Carry out write processing after stopping the count operation with the START bit in RCR2.

RWKCNT is not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7 to 3	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
2 to 0	—	—	R/W	Counter for the day of week in the BCD-code. The range that can be set is 0 to 6 (decimal). Code Day of Week 0: Sunday 1: Monday 2: Tuesday 3: Wednesday 4: Thursday 5: Friday 6: Saturday

15.3.6 Date Counter (RDAYCNT)

The date counter (RDAYCNT) is an 8-bit readable/writable register used for setting/counting in the BCD-coded date section. The count operation is performed by a carry for each day of the hour counter.

The range of date that can be set changes within 01 to 31 (decimal) with some months and in leap years. Please confirm the correct setting. Errant operation will result if any other value is set. Carry out write processing after stopping the count operation with the START bit in RCR2.

RDAYCNT is not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7, 6	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
5, 4	—	—	R/W	10-unit of the date counter in the BCD-code. The range that can be set is 0 to 3 (decimal).
3 to 0	—	—	R/W	1-unit of the date counter in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.7 Month Counter (RMONCNT)

The month counter (RMONCNT) is an 8-bit readable/writable register used for setting/counting in the BCD-coded month section. The count operation is performed by a carry for each month of the date counter.

The range of month that can be set is 01 to 12 (decimal). Errant operation will result if any other value is set. Carry out write processing after stopping the count operation with the START bit in RCR2.

RMONCNT is not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7 to 5	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
4	—	—	R/W	10-unit of the month counter in the BCD-code. The range that can be set is 0 to 1 (decimal).
3 to 0	—	—	R/W	1-unit of the month counter in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.8 Year Counter (RYRCNT)

The year counter (RYRCNT) is a 16-bit readable/writable register used for setting/counting in the BCD-coded year section. The four digits of the western calendar year are counted. The count operation is performed by a carry for each year of the month counter.

The range for year that can be set is 0000 to 9999 (decimal). Errant operation will result if any other value is set. Carry out write processing after stopping the count operation with the START bit in RCR2 or using a carry flag.

RYRCNT is not initialized by a power-on reset or manual reset, or in standby mode.

Leap years are recognized by dividing the year counter value by 4 and obtaining a fractional result of 0. The year counter value 0000 is recognized as a leap year.

Bit	Bit Name	Initial Value	R/W	Description
15 to 12	—	—	R/W	1000-unit of the year counter in the BCD-code. The range that can be set is 0 to 9 (decimal).
11 to 8	—	—	R/W	100-unit of the year counter in the BCD-code. The range that can be set is 0 to 9 (decimal).
7 to 4	—	—	R/W	10-unit of the year counter in the BCD-code. The range that can be set is 0 to 9 (decimal).
3 to 0	—	—	R/W	1-unit of the year counter in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.9 Second Alarm Register (RSECAR)

The second alarm register (RSECAR) is an 8-bit readable/writable register, and an alarm register corresponding to the second counter RSECCNT. When the ENB bit is set to 1, a comparison with the RSECCNT value is performed. For alarm registers RSECAR, RMINAR, RHRAR, RWKAR, RDAYAR, and RMONAR, a comparison with the corresponding counter value is performed for those whose ENB bit is set to 1, and for RCR3, a comparison is performed when the YAEN bit is set to 1. If all of those match, an RTC alarm interrupt is generated.

The range of second alarm that can be set is 00 to 59 (decimal). Errant operation will result if any other value is set.

The ENB bit in RSECAR is initialized to 0 by a power-on reset, and it is not initialized by manual reset and standby mode. The remaining RSECAR fields are not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	ENB	0	R/W	Second Alarm Enable Specifies whether to compare RSECCNT with RSECAR to generate a second alarm. 0: Not compared 1: Compared
6 to 4	—	—	R/W	10-unit of second alarm setting in the BCD-code. The range that can be set is 0 to 5 (decimal).
3 to 0	—	—	R/W	1-unit of second alarm setting in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.10 Minute Alarm Register (RMINAR)

The minute alarm register (RMINAR) is an 8-bit readable/writable register, and an alarm register corresponding to the minute counter RMINCNT. When the ENB bit is set to 1, a comparison with the RMINCNT value is performed. For alarm registers RSECAR, RMINAR, RHRAR, RWKAR, RDAYAR, and RMONAR, a comparison with the corresponding counter value is performed for those whose ENB bit is set to 1, and for RCR3, a comparison is performed when the YAEN bit is set to 1. If all of those match, an RTC alarm interrupt is generated.

The range of minute alarm that can be set is 00 to 59 (decimal). Errant operation will result if any other value is set.

The ENB bit in RMINAR is initialized by a power-on reset, and it is not initialized by manual reset and standby mode. The remaining RMINAR fields are not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	ENB	0	R/W	Minute Alarm Enable Specifies whether to compare RMINCNT with RMINAR to generate a second alarm. 0: Not compared 1: Compared
6 to 4	—	—	R/W	10-unit of minute alarm setting in the BCD-code. The range that can be set is 0 to 5 (decimal).
3 to 0	—	—	R/W	1-unit of minute alarm setting in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.11 Hour Alarm Register (RHRAR)

The hour alarm register (RHRAR) is an 8-bit readable/writable register, and an alarm register corresponding to the hour counter RHRCNT. When the ENB bit is set to 1, a comparison with the RHRCNT value is performed. For alarm registers RSECAR, RMINAR, RHRAR, RWKAR, RDAYAR, and RMONAR, a comparison with the corresponding counter value is performed for those whose ENB bit is set to 1, and for RCR3, a comparison is performed when the YAEN bit is set to 1. If all of those match, an RTC alarm interrupt is generated.

The range of hour alarm that can be set is 00 to 23 (decimal). Errant operation will result if any other value is set.

The ENB bit in RHRAR is initialized by a power-on reset, and it is not initialized by manual reset and standby mode. The remaining RHRAR fields are not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	ENB	0	R/W	Hour Alarm Enable Specifies whether to compare RHRCNT with RHRAR to generate a second alarm. 0: Not compared 1: Compared
6	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
5, 4	—	—	R/W	10-unit of hour alarm setting in the BCD-code. The range that can be set is 0 to 2 (decimal).
3 to 0	—	—	R/W	1-unit of hour alarm setting in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.12 Day of Week Alarm Register (RWKAR)

The day of week alarm register (RWKAR) is an 8-bit readable/writable register, and an alarm register corresponding to the day of week counter RWKCNT. When the ENB bit is set to 1, a comparison with the RWKCNT value is performed. For alarm registers RSECAR, RMINAR, RHRAR, RWKAR, RDAYAR, and RMONAR, a comparison with the corresponding counter value is performed for those whose ENB bit is set to 1, and for RCR3, a comparison is performed when the YAEN bit is set to 1. If all of those match, an RTC alarm interrupt is generated.

The range of day of the week alarm that can be set is 0 to 6 (decimal). Errant operation will result if any other value is set.

The ENB bit in RWKAR is initialized by a power-on reset, and it is not initialized by manual reset and standby mode. The remaining RWKAR fields are not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	ENB	0	R/W	Day of Week Alarm Enable Specifies whether to compare RWKCNT with RWKAR to generate a second alarm. 0: Not compared 1: Compared
6 to 3	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
2 to 0	—	—	R/W	Day of Week Alarm Code The range that can be set is 0 to 6 (decimal). Code Day of the Week 0: Sunday 1: Monday 2: Tuesday 3: Wednesday 4: Thursday 5: Friday 6: Saturday

15.3.13 Date Alarm Register (RDAYAR)

The date alarm register (RDAYAR) is an 8-bit readable/writable register, and an alarm register corresponding to the date counter RDAYCNT. When the ENB bit is set to 1, a comparison with the RDAYCNT value is performed. For alarm registers RSECAR, RMINAR, RHRAR, RWKAR, RDAYAR, and RMONAR, a comparison with the corresponding counter value is performed for those whose ENB bit is set to 1, and for RCR3, a comparison is performed when the YAEN bit is set to 1. If all of those match, an RTC alarm interrupt is generated.

The range of date alarm that can be set is 01 to 31 (decimal). Errant operation will result if any other value is set. The RDAYCNT range that can be set changes with some months and in leap years. Please confirm the correct setting.

The ENB bit in RDAYAR is initialized by a power-on reset, and it is not initialized by manual reset and standby mode. The remaining RDAYAR fields are not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	ENB	0	R/W	Date Alarm Enable Specifies whether to compare RDAYCNT with RDAYAR to generate a second alarm. 0: Not compared 1: Compared
6	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
5, 4	—	—	R/W	10-unit of date alarm setting in the BCD-code. The range that can be set is 0 to 3 (decimal).
3 to 0	—	—	R/W	1-unit of date alarm setting in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.14 Month Alarm Register (RMONAR)

The month alarm register (RMONAR) is an 8-bit readable/writable register, and an alarm register corresponding to the month counter RMONCNT. When the ENB bit is set to 1, a comparison with the RMONCNT value is performed. For alarm registers RSECAR, RMINAR, RHRAR, RWKAR, RDAYAR, and RMONAR, a comparison with the corresponding counter value is performed for those whose ENB bit is set to 1, and for RCR3, a comparison is performed when the YAEN bit is set to 1. If all of those match, an RTC alarm interrupt is generated.

The range of month alarm that can be set is 01 to 12 (decimal). Errant operation will result if any other value is set.

The ENB bit in RMONAR is initialized by a power-on reset, and it is not initialized by manual reset and standby mode. The remaining RMONAR fields are not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	ENB	0	R/W	Month Alarm Enable Specifies whether to compare RMONCNT with RMONAR to generate a second alarm. 0: Not compared 1: Compared
6, 5	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
4	—	—	R/W	10-unit of month alarm setting in the BCD-code. The range that can be set is 0 to 1 (decimal).
3 to 0	—	—	R/W	1-unit of month alarm setting in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.15 Year Alarm Register (RYRAR)

The year alarm register (RYRAR) is a 16-bit readable/writable register, and an alarm register corresponding to the year counter RYRCNT. When the YAEN bit in RCR3 is set to 1, a comparison with the RYRCNT value is performed. For alarm registers RSECAR, RMINAR, RHRAR, RWKAR, RDAYAR, and RMONAR, a comparison with the corresponding counter value is performed for those whose ENB bit is set to 1, and for RCR3, a comparison is performed when the YAEN bit is set to 1. If all of those match, an RTC alarm interrupt is generated.

The range of year alarm that can be set is 0000 to 9999 (decimal). Errant operation will result if any other value is set.

The RYRAR contents are not initialized by a power-on reset or manual reset, or in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
15 to 12	—	—	R/W	1000-unit of year alarm setting in the BCD-code. The range that can be set is 0 to 9 (decimal).
11 to 8	—	—	R/W	100-unit of year alarm setting in the BCD-code. The range that can be set is 0 to 9 (decimal).
7 to 4	—	—	R/W	10-unit of year alarm setting in the BCD-code. The range that can be set is 0 to 9 (decimal).
3 to 0	—	—	R/W	1-unit of year alarm setting in the BCD-code. The range that can be set is 0 to 9 (decimal).

15.3.16 RTC Control Register 1 (RCR1)

The RTC control register 1 (RCR1) is an 8-bit readable/writable register that affects carry flags and alarm flags. It also selects whether to generate interrupts for each flag. Because flags are sometimes set after an operand read, do not use this register in read-modify-write processing.

RCR1 is initialized to H'00 by a power-on reset or a manual reset. In a reset, all bits are initialized to 0 except for the CF flag, which is undefined. When using the CF flag, it must be initialized beforehand. This register is not initialized in standby mode.

Bit	Bit Name	Initial Value	R/W	Description
7	CF	Undefined	R/W	Carry Flag Status flag that indicates that a carry has occurred. CF is set to 1 when R64CNT or RSECCNT is read during a carry occurrence by R64CNT or RSECCNT. A count register value read at this time cannot be guaranteed; another read is required. 0: No carry by R64CNT or RSECCNT. [Clearing condition] When 0 is written to CF 1: [Setting condition] When R64CNT or RSECCNT is read during a carry occurrence by R64CNT or RSECCNT, or 1 is written to CF
6, 5	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
4	CIE	0	R/W	Carry Interrupt Enable Flag When the carry flag (CF) is set to 1, the CIE bit enables interrupts. 0: A carry interrupt is not generated when the CF flag is set to 1 1: A carry interrupt is generated when the CF flag is set to 1
3	AIE	0	R/W	Alarm Interrupt Enable Flag When the alarm flag (AF) is set to 1, the AIE bit enables interrupts. 0: An alarm interrupt is not generated when the AF flag is set to 1 1: An alarm interrupt is generated when the AF flag is set to 1

Bit	Bit Name	Initial Value	R/W	Description
2, 1	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
0	AF	0	R/W	Alarm Flag The AF flag is set to 1 when the alarm time set in an alarm register (only registers with ENB bit of the corresponding alarm registers and YAEN bit in RCR3 set to 1) matches the clock and calendar time. This flag is cleared to 0 when 0 is written, but holds the previous value when 1 is written. 0: Clock/calendar and alarm register have not matched. [Clearing condition] When 0 is written to AF 1: [Setting condition] Clock/calendar and alarm register have matched (only registers that ENB bit and YAEN bit is 1)

15.3.17 RTC Control Register 2 (RCR2)

The RTC control register 2 (RCR2) is an 8-bit readable/writable register for periodic interrupt control, 30-second adjustment ADJ, divider circuit RESET, and RTC count start/stop control. It is initialized to H'09 by a power-on reset. It is initialized except for RTCEN and START by a manual reset. It is not initialized in standby mode, and retains its contents.

Bit	Bit Name	Initial Value	R/W	Description
7	PEF	0	R/W	Periodic Interrupt Flag Indicates interrupt generation with the period designated by the PES2 to PES0 bits. When set to 1, PEF generates periodic interrupts. 0: Interrupts not generated with the period designated by the PES bits. [Clearing condition] When 0 is written to PEF 1: [Setting condition] When interrupts are generated with the period designated by the PES bits or 1 is written to PEF

Bit	Bit Name	Initial Value	R/W	Description
6	PES2	0	R/W	Periodic Interrupt Interval
5	PES1	0	R/W	These bits specify the periodic interrupt interval.
4	PES0	0	R/W	000: No periodic interrupts generated
				001: Periodic interrupt generated every 1/256 second
				010: Periodic interrupt generated every 1/64 second
				011: Periodic interrupt generated every 1/16 second
				100: Periodic interrupt generated every 1/4 second
				101: Periodic interrupt generated every 1/2 second
				110: Periodic interrupt generated every 1 second
				111: Periodic interrupt generated every 2 seconds
3	RTCEN	1	R/W	Controls the operation of the crystal oscillator for the RTC.
				0: Halts the crystal oscillator for the RTC.
				1: Runs the crystal oscillator for the RTC.
2	ADJ	0	R/W	30 Second Adjustment
				When 1 is written to the ADJ bit, times of 29 seconds or less will be rounded to 00 seconds and 30 seconds or more to 1 minute. The divider circuit will be simultaneously reset. This bit is always read as 0.
				0: Runs normally.
				1: 30-second adjustment.
1	RESET	0	R/W	Reset
				When 1 is written, initializes the divider circuit (RTC prescaler and R64CNT). This bit is always read as 0.
				0: Runs normally.
				1: Divider circuit is reset.

Bit	Bit Name	Initial Value	R/W	Description
0	START	1	R/W	Start Bit Halts and restarts the counter (clock). 0: Second/minute/hour/day/week/month/year counter halts. 1: Second/minute/hour/day/week/month/year counter runs normally. Note: The 64-Hz counter always runs unless stopped with the RTCEN bit.

15.3.18 RTC Control Register 3 (RCR3)

The RTC control register 3 (RCR3) is an 8-bit readable/writable register that controls the comparison between the BCD-coded year section counter RYRCNT of the RTC and the year alarm register RYRAR.

Bit	Bit Name	Initial Value	R/W	Description
7	YAEN	0	R/W	Year Alarm Enable When this bit is set to 1, the year alarm register (RYRAR) is compared with the year counter (RYRCNT). For alarm registers RSECAR, RMINAR, RHRAR, RWKAR, RDAYAR, and RMONAR, a comparison with the corresponding counter value is performed for those whose ENB bit is set to 1, and for RCR3, a comparison is performed when this bit is set to 1. If all of those match, an RTC alarm interrupt is generated.
6 to 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

15.4 Operation

15.4.1 Initial Settings of Registers after Power-On

All the registers should be set after the power is turned on.

15.4.2 Setting Time

Figure 15.2 shows how to set the time when the clock is stopped.

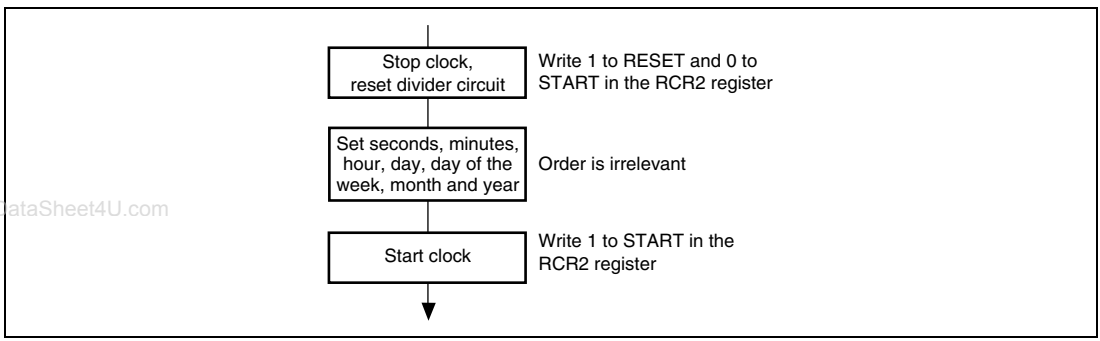


Figure 15.2 Setting Time

15.4.3 Reading the Time

Figure 15.3 shows how to read the time. If a carry occurs while reading the time, the correct time will not be obtained, so it must be read again. Part (a) in figure 15.3 shows the method of reading the time without using interrupts; part (b) in figure 15.3 shows the method using interrupts. To keep programming simple, method (a) should normally be used.

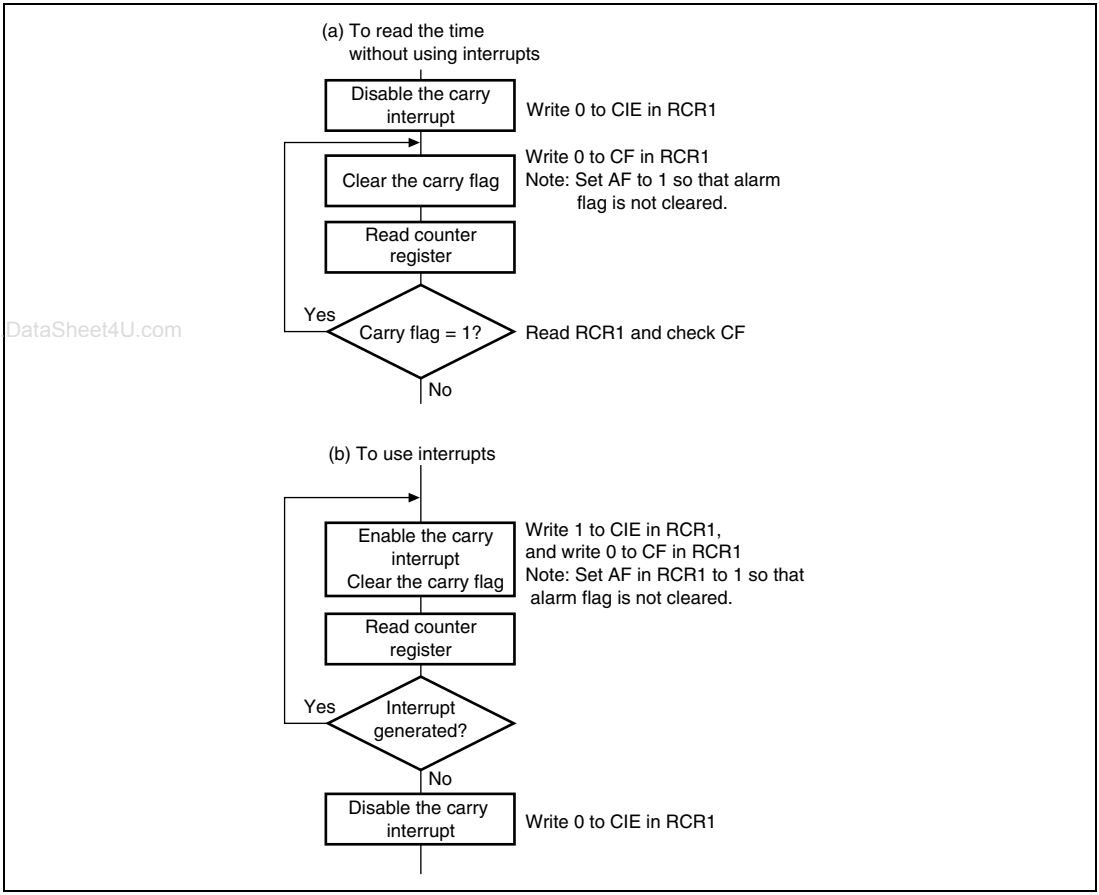


Figure 15.3 Reading the Time

15.4.4 Alarm Function

Figure 15.4 shows how to use the alarm function.

Alarms can be generated using seconds, minutes, hours, day of the week, date, month, year, or any combination of these. Set the ENB or YAEN bit for the register on which the alarm is placed to 1, and then set the alarm time in the lower bits. Clear the ENB or YAEN bit for the register on which the alarm is not placed to 0.

When the clock and alarm times match, 1 is set in the AF bit in RCR1. Alarm detection can be checked by reading this bit, but normally it is done by interrupt. If 1 is placed in the AIE bit in RCR1, an interrupt is generated when an alarm occurs.

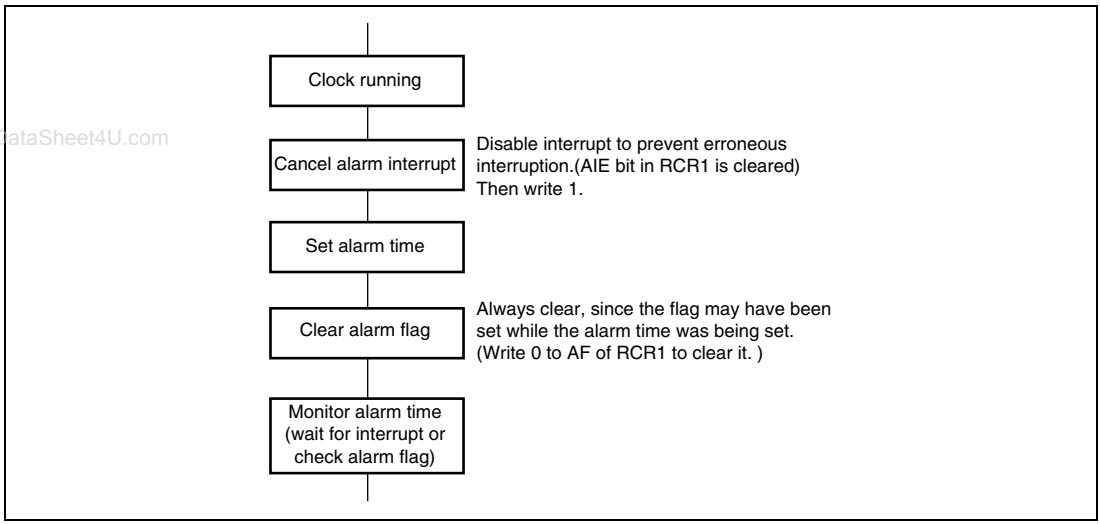


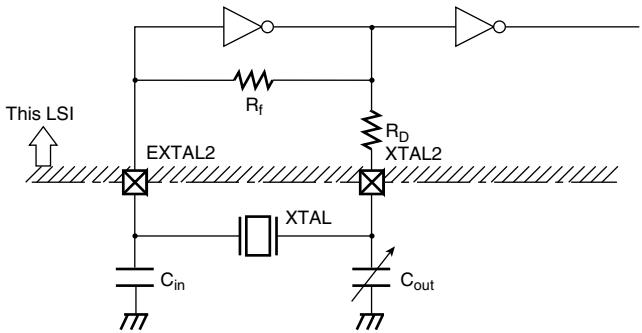
Figure 15.4 Using the Alarm Function

15.4.5 Crystal Oscillator Circuit

Crystal oscillator circuit constants (recommended values) are shown in table 15.2, and the RTC crystal oscillator circuit in figure 15.5.

Table 15.2 Recommended Oscillator Circuit Constants (Recommended Values)

f_{osc}	C_{in}	C_{out}
32.768 kHz	10 to 22 pF	10 to 22 pF



Notes:
1. Select either the C_{in} or C_{out} side for frequency adjustment variable capacitor according to requirements such as frequency range, stability, etc.
2. Built-in resistance value R_f (Typ value) = 10 MΩ, R_D (Typ value) = 400 kΩ
3. C_{in} and C_{out} values include stray capacitance due to the wiring. Take care when using a ground plane.
4. The crystal oscillation settling time depends on the mounted circuit constants, stray capacitance, etc., and should be decided after consultation with the crystal resonator manufacturer.
5. Place the crystal resonator and load capacitors C_{in} and C_{out} as close as possible to the chip.
   (Correct oscillation may not be possible if there is externally induced noise in the EXTAL2 and XTAL2 pins.)
6. Ensure that the crystal resonator connection pin (EXTAL2, XTAL2) wiring is routed as far away as possible from other power lines (except GND) and signal lines.

Figure 15.5 Example of Crystal Oscillator Circuit Connection

15.5 Notes for Usage

15.5.1 Register Writing during RTC Count

The following RTC registers cannot be written to during an RTC count (while the START bit in RCR2 = 1).

RSECCNT, RMINCNT, RHRCNT, RDAYCNT, RWKCNT, RMONCNT, RYRCNT

The RTC count must be halted before writing to any of the above registers.

15.5.2 Use of Realtime Clock (RTC) Periodic Interrupts

The method of using the periodic interrupt function is shown in figure 15.6.

A periodic interrupt can be generated periodically at the interval set by the periodic interrupt interval bits (PES0 to PES2) in RCR2. When the time set by the PES0 to PES2 bits has elapsed, the PEF bit is set to 1.

The PEF is cleared to 0 upon periodic interrupt generation when the periodic interrupt interval bits (PES0 to PES2) is set. Periodic interrupt generation can be confirmed by reading this bit, but normally the interrupt function is used.

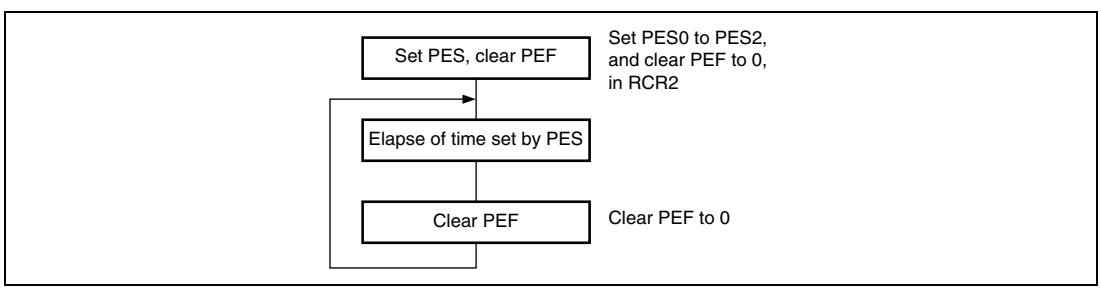


Figure 15.6 Using Periodic Interrupt Function

15.5.3 Standby Mode after Register Setting

If the standby mode is entered after the RTC registers are set, the time cannot be counted correctly. After setting the registers, wait for 2 RTC clock cycles or longer before the standby mode is entered.

Section 16 Serial Communication Interface with FIFO (SCIF)

This LSI has a two-channel serial communication interface with on-chip FIFO buffers (Serial Communication Interface with FIFO: SCIF). The SCIF can perform asynchronous and clock synchronous serial communication.

64-stage FIFO registers are provided for both transmission and reception, enabling fast, efficient, and continuous communication.

16.1 Features

- Asynchronous mode

  Serial data communication is executed using an asynchronous system in which synchronization is achieved character by character. Serial data communication can be carried out with standard asynchronous communication chips such as a Universal Asynchronous Receiver/Transmitter (UART) or Asynchronous Communication Interface Adapter (ACIA).

  There is a choice of eight serial data communication formats.

  — Data length: 7 or 8 bits
  — Stop bit length: 1 or 2 bits
  — Parity: Even/odd/none
  — LSB-first transfer
  — Receive error detection: Parity, framing, and overrun errors
  — Break detection: If a framing error is followed by at least one frame at the space “0” (low) level, a break is detected.
- Clock synchronous mode

  Serial data communication is synchronized with a clock. Serial data communication can be carried out with other chips that have a synchronous communication function.

  — Data length: 8 bits
  — LSB-first transfer
- Full-duplex communication capability

  The transmitter and receiver are independent units, enabling transmission and reception to be performed simultaneously.

  The transmitter and receiver both have a 64-stage FIFO buffer structure, enabling fast and continuous serial data transmission and reception.
- On-chip baud rate generator allows any bit rate to be selected.
- Choice of serial clock source: internal clock from baud rate generator or external clock from SCK pin.

- Six interrupt sources in asynchronous mode

  There are six interrupt sources—transmit-data-stop, transmit-FIFO-data-empty, receive-FIFO-data-full, receive-error (framing/parity error), break-receive, and receive-data-ready interrupts.
- Two interrupt sources in clock synchronous mode

  There are two interrupt sources—transmit-FIFO-data-empty and receive-FIFO-data-full interrupts.
- The DMA controller (DMAC) can be activated to execute a data transfer in the event of a transmit-FIFO-data-empty, transmit-data-stop, or receive-FIFO-data-full interrupt. The DMAC requests of transmit-FIFO-data-empty and transmit-data-stop interrupts are the same.
- On-chip modem control functions ($\overline{\text{CTS}}$ and $\overline{\text{RTS}}$)
- On-chip transmit-data-stop functions (only in asynchronous mode)
- When not in use, the SCIF can be stopped by halting its clock supply to reduce power consumption.
- The amount of data in the transmit/receive FIFO registers and the number of receive errors in the receive data in the receive FIFO register can be ascertained.

Figure 16.1 shows a block diagram of the SCIF.

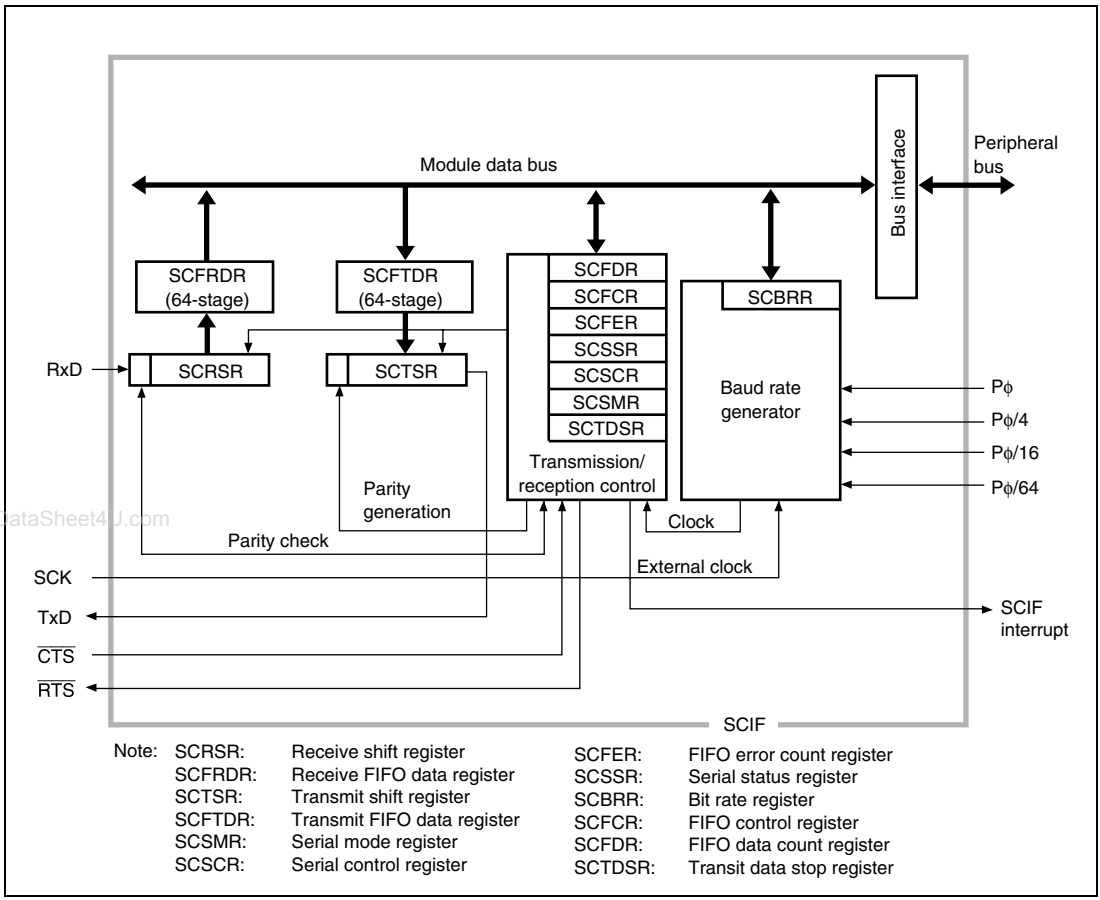


Figure 16.1 Block Diagram of SCIF

16.2 Input/Output Pins

Table 16.1 shows the SCIF pin configuration.

Table 16.1 Pin Configuration

Channel	Pin Name		Abbreviation*[1]	I/O	Function
0	Serial clock	SCK0	SCK	Input/output	Clock input/output
	Receive data	RxD0	RxD*[2]	Input	Receive data input
	Transmit data	TxD0	TxD*[2]	Output	Transmit data output
	Modem control	$\overline{\text{CTS0}}$	$\overline{\text{CTS}}$	Input	Transmission possible
	Modem control	$\overline{\text{RTS0}}$	$\overline{\text{RTS}}$	Output	Transmit request
2	Serial clock	SCK2	SCK	Input/output	Clock input/output
	Receive data	RxD2	RxD*[2]	Input	Receive data input
	Transmit data	TxD2	TxD*[2]	Output	Transmit data output
	Modem control	$\overline{\text{CTS2}}$	$\overline{\text{CTS}}$	Input	Transmission possible
	Modem control	$\overline{\text{RTS2}}$	$\overline{\text{RTS}}$	Output	Transmit request

Notes: *1. The pins are collectively called SCK, RxD, TxD, $\overline{\text{CTS}}$, and $\overline{\text{RTS}}$ without channel number in the following descriptions.

*2. These pins are made to function as serial pins by setting SCIF operation with the TE and RE bits in SCSCR.

16.3 Register Descriptions

The SCIF has the following internal registers. For details on register addresses and register states in each processing state, refer to section 24, List of Registers.

1. Channel 0

- Serial mode register 0 (SCSMR_0)
- Bit rate register 0 (SCBRR_0)
- Serial control register 0 (SCSCR_0)
- Transmit data stop register 0 (SCTDSR_0)
- FIFO error count register 0 (SCFER_0)
- Serial status register 0 (SCSSR_0)
- FIFO control register 0 (SCFCR_0)
- FIFO data count register 0 (SCFDR_0)
- Transmit FIFO data register 0 (SCFTDR_0)
- Receive FIFO data register 0 (SCFRDR_0)

2. Channel 2

- Serial mode register 2 (SCSMR_2)
- Bit rate register 2 (SCBRR_2)
- Serial control register 2 (SCSCR_2)
- Transmit data stop register 2 (SCTDSR_2)
- FIFO error count register 2 (SCFER_2)
- Serial status register 2 (SCSSR_2)
- FIFO control register 2 (SCFCR_2)
- FIFO data count register 2 (SCFDR_2)
- Transmit FIFO data register 2 (SCFTDR_2)
- Receive FIFO data register 2 (SCFRDR_2)

16.3.1 Receive Shift Register (SCRSR)

SCRSR is the register used to receive serial data.

The SCIF sets serial data input from the RxD pin in SCRSR in the order received, starting with the LSB (bit 0), and converts it to parallel data. When one byte of data has been received, it is transferred to the receive FIFO data register, SCFRDR, automatically.

SCRSR cannot be directly read or written to by the CPU.

16.3.2 Receive FIFO Data Register (SCFRDR)

SCFRDR is a 64-stage 8-bit FIFO register that stores received serial data.

When the SCIF has received one byte of serial data, it transfers the received data from SCRSR to SCFRDR where it is stored, and completes the receive operation. SCRSR is then enabled for reception, and consecutive receive operations can be performed until the receive FIFO data register is full (64 data bytes).

SCFRDR is a read-only register, and cannot be written to by the CPU.

If a read is performed when there is no receive data in the receive FIFO data register, an undefined value will be returned. When the receive FIFO data register is full of receive data, subsequent serial data is lost.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	SCFRD7 to SCFRD0	Undefined	R	Serial Receive Data FIFO

16.3.3 Transmit Shift Register (SCTSR)

SCTSR is the register used to transmit serial data.

To perform serial data transmission, the SCIF first transfers transmit data from SCFTDR to SCTSR, then sends the data sequentially to the TxD pin starting with the LSB (bit 0).

When transmission of one byte is completed, the next transmit data is transferred from SCFTDR to SCTSR, and transmission is started automatically.

SCTSR cannot be directly read or written to by the CPU.

16.3.4 Transmit FIFO Data Register (SCFTDR)

SCFTDR is an 8-bit 64-stage FIFO data register that stores data for serial transmission.

If SCTSR is empty when transmit data is written to SCFTDR, the SCIF transfers the transmit data written in SCFTDR to SCTSR and starts serial transmission.

SCFTDR is a write-only register, and cannot be read by the CPU.

The next data cannot be written when SCFTDR is filled with 64 bytes of transmit data. Data written in this case is ignored.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	SCFTD7 to SCFTD0	Undefined	W	Serial Transmit Data FIFO

16.3.5 Serial Mode Register (SCSMR)

SCSMR is a 16-bit readable/writable register used to set the SCIF's serial transfer format and select the baud rate generator clock source and the sampling rate.

Bit	Bit Name	Initial Value	R/W	Description
15 to 11	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
10	SRC2	0	R/W	Sampling Control
9	SRC1	0	R/W	Select the sampling rate in asynchronous mode. This setting is valid only in asynchronous mode.
8	SRC0	0	R/W	000: Sampling rate 1/16 001: Sampling rate 1/5 010: Sampling rate 1/11 011: Sampling rate 1/13 100: Sampling rate 1/29 101: Setting prohibited 110: Setting prohibited 111: Setting prohibited
7	C/A	0	R/W	Communication Mode Selects whether the SCI operates in the asynchronous or clock synchronous mode. 0: Asynchronous mode 1: Clock synchronous mode
6	CHR	0	R/W	Character Length Selects seven or eight bits as the data length. This setting is only valid in asynchronous mode. In clock synchronous mode, the data length is always eight bits, regardless of the CHR setting. 0: 8-bit data 1: 7-bit data* Note: * When the 7-bit data is selected, the MSB bit (bit 7) in the transmit FIFO data register (SCFTDR) is not transmitted.

Bit	Bit Name	Initial Value	R/W	Description
5	PE	0	R/W	Parity Enable Selects whether or not parity bit addition is performed in transmission, and parity bit checking in reception. This setting is only valid in asynchronous mode. In synchronous mode, parity bit addition and checking is not performed, regardless of the PE setting. 0: Parity bit addition and checking disabled 1: Parity bit addition and checking enabled* Note: * When the PE bit is set to 1, the parity (even or odd) specified by the O/E bit is added to transmit data before transmission. In reception, the parity bit is checked for the parity (even or odd) specified by the O/E bit.
4	O/E	0	R/W	Parity Mode Selects either even or odd parity for use in parity addition and checking. The O/E bit setting is only valid when the PE bit is set to 1, enabling parity bit addition and checking. The O/E bit setting is invalid when parity addition and checking is disabled in asynchronous and clock synchronous mode. 0: Even parity*[1] 1: Odd parity*[2] Notes: 1. When even parity is set, parity bit addition is performed in transmission so that the total number of 1-bits in the transmit character plus the parity bit is even. In reception, a check is performed to see if the total number of 1-bits in the receive character plus the parity bit is even. 2. When odd parity is set, parity bit addition is performed in transmission so that the total number of 1-bits in the transmit character plus the parity bit is odd. In reception, a check is performed to see if the total number of 1-bits in the receive character plus the parity bit is odd.

Bit	Bit Name	Initial Value	R/W	Description
3	STOP	0	R/W	Stop Bit Length Selects one or two bits as the stop bit length. In reception, only the first stop bit is checked, regardless of the STOP bit setting. If the second stop bit is 1, it is treated as a stop bit; if it is 0, it is treated as the start bit of the next transmit character. This setting is only valid in asynchronous mode. In clock synchronous mode, this setting is invalid since stop bits are not added. 0: One stop bit*[1] 1: Two stop bits*[2] Notes: 1. In transmission, a single 1-bit (stop bit) is added to the end of a transmit character before it is sent. 2. In transmission, two 1-bits (stop bits) are added to the end of a transmit character before it is sent.
2	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
1	CKS1	0	R/W	Clock Select
0	CKS0	0	R/W	Select the clock source for the on-chip baud rate generator. 00: Pϕ 01: Pϕ/4 10: Pϕ/16 11: Pϕ/64

Note: When the clock synchronous mode is selected (C/A bit = 1), the bits other than CKS1 and CKS0 bits are all fixed to 0.

16.3.6 Serial Control Register (SCSCR)

SCSCR is a 16-bit readable/writable register that enables or disables the SCIF transfer operations and interrupt requests, and selects the serial clock source.

Bit	Bit Name	Initial Value	R/W	Description
15 to 12	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
11	TSIE	0	R/W	Transmit Data Stop Interrupt Enable Enables or disables generation of a transmit-data-stop interrupt when the TSE bit in SCFCR is enabled and the TSF flag in SCSSR is set to 1. 0: Transmit-data-stop interrupt disabled* 1: Transmit-data-stop interrupt enabled Note: * The interrupt request is cleared by clearing the TSF flag to 0 after reading 1 from it or clearing the TSIE bit to 0.
10	ERIE	0	R/W	Receive Error Interrupt Enable Enables or disables generation of a receive-error (framing or parity error) interrupt when the ER flag in SCSSR is set to 1. 0: Receive-error interrupt disabled* 1: Receive-error interrupt enabled Note: * The interrupt request is cleared by clearing the ER flag to 0 after reading 1 from it or clearing the ERIE bit to 0.

Bit	Bit Name	Initial Value	R/W	Description
9	BRIE	0	R/W	Break Interrupt Enable Enables or disables generation of a break-receive interrupt when the BRK flag in SCSSR is set to 1. 0: Break-receive interrupt disabled* 1: Break-receive interrupt enabled Note: * The interrupt request is cleared by clearing the BRK flag to 0 after reading 1 from it or clearing the BRIE bit to 0.
8	DRIE	0	R/W	Receive Data Ready Interrupt Enable Enables or disables generation of a receive-data-ready interrupt when the DR flag in SCSSR is set to 1. 0: Receive-data-ready interrupt disabled* 1: Receive-data-ready interrupt enabled Note: * The interrupt request is cleared by clearing the DR flag to 0 after reading 1 from it or clearing the DRIE bit to 0.
7	TIE	0	R/W	Transmit Interrupt Enable Enables or disables generation of a transmit-FIFO-data-empty interrupt request when the TDFE flag in SCSSR is set to 1. 0: Transmit-FIFO-data-empty interrupt request disabled* 1: Transmit-FIFO-data-empty interrupt request enabled Note: * The interrupt request is cleared by writing transmit data exceeding the transmit trigger set number to SCFTDR, reading 1 from the TDFE flag, then clearing it to 0, or clearing the TIE bit to 0.
6	RIE	0	R/W	Receive Interrupt Enable Enables or disables generation of a receive-FIFO-data-full interrupt request when the RDF flag in SCSSR is set to 1. 0: Receive-FIFO-data-full interrupt request disabled* 1: Receive-FIFO-data-full interrupt request enabled Note: * The interrupt requests is cleared by reading 1 from the RDF flag, then clearing the flag to 0, or clearing the RIE bit to 0.

Bit	Bit Name	Initial Value	R/W	Description
5	TE	0	R/W	Transmit Enable Enables or disables the start of serial transmission by the SCIF. 0: Transmission disabled 1: Transmission enabled* Note: * The serial mode register (SCSMR) and FIFO control register (SCFCR) settings must be made, the transmit format decided, and the transmit FIFO reset, before the TE bit is set to 1.
4	RE	0	R/W	Receive Enable Enables or disables the start of serial reception by the SCIF. 0: Reception disabled*[1] 1: Reception enabled*[2] Notes: 1. Clearing the RE bit to 0 does not affect the DR, ER, BRK, RDF, FER, PER, and ORER flags, which retain their state. 2. The serial mode register (SCSMR) and FIFO control register (SCFCR) settings must be made, the receive format decided, and the receive FIFO reset, before the RE bit is set to 1.
3, 2	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
1	CKE1	0	R/W	Clock Enable
0	CKE0	0	R/W	Select the SCIF clock source. The CKE1 and CKE0 bits must be set before determining the SCIF operating mode with SCSMR. 00: Internal clock/SCK pin functions as input pin (input signal ignored) 01: Internal clock/SCK pin functions as serial clock output*1 10: External clock/SCK pin functions as clock input*2 11: External clock/SCK pin functions as clock input*2 When data is sampled by the on-chip baud rate generator, set bits CKE1 and CKE0 to B′00 (internal clock/SCK pin functions as input pin (input signal ignored)). When using the SCK pin as a port, set bits CKE1 and CKE0 to B'00. Notes: *1. In synchronous mode, a clock with a frequency equal to the bit rate is output. *2. In asynchronous mode, a clock with a sampling rate should be input. For example, when the sampling rate is 1/16, a clock with a frequency of 8 times the bit rate should be input. When an external clock is not input, set bits CKE1 and CKE0 to B′00 or B′01.

16.3.7 FIFO Error Count Register (SCFER)

SCFER is a 16-bit read-only register that indicates the number of receive errors (framing or parity error).

Bit	Bit Name	Initial Value	R/W	Description
15, 14	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
13 to 8	PER5 to PER0	All 0	R	Parity Error Count Indicates the number of data, in which parity errors are generated, in receive data stored in the receive FIFO data register (SCFRDR) in asynchronous mode. After setting the ER bit in SCSSR, the value of bits 13 to 8 indicates the number of parity error generated data. When all 64 bytes of receive data in SCFRDR have parity errors, the PER5 to PER0 bits indicate 0.
7, 6	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
5 to 0	FER5 to FER0	All 0	R	Framing Error Count Indicates the number of data, in which framing errors are generated, in receive data stored in the receive FIFO data register (SCFRDR) in asynchronous mode. After setting the ER bit in SCSSR, the value of bits 5 to 0 indicates the number of framing error generated data. When all 64 bytes of receive data in SCFRDR have framing errors, the FER5 to FER0 bits indicate 0.

16.3.8 Serial Status Register (SCSSR)

SCSSR is a 16-bit readable/writable register that indicates the SCIF status.

However, 1 cannot be written to the ORER, TSF, ER, TDFE, BRK, RDF, and DR flags. Also note that in order to clear these flags to 0, they must be read as 1 beforehand. The TEND, FER, and PER flags are read-only flags and cannot be modified.

Bit	Bit Name	Initial Value	R/W	Description
15 to 10	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
9	ORER	0	R/(W)*	Overrun Error Indicates that an overrun error occurred during reception. This bit is only valid in asynchronous mode. 0: Reception in progress, or reception has ended successfully*1 [Clearing conditions] • Power-on reset or manual reset • When 0 is written to ORER after reading ORER = 1 1: An overrun error occurred during reception*2 [Setting condition] When serial reception is completed while receive FIFO is full Notes: *1. The ORER flag is not affected and retains its previous state when the RE bit in SCSCR is cleared to 0. *2. The receive data prior to the overrun error is retained in SCFRDR, and the data received subsequently is lost. Serial reception cannot be continued while the ORER flag is set to 1.

Bit	Bit Name	Initial Value	R/W	Description
8	TSF	0	R/(W)*	Transmit Data Stop Indicates that the number of transmit data matches the value of SCTDSR. 0: Number of transmit data does not match the value of SCTDSR [Clearing conditions] • Power-on reset or manual reset • When 0 is written to TSF after reading TSF = 1 1: Number of transmit data matches the value of SCTDSR
7	ER	0	R/(W)*	Receive Error Indicates that a framing error or parity error occurred during reception in asynchronous mode.*1 0: No framing error or parity error occurred during reception [Clearing conditions] • Power-on reset or manual reset • When 0 is written to ER after reading ER = 1 1: A framing error or parity error occurred during reception [Setting conditions] • When the SCIF checks whether the stop bit at the end of the receive data is 1 when reception ends, and the stop bit is 0*2 • When, in reception, the number of 1-bits in the receive data plus the parity bit does not match the parity setting (even or odd) specified by the O/E bit in SCSMR Notes: *1. The ER flag is not affected and retains its previous state when the RE bit in SCSCR is cleared to 0. When a receive error occurs, the receive data is still transferred to SCFRDR, and reception continues. The FER and PER bits in SCSSR can be used to determine whether there is a receive error in the data read from SCFRDR. *2. When the stop length is two bits, only the first stop bit is checked for a value of 1; the second stop bit is not checked.

Bit	Bit Name	Initial Value	R/W	Description
6	TEND	1	R	Transmit End Indicates that there is no valid data in SCFTDR when the last bit of the transmit character is sent, and transmission has been ended. 0: Transmission is in progress [Clearing condition] When data is written to SCFTDR 1: Transmission has been ended [Setting condition] When there is no transmit data in SCFTDR on transmission of a 1-byte serial transmit character
5	TDFE	1	R/(W)*	Transmit FIFO Data Empty Indicates that data has been transferred from SCFTDR to SCTSR, the number of data bytes in SCFTDR has fallen to or below the transmit trigger data number set by bits TTRG1 and TTRG0 in the FIFO control register (SCFCR), and new transmit data can be written to SCFTDR. 0: A number of transmit data bytes exceeding the transmit trigger set number have been written to SCFTDR [Clearing condition] When transmit data exceeding the transmit trigger set number is written to SCFTDR, and 0 is written to TDFE after reading TDFE = 1 1: The number of transmit data bytes in SCFTDR does not exceed the transmit trigger set number [Setting conditions] • Power-on reset or manual reset • When the number of SCFTDR transmit data bytes falls to or below the transmit trigger set number as the result of a transmit operation*[1] Note:*1 As SCFTDR is a 64-byte FIFO register, the maximum number of bytes that can be written when TDFE = 1 is 64 – (transmit trigger set number). Data written in excess of this will be ignored. The number of data bytes in SCFTDR is indicated by SCFDR.

Bit	Bit Name	Initial Value	R/W	Description
4	BRK	0	R/(W)*	Break Detect Indicates that a receive data break signal has been detected in asynchronous mode. 0: A break signal has not been received [Clearing conditions] • Power-on reset or manual reset • When 0 is written to BRK after reading BRK = 1 1: A break signal has been received*[1] [Setting condition] When data with a framing error is received, followed by the space 0 level (low level) for at least one frame length Note: *1 When a break is detected, the receive data (H'00) following detection is not transferred to SCFRDR. When the break ends and the receive signal returns to mark 1, receive data transfer is resumed.
3	FER	0	R	Framing Error Indicates a framing error in the data read from SCFRDR in asynchronous mode. 0: There is no framing error in the receive data read from SCFRDR [Clearing conditions] • Power-on reset or manual reset • When there is no framing error in SCFRDR read data 1: There is a framing error in the receive data read from SCFRDR [Setting condition] When there is a framing error in SCFRDR read data

Bit	Bit Name	Initial Value	R/W	Description
2	PER	0	R	Parity Error Indicates a parity error in the data read from SCFRDR in asynchronous mode. 0: There is no parity error in the receive data read from SCFRDR [Clearing conditions] • Power-on reset or manual reset • When there is no parity error in SCFRDR read data 1: There is a parity error in the receive data read from SCFRDR [Setting condition] When there is a parity error in SCFRDR read data
1	RDF	0	R/(W)*	Receive FIFO Data Full Indicates that the received data has been transferred from SCRSR to SCFRDR, and the number of receive data bytes in SCFRDR is equal to or greater than the receive trigger number set by bits RTRG1 and RTRG0 in the FIFO control register (SCFCR). 0: The number of receive data bytes in SCFRDR is less than the receive trigger set number [Clearing conditions] • Power-on reset or manual reset • When SCFRDR is read until the number of receive data bytes in SCFRDR falls below the receive trigger set number, and 0 is written to RDF after reading RDF = 1 1: The number of receive data bytes in SCFRDR is equal to or greater than the receive trigger set number [Setting condition] When SCFRDR contains at least the receive trigger set number of receive data bytes*[1] Note:*1 SCFRDR is a 64-byte FIFO register. When RDF = 1, at least the receive trigger set number of data bytes can be read. If data is read when SCFRDR is empty, an undefined value will be returned. The number of receive data bytes in SCFRDR is indicated by the lower bits of SCFDR.

Bit	Bit Name	Initial Value	R/W	Description
0	DR	0	R/(W)*	Receive Data Ready Indicates that there are fewer than the receive trigger set number of data bytes in SCFRDR and no further data will arrive in asynchronous mode. 0: Reception is in progress or has ended successfully and there is no receive data left in SCFRDR [Clearing conditions] • Power-on reset or manual reset • When all the receive data in SCFRDR has been read, and 0 is written to DR after reading DR = 1 1: No further receive data has arrived [Setting condition] When SCFRDR contains fewer than the receive trigger set number of receive data bytes and no further data will arrive.*1 Note: *1 The DR bit is set 15 etu after the last data is received at a sampling rate of 1/16 regardless of the setting of the sampling control bits in SCSMR. etu: Elementary time unit (time for transfer of one bit)

Note: * Only 0 can be written for clearing the flags.

16.3.9 Bit Rate Register (SCBRR)

SCBRR is an 8-bit readable/writable register that sets the serial transfer bit rate in accordance with the baud rate generator operating clock selected by bits CKS1 and CKS0 in SCSMR.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	SCBR7 to SCBR0	H'FF	R/W	Bit Rate Setting

The SCBRR setting is found from the following equation.

Asynchronous Mode:

1. When sampling rate is 1/16

$$N = \frac{P\phi}{32 \times 2^{2n-1} \times B} \times 10^6 - 1$$

2. When sampling rate is 1/5

$$N = \frac{P\phi}{10 \times 2^{2n-1} \times B} \times 10^6 - 1$$

3. When sampling rate is 1/11

$$N = \frac{P\phi}{22 \times 2^{2n-1} \times B} \times 10^6 - 1$$

4. When sampling rate is 1/13

$$N = \frac{P\phi}{26 \times 2^{2n-1} \times B} \times 10^6 - 1$$

5. When sampling rate is 1/29

$$N = \frac{P\phi}{58 \times 2^{2n-1} \times B} \times 10^6 - 1$$

Clock Synchronous Mode:

$$N = \frac{P\phi}{4 \times 2^{2n-1} \times B} \times 10^6 - 1$$

Where B: Bit rate (bits/s)
N: SCBRR setting for baud rate generator
Asynchronous mode: $0 \le N \le 255$
Clock synchronous mode: $1 \le N \le 255$
Pϕ: Peripheral module operating frequency (MHz)
n: Baud rate generator input clock (n = 0 to 3)
(See the table below for the relation between n and the clock.)

		SCSMR Setting	
n	**Clock**	**CKS1**	**CKS0**
0	Pϕ	0	0
1	Pϕ/4	0	1
2	Pϕ/16	1	0
3	Pϕ/64	1	1

The bit rate error in asynchronous mode is found from the following equation:

1. When sampling rate is 1/16

$$\text{Error (\%)} = \left(\frac{P\phi \times 10^6}{(1+N) \times B \times 32 \times 2^{2n-1}} - 1 \right) \times 100$$

2. When sampling rate is 1/5

$$\text{Error (\%)} = \left(\frac{P\phi \times 10^6}{(1+N) \times B \times 10 \times 2^{2n-1}} - 1 \right) \times 100$$

3. When sampling rate is 1/11

$$\text{Error (\%)} = \left(\frac{P\phi \times 10^6}{(1+N) \times B \times 22 \times 2^{2n-1}} - 1 \right) \times 100$$

4. When sampling rate is 1/13

$$\text{Error (\%)} = \left(\frac{P\phi \times 10^6}{(1+N) \times B \times 26 \times 2^{2n-1}} - 1 \right) \times 100$$

5. When sampling rate is 1/27

$$\text{Error (\%)} = \left(\frac{P\phi \times 10^6}{(1+N) \times B \times 58 \times 2^{2n-1}} - 1 \right) \times 100$$

16.3.10 FIFO Control Register (SCFCR)

SCFCR is a 16-bit readable/writable register that resets the data count and sets the trigger data number for the transmit and receive FIFO registers, and also contains a loopback test enable bit.

Bit	Bit Name	Initial Value	R/W	Description
15	TSE	0	R/W	Transmit Data Stop Enable Enables or disables the transmit data stop function. This function is enabled only in asynchronous mode. Since this function is not supported in clock synchronous mode, clear this bit to 0 in clock synchronous mode. 0: Transmit data stop function disabled 1: Transmit data stop function enabled
14	TCRST	0	R/W	Transmit Count Reset Clears the transmit count to 0. This bit is valid only when the transmit data stop function is used. 0: Transmit count reset disabled* 1: Transmit count reset enabled (clearing to 0) Note:* The transmit count is reset (clearing to 0) is performed in power-on reset or manual reset.
13 to 11	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
10 9 8	RSTRG2 RSTRG1 RSTRG0	0 0 0	R/W R/W R/W	$\overline{\text{RTS}}$ Output Active Trigger The $\overline{\text{RTS}}$ signal goes high when the number of receive data bytes in SCFRDR is equal to or greater than the trigger set number shown in below. 000: 63 001: 1 010: 8 011: 16 100: 32 101: 48 110: 54 111: 60

Bit	Bit Name	Initial Value	R/W	Description
7	RTRG1	0	R/W	Receive FIFO Data Number Trigger
6	RTRG0	0	R/W	Set the number of receive data bytes that sets the receive data full (RDF) flag in the serial status register (SCSSR). The RDF flag is set when the number of receive data bytes in SCFRDR is equal to or greater than the trigger set number shown in below. 00: 1 01: 16 10: 32 11: 48
5	TTRG1	0	R/W	Transmit FIFO Data Number Trigger
4	TTRG0	0	R/W	Set the number of remaining transmit data bytes that sets the transmit FIFO data register empty (TDFE) flag in the serial status register (SCSSR). The TDFE flag is set when, as the result of a transmit operation, the number of transmit data bytes in the transmit FIFO data register (SCFTDR) falls to or below the trigger set number shown in below. 00: 32 (32) 01: 16 (48) 10: 2 (62) 11: 0 (64) Note: The values in parentheses are the number of empty bytes in SCFTDR when the flag is set.
3	MCE	0	R/W	Modem Control Enable Enables modem control signals $\overline{\text{CTS}}$ and $\overline{\text{RTS}}$. This setting is only valid in asynchronous mode. 0: Modem signal disabled* 1: Modem signal enabled Note: $\overline{\text{CTS}}$ is fixed at active 0 regardless of the input value, and $\overline{\text{RTS}}$ is also fixed at 0.

Bit	Bit Name	Initial Value	R/W	Description
2	TFRST	0	R/W	Transmit FIFO Data Register Reset Invalidates the transmit data in the transmit FIFO data register and resets it to the empty state. 0: Reset operation disabled* 1: Reset operation enabled Note:* A reset operation is performed in the event of a power-on reset or manual reset.
1	RFRST	0	R/W	Receive FIFO Data Register Reset Invalidates the receive data in the receive FIFO data register and resets it to the empty state. 0: Reset operation disabled* 1: Reset operation enabled Note:* A reset operation is performed in the event of a power-on reset or manual reset.
0	LOOP	0	R/W	Loopback Test Internally connects the transmit output pin (TxD) and receive input pin (RxD), and $\overline{\text{RTS}}$ pin and $\overline{\text{CTS}}$ pin, enabling loopback testing. 0: Loopback test disabled 1: Loopback test enabled

16.3.11 FIFO Data Count Register (SCFDR)

SCFDR is a 16-bit read-only register that indicates the number of data bytes stored in the transmit FIFO data register (SCFTDR) and receive FIFO data register (SCFRDR).

Bits 14 to 8 show the number of transmit data bytes in SCFTDR, and bits 6 to 0 show the number of receive data bytes in SCFRDR.

Bit	Bit Name	Initial Value	R/W	Description
15	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
14 to 8	T6 to T0	All 0	R	These bits show the number of untransmitted data bytes in SCFTDR. A value of H'00 means that there is no transmit data, and a value of H'40 means that SCFTDR is full of transmit data.
7	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
6 to 0	R6 to R0	All 0	R	These bits show the number of receive data bytes in SCFRDR. A value of H'00 means that there is no receive data, and a value of H'40 means that SCFRDR is full of receive data.

16.3.12 Transmit Data Stop Register (SCTDSR)

SCTDSR is an 8-bit readable/writable register that sets the number of transmit data bytes. SCTDSR is valid only when the TSE bit in the FIFO control register (SCFCR) is enabled. Transmit operation is stopped when the number of data bytes set in SCTDSR is transmitted. The setting value should be H’00 (one byte) to H’FF (256 bytes). This function is only enabled in asynchronous mode.

SCTDSR is initialized to H'FF.

16.4 Operation

16.4.1 Overview

The SCIF can carry out serial communication in asynchronous mode, in which synchronization is achieved character by character, and in clock synchronous mode, in which synchronization is achieved with clock pulses.

64-stage FIFO buffers are provided for both transmission and reception, reducing the CPU overhead and enabling fast, continuous communication to be performed.

16.4.2 Asynchronous Mode

The transfer format is selected using the serial mode register (SCSMR), as shown in table 16.2. The SCIF clock source is determined by the CKE1 and CKE0 bits in the serial control register (SCSCR).

- Data length: Choice of seven or eight bits
- Choice of parity addition and addition of one or two stop bits (the combination of these parameters determines the transfer format and character length)
- Detection of framing errors, parity errors, overrun errors, receive-FIFO-data-full state, receive-data-ready state, and breaks, during reception
- Indication of the number of data bytes stored in the transmit and receive FIFO registers
- Choice of internal or external clock as the SCIF clock source
  - When internal clock is selected: the SCIF operates on the baud rate generator clock.
  - When external clock is selected: A clock must be input according to the sampling rate. For example, when the sampling rate is 1/16, a clock with a frequency of 8 times the bit rate must be input (the on-chip baud rate generator is not used.)

Table 16.2 SCSMR Settings for Serial Transfer Format Selection

SCSMR Settings				SCIF Transfer Format			
Bit 6: CHR	**Bit 5: PE**	**Bit 3: STOP**	**Mode**	**Data Length**	**Multiprocessor Bit**	**Parity Bit**	**Stop Bit Length**
0	0	0	Asynchronous mode	8-bit data	None	No	1 bit
		1					2 bits
	1	0				Yes	1 bit
		1					2 bits
1	0	0		7-bit data		No	1 bit
		1					2 bits
	1	0				Yes	1 bit
		1					2 bits

16.4.3 Serial Operation in Asynchronous Mode

1. Data Transfer Format

Table 16.3 shows the transfer formats that can be used in asynchronous mode. Any of eight transfer formats can be selected according to the SCSMR settings.

Table 16.3 Serial Transfer Formats

SCSMR Settings			Serial Transfer Format and Frame Length											
CHR	PE	STOP	1	2	3	4	5	6	7	8	9	10	11	12
0	0	0	S	8-bit data								STOP		
		1	S	8-bit data								STOP	STOP	
	1	0	S	8-bit data								P	STOP	
		1	S	8-bit data								P	STOP	STOP
1	0	0	S	7-bit data							STOP			
		1	S	7-bit data							STOP	STOP		
	1	0	S	7-bit data							P	STOP		
		1	S	7-bit data							P	STOP	STOP	

S: Start bit
STOP: Stop bit
P: Parity bit

2. Clock

Either an internal clock generated by the on-chip baud rate generator or an external clock input at the SCK pin can be selected as the serial clock for the SCIF, according to the setting of the CKE1 and CKE0 bits in SCSCR.

When an external clock is input at the SCK pin, a clock must be input according to the sampling rate. For example, when the sampling rate is 1/16, a clock with a frequency of 8 times the bit rate must be input.

3. Data Transfer Operations

a. SCIF Initialization

Before transmitting and receiving data, it is necessary to clear the TE and RE bits in SCSCR to 0, then initialize the SCIF as described below.

When the transfer format, etc., is changed, the TE and RE bits must be cleared to 0 before making the change using the following procedure. When the TE bit is cleared to 0, the transmit shift register (SCTSR) is initialized. Note that clearing the TE and RE bits to 0 does not change the contents of SCSSR, SCFTDR, or SCFRDR. The TE bit should be cleared to 0 after all transmit data has been sent and the TEND bit in SCSSR has been set to 1. Clearing to 0 can also be performed during transmission, but the data being transmitted will go to the high-impedance state after the clearance. Before setting TE to 1 again to start transmission, the TFRST bit in SCFCR should first be set to 1 to reset SCFTDR.

When an external clock is used, the clock should not be stopped during operation, including initialization, since operation will be unreliable in this case.

Figure 16.2 shows a sample SCIF initialization flowchart.

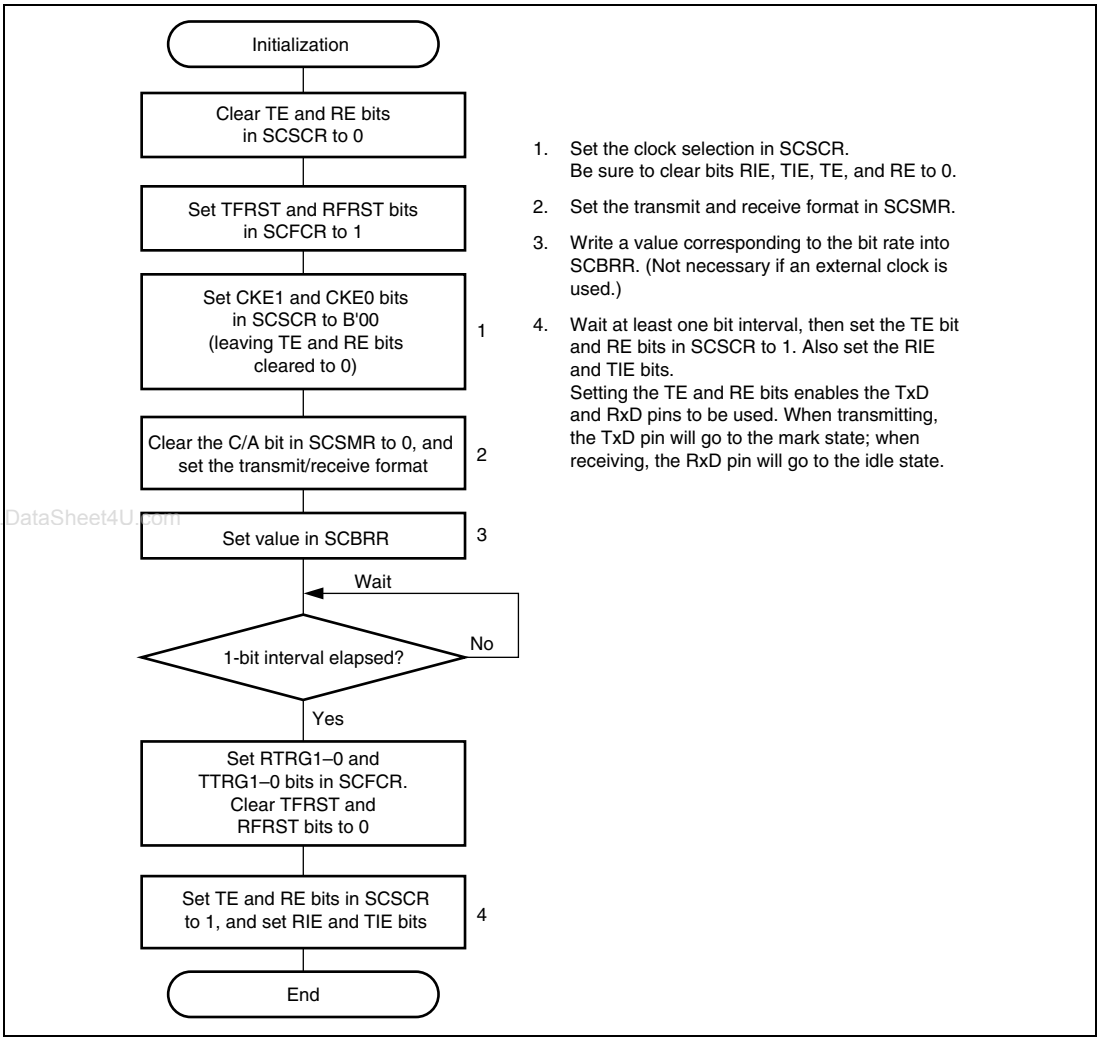


Figure 16.2 Sample SCIF Initialization Flowchart

b. Serial Data Transmission

Figure 16.3 shows a sample flowchart for serial transmission.

Use the following procedure for serial data transmission after enabling the SCIF for transmission.

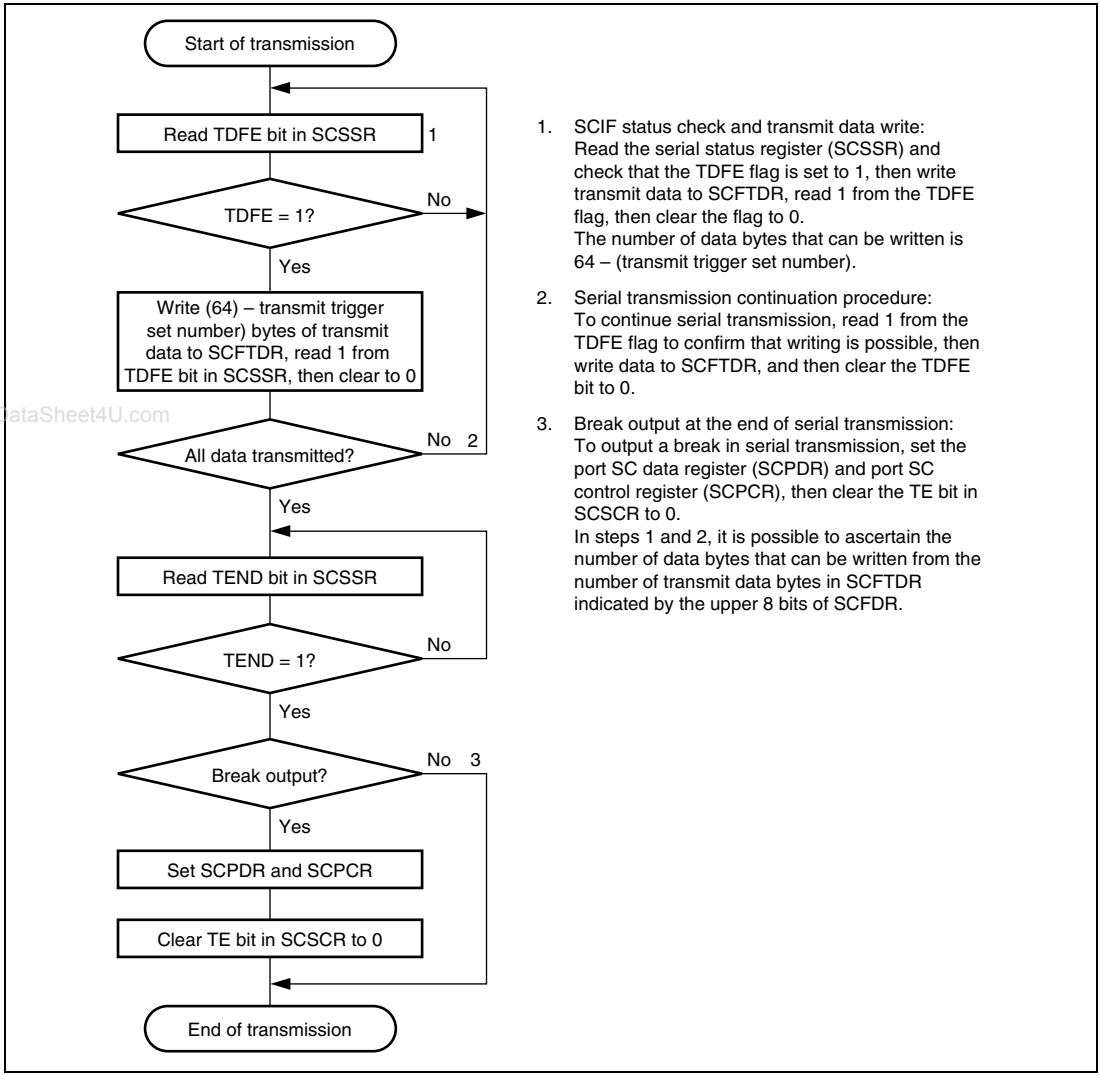


Figure 16.3 Sample Serial Transmission Flowchart

In serial transmission, the SCIF operates as described below.

1. When data is written into SCFTDR, the SCIF transfers the data from SCFTDR to SCTSR and starts transmitting. Confirm that the TDFE flag in the serial status register (SCSSR) is set to 1 before writing transmit data to SCFTDR. The number of data bytes that can be written is at least 64 – (transmit trigger set number).

2. When data is transferred from SCFTDR to SCTSR and transmission is started, consecutive transmit operations are performed until there is no transmit data left in SCFTDR. When the number of transmit data bytes in SCFTDR falls to or below the transmit trigger number set in the FIFO control register (SCFCR), the TDFE flag is set. If the TIE bit in SCSCR is set to 1 at this time, a transmit-FIFO-data-empty interrupt (TXI) request is generated.

   When the transmit data stop function is used and the number of data bytes set in the transmit data stop register (SCTDSR) is matched, transmit operation is stopped, and the TSF flag in the serial status register (SCSSR) is set. If the TSIE bit in the serial control register (SCSCR) is set to 1, a transmit-data-stop-interrupt (TDI) request is generated. The vectors of transmit-FIFO-data-empty and transmit-data-stop interrupts are the same.

   The serial transmit data is sent from the TxD pin in the following order.

   a. Start bit: One 0-bit is output.
   b. Transmit data: 8-bit or 7-bit data is output in LSB-first order.
   c. Parity bit: One parity bit (even or odd parity) is output.
   d. A format in which a parity bit is not output can also be selected.
   e. Stop bit(s): One or two 1-bits (stop bits) are output.
   f. Mark state: 1 is output continuously until the start bit that starts the next transmission is sent.

3. The SCIF checks the SCFTDR transmit data at the timing for sending the stop bit. If data is present, the data is transferred from SCFTDR to SCTSR, the stop bit is sent, and then serial transmission of the next frame is started.

   If there is no transmit data, the TEND flag in SCSSR is set to 1, the stop bit is sent, and then the line goes to the mark state in which 1 is output.

Figure 16.4 shows an example of the operation for transmission in asynchronous mode.

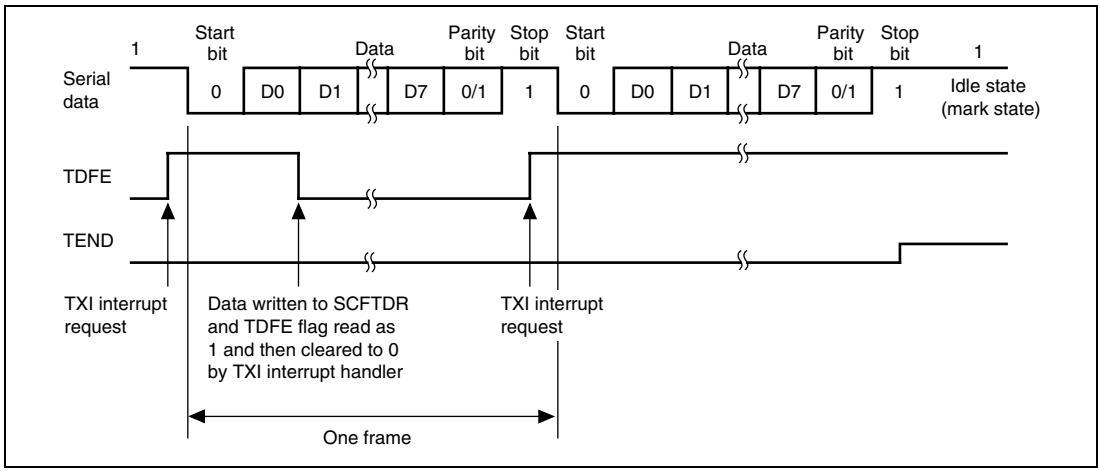


Figure 16.4 Example of Transmit Operation (Example with 8-Bit Data, Parity, One Stop Bit)

- Transmit Data Stop Function

When a value in the SCTDSR register is matched with the number of transmit data bytes, this function stops the transmit operation. Interrupts can be generated and the DMAC can be activated by setting the TSIE bit (interrupt enable bit).

Figure 16.5 shows an example of operation for the transmit data stop function.

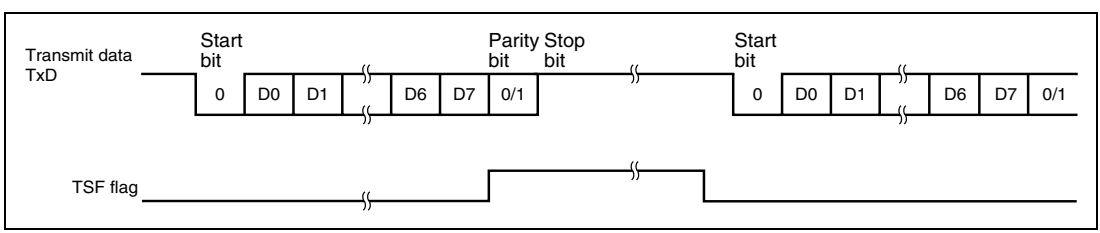


Figure 16.5 Example of Transmit Data Stop Function

Figure 16.6 shows a flowchart for the transmit data stop function.

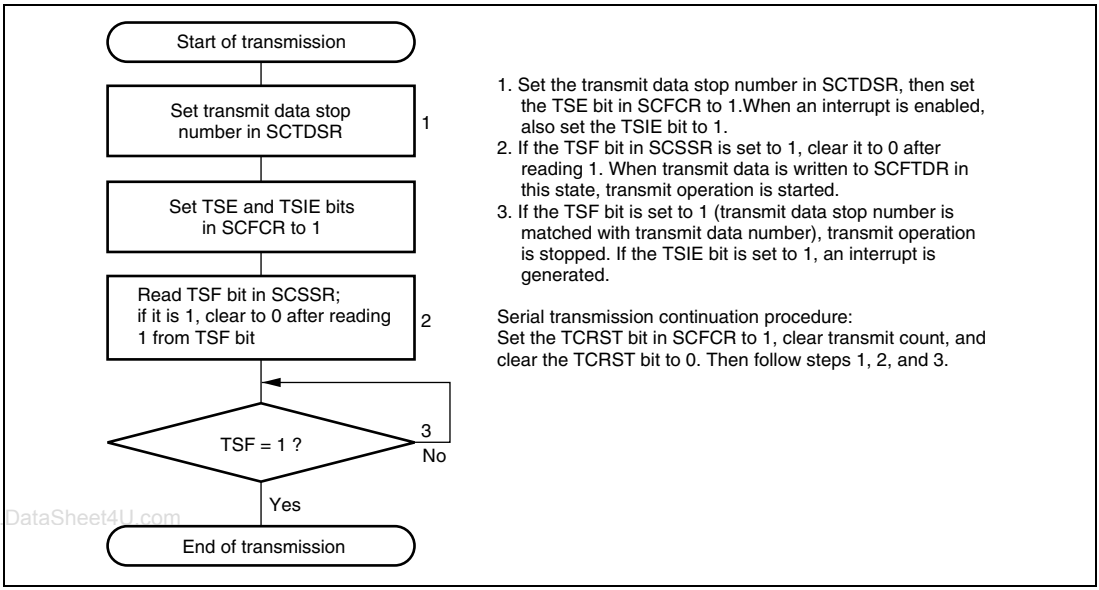
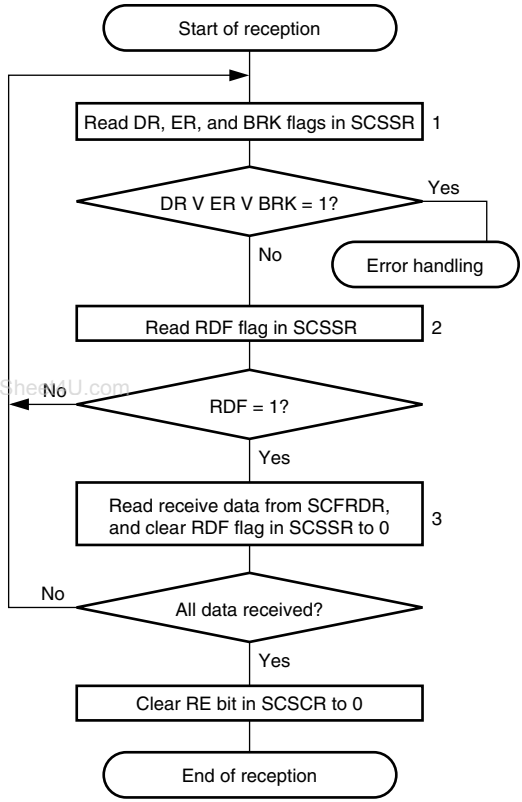


Figure 16.6 Transmit Data Stop Function Flowchart

c. Serial Data Reception

Figures 16.7 and 16.8 show sample flowcharts for serial reception.

Use the following procedure for serial data reception after enabling the SCIF for reception.



1. Receive error handling and break detection:
   Read the DR, ER, and BRK flags in SCSSR to identify any error, perform the appropriate error handling, then clear the DR, ER, and BRK flags to 0. In the case of a framing error, a break can also be detected by reading the value of the RxD pin.
2. SCIF status check and receive data read:
   Read SCSSR and check that RDF = 1, then read the receive data in SCFRDR, read 1 from the RDF flag, and then clear the RDF flag to 0. The transition of the RDF flag from 0 to 1 can also be identified by an RXI interrupt.
3. Serial reception continuation procedure:
   To continue serial reception, read at least the receive trigger set number of data bytes from SCFRDR, read 1 from the RDF flag, and then clear the RDF flag to 0. The number of receive data bytes in SCFRDR can be ascertained by reading the lower bits of SCFDR.

Figure 16.7 Sample Serial Reception Flowchart (1)

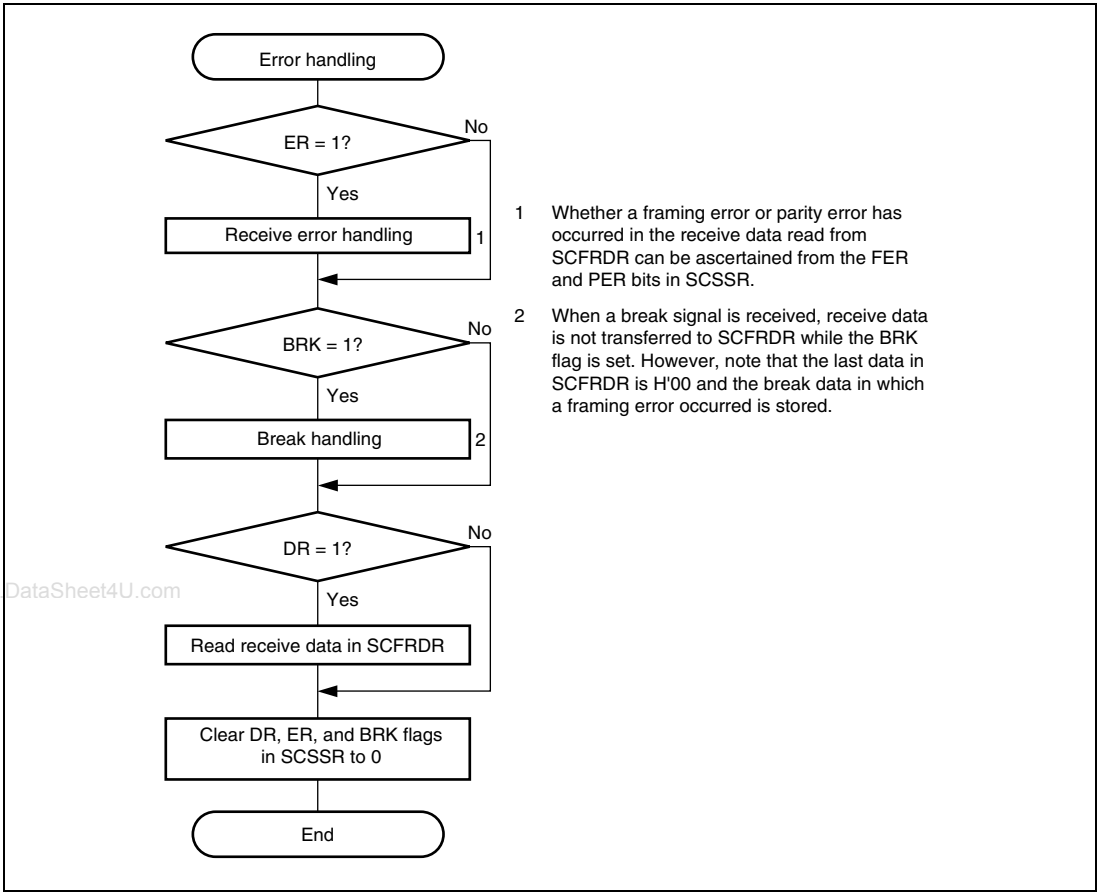


Figure 16.8 Sample Serial Reception Flowchart (2)

In serial reception, the SCIF operates as described below.

1. The SCIF monitors the communication line, and if 0 of a start bit is detected, performs internal synchronization and starts reception.

2. The received data is stored in SCRSR in LSB-to-MSB order.

3. The parity bit and stop bit are received.

   After receiving these bits, the SCIF carries out the following checks.

   a. Stop bit check: the SCIF checks whether the stop bit is 1. If there are two stop bits, only the first is checked.
   b. The SCIF checks whether receive data can be transferred from the receive shift register (SCRSR) to SCFRDR.
   c. Break check: the SCIF checks that the BRK flag is 0, indicating that the break state is not set.

   If all the above checks are passed, the receive data is stored in SCFRDR.

Note: Reception continues when a receive error (a framing error or parity error) occurs.

4. If the RIE bit in SCSCR is set to 1 when the RDF flag changes to 1, a receive-FIFO-data-full interrupt (RXI) request is generated.
   If the ERIE bit in SCSCR is set to 1 when the ER flag changes to 1, a receive-error interrupt (ERI) request is generated.
   If the BRIE bit in SCSCR is set to 1 when the BRK flag changes to 1, a break reception interrupt (BRI) request is generated.
   If the DRIE bit in SCSCR is set to 1 when the DR flag changes to 1, a receive-data-ready interrupt (DRI) request is generated.
   The vectors of receive-FIFO-data-full and receive-data-ready interrupts are the same. The vectors of receive-error and break reception interrupts are the same.

Figure 16.9 shows an example of the operation for reception in asynchronous mode.

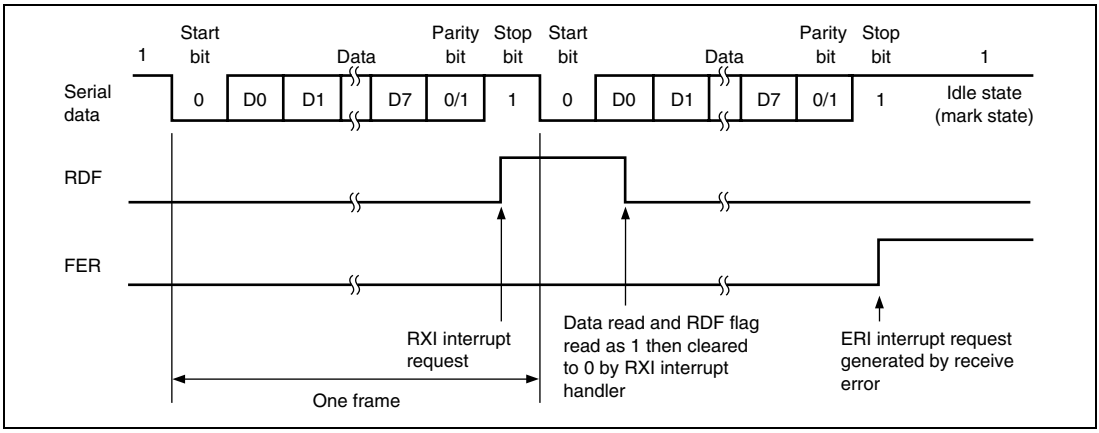


Figure 16.9 Example of SCIF Receive Operation (Example with 8-Bit Data, Parity, One Stop Bit)

- Modem Function

When using a modem function, transmission can be stopped and started again according to the $\overline{\text{CTS}}$ input value. When the $\overline{\text{CTS}}$ is set to 1 during transmission, the data enters a mark state after transmitting one frame. When $\overline{\text{CTS}}$ is set to 0, the next transmit data is output starting with a start bit.

Figure 16.10 shows an example of operation for the $\overline{\text{CTS}}$ control.

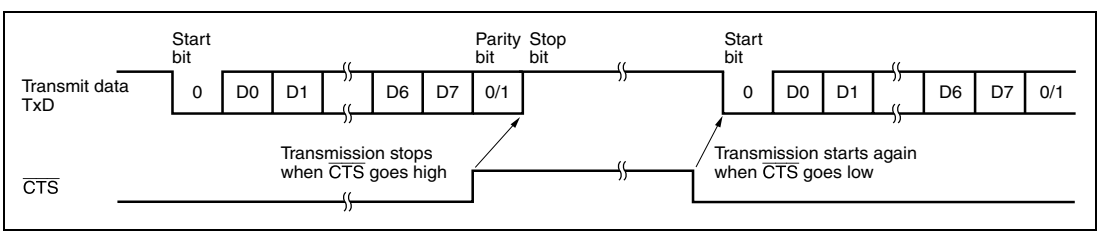


Figure 16.10 $\overline{\text{CTS}}$ Control Operation

When using a modem function and the receive FIFO (SCFRDR) is at least the number of the $\overline{\text{RTS}}$ output trigger, the $\overline{\text{RTS}}$ signal goes high.

Figure 16.11 shows an example of operation for the $\overline{\text{RTS}}$ control.

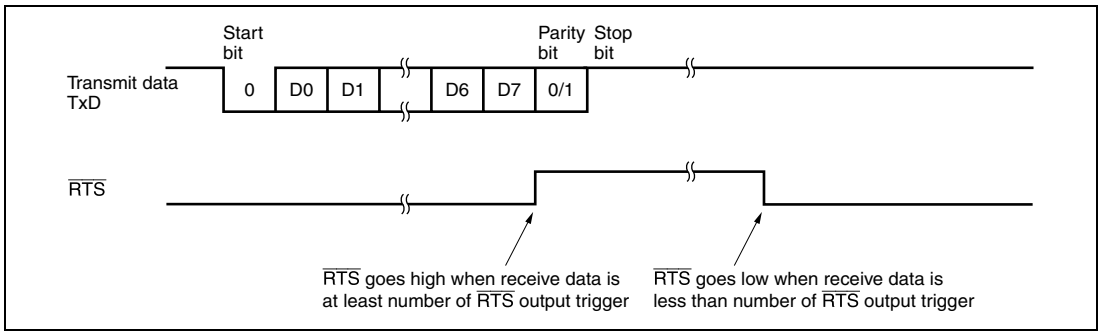


Figure 16.11 $\overline{\text{RTS}}$ Control Operation

16.4.4 Clock Synchronous Mode

64-stage FIFO buffers are provided for both transmission and reception, reducing the CPU overhead and enabling fast, continuous communication to be performed.

The operating clock source is selected using the serial mode register (SCSMR). The SCIF clock source is determined by the CKE1 and CKE0 bits in the serial control register (SCSCR).

- Transmit/receive format: Fixed 8-bit data
- Indication of the number of data bytes stored in the transmit and receive FIFO registers
- Internal clock or external clock used as the SCIF clock source

  When the internal clock is selected:
  The SCIF operates on the baud rate generator clock and outputs a serial clock from SCK pin.

  When the external clock is selected:
  The SCIF operates on the external clock input through the SCK pin.

16.4.5 Serial Operation in Clock Synchronous Mode

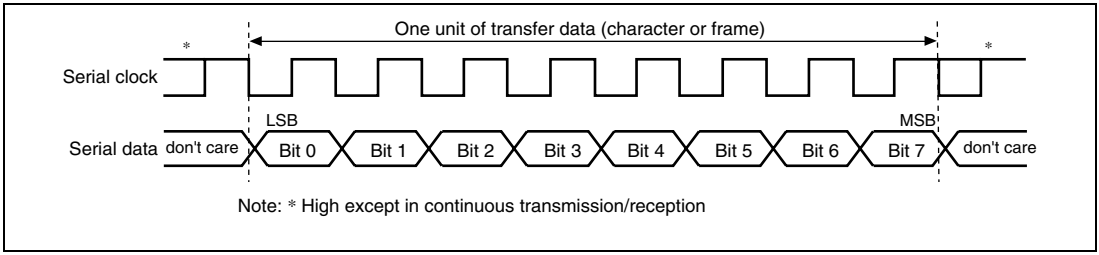


Figure 16.12 Data Format in Clock Synchronous Communication

In clock synchronous serial communication, data on the communication line is output from a falling edge of the serial clock to the next falling edge. Data is guaranteed valid at the rising edge of the serial clock.

In serial communication, each character is output starting with the LSB and ending with the MSB. After the MSB is output, the communication line remains in the state of the MSB.

In clock synchronous mode, the SCIF receives data in synchronization with the rising edge of the serial clock.

1. Data Transfer Format

A fixed 8-bit data format is used. No parity or multiprocessor bits are added.

2. Clock:

An internal clock generated by the on-chip baud rate generator or an external clock input through the SCK pin can be selected as the serial clock for the SCIF, according to the setting of the CKE1 and CKE0 bits in SCSCR.

Eight serial clock pulses are output in the transfer of one character, and when no transmission/reception is performed, the clock is fixed high. However, when the operation mode is reception only, the synchronous clock output continues while the RE bit is set to 1. To fix the clock high every time one character is transferred, write to the transmit FIFO data register (SCFTDR) the same number of dummy data bytes as the data bytes to be received and set the TE and RE bits to 1 at the same time to transmit the dummy data. When the specified number of data bytes are transmitted, the clock is fixed high.

3. Data Transfer Operations

a. SCIF Initialization:

Before transmitting and receiving data, it is necessary to clear the TE and RE bits in SCSCR to 0, then initialize the SCIF as described below.

When the clock source, etc., is changed, the TE and RE bits must be cleared to 0 before making the change using the following procedure. When the TE bit is cleared to 0, the transmit shift register (SCTSR) is initialized. Note that clearing the TE and RE bits to 0 does not change the contents of SCSSR, SCFTDR, or SCFRDR. The TE bit should be cleared to 0 after all transmit data has been sent and the TEND bit in SCSSR has been set to 1. The TE bit should not be cleared to 0 during transmission; if attempted, the TxD pin will go to the high-impedance state. Before setting TE to 1 again to start transmission, the TFRST bit in SCFCR should first be set to 1 to reset SCFTDR.

Figure 16.13 shows sample SCIF initialization flowcharts.

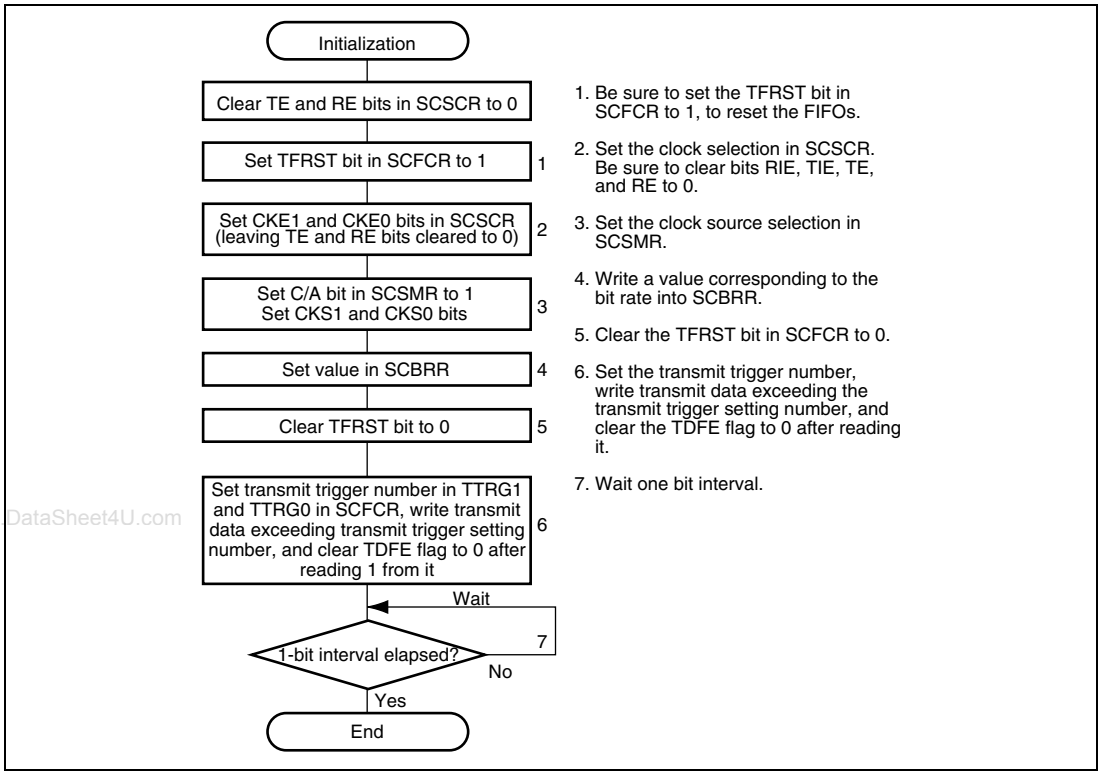


Figure 16.13 Sample SCIF Initialization Flowchart (1) (Transmission)

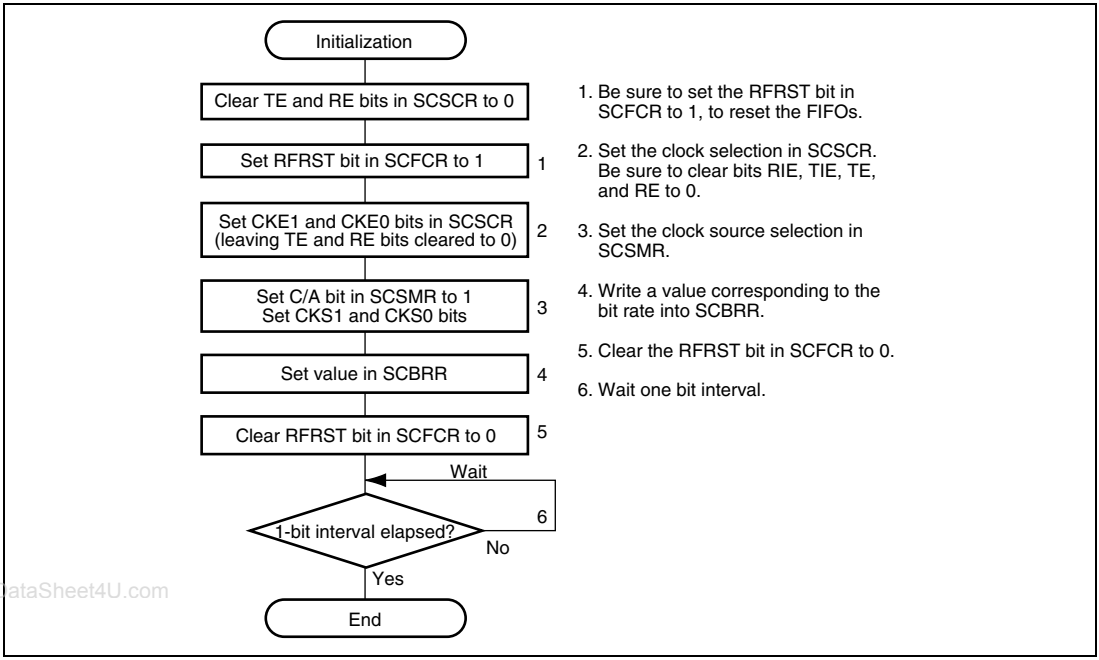


Figure 16.13 Sample SCIF Initialization Flowchart (2) (Reception)

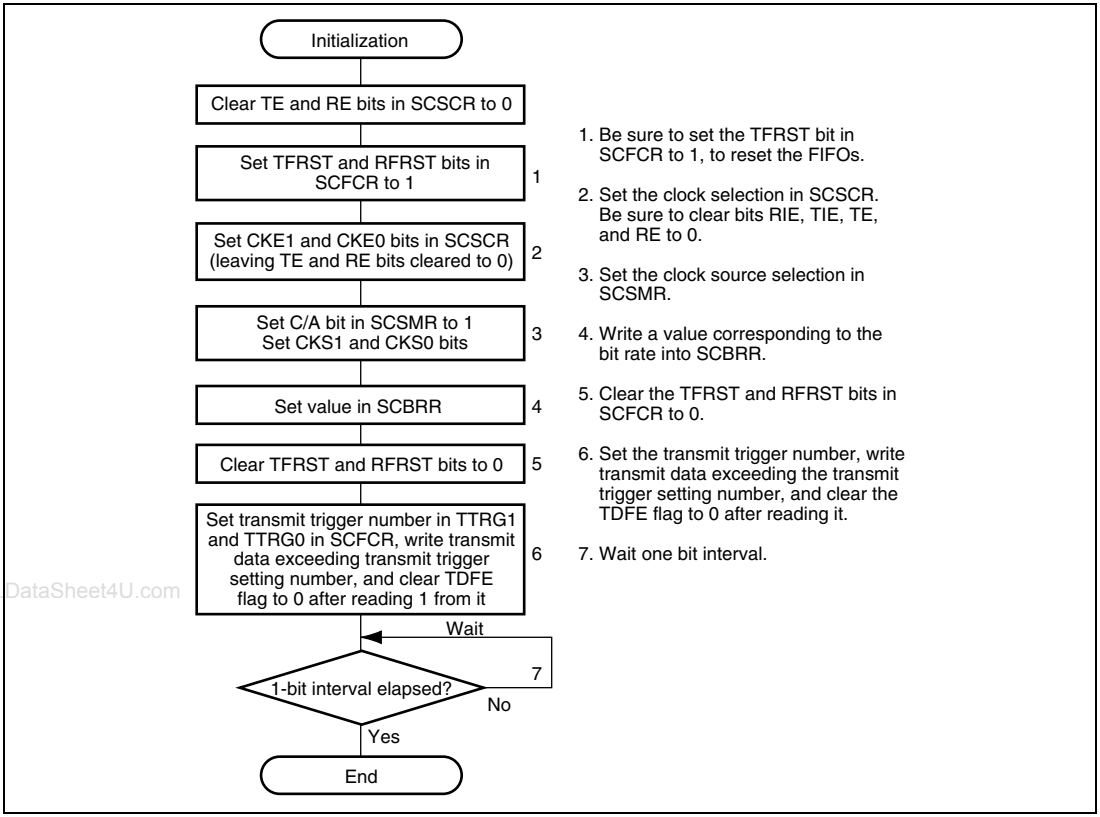


Figure 16.13 Sample SCIF Initialization Flowchart (3)
(Simultaneous Transmission and Reception)

b. Serial Data Transmission:

Figure 16.14 shows sample flowcharts for serial transmission.

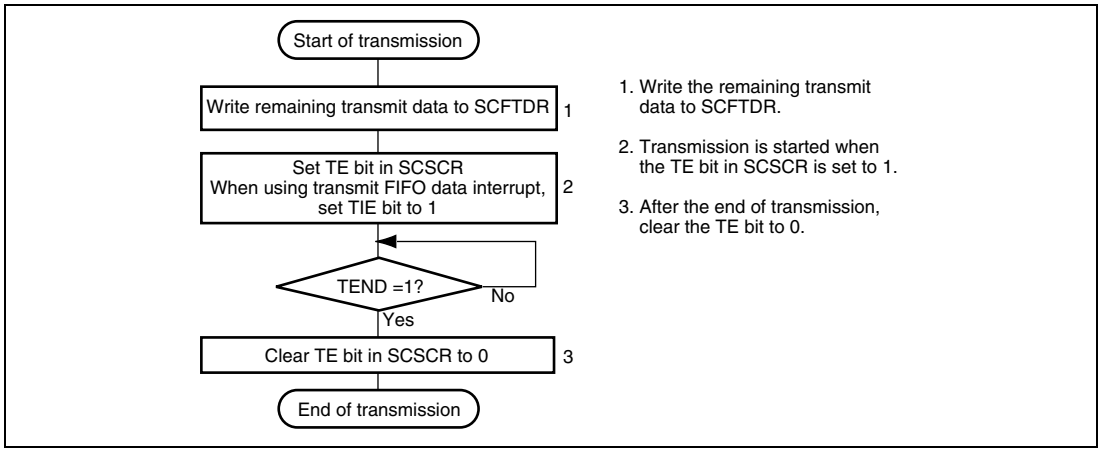


Figure 16.14 Sample Serial Transmission Flowchart (1)
(First Transmission after Initialization)

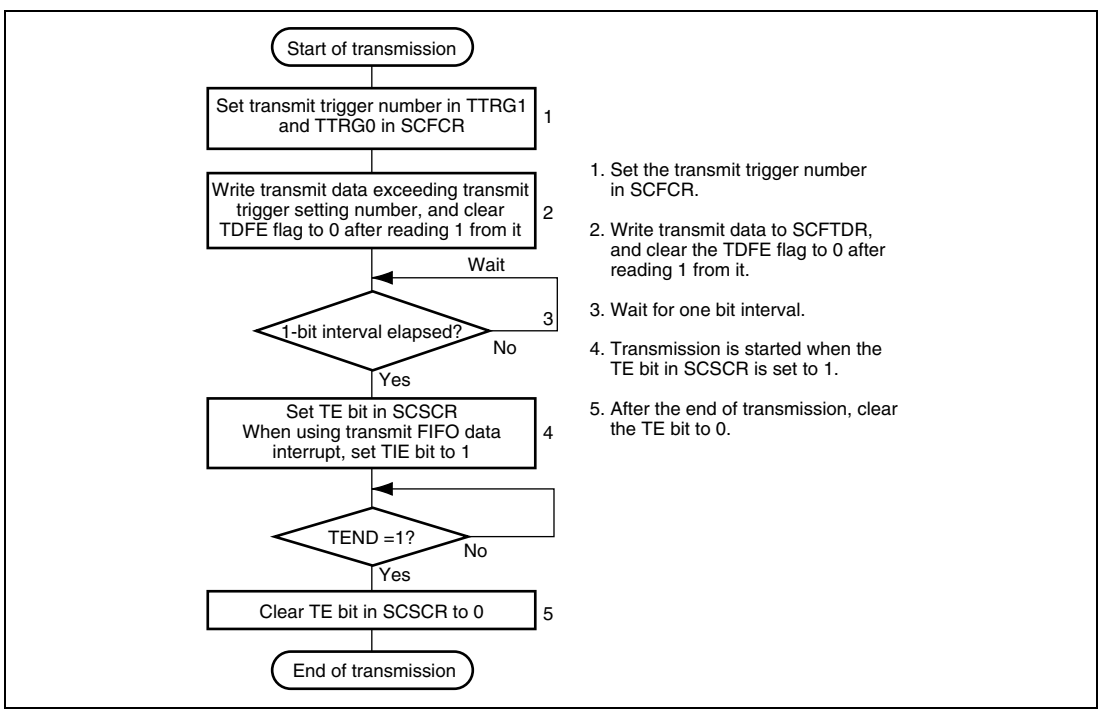


Figure 16.14 Sample Serial Transmission Flowchart (2)
(Second and Subsequent Transmission)

c. Serial Data Reception

Figure 16.15 shows sample flowcharts for serial reception.

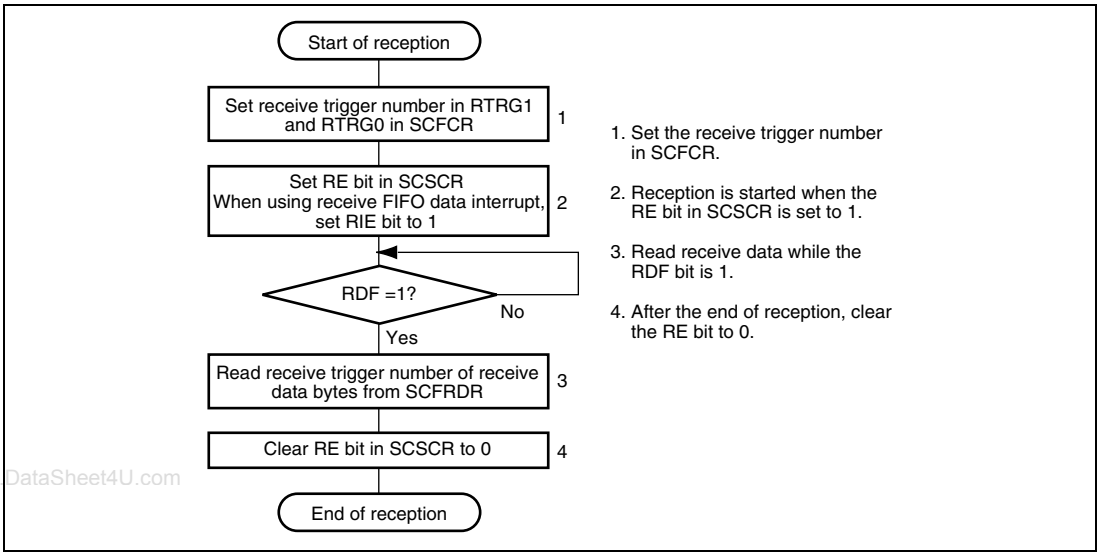


Figure 16.15 Sample Serial Reception Flowchart (1)
(First Reception after Initialization)

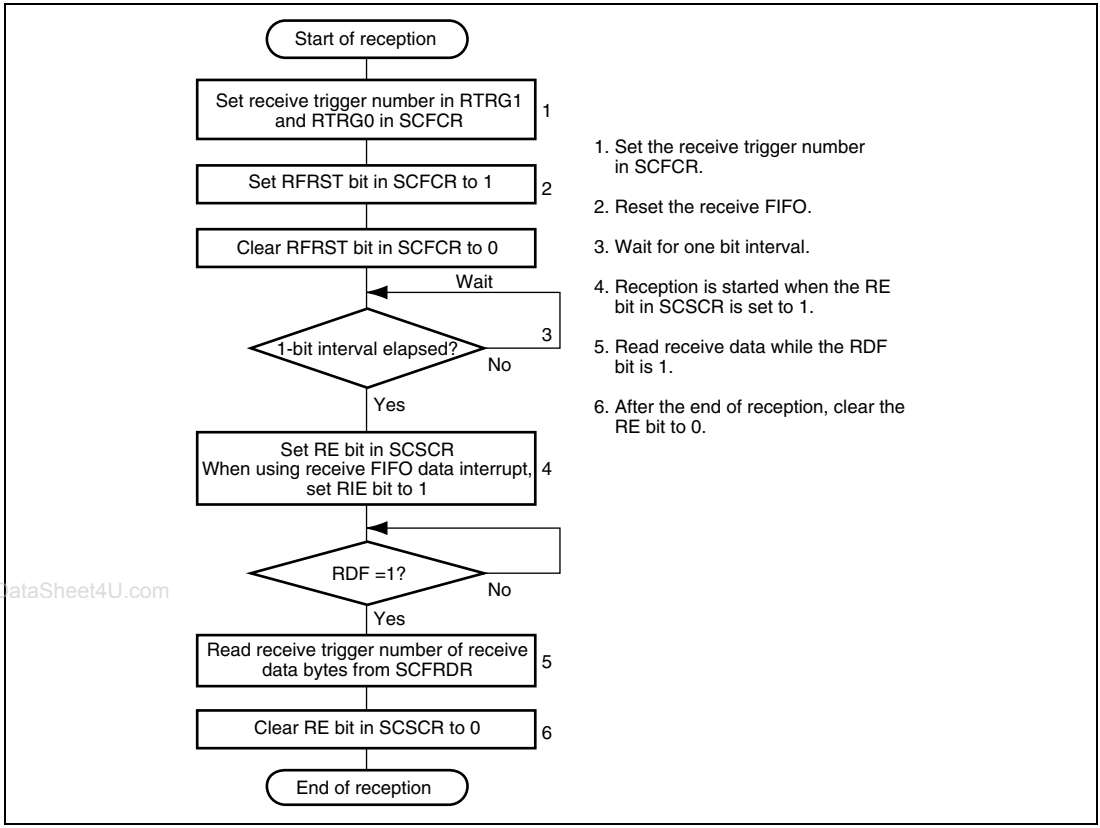


Figure 16.15 Sample Serial Reception Flowchart (2)
(Second and Subsequent Reception)

d. Simultaneous Serial Data Transmission and Reception

Figure 16.16 shows sample flowcharts for simultaneous serial transmission and reception.

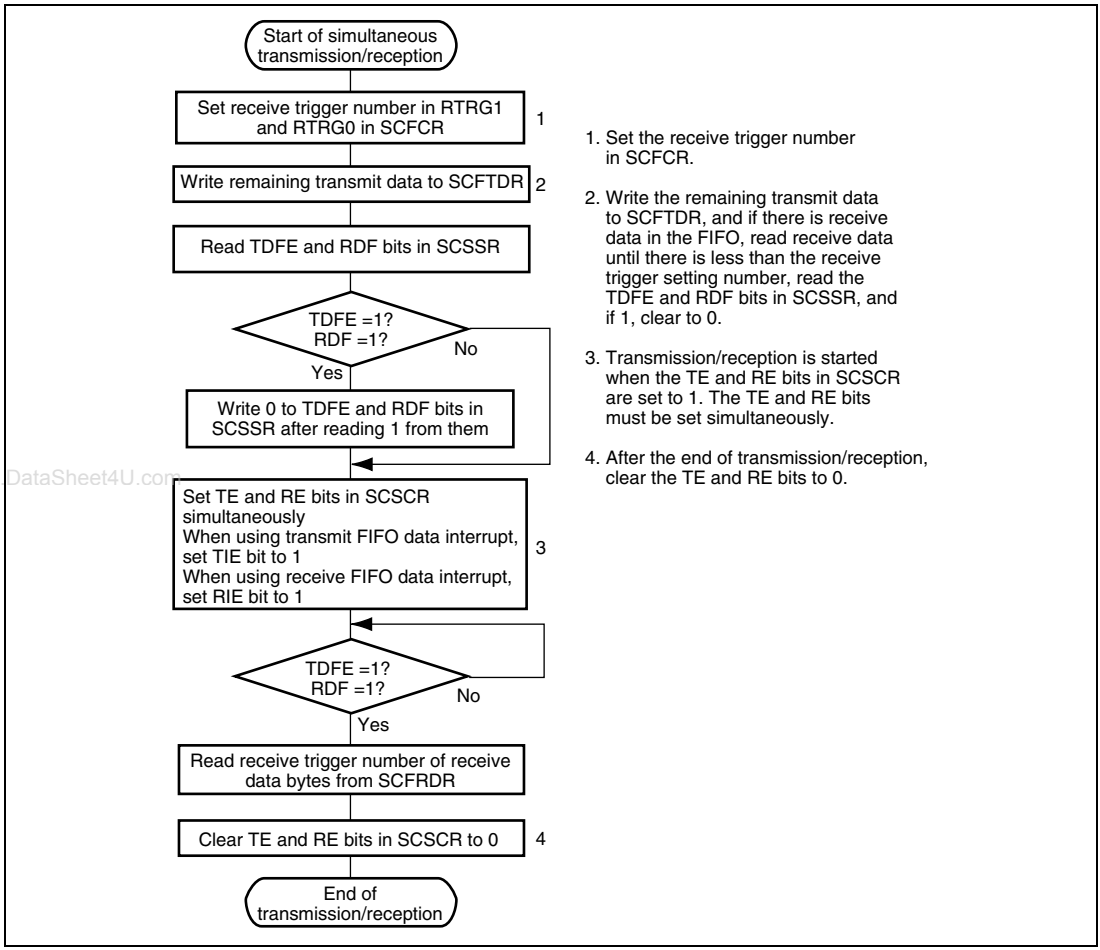
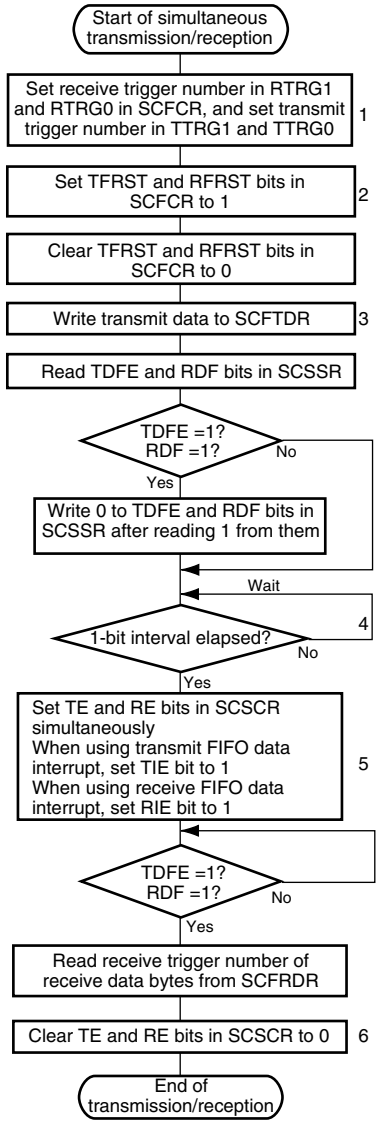


Figure 16.16 Sample Simultaneous Serial Transmission and Reception Flowchart (1) (First Transfer after Initialization)



1. Set the receive trigger number and transmit trigger number in SCFCR.
2. Reset the receive FIFO and transmit FIFO.
3. Write transmit data to SCFTDR, and if there is receive data in the FIFO, read receive data until there is less than the receive trigger setting number, read the TDFE and RDF bits in SCSSR, and if 1, clear to 0.
4. Wait for one bit interval.
5. Transmission/reception is started when the TE and RE bits in SCSCR are set to 1. The TE and RE bits must be set simultaneously.
6. After the end of transmission/reception, clear the TE and RE bits to 0.

Figure 16.16 Sample Simultaneous Serial Transmission and Reception Flowchart (2) (Second and Subsequent Transfer)

16.5 SCIF Interrupt Sources and DMAC

The SCIF supports six interrupts in asynchronous mode—transmit-FIFO-data-empty (TXI), transmit-data-stop (TDI), receive-error (ERI), receive-FIFO-data-full (RXI), break-receive (BRI), and receive-data-ready (DRI). The vectors of transmit-data-stop and transmit-FIFO-data-empty interrupts are the same. The vectors of receive-error and break-receive interrupts are the same. The vectors of receive-FIFO-data-full and receive-data-ready interrupts are the same.

In clock synchronous mode, the SCIF supports two interrupts—transmit-FIFO-data-empty (TXI) and receive-FIFO-data-full (RXI).

Table 16.4 shows the interrupt sources. The interrupt sources can be enabled or disabled by means of the TIE, RIE, ERIE, BRIE, DRIE, and TSIE bits in SCSCR.

When the TDFE flag in SCSSR is set to 1, a TXI interrupt request is generated. When the TSF flag in SCSSR is set to 1, a TDI interrupt request is generated. The DMAC can be activated and data transfer performed on generation of TXI and TDI interrupt requests. The DMAC requests of TXI and TDI are assigned to the same vector.

When the RDF flag in SCSSR is set to 1, an RXI interrupt request is generated. The DMAC can be activated and data transfer performed on generation of an RXI interrupt request.

When using the DMAC for transmission/reception, set and enable the DMAC before making SCIF settings. See section 8, Direct Memory Access Controller (DMAC), for details of the DMAC setting procedure.

When the ER flag in SCSSR is set to 1, an ERI interrupt request is generated. When the BRK flag in SCSSR is set to 1, a BRI interrupt request is generated. When the DR flag in SCSSR is set to 1, a DRI interrupt request is generated. When the TSF flag in SCSSR is set to 1, a TDI interrupt request is generated.

The vectors of TXI and TDI, ERI and BRI, and RXI and DRI are the same.

The DMAC activation and interrupts cannot be generated simultaneously by the same source. The following procedure should be used for the DMAC activation.

1. Set the interrupt enable bits (TIE and RIE) corresponding to the generated source to 1.
2. Mask the corresponding interrupt requests by using the interrupt mask register of the interrupt controller.

Table 16.4 SCIF Interrupt Sources

Description	DMAC Activation
Interrupt initiated by receive error flag (ER) or break flag (BRK)	Not possible
Interrupt initiated by receive FIFO data full flag (RDF) or receive data ready (DR)	Possible*1
Interrupt initiated by transmit FIFO data empty flag (TDFE) or transmit data stop flag (TSF)	Possible*2

Notes: *1 The DMAC can be activated only by a receive-FIFO-data-full interrupt request.

*2 The DMAC can be activated by a transmit-FIFO-data-empty (TDFE) or transmit-data-stop (TSF) interrupt request. When the DMAC is activated by the TSF interrupt, it is cleared by either of two cases listed below.
(1) The TSF flag is read by the CPU.
(2) The transmit FIFO is full.

See section 5, Exception Handling, for priorities and the relationship with non-SCIF interrupts.

16.6 Notes on Usage

Note the following when using the SCIF.

a. SCFTDR Writing and the TDFE Flag:

The TDFE flag in the serial status register (SCSSR) is set when the number of transmit data bytes written in the transmit FIFO data register (SCFTDR) has fallen to or below the transmit trigger number set by bits TTRG1 and TTRG0 in the FIFO control register (SCFCR). After TDFE is set, transmit data up to the number of empty bytes in SCFTDR can be written, allowing efficient continuous transmission.

However, if the number of data bytes written in SCFTDR is equal to or less than the transmit trigger number, the TDFE flag will be set to 1 again after being read as 1 and cleared to 0. TDFE clearing should therefore be carried out when SCFTDR contains more than the transmit trigger number of transmit data bytes.

The number of transmit data bytes in SCFTDR can be found from the 14 to 8 bits of the FIFO data count register (SCFDR).

b. SCFRDR Reading and the RDF Flag:

The RDF flag in the serial status register (SCSSR) is set when the number of receive data bytes in the receive FIFO data register (SCFRDR) has become equal to or greater than the receive trigger number set by bits RTRG1 and RTRG0 in the FIFO control register (SCFCR). After RDF is set, receive data equivalent to the trigger number can be read from SCFRDR, allowing efficient continuous reception.

However, if the number of data bytes in SCFRDR is still equal to or greater than the trigger number after a read, the RDF flag will be set to 1 again if it is cleared to 0. RDF should therefore be cleared to 0 after being read as 1 after all receive data has been read.

The number of receive data bytes in SCFRDR can be found from the 6 to 0 bits of the FIFO data count register (SCFDR).

c. Break Detection and Processing:

Break signals can be detected by reading the RxD pin directly when a framing error (FER) is detected. In the break state the input from the RxD pin consists of all 0s, so the FER flag is set and the parity error flag (PER) may also be set.

Although the SCIF stops transferring receive data to SCFRDR after receiving a break, the receive operation continues.

d. Receive Data Sampling Timing and Receive Margin:

As an example, when the sampling rate is 1/16, the SCIF operates on a base clock with a frequency of 8 times the transfer rate.

In reception, the SCIF synchronizes internally with the fall of the start bit, which it samples on the base clock. Receive data is latched at the rising edge of the fourth base clock pulse.

The receive margin can therefore be expressed as shown in equation (1).

$$M = \left| \left(0.5 - \frac{1}{2N}\right) - (L - 0.5)F - \frac{|D - 0.5|}{N}(1 + F) \right| \times 100\% \quad \text{..... (1)}$$

M: Receive margin (%)
N: Ratio of clock frequency to bit rate (N = 16)
D: Clock duty cycle (D = 0 to 1.0)
L: Frame length (L = 9 to 12)
F: Absolute deviation of clock frequency

From equation (1), if F = 0 and D = 0.5, the receive margin is 46.875%, as given by equation (2).

When D = 0.5 and F = 0:

$$M = (0.5 - 1/(2 \times 16)) \times 100\% = 46.875\% \quad \text{..... (2)}$$

This is a theoretical value. A reasonable margin to allow in system designs is 20% to 30%.

Section 17 Infrared Data Association Module (IrDA)

This LSI has an on-chip Infrared Data Association (IrDA) interface that is based on the IrDA 1.0 system and can perform infrared communication.

The IrDA is an optional module used for modulation and demodulation of signals for the SCIF module, and it must always be used together with the SCIF module.

17.1 Features

- Conforms to the IrDA 1.0 system
- Asynchronous serial communication
  - Data length: 8 bits
  - Stop bit length: 1 bit
  - Parity bit: None
- On-chip 64-stage FIFO buffers for both transmit and receive operations
- On-chip baud rate generator with selectable bit rates
- Guard functions to protect the receiver during transmission
- Clock supply halted to reduce power consumption when not using the IrDA interface

Figure 17.1 shows a block diagram of the IrDA.

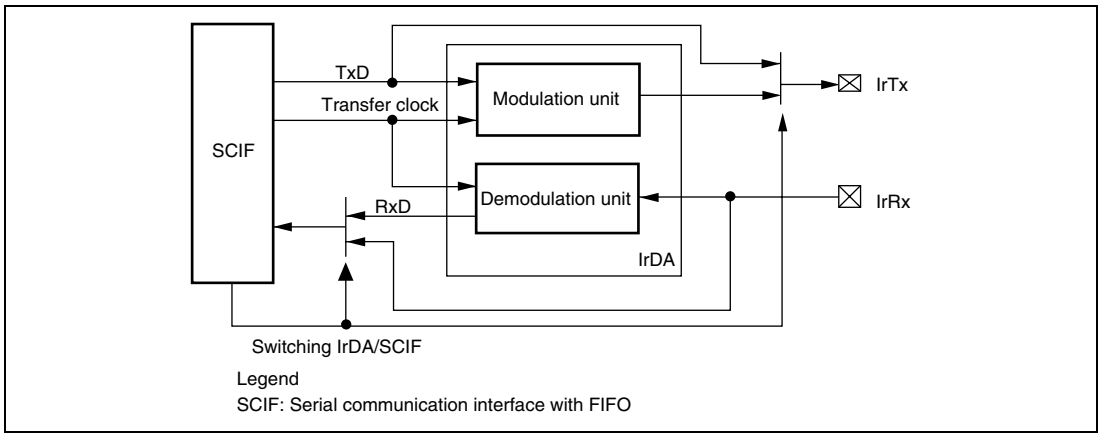


Figure 17.1 Block Diagram of IrDA

17.2 Input/Output Pins

Table 17.1 shows the IrDA pin configuration.

Table 17.1 Pin Configuration

Pin Name	Signal Name	I/O	Function
Receive data pin	IrRx	Input	Receive data input
Transmit data pin	IrTx	Output	Transmit data output

Note: Clock input from the serial clock pin cannot be set in IrDA mode.

17.3 Register Description

The IrDA has the following internal registers. For details on register addresses and register states in each processing state, refer to section 24, List of Registers.

- IrDA mode register (SCSMR_Ir)

17.3.1 IrDA Mode Register (SCSMR_Ir)

SCSMR_Ir is a 16-bit register that selects IrDA or SCIF mode and selects the IrDA output pulse width.

This module operates as IrDA when the IRMOD bit is set to 1. When the IRMOD bit is cleared to 0, this module can also operate as an SCIF.

Bit	Bit Name	Initial Value	R/W	Description
15 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7	IRMOD	0	R/W	IrDA Mode Selects whether this module operates as an IrDA serial communication interface or as an SCIF. 0: Operates as an SCIF 1: Operates as an IrDA
6 to 3	ICK3 to ICK0	All 0	R/W	Output Pulse Division Ratio Specifies the ratio for dividing the peripheral clock (Pϕ) to generate the IRCLK clock pulse to be used for IrDA. IRCLK is obtained as follows: IRCLK = 1/(2N + 2) × Pϕ N = Value set by ICK3 to ICK0
2	PSEL	0	R/W	Output Pulse Width Select PSEL selects an IrDA output pulse width that is 3/16 of the bit length for 115 kbps or 3/16 of the bit length for the selected baud rate. 0: Pulse width is 3/16 of the bit length 1: Pulse width is 3/16 of 115 kbps bit length for the baud rate selected by ICK3 to ICK0
1, 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Example:

Pϕ clock: 14.7456 MHz

IRCLK: 921.6 kHz (fixed)

N: Setting of ICK3 to ICK0 ($0 \leq N \leq 15$)

$$N \geq \frac{P\phi}{2 \times IRCLK} - 1 \geq 7$$

Accordingly, N is 7.

17.4 Operation

The IrDA module can perform infrared communication conforming to IrDA 1.0 by connecting infrared transmit/receive units. The serial communication interface unit includes a buffer in the transmit unit and the receive unit, allowing CPU overhead to be reduced and continuous high-speed communication to be performed.

17.4.1 Overview

The IrDA module modifies IrTx/IrRx transmit/receive data waveforms to satisfy the IrDA 1.0 specification for infrared communication.

In the IrDA 1.0 specification, communication is first performed at a speed of 9600 bps, and the communication speed is changed. However, the communication rate cannot be automatically changed in this module, so the communication speed should be confirmed, and the appropriate speed set for this module by software.

17.4.2 Transmitting

The waveforms of a serial output signal (UART frame) from the SCIF are modified and the signal is converted into the IR frame serial output signal by the IrDA module, as shown in figure 17.2.

When serial data is 0, a pulse of 3/16 the IR frame bit width is generated and output. When serial data is 1, no pulse is output.

17.4.3 Receiving

Received 3/16 IR frame bit-width pulses are demodulated and converted to a UART frame, as shown in figure 17.2.

Demodulation to 0 is performed for pulse output, and demodulation to 1 is performed for no pulse output.

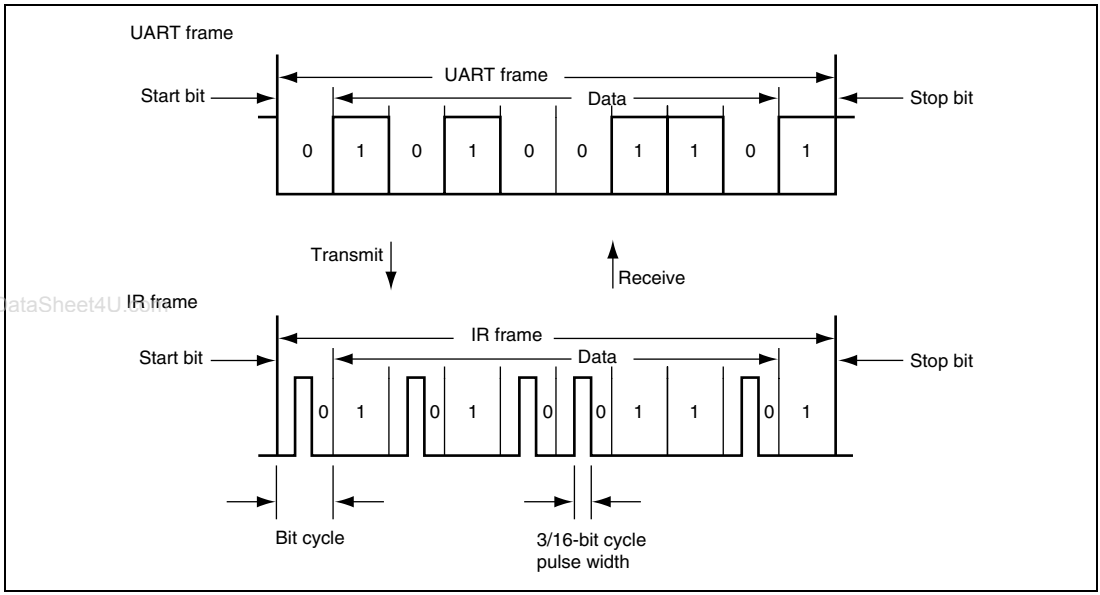


Figure 17.2 Transmit/Receive Operation

17.4.4 Data Format Specification

The data format of UART frames used for IrDA communication must be specified by the SCIF0 registers. The UART frame has eight data bits, no parity bit, and one stop bit.

IrDA communication is performed in asynchronous mode, and this mode must also be specified by the SCIF0 registers. The sampling rate must be set to 1/16.

The internal clock must be selected for the SCIF0 operation clock and the SCK0 pin must be specified for the synchronizing clock output pin.

The IrDA communication rate is the same as the SCIF0 bit rate, which is specified by the SCIF0 registers.

For details on SCIF0 registers, refer to section 16, Serial Communication Interface with FIFO (SCIF).

Section 18 USB Function Module

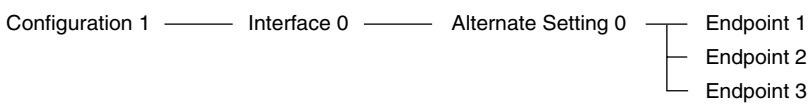
This LSI incorporates a USB function module (USB).

18.1 Features

- The UDC (USB device controller) conforming to USB1.1 and transceiver process USB protocol automatically.

  Automatic processing of USB standard commands for endpoint 0 (some commands and class/vendor commands require decoding and processing by firmware)
- Transfer speed: Full-speed
- Endpoint configuration:

Endpoint Name	Abbreviation	Transfer Type	Maximum Packet Size	FIFO Buffer Capacity (Byte)	DMA Transfer
Endpoint 0	EP0s	Setup	8	8	—
	EP0i	Control-in	8	8	—
	EP0o	Control-out	8	8	—
Endpoint 1	EP1	Bulk-out	64	128	Possible
Endpoint 2	EP2	Bulk-in	64	128	Possible
Endpoint 3	EP3	Interrupt	8	8	—



- Interrupt requests: Generates various interrupt signals necessary for USB transmission/reception
- Clock: External input (48 MHz) (Refer to section 9.4.1, Frequency Control Register (FRQCR), and section 9.4.2, USB Clock Frequency Control Register (UCLKCR))
- Power-down mode

  Power consumption can be reduced by stopping UDC internal clock when USB cable is disconnected

  Automatic transition to/recovery from suspend state
- Can be connected to a Philips PDIUSBP11 Series transceiver or compatible product in internal transceiver bypass mode (the XVEROFF bit in XVERCR is set to 1)

  When using a compatible product, carry out evaluation and investigation with the manufacturer supplying the transceiver beforehand.
- Power mode: Self-powered

Figure 18.1 shows the block diagram of the USB.

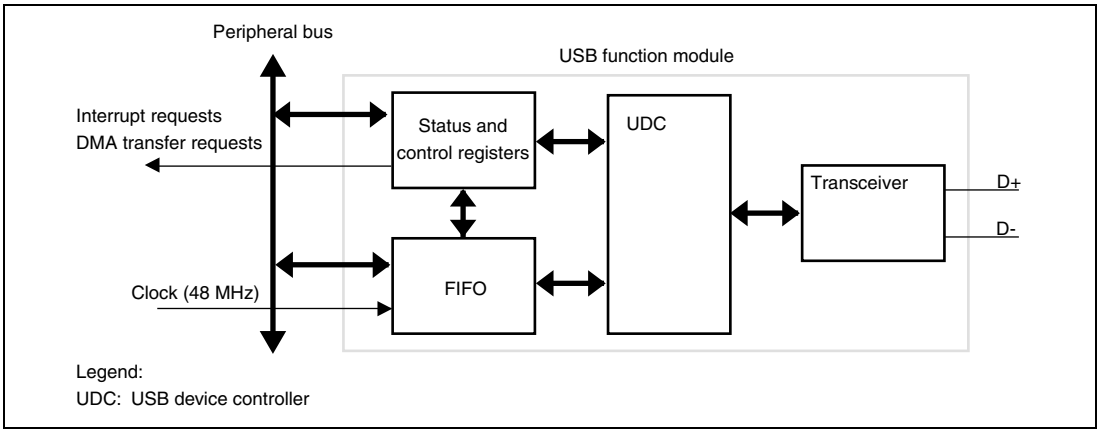


Figure 18.1 Block Diagram of USB

18.2 Input/Output Pins

Table 18.1 shows the USB pin configuration.

Table 18.1 Pin Configuration

Pin Name	I/O	Function	XVEROFF Condition
XVDATA	Input	Input pin for receive data from differential receiver	1
DPLS	Input	Input pin to driver for D+ signal from receiver	1
DMNS	Input	Input pin to driver for D– signal from receiver	1
TXDPLS	Output	D+ transmit output pin to driver	1
TXDMNS	Output	D- transmit output pin to driver	1
TXENL	Output	Driver output enable pin	1
VBUS	Input	USB cable connection monitor pin	1 or 0
SUSPND	Output	Transceiver suspend state output pin	1
EXTAL_USB	Input	USB clock input pin (external clock input/crystal resonator connect)	
XTAL_USB	Output	USB clock pin (crystal resonator connect)	
D+	I/O	USB internal transceiver D+	
D-	I/O	USB internal transceiver D–	
Vcc-USB	Input	Power supply for USB	
Vss-USB	Input	Ground for USB	

Note: The USB can be connected to a Philips PDIUSBP11 Series transceiver or compatible product in internal transceiver bypass mode (the XVEROFF bit in XVERCR is set to 1). When using a compatible product, carry out evaluation and investigation with the manufacturer supplying the transceiver beforehand.

18.3 Register Descriptions

The USB has following registers. For the information on the addresses of these registers and the state of the register in each processing condition, see section 24, List of Registers.

- Interrupt flag register 0 (IFR0)
- Interrupt flag register 1 (IFR1)
- Interrupt select register 0 (ISR0)
- Interrupt select register 1 (ISR1)
- Interrupt enable register 0 (IER0)
- Interrupt enable register 1 (IER1)
- EP0i data register (EPDR0i)
- EP0o data register (EPDR0o)
- EP0s data register (EPDR0s)
- EP1 data register (EPDR1)
- EP2 data register (EPDR2)
- EP3 data register (EPDR3)
- EP0o receive data size register (EPSZ0o)
- EP1 receive data size register (EPSZ1)
- Trigger register (TRG)
- Data status register (DASTS)
- FIFO clear register (FCLR)
- DMA transfer setting register (DMAR)
- Endpoint stall register (EPSTL)
- Transceiver control register (XVERCR)

18.3.1 Interrupt Flag Register 0 (IFR0)

IFR0, together with interrupt flag register 1 (IFR1), indicates interrupt status information required by the application. When an interrupt source is generated, the corresponding bit is set to 1 and an interrupt request is sent to the CPU according to the combination with interrupt enable register 0 (IER0). Clearing is performed by writing 0 to the bit to be cleared, and 1 to the other bits. However, EP1FULL and EP2EMPTY are status bits, and cannot be cleared.

Bit	Bit Name	Initial Value	R/W	Description
7	BRST	0	R/W	Bus Reset This bit is set to 1 when a bus reset signal is detected on the USB bus.
6	EP1FULL	0	R	EP1 FIFO Full This bit is set when endpoint 1 receives one packet of data successfully from the host, and holds a value of 1 as long as there is valid data in the FIFO buffer. This is a status bit, and cannot be cleared.
5	EP2TR	0	R/W	EP2 Transfer Request This bit is set if there is no valid transmit data in the FIFO buffer when an IN token for endpoint 2 is received from the host. A NACK handshake is returned to the host until data is written to the FIFO buffer and packet transmission is enabled.
4	EP2EMPTY	1	R	EP2 FIFO Empty This bit is set when at least one of the dual endpoint 2 transmit FIFO buffers is ready for transmit data to be written. This is a status bit, and cannot be cleared.
3	SETUPTS	0	R/W	Setup Command Receive Complete This bit is set to 1 when endpoint 0 receives successfully a setup command requiring decoding on the application side, and returns an ACK handshake to the host.
2	EP0oTS	0	R/W	EP0o Receive Complete This bit is set to 1 when endpoint 0 receives data from the host successfully, stores the data in the FIFO buffer, and returns an ACK handshake to the host.

Bit	Bit Name	Initial Value	R/W	Description
1	EP0iTR	0	R/W	EP0i Transfer Request This bit is set if there is no valid transmit data in the FIFO buffer when an IN token for endpoint 0 is received from the host. A NACK handshake is returned to the host until data is written to the FIFO buffer and packet transmission is enabled.
0	EP0iTS	0	R/W	EP0i Transmit Complete This bit is set when data is transmitted to the host from endpoint 0 and an ACK handshake is returned.

18.3.2 Interrupt Flag Register 1 (IFR1)

IFR1, together with interrupt flag register 0 (IFR0), indicates interrupt status information required by the application. When an interrupt source is generated, the corresponding bit is set to 1 and an interrupt request is sent to the CPU according to the combination with interrupt enable register 1 (IER1). Clearing is performed by writing 0 to the bit to be cleared, and 1 to the other bits.

Bit	Bit Name	Initial Value	R/W	Description
7 to 4	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
3	VBUSMN	0	R	This is a status bit which monitors the state of the VBUS pin. This bit reflects the state of the VBUS pin.
2	EP3TR	0	R/W	EP3 Transfer Request This bit is set if there is no valid transmit data in the FIFO buffer when an IN token for endpoint 3 is received from the host. A NACK handshake is returned to the host until data is written to the FIFO buffer and packet transmission is enabled.
1	EP3TS	0	R/W	EP3 Transmit Complete This bit is set when data is transmitted to the host from endpoint 3 and an ACK handshake is returned.
0	VBUS	0	R/W	USB Disconnection Detection When the function is connected to the USB bus or disconnected from it, this bit is set to 1. The VBUS pin of this module is used for detecting connection or disconnection.

18.3.3 Interrupt Select Register 0 (ISR0)

ISR0 selects the vector numbers of the interrupt requests indicated in interrupt flag register 0 (IFR0). If the USB issues an interrupt request to the INTC when a bit in ISR0 is cleared to 0, the interrupt corresponding to the bit will be USI0 (USB interrupt 0). If the USB issues an interrupt request to the INTC when a bit in ISR0 is set to 1, the corresponding interrupt will be USI1 (USB interrupt 1). If interrupts occur simultaneously, USI0 has priority by default.

Bit	Bit Name	Initial Value	R/W	Description
7	BRST	0	R/W	Bus Reset
6	EP1FULL	0	R/W	EP1 FIFO Full
5	EP2TR	0	R/W	EP2 Transfer Request
4	EP2EMPTY	0	R/W	EP2 FIFO Empty
3	SETUPTS	0	R/W	Setup Command Receive Complete
2	EP0oTS	0	R/W	EP0o Receive Complete
1	EP0iTR	0	R/W	EP0i Transfer Request
0	EP0iTS	0	R/W	EP0i Transmit Complete

18.3.4 Interrupt Select Register 1 (ISR1)

ISR1 selects the vector numbers of the interrupt requests indicated in interrupt flag register 1 (IFR1). If the USB issues an interrupt request to the INTC when a bit in ISR1 is cleared to 0, the interrupt corresponding to the bit will be USI0 (USB interrupt 0). If the USB issues an interrupt request to the INTC when a bit in ISR1 is set to 1, the corresponding interrupt will be USI1 (USB interrupt 1). If interrupts occur simultaneously, USI0 has priority by default.

Bit	Bit Name	Initial Value	R/W	Description
7 to 3	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
2	EP3TR	1	R/W	EP3 Transfer Request
1	EP3TS	1	R/W	EP3 Transmit Complete
0	VBUS	1	R/W	USB Bus Connect

18.3.5 Interrupt Enable Register 0 (IER0)

IER0 enables the interrupt requests of interrupt flag register 0 (IFR0). When an interrupt flag is set to 1 while the corresponding bit of each interrupt is set to 1, an interrupt request is sent to the CPU. The interrupt vector number is determined by the contents of interrupt select register 0 (ISR0).

Bit	Bit Name	Initial Value	R/W	Description
7	BRST	0	R/W	Bus Reset
6	EP1FULL	0	R/W	EP1 FIFO Full
5	EP2TR	0	R/W	EP2 Transfer Request
4	EP2EMPTY	1	R/W	EP2 FIFO Empty
3	SETUPTS	0	R/W	Setup Command Receive Complete
2	EP0oTS	0	R/W	EP0o Receive Complete
1	EP0iTR	0	R/W	EP0i Transfer Request
0	EP0iTS	0	R/W	EP0i Transmit Complete

18.3.6 Interrupt Enable Register 1 (IER1)

IER1 enables the interrupt requests of interrupt flag register 1 (IFR1). When an interrupt flag is set to 1 while the corresponding bit of each interrupt is set to 1, an interrupt request is sent to the CPU. The interrupt vector number is determined by the contents of interrupt select register 1 (ISR1).

Bit	Bit Name	Initial Value	R/W	Description
7 to 3	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
2	EP3TR	0	R/W	EP3 Transfer Request
1	EP3TS	0	R/W	EP3 Transmit Complete
0	VBUS	0	R/W	USB Bus Connect

18.3.7 EP0i Data Register (EPDR0i)

EPDR0i is an 8-byte transmit FIFO buffer for endpoint 0. EPDR0i holds one packet of transmit data for control-in. Transmit data is fixed by writing one packet of data and setting EP0iPKTE in the trigger register. When an ACK handshake is returned from the host after the data has been transmitted, EP0iTS in interrupt flag register 0 is set. This FIFO buffer can be initialized by means of EP0iCLR in the FCLR register.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	D7 to D0	Undefined	W	Data register for control-in transfer

18.3.8 EP0o Data Register (EPDR0o)

EPDR0o is an 8-byte receive FIFO buffer for endpoint 0. EPDR0o holds endpoint 0 receive data other than setup commands. When data is received successfully, EP0oTS in interrupt flag register 0 is set, and the number of receive bytes is indicated in the EP0o receive data size register. After the data has been read, setting EP0oRDFN in the trigger register enables the next packet to be received. This FIFO buffer can be initialized by means of BP0oCLR in the FCLR register.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	D7 to D0	Undefined	R	Data register for control-out transfer

18.3.9 EP0s Data Register (EPDR0s)

EPDR0s is an 8-byte FIFO buffer specifically for receiving endpoint 0 setup commands. Only the setup command to be processed by the application is received. When command data is received successfully, the SETUPTS bit in interrupt flag register 0 is set.

As a latest setup command must be received in high priority, if data is left in this buffer, it will be overwritten with new data. If reception of the next command is started while the current command is being read, command reception has priority, the read by the application is forcibly stopped, and the read data is invalid.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	D7 to D0	Undefined	R	Data register for storing the setup command at the control-out transfer

18.3.10 EP1 Data Register (EPDR1)

EPDR1 is a 128-byte receive FIFO buffer for endpoint 1. EPDR1 has a dual-buffer configuration, and has a capacity of twice the maximum packet size. When one packet of data is received successfully, EP1FULL in interrupt flag register 0 is set, and the number of receive bytes is indicated in the EP1 receive data size register. After the data has been read, the buffer that was read is enabled to receive data again by writing 1 to the EP1RDFN bit in the trigger register. The receive data in this FIFO buffer can be transferred by DMA. This FIFO buffer can be initialized by means of EP1CLR in the FCLR register.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	D7 to D0	Undefined	R	Data register for endpoint 1 transfer

18.3.11 EP2 Data Register (EPDR2)

EPDR2 is a 128-byte transmit FIFO buffer for endpoint 2. EPDR2 has a dual-buffer configuration, and has a capacity of twice the maximum packet size. When transmit data is written to this FIFO buffer and EP2PKTE in the trigger register is set, one packet of transmit data is fixed, and the dual-FIFO buffer is switched over. The transmit data for this FIFO buffer can be transferred by DMA. This FIFO buffer can be initialized by means of EP2CLR in the FCLR register.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	D7 to D0	Undefined	W	Data register for endpoint 2 transfer

18.3.12 EP3 Data Register (EPDR3)

EPDR3 is an 8-byte transmit FIFO buffer for endpoint 3. EPDR3 holds one packet of transmit data for the interrupt transfer of endpoint 3. Transmit data is fixed by writing one packet of data and setting EP3PKTE in the trigger register. When an ACK handshake is returned from the host after one packet of data has been transmitted successfully, EP3TS in interrupt flag register 0 is set. This FIFO buffer can be initialized by means of EP3CLR in the FCLR register.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	D7 to D0	Undefined	R	Data register for endpoint 3 transfer

18.3.13 EP0o Receive Data Size Register (EPSZ0o)

EPSZ0o indicates the number of bytes received at endpoint 0 from the host.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	—	All 0	R	Number of receive data for endpoint 0

18.3.14 EP1 Receive Data Size Register (EPSZ1)

EPSZ1 is a receive data size resister for endpoint 1. EPSZ1 indicates the number of bytes received from the host. The FIFO for endpoint 1 has a dual-buffer configuration. The size of the received data indicated by this register is the size of the currently selected side (can be read by CPU).

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	—	All 0	R	Number of received bytes for endpoint 1

18.3.15 Trigger Register (TRG)

TRG generates one-shot triggers to control the transfer sequence for each endpoint.

Bit	Bit Name	Initial Value	R/W	Description
7	—	Undefined	—	Reserved The write value should always be 0.
6	EP3PKTE	Undefined	W	EP3 Packet Enable After one packet of data has been written to the endpoint 3 transmit FIFO buffer, the transmit data is fixed by writing 1 to this bit.
5	EP1RDFN	Undefined	W	EP1 Read Complete Write 1 to this bit after one packet of data has been read from the endpoint 1 FIFO buffer. The endpoint 1 receive FIFO buffer has a dual-buffer configuration. Writing 1 to this bit initializes the FIFO that was read, enabling the next packet to be received.
4	EP2PKTE	Undefined	W	EP2 Packet Enable After one packet of data has been written to the endpoint 2 transmit FIFO buffer, the transmit data is fixed by writing 1 to this bit.
3	—	Undefined	—	Reserved The write value should always be 0.
2	EP0sRDFN	Undefined	W	EP0s Read Complete Write 1 to this bit after data for the EP0s command FIFO has been read. Writing 1 to this bit enables transfer of data in the following data stage. A NACK handshake is returned in response to transfer requests from the host in the data stage until 1 is written to this bit.
1	EP0oRDFN	Undefined	W	EP0o Read Complete Writing 1 to this bit after one packet of data has been read from the endpoint 0 transmit FIFO buffer initializes the FIFO buffer, enabling the next packet to be received.
0	EP0iPKTE	Undefined	W	EP0i Packet Enable After one packet of data has been written to the endpoint 0 transmit FIFO buffer, the transmit data is fixed by writing 1 to this bit.

18.3.16 Data Status Register (DASTS)

DASTS indicates whether the transmit FIFO buffers contain valid data. A bit is set when data is written to the corresponding FIFO buffer and the packet enable state is set, and cleared when all data has been transmitted to the host.

Bit	Bit Name	Initial Value	R/W	Description
7, 6	—	All 0	R	Reserved This bit is always read as 0.
5	EP3DE	0	R	EP3 Data Present This bit is set when the endpoint 3 FIFO buffer contains valid data.
4	EP2DE	0	R	EP2 Data Present This bit is set when the endpoint 2 FIFO buffer contains valid data.
3 to 1	—	All 0	R	Reserved This bit is always read as 0.
0	EP0iDE	0	R	EP0i Data Present This bit is set when the endpoint 0 FIFO buffer contains valid data.

18.3.17 FIFO Clear Register (FCLR)

FCLR is a register to initialize the FIFO buffers for each endpoint. Writing 1 to a bit clears all the data in the corresponding FIFO buffer. Note that the corresponding interrupt flag is not cleared. Do not clear a FIFO buffer during transfer.

Bit	Bit Name	Initial Value	R/W	Description
7	—	Undefined	—	Reserved The write value should always be 0.
6	EP3CLR	Undefined	W	EP3 Clear Writing 1 to this bit initializes the endpoint 3 transmit FIFO buffer.
5	EP1CLR	Undefined	W	EP1 Clear Writing 1 to this bit initializes both sides of the endpoint 1 receive FIFO buffer.

Bit	Bit Name	Initial Value	R/W	Description
4	EP2CLR	Undefined	W	EP2 Clear Writing 1 to this bit initializes both sides of the endpoint 2 transmit FIFO buffer.
3, 2	—	Undefined	—	Reserved The write value should always be 0.
1	EP0oCLR	Undefined	W	EP0o Clear Writing 1 to this bit initializes the endpoint 0 receive FIFO buffer.
0	EP0iCLR	Undefined	W	EP0i Clear Writing 1 to this bit initializes the endpoint 0 transmit FIFO buffer.

18.3.18 DMA Transfer Setting Register (DMAR)

DMA transfer can be carried out between the endpoint 1 and 2 data registers and memory by means of the on-chip direct memory access controller (DMA). Dual address transfer is performed in bytes. To start DMA transfer, DMAC settings must be made in addition to the settings in this register.

Bit	Bit Name	Initial Value	R/W	Description
7 to 2	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
1	EP2DMAE	0	R/W	Endpoint 2 DMA Transfer Enable When this bit is set, DMA transfer is enabled from memory to the endpoint 2 transmit FIFO buffer. If there is at least one byte of space in the FIFO buffer, a transfer request is asserted for the DMAC. In DMA transfer, when 64 bytes are written to the FIFO buffer the EP2 packet enable bit is set automatically, allowing 64 bytes of data to be transferred, and if there is still space in the other of the two FIFOs, a transfer request is asserted for the DMAC again. However, if the size of the data packet to be transmitted is less than 64 bytes, the EP2 packet enable bit is not set automatically, and so should be set by the CPU with a DMA transfer end interrupt. As EP2-related interrupt requests to the CPU are not automatically masked, interrupt requests should be masked as necessary in the interrupt enable register. • Operating procedure 1. Write of 1 to the EP2 DMAE bit in DMAR 2. Transfer count setting in the DMAC 3. DMAC activation 4. DMA transfer 5. DMA transfer end interrupt generated Refer to section 18.7.3, DMA Transfer for Endpoint 2.

Bit	Bit Name	Initial Value	R/W	Description
0	EP1DMAE	0	R/W	Endpoint 1 DMA Transfer Enable When this bit is set, DMA transfer is enabled from the endpoint 1 receive FIFO buffer to memory. If there is at least one byte of receive data in the FIFO buffer, a transfer request is asserted for the DMAC. In DMA transfer, when all the received data is read, EP1 is read automatically and the completion trigger operates. EP1-related interrupt requests to the CPU are not automatically masked. • Operating procedure: 1. Write of 1 to the EP1 DMAE bit in DMAR 2. Transfer count setting in the DMAC 3. DMAC activation 4. DMA transfer 5. DMA transfer end interrupt generated Refer to section 18.7.2, DMA Transfer for Endpoint 1.

18.3.19 Endpoint Stall Register (EPSTL)

The bits in EPSTL are used to forcibly stall the endpoints on the application side. While a bit is set to 1, the corresponding endpoint returns a stall handshake to the host. The stall bit for endpoint 0 is cleared automatically on reception of 8-byte command data for which decoding is performed by the function and the EP0 STL bit is cleared. When the SETUPTS flag in the IFR0 register is set to 1, writing 1 to the EP0 STL bit is ignored. For detailed operation, see section 18.6, Stall Operations.

Bit	Bit Name	Initial Value	R/W	Description
7 to 4	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
3	EP3STL	0	R/W	EP3 Stall When this bit is set to 1, endpoint 3 is placed in the stall state.
2	EP2STL	0	R/W	EP2 Stall When this bit is set to 1, endpoint 2 is placed in the stall state.
1	EP1STL	0	R/W	EP1 Stall When this bit is set to 1, endpoint 1 is placed in the stall state.
0	EP0STL	0	R/W	EP0 Stall When this bit is set to 1, endpoint 0 is placed in the stall state.

18.3.20 Transceiver Control Register (XVERCR)

The Transceiver Control Register sets either the internal transceiver or external transceiver for use.

Bit	Bit Name	Initial Value	R/W	Description
7 to 1	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
0	XVEROFF	0	R/W	Transceiver Control 1: The internal transceiver function is stopped and a digital signal for the external transceiver is output from the port. 0: The internal transceiver is operated.

18.4 Operation

18.4.1 Cable Connection

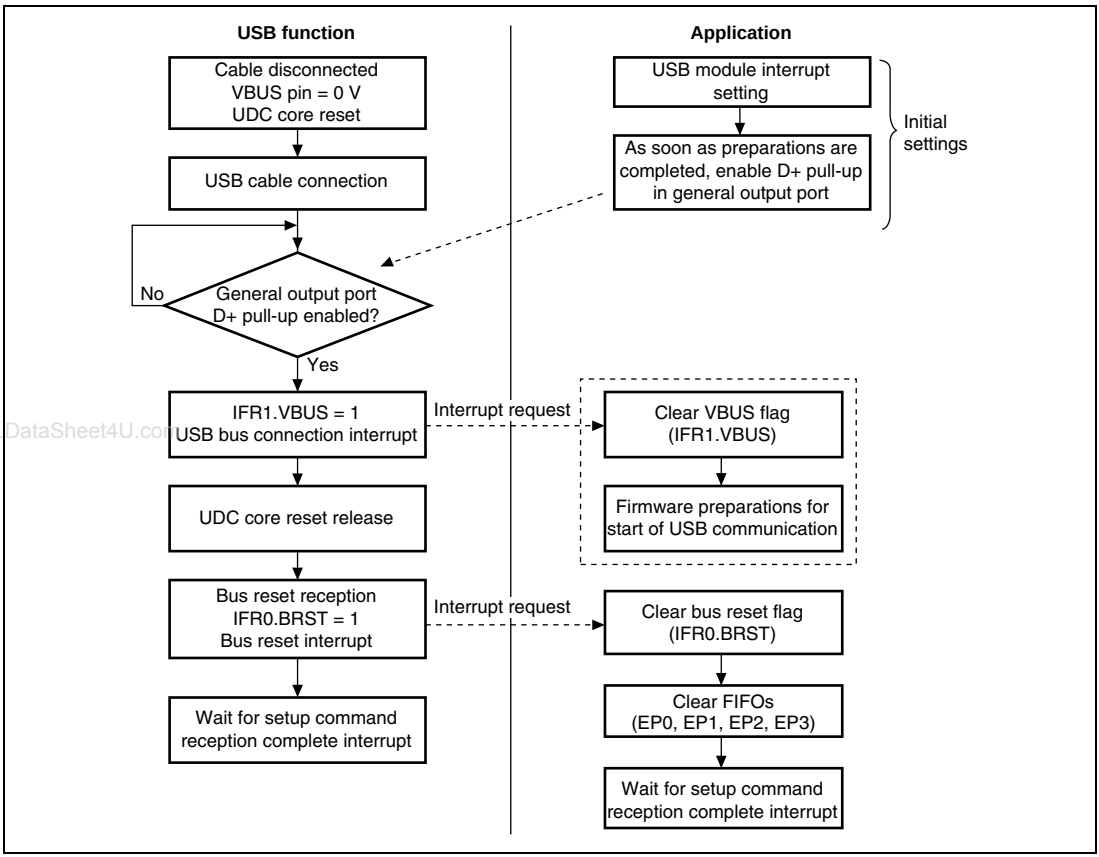


Figure 18.2 Cable Connection Operation

The above flowchart shows the operation in the case of in section 18.8, Example of USB External Circuitry.

In applications that do not require USB cable connection to be detected, processing by the USB bus connection interrupt is not necessary. Preparations should be made with the bus-reset interrupt.

18.4.2 Cable Disconnection

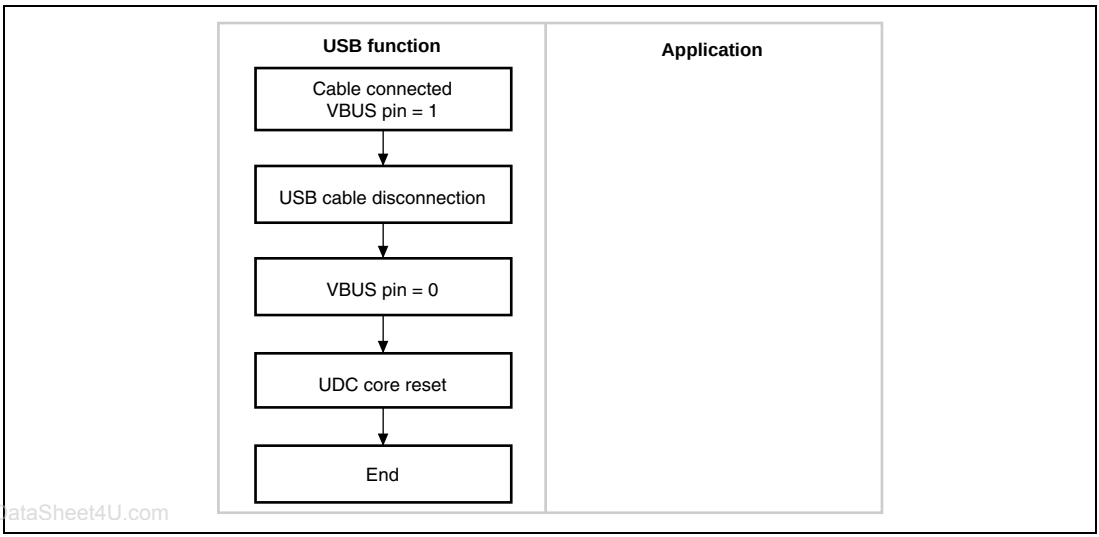


Figure 18.3 Cable Disconnection Operation

The above flowchart shows the operation in section 18.8, Example of USB External Circuitry.

18.4.3 Control Transfer

Control transfer consists of three stages: setup, data (not always included), and status (figure 18.4). The data stage comprises a number of bus transactions. Operation flowcharts for each stage are shown below.

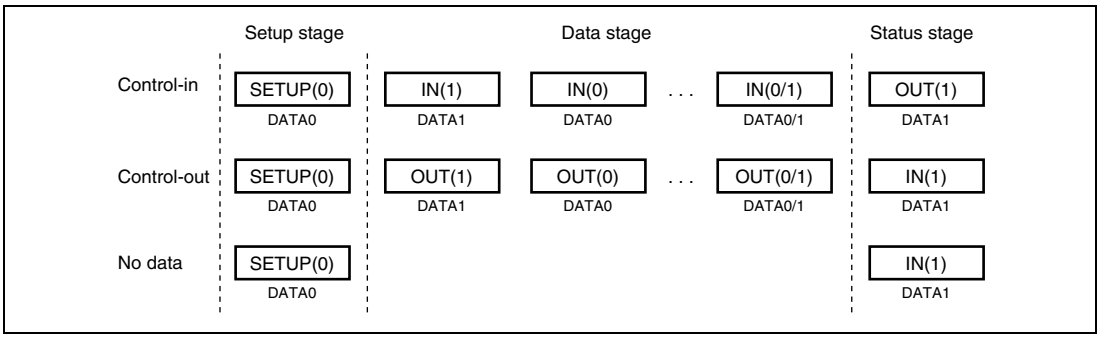
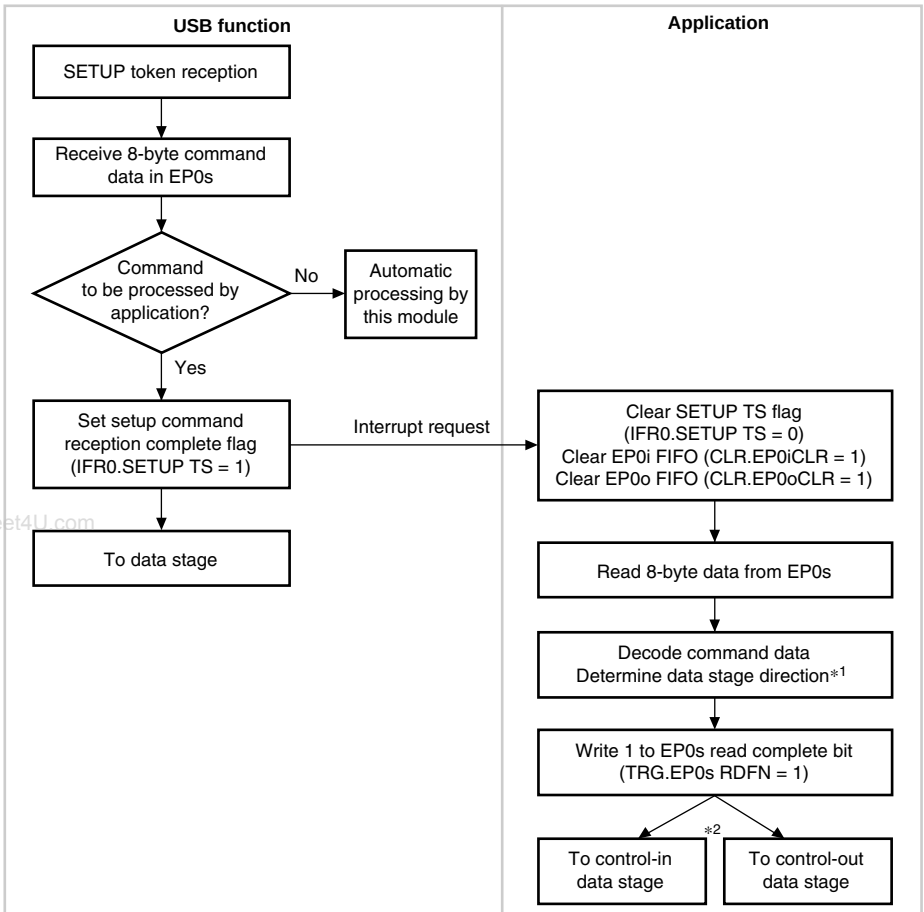


Figure 18.4 Transfer Stages in Control Transfer

1. Setup Stage



Notes: 1 In the setup stage, the application analyzes command data from the host requiring processing by the application, and determines the subsequent processing (for example, data stage direction, etc.).
2 When the transfer direction is control-out, the EP0i transfer request interrupt required in the status stage should be enabled here. When the transfer direction is control-in, this interrupt is not required and should be disabled.

Figure 18.5 Setup Stage Operation

2. Data Stage (Control-In)

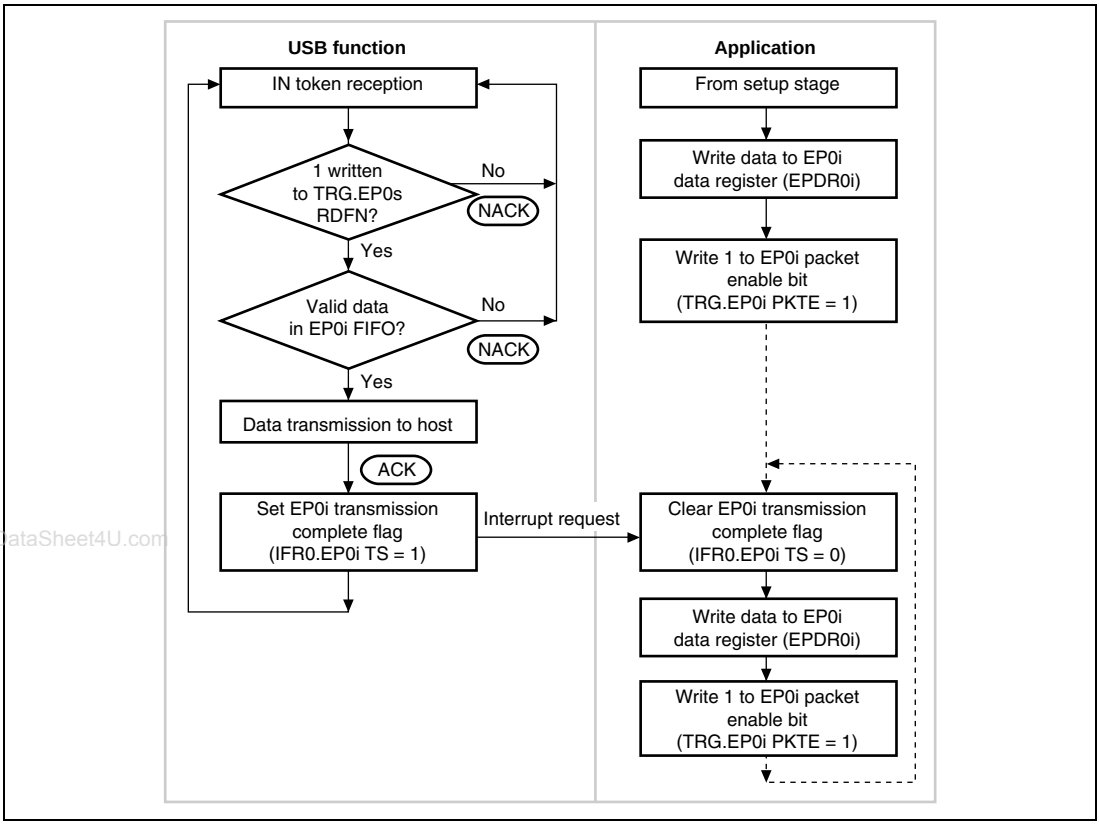


Figure 18.6 Data Stage (Control-In) Operation

The application first analyzes command data from the host in the setup stage, and determines the subsequent data stage direction. If the result of command data analysis is that the data stage is in-transfer, one packet of data to be sent to the host is written to the FIFO. If there is more data to be sent, this data is written to the FIFO after the data written first has been sent to the host (EP0iTS bit in IFR0 = 1).

The end of the data stage is identified when the host transmits an OUT token and the status stage is entered.

Note: If the size of the data transmitted by the function is smaller than the data size requested by the host, the function indicates the end of the data stage by returning to the host a packet shorter than the maximum packet size. If the size of the data transmitted by the function is an integral multiple of the maximum packet size, the function indicates the end of the data stage by transmitting a zero-length packet.

3. Data Stage (Control-Out)

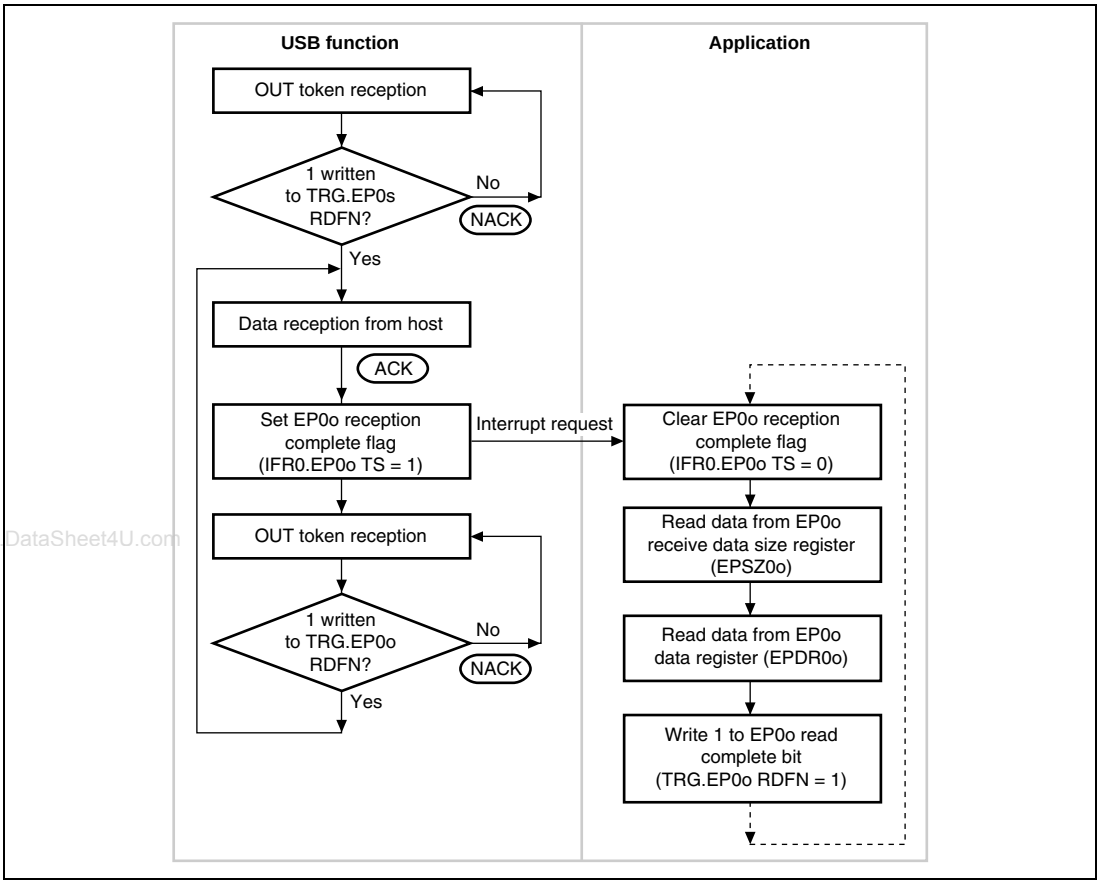


Figure 18.7 Data Stage (Control-Out) Operation

The application first analyzes command data from the host in the setup stage, and determines the subsequent data stage direction. If the result of command data analysis is that the data stage is out-transfer, the application waits for data from the host, and after data is received (EP0oTS bit in IFR0 = 1), reads data from the FIFO. Next, the application writes 1 to the EP0o read complete bit, empties the receive FIFO, and waits for reception of the next data.

The end of the data stage is identified when the host transmits an IN token and the status stage is entered.

4. Status Stage (Control-In)

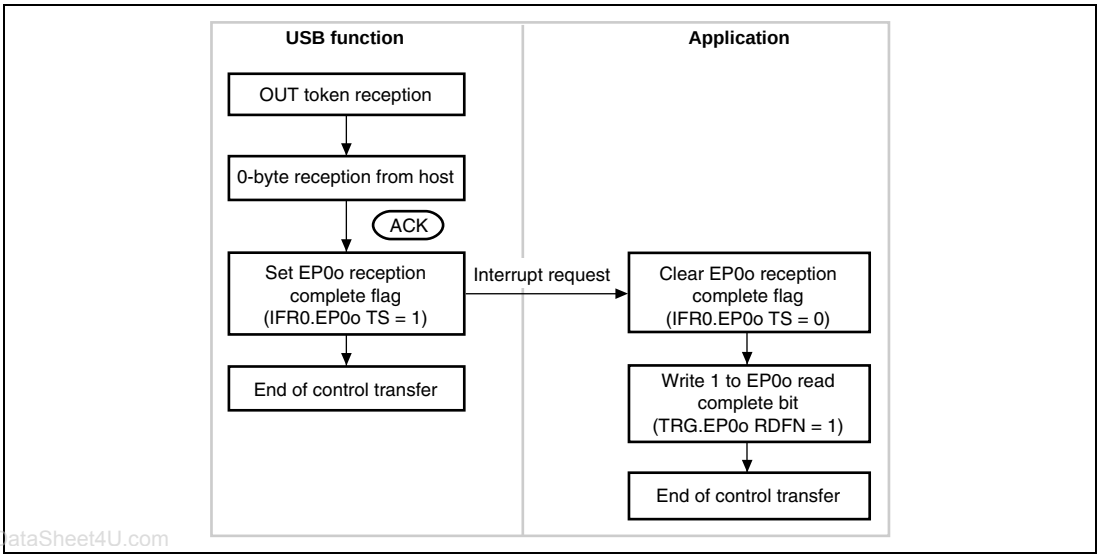


Figure 18.8 Status Stage (Control-In) Operation

The control-in status stage starts with an OUT token from the host. The application receives 0-byte data from the host, and ends control transfer.

5. Status Stage (Control-Out)

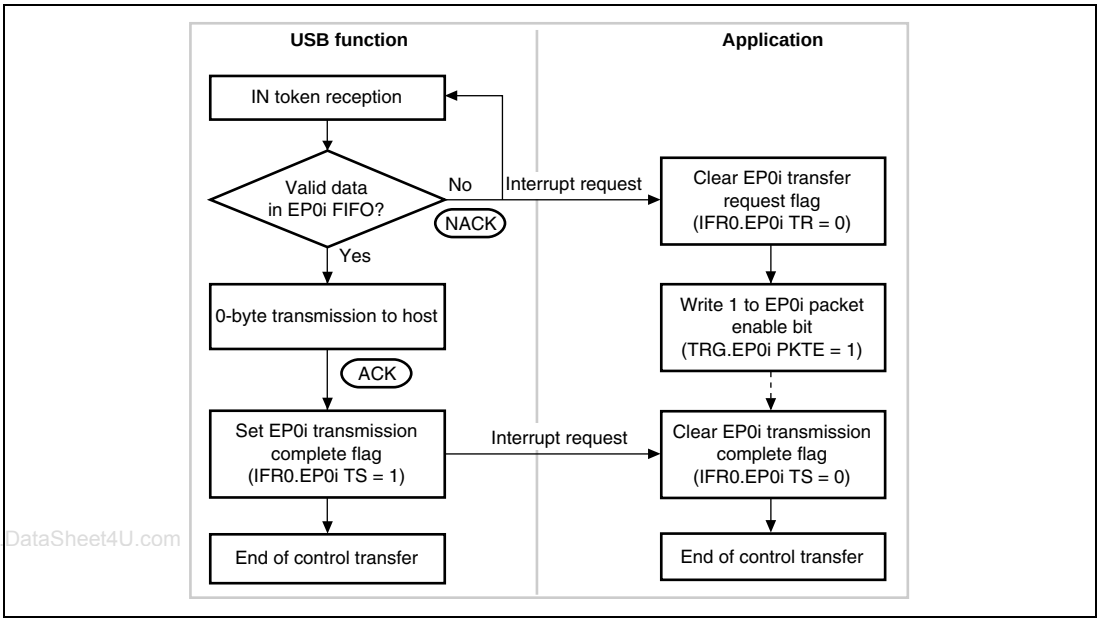


Figure 18.9 Status Stage (Control-Out) Operation

The control-out status stage starts with an IN token from the host. When an IN-token is received at the start of the status stage, there is not yet any data in the EP0i FIFO, and so an EP0i transfer request interrupt is generated. The application recognizes from this interrupt that the status stage has started. Next, in order to transmit 0-byte data to the host, 1 is written to the EP0i packet enable bit but no data is written to the EP0i FIFO. As a result, the next IN token causes 0-byte data to be transmitted to the host, and control transfer ends.

After the application has finished all processing relating to the data stage, 1 should be written to the EP0i packet enable bit.

18.4.4 EP1 Bulk-Out Transfer (Dual FIFOs)

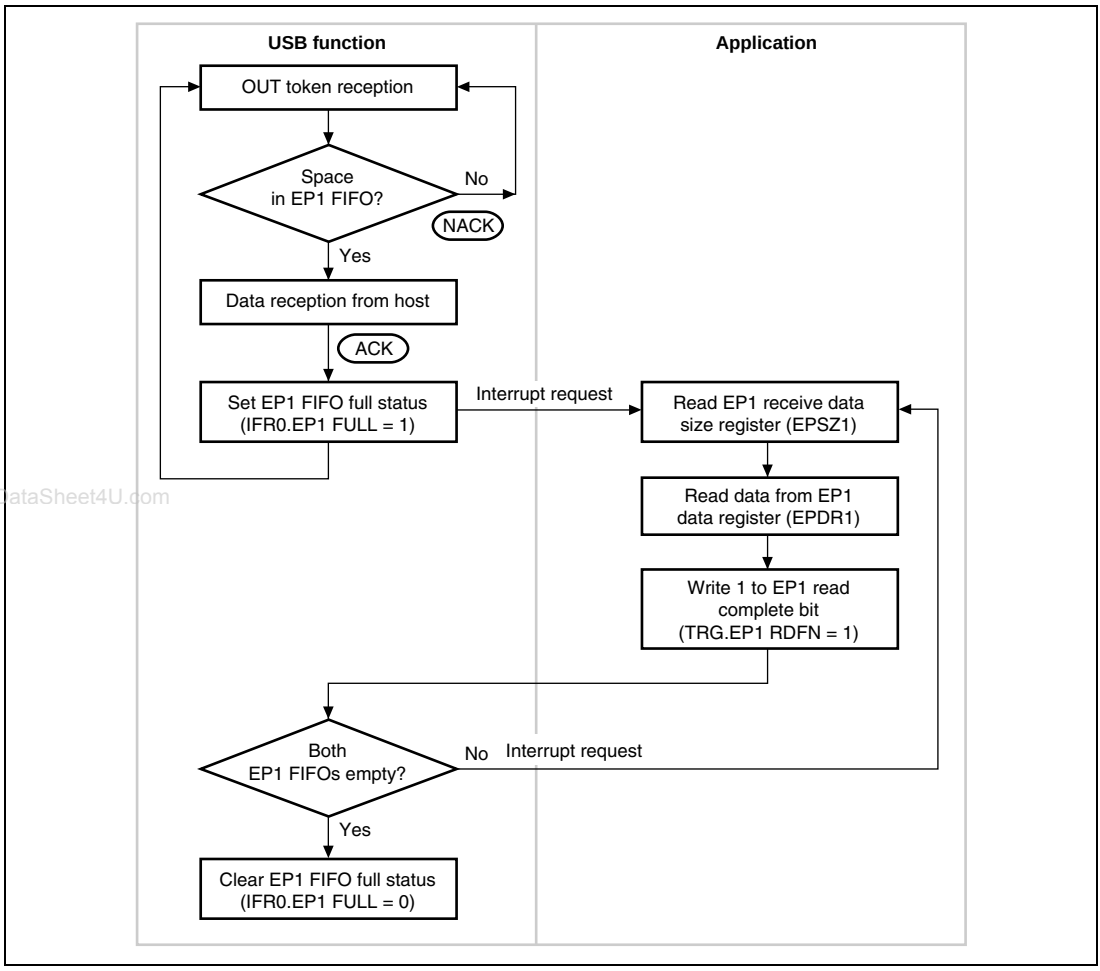


Figure 18.10 EP1 Bulk-Out Transfer Operation

EP1 has two 64-byte FIFOs, but the user can receive data and read receive data without being aware of this dual-FIFO configuration.

When one FIFO is full after reception is completed, the EP1FULL bit in IFR0 is set. After the first receive operation into one of the FIFOs when both FIFOs are empty, the other FIFO is empty, and so the next packet can be received immediately. When both FIFOs are full, NACK is returned to the host automatically. When reading of the receive data is completed following data reception, 1 is written to the EP1RDFN bit in TRG. This operation empties the FIFO that has just been read, and makes it ready to receive the next packet.

18.4.5 EP2 Bulk-In Transfer (Dual FIFOs)

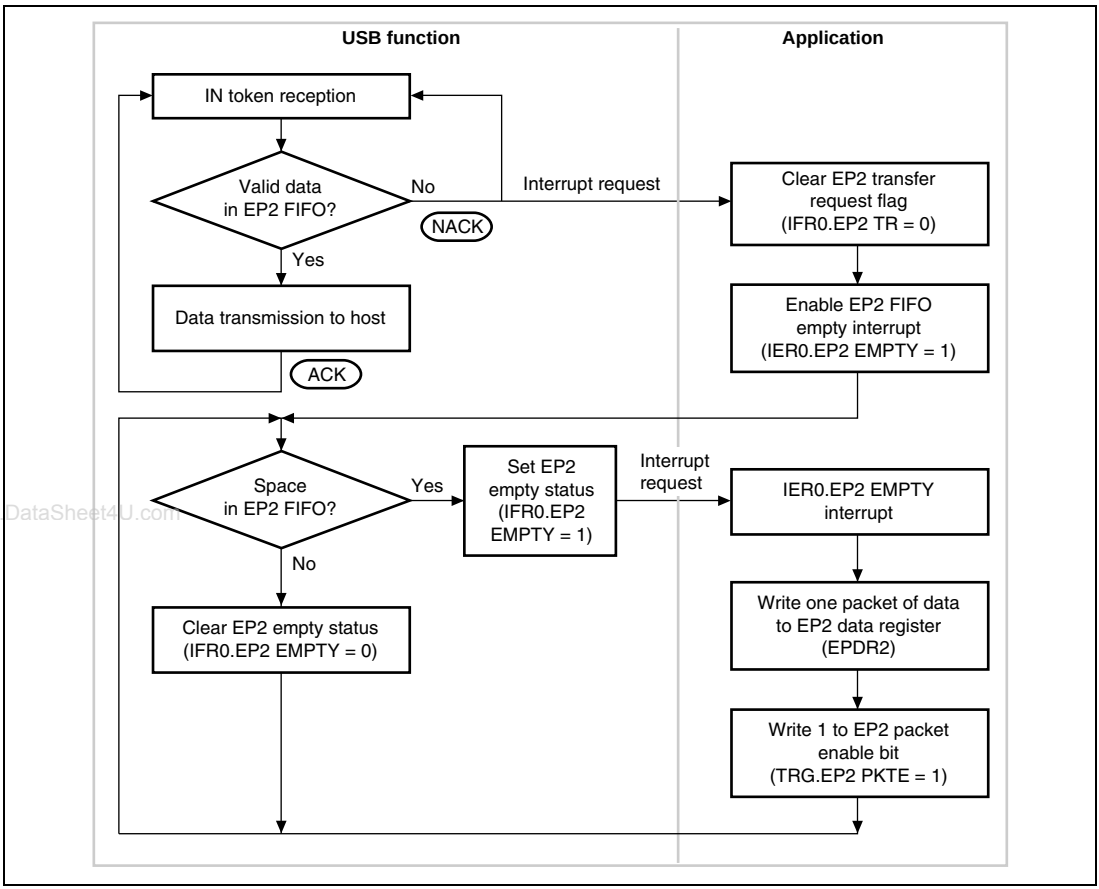


Figure 18.11 EP2 Bulk-In Transfer Operation

EP2 has two 64-byte FIFOs, but the user can transmit data and write transmit data without being aware of this dual-FIFO configuration. However, one data write is performed for one FIFO. For example, even if both FIFOs are empty, it is not possible to perform EP2PKTE at one time after consecutively writing 128 bytes of data. EP2PKTE must be performed for each 64-byte write.

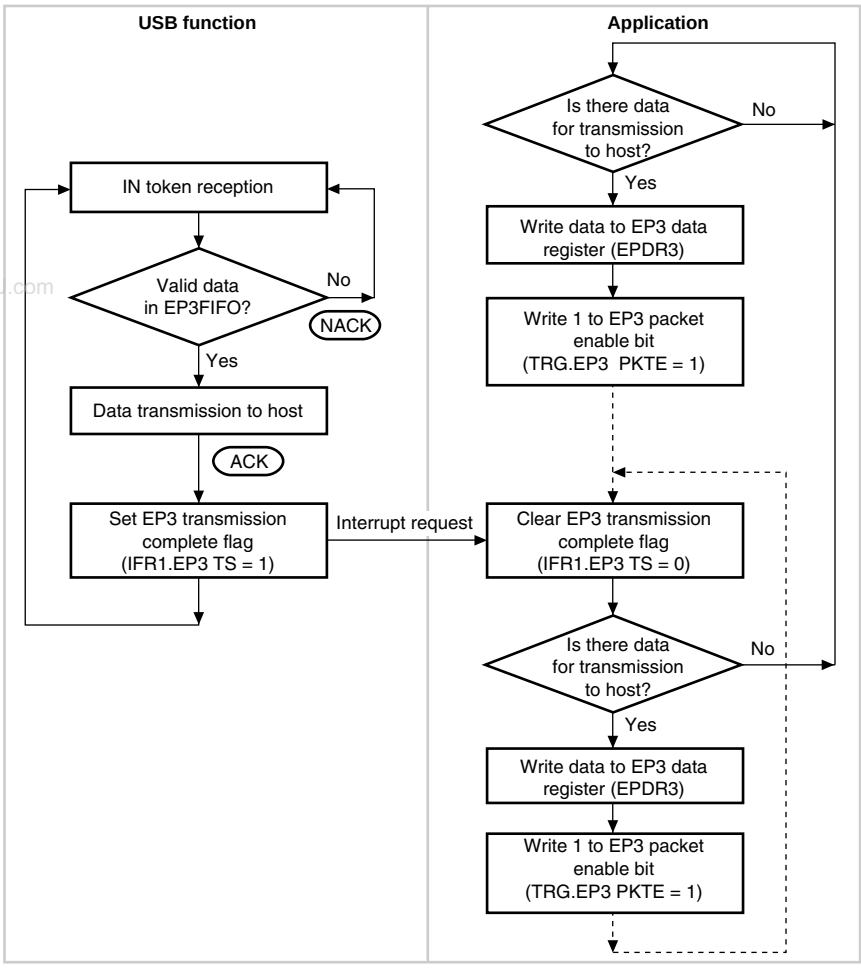
When performing bulk-in transfer, as there is no valid data in the FIFOs on reception of the first IN token, an EP2TR bit interrupt in IFR0 is requested. With this interrupt, 1 is written to the EP2EMPTY bit in IER0, and the EP2 FIFO empty interrupt is enabled. At first, both EP2 FIFOs are empty, and so an EP2 FIFO empty interrupt is generated immediately.

The data to be transmitted is written to the data register using this interrupt. After the first transmit data write for one FIFO, the other FIFO is empty, and so the next transmit data can be written to the other FIFO immediately. When both FIFOs are full, EP2 EMPTY is cleared to 0. If at least one FIFO is empty, the EP2EMPTY bit in IFR0 is set to 1. When ACK is returned from the host after

data transmission is completed, the FIFO used in the data transmission becomes empty. If the other FIFO contains valid transmit data at this time, transmission can be continued.

When transmission of all data has been completed, write 0 to the EP2EMPTY bit in IER0 and disable interrupt requests.

18.4.6 EP3 Interrupt-In Transfer



Note: This flowchart shows just one example of interrupt transfer processing. Other possibilities include an operation flow in which, if there is data to be transferred, the EP3 DE bit in the data status register is referenced to confirm that the FIFO is empty, and then data is written to the FIFO.

Figure 18.12 Operation of EP3 Interrupt-In Transfer

18.5 Processing of USB Standard Commands and Class/Vendor Commands

18.5.1 Processing of Commands Transmitted by Control Transfer

A command transmitted from the host by control transfer may require decoding and execution of command processing on the application side. Whether command decoding is required on the application side is indicated in table 18.2 below.

Table 18.2 Command Decoding on Application Side

Decoding not Necessary on Application Side	Decoding Necessary on Application Side
Clear Feature	Get Descriptor
Get Configuration	Class/Vendor command
Get Interface	Set Descriptor
Get Status	Sync Frame
Set Address	
Set Configuration	
Set Feature	
Set Interface	

If decoding is not necessary on the application side, command decoding and data stage and status stage processing are performed automatically. No processing is necessary by the user. An interrupt is not generated in this case.

If decoding is necessary on the application side, this module stores the command in the EP0s FIFO. After reception is completed successfully, the IFR0/SETUP TS flag is set and an interrupt request is generated. In the interrupt routine, eight bytes of data must be read from the EP0s data register (EPDR0s) and decoded by firmware. The necessary data stage and status stage processing should then be carried out according to the result of the decoding operation.

18.6 Stall Operations

18.6.1 Overview

This section describes stall operations in this module. There are two cases in which the USB function module stall function is used:

- When the application forcibly stalls an endpoint for some reason
- When a stall is performed automatically within the USB function module due to a USB specification violation

The USB function module has internal status bits that hold the status (stall or non-stall) of each endpoint. When a transaction is sent from the host, the module references these internal status bits and determines whether to return a stall to the host. These bits cannot be cleared by the application; they must be cleared with a Clear Feature command from the host.

18.6.2 Forcible Stall by Application

The application uses the EPSTL register to issue a stall request for the USB function module. When the application wishes to stall a specific endpoint, it sets the corresponding bit in EPSTL (1-1 in figure 18.13). The internal status bits are not changed at this time. When a transaction is sent from the host for the endpoint for which the EPSTL bit was set, the USB function module references the internal status bit, and if this is not set, references the corresponding bit in EPSTL (1-2 in figure 18.13). If the corresponding bit in EPSTL is set, the USB function module sets the internal status bit and returns a stall handshake to the host (1-3 in figure 18.13). If the corresponding bit in EPSTL is not set, the internal status bit is not changed and the transaction is accepted.

Once an internal status bit is set, it remains set until cleared by a Clear Feature command from the host, without regard to the EPSTL register. Even after a bit is cleared by the Clear Feature command (3-1 in figure 18.13), the USB function module continues to return a stall handshake while the bit in EPSTL is set, since the internal status bit is set each time a transaction is executed for the corresponding endpoint (1-2 in figure 18.13). To clear a stall, therefore, it is necessary for the corresponding bit in EPSTL to be cleared by the application, and also for the internal status bit to be cleared with a Clear Feature command (2-1, 2-2, and 2-3 in figure 18.13).

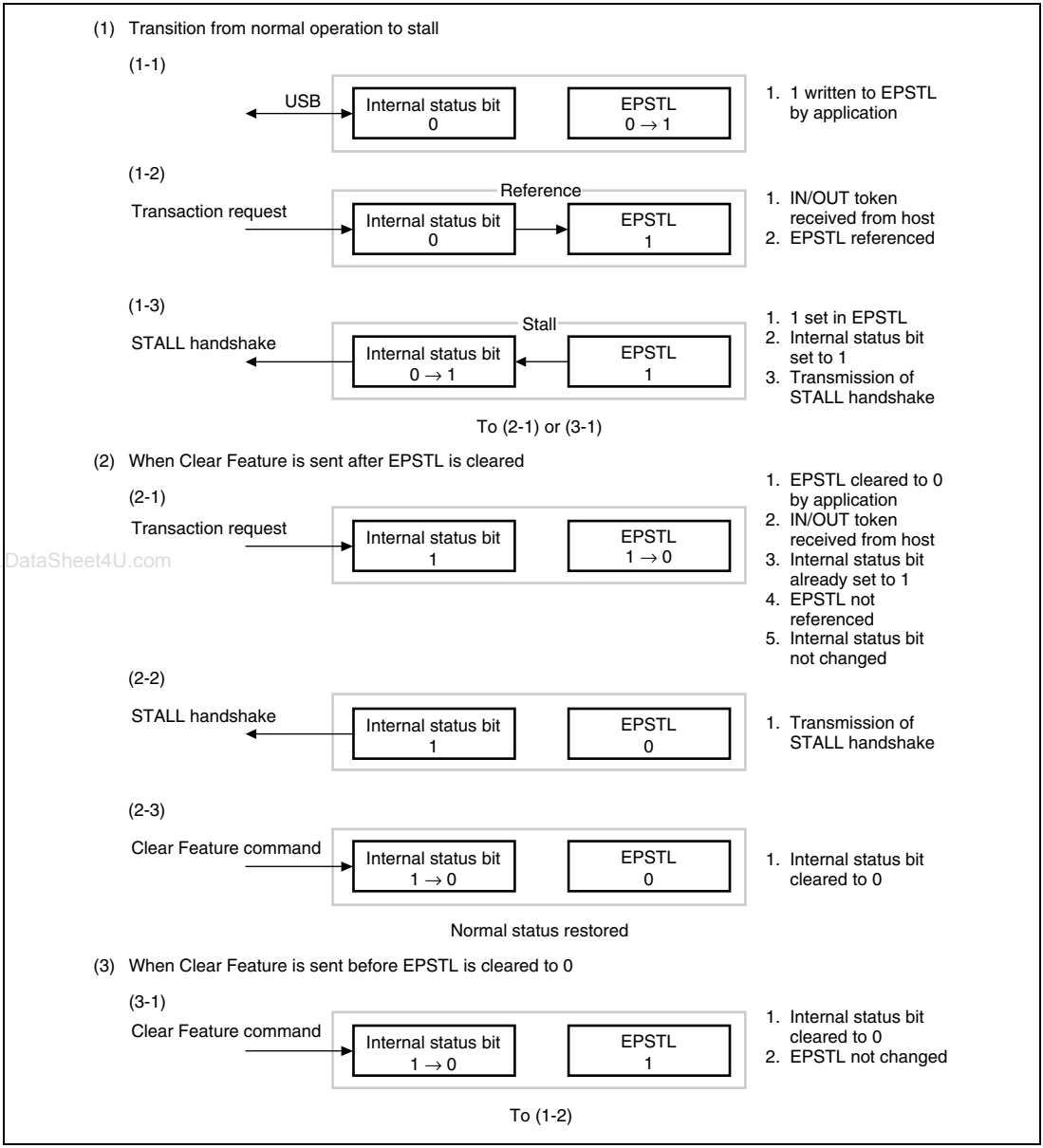


Figure 18.13 Forcible Stall by Application

18.6.3 Automatic Stall by USB Function Module

When a stall setting is made with the Set Feature command, or in the event of a USB specification violation, the USB function module automatically sets the internal status bit for the relevant endpoint without regard to the EPSTL register, and returns a stall handshake (1-1 in figure 18.14).

Once an internal status bit is set, it remains set until cleared by a Clear Feature command from the host, without regard to the EPSTL register. After a bit is cleared by the Clear Feature command, EPSTL is referenced (3-1 in figure 18.14). The USB function module continues to return a stall handshake while the internal status bit is set, since the internal status bit is set even if a transaction is executed for the corresponding endpoint (2-1 and 2-2 in figure 18.14). To clear a stall, therefore, the internal status bit must be cleared with a Clear Feature command (3-1 in figure 18.14). If set by the application, EPSTL should also be cleared (2-1 in figure 18.14).

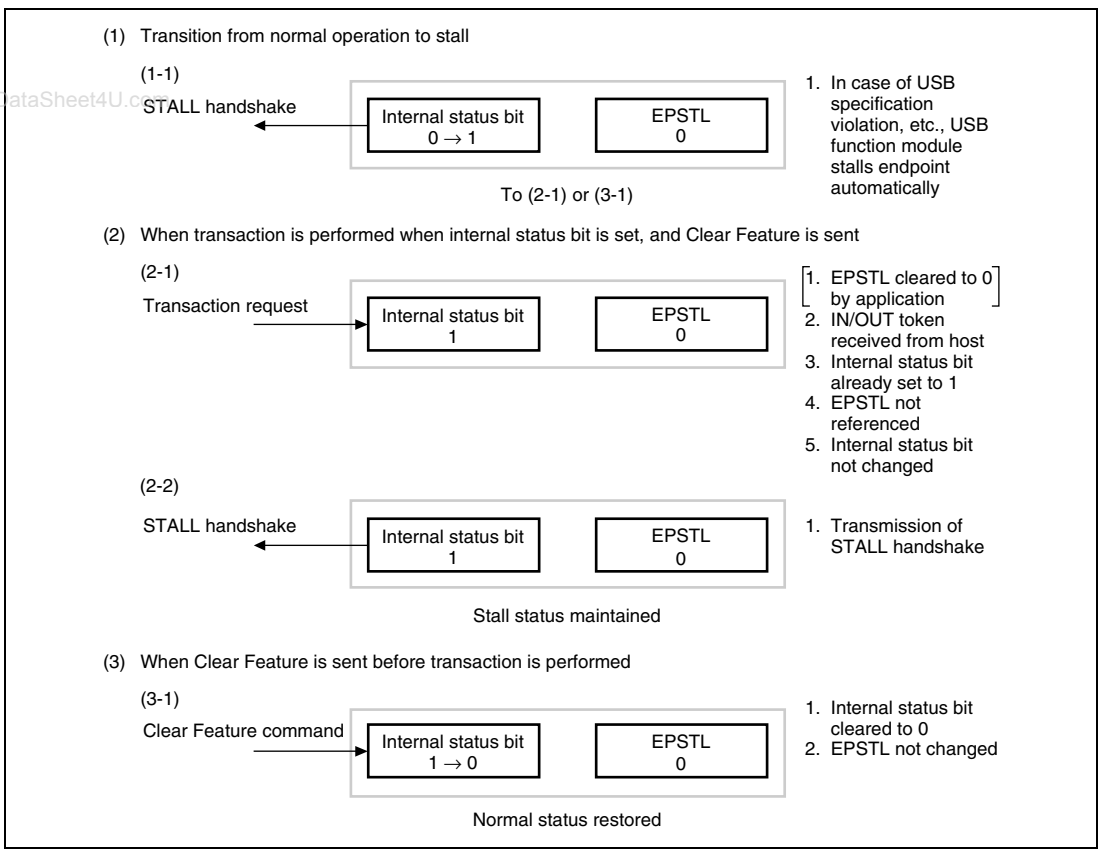


Figure 18.14 Automatic Stall by USB Function Module

18.7 DMA Transfer

18.7.1 Overview

DMA transfer can be performed for endpoints 1 and 2 in this module. Note that word or longword data cannot be transferred.

When endpoint 1 holds at least one byte of valid receive data, a DMA request for endpoint 1 is generated. When endpoint 2 holds no valid data, a DMA request for endpoint 2 is generated.

If the DMA transfer is enabled by setting the EP1DMAE bit to 1 in the DMA transfer setting register, zero-length data reception at endpoint 1 is ignored. When the DMA transfer is enabled, the RDFN bit for EP1 and PKTE bit for EP2 do not need to be set to 1 in TRG (note that the PKTE bit must be set to 1 when the transfer data is less than the maximum number of bytes). When all the data received at EP1 is read, the FIFO automatically enters the EMPTY state. When the maximum number of bytes (64 bytes) are written to the EP2 FIFO, the FIFO automatically enters the FULL state, and the data in the FIFO can be transmitted (see figures 18.15 and 18.16).

18.7.2 DMA Transfer for Endpoint 1

When the data received at EP1 is transferred by the DMAC, the USB function module automatically performs the same processing as writing 1 to the RDFN bit in TRG if the currently selected FIFO becomes empty. Accordingly, in DMA transfer, do not write 1 to the RDFN bit in TRG. If the user writes 1 to the RDFN bit in DMA transfer, correct operation cannot be guaranteed.

Figure 18.15 shows an example of receiving 150 bytes of data from the host. In this case, internal processing which is the same as writing 1 to the RDFN bit in TRG is automatically performed three times. This internal processing is performed when the currently selected data FIFO becomes empty. Accordingly, this processing is automatically performed both when 64-byte data is sent and when data less than 64 bytes is sent.

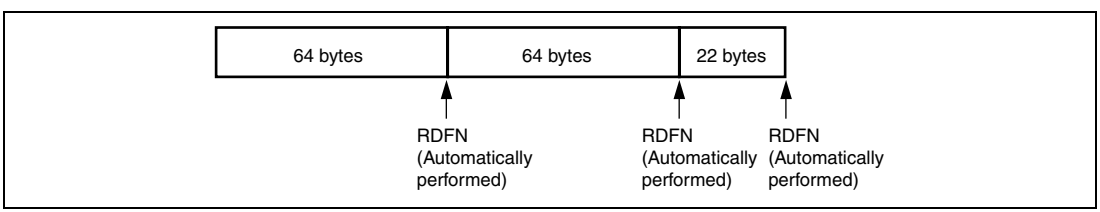


Figure 18.15 RDFN Bit Operation for EP1

18.7.3 DMA Transfer for Endpoint 2

When the transmit data at EP2 is transferred by the DMAC, the USB function module automatically performs the same processing as writing 1 to the PKTE bit in TRG if the currently selected FIFO (64 bytes) becomes full. Accordingly, to transfer data of a multiple of 64 bytes, the user need not write 1 to the PKTE bit. To transfer data of less than 64 bytes, the user must write 1 to the PKTE bit using the DMA transfer end interrupt of the on-chip DMAC. If the user writes 1 to the PKTE bit when the maximum number of bytes (64 bytes) are transferred, correct operation cannot be guaranteed.

Figure 18.16 shows an example for transmitting 150 bytes of data to the host. In this case, internal processing which is the same as writing 1 to the PKTE bit in TRG is automatically performed twice. This internal processing is performed when the currently selected data FIFO becomes full. Accordingly, this processing is automatically performed only when 64-byte data is sent.

When the last 22 bytes are sent, the internal processing for writing 1 to the PKTE bit is not performed, and the user must write 1 to the PKTE bit by software. In this case, the application has no more data to transfer but the USB function module continues to output DMA requests for EP2 as long as the FIFO has an empty space. When all data has been transferred, write 0 to the EP2DMAE bit in DMAR to cancel DMA requests for EP2.

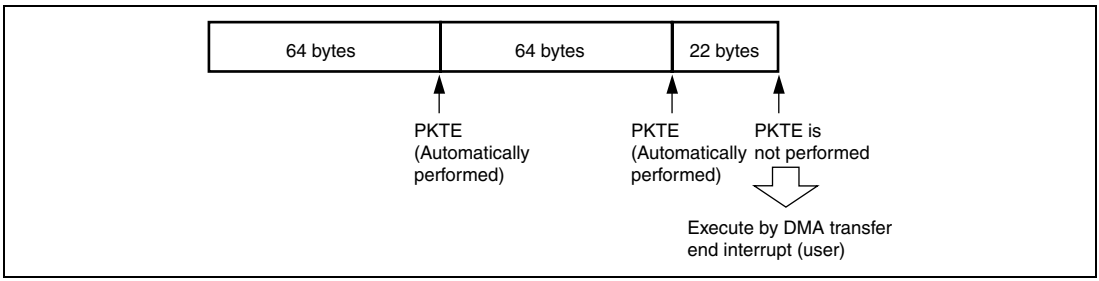


Figure 18.16 PKTE Bit Operation for EP2

18.8 Example of USB External Circuitry

1. USB Transceiver

   A USB transceiver IC (such as a PDIUSBP11) should be connected externally when no internal transceiver is used. The USB transceiver manufacturer should be consulted concerning the recommended circuit from the USB transceiver to the USB connector, etc.

2. D+ Pull-Up Control

   In a system where it is wished to disable USB host/hub connection notification (D+ pull-up) (during high-priority processing or initialization processing, for example), D+ pull-up should be controlled using a general output port. However, if a USB cable is already connected to the host/hub and D+ pull-up is prohibited, D+ and D– will both go low (both of D+ and D– pulled down on the host/hub side) and the USB module will mistakenly identify this as reception of a USB bus reset from the host. Therefore, the D+ pull-up control signal and VBUS pin input signal should be controlled using a general output port and the USB cable VBUS (AND circuit) as shown in figure 18.17. (The UDC core in this LSI maintains the powered state when the VBUS pin is low, regardless of the D+/D– state.)

3. Detection of USB Cable Connection/Disconnection

   As USB states, etc., are managed by hardware in this module, a VBUS signal that recognizes connection/disconnection is necessary. The power supply signal (VBUS) in the USB cable is used for this purpose. However, if the cable is connected to the USB host/hub when the function (system installing this LSI) power is off, a voltage (5 V) will be applied from the USB host/hub. Therefore, an IC (such as an HD74LV1G08A or 2G08A) that allows voltage application when the system power is off should be connected externally.

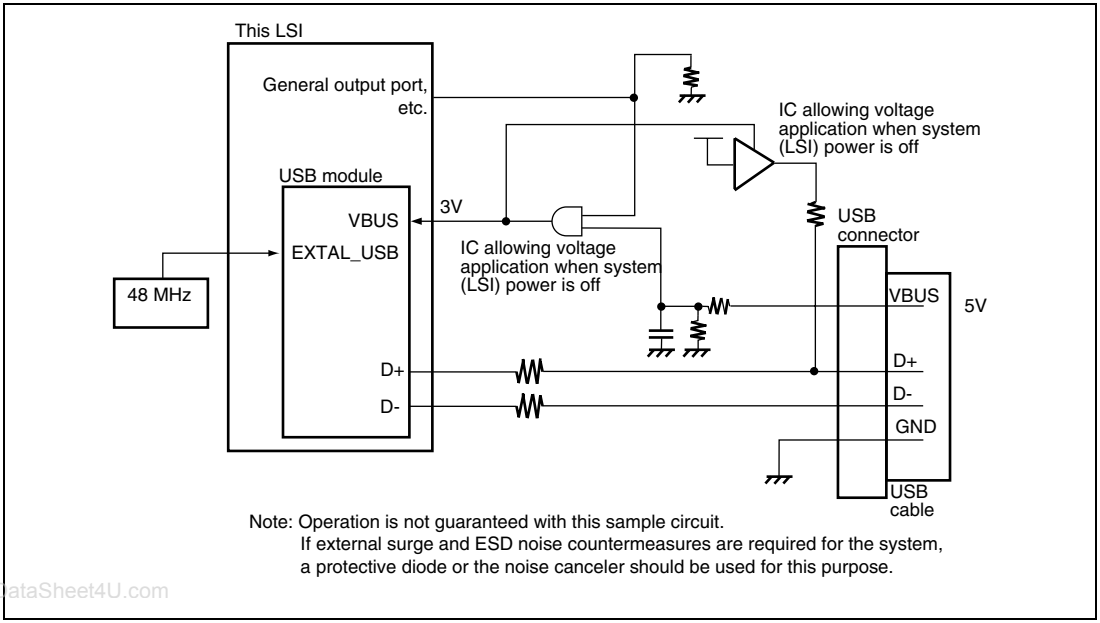


Figure 18.17 Example of USB Function Module External Circuitry (Internal Transceiver)

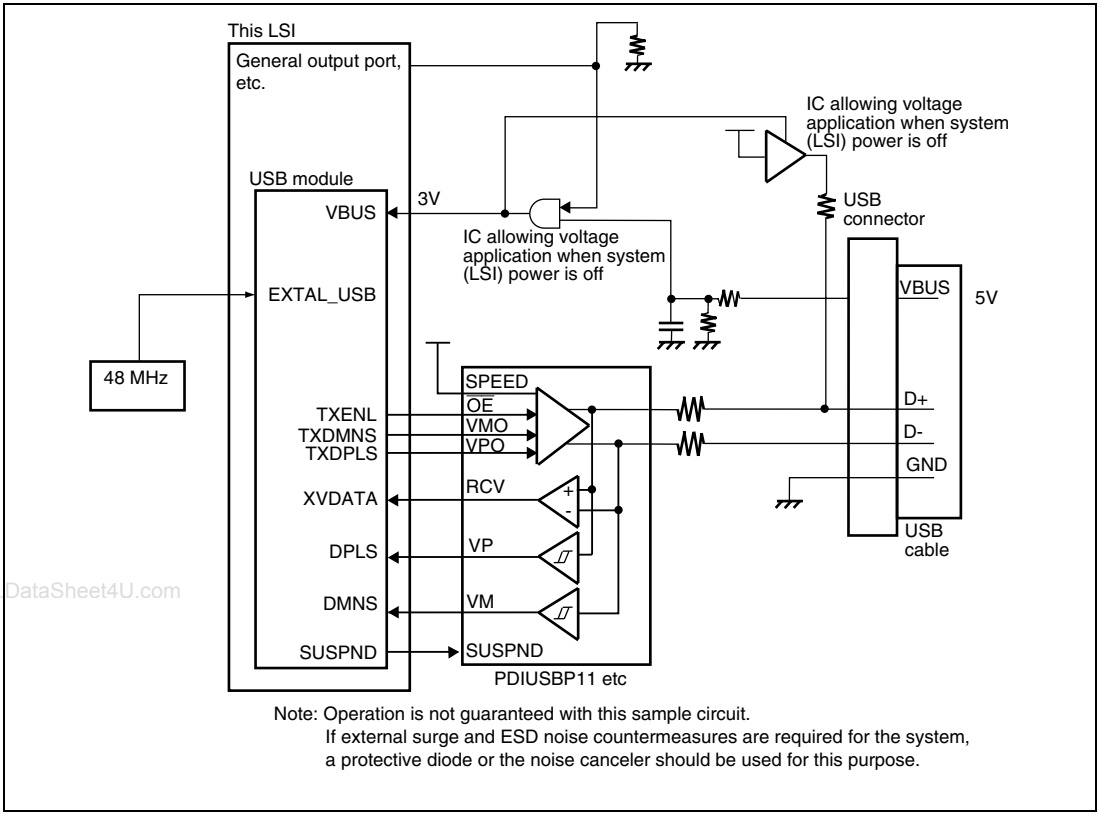


Figure 18.18 Example of USB Function Module External Circuitry (External Transceiver)

18.9 Usage Notes

18.9.1 Receiving Setup Data

Note the following for EPDR0s that receives 8-byte setup data:

1. As a latest setup command must be received in high priority, the write from the USB bus takes priority over the read from the CPU. If the next setup command reception is started while the CPU is reading data after the data is received, the read from the CPU is forcibly terminated. Therefore, the data read after reception is started becomes invalid.
2. EPDR0s must always be read in 8-byte units. If the read is terminated at a midpoint, the data received at the next setup cannot be read correctly.

18.9.2 Clearing the FIFO

If a USB cable is disconnected during data transfer, the data being received or transmitted may remain in the FIFO. When disconnecting a USB cable, clear the FIFO.

While a FIFO is transferring data, it must not be cleared.

18.9.3 Overreading and Overwriting the Data Registers

Note the following when reading or writing to a data register of this module.

(1) Receive data registers

The receive data registers must not be read exceeding the valid amount of receive data, that is, the number of bytes indicated by the receive data size register. Even for EPDR1 which has double FIFO buffers, the maximum data to be read at one time is 64 bytes. After the data is read from the current valid FIFO buffer, be sure to write 1 to EP1RDFN in TRG, which switches the valid buffer, updates the receive data size to the new number of bytes, and enables the next data to be received.

(2) Transmit data registers

The transmit data registers must not be written to exceeding the maximum packet size. Even for EPDR2 which has double FIFO buffers, write data within the maximum packet size at one time. After the data is written, write 1 to PKTE in TRG to switch the valid buffer and enable the next data to be written. Data must not be continuously written to the two FIFO buffers.

18.9.4 Assigning Interrupt Sources to EP0

The EP0-related interrupt sources indicated by the interrupt source bits (bits 0 to 3) in IFR0 must be assigned to the same interrupt signal with ISR0. The other interrupt sources have no limitations.

18.9.5 Clearing the FIFO When DMA Transfer is Enabled

The endpoint 1 data register (EPDR1) cannot be cleared when DMA transfer for endpoint 1 is enabled (EP1 DMAE in DMAR = 1). Cancel DMA transfer before clearing the register.

18.9.6 Notes on TR Interrupt

Note the following when using the transfer request interrupt (TR interrupt) for IN transfer to EP0i, EP2, or EP3.

The TR interrupt flag is set if the FIFO for the target EP has no data when the IN token is sent from the USB host. However, at the timing shown in figure 18.19, multiple TR interrupts occur successively. Take appropriate measures against malfunction in such a case.

Note: This module determines whether to return NAK if the FIFO of the target EP has no data when receiving the IN token, but the TR interrupt flag is set only after a NAK handshake is sent. If the next IN token is sent before PKTE of TRG is written to, the TR interrupt flag is set again.

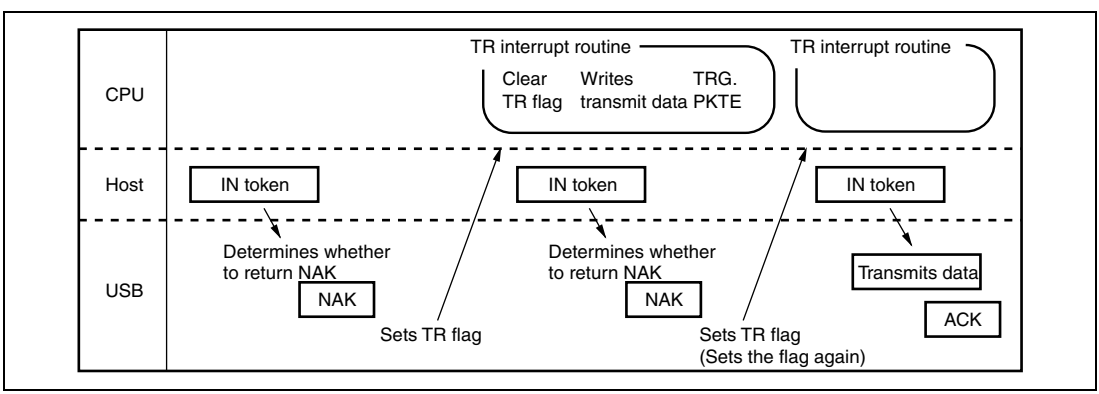


Figure 18.19 TR Interrupt Flag Set Timing

Section 19 Pin Function Controller

19.1 Overview

The pin function controller (PFC) consists of registers to select the pin functions and I/O directions of multiplex pins. Pin functions and I/O directions can be individually selected for every pin regardless of the LSI operating mode. Table 19.1 lists the multiplex pins of this LSI.

Table 19.1 Multiplex Pins

Port	Port Function (Related Module)	Other Functions (Related Module)
A	PTA7 input/output (port)/PINT7 input (INTC)	D23 input/output (BSC)
A	PTA6 input/output (port)/PINT6 input (INTC)	D22 input/output (BSC)
A	PTA5 input/output (port)/PINT5 input (INTC)	D21 input/output (BSC)
A	PTA4 input/output (port)/PINT4 input (INTC)	D20 input/output (BSC)
A	PTA3 input/output (port)/PINT3 input (INTC)	D19 input/output (BSC)
A	PTA2 input/output (port)/PINT2 input (INTC)	D18 input/output (BSC)
A	PTA1 input/output (port)/PINT1 input (INTC)	D17 input/output (BSC)
A	PTA0 input/output (port)/PINT0 input (INTC)	D16 input/output (BSC)
B	PTB7 input/output (port)/PINT15 input (INTC)	D31 input/output (BSC)
B	PTB6 input/output (port)/PINT14 input (INTC)	D30 input/output (BSC)
B	PTB5 input/output (port)/PINT13 input (INTC)	D29 input/output (BSC)
B	PTB4 input/output (port)/PINT12 input (INTC)	D28 input/output (BSC)
B	PTB3 input/output (port)/PINT11 input (INTC)	D27 input/output (BSC)
B	PTB2 input/output (port)/PINT10 input (INTC)	D26 input/output (BSC)
B	PTB1 input/output (port)/PINT9 input (INTC)	D25 input/output (BSC)
B	PTB0 input/output (port)/PINT8 input (INTC)	D24 input/output (BSC)
C	PTC7 input/output (port)	$\overline{\text{CS6A}}$ output (BSC)
C	PTC6 input/output (port)	$\overline{\text{CS5A}}$ output (BSC)
C	PTC5 input/output (port)	$\overline{\text{CS4}}$ output (BSC)
C	PTC4 input/output (port)	$\overline{\text{CS3}}$ output (BSC)
C	PTC3 input/output (port)	$\overline{\text{CS2}}$ output (BSC)
C	PTC2 input/output (port)	$\overline{\text{WE3}}$ output (BSC)/DQMUU output (BSC)/ $\overline{\text{AH}}$ output (BSC)
C	PTC1 input/output (port)	$\overline{\text{WE2}}$ output (BSC)/DQMUL output (BSC)
C	PTC0 input/output (port)	$\overline{\text{BS}}$ output (BSC)

Port	Port Function (Related Module)	Other Functions (Related Module)
D	PTD7 input/output (port)	$\overline{CS6B}$ output (BSC)
D	PTD6 input/output (port)	$\overline{CS5B}$ output (BSC)
D	PTD5 input (port)	NF*[1]
D	PTD4 input/output (port)	CKE output (BSC)
D	PTD3 input/output (port)	$\overline{CASU}$ output (BSC)
D	PTD2 input/output (port)	$\overline{CASL}$ output (BSC)
D	PTD1 input/output (port)	$\overline{RASU}$ output (BSC)
D	PTD0 input/output (port)	$\overline{RASL}$ output (BSC)
E	PTE7 input/output (port)	—
E	PTE6 input/output (port)	TCLK input (TMU)
E	PTE5 input/output (port)	STATUS1 output (CPG)/$\overline{CTS0}$ input (SCIF0)
E	PTE4 input/output (port)	STATUS0 output (CPG)/$\overline{RTS0}$ output (SCIF0)
E	PTE3 input/output (port)	TEND0 output (DMAC)
E	PTE2 input/output (port)	IRQ5 input (INTC)
E	PTE1 input/output (port)	DACK1 output (DMAC)
E	PTE0 input/output (port)	DACK0 output (DMAC)
F	PTF7 input/output (port)	$\overline{ASEMD0}$ input
F	PTF6 input/output (port)	$\overline{ASEBRKAK}$ output
F	PTF5 input/output (port)	TDO output (H-UDI)
F	PTF4 input/output (port)	$\overline{AUDSYNC}$ output (AUD)
F	PTF3 input/output (port)	AUDATA3 output (AUD)/TO3 output (TPU)
F	PTF2 input/output (port)	AUDATA2 output (AUD)/TO2 output (TPU)
F	PTF1 input/output (port)	AUDATA1 output (AUD)/TO1 output (TPU)
F	PTF0 input/output (port)	AUDATA0 output (AUD)/TO0 output (TPU)
G	PTG7 input/output (port)	$\overline{WAIT}$ input (BSC)
G	PTG6 input/output (port)	$\overline{BREQ}$ input (BSC)
G	PTG5 input/output (port)	$\overline{BACK}$ output (BSC)
G	PTG4 input/output (port)	AUDCK output (AUD)
G	PTG3 input/output (port)	$\overline{TRST}$ input (H-UDI)
G	PTG2 input/output (port)	TMS input (H-UDI)
G	PTG1 input/output (port)	TCK input (H-UDI)
G	PTG0 input/output (port)	TDI input (H-UDI)

Port	Port Function (Related Module)	Other Functions (Related Module)
H	PTH6 input/output (port)	DREQ1 input (DMAC)
H	PTH5 input/output (port)	DREQ0 input (DMAC)
H	PTH4 input/output (port)	IRQ4 input (INTC)
H	PTH3 input/output (port)	IRQ3 input (INTC)/$\overline{\text{IRL3}}$ input (INTC)
H	PTH2 input/output (port)	IRQ2 input (INTC)/$\overline{\text{IRL2}}$ input (INTC)
H	PTH1 input/output (port)	IRQ1 input (INTC)/$\overline{\text{IRL1}}$ input (INTC)
H	PTH0 input/output (port)	IRQ0 input (INTC)/$\overline{\text{IRL0}}$ input (INTC)
J	PTJ7 output (port)	NF*[1]
J	PTJ6 output (port)	NF*[1]
J	PTJ5 output (port)	NF*[1]
J	PTJ4 output (port)	NF*[1]
J	PTJ3 output (port)	NF*[1]
J	PTJ2 output (port)	NF*[1]
J	PTJ1 output (port)	NF*[1]
J	PTJ0 output (port)	NF*[1]
K	PTK7 input/output (port)	A25 output (BSC)
K	PTK6 input/output (port)	A24 output (BSC)
K	PTK5 input/output (port)	A23 output (BSC)
K	PTK4 input/output (port)	A22 output (BSC)
K	PTK3 input/output (port)	A21 output (BSC)
K	PTK2 input/output (port)	A20 output (BSC)
K	PTK1 input/output (port)	A19 output (BSC)
K	PTK0 input/output (port)	A0 output (BSC)
L	PTL3 input (port)	AN3 input (ADC)
L	PTL2 input (port)	AN2 input (ADC)
L	PTL1 input (port)	AN1 input (ADC)
L	PTL0 input (port)	AN0 input (ADC)
M	PTM6 input/output (port)	VBUS input (USB)
M	PTM4 input (port)	NF*[1]
M	PTM3 input/output (port)	—
M	PTM2 input/output (port)	—
M	PTM1 input/output (port)	—
M	PTM0 input/output (port)	—

Port	Port Function (Related Module)	Other Functions (Related Module)
N	PTN7 input/output (port)	—
N	PTN6 input/output (port)	DPLS input (USB)
N	PTN5 input/output (port)	DMNS input (USB)
N	PTN4 input/output (port)	TXDPLS output (USB)
N	PTN3 input/output (port)	TXDMNS output (USB)
N	PTN2 input/output (port)	XVDATA input (USB)
N	PTN1 input/output (port)	TXENL output (USB)
N	PTN0 input/output (port)	SUSPND output (USB)
SCPT	SCPT5 input/output (port)	$\overline{\text{CTS2}}$ input (SCIF2)
SCPT	SCPT4 input/output (port)	$\overline{\text{RTS2}}$ output (SCIF2)
SCPT	SCPT3 input/output (port)	SCK2 input/output (SCIF2)
SCPT	SCPT2 input (port)*2	RXD2 input (SCIF2)
SCPT	SCPT2 output (port)*2	TXD2 output (SCIF2)
SCPT	SCPT1 input/output (port)	SCK0 input/output (SCIF0)
SCPT	SCPT0 input (port)*2	RXD0 input (SCIF0)/IrRX input (IrDA)
SCPT	SCPT0 output (port)*2	TXD0 output (SCIF0)/IrTX output (IrDA)

Notes: *1 The initial functions of NF (No Function) pins are not assigned after power-on reset. Specifies the functions with Pin Function Controller (PFC).
PTD5 and PTM4 must be pulled up.
PTJ[7:0] must be open except for the pins specified as port output pins.

*2 SCPT0 and SCPT2 each have two separate pins for input and output, however, a common data register is accessed.

In table 19.1, pin functions in the shaded column can be used immediately after a power-on reset.

19.2 Register Descriptions

The PFC has the following registers. For details on register addresses and access sizes, see section 24, List of Registers.

- Port A control register (PACR)
- Port B control register (PBCR)
- Port C control register (PCCR)
- Port D control register (PDCR)
- Port E control register (PECR)
- Port E control register 2 (PECR2)
- Port F control register (PFCR)
- Port F control register 2 (PFCR2)
- Port G control register (PGCR)
- Port H control register (PHCR)
- Port J control register (PJCR)
- Port K control register (PKCR)
- Port L control register (PLCR)
- Port M control register (PMCR)
- Port N control register (PNCR)
- Port N control register 2 (PNCR2)
- Port SC control register (SCPCR)

19.2.1 Port A Control Register (PACR)

PACR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15	PA7MD1	0	R/W	PTA7 Mode
14	PA7MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
13	PA6MD1	0	R/W	PTA6 Mode
12	PA6MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
11	PA5MD1	0	R/W	PTA5 Mode
10	PA5MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
9	PA4MD1	0	R/W	PTA4 Mode
8	PA4MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
7	PA3MD1	0	R/W	PTA3 Mode
6	PA3MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
5	PA2MD1	0	R/W	PTA2 Mode
4	PA2MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
3	PA1MD1	0	R/W	PTA1 Mode
2	PA1MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
1	PA0MD1	0	R/W	PTA0 Mode
0	PA0MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

19.2.2 Port B Control Register (PBCR)

PBCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15	PB7MD1	0	R/W	PTB7 Mode
14	PB7MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
13	PB6MD1	0	R/W	PTB6 Mode
12	PB6MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
11	PB5MD1	0	R/W	PTB5 Mode
10	PB5MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
9	PB4MD1	0	R/W	PTB4 Mode
8	PB4MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
7	PB3MD1	0	R/W	PTB3 Mode
6	PB3MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
5	PB2MD1	0	R/W	PTB2 Mode
4	PB2MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
3	PB1MD1	0	R/W	PTB1 Mode
2	PB1MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
1	PB0MD1	0	R/W	PTB0 Mode
0	PB0MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

19.2.3 Port C Control Register (PCCR)

PCCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15	PC7MD1	1	R/W	PTC7 Mode
14	PC7MD0	1	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
13	PC6MD1	1	R/W	PTC6 Mode
12	PC6MD0	1	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
11	PC5MD1	0	R/W	PTC5 Mode
10	PC5MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
9	PC4MD1	0	R/W	PTC4 Mode
8	PC4MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
7	PC3MD1	0	R/W	PTC3 Mode
6	PC3MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
5	PC2MD1	0	R/W	PTC2 Mode
4	PC2MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
3	PC1MD1	0	R/W	PTC1 Mode
2	PC1MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
1	PC0MD1	0	R/W	PTC0 Mode
0	PC0MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

19.2.4 Port D Control Register (PDCR)

PDCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15	PD7MD1	1	R/W	PTD7 Mode
14	PD7MD0	1	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
13	PD6MD1	1	R/W	PTD6 Mode
12	PD6MD0	1	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
11	PD5MD1	0	R/W	PTD5 Mode
10	PD5MD0	0	R/W	00: NF
				01: Setting prohibited
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
9	PD4MD1	0	R/W	PTD4 Mode
8	PD4MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
7	PD3MD1	1	R/W	PTD3 Mode
6	PD3MD0	1	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
5	PD2MD1	0	R/W	PTD2 Mode
4	PD2MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
3	PD1MD1	1	R/W	PTD1 Mode
2	PD1MD0	1	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
1	PD0MD1	0	R/W	PTD0 Mode
0	PD0MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

19.2.5 Port E Control Register (PECR)

PECR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15	PE7MD1	1	R/W	PTE7 Mode
14	PE7MD0	0	R/W	00: Setting prohibited 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
13	PE6MD1	1	R/W	PTE6 Mode
12	PE6MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
11	PE5MD1	0	R/W	PTE5 Mode
10	PE5MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
9	PE4MD1	0	R/W	PTE4 Mode
8	PE4MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
7	PE3MD1	1	R/W	PTE3 Mode
6	PE3MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
5	PE2MD1	1	R/W	PTE2 Mode
4	PE2MD0	1	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
3	PE1MD1	1	R/W	PTE1 Mode
2	PE1MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
1	PE0MD1	1	R/W	PTE0 Mode
0	PE0MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

19.2.6 Port E Control Register 2 (PECR2)

PECR2 is an 8-bit readable/writable register that selects the pin function.

Bit	Bit Name	Initial Value	R/W	Description
7, 6	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
5	PE5MD2	0	R/W	PE5 Mode 2 This bit is valid when the PE5MD[1:0] bits in PECR are set to B'00 (other functions). 0: STATUS1 (CPG) 1: $\overline{\text{CTS0}}$ (SCIF0)
4	PE4MD2	0	R/W	PE4 Mode 2 This bit is valid when the PE4MD[1:0] bits in PECR are set to B'00 (other functions). 0: STATUS0 (CPG) 1: $\overline{\text{RTS0}}$ (SCIF0)
3 to 0	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

19.2.7 Port F Control Register (PFCR)

PFCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15	PF7MD1	0	R/W	PTF7 Mode
14	PF7MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
13	PF6MD1	1*	R/W	PTF6 Mode
12	PF6MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
11	PF5MD1	0	R/W	PTF5 Mode
10	PF5MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
9	PF4MD1	1*	R/W	PTF4 Mode
8	PF4MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
7	PF3MD1	1*	R/W	PTF3 Mode
6	PF3MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
5	PF2MD1	1*	R/W	PTF2 Mode
4	PF2MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
3	PF1MD1	1*	R/W	PTF1 Mode
2	PF1MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
1	PF0MD1	1*	R/W	PTF0 Mode
0	PF0MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

Note: * Indicates the initial value when $\overline{\text{ASEMD0}}$ = 1. When $\overline{\text{ASEMD0}}$ = 0, the relevant bit becomes 0, and other functions is selected.

19.2.8 Port F Control Register 2 (PFCR2)

PFCR2 is an 8-bit readable/writable register that selects the pin function.

Bit	Bit Name	Initial Value	R/W	Description
7 to 4	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
3	PF3MD2	0	R/W	PTF3 Mode 2 This bit is valid when the PF3MD[1:0] bits in PFCR are set to B'00 (other functions). 0: AUDATA3 (AUD) 1: TO3 (TPU)
2	PF2MD2	0	R/W	PTF2 Mode 2 This bit is valid when the PF2MD[1:0] bits in PFCR are set to B'00 (other functions). 0: AUDATA2 (AUD) 1: TO2 (TPU)

Bit	Bit Name	Initial Value	R/W	Description
1	PF1MD2	0	R/W	PTF1 Mode 2 This bit is valid when the PF1MD[1:0] bits in PFCR are set to B'00 (other functions). 0: AUDATA1 (AUD) 1: TO1 (TPU)
0	PF0MD2	0	R/W	PTF0 Mode 2 This bit is valid when the PF0MD[1:0] bits in PFCR are set to B'00 (other functions). 0: AUDATA0 (AUD) 1: TO0 (TPU)

19.2.9 Port G Control Register (PGCR)

PGCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15	PG7MD1	0	R/W	PTG7 Mode
14	PG7MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
13	PG6MD1	0	R/W	PTG6 Mode
12	PG6MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
11	PG5MD1	0	R/W	PTG5 Mode
10	PG5MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
9	PG4MD1	1*	R/W	PTG4 Mode
8	PG4MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
7	PG3MD1	0	R/W	PTG3 Mode
6	PG3MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
5	PG2MD1	0	R/W	PTG2 Mode
4	PG2MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
3	PG1MD1	0	R/W	PTG1 Mode
2	PG1MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
1	PG0MD1	0	R/W	PTG0 Mode
0	PG0MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

Note: * Indicates the initial value when $\overline{\text{ASEMD0}}$ = 1. When $\overline{\text{ASEMD0}}$ = 0, the relevant bit becomes 0, and other functions is selected.

19.2.10 Port H Control Register (PHCR)

PHCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15, 14	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
13	PH6MD1	1	R/W	PTH6 Mode
12	PH6MD0	1	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
11	PH5MD1	1	R/W	PTH5 Mode
10	PH5MD0	1	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
9	PH4MD1	0	R/W	PTH4 Mode
8	PH4MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
7	PH3MD1	0	R/W	PTH3 Mode
6	PH3MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
5	PH2MD1	0	R/W	PTH2 Mode
4	PH2MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
3	PH1MD1	0	R/W	PTH1 Mode
2	PH1MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
1	PH0MD1	0	R/W	PTH0 Mode
0	PH0MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

19.2.11 Port J Control Register (PJCR)

PJCR is a 16-bit readable/writable register that selects the pin function.

Bit	Bit Name	Initial Value	R/W	Description
15	PJ7MD1	0	R/W	PTJ7 Mode
14	PJ7MD0	0	R/W	00: NF
				01: Port output
				10: Setting prohibited
				11: Setting prohibited
13	PJ6MD1	0	R/W	PTJ6 Mode
12	PJ6MD0	0	R/W	00: NF
				01: Port output
				10: Setting prohibited
				11: Setting prohibited
11	PJ5MD1	0	R/W	PTJ5 Mode
10	PJ5MD0	0	R/W	00: NF
				01: Port output
				10: Setting prohibited
				11: Setting prohibited

Bit	Bit Name	Initial Value	R/W	Description
9	PJ4MD1	0	R/W	PTJ4 Mode
8	PJ4MD0	0	R/W	00: NF
				01: Port output
				10: Setting prohibited
				11: Setting prohibited
7	PJ3MD1	0	R/W	PTJ3 Mode
6	PJ3MD0	0	R/W	00: NF
				01: Port output
				10: Setting prohibited
				11: Setting prohibited
5	PJ2MD1	0	R/W	PTJ2 Mode
4	PJ2MD0	0	R/W	00: NF
				01: Port output
				10: Setting prohibited
				11: Setting prohibited
3	PJ1MD1	0	R/W	PTJ1 Mode
2	PJ1MD0	0	R/W	00: NF
				01: Port output
				10: Setting prohibited
				11: Setting prohibited
1	PJ0MD1	0	R/W	PTJ0 Mode
0	PJ0MD0	0	R/W	00: NF
				01: Port output
				10: Setting prohibited
				11: Setting prohibited

19.2.12 Port K Control Register (PKCR)

PKCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15	PK7MD1	0	R/W	PTK7 Mode
14	PK7MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
13	PK6MD1	0	R/W	PTK6 Mode
12	PK6MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
11	PK5MD1	0	R/W	PTK5 Mode
10	PK5MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
9	PK4MD1	0	R/W	PTK4 Mode
8	PK4MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
7	PK3MD1	0	R/W	PTK3 Mode
6	PK3MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
5	PK2MD1	0	R/W	PTK2 Mode
4	PK2MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
3	PK1MD1	0	R/W	PTK1 Mode
2	PK1MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)
1	PK0MD1	0	R/W	PTK0 Mode
0	PK0MD0	0	R/W	00: Other functions (see table 19.1)
				01: Port output
				10: Port input (pull-up MOS: On)
				11: Port input (pull-up MOS: Off)

19.2.13 Port L Control Register (PLCR)

PLCR is a 16-bit readable/writable register that selects the pin function.

Bit	Bit Name	Initial Value	R/W	Description
15 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7	PL3MD1	0	R/W	PTL3 Mode
6	PL3MD0	0	R/W	00: Other functions (see table 19.1) 01: Setting prohibited 10: Setting prohibited 11: Port input (pull-up MOS: Off)
5	PL2MD1	0	R/W	PTL2 Mode
4	PL2MD0	0	R/W	00: Other functions (see table 19.1) 01: Setting prohibited 10: Setting prohibited 11: Port input (pull-up MOS: Off)
3	PL1MD1	0	R/W	PTL1 Mode
2	PL1MD0	0	R/W	00: Other functions (see table 19.1) 01: Setting prohibited 10: Setting prohibited 11: Port input (pull-up MOS: Off)
1	PL0MD1	0	R/W	PTL0 Mode
0	PL0MD0	0	R/W	00: Other functions (see table 19.1) 01: Setting prohibited 10: Setting prohibited 11: Port input (pull-up MOS: Off)

19.2.14 Port M Control Register (PMCR)

PMCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15, 14	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
13	PM6MD1	1	R/W	PTM6 Mode
12	PM6MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
11, 10	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
9	PM4MD1	0	R/W	PTM4 Mode
8	PM4MD0	0	R/W	00: NF 01: Setting prohibited 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
7	PM3MD1	1	R/W	PTM3 Mode
6	PM3MD0	0	R/W	00: Setting prohibited 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
5	PM2MD1	1	R/W	PTM2 Mode
4	PM2MD0	0	R/W	00: Setting prohibited 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
3	PM1MD1	1	R/W	PTM1 Mode
2	PM1MD0	0	R/W	00: Setting prohibited 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
1	PM0MD1	1	R/W	PTM0 Mode
0	PM0MD0	0	R/W	00: Setting prohibited 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

19.2.15 Port N Control Register (PNCR)

PNCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control.

Bit	Bit Name	Initial Value	R/W	Description
15	PN7MD1	1	R/W	PTN7 Mode
14	PN7MD0	0	R/W	00: Setting prohibited 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
13	PN6MD1	1	R/W	PTN6 Mode
12	PN6MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
11	PN5MD1	1	R/W	PTN5 Mode
10	PN5MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
9	PN4MD1	1	R/W	PTN4 Mode
8	PN4MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
7	PN3MD1	1	R/W	PTN3 Mode
6	PN3MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
5	PN2MD1	1	R/W	PTN2 Mode
4	PN2MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
3	PN1MD1	1	R/W	PTN1 Mode
2	PN1MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
1	PN0MD1	1	R/W	PTN0 Mode
0	PN0MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

19.2.16 Port N Control Register 2 (PNCR2)

PNCR2 is an 8-bit readable/writable register that selects the pin function.

Bit	Bit Name	Initial Value	R/W	Description
7	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
6	PN6MD2	0	R/W	PTN6 Mode 2 This bit is valid when the PN6MD[1:0] bits in PNCR are set to B'00 (other functions). 0: Setting prohibited 1: DPLS (USB)
5	PN5MD2	0	R/W	PTN5 Mode 2 This bit is valid when the PN5MD[1:0] bits in PNCR are set to B'00 (other functions). 0: Setting prohibited 1: DMNS (USB)
4	PN4MD2	0	R/W	PTN4 Mode 2 This bit is valid when the PN4MD[1:0] bits in PNCR are set to B'00 (other functions). 0: Setting prohibited 1: TXDPLS (USB)
3	PN3MD2	0	R/W	PTN3 Mode 2 This bit is valid when the PN3MD[1:0] bits in PNCR are set to B'00 (other functions). 0: Setting prohibited 1: TXDMNS (USB)
2	PN2MD2	0	R/W	PTN2 Mode 2 This bit is valid when the PN2MD[1:0] bits in PNCR are set to B'00 (other functions). 0: Setting prohibited 1: XVDATA (USB)

Bit	Bit Name	Initial Value	R/W	Description
1	PN1MD2	0	R/W	PTN1 Mode 2 This bit is valid when the PN1MD[1:0] bits in PNCR are set to B'00 (other functions). 0: Setting prohibited 1: TXENL (USB)
0	PN0MD2	0	R/W	PTN0 Mode 2 This bit is valid when the PN0MD[1:0] bits in PNCR are set to B'00 (other functions). 0: Setting prohibited 1: SUSPND (USB)

19.2.17 Port SC Control Register (SCPCR)

SCPCR is a 16-bit readable/writable register that selects the pin function and input pull-up MOS control. The settings of SCPCR become valid only when transmission/reception operation is disabled by the settings of SCSCR in the on-chip serial communication interface (SCIF).

When the TE bit in SCSCR_0 or SCSCR_2 of the SCIF is set to 1, the output status of “other functions: TxD0 or TxD2” has priority for the setting of SCPCR.

Similarly, when the RE bit in SCSCR_0 or SCSCR_2 is set to 1, the input status of “other functions: RxD0 or RxD2” has priority for the setting of SCPCR.

Bit	Bit Name	Initial Value	R/W	Description
15 to 12	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
11	SCP5MD1	0	R/W	SCPT5 Mode
10	SCP5MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)

Bit	Bit Name	Initial Value	R/W	Description
9	SCP4MD1	0	R/W	SCPT4 Mode
8	SCP4MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
7	SCP3MD1	0	R/W	SCPT3 Mode
6	SCP3MD0	0	R/W	00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
5	SCP2MD1	0	R/W	SCPT2 Mode
4	SCP2MD0	0	R/W	These bits select pin function and input pull-up MOS control. When TE = 0 and RE = 0 in SCSCR_2, operation is as follows: 00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off) When TE = 1 in SCSCR_2, the SCPT2/TxD2 pin functions as TxD2. When RE = 1 in SCSCR_2, the SCPT2/RxD2 pin functions as RxD2. Note: Since two pins (TxD2 and RxD2) are used to access one bit (SCPT2), there is no combination of simultaneous input/output of SCPT2. When port input is set (when bit SCP2MD1 is set to 1), the TxD2 pin enters an output state when the TE bit in SCSCR_2 is set to 1, whereas it enters high-impedance state when the TE bit is cleared to 0.

Bit	Bit Name	Initial Value	R/W	Description
3	SCP1MD1	0	R/W	SCPT1 Mode
2	SCP1MD0	0	R/W	These bits select pin function and input pull-up MOS control. 00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off)
1	SCP0MD1	0	R/W	SCPT0 Mode
0	SCP0MD0	0	R/W	These bits select pin function and input pull-up MOS control. When TE = 0 and RE = 0 in SCSCR_0, operation is as follows: 00: Other functions (see table 19.1) 01: Port output 10: Port input (pull-up MOS: On) 11: Port input (pull-up MOS: Off) When TE = 1 in SCSCR_0, the SCPT0/TxD0 pin functions as TxD0. When RE = 1 in SCSCR_0, the SCPT0/RxD0 pin functions as RxD0. Note: Since two pins (TxD0 and RxD0) are used to access one bit (SCPT0), there is no combination of simultaneous input/output of SCPT0. When port input is set (when bit SCP0MD1 is set to 1), the TxD0 pin enters an output state when the TE bit in SCSCR_0 is set to 1, whereas it enters high-impedance state when the TE bit is cleared to 0.

Section 20 I/O Ports

This LSI has fourteen I/O ports (ports A to H, J to N, and SC). All port pins are multiplexed with other pin functions (the pin function controller (PFC) handles the selection of pin functions and pull-up MOS control). Each port has a data register which stores data for the pins.

20.1 Port A

Port A is an 8-bit input/output port with the pin configuration shown in figure 20.1. Each pin has an input pull-up MOS, which is controlled by the port A control register (PACR) in the PFC.

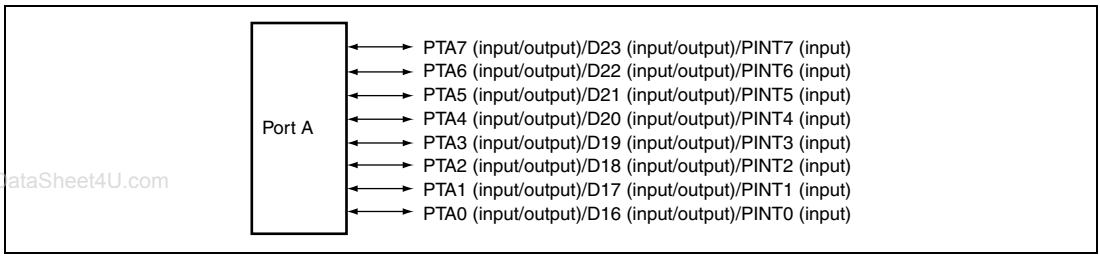


Figure 20.1 Port A

20.1.1 Register Description

Port A has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port A data register (PADR)

20.1.2 Port A Data Register (PADR)

PADR is an 8-bit readable/writable register that stores data for pins PTA7 to PTA0. Bits PA7DT to PA0DT correspond to pins PTA7 to PTA0. When the pin function is general output port, if the port is read, the value of the corresponding PADR bit is returned directly. When the function is general input port, if the port is read the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PA7DT to PA0DT	All 0	R/W	Table 20.1 shows the function of PADR.

Table 20.1 Port A Data Register (PADR) Read/Write Operations

PACR State				
PAnMD1	PAnMD0	Pin State	Read	Write
0	0	Other function	PADR value	Data can be written to PADR but no effect on pin state.
	1	Output	PADR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PADR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PADR but no effect on pin state.

Note: n = 0 to 7

20.2 Port B

Port B is an 8-bit input/output port with the pin configuration shown in figure 20.2. Each pin has an input pull-up MOS, which is controlled by the port B control register (PBCR) in the PFC.

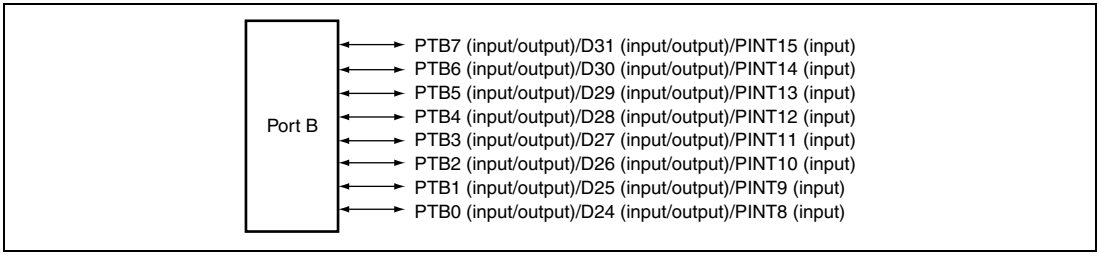


Figure 20.2 Port B

20.2.1 Register Description

Port B has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port B data register (PBDR)

20.2.2 Port B Data Register (PBDR)

PBDR is an 8-bit readable/writable register that stores data for pins PTB7 to PTB0. Bits PB7DT to PB0DT correspond to pins PTB7 to PTB0. When the pin function is general output port, if the port is read the value of the corresponding PBDR bit is returned directly. When the function is general input port, if the port is read, the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PB7DT to PB0DT	All 0	R/W	Table 20.2 shows the function of PBDR.

Table 20.2 Port B Data Register (PBDR) Read/Write Operations

PBCR State				
PBnMD1	**PBnMD0**	**Pin State**	**Read**	**Write**
0	0	Other function	PBDR value	Data can be written to PBDR but no effect on pin state.
	1	Output	PBDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PBDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PBDR but no effect on pin state.

Note: n = 0 to 7

20.3 Port C

Port C is an 8-bit input/output port with the pin configuration shown in figure 20.3. Each pin has an input pull-up MOS, which is controlled by the port C control register (PCCR) in the PFC.

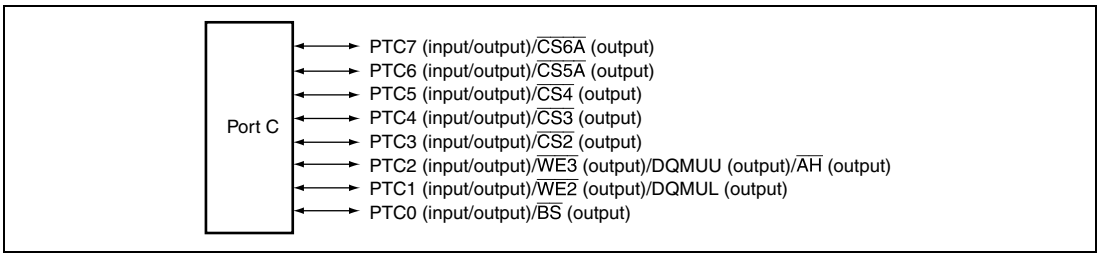


Figure 20.3 Port C

20.3.1 Register Description

Port C has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port C data register (PCDR)

20.3.2 Port C Data Register (PCDR)

PCDR is an 8-bit readable/writable register that stores data for pins PTC7 to PTC0. Bits PC7DT to PC0DT correspond to pins PTC7 to PTC0. When the pin function is general output port, if the port is read, the value of the corresponding PCDR bit is returned directly. When the function is general input port, if the port is read, the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PC7DT to PC0DT	All 0	R/W	Table 20.3 shows the function of PCDR.

Table 20.3 Port C Data Register (PCDR) Read/Write Operations

PCCR State				
PCnMD1	**PCnMD0**	**Pin State**	**Read**	**Write**
0	0	Other function	PCDR value	Data can be written to PCDR but no effect on pin state.
	1	Output	PCDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PCDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PCDR but no effect on pin state.

Note: n = 0 to 7

20.4 Port D

Port D is an 8-bit input/output port with the pin configuration shown in figure 20.4. Each pin has an input pull-up MOS, which is controlled by the port D control register (PDCR) in the PFC.

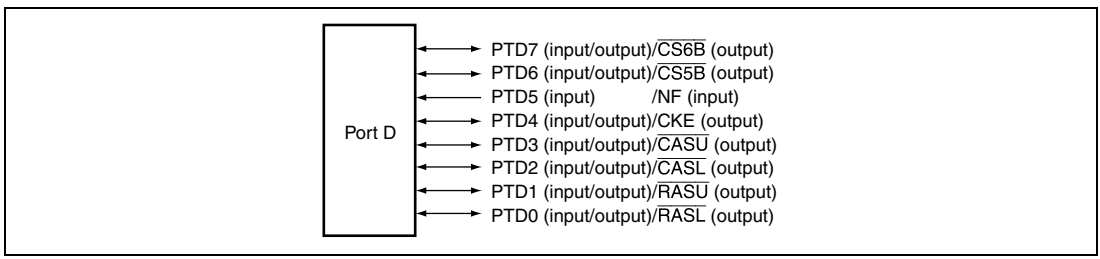


Figure 20.4 Port D

20.4.1 Register Description

Port D has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port D data register (PDDR)

20.4.2 Port D Data Register (PDDR)

PDDR is an 8-bit readable/writable register that stores data for pins PTD7 to PTD0. Bits PD7DT to PD0DT correspond to pins PTD7 to PTD0. When the pin function is general output port, if the port is read, the value of the corresponding PDDR bit is returned directly. When the function is general input port, if the port is read, the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PD7DT to PD0DT	All 0	R/W	Table 20.4 shows the function of PDDR.

Table 20.4 Port D Data Register (PDDR) Read/Write Operations

PDCR State				
PDnMD1	**PDnMD0**	**Pin State**	**Read**	**Write**
0	0	Other function	PDDR value	Data can be written to PDDR but no effect on pin state.
	1	Output	PDDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PDDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PDDR but no effect on pin state.

Note: n = 0 to 4, 6, and 7

PDCR State				
PD5MD1	**PD5MD0**	**Pin State**	**Read**	**Write**
0	0	NF	PDDR value	Data can be written to PDDR but no effect on pin state.
	1	Setting Prohibited	—	—
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PDDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PDDR but no effect on pin state.

20.5 Port E

Port E is an 8-bit input/output port with the pin configuration shown in figure 20.5. Each pin has an input pull-up MOS, which is controlled by the port E control register (PECR) in the PFC.

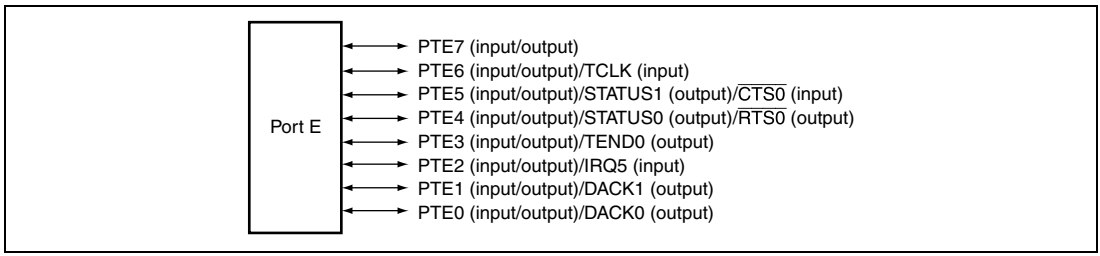


Figure 20.5 Port E

20.5.1 Register Description

Port E has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port E data register (PEDR)

20.5.2 Port E Data Register (PEDR)

PEDR is an 8-bit readable/writable register that stores data for pins PTE7 to PTE0. Bits PE7DT to PE0DT correspond to pins PTE7 to PTE0. When the pin function is general output port, if the port is read, the value of the corresponding PEDR bit is returned directly. When the function is general input port, if the port is read the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PE7DT to PE0DT	All 0	R/W	Table 20.5 shows the function of PEDR.

Table 20.5 Port E Data Register (PEDR) Read/Write Operations

PECR State				
PEnMD1	**PEnMD0**	**Pin State**	**Read**	**Write**
0	0	Other function	PEDR value	Data can be written to PEDR but no effect on pin state.
	1	Output	PEDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PEDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PEDR but no effect on pin state.

Note: n = 0 to 7

20.6 Port F

Port F is an 8-bit input port with the pin configuration shown in figure 20.6. Each pin has an input pull-up MOS, which is controlled by the port F control register (PFCR) in the PFC.

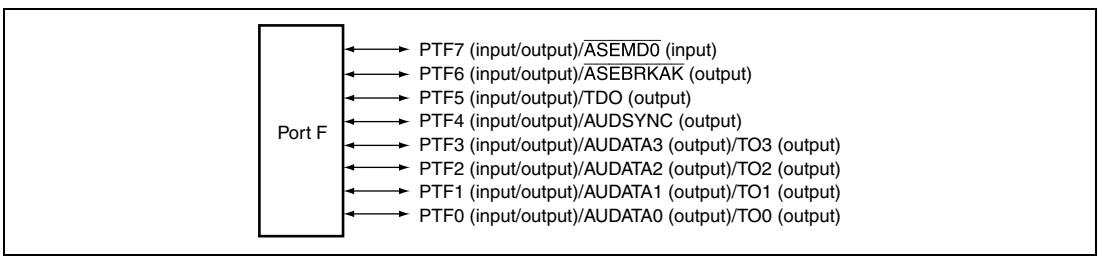


Figure 20.6 Port F

20.6.1 Register Description

Port F has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port F data register (PFDR)

20.6.2 Port F Data Register (PFDR)

PFDR is an 8-bit readable/writable register that stores data for pins PTF7 to PTF0. Bits PF7DT to PF0DT correspond to pins PTF7 to PTF0. When the pin function is general output port, if the port is read, the value of the corresponding PFDR bit is returned directly. When the function is general input port, if the port is read the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PF7DT to PF0DT	All 0	R/W	Table 20.6 shows the function of PFDR.

Table 20.6 Port F Data Register (PFDR) Read/Write Operations

PFCR State				
PFnMD1	PFnMD0	Pin State	Read	Write
0	0	Other function	PFDR value	Data can be written to PFDR but no effect on pin state.
	1	Output	PFDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PFDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PFDR but no effect on pin state.

Note: n = 0 to 7

20.7 Port G

Port G is an 8-bit input port with the pin configuration shown in figure 20.7. Each pin has an input pull-up MOS, which is controlled by the port G control register (PGCR) in the PFC.

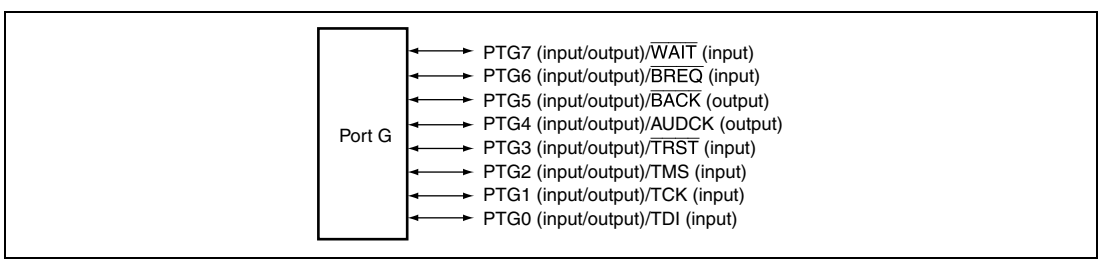


Figure 20.7 Port G

20.7.1 Register Description

Port G has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port G data register (PGDR)

20.7.2 Port G Data Register (PGDR)

PGDR is an 8-bit readable/writable register that stores data for pins PTG7 to PTG0. Bits PG7DT to PG0DT correspond to pins PTG7 to PTG0. When the pin function is general output port, if the port is read, the value of the corresponding PGDR bit is returned directly. When the function is general input port, if the port is read the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PG7DT to PG0DT	All 0	R/W	Table 20.7 shows the function of PGDR.

Table 20.7 Port G Data Register (PGDR) Read/Write Operations

PGCR State				
PGnMD1	PGnMD0	Pin State	Read	Write
0	0	Other function	PGDR value	Data can be written to PGDR but no effect on pin state.
	1	Output	PGDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PGDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PGDR but no effect on pin state.

Note: n = 0 to 7

20.8 Port H

Port H is a 7-bit input/output port with the pin configuration shown in figure 20.8. Each pin has an input pull-up MOS, which is controlled by the port H control register (PHCR) in the PFC.

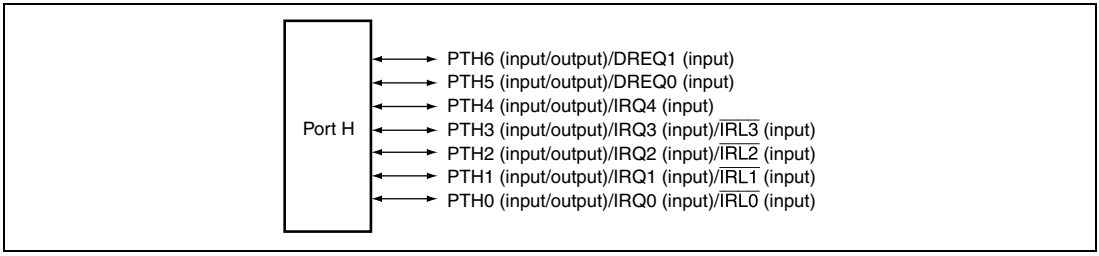


Figure 20.8 Port H

20.8.1 Register Description

Port H has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port H data register (PHDR)

20.8.2 Port H Data Register (PHDR)

PHDR is an 8-bit readable/writable register that stores data for pins PTH6 to PTH0. Bits PH6DT to PH0DT correspond to pins PTH6 to PTH0. When the pin function is general output port, if the port is read, the value of the corresponding PHDR bit is returned directly. When the function is general input port, if the port is read, the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
6 to 0	PH6DT to PH0DT	All 0	R/W	Table 20.8 shows the function of PHDR.

Table 20.8 Port H Data Register (PHDR) Read/Write Operations

PHCR State				
PHnMD1	PHnMD0	Pin State	Read	Write
0	0	Other function	PHDR value	Data can be written to PHDR but no effect on pin state.
	1	Output	PHDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PHDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PHDR but no effect on pin state.

Note: n = 0 to 6

20.9 Port J

Port J is an 8-bit output port with the pin configuration shown in figure 20.9.

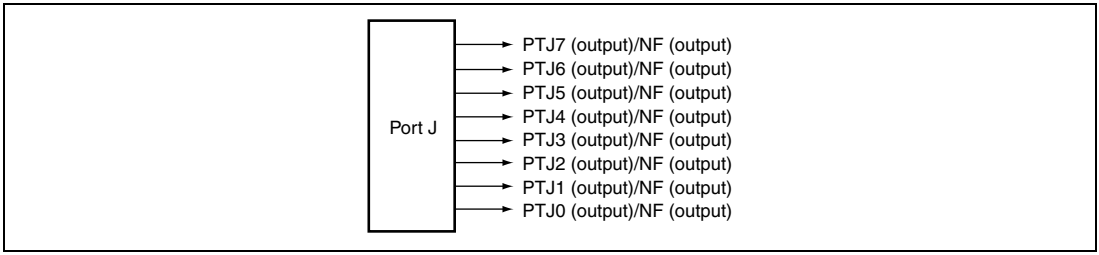


Figure 20.9 Port J

20.9.1 Register Description

Port J has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port J data register (PJDR)

20.9.2 Port J Data Register (PJDR)

PJDR is an 8-bit readable/writable register that stores data for pins PTJ7 to PTJ0. Bits PJ7DT to PJ0DT correspond to pins PTJ7 to PTJ0. When the pin function is general output port, if the port is read, the value of the corresponding PJDR bit is returned directly.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PJ7DT to PJ0DT	All 0	R/W	Table 20.9 shows the function of PJDR.

Table 20.9 Port J Data Register (PJDR) Read/Write Operations

PJCR State				
PJnMD1	**PJnMD0**	**Pin State**	**Read**	**Write**
0	0	NF	PJDR value	Data can be written to PJDR but no effect on pin state.
	1	Output	PJDR value	Written data is output from the pin.
1	0	Setting Prohibited	—	—
	1	Setting Prohibited	—	—

Note: n = 0 to 7

20.10 Port K

Port K is an 8-bit input/output port with the pin configuration shown in figure 20.10. Each pin has an input pull-up MOS, which is controlled by the port K control register (PKCR) in the PFC.

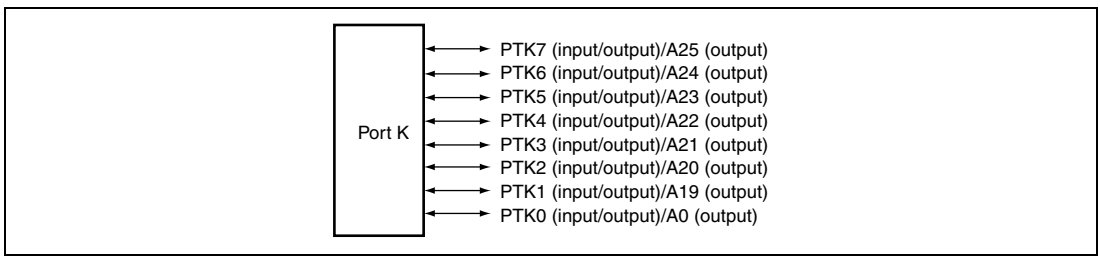


Figure 20.10 Port K

20.10.1 Register Description

Port K has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port K data register (PKDR)

20.10.2 Port K Data Register (PKDR)

PKDR is an 8-bit readable/writable register that stores data for pins PTK7 to PTK0. Bits PK7DT to PK0DT correspond to pins PTK7 to PTK0. When the pin function is general output port, if the port is read, the value of the corresponding PKDR bit is returned directly. When the function is general input port, if the port is read, the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PK7DT to PK0DT	All 0	R/W	Table 20.10 shows the function of PKDR.

Table 20.10 Port K Data Register (PKDR) Read/Write Operations

PKCR State				
PKnMD1	PKnMD0	Pin State	Read	Write
0	0	Other function	PKDR value	Data can be written to PKDR but no effect on pin state.
	1	Output	PKDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PKDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PKDR but no effect on pin state.

Note: n = 0 to 7

20.11 Port L

Port L is a 4-bit input port with the pin configuration shown in figure 20.11.

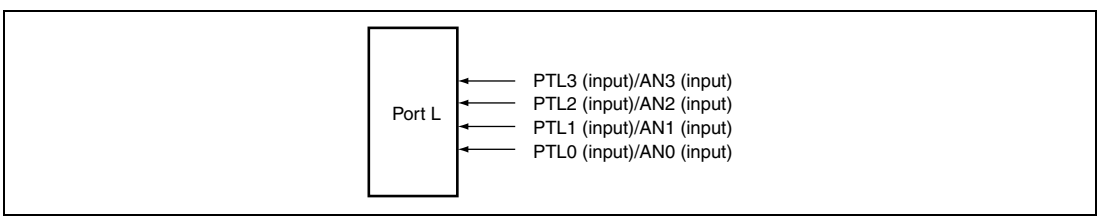


Figure 20.11 Port L

20.11.1 Register Description

Port L has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port L data register (PLDR)

20.11.2 Port L Data Register (PLDR)

PLDR is an 8-bit read-only register that stores data for pins PTL3 to PTL0. Bits PL3DT to PL0DT correspond to pins PTL3 to PTL0. If the port is read, the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 4	—	All 0	R	Reserved These bits are always read as 0.
3 to 0	PL3DT to PL0DT	All 0	R	Table 20.11 shows the function of PLDR.

Table 20.11 Port L Data Register (PLDR) Read/Write Operation

PLCR State				
PLnMD1	PLnMD0	Pin State	Read	Write
0	0	Other function	Read as 0	Invalid (no effect on pin state)
	1	Setting prohibited	—	—
1	0	Setting prohibited	—	—
	1	Input (Pull-up MOS off)	Pin state	Invalid (no effect on pin state)

Note: n = 0 to 3

20.12 Port M

Port M is a 6-bit input/output port with the pin configuration shown in figure 20.12. Each pin has an input pull-up MOS, which is controlled by the port M control register (PMCR) in the PFC.

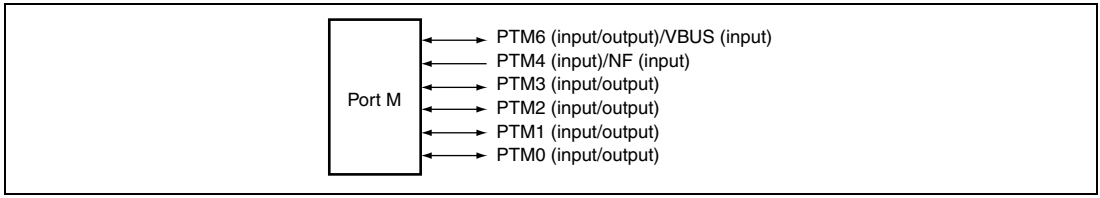


Figure 20.12 Port M

20.12.1 Register Description

Port M has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port M data register (PMDR)

20.12.2 Port M Data Register (PMDR)

PMDR is an 8-bit readable/writable register that stores data for pins PTM6 and PTM4 to PTM0. Bits PM6DT and PM4DT to PM0DT correspond to pins PTM6 and PTM4 to PTM0. When the pin function is general output port, if the port is read, the value of the corresponding PMDR bit is returned directly. When the function is general input port, if the port is read, the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
6	PM6DT	0	R/W	Table 20.12 shows the function of PMDR.
5	—	0	R	Reserved This bit is always read as 0. The write value should always be 0.
4 to 0	PM4DT to PM0DT	All 0	R/W	Table 20.12 shows the function of PMDR.

Table 20.12 Port M Data Register (PMDR) Read/Write Operations

PMCR State				
PMnMD1	PMnMD0	Pin State	Read	Write
0	0	Other function	PMDR value	Data can be written to PMDR but no effect on pin state.
	1	Output	PMDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PMDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PMDR but no effect on pin state.

Note: n = 0 to 3 and 6

PMCR State				
PM4MD1	**PM4MD0**	**Pin State**	**Read**	**Write**
0	0	NF	PMDR value	Data can be written to PMDR but no effect on pin state.
	1	Setting Prohibited	PMDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PMDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PMDR but no effect on pin state.

20.13 Port N

Port N is an 8-bit input/output port with the pin configuration shown in figure 20.13. Each pin has an input pull-up MOS, which is controlled by the port N control register (PNCR) in the PFC.

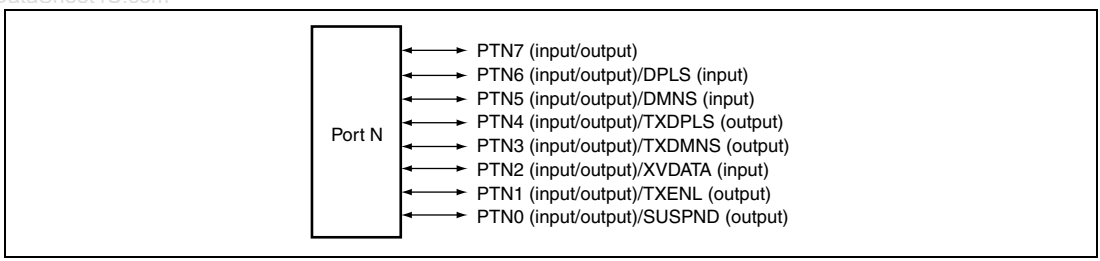


Figure 20.13 Port N

20.13.1 Register Description

Port N has the following register. For details on the register address and access size, see section 24, List of Registers.

- Port N data register (PNDR)

20.13.2 Port N Data Register (PNDR)

PNDR is an 8-bit readable/writable register that stores data for pins PTN7 to PTN0. Bits PN7DT to PN0DT correspond to pins PTN7 to PTN0. When the pin function is general output port, if the port is read, the value of the corresponding PNDR bit is returned directly. When the function is general input port, if the port is read, the corresponding pin level is read.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	PN7DT to PN0DT	All 0	R/W	Table 20.13 shows the function of PNDR.

Table 20.13 Port N Data Register (PNDR) Read/Write Operations

PNCR State				
PNnMD1	**PNnMD0**	**Pin State**	**Read**	**Write**
0	0	Other function	PNDR value	Data can be written to PNDR but no effect on pin state.
	1	Output	PNDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to PNDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to PNDR but no effect on pin state.

Note: n = 0 to 7

20.14 SC port

The SC port is an 8-bit input/output port with the pin configuration shown in figure 20.14. Each pin has an input pull-up MOS, which is controlled by the SC port control register (SCPCR) in the PFC.

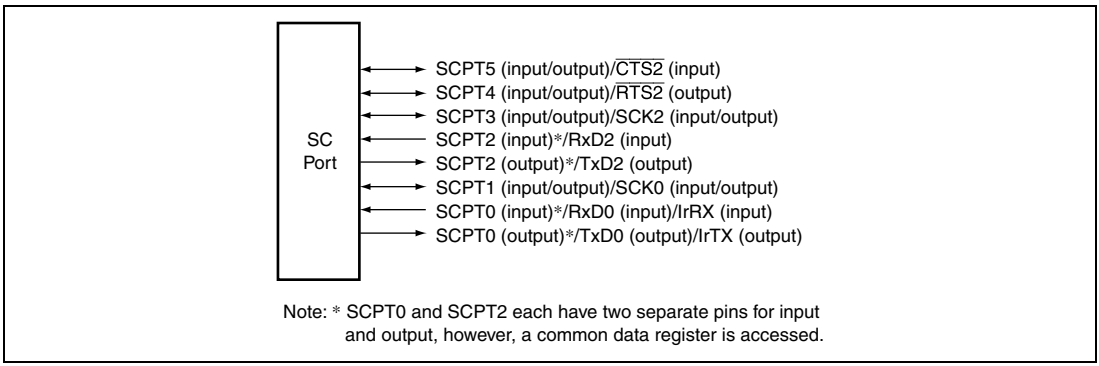


Figure 20.14 SC Port

20.14.1 Register Description

Port SC has the following register. For details on the register address and access size, see section 24, List of Registers.

- SC port data register (SCPDR)

20.14.2 Port SC Data Register (SCPDR)

SCPDR is an 8-bit readable/writable that stores data for pins SCPT5 to SCPT0. Bits SCP5DT to SCP0DT correspond to pins SCPT5 to SCPT0. When the pin function is general output port, if the port is read, the value of the corresponding SCPDR bit is returned directly. When the function is general input port, if the port is read, the corresponding pin level is read.

When the RE bit of SCSCR_2 or SCSCR_0 in the serial communication interface with FIFO (SCIF) is set to 1, the RxD2 and RxD0 pins become input pins, and their states can be read regardless of the setting of SCPCR.

Bit	Bit Name	Initial Value	R/W	Description
7, 6	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
5 to 0	SCP5DT to SCP0DT	All 0	R/W	Table 20.14 shows the function of SCPDR.

Table 20.14 SC Port Data Register (SCPDR) Read/Write Operations

- SCP1DR and SCP3DR to SCP5DR

SCPCR State				
SCPnMD1	**SCPnMD0**	**Pin State**	**Read**	**Write**
0	0	Other function	SCPDR value	Data can be written to SCPDR but no effect on pin state.
	1	Output	SCPDR value	Written data is output from the pin.
1	0	Input (Pull-up MOS on)	Pin state	Data can be written to SCPDR but no effect on pin state.
	1	Input (Pull-up MOS off)	Pin state	Data can be written to SCPDR but no effect on pin state.

Note: n= 1 and 3 to 5

- SCP0DR and SCP2DR

SCPCR State

SCPnMD1	SCPnMD0	Pin State	Read	Write
0	0	Other function	Prohibited	Prohibited
	1	TxD: Output	SCPDR value	Written data is output on TxD pin.
		RxD: Input (cannot be read)		
1	0	TxD: Output high impedance	RxD pin state	Data can be written to SCPDR but no effect on pin state.
		RxD: Input (Pull-up MOS on)		
	1	TxD: Output high impedance	RxD pin state	Data can be written to SCPDR but no effect on pin state.
		RxD: Input (Pull-up MOS off)		

Note: n = 0 and 2

The operations are not guaranteed when read and write operations are prohibited.

Section 21 A/D Converter

This LSI includes a 10-bit successive-approximation A/D converter allowing selection of up to four analog input channels.

21.1 Features

- 10-bit resolution
- Four input channels
- Minimum conversion time: 8.5 µs per channel (Pϕ = 33 MHz operation)
- Three conversion modes
  - — Single mode: A/D conversion on one channel
  - — Multi mode: A/D conversion on one to four channels
  - — Scan mode: Continuous A/D conversion on one to four channels
- Four 16-bit data registers
  - — A/D conversion results are transferred for storage into 16-bit data registers corresponding to the channels.
- Sample-and-hold function
- Interrupt source
  - — At the end of A/D conversion, an A/D conversion end interrupt (ADI) can be requested.
- Module standby mode can be set

Figure 21.1 shows a block diagram of the A/D converter.

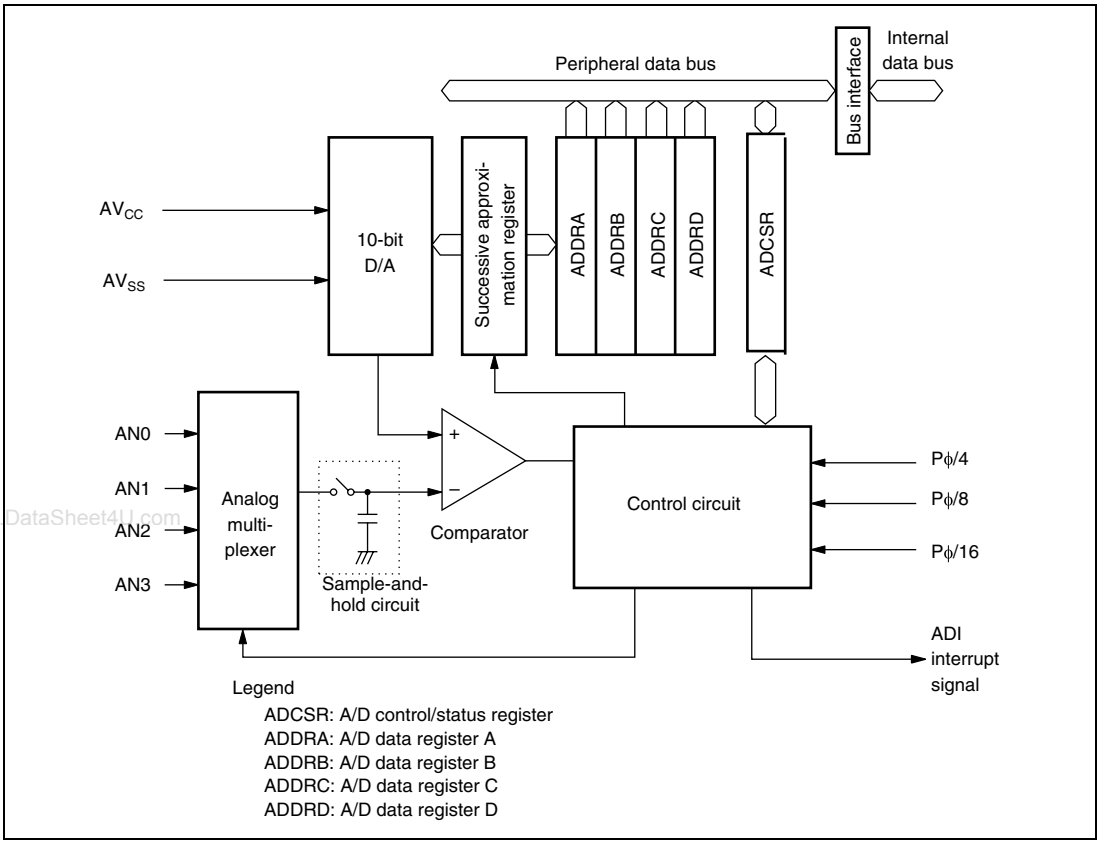


Figure 21.1 Block Diagram of A/D Converter

21.2 Input/Output Pins

Table 21.1 summarizes the A/D converter's pins. The AV_{CC} and AV_{SS} pins are the power supply for the analog circuits in the A/D converter. The AV_{CC} pin also functions as the A/D conversion reference voltage pin.

Table 21.1 Pin Configuration

Pin Name	Abbreviation	Input/ Output	Function
Analog power supply	AVcc	Input	Analog power supply and reference voltage for A/D conversion
Analog ground	AVss	Input	Analog ground and reference voltage for A/D conversion
Analog input 0	AN0	Input	Analog input 0
Analog input 1	AN1	Input	Analog input 1
Analog input 2	AN2	Input	Analog input 2
Analog input 3	AN3	Input	Analog input 3

21.3 Register Descriptions

The A/D converter has the following registers. For more information on addresses of registers and register states in the processing, see section 24, List of Registers.

- A/D data register A (ADDRA)
- A/D data register B (ADDRB)
- A/D data register C (ADDRC)
- A/D data register D (ADDRD)
- A/D control/status register (ADCSR)

21.3.1 A/D Data Registers A to D (ADDRA to ADDRD)

The four A/D data registers (ADDRA to ADDRD) are 16-bit read-only registers that store the results of A/D conversion. Table 21.2 indicates the pairings of analog input channels and A/D data registers that store the results of A/D conversion.

An A/D conversion produces 10-bit data, which is transferred for storage into bits 15 to 6 in the A/D data register corresponding to the selected channel. Bits 5 to 0 of an A/D data register are reserved bits that are always read as 0.

The A/D data registers are initialized to H'0000.

Table 21.2 Analog Input Channels and A/D Data Registers

Analog Input Channel	A/D Data Register that Store Results of A/D Conversion
AN0	ADDRA
AN1	ADDRB
AN2	ADDRC
AN3	ADDRD

21.3.2 A/D Control/Status Registers (ADCSR)

ADCSR is a 16-bit readable/writable register that selects the mode and controls the A/D converter.

Bit	Bit Name	Initial Value	R/W	Description
15	ADF	0	R/(W)*	A/D End Flag Indicates the end of A/D conversion. [Setting conditions] Single mode: A/D conversion ends Multi mode: A/D conversion ends cycling through the selected channels Scan mode: A/D conversion ends cycling through the selected channels [Clearing conditions] (1) Reading ADF while ADF = 1, then writing 0 to ADF (2) DMAC is activated by ADI interrupt and ADDR is read Note: * Clear this bit by writing 0. Writing 1 is ignored.

Bit	Bit Name	Initial Value	R/W	Description
14	ADIE	0	R/W	A/D Interrupt Enable Enables or disables the interrupt (ADI) requested by ADF. Set the ADIE bit while the ADST bit is 0. 0: Interrupt (ADI) requested by ADF is disabled 1: Interrupt (ADI) requested by ADF is enabled
13	ADST	0	R/W	A/D Start Starts or stops A/D conversion. The ADST bit remains set to 1 during A/D conversion. 0: A/D conversion is stopped. 1: Single mode: A/D conversion starts; ADST is automatically cleared to 0 when conversion ends on selected channels. Multi mode: A/D conversion starts; when conversion is completed cycling through the selected channels, ADST is automatically cleared. Scan mode: A/D conversion starts and continues, A/D conversion is continuously performed until ADST is cleared to 0 by software, by a reset, or by a transition to standby mode.
12	DMASL	0	R/W	DMAC Select Selects an interrupt due to ADF or activation of the DMAC. Set the DMASL bit while the ADST bit is 0. 0: An interrupt by ADF is selected. 1: Activation of the DMAC by ADF is selected.
11 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
7	CKS1	0	R/W	Clock Select
6	CKS0	1	R/W	Selects the A/D conversion time. Clear the ADST bit to 0 before changing the conversion time. 00: Conversion time = 151 states (maximum) at Pϕ/4 01: Conversion time = 285 states (maximum) at Pϕ/8 10: Conversion time = 545 states (maximum) at Pϕ/16 11: Setting prohibited Note: If the minimum conversion time is not satisfied, lack of accuracy or abnormal operation may occur.
5	MULTI1	0	R/W	Mode Select
4	MULTI0	0	R/W	Selects single mode, multi mode, or scan mode. 00: Single mode 01: Setting prohibited 10: Multi mode 11: Scan mode
3	—	0	R	Reserved
2	—	0	R	These bits are always read as 0. The write value should always be 0.
1	CH1	0	R/W	Channel Select
0	CH0	0	R/W	These bits and the MULTI bit select the analog input channels. Clear the ADST bit to 0 before changing the channel selection. Single mode / Multi mode or scan mode 00: AN0 / AN0 01: AN1 / AN0, AN1 10: AN2 / AN0 to AN2 11: AN3 / AN0 to AN3

21.4 Operation

The A/D converter operates by successive approximations with 10-bit resolution. It has three operating modes: single mode, multi mode, and scan mode. To avoid malfunction, switch operating modes while the ADST bit of ADCSR is 0. Changing operating modes and channels and setting the ADST bit can be performed simultaneously.

21.4.1 Single Mode

Single mode should be selected when only one A/D conversion on one channel is required.

1. A/D conversion of the selected channel starts when the ADST bit of ADCSR is set to 1 by software.

2. When conversion ends, the conversion results are transmitted to the A/D data register that corresponds to the channel.

3. When conversion ends, the ADF bit of ADCSR is set to 1. If the ADIE bit is also set to 1, an ADI interrupt is requested at this time.

4. The ADST bit holds 1 during A/D conversion. When A/D conversion is completed, the ADST bit is cleared to 0 and the A/D converter becomes idle. When the ADST bit is cleared to 0 during A/D conversion, the conversion is halted and the A/D converter becomes idle.
   To clear the ADF flag to 0, first read ADF, then write 0 to ADF.

21.4.2 Multi Mode

Multi mode should be selected when performing A/D conversions on one or more channels.

1. When the ADST bit is set to 1 by software, A/D conversion starts with the smaller number of the analog input channel in the group (for instance, AN0, and AN1 to AN3).

2. When conversion of each channel ends, the conversion results are transmitted to the A/D data register that corresponds to the channel.

3. When conversion of all selected channels ends, the ADF bit of ADCSR is set to 1. If the ADIE bit is also set to 1, an ADI interrupt is requested at this time.

4. When A/D conversion is completed, the ADST bit is cleared to 0 and the A/D converter becomes idle. When the ADST bit is cleared to 0 during A/D conversion, the conversion is halted and the A/D converter becomes idle.
   To clear the ADF flag to 0, first read ADF, then write 0 to ADF.

21.4.3 Scan Mode

Scan mode should be selected when performing A/D conversions of analog inputs on one or more specified channels. Scan mode is useful for monitoring analog inputs.

1. When the ADST bit is set to 1 by software, A/D conversion starts with the smaller number of the analog input channel in the group (for instance, AN0, and AN1 to AN3).

2. When conversion of each channel ends, the conversion results are transmitted to the A/D data register that corresponds to the channel.

3. When conversion of all selected channels ends, the ADF bit of ADCSR is set to 1. If the ADIE bit is also set to 1, an ADI interrupt is requested at this time. A/D conversion then starts with the smaller number of the analog input channel.

4. The ADST bit is not automatically cleared to 0. When the ADST bit is set to 1, steps 2 and 3 above are repeated. When the ADST bit is cleared to 0, the conversion is halted and the A/D converter becomes idle.

To clear the ADF flag to 0, first read ADF, then write 0 to ADF.

21.4.4 Input Sampling and A/D Conversion Time

The A/D converter has a built-in sample-and-hold circuit. The A/D converter samples the analog input at an A/D conversion start delay time t_D after the ADST bit is set to 1, then starts conversion. Figure 21.2 shows the A/D conversion timing. Table 21.3 indicates the A/D conversion time.

As indicated in figure 21.2, the A/D conversion time (t_{CONV}) includes t_D and the input sampling time (t_{SPL}). The length of t_D varies depending on the timing of the write access to ADCSR. The total conversion time therefore varies within the ranges indicated in table 21.3.

In multi mode and scan mode, the values given in table 21.3 apply to the first conversion. In the second and subsequent conversions, the values given in table 21.4 apply to the first conversion.

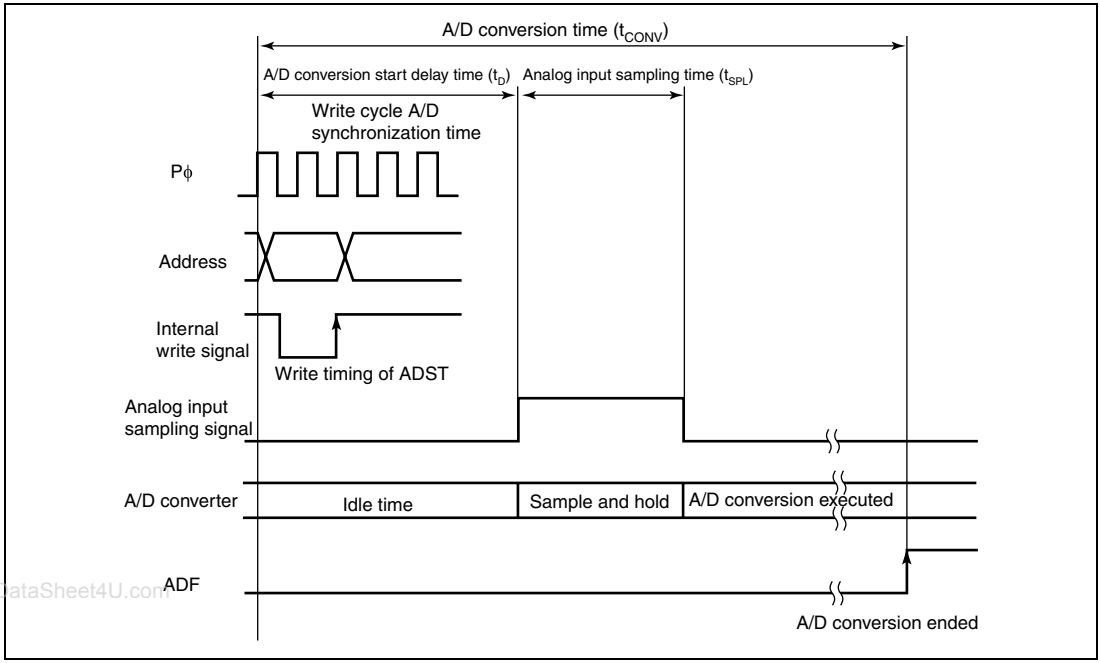


Figure 21.2 A/D Conversion Timing

Table 21.3 A/D Conversion Time (Single Mode)

		CKS1 = 1, CKS0 = 0			CKS1 = 0, CKS0 = 1			CKS1 = 0, CKS0 = 0		
	Symbol	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**
A/D conversion start delay	t_D	18	—	21	10	—	13	6	—	9
Input sampling time	t_{SPL}	—	129	—	—	65	—	—	33	—
A/D conversion time	t_{CONV}	535	—	545	275	—	285	141	—	151

Note: Values in the table are numbers of states for Pϕ.

Table 21.4 A/D Conversion Time (Multi Mode and Scan Mode)

CKS1	CKS0	Conversion Time (cycles)
0	0	128 (fixed)
0	1	256 (fixed)
1	0	512 (fixed)
1	1	Unused

21.5 Interrupts and DMAC Transfer Request

The A/D converter generates an interrupt (ADI) at the end of A/D conversion. The ADI interrupt request is enabled when ADF in ADCSR is set to 1and the ADIE bit in ADCSR is set to 1 after A/D conversion. The ADI interrupt can activate the direct memory access controller (DMAC) by setting the ADIE and DMASL bits to 1. Continuous conversion without loads of software is enabled by reading data that has been converted by the ADI interrupt with DMAC.

When activating DMAC by ADI, the ADF bit in ADCSR is automatically cleared to 0 at DMAC data transfer.

Table 21.5 A/D Converter Interrupt Source

Name	Interrupt source	Interrupt flag	DMAC activation
ADI	A/D conversion end	ADF	Yes

21.6 Definitions of A/D Conversion Accuracy

The following shows the definitions of A/D conversion accuracy. In the figure, the 10 bits of the A/D converter have been simplified to 3 bits.

- Resolution
  Digital output code number of the A/D converter
- Quantization error
  Intrinsic error of the A/D converter and is expressed as 1/2 LSB (figure 21.3)
- Offset error
  Deviation between analog input voltage and ideal A/D conversion characteristics when the digital output value changes from the minimum (zero voltage) 0000000000 (H'00; 000 in figure 21.3) to 0000000001 (H'01; 001 in figure 21.3) (figure 21.4)
- Full-scale error
  Deviation between analog input voltage and ideal A/D conversion characteristics when the digital output value changes from the 1111111110 (H'3EF; 110 in figure 21.3) to the maximum 1111111111 (H'3FF; 111 in figure 21.3) (figure 21.4).
- Nonlinearity error
  Deviation between analog input voltage and ideal A/D conversion characteristics between zero voltage and full-scale voltage (figure 21.4). Note that it does not include offset, full-scale, or quantization error.
- Absolute accuracy
  Deviation between analog and digital input values. Note that it includes offset, full-scale, quantization, or nonlinearity error.

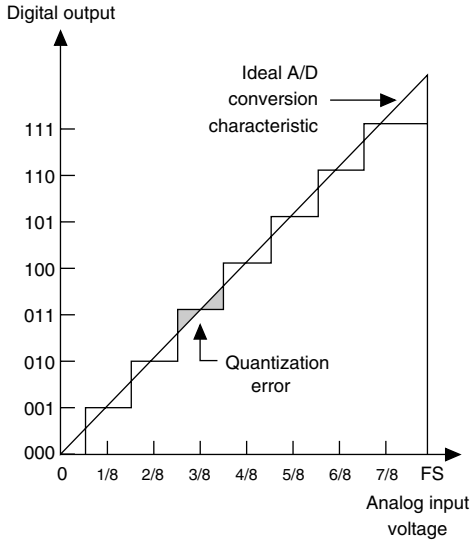


Figure 21.3 Definitions of A/D Conversion Accuracy

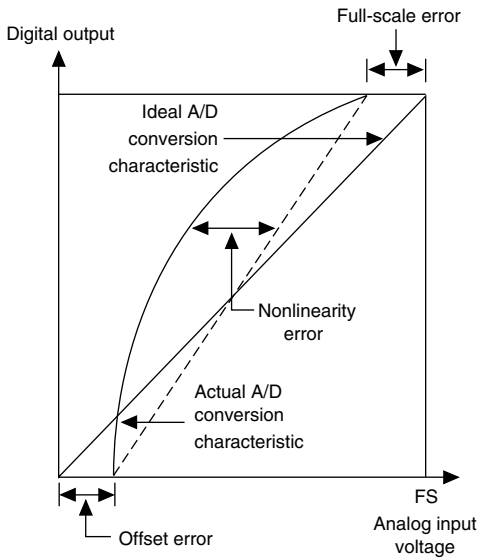


Figure 21.4 Definitions of A/D Conversion Accuracy

21.7 Usage Notes

21.7.1 Allowable Signal-Source Impedance

For the analog input design of this LSI, conversion accuracy is guaranteed for an input signal with signal-source impedance of 5 kΩ or less. The specification is for charging input capacitance of the sample and hold circuit of the A/D converter within sampling time. When the output impedance of the sensor exceeds 5 kΩ, conversion accuracy is not guaranteed due to insufficient charging. If large external capacitance is set at conversion in single mode, signal-source impedance is ignored since input load is only internal input resistance of 3 kΩ. However, an analog signal with large differential coefficient (5 mV/μs or greater) cannot be followed up because of a low-pass filter (figure 21.5). When converting high-speed analog signals or converting in scan mode, insert a low-impedance buffer.

21.7.2 Influence to Absolute Accuracy

By adding capacitance, absolute accuracy may be degraded if noise is on GND because there is coupling with GND. Therefore, connect electrically stable GND such as AVcc to prevent absolute accuracy from being degraded.

A filter circuit must not interfere with digital signals, or must not be an antenna on a mounting board.

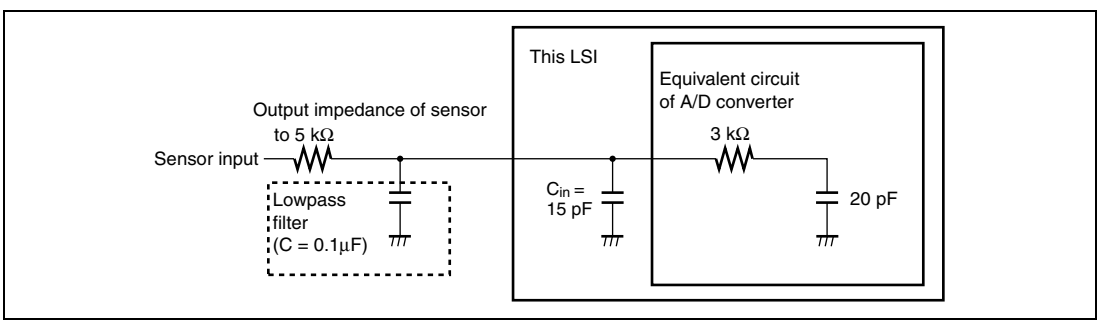


Figure 21.5 Analog Input Circuit Example

21.7.3 Setting Analog Input Voltage

Operating the chip in excess of the following voltage range may result in damage to chip reliability.

- Analog Input Voltage Range: During A/D conversion, the voltages (VANn) input to the analog input pins ANn should be in the range $AV_{SS} \leq VANn \leq AV_{CC}$ (n = 0 to 3).

- Relationships of AV_{CC}, AV_{SS} and $V_{CC}Q$, $V_{SS}Q$: $AV_{CC} = V_{CC}Q \pm 0.2$ V and $AV_{SS} = V_{SS}Q$. Even when the A/D converter is not used, do not open AV_{CC} and AV_{SS}.

21.7.4 Notes on Board Design

In designing a board, separate digital circuits and analog circuits. Do not intersect or locate closely signal lines of a digital circuit and an analog circuit. An analog circuit may malfunction due to induction, thus affecting A/D conversion values. Separate analog input pins (AN0 to AN3) and the analog power voltage (AVcc) from digital circuits with analog ground (AVss). Connect analog ground (AVss) to one point of stable ground (Vss) on the board.

21.7.5 Notes on Countermeasures to Noise

Connect a protective circuit between AVcc and AVss, as shown in figure 21.6, to prevent damage of analog input pins (AN0 to AN3) due to abnormal voltage such as excessive serge. Connect a bypass capacitor that is connected to AVcc and a capacitor for a filter that is connected to AN0 to AN3 to AVss.

When a capacitor for a filter is connected, input currents of AN0 to AN3 are averaged, may causing errors. If A/D conversion is frequently performed in scan mode, voltages of analog input pins cause errors when a current that is charged/discharged for capacitance of a sample & hold circuit in the A/D converter is higher than a current that is input through input impedance (Rin). Therefore, determine a circuit constant carefully.

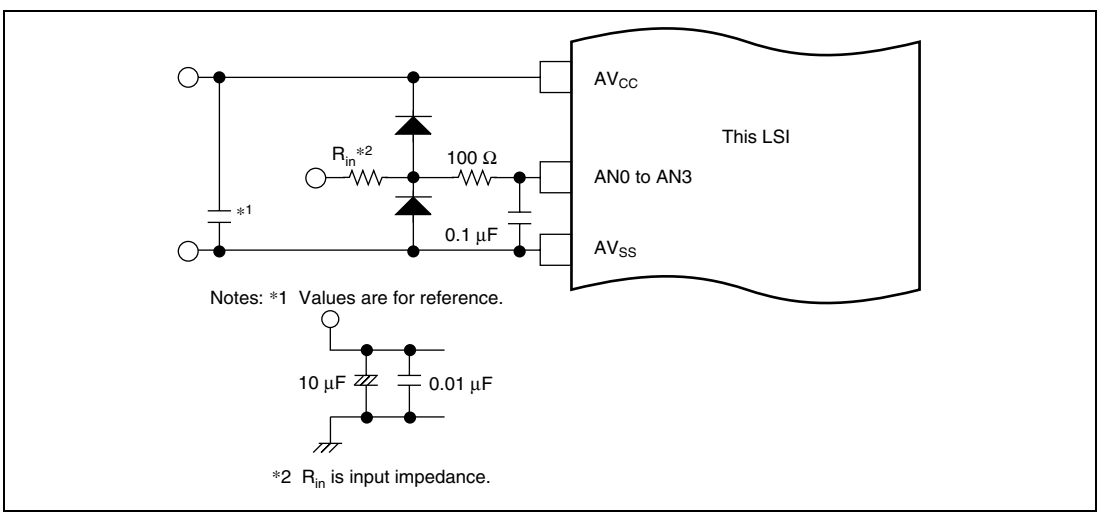
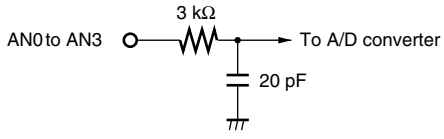


Figure 21.6 Example of Analog Input Protection Circuit

Table 21.6 Analog Input Pin Ratings

Item	Min	Max	Unit
Analog input capacitance	—	20	pF
Allowable signal-source impedance	—	5	kΩ



Note: Values are for reference.

Figure 21.7 Analog Input Pin Equivalent Circuit

Section 22 User Break Controller

The user break controller (UBC) provides functions that simplify program debugging. These functions make it easy to design an effective self-monitoring debugger, enabling the chip to debug programs without using an in-circuit emulator. Break conditions that can be set in the UBC are instruction fetch or data read/write access, data size, data contents, address value, and stop timing in the case of instruction fetch.

22.1 Features

The UBC has the following features:

- The following break comparison conditions can be set.

  Number of break channels: two channels (channels A and B)
  User break can be requested as either the independent or sequential condition on channels A and B (sequential break setting: channel A and then channel B match with break conditions, but not in the same bus cycle).

  — Address (Compares 40 bits configured of the ASID and addresses 32 bits: the ASID can be selected either all-bit comparison or all-bit mask. Comparison bits for the address are maskable in 1-bit units; user can mask addresses at lower 12 bits (4 k page), lower 10 bits (1 k page), or any size of page, etc.)

    One of the two address buses (L bus address (LAB) and I bus address (IAB)) can be selected.

  — Data (only on channel B, 32-bit maskable)

    One of the two data buses (L bus data (LDB) and I bus data (IDB)) can be selected.

  — Bus cycle: Instruction fetch or data access

  — Read/write

  — Operand size: Byte, word, or longword
- User break is generated upon satisfying break conditions. A user-designed user-break condition exception processing routine can be run.
- In an instruction fetch cycle, it can be selected that a break is set before or after an instruction is executed.
- Maximum repeat times for the break condition (only for channel B): $2^{12} - 1$ times.
- Eight pairs of branch source/destination buffers.

Figure 22.1 shows a block diagram of the UBC.

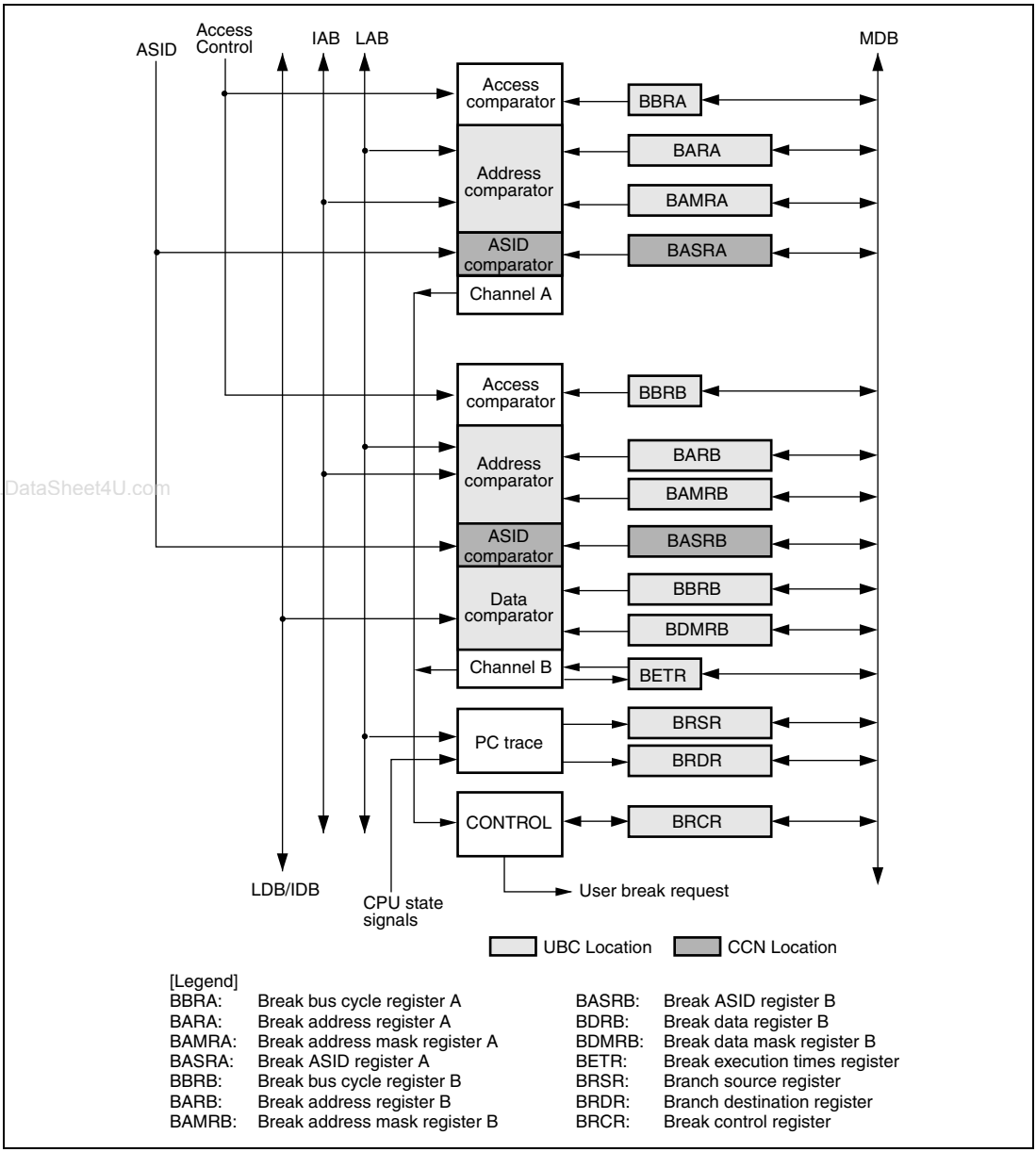


Figure 22.1 Block Diagram of User Break Controller

22.2 Register Descriptions

The user break controller has the following registers. For details on register addresses and access sizes, refer to section 24, List of Registers.

- Break address register A (BARA)
- Break address mask register A (BAMRA)
- Break bus cycle register A (BBRA)
- Break address register B (BARB)
- Break address mask register B (BAMRB)
- Break bus cycle register B (BBRB)
- Break data register B (BDRB)
- Break data mask register B (BDMRB)
- Break control register (BRCR)
- Execution times break register (BETR)
- Branch source register (BRSR)
- Branch destination register (BRDR)
- Break ASID register A (BASRA)
- Break ASID register B (BASRB)

22.2.1 Break Address Register A (BARA)

BARA is a 32-bit readable/writable register. BARA specifies the address used as a break condition in channel A.

Bit	Bit Name	Initial Value	R/W	Description
31 to 0	BAA31 to BAA0	All 0	R/W	Break Address A Store the address on the LAB or IAB specifying break conditions of channel A.

22.2.2 Break Address Mask Register A (BAMRA)

BAMRA is a 32-bit readable/writable register. BAMRA specifies bits masked in the break address specified by BARA.

Bit	Bit Name	Initial Value	R/W	Description
31 to 0	BAMA31 to BAMA0	All 0	R/W	Break Address Mask A Specify bits masked in the channel A break address bits specified by BARA (BAA31 to BAA0). 0: Break address bit BAAn of channel A is included in the break condition 1: Break address bit BAAn of channel A is masked and is not included in the break condition Note: n = 31 to 0

22.2.3 Break Bus Cycle Register A (BBRA)

BBRA is a 16-bit readable/writable register, which specifies (1) L bus cycle or I bus cycle, (2) instruction fetch or data access, (3) read or write, and (4) operand size in the break conditions of channel A.

Bit	Bit Name	Initial Value	R/W	Description
15 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7	CDA1	0	R/W	L Bus Cycle/I Bus Cycle Select A
6	CDA0	0	R/W	Select the L bus cycle or I bus cycle as the bus cycle of the channel A break condition. 00: Condition comparison is not performed 01: The break condition is the L bus cycle 10: The break condition is the I bus cycle 11: The break condition is the L bus cycle

Bit	Bit Name	Initial Value	R/W	Description
5	IDA1	0	R/W	Instruction Fetch/Data Access Select A
4	IDA0	0	R/W	Select the instruction fetch cycle or data access cycle as the bus cycle of the channel A break condition. 00: Condition comparison is not performed 01: The break condition is the instruction fetch cycle 10: The break condition is the data access cycle 11: The break condition is the instruction fetch cycle or data access cycle
3	RWA1	0	R/W	Read/Write Select A
2	RWA0	0	R/W	Select the read cycle or write cycle as the bus cycle of the channel A break condition. 00: Condition comparison is not performed 01: The break condition is the read cycle 10: The break condition is the write cycle 11: The break condition is the read cycle or write cycle
1	SZA1	0	R/W	Operand Size Select A
0	SZA0	0	R/W	Select the operand size of the bus cycle for the channel A break condition. 00: The break condition does not include operand size 01: The break condition is byte access 10: The break condition is word access 11: The break condition is longword access

22.2.4 Break Address Register B (BARB)

BARB is a 32-bit readable/writable register. BARB specifies the address used as a break condition in channel B.

Bit	Bit Name	Initial Value	R/W	Description
31 to 0	BAB31 to BAB0	All 0	R/W	Break Address B Stores an address which specifies a break condition in channel B. BARB specifies the break address on LAB or IAB.

22.2.5 Break Address Mask Register B (BAMRB)

BAMRB is a 32-bit readable/writable register. BAMRB specifies bits masked in the break address specified by BARB.

Bit	Bit Name	Initial Value	R/W	Description
31 to 0	BAMB31 to BAMB0	All 0	R/W	Break Address Mask B Specifies bits masked in the break address of channel B specified by BARB (BAB31 to BAB0). 0: Break address BABn of channel B is included in the break condition 1: Break address BABn of channel B is masked and is not included in the break condition Note: n = 31 to 0

22.2.6 Break Data Register B (BDRB)

BDRB is a 32-bit readable/writable register.

Bit	Bit Name	Initial Value	R/W	Description
31 to 0	BDB31 to BDB0	All 0	R/W	Break Data Bit B Stores data which specifies a break condition in channel B. BDRB specifies the break data on LDB or IDB.

Notes: 1. Specify an operand size when including the value of the data bus in the break condition.
2. When the byte size is selected as a break condition, the same byte data must be set in bits 15 to 8 and 7 to 0 in BDRB as the break data.

22.2.7 Break Data Mask Register B (BDMRB)

BDMRB is a 32-bit readable/writable register. BDMRB specifies bits masked in the break data specified by BDRB.

Bit	Bit Name	Initial Value	R/W	Description
31 to 0	BDMB31 to BDMB0	All 0	R/W	Break Data Mask B Specifies bits masked in the break data of channel B specified by BDRB (BDB31 to BDB0). 0: Break data BDBn of channel B is included in the break condition 1: Break data BDBn of channel B is masked and is not included in the break condition Note: n = 31 to 0

Notes: 1. Specify an operand size when including the value of the data bus in the break condition.

2. When the byte size is selected as a break condition, the same byte data must be set in bits 15 to 8 and 7 to 0 in BDRB as the break mask data in BDMRB.

22.2.8 Break Bus Cycle Register B (BBRB)

BBRB is a 16-bit readable/writable register, which specifies (1) L bus cycle or I bus cycle, (2) instruction fetch or data access, (3) read or write, and (4) operand size in the break conditions of channel B.

Bit	Bit Name	Initial Value	R/W	Description
15 to 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
7	CDB1	0	R/W	L Bus Cycle/I Bus Cycle Select B
6	CDB0	0	R/W	Select the L bus cycle or I bus cycle as the bus cycle of the channel B break condition. 00: Condition comparison is not performed 01: The break condition is the L bus cycle 10: The break condition is the I bus cycle 11: The break condition is the L bus cycle
5	IDB1	0	R/W	Instruction Fetch/Data Access Select B
4	IDB0	0	R/W	Select the instruction fetch cycle or data access cycle as the bus cycle of the channel B break condition. 00: Condition comparison is not performed 01: The break condition is the instruction fetch cycle 10: The break condition is the data access cycle 11: The break condition is the instruction fetch cycle or data access cycle
3	RWB1	0	R/W	Read/Write Select B
2	RWB0	0	R/W	Select the read cycle or write cycle as the bus cycle of the channel B break condition. 00: Condition comparison is not performed 01: The break condition is the read cycle 10: The break condition is the write cycle 11: The break condition is the read cycle or write cycle
1	SZB1	0	R/W	Operand Size Select B
0	SZB0	0	R/W	Select the operand size of the bus cycle for the channel B break condition. 00: The break condition does not include operand size 01: The break condition is byte access 10: The break condition is word access 11: The break condition is longword access

22.2.9 Break Control Register (BRCR)

BRCR sets the following conditions:

1. Specifies whether channels A and B are used in two independent channel conditions or under the sequential condition.
2. Specifies whether a break is set before or after instruction execution.
3. Specifies whether to include the number of execution times on channel B in comparison conditions.
4. Specifies whether to include data bus on channel B in comparison conditions.
5. Enables PC trace.
6. Enables ASID check.

BRCR is a 32-bit readable/writable register that has break conditions match flags and bits for setting a variety of break conditions.

Bit	Bit Name	Initial Value	R/W	Description
31 to 22	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
21	BASMA	0	R/W	Break ASID Mask A Specifies whether bits in channel A break ASID7 to ASID0 (BASA7 to BASA0) which are set in BASRA are masked or not. 0: All BASRA bits are included in the break conditions and the ASID is checked 1: All BASRA bits are not included in the break conditions and the ASID is not checked
20	BASMB	0	R/W	Break ASID Mask B Specifies whether bits in channel B break ASID7 to ASID0 (BASB7 to BASB0) which are set in BASRB are masked or not. 0: All BASRB bits are included in the break conditions and the ASID is checked 1: All BASRB bits are not included in the break conditions and the ASID is not checked
19 to 16	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.

Bit	Bit Name	Initial Value	R/W	Description
15	SCMFCA	0	R/W	L Bus Cycle Condition Match Flag A When the L bus cycle condition in the break conditions set for channel A is satisfied, this flag is set to 1. In order to clear this flag, write 0 into this bit. 0: The L bus cycle condition for channel A does not match 1: The L bus cycle condition for channel A matches
14	SCMFCB	0	R/W	L Bus Cycle Condition Match Flag B When the L bus cycle condition in the break conditions set for channel B is satisfied, this flag is set to 1. In order to clear this flag, write 0 into this bit. 0: The L bus cycle condition for channel B does not match 1: The L bus cycle condition for channel B matches
13	SCMFDA	0	R/W	I Bus Cycle Condition Match Flag A When the I bus cycle condition in the break conditions set for channel A is satisfied, this flag is set to 1. In order to clear this flag, write 0 into this bit. 0: The I bus cycle condition for channel A does not match 1: The I bus cycle condition for channel A matches
12	SCMFDB	0	R/W	I Bus Cycle Condition Match Flag B When the I bus cycle condition in the break conditions set for channel B is satisfied, this flag is set to 1. In order to clear this flag, write 0 into this bit. 0: The I bus cycle condition for channel B does not match 1: The I bus cycle condition for channel B matches
11	PCTE	0	R/W	PC Trace Enable 0: Disables PC trace 1: Enables PC trace
10	PCBA	0	R/W	PC Break Select A Selects the break timing of the instruction fetch cycle for channel A as before or after instruction execution. 0: PC break of channel A is set before instruction execution 1: PC break of channel A is set after instruction execution

Bit	Bit Name	Initial Value	R/W	Description
9, 8	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
7	DBEB	0	R/W	Data Break Enable B Selects whether or not the data bus condition is included in the break condition of channel B. 0: No data bus condition is included in the condition of channel B 1: The data bus condition is included in the condition of channel B
6	PCBB	0	R/W	PC Break Select B Selects the break timing of the instruction fetch cycle for channel B as before or after instruction execution. 0: PC break of channel B is set before instruction execution 1: PC break of channel B is set after instruction execution
5, 4	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
3	SEQ	0	R/W	Sequence Condition Select Selects two conditions of channels A and B as independent or sequential conditions. 0: Channels A and B are compared under independent conditions 1: Channels A and B are compared under sequential conditions (channel A, then channel B)
2, 1	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
0	ETBE	0	R/W	Number of Execution Times Break Enable Enables the execution-times break condition only on channel B. If this bit is 1 (break enable), a user break is issued when the number of satisfied break conditions matches with the number of execution times that is specified by BETR. 0: The execution-times break condition is disabled on channel B 1: The execution-times break condition is enabled on channel B

22.2.10 Execution Times Break Register (BETR)

BETR is a 16-bit readable/writable register. When the execution-times break condition of channel B is enabled, this register specifies the number of execution times to make the break. The maximum number is $2^{12} - 1$ times. When a break condition is satisfied, it decrements the BETR value. A break is issued when the break condition is satisfied after BETR becomes H'0001.

Bit	Bit Name	Initial Value	R/W	Description
15 to 12	—	All 0	R	Reserved These bits are always read as 0. The write value should always be 0.
11 to 0	BET11 to BET0	All 0	R/W	Number of Execution Times

22.2.11 Branch Source Register (BRSR)

BRSR is a 32-bit read-only register. BRSR stores bits 27 to 0 in the address of the branch source instruction. BRSR has the flag bit that is set to 1 when a branch occurs. This flag bit is cleared to 0 when BRSR is read, the setting to enable PC trace is made, or BRSR is initialized by a power-on reset. Other bits are not initialized by a power-on reset. The eight BRSR registers have a queue structure and a stored register is shifted at every branch.

Bit	Bit Name	Initial Value	R/W	Description
31	SVF	0	R	BRSR Valid Flag Indicates whether the branch source address is stored. When a branch source address is fetched, this flag is set to 1. This flag is cleared to 0 by reading from BRSR. 0: The value of BRSR register is invalid 1: The value of BRSR register is valid
30 to 28	—	All 0	R	Reserved These bits are always read as 0.
27 to 0	BSA27 to BSA0	Undefined	R	Branch Source Address Store bits 27 to 0 of the branch source address.

22.2.12 Branch Destination Register (BRDR)

BRDR is a 32-bit read-only register. BRDR stores bits 27 to 0 in the address of the branch destination instruction. BRDR has the flag bit that is set to 1 when a branch occurs. This flag bit is cleared to 0 when BRDR is read, the setting to enable PC trace is made, or BRDR is initialized by a power-on reset. Other bits are not initialized by a power-on reset. The eight BRDR registers have a queue structure and a stored register is shifted at every branch.

Bit	Bit Name	Initial Value	R/W	Description
31	DVF	0	R	BRDR Valid Flag Indicates whether a branch destination address is stored. When a branch destination address is fetched, this flag is set to 1. This flag is cleared to 0 by reading BRDR. 0: The value of BRDR register is invalid 1: The value of BRDR register is valid
30 to 28	—	All 0	R	Reserved These bits are always read as 0.
27 to 0	BDA27 to BDA0	Undefined	R	Branch Destination Address Store bits 27 to 0 of the branch destination address.

22.2.13 Break ASID Register A (BASRA)

BASRA is an 8-bit readable/writable register that specifies ASID which becomes the break condition for channel A. BASRA is in CCN.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	BASA7 to BASA0	—	R/W	Break ASID A Store ASID (bits 7 to 0) which is the break condition for channel A.

22.2.14 Break ASID Register B (BASRB)

BASRB is an 8-bit readable/writable register that specifies ASID which becomes the break condition for channel B. BASRB is in CCN.

Bit	Bit Name	Initial Value	R/W	Description
7 to 0	BASB7 to BASB0	—	R/W	Break ASID B Store ASID (bits 7 to 0) which is the break condition for channel B.

22.3 Operation

22.3.1 Flow of the User Break Operation

The flow from setting of break conditions to user break exception processing is described below:

1. The break addresses and corresponding ASID are set in the break address registers (BARA and BARB) and break ASID registers (BASRA and BASRB in CNN). The masked addresses are set in the break address mask registers (BAMRA and BAMRB). The break data is set in the break data register (BDRB). The masked data is set in the break data mask register (BDMRB). The bus break conditions are set in the break bus cycle registers (BBRA and BBRB). Three groups of BBRA and BBRB (L bus cycle/I bus cycle select, instruction fetch/data access select, and read/write select) are each set. No user break will be generated if even one of these groups is set with 00. The respective conditions are set in the bits of the break control register (BRCR). Make sure to set all registers related to breaks before setting BBRA/BBRB.
2. When the break conditions are satisfied, the UBC sends a user break request to the CPU and sets the L bus condition match flag (SCMFCA or SCMFCB) and the I bus condition match flag (SCMFDA or SCMFDB) for the appropriate channel.
3. The appropriate condition match flags (SCMFCA, SCMFDA, SCMFCB, and SCMFDB) can be used to check if the set conditions match or not. The matching of the conditions sets flags, but they are not reset. 0 must first be written to them before they can be used again.
4. There is a chance that the data access break and its following instruction fetch break occur around the same time. There will be only one break request to the CPU, but these two break channel match flags could be both set.

5. When selecting the I bus as the break condition, note the following:
   - Several bus masters, including the CPU and DMAC, are connected to the I bus. The UBC monitors bus cycles generated by all bus masters, and determines the condition match.
   - Physical addresses are used for the I bus. Set a physical address in break address registers (BARA and BARB). The bus cycles for logical addresses issued on the L bus by the CPU are converted to physical addresses before being output to the I bus. (If the address translation function is enabled, address translation by the MMU is carried out.)
   - For data access cycles issued on the L bus by the CPU, if their logical addresses are not to be cached, they are issued with the data size specified on the L bus and their addresses are not rounded.
   - For instruction fetch cycles issued on the L bus by the CPU, even though their logical addresses are not to be cached, they are issued in longwords and their addresses are rounded to match longword boundaries.
   - If a logical address issued on the L bus by the CPU is an address to be cached and a cache miss occurs, its bus cycle is issued as a cache fill cycle on the I bus. In this case, it is issued in longwords and its address is rounded to match longword boundaries. However note that cache fill is not performed for a write miss in write through mode. In this case, the bus cycle is issued with the data size specified on the L bus and its address is not rounded. In write back mode, a write back cycle may be issued in addition to a read fill cycle. It is a longword bus cycle whose address is rounded to match longword boundaries.
   - I bus cycles (including read fill cycles) resulting from instruction fetches on the L bus by the CPU are defined as instruction fetch cycles on the I bus, while other bus cycles are defined as data access cycles.
   - The DMAC only issues data access cycles for I bus cycles.
   - If a break condition is specified for the I bus, even when the condition matches in an I bus cycle resulting from an instruction executed by the CPU, at which instruction the break is to be accepted cannot be clearly defined.
6. While the block bit (BL) in the CPU status register (SR) is set to 1, no breaks can be accepted. However, condition determination will be carried out, and if the condition matches, the corresponding condition match flag is set to 1.

22.3.2 Break on Instruction Fetch Cycle

1. When L bus/instruction fetch/read/word or longword is set in the break bus cycle register (BBRA or BBRB), the break condition becomes the L bus instruction fetch cycle. Whether it breaks before or after the execution of the instruction can then be selected with the PCBA or PCBB bit of the break control register (BRCR) for the appropriate channel. If an instruction fetch cycle is set as a break condition, clear LSB in the break address register (BARA or BARB) to 0. A break cannot be generated as long as this bit is set to 1.
2. An instruction set for a break before execution breaks when it is confirmed that the instruction has been fetched and will be executed. This means this feature cannot be used on instructions fetched by overrun (instructions fetched at a branch or during an interrupt transition, but not to be executed). When this kind of break is set for the delay slot of a delayed branch instruction, the break is generated prior to execution of the delayed branch instruction.

   Note: If a branch does not occur at a delayed conditional branch instruction, the subsequent instruction is not recognized as a delay slot.

3. When the condition is specified to be occurred after execution, the instruction set with the break condition is executed and then the break is generated prior to the execution of the next instruction. As with pre-execution breaks, this cannot be used with overrun fetch instructions. When this kind of break is set for a delayed branch instruction and its delay slot, a break is not generated until the first instruction at the branch destination.
4. When an instruction fetch cycle is set for channel B, the break data register B (BDRB) is ignored. Therefore, break data cannot be set for the break of the instruction fetch cycle.
5. If the I bus is set for a break of an instruction fetch cycle, the condition is determined for the instruction fetch cycles on the I bus. For details, see 5 in section 22.3.1, Flow of the User Break Operation.

22.3.3 Break on Data Access Cycle

1. If the L bus is specified as a break condition for data access break, condition comparison is performed for the logical addresses (and data) accessed by the executed instructions, and a break occurs if the condition is satisfied. If the I bus is specified as a break condition, condition comparison is performed for the physical addresses (and data) of the data access cycles that are issued on the I bus by all bus masters including the CPU, and a break occurs if the condition is satisfied. For details on the CPU bus cycles issued on the I bus, see 5 in section 22.3.1, Flow of the User Break Operation.
2. The relationship between the data access cycle address and the comparison condition for each operand size is listed in table 22.1.

Table 22.1 Data Access Cycle Addresses and Operand Size Comparison Conditions

Access Size	Address Compared
Longword	Compares break address register bits 31 to 2 to address bus bits 31 to 2
Word	Compares break address register bits 31 to 1 to address bus bits 31 to 1
Byte	Compares break address register bits 31 to 0 to address bus bits 31 to 0

This means that when address H'00001003 is set in the break address register (BARA or BARB), for example, the bus cycle in which the break condition is satisfied is as follows (where other conditions are met).

Longword access at H'00001000

Word access at H'00001002

Byte access at H'00001003

3. When the data value is included in the break conditions on channel B:

   When the data value is included in the break conditions, either longword, word, or byte is specified as the operand size of the break bus cycle register B (BBRB). When data values are included in break conditions, a break is generated when the address conditions and data conditions both match. To specify byte data for this case, set the same data in two bytes at bits 15 to 8 and bits 7 to 0 of the break data register B (BDRB) and break data mask register B (BDMRB). When word or byte is set, bits 31 to 16 of BDRB and BDMRB are ignored.
4. Access by a PREF instruction is handled as read access in longword units without access data. Therefore, if including the value of the data bus when a PREF instruction is specified as a break condition, a break will not occur.
5. If the L bus is selected, a break occurs on ending execution of the instruction that matches the break condition, and immediately before the next instruction is executed. However, when data is also specified as the break condition, the break may occur on ending execution of the instruction following the instruction that matches the break condition. If the I bus is selected, the instruction at which the break will occur cannot be determined. When this kind of break

occurs at a delayed branch instruction or its delay slot, the break may not actually take place until the first instruction at the branch destination.

22.3.4 Sequential Break

1. By setting the SEQ bit in BRCR to 1, the sequential break is issued when a channel B break condition matches after a channel A break condition matches. A user break is not generated even if a channel B break condition matches before a channel A break condition matches. When channels A and B conditions match at the same time, the sequential break is not issued. To clear the channel A condition match when a channel A condition match has occurred but a channel B condition match has not yet occurred in a sequential break specification, clear the SEQ bit in BRCR to 0.
2. In sequential break specification, the L or I bus can be selected and the execution times break condition can be also specified. For example, when the execution times break condition is specified, the break condition is satisfied when a channel B condition matches with BETR = H'0001 after a channel A condition has matched.

22.3.5 Value of Saved Program Counter

When a break occurs, the address of the instruction from where execution is to be resumed is saved in the SPC, and the exception handling state is entered. If the L bus is specified as a break condition, the instruction at which the break should occur can be clearly determined (except for when data is included in the break condition). If the I bus is specified as a break condition, the instruction at which the break should occur cannot be clearly determined.

1. When instruction fetch (before instruction execution) is specified as a break condition:

   The address of the instruction that matched the break condition is saved in the SPC. The instruction that matched the condition is not executed, and the break occurs before it. However when a delay slot instruction matches the condition, the address of the delayed branch instruction is saved in the SPC.

2. When instruction fetch (after instruction execution) is specified as a break condition:

   The address of the instruction following the instruction that matched the break condition is saved in the SPC. The instruction that matches the condition is executed, and the break occurs before the next instruction is executed. However when a delayed branch instruction or delay slot matches the condition, these instructions are executed, and the branch destination address is saved in the SPC.

3. When data access (address only) is specified as a break condition:

   The address of the instruction immediately after the instruction that matched the break condition is saved in the SPC. The instruction that matches the condition is executed, and the break occurs before the next instruction is executed. However when a delay slot instruction matches the condition, the branch destination address is saved in the SPC.

4. When data access (address + data) is specified as a break condition:

   When a data value is added to the break conditions, the address of an instruction that is within two instructions of the instruction that matched the break condition is saved in the SPC. At which instruction the break occurs cannot be determined accurately.

   When a delay slot instruction matches the condition, the branch destination address is saved in the SPC. If the instruction following the instruction that matches the break condition is a branch instruction, the break may occur after the branch instruction or delay slot has finished. In this case, the branch destination address is saved in the SPC.

22.3.6 PC Trace

1. Setting PCTE in BRCR to 1 enables PC traces. When branch (branch instruction, and interrupt exception) is generated, the branch source address and branch destination address are stored in BRSR and BRDR, respectively.
2. The values stored in BRSR and BRDR are as given below due to the kind of branch.
   - If a branch occurs due to a branch instruction, the address of the branch instruction is saved in BRSR and the address of the branch destination instruction is saved in BRDR.
   - If a branch occurs due to an interrupt or exception, the value saved in SPC due to exception occurrence is saved in BRSR and the start address of the exception handling routine is saved in BRDR.
3. BRSR and BRDR have eight pairs of queue structures. The top of queues is read first when the address stored in the PC trace register is read. BRSR and BRDR share the read pointer. Read BRSR and BRDR in order, the queue only shifts after BRDR is read. After switching the PCTE bit (in BRCR) off and on, the values in the queues are invalid.

22.3.7 Usage Examples

Break Condition Specified for an L Bus Instruction Fetch Cycle

1. Register specifications

   BARA = H'00000404, BAMRA = H'00000000, BBRA = H'0054, BARB = H'00008010, BAMRB = H'00000006, BBRB = H'0054, BDRB = H'00000000, BDMRB = H'00000000, BRCR = H'00300400

   Specified conditions: Channel A/channel B independent mode

   - Channel A

     Address: H'00000404, Address mask: H'00000000

     Bus cycle: L bus/instruction fetch (after instruction execution)/read (operand size is not included in the condition)

     The ASID check is not included.

   - Channel B

     Address: H'00008010, Address mask: H'00000006

     Data: H'00000000, Data mask: H'00000000

     Bus cycle: L bus/instruction fetch (before instruction execution)/read (operand size is not included in the condition)

     The ASID check is not included.

   A user break occurs after an instruction of address H'00000404 is executed or before instructions of addresses H'00008010 to H'00008016 are executed.

2. Register specifications

   BARA = H'00037226, BAMRA = H'00000000, BBRA = H'0056, BARB = H'0003722E, BAMRB = H'00000000, BBRB = H'0056, BDRB = H'00000000, BDMRB = H'00000000, BRCR = H'00000008, BASRA = H'80, BASRB = H'70

   Specified conditions: Channel A/channel B sequential mode

   - Channel A

     Address: H'00037226, Address mask: H'00000000, ASID = H'80

     Bus cycle: L bus/instruction fetch (before instruction execution)/read/word

   - Channel B

     Address: H'0003722E, Address mask: H'00000000, ASID = H'70

     Data: H'00000000, Data mask: H'00000000

     Bus cycle: L bus/instruction fetch (before instruction execution)/read/word

   After an instruction with ASID = H’80 and address H'00037226 is executed, a user break occurs before an instruction with ASID = H’70 and address H'0003722E is executed.

3. Register specifications

   BARA = H'00027128, BAMRA = H'00000000, BBRA = H'005A, BARB = H'00031415, BAMRB = H'00000000, BBRB = H'0054, BDRB = H'00000000, BDMRB = H'00000000, BRCR = H'00300000

   Specified conditions: Channel A/channel B independent mode

   - Channel A

     Address: H'00027128, Address mask: H'00000000

     Bus cycle: L bus/instruction fetch (before instruction execution)/write/word

     The ASID check is not included.

   - Channel B

     Address: H'00031415, Address mask: H'00000000

     Data: H'00000000, Data mask: H'00000000

     The ASID check is not included.

     Bus cycle: L bus/instruction fetch (before instruction execution)/read (operand size is not included in the condition)

   On channel A, no user break occurs since instruction fetch is not a write cycle. On channel B, no user break occurs since instruction fetch is performed for an even address.

4. Register specifications

   BARA = H'00037226, BAMRA = H'00000000, BBRA = H'005A, BARB = H'0003722E, BAMRB = H'00000000, BBRB = H'0056, BDRB = H'00000000, BDMRB = H'00000000, BRCR = H'00000008, BASRA = H'80, BASRB = H'70

   Specified conditions: Channel A/channel B sequential mode

   - Channel A

     Address: H'00037226, Address mask: H'00000000, ASID = H'80

     Bus cycle: L bus/instruction fetch (before instruction execution)/write/word

   - Channel B

     Address: H'0003722E, Address mask: H'00000000, ASID = H'70

     Data: H'00000000, Data mask: H'00000000

     Bus cycle: L bus/instruction fetch (before instruction execution)/read/word

   Since instruction fetch is not a write cycle on channel A, a sequential condition does not match. Therefore, no user break occurs.

5. Register specifications

   BARA = H'00000500, BAMRA = H'00000000, BBRA = H'0057, BARB = H'00001000, BAMRB = H'00000000, BBRB = H'0057, BDRB = H'00000000, BDMRB = H'00000000, BRCR = H'00300001, BETR = H'0005

   Specified conditions: Channel A/channel B independent mode

   - Channel A

     Address: H'00000500, Address mask: H'00000000

     Bus cycle: L bus/instruction fetch (before instruction execution)/read/longword

     The ASID check is not included.

   - Channel B

     Address: H'00001000, Address mask: H'00000000

     Data: H'00000000, Data mask: H'00000000

     Bus cycle: L bus/instruction fetch (before instruction execution)/read/longword

     The number of execution-times break enable (5 times)

     The ASID check is not included.

   On channel A, a user break occurs before an instruction of address H'00000500 is executed. On channel B, a user break occurs after the instruction of address H'00001000 are executed four times and before the fifth time.

6. Register specifications

   BARA = H'00008404, BAMRA = H'00000FFF, BBRA = H'0054, BARB = H'00008010, BAMRB = H'00000006, BBRB = H'0054, BDRB = H'00000000, BDMRB = H'00000000, BRCR = H'00000400, BASRA = H'80, BASRB = H'70

   Specified conditions: Channel A/channel B independent mode

   - Channel A

     Address: H'00008404, Address mask: H'00000FFF, ASID = H'80

     Bus cycle: L bus/instruction fetch (after instruction execution)/read (operand size is not included in the condition)

   - Channel B

     Address: H'00008010, Address mask: H'00000006, ASID = H'70

     Data: H'00000000, Data mask: H'00000000

     Bus cycle: L bus/instruction fetch (before instruction execution)/read (operand size is not included in the condition)

   A user break occurs after an instruction with ASID = H’80 and addresses H'00008000 to H'00008FFE is executed or before an instruction with ASID = H’70 and addresses H'00008010 to H'00008016 are executed.

Register specifications:

BARA = H'00123456, BAMRA = H'00000000, BBRA = H'0064, BARB = H'000ABCDE, BAMRB = H'000000FF, BBRB = H'006A, BDRB = H'0000A512, BDMRB = H'00000000, BRCR = H'00000080, BASRA = H'80, BASRB = H'70

Specified conditions: Channel A/channel B independent mode

- Channel A

  Address: H'00123456, Address mask: H'00000000, ASID = H’80

  Bus cycle: L bus/data access/read (operand size is not included in the condition)

- Channel B

  Address: H'000ABCDE, Address mask: H'000000FF, ASID = H’70

  Data: H'0000A512, Data mask: H'00000000

  Bus cycle: L bus/data access/write/word

On channel A, a user break occurs with longword read from ASID = H’80 and address H'00123454, word read from address H'00123456, or byte read from address H'00123456. On channel B, a user break occurs when word H'A512 is written in ASID = H’70 and addresses H'000ABC00 to H'000ABCFE.

Break Condition Specified for an I Bus Data Access Cycle

Register specifications:

BARA = H'00314156, BAMRA = H'00000000, BBRA = H'0094, BARB = H'00055555, BAMRB = H'00000000, BBRB = H'00A9, BDRB = H'00007878, BDMRB = H'00000F0F, BRCR = H'00000080, BASRA = H'80, BASRB = H'70

Specified conditions: Channel A/channel B independent mode

- Channel A

  Address: H'00314156, Address mask: H'00000000, ASID = H'80

  Bus cycle: I bus/instruction fetch/read (operand size is not included in the condition)

- Channel B

  Address: H'00055555, Address mask: H'00000000, ASID = H'70

  Data: H'00000078, Data mask: H'0000000F

  Bus cycle: I bus/data access/write/byte

On channel A, a user break occurs when instruction fetch is performed for ASID = H’80 and address H'00314156 in the memory space.

On channel B, a user break occurs when byte data H'7* is written in address H'00055555 with ASID = H’70 on the I bus.

22.3.8 Notes

1. The CPU can read from or write to the UBC registers via the I bus. Accordingly, during the period from executing an instruction to rewrite the UBC register till the new value is actually rewritten, the desired break may not occur. In order to know the timing when the UBC register is changed, read from the last written register. Instructions after then are valid for the newly written register value.
2. UBC cannot monitor access to the L bus and I bus in the same channel.
3. Note on specification of sequential break:

   A condition match occurs when a B-channel match occurs in a bus cycle after an A-channel match occurs in another bus cycle in sequential break setting. Therefore, no break occurs even if a bus cycle, in which an A-channel match and a channel B match occur simultaneously, is set.
4. When a user break and another exception occur at the same instruction, which has higher priority is determined according to the priority levels defined in table 5.1 in section 5, Exception Handling. If an exception with higher priority occurs, the user break is not generated.

   — Pre-execution break has the highest priority.
   — When a post-execution break or data access break occurs simultaneously with a re-execution-type exception (including pre-execution break) that has higher priority, the re-execution-type exception is accepted, and the condition match flag is not set (see the exception in the following note). The break will occur and the condition match flag will be set only after the exception source of the re-execution-type exception has been cleared by the exception handling routine and re-execution of the same instruction has ended.
   — When a post-execution break or data access break occurs simultaneously with a completion-type exception (TRAPA) that has higher priority, though a break does not occur, the condition match flag is set.
5. Note the following exception for the above note.

   If a post-execution break or data access break is satisfied by an instruction that generates a CPU address error (or TLB related exception) by data access, the CPU address error (or TLB related exception) is given priority to the break. Note that the UBC condition match flag is set in this case.
6. Note the following when a break occurs in a delay slot.

   If a pre-execution break is set at the delay slot instruction of the RTE instruction, the break does not occur until the branch destination of the RTE instruction.
7. User breaks are disabled during USB module standby mode. Do not read from or write to the UBC registers during USB module standby mode; the values are not guaranteed.

Section 23 Hitachi User Debugging Interface (H-UDI)

This LSI incorporates a Hitachi user debugging interface (H-UDI) and advanced user debugger (AUD) for a boundary scan function and emulator support.

This section describes the H-UDI. The AUD is a function exclusively for use by an emulator. Refer to the User's Manual for the relevant emulator for details of the AUD.

23.1 Features

The H-UDI (Hitachi user debugging interface) is a serial I/O interface which supports with JTAG (Joint Test Action Group, IEEE Standard 1149.1 and IEEE Standard Test Access Port and Boundary-Scan Architecture) specifications.

The H-UDI in this LSI supports a boundary scan mode, and is also used for emulator connection.

When using an emulator, H-UDI functions should not be used. Refer to the emulator manual for the method of connecting the emulator.

Figure 23.1 shows a block diagram of the H-UDI.

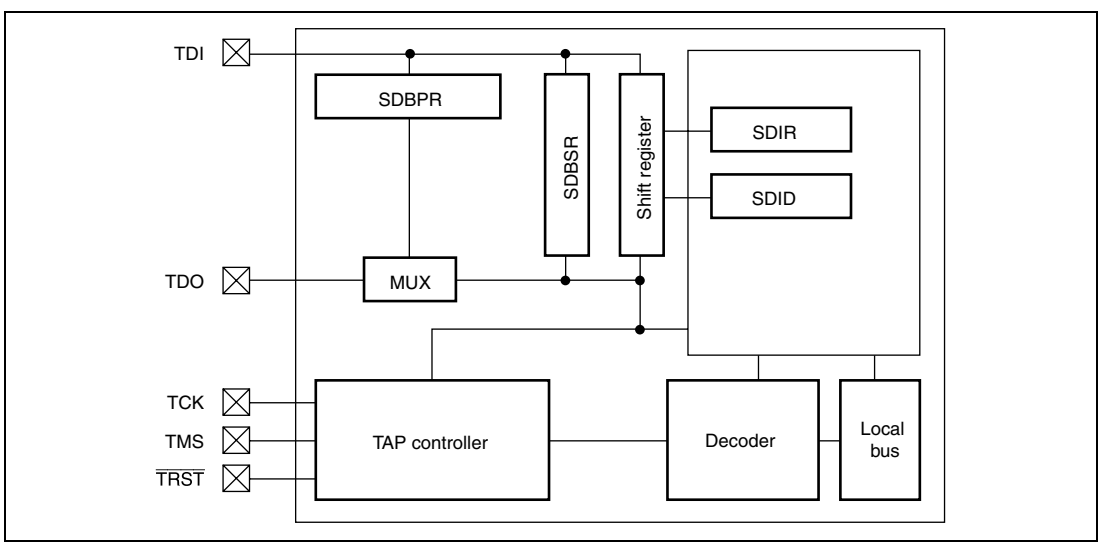


Figure 23.1 Block Diagram of H-UDI

23.2 Input/Output Pins

Table 23.1 shows the pin configuration of the H-UDI.

Table 23.1 Pin Configuration

Pin Name	Input/Output	Description
TCK	Input	Serial Data Input/Output Clock Pin Data is serially supplied to the H-UDI from the data input pin (TDI), and output from the data output pin (TDO), in synchronization with this clock.
TMS	Input	Mode Select Input Pin The state of the TAP control circuit is determined by changing this signal in synchronization with TCK. The protocol is supported to the JTAG standard (IEEE Std.1149.1).
$\overline{\text{TRST}}$	Input	Reset Input Pin Input is accepted asynchronously with respect to TCK, and when low, the H-UDI is reset. $\overline{\text{TRST}}$ must be held low for a constant period when power is turned on regardless of using the H-UDI function. As the same as the $\overline{\text{RESETP}}$ pin, the $\overline{\text{TRST}}$ pin should be driven low at the power-on reset state and driven high after the power-on reset state is released. This is different from the JTAG standard. See section 23.4.2, Reset Configuration, for more information.
TDI	Input	Serial Data Input Pin Data transfer to the H-UDI is executed by changing this signal in synchronization with TCK.
TDO	Output	Serial Data Output Pin Data read from the H-UDI is executed by reading this pin in synchronization with TCK. The data output timing depends on the command type set in the SDIR. See section 23.3.2, Instruction Register (SDIR), for more information.
$\overline{\text{ASEMD0}}$	Input	ASE Mode Select Pin If a low level is input at the $\overline{\text{ASEMD0}}$ pin while the $\overline{\text{RESETP}}$ pin is asserted, ASE mode is entered; if a high level is input, normal mode is entered. In ASE mode, dedicated emulator function can be used. The input level at the $\overline{\text{ASEMD0}}$ pin should be held for at least one cycle after $\overline{\text{RESETP}}$ negation. See section 23.4.2, Reset Configuration, for more information.

Pin Name	Input/Output	Description
$\overline{\text{ASEBRKAK}}$ AUDSYNC AUDATA3 to 0 AUDCK	Output	Dedicated emulator pin

23.3 Register Descriptions

The H-UDI has the following registers. For details on register addresses and register states in each processing state, see section 24, List of Registers.

- Bypass register (SDBPR)
- Instruction register (SDIR)
- Boundary scan register (SDBSR)
- ID register (SDID)

23.3.1 Bypass Register (SDBPR)

SDBPR is a 1-bit register that cannot be accessed by the CPU. When SDIR is set to the bypass mode, SDBPR is connected between H-UDI pins TDI and TDO. The initial value is undefined but SDBPR is initialized when the TAP enters the Capture-DR state.

23.3.2 Instruction Register (SDIR)

SDIR is a 16-bit read-only register. The register is in JTAG IDCODE in its initial state. It is initialized by $\overline{\text{TRST}}$ assertion or in the TAP test-logic-reset state, and can be written to by the H-UDI irrespective of the CPU mode. Operation is not guaranteed if a reserved command is set in this register.

Bit	Bit Name	Initial Value	R/W	Description
15 to 13	TI7 to TI5	All 1	R	Test Instruction 7 to 0
12	TI4	0	R	The H-UDI instruction is transferred to SDIR by a serial input from TDI. For commands, see table 23.2.
11 to 8	TI3 to TI0	All 1	R	
7 to 2	—	All 1	R	Reserved These bits are always read as 1.
1	—	0	R	Reserved This bit is always read as 0.
0	—	1	R	Reserved This bit is always read as 1.

Table 23.2 H-UDI Commands

Bits 15 to 8								
TI7	**TI6**	**TI5**	**TI4**	**TI3**	**TI2**	**TI1**	**TI0**	**Description**
0	0	0	0	—	—	—	—	JTAG EXTEST
0	0	1	0	—	—	—	—	JTAG CLAMP
0	0	1	1	—	—	—	—	JTAG HIGHZ
0	1	0	0	—	—	—	—	JTAG SAMPLE/PRELOAD
0	1	1	0	—	—	—	—	H-UDI reset negate
0	1	1	1	—	—	—	—	H-UDI reset assert
1	0	1	—	—	—	—	—	H-UDI interrupt
1	1	1	0	—	—	—	—	JTAG IDCODE (Initial value)
1	1	1	1	—	—	—	—	JTAG BYPASS
Other than the above								Reserved

23.3.3 Boundary Scan Register (SDBSR)

SDBSR is a 384-bit shift register, located on the PAD, for controlling the input/output pins of this LSI. The initial value is undefined. SDBSR cannot be accessed by the CPU.

Using the EXTEST, SAMPLE/PRELOAD, CLAMP, and HIGHZ commands, a boundary scan test which supports the JTAG standard can be carried out. Table 23.3 shows the correspondence between this LSI's pins and boundary scan register bits.

Table 23.3 SH7705 Pins and Boundary Scan Register Bits

Bit	Pin Name	I/O	Bit	Pin Name	I/O
	from TDI		353	D2	IN
384	VBUS/PTM6	IN	352	D1	IN
383	MD6	IN	351	D0	IN
382	D31/PTB7/PINT15	IN	350	VBUS/PTM6	OUT
381	D30/PTB6/PINT14	IN	349	D31/PTB7/PINT15	OUT
380	D29/PTB5/PINT13	IN	348	D30/PTB6/PINT14	OUT
379	D28/PTB4/PINT12	IN	347	D29/PTB5/PINT13	OUT
378	D27/PTB3/PINT11	IN	346	D28/PTB4/PINT12	OUT
377	D26/PTB2/PINT10	IN	345	D27/PTB3/PINT11	OUT
376	D25/PTB1/PINT9	IN	344	D26/PTB2/PINT10	OUT
375	D24/PTB0/PINT8	IN	343	D25/PTB1/PINT9	OUT
374	D23/PTA7/PINT7	IN	342	D24/PTB0/PINT8	OUT
373	D22/PTA6/PINT6	IN	341	D23/PTA7/PINT7	OUT
372	D21/PTA5/PINT5	IN	340	D22/PTA6/PINT6	OUT
371	D20/PTA4/PINT4	IN	339	D21/PTA5/PINT5	OUT
370	D19/PTA3/PINT3	IN	338	D20/PTA4/PINT4	OUT
369	D18/PTA2/PINT2	IN	337	D19/PTA3/PINT3	OUT
368	D17/PTA1/PINT1	IN	336	D18/PTA2/PINT2	OUT
367	D16/PTA0/PINT0	IN	335	D17/PTA1/PINT1	OUT
366	D15	IN	334	D16/PTA0/PINT0	OUT
365	D14	IN	333	D15	OUT
364	D13	IN	332	D14	OUT
363	D12	IN	331	D13	OUT
362	D11	IN	330	D12	OUT
361	D10	IN	329	D11	OUT
360	D9	IN	328	D10	OUT
359	D8	IN	327	D9	OUT
358	D7	IN	326	D8	OUT
357	D6	IN	325	D7	OUT
356	D5	IN	324	D6	OUT
355	D4	IN	323	D5	OUT
354	D3	IN	322	D4	OUT

Bit	Pin Name	I/O	Bit	Pin Name	I/O
321	D3	OUT	288	D3	Control
320	D2	OUT	287	D2	Control
319	D1	OUT	286	D1	Control
318	D0	OUT	285	D0	Control
317	VBUS/PTM6	Control	284	A0/PTK0	IN
316	D31/PTB7/PINT15	Control	283	A19/PTK1	IN
315	D30/PTB6/PINT14	Control	282	A20/PTK2	IN
314	D29/PTB5/PINT13	Control	281	A21/PTK3	IN
313	D28/PTB4/PINT12	Control	280	A22/PTK4	IN
312	D27/PTB3/PINT11	Control	279	A23/PTK5	IN
311	D26/PTB2/PINT10	Control	278	A24/PTK6	IN
310	D25/PTB1/PINT9	Control	277	A25/PTK7	IN
309	D24/PTB0/PINT8	Control	276	$\overline{BS}$/PTC0	IN
308	D23/PTA7/PINT7	Control	275	$\overline{WE2}$/DQMUL/PTC1	IN
307	D22/PTA6/PINT6	Control	274	$\overline{WE3}$/DQMUU/$\overline{AH}$/PTC2	IN
306	D21/PTA5/PINT5	Control	273	$\overline{CS2}$/PTC3	IN
305	D20/PTA4/PINT4	Control	272	$\overline{CS3}$/PTC4	IN
304	D19/PTA3/PINT3	Control	271	$\overline{CS4}$/PTC5	IN
303	D18/PTA2/PINT2	Control	270	$\overline{CS5A}$/PTC6	IN
302	D17/PTA1/PINT1	Control	269	$\overline{CS5B}$/PTD6	IN
301	D16/PTA0/PINT0	Control	268	$\overline{CS6A}$/PTC7	IN
300	D15	Control	267	$\overline{CS6B}$/PTD7	IN
299	D14	Control	266	$\overline{RASL}$/PTD0	IN
298	D13	Control	265	$\overline{RASU}$/PTD1	IN
297	D12	Control	264	$\overline{CASL}$/PTD2	IN
296	D11	Control	263	A0/PTK0	OUT
295	D10	Control	262	A1	OUT
294	D9	Control	261	A2	OUT
293	D8	Control	260	A3	OUT
292	D7	Control	259	A4	OUT
291	D6	Control	258	A5	OUT
290	D5	Control	257	A6	OUT
289	D4	Control	256	A7	OUT

Bit	Pin Name	I/O	Bit	Pin Name	I/O
255	A8	OUT	222	$\overline{\text{RASL}}$/PTD0	OUT
254	A9	OUT	221	$\overline{\text{RASU}}$/PTD1	OUT
253	A10	OUT	220	$\overline{\text{CASL}}$/PTD2	OUT
252	A11	OUT	219	A0/PTK0	Control
251	A12	OUT	218	A1	Control
250	A13	OUT	217	A2	Control
249	A14	OUT	216	A3	Control
248	A15	OUT	215	A4	Control
247	A16	OUT	214	A5	Control
246	A17	OUT	213	A6	Control
245	A18	OUT	212	A7	Control
244	A19/PTK1	OUT	211	A8	Control
243	A20/PTK2	OUT	210	A9	Control
242	A21/PTK3	OUT	209	A10	Control
241	A22/PTK4	OUT	208	A11	Control
240	A23/PTK5	OUT	207	A12	Control
239	A24/PTK6	OUT	206	A13	Control
238	A25/PTK7	OUT	205	A14	Control
237	$\overline{\text{BS}}$/PTC0	OUT	204	A15	Control
236	$\overline{\text{RD}}$	OUT	203	A16	Control
235	$\overline{\text{WE0}}$/DQMLL	OUT	202	A17	Control
234	$\overline{\text{WE1}}$/DQMLU	OUT	201	A18	Control
233	$\overline{\text{WE2}}$/DQMUL/PTC1	OUT	200	A19/PTK1	Control
232	$\overline{\text{WE3}}$/DQMUU/$\overline{\text{AH}}$/PTC2	OUT	199	A20/PTK2	Control
231	RD/$\overline{\text{WR}}$	OUT	198	A21/PTK3	Control
230	$\overline{\text{CS0}}$	OUT	197	A22/PTK4	Control
229	$\overline{\text{CS2}}$/PTC3	OUT	196	A23/PTK5	Control
228	$\overline{\text{CS3}}$/PTC4	OUT	195	A24/PTK6	Control
227	$\overline{\text{CS4}}$/PTC5	OUT	194	A25/PTK7	Control
226	$\overline{\text{CS5A}}$/PTC6	OUT	193	$\overline{\text{BS}}$/PTC0	Control
225	$\overline{\text{CS5B}}$/PTD6	OUT	192	$\overline{\text{RD}}$	Control
224	$\overline{\text{CS6A}}$/PTC7	OUT	191	$\overline{\text{WE0}}$/DQMLL	Control
223	$\overline{\text{CS6B}}$/PTD7	OUT	190	$\overline{\text{WE1}}$/DQMLU	Control

Bit	Pin Name	I/O	Bit	Pin Name	I/O
189	$\overline{WE2}$/DQMUL/PTC1	Control	156	NF/PTJ5	IN
188	$\overline{WE3}$/DQMUU/$\overline{AH}$/PTC2	Control	155	NF/PTJ6	IN
187	RD/$\overline{WR}$	Control	154	NF/PTJ7	IN
186	$\overline{CS0}$	Control	153	NF/PTM4	IN
185	$\overline{CS2}$/PTC3	Control	152	PTM0	IN
184	$\overline{CS3}$/PTC4	Control	151	PTM1	IN
183	$\overline{CS4}$/PTC5	Control	150	PTM2	IN
182	$\overline{CS5A}$/PTC6	Control	149	PTM3	IN
181	$\overline{CS5B}$/PTD6	Control	148	$\overline{ASEBRKAK}$/PTF6	IN
180	$\overline{CS6A}$/PTC7	Control	147	MD0	IN
179	$\overline{CS6B}$/PTD7	Control	146	MD1	IN
178	$\overline{RASL}$/PTD0	Control	145	MD2	IN
177	$\overline{RASU}$/PTD1	Control	144	MD5	IN
176	$\overline{CASL}$/PTD2	Control	143	$\overline{CASU}$/PTD3	OUT
175	$\overline{CASU}$/PTD3	IN	142	CKE/PTD4	OUT
174	CKE/PTD4	IN	141	PTD5/NF	OUT
173	PTD5/NF	IN	140	$\overline{BACK}$/PTG5	OUT
172	$\overline{BACK}$/PTG5	IN	139	$\overline{BREQ}$/PTG6	OUT
171	$\overline{BREQ}$/PTG6	IN	138	$\overline{WAIT}$/PTG7	OUT
170	$\overline{WAIT}$/PTG7	IN	137	DACK0/PTE0	OUT
169	DACK0/PTE0	IN	136	DACK1/PTE1	OUT
168	DACK1/PTE1	IN	135	TEND0/PTE3	OUT
167	TEND0/PTE3	IN	134	AUDSYNC/PTF4	OUT
166	AUDSYNC/PTF4	IN	133	AUDATA0/PTF0/TO0	OUT
165	AUDATA0/PTF0/TO0	IN	132	AUDATA1/PTF1/TO1	OUT
164	AUDATA1/PTF1/TO1	IN	131	AUDATA2/PTF2/TO2	OUT
163	AUDATA2/PTF2/TO2	IN	130	AUDATA3/PTF3/TO3	OUT
162	AUDATA3/PTF3/TO3	IN	129	NF/PTJ0	OUT
161	NF/PTJ0	IN	128	NF/PTJ1	OUT
160	NF/PTJ1	IN	127	NF/PTJ2	OUT
159	NF/PTJ2	IN	126	NF/PTJ3	OUT
158	NF/PTJ3	IN	125	NF/PTJ4	OUT
157	NF/PTJ4	IN	124	NF/PTJ5	OUT

Bit	Pin Name	I/O	Bit	Pin Name	I/O
123	NF/PTJ6	OUT	90	PTM2	Control
122	NF/PTJ7	OUT	89	PTM3	Control
121	NF/PTM4	OUT	88	$\overline{\text{ASEBRKAK}}$/PTF6	Control
120	PTM0	OUT	87	STATUS0/PTE4/$\overline{\text{RTS0}}$	IN
119	PTM1	OUT	86	STATUS1/PTE5/$\overline{\text{CTS0}}$	IN
118	PTM2	OUT	85	PTN0/SUSPND	IN
117	PTM3	OUT	84	PTN1/TXENL	IN
116	$\overline{\text{ASEBRKAK}}$/PTF6	OUT	83	PTN2/XVDATA	IN
115	$\overline{\text{CASU}}$/PTD3	Control	82	PTN3/TXDMNS	IN
114	CKE/PTD4	Control	81	PTN4/TXDPLS	IN
113	PTD5/NF	Control	80	PTN5/DMNS	IN
112	$\overline{\text{BACK}}$/PTG5	Control	79	PTN6/DPLS	IN
111	$\overline{\text{BREQ}}$/PTG6	Control	78	PTN7	IN
110	$\overline{\text{WAIT}}$/PTG7	Control	77	TCLK/PTE6	IN
109	DACK0/PTE0	Control	76	PTE7	IN
108	DACK1/PTE1	Control	75	SCK0/SCPT1	IN
107	TEND0/PTE3	Control	74	SCK2/SCPT3	IN
106	AUDSYNC/PTF4	Control	73	$\overline{\text{RTS2}}$/SCPT4	IN
105	AUDATA0/PTF0/TO0	Control	72	RXD0/SCPT0/IrRX	IN
104	AUDATA1/PTF1/TO1	Control	71	RXD2/SCPT2	IN
103	AUDATA2/PTF2/TO2	Control	70	$\overline{\text{CTS2}}$/SCPT5	IN
102	AUDATA3/PTF3/TO3	Control	69	IRQ0/$\overline{\text{IRL0}}$/PTH0	IN
101	NF/PTJ0	Control	68	IRQ1/$\overline{\text{IRL1}}$/PTH1	IN
100	NAF/PTJ1	Control	67	IRQ2/$\overline{\text{IRL2}}$/PTH2	IN
99	NF/PTJ2	Control	66	IRQ3/$\overline{\text{IRL3}}$/PTH3	IN
98	NF/PTJ3	Control	65	IRQ4/PTH4	IN
97	NF/PTJ4	Control	64	IRQ5/PTE2	IN
96	NF/PTJ5	Control	63	AUDCK/PTG4	IN
95	NF/PTJ6	Control	62	NMI	IN
94	NF/PTJ7	Control	61	DREQ0/PTH5	IN
93	NF/PTM4	Control	60	DREQ1/PTH6	IN
92	PTM0	Control	59	MD3	IN
91	PTM1	Control	58	MD4	IN

Bit	Pin Name	I/O	Bit	Pin Name	I/O
57	AN0/PTL0	IN	27	DREQ1/PTH6	OUT
56	AN1/PTL1	IN	26	STATUS0/PTE4/$\overline{\text{RTS0}}$	Control
55	AN2/PTL2	IN	25	STATUS1/PTE5/$\overline{\text{CTS0}}$	Control
54	AN3/PTL3	IN	24	PTN0/SUSPND	Control
53	STATUS0/PTE4/$\overline{\text{RTS0}}$	OUT	23	PTN1/TXENL	Control
52	STATUS1/PTE5/$\overline{\text{CTS0}}$	OUT	22	PTN2/XVDATA	Control
51	PTN0/SUSPND	OUT	21	PTN3/TXDMNS	Control
50	PTN1/TXENL	OUT	20	PTN4/TXDPLS	Control
49	PTN2/XVDATA	OUT	19	PTN5/DMNS	Control
48	PTN3/TXDMNS	OUT	18	PTN6/DPLS	Control
47	PTN4/TXDPLS	OUT	17	PTN7	Control
46	PTN5/DMNS	OUT	16	TCLK/PTE6	Control
45	PTN6/DPLS	OUT	15	PTE7	Control
44	PTN7	OUT	14	TXD0/SCPT0/IrTX	Control
43	TCLK/PTE6	OUT	13	SCK0/SCPT1	Control
42	PTE7	OUT	12	TxD2/SCPT2	Control
41	TXD0/SCPT0/IrTX	OUT	11	SCK2/SCPT3	Control
40	SCK0/SCPT1	OUT	10	$\overline{\text{RTS2}}$/SCPT4	Control
39	TXD2/SCPT2	OUT	9	$\overline{\text{CTS2}}$/SCPT5	Control
38	SCK2/SCPT3	OUT	8	IRQ0/$\overline{\text{IRL0}}$/PTH0	Control
37	$\overline{\text{RTS2}}$/SCPT4	OUT	7	IRQ1/$\overline{\text{IRL1}}$/PTH1	Control
36	$\overline{\text{CTS2}}$/SCPT5	OUT	6	IRQ2/$\overline{\text{IRL2}}$/PTH2	Control
35	IRQ0/$\overline{\text{IRL0}}$/PTH0	OUT	5	IRQ3/$\overline{\text{IRL3}}$/PTH3	Control
34	IRQ1/$\overline{\text{IRL1}}$/PTH1	OUT	4	IRQ4/PTH4	Control
33	IRQ2/$\overline{\text{IRL2}}$/PTH2	OUT	3	IRQ5/PTE2	Control
32	IRQ3/$\overline{\text{IRL3}}$/PTH3	OUT	2	AUDCK/PTG4	Control
31	IRQ4/PTH4	OUT	1	DREQ0/PTH5	Control
30	IRQ5/PTE2	OUT	0	DREQ1/PTH6	Control
29	AUDCK/PTG4	OUT	to TDO		
28	DREQ0/PTH5	OUT			

Note: Control is an active-low signal.
When Control is driven low, the corresponding pin is driven by the value of OUT.

23.3.4 ID Register (SDID)

SDID is a 32-bit read-only register that consists of connected 16-bit registers SDIDH and SDIDL, each of which can be read by the CPU.

The IDCODE command is set from the H-UDI pin. This register can be read from the TDO when the TAP state is Shift-DR. Writing is disabled.

Bit	Bit Name	Initial Value	R/W	Description
31 to 0	DID31 to DID0	Refer to description	R	Device ID31 to 0 Device ID register that is stipulated by JTAG. H'001A200F (initial value) for this LSI. Upper four bits may be changed by the chip version. SDIDH corresponds to bits 31 to 16. SDIDL corresponds to bits 15 to 0.

23.4 Operation

23.4.1 TAP Controller

Figure 23.2 shows the internal states of the TAP controller. State transitions basically conform to the JTAG standard.

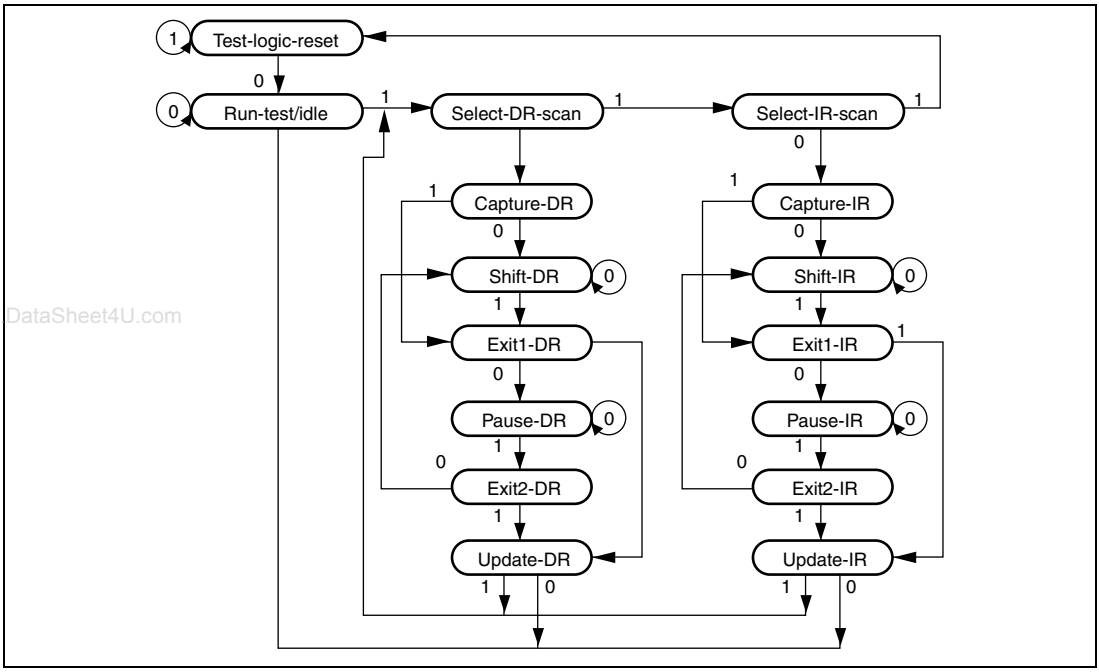


Figure 23.2 TAP Controller State Transitions

Note: The transition condition is the TMS value at the rising edge of TCK. The TDI value is sampled at the rising edge of TCK; shifting occurs at the falling edge of TCK. For details on change timing of the TDO value, see section 23.4.3, TDO Output Timing. The TDO is at high impedance, except with shift-DR and shift-IR states. During the change to $\overline{\text{TRST}}$ = 0, there is a transition to test-logic-reset asynchronously with TCK.

23.4.2 Reset Configuration

Table 23.4 Reset Configuration

$\overline{\text{ASEMD0}}$*1	$\overline{\text{RESETP}}$	$\overline{\text{TRST}}$	Chip State
H	L	L	Normal reset and H-UDI reset*4
		H	Normal reset*4
	H	L	H-UDI reset only
		H	Normal operation
L	L	L	Reset hold*2
		H	In ASE user mode*3: Normal reset In ASE break mode*3: $\overline{\text{RESETP}}$ assert is masked
	H	L	H-UDI reset only
		H	Normal operation

Notes: *1 Performs normal mode and ASE mode settings
$\overline{\text{ASEMD0}}$ = H, normal mode
$\overline{\text{ASEMD0}}$ = L, ASE mode

*2 In ASE mode, reset hold is enabled by driving the $\overline{\text{RESETP}}$ and $\overline{\text{TRST}}$ pins low for a constant cycle. In this state, the CPU does not start up, even if $\overline{\text{RESETP}}$ is driven high. When $\overline{\text{TRST}}$ is driven high, H-UDI operation is enabled, but the CPU does not start up. The reset hold state is canceled by the following:
- Another $\overline{\text{RESETP}}$ assert (power-on reset)
- $\overline{\text{TRST}}$ reassert

*3 ASE mode is classified into two modes; ASE break mode to execute the firm program of an emulator and ASE user mode to execute the user program.

*4 Make sure the $\overline{\text{TRST}}$ pin is low when the power is turned on.

23.4.3 TDO Output Timing

The timing of data output from the TDO is switched by the command type set in the SDIR. The timing changes at the TCK falling edge when JTAG commands (EXTEST, CLAMP, HIGHZ, SAMPLE/PRELOAD, IDCODE, and BYPASS) are set. This is a timing of the JTAG standard. When the H-UDI commands (H-UDI reset negate, H-UDI reset assert, and H-UDI interrupt) are set, TDO is output at the TCK rising edge earlier than the JTAG standard by a half cycle.

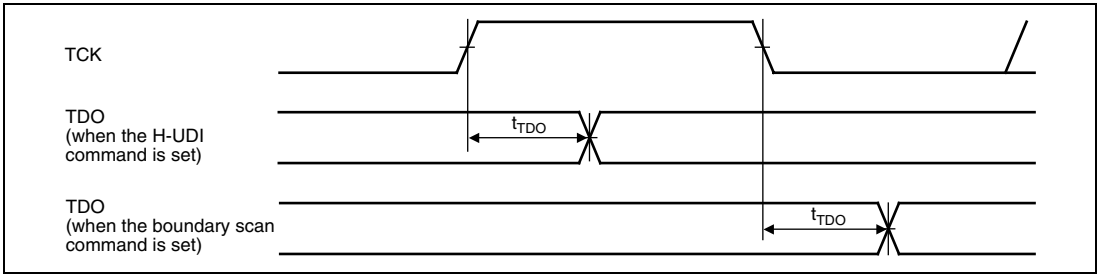


Figure 23.3 H-UDI Data Transfer Timing

23.4.4 H-UDI Reset

An H-UDI reset is executed by setting an H-UDI reset assert command in SDIR. An H-UDI reset is of the same kind as a power-on reset. An H-UDI reset is released by inputting an H-UDI reset negate command. The required time between the H-UDI reset assert command and H-UDI reset negate command is the same as time for keeping the $\overline{\text{RESETP}}$ pin low to apply a power-on reset.

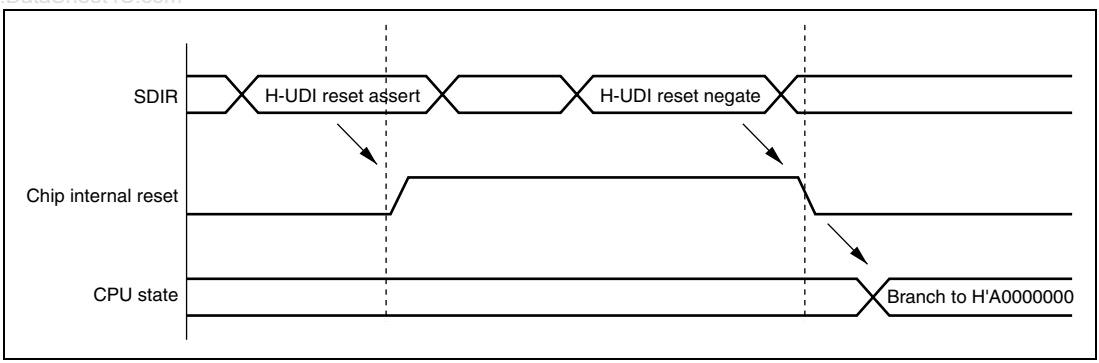


Figure 23.4 H-UDI Reset

23.4.5 H-UDI Interrupt

The H-UDI interrupt function generates an interrupt by setting a command from the H-UDI in the SDIR. An H-UDI interrupt is a general exception/interrupt operation, resulting in a branch to an address based on the VBR value plus offset, and with return by the RTE instruction. This interrupt request has a fixed priority level of 15.

H-UDI interrupts are accepted in sleep mode, but not in standby mode.

23.5 Boundary Scan

A command can be set in SDIR by the H-UDI to place the H-UDI pins in boundary scan mode stipulated by JTAG.

23.5.1 Supported Instructions

This LSI supports the three essential instructions defined in the JTAG standard (BYPASS, SAMPLE/PRELOAD, and EXTEST) and three option instructions (IDCODE, CLAMP, and HIGHZ).

1. BYPASS:

   The BYPASS instruction is an essential standard instruction that operates the bypass register. This instruction shortens the shift path to speed up serial data transfer involving other chips on the printed circuit board. While this instruction is executing, the test circuit has no effect on the system circuits. The upper four bits of the instruction code are 1111.

2. SAMPLE/PRELOAD:

   The SAMPLE/PRELOAD instruction inputs values from this LSI's internal circuitry to the boundary scan register, outputs values from the scan path, and loads data onto the scan path. When this instruction is executing, this LSI's input pin signals are transmitted directly to the internal circuitry, and internal circuit values are directly output externally from the output pins. This LSI's system circuits are not affected by execution of this instruction. The upper four bits of the instruction code are 0100.

   In a SAMPLE operation, a snapshot of a value to be transferred from an input pin to the internal circuitry, or a value to be transferred from the internal circuitry to an output pin, is latched into the boundary scan register and read from the scan path. Snapshot latching is performed in synchronization with the rise of TCK in the Capture-DR state. Snapshot latching does not affect normal operation of this LSI.

   In a PRELOAD operation, an initial value is set in the parallel output latch of the boundary scan register from the scan path prior to the EXTEST instruction. Without a PRELOAD operation, when the EXTEST instruction was executed an undefined value would be output from the output pin until completion of the initial scan sequence (transfer to the output latch) (with the EXTEST instruction, the parallel output latch value is constantly output to the output pin).

3. EXTEST:

   This instruction is provided to test external circuitry when this LSI is mounted on a printed circuit board. When this instruction is executed, output pins are used to output test data (previously set by the SAMPLE/PRELOAD instruction) from the boundary scan register to the printed circuit board, and input pins are used to latch test results into the boundary scan register from the printed circuit board. If testing is carried out by using the EXTEST instruction N times, the Nth test data is scanned-in when test data (N-1) is scanned out.

   Data loaded into the output pin boundary scan register in the Capture-DR state is not used for external circuit testing (it is replaced by a shift operation).

   The upper four bits of the instruction code are 0000.

4. IDCODE:

   A command can be set in SDIR by the H-UDI pins to place the H-UDI pins in the IDCODE mode stipulated by JTAG. When the H-UDI is initialized ($\overline{\text{TRST}}$ is asserted or TAP is in the Test-Logic-Reset state), the IDCODE mode is entered.

5. CLAMP, HIGHZ:

   A command can be set in SDIR by the H-UDI pins to place the H-UDI pins in the CLAMP or HIGHZ mode stipulated by JTAG.

23.5.2 Points for Attention

1. Boundary scan mode does not cover clock-related signals (EXTAL, EXTAL2, XTAL, XTAL2, EXTAL_USB, XTAL_USB, and CKIO).
2. Boundary scan mode does not cover reset-related signals ($\overline{\text{RESETP}}$, $\overline{\text{RESETM}}$, and CA).
3. Boundary scan mode does not cover H-UDI-related signals (TCK, TDI, TDO, TMS, and $\overline{\text{TRST}}$).
4. Fix the $\overline{\text{RESETP}}$ pin low during boundary scan.
5. Fix the CA pin high during boundary scan.
6. Fix the $\overline{\text{ASEMD0}}$ pin high during boundary scan.

23.6 Usage Notes

1. An H-UDI command, once set, will not be modified as long as another command is not re-issued from the H-UDI. If the same command is given continuously, the command must be set after a command (BYPASS, etc.) that does not affect chip operations is once set.
2. Because chip operations are suspended in standby mode, H-UDI commands are not accepted. To keep the TAP state constant before and after standby mode, TCK must be high during standby mode transition.
3. The H-UDI is used for emulator connection. Therefore, H-UDI functions cannot be used when using an emulator.

23.7 Advanced User Debugger (AUD)

The AUD is a function only for an emulator. For details on the AUD, refer to each emulator's User's Manual.

Section 24 List of Registers

This section gives information on the on-chip I/O registers and is configured as described below.

1. Register Addresses (by functional module, in order of the corresponding section numbers)

- Descriptions by functional module, in order of the corresponding section numbers
  Entries that consist of — lines are for separation of the functional modules.
- Access to reserved addresses which are not described in this list is prohibited.
- When registers consist of 16 or 32 bits, the addresses of the MSBs are given, on the presumption of a big-endian system.

2. Register Bits

- Bit configurations of the registers are described in the same order as the Register Addresses (by functional module, in order of the corresponding section numbers).
- Reserved bits are indicated by — in the bit name.

- No entry in the bit-name column indicates that the whole register is allocated as a counter or for holding data.
- When registers consist of 16 or 32 bits, bits are described from the MSB side.
  The order in which bytes are described is on the presumption of a big-endian system.

3. Register States in Each Operating Mode

- Register states are described in the same order as the Register Addresses (by functional module, in order of the corresponding section numbers).
- For the initial state of each bit, refer to the description of the register in the corresponding section.
- The register states described are for the basic operating modes. If there is a specific reset for an on-chip module, refer to the section on that on-chip module.

24.1 Register Addresses (by functional module, in order of the corresponding section numbers)

Entries under Access size indicates numbers of bits.

Note: Access to undefined or reserved addresses is prohibited. Since operation or continued operation is not guaranteed when these registers are accessed, do not attempt such access.

Register Name	Abbreviation	Number of Bits	Address	Module	Access Size
MMU control register	MMUCR	32	H'FFFF FFE0	MMU	32
Page table entry register high	PTEH	32	H'FFFF FFF0		32
Page table entry register low	PTEL	32	H'FFFF FFF4		32
Translation table base register	TTB	32	H'FFFF FFF8		32
—	—	—	—	—	—
Cache control register 1	CCR1	32	H'FFFF FFEC	Cache	32
Cache control register 2	CCR2	32	H'A400 00B0		32
Cache control register 3	CCR3	32	H'A400 00B4		32
—	—	—	—	—	—
Interrupt event register 2	INTEVT2	32	H'A400 0000	Exception handling	32
TRAPA exception register	TRA	32	H'FFFF FFD0		32
Exception event register	EXPEVT	32	H'FFFF FFD4		32
Interrupt event register	INTEVT	32	H'FFFF FFD8		32
TLB exception address register	TEA	32	H'FFFF FFFC		32
—	—	—	—	—	—
Interrupt priority level setting register A	IPRA	16	H'FFFF FEE2	INTC	16
Interrupt priority level setting register B	IPRB	16	H'FFFF FEE4		16
Interrupt priority level setting register C	IPRC	16	H'A400 0016		16
Interrupt priority level setting register D	IPRD	16	H'A400 0018		16
Interrupt priority level setting register E	IPRE	16	H'A400 001A		16
Interrupt priority level setting register F	IPRF	16	H'A408 0000		16
Interrupt priority level setting register G	IPRG	16	H'A408 0002		16
Interrupt priority level setting register H	IPRH	16	H'A408 0004		16

Register Name	Abbreviation	Number of Bits	Address	Module	Access Size
Interrupt control register 0	ICR0	16	H'FFFF FEE0	INTC	16
Interrupt control register 1	ICR1	16	H'A400 0010		16
Interrupt control register 2	ICR2	16	H'A400 0012		16
Interrupt request register 0	IRR0	8	H'A400 0004		8
Interrupt request register 1	IRR1	8	H'A400 0006		8
Interrupt request register 2	IRR2	8	H'A400 0008		8
PINT interrupt enable register	PINTER	16	H'A400 0014		16
—	—	—	—	—	—
Common control register	CMNCR	32	H'A4FD 0000	BSC	32
Bus control register for CS0 space	CS0BCR	32	H'A4FD 0004		32
Bus control register for CS2 space	CS2BCR	32	H'A4FD 0008		32
Bus control register for CS3 space	CS3BCR	32	H'A4FD 000C		32
Bus control register for CS4 space	CS4BCR	32	H'A4FD 0010		32
Bus control register for CS5A space	CS5ABCR	32	H'A4FD 0014		32
Bus control register for CS5B space	CS5BBCR	32	H'A4FD 0018		32
Bus control register for CS6A space	CS6ABCR	32	H'A4FD 001C		32
Bus control register for CS6B space	CS6BBCR	32	H'A4FD 0020		32
Wait control register for CS0 space	CS0WCR	32	H'A4FD 0024		32
Wait control register for CS2 space	CS2 WCR	32	H'A4FD 0028		32
Wait control register for CS3 space	CS3 WCR	32	H'A4FD 002C		32
Wait control register for CS4 space	CS4 WCR	32	H'A4FD 0030		32
Wait control register for CS5A space	CS5A WCR	32	H'A4FD 0034		32
Wait control register for CS5B space	CS5B WCR	32	H'A4FD 0038		32
Wait control register for CS6A space	CS6A WCR	32	H'A4FD 003C		32
Wait control register for CS6B space	CS6B WCR	32	H'A4FD 0040		32
SDRAM control register	SDCR	32	H'A4FD 0044		32
Refresh timer control/status register	RTCSR	32	H'A4FD 0048		32
Refresh timer counter	RTCNT	32	H'A4FD 004C		32
Refresh time constant register	RTCOR	32	H'A4FD 0050		32
SDRAM mode register for CS2 space	SDMR2	—	H'A4FD 4xxx*[2]		16
SDRAM mode register for CS3 space	SDMR3	—	H'A4FD 5xxx*[2]		16
—	—	—	—	—	—

Register Name	Abbreviation	Number of Bits	Address	Module	Access Size
DMA source address register_0	SAR_0	32	H'A400 0020	DMAC	16/32
DMA destination address register_0	DAR_0	32	H'A400 0024		16/32
DMA transfer count register_0	DMATCR_0	32	H'A400 0028		16/32
DMA channel control register_0	CHCR_0	32	H'A400 002C		8/16/32
DMA source address register_1	SAR_1	32	H'A400 0030		16/32
DMA destination address register_1	DAR_1	32	H'A400 0034		16/32
DMA transfer count register_1	DMATCR_1	32	H'A400 0038		16/32
DMA channel control register_1	CHCR_1	32	H'A400 003C		8/16/32
DMA source address register_2	SAR_2	32	H'A400 0040		16/32
DMA destination address register_2	DAR_2	32	H'A400 0044		16/32
DMA transfer count register_2	DMATCR_2	32	H'A400 0048		16/32
DMA channel control register_2	CHCR_2	32	H'A400 004C		8/16/32
DMA source address register_3	SAR_3	32	H'A400 0050		16/32
DMA destination address register_3	DAR_3	32	H'A400 0054		16/32
DMA transfer count register_3	DMATCR_3	32	H'A400 0058		16/32
DMA channel control register_3	CHCR_3	32	H'A400 005C		8/16/32
DMA operation register	DMAOR	16	H'A400 0060		8/16
DMA extended resource selector 0	DMARS0	16	H'A409 0000		16
DMA extended resource selector 1	DMARS1	16	H'A409 0004		16
—	—	—	—	—	—
USB clock control register	UCLKCR	8	H'A40A 0008	CPG	8/16*[1]
Frequency control register	FRQCR	16	H'FFFF FF80		16
—	—	—	—	—	—
Watchdog timer counter	WTCNT	8	H'FFFF FF84	WDT	8/16*[1]
Watchdog timer control/status register	WTCSR	8	H'FFFF FF86		8/16*[1]
—	—	—	—	—	—
Standby control register	STBCR	8	H'FFFF FF82	Power-down modes	8
Standby control register 2	STBCR2	8	H'FFFF FF88		8
Standby control register 3	STBCR3	8	H'A40A 0000		8
—	—	—	—	—	—

Register Name	Abbreviation	Number of Bits	Address	Module	Access Size
Timer start register	TSTR	8	H'FFFF FE92	TMU	8
Timer constant register_0	TCOR_0	32	H'FFFF FE94		32
Timer counter_0	TCNT_0	32	H'FFFF FE98		32
Timer control register_0	TCR_0	16	H'FFFF FE9C		16
Timer constant register_1	TCOR_1	32	H'FFFF FEA0		32
Timer counter_1	TCNT_1	32	H'FFFF FEA4		32
Timer control register_1	TCR_1	16	H'FFFF FEA8		16
Timer constant register_2	TCOR_2	32	H'FFFF FEAC		32
Timer counter_2	TCNT_2	32	H'FFFF FEB0		32
Timer control register_2	TCR_2	16	H'FFFF FEB4		16
Input capture register_2	TCPR_2	32	H'FFFF FEB8		32
—	—	—	—	—	—
Compare match timer start register	CMSTR	16	H'A400 0070	CMT	16
Compare match timer control/status register	CMCSR	16	H'A400 0074		16
Compare match timer counter	CMCNT	16	H'A400 0078		16
Compare match timer constant register	CMCOR	16	H'A400 007C		16
—	—	—	—	—	—
Timer start register	TSTR	16	H'A449 0000	TPU	16
Timer control register_0	TCR_0	16	H'A449 0010		16
Timer mode register_0	TMDR_0	16	H'A449 0014		16
Timer I/O control register_0	TIOR_0	16	H'A449 0018		16
Timer interrupt enable register_0	TIER_0	16	H'A449 001C		16
Timer status register_0	TSR_0	16	H'A449 0020		16
Timer counter_0	TCNT_0	16	H'A449 0024		16
Timer general register A_0	TGRA_0	16	H'A449 0028		16
Timer general register B_0	TGRB_0	16	H'A449 002C		16
Timer general register C_0	TGRC_0	16	H'A449 0030		16
Timer general register D_0	TGRD_0	16	H'A449 0034		16
Timer control register_1	TCR_1	16	H'A449 0050		16
Timer mode register_1	TMDR_1	16	H'A449 0054		16
Timer I/O control register_1	TIOR_1	16	H'A449 0058		16

Register Name	Abbreviation	Number of Bits	Address	Module	Access Size
Timer interrupt enable register_1	TIER_1	16	H'A449 005C	TPU	16
Timer status register_1	TSR_1	16	H'A449 0060		16
Timer counter_1	TCNT_1	16	H'A449 0064		16
Timer general register A_1	TGRA_1	16	H'A449 0068		16
Timer general register B_1	TGRB_1	16	H'A449 006C		16
Timer general register C_1	TGRC_1	16	H'A449 0070		16
Timer general register D_1	TGRD_1	16	H'A449 0074		16
Timer control register_2	TCR_2	16	H'A449 0090		16
Timer mode register_2	TMDR_2	16	H'A449 0094		16
Timer I/O control register_2	TIOR_2	16	H'A449 0098		16
Timer interrupt enable register_2	TIER_2	16	H'A449 009C		16
Timer status register_2	TSR_2	16	H'A449 00A0		16
Timer counter_2	TCNT_2	16	H'A449 00A4		16
Timer general register A_2	TGRA_2	16	H'A449 00A8		16
Timer general register B_2	TGRB_2	16	H'A449 00AC		16
Timer general register C_2	TGRC_2	16	H'A449 00B0		16
Timer general register D_2	TGRD_2	16	H'A449 00B4		16
Timer control register_3	TCR_3	16	H'A449 00D0		16
Timer mode register_3	TMDR_3	16	H'A449 00D4		16
Timer I/O control register_3	TIOR_3	16	H'A449 00D8		16
Timer interrupt enable register_3	TIER_3	16	H'A449 00DC		16
Timer status register_3	TSR_3	16	H'A449 00E0		16
Timer counter_3	TCNT_3	16	H'A449 00E4		16
Timer general register A_3	TGRA_3	16	H'A449 00E8		16
Timer general register B_3	TGRB_3	16	H'A449 00EC		16
Timer general register C_3	TGRC_3	16	H'A449 00F0		16
Timer general register D_3	TGRD_3	16	H'A449 00F4		16
—	—	—	—	—	—

Register Name	Abbreviation	Number of Bits	Address	Module	Access Size
64-Hz counter	R64CNT	8	H'FFFF FEC0	RTC	8
Second counter	RSECCNT	8	H'FFFF FEC2		8
Minute counter	RMINCNT	8	H'FFFF FEC4		8
Hour counter	RHRCNT	8	H'FFFF FEC6		8
Day of week counter	RWKCNT	8	H'FFFF FEC8		8
Date counter	RDAYCNT	8	H'FFFF FECA		8
Month counter	RMONCNT	8	H'FFFF FECC		8
Year counter	RYRCNT	16	H'FFFF FECE		16
Second alarm register	RSECAR	8	H'FFFF FED0		8
Minute alarm register	RMINAR	8	H'FFFF FED2		8
Hour alarm register	RHRAR	8	H'FFFF FED4		8
Day of week alarm register	RWKAR	8	H'FFFF FED6		8
Date alarm register	RDAYAR	8	H'FFFF FED8		8
Month alarm register	RMONAR	8	H'FFFF FEDA		8
RTC control register 1	RCR1	8	H'FFFF FEDC		8
RTC control register 2	RCR2	8	H'FFFF FEDE		8
Year alarm register	RYRAR	16	H'A413 FEE0		16
RTC control register 3	RCR3	8	H'A413 FEE4		8
—	—	—	—	—	—
Serial mode register_0	SCSMR_0	16	H'A440 0000	SCIF_0	16
Bit rate register_0	SCBRR_0	8	H'A440 0004	(Channel 0)	8
Serial control register_0	SCSCR_0	16	H'A440 0008		16
Transmit data stop register_0	SCTDSR_0	8	H'A440 000C		8
FIFO error count register_0	SCFER_0	16	H'A440 0010		16
Serial status register_0	SCSSR_0	16	H'A440 0014		16
FIFO control register_0	SCFCR_0	16	H'A440 0018		16
FIFO data count register_0	SCFDR_0	16	H'A440 001C		16
Transmit FIFO data register_0	SCFTDR_0	8	H'A440 0020		8
Receive FIFO data register_0	SCFRDR_0	8	H'A440 0024		8
—	—	—	—	—	—

Register Name	Abbreviation	Number of Bits	Address	Module	Access Size
Serial mode register_2	SCSMR_2	16	H'A441 0000	SCIF_2	16
Bit rate register_2	SCBRR_2	8	H'A441 0004	(Channel 2)	8
Serial control register_2	SCSCR_2	16	H'A441 0008		16
Transmit data stop register_2	SCTDSR_2	8	H'A441 000C		8
FIFO error count register_2	SCFER_2	16	H'A441 0010		16
Serial status register_2	SCSSR_2	16	H'A441 0014		16
FIFO control register_2	SCFCR_2	16	H'A441 0018		16
FIFO data count register_2	SCFDR_2	16	H'A441 001C		16
Transmit FIFO data register_2	SCFTDR_2	8	H'A441 0020		8
Receive FIFO data register_2	SCFRDR_2	8	H'A441 0024		8
—	—	—	—	—	—
IrDA mode register	SCSMR_Ir	16	H'A44A 0000	IrDA	16
—	—	—	—	—	—
EP0i data register	EPDR0i	8B	H'A448 0000	USB	8
EP0o data register	EPDR0o	8B	H'A448 0004		8
EP0s data register	EPDR0s	8B	H'A448 0008		8
EP1 data register	EPDR1	128B	H'A448 000C		8
EP2 data register	EPDR2	128B	H'A448 0010		8
EP3 data register	EPDR3	8B	H'A448 0014		8
Interrupt flag register 0	IFR0	8	H'A448 0018		8
Interrupt flag register 1	IFR1	8	H'A448 001C		8
Trigger register	TRG	8	H'A448 0020		8
FIFO clear register	FCLR	8	H'A448 0024		8
EP0o receive data size register	EPSZ0o	8	H'A448 0028		8
Data status register	DASTS	8	H'A448 002C		8
Endpoint stall register	EPSTL	8	H'A448 0030		8
Interrupt enable register 0	IER0	8	H'A448 0034		8
Interrupt enable register 1	IER1	8	H'A448 0038		8
EP1 receive data size register	EPSZ1	8	H'A448 003C		8
DMA transfer setting register	DMAR	8	H'A448 0040		8
Interrupt select register 0	ISR0	8	H'A448 0044		8
Interrupt select register 1	ISR1	8	H'A448 0048		8
Transceiver control register	XVERCR	8	H'A448 0060		8

Register Name	Abbreviation	Number of Bits	Address	Module	Access Size
—	—	—	—	—	—
Port A control register	PACR	16	H'A400 0100	PFC	16
Port B control register	PBCR	16	H'A400 0102		16
Port C control register	PCCR	16	H'A400 0104		16
Port D control register	PDCR	16	H'A400 0106		16
Port E control register	PECR	16	H'A400 0108		16
Port E control register 2	PECR2	8	H'A405 0148		8
Port F control register	PFCR	16	H'A400 010A		16
Port F control register 2	PFCR2	8	H'A405 014A		8
Port G control register	PGCR	16	H'A400 010C		16
Port H control register	PHCR	16	H'A400 010E		16
Port J control register	PJCR	16	H'A400 0110		16
Port K control register	PKCR	16	H'A400 0112		16
Port L control register	PLCR	16	H'A400 0114		16
Port SC control register	SCPCR	16	H'A400 0116		16
Port M control register	PMCR	16	H'A400 0118		16
Port N control register	PNCR	16	H'A400 011A		16
Port N control register 2	PNCR2	8	H'A405 015A		8
—	—	—	—	—	—
Port A data register	PADR	8	H'A400 0120	Port	8
Port B data register	PBDR	8	H'A400 0122		8
Port C data register	PCDR	8	H'A400 0124		8
Port D data register	PDDR	8	H'A400 0126		8
Port E data register	PEDR	8	H'A400 0128		8
Port F data register	PFDR	8	H'A400 012A		8
Port G data register	PGDR	8	H'A400 012C		8
Port H data register	PHDR	8	H'A400 012E		8
Port J data register	PJDR	8	H'A400 0130		8
Port K data register	PKDR	8	H'A405 0132		8
Port L data register	PLDR	8	H'A400 0134		8
SC port data register	SCPDR	8	H'A400 0136		8
Port M data register	PMDR	8	H'A400 0138		8
Port N data register	PNDR	8	H'A400 013A		8

Register Name	Abbreviation	Number of Bits	Address	Module	Access Size
—	—	—	—	—	—
A/D data register A	ADDRA	16	H'A400 0080	ADC	16
A/D data register B	ADDRB	16	H'A400 0082		16
A/D data register C	ADDRC	16	H'A400 0084		16
A/D data register D	ADDRD	16	H'A400 0086		16
A/D control/status register	ADCSR	16	H'A400 0088		16
—	—	—	—	—	—
Break data register B	BDRB	32	H'FFFF FF90	UBC	32
Break data mask register B	BDMRB	32	H'FFFF FF94		32
Break control register	BRCR	32	H'FFFF FF98		32
Execution count break register	BETR	16	H'FFFF FF9C		16
Break address register B	BARB	32	H'FFFF FFA0		32
Break address mask register B	BAMRB	32	H'FFFF FFA4		32
Break bus cycle register B	BBRB	16	H'FFFF FFA8		16
Branch source register	BRSR	32	H'FFFF FFAC		32
Break address register A	BARA	32	H'FFFF FFB0		32
Break address mask register A	BAMRA	32	H'FFFF FFB4		32
Break bus cycle register A	BBRA	16	H'FFFF FFB8		16
Branch destination register	BRDR	32	H'FFFF FFBC		32
Break ASID register A	BASRA	8	H'FFFF FFE4		8
Break ASID register B	BASRB	8	H'FFFF FFE8		8
—	—	—	—	—	—
Instruction register	SDIR	16	H'A400 0200	H-UDI	16
ID register	SDID/SDIDH	16	H'A400 0214		16
ID register	SDIDL	16	H'A400 0216		16

Note: *1 8 bits when reading and 16 bits when writing.

*2 The value of xxx depends on the setting value because of access control for the SDRAM mode register.

24.2 Register Bits

Register addresses and bit names of the on-chip peripheral modules are described below.

Each line covers eight bits, and 16-bit and 32-bit registers are shown as 2 or 4 lines, respectively.

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
MMUCR	—	—	—	—	—	—	—	—	MMU
	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	SV	
	—	—	RC1	RC0	—	TF	IX	AT	
PTEH	VPN	VPN	VPN	VPN	VPN	VPN	VPN	VPN	
	VPN	VPN	VPN	VPN	VPN	VPN	VPN	VPN	
	VPN	VPN	VPN	VPN	VPN	VPN	—	—	
	ASID7	ASID6	ASID5	ASID4	ASID3	ASID2	ASID1	ASID0	
PTEL	—	—	—	PPN	PPN	PPN	PPN	PPN	
	PPN	PPN	PPN	PPN	PPN	PPN	PPN	PPN	
	PPN	PPN	PPN	PPN	PPN	PPN	—	V	
	—	PR1	PR0	SZ	C	D	SH	—	
TTB									

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
CCR1	—	—	—	—	—	—	—	—	Cache
	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	—	CF	CB	WT	CE	
CCR2	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	LE	
	—	—	—	—	—	—	W3LOAD	W3LOCK	
	—	—	—	—	—	—	W2LOAD	W2LOCK	
CCR3	—	—	—	—	—	—	—	—	
	CSIZE7	CSIZE6	CSIZE5	CSIZE4	CSIZE3	CSIZE2	CSIZE1	CSIZE0	
	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
INTEVT2	—	—	—	—	—	—	—	—	Exception handing
	—	—	—	—	—	—	—	—	
	—	—	—	—					
TRA	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	imm	imm	
	imm	imm	imm	imm	imm	imm	—	—	
EXPEVT	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	—					
INTEVT	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	—					

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
TEA									Exception handing
IPRA	IPR15	IPR14	IPR13	IPR12	IPR11	IPR10	IPR9	IPR8	INTC
	IPR7	IPR6	IPR5	IPR4	IPR3	IPR2	IPR1	IPR0	
IPRB	IPR15	IPR14	IPR13	IPR12	IPR11	IPR10	IPR9	IPR8	
	IPR7	IPR6	IPR5	IPR4	IPR3	IPR2	IPR1	IPR0	
IPRC	IPR15	IPR14	IPR13	IPR12	IPR11	IPR10	IPR9	IPR8	
	IPR7	IPR6	IPR5	IPR4	IPR3	IPR2	IPR1	IPR0	
IPRD	IPR15	IPR14	IPR13	IPR12	IPR11	IPR10	IPR9	IPR8	
	IPR7	IPR6	IPR5	IPR4	IPR3	IPR2	IPR1	IPR0	
IPRE	IPR15	IPR14	IPR13	IPR12	IPR11	IPR10	IPR9	IPR8	
	IPR7	IPR6	IPR5	IPR4	IPR3	IPR2	IPR1	IPR0	
IPRF	IPR15	IPR14	IPR13	IPR12	IPR11	IPR10	IPR9	IPR8	
	IPR7	IPR6	IPR5	IPR4	IPR3	IPR2	IPR1	IPR0	
IPRG	IPR15	IPR14	IPR13	IPR12	IPR11	IPR10	IPR9	IPR8	
	IPR7	IPR6	IPR5	IPR4	IPR3	IPR2	IPR1	IPR0	
IPRH	IPR15	IPR14	IPR13	IPR12	IPR11	IPR10	IPR9	IPR8	
	IPR7	IPR6	IPR5	IPR4	IPR3	IPR2	IPR1	IPR0	
ICR0	NMIL	—	—	—	—	—	—	NMIE	
	—	—	—	—	—	—	—	—	
ICR1	MAI	IRQLVL	BLMSK	—	IRQ51S	IRQ50S	IRQ41S	IRQ40S	
	IRQ31S	IRQ30S	IRQ21S	IRQ20S	IRQ11S	IRQ10S	IRQ01S	IRQ00S	
ICR2	PINT15S	PINT14S	PINT13S	PINT12S	PINT11S	PINT10S	PINT9S	PINT8S	
	PINT7S	PINT6S	PINT5S	PINT4S	PINT3S	PINT2S	PINT1S	PINT0S	
IRR0	PINT0R	PINT1R	IRQ5R	IRQ4R	IRQ3R	IRQ2R	IRQ1R	IRQ0R	
IRR1	TXI0R	—	RXI0R	ERI0R	DEI3R	DEI2R	DEI1R	DEI0R	
IRR2	—	—	—	ADIR	TXI2R	—	RXI2R	ERI2R	
PINTER	PINT15E	PINT14E	PINT13E	PINT12E	PINT11E	PINT10E	PINT9E	PINT8E	
	PINT7E	PINT6E	PINT5E	PINT4E	PINT3E	PINT2E	PINT1E	PINT0E	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
CMNCR	—	—	—	—	—	—	—	—	BSC
	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	DMAIW1	DMAIW0	DMAIWA	—	ENDIAN	—	HIZMEM	HIZCNT	
CS0BCR	—	—	IWW1	IWW0	—	IWRWD1	IWRWD0	—	
	IWRWS1	IWRWS0	—	IWRRD1	IWRRD0	—	IWRRS1	IWRRS0	
	—	TYPE2	TYPE1	TYPE0	—	BSZ1	BSZ0	—	
	—	—	—	—	—	—	—	—	
CS2BCR	—	—	IWW1	IWW0	—	IWRWD1	IWRWD0	—	
	IWRWS1	IWRWS0	—	IWRRD1	IWRRD0	—	IWRRS1	IWRRS0	
	—	TYPE2	TYPE1	TYPE0	—	BSZ1	BSZ0	—	
	—	—	—	—	—	—	—	—	
CS3BCR	—	—	IWW1	IWW0	—	IWRWD1	IWRWD0	—	
	IWRWS1	IWRWS0	—	IWRRD1	IWRRD0	—	IWRRS1	IWRRS0	
	—	TYPE2	TYPE1	TYPE0	—	BSZ1	BSZ0	—	
	—	—	—	—	—	—	—	—	
CS4BCR	—	—	IWW1	IWW0	—	IWRWD1	IWRWD0	—	
	IWRWS1	IWRWS0	—	IWRRD1	IWRRD0	—	IWRRS1	IWRRS0	
	—	TYPE2	TYPE1	TYPE0	—	BSZ1	BSZ0	—	
	—	—	—	—	—	—	—	—	
CS5ABCR	—	—	IWW1	IWW0	—	IWRWD1	IWRWD0	—	
	IWRWS1	IWRWS0	—	IWRRD1	IWRRD0	—	IWRRS1	IWRRS0	
	—	TYPE2	TYPE1	TYPE0	—	BSZ1	BSZ0	—	
	—	—	—	—	—	—	—	—	
CS5BBCR	—	—	IWW1	IWW0	—	IWRWD1	IWRWD0	—	
	IWRWS1	IWRWS0	—	IWRRD1	IWRRD0	—	IWRRS1	IWRRS0	
	—	TYPE2	TYPE1	TYPE0	—	BSZ1	BSZ0	—	
	—	—	—	—	—	—	—	—	
CS6ABCR	—	—	IWW1	IWW0	—	IWRWD1	IWRWD0	—	
	IWRWS1	IWRWS0	—	IWRRD1	IWRRD0	—	IWRRS1	IWRRS0	
	—	TYPE2	TYPE1	TYPE0	—	BSZ1	BSZ0	—	
	—	—	—	—	—	—	—	—	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
CS6BBCR	—	—	IWW1	IWW0	—	IWRWD1	IWRWD0	—	BSC
	IWRWS1	IWRWS0	—	IWRRD1	IWRRD0	—	IWRRS1	IWRRS0	
	—	TYPE2	TYPE1	TYPE0	—	BSZ1	BSZ0	—	
	—	—	—	—	—	—	—	—	
CS0WCR (except burst ROM)	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	SW1	SW0	WR3	WR2	WR1	
	WR0	WM	—	—	—	—	HW1	HW0	
CS0WCR (burst ROM)	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	BW1	BW0	
	—	—	—	—	—	W3	W2	W1	
	W0	WM	—	—	—	—	—	—	
CS2 WCR (except SDRAM)	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	—	—	WR3	WR2	WR1	
	WR0	WM	—	—	—	—	—	—	
CS2 WCR (SDRAM)	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	A2CL1	
	A2CL0	—	—	—	—	—	—	—	
CS3 WCR (except SDRAM)	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	—	—	WR3	WR2	WR1	
	WR0	WM	—	—	—	—	—	—	
CS3 WCR (SDRAM)	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	TRP1	TRP0	—	TRCD1	TRCD0	—	A3CL1	
	A3CL0	—	—	—	TRWL1	TRWL0	TRC1	TRC0	
CS4 WCR (except burst ROM)	—	—	—	—	—	—	—	—	
	—	—	—	—	—	WW2	WW1	WW0	
	—	—	—	SW1	SW0	WR3	WR2	WR1	
	WR0	WM	—	—	—	—	HW1	HW0	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
CS4 WCR (burst ROM)	—	—	—	—	—	—	—	—	BSC
	—	—	—	—	—	—	BW1	BW0	
	—	—	—	SW1	SW0	W3	W2	W1	
	W0	WM	—	—	—	—	HW1	HW0	
CS5A WCR	—	—	—	—	—	—	—	—	
	—	—	—	—	—	WW2	WW1	WW0	
	—	—	—	SW1	SW0	WR3	WR2	WR1	
	WR0	WM	—	—	—	—	HW1	HW0	
CS5B WCR	—	—	—	—	—	—	—	—	
	—	—	—	MPXW	—	WW2	WW1	WW0	
	—	—	—	SW1	SW0	WR3	WR2	WR1	
	WR0	WM	—	—	—	—	HW1	HW0	
CS6A WCR	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	SW1	SW0	WR3	WR2	WR1	
	WR0	WM	—	—	—	—	HW1	HW0	
CS6B WCR	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	SW1	SW0	WR3	WR2	WR1	
	WR0	WM	—	—	—	—	HW1	HW0	
SDCR	—	—	—	—	—	—	—	—	
	—	—	—	A2ROW1	A2ROW0	—	A2COL1	A2COL0	
	—	—	—	SLOW	RFSH	RMODE	—	BACTV	
	—	—	—	A3ROW1	A3ROW0	—	A3COL1	A3COL0	
RTCSR	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	CMF	CMIE	CKS2	CKS1	CKS0	RRC2	RRC1	RRC0	
RTCNT	—	—	—	—	—	—	—	—	
RTCOR	—	—	—	—	—	—	—	—	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
SDMR2									BSC
SDMR3									
SAR_0									DMAC
DAR_0									
DMATCR_0	—	—	—	—	—	—	—	—	
CHCR_0	—	—	—	—	—	—	—	—	
	DO	TL	—	—	—	—	AM	AL	
	DM1	DM0	SM1	SM0	RS3	RS2	RS1	RS0	
	DL	DS	TB	TS1	TS0	IE	TE	DE	
SAR_1									
DAR_1									
DMATCR_1	—	—	—	—	—	—	—	—	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
CHCR_1	—	—	—	—	—	—	—	—	DMAC
	DO	—	—	—	—	—	AM	AL	
	DM1	DM0	SM1	SM0	RS3	RS2	RS1	RS0	
	DL	DS	TB	TS1	TS0	IE	TE	DE	
SAR_2									
DAR_2									
DMATCR_2	—	—	—	—	—	—	—	—	
CHCR_2	—	—	—	—	—	—	—	—	
	—	—	—	—	—	—	—	—	
	DM1	DM0	SM1	SM0	RS3	RS2	RS1	RS0	
	—	—	TB	TS1	TS0	IE	TE	DE	
SAR_3									
DAR_3									
DMATCR_3	—	—	—	—	—	—	—	—	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
CHCR_3	—	—	—	—	—	—	—	—	DMAC
	—	—	—	—	—	—	—	—	
	DM1	DM0	SM1	SM0	RS3	RS2	RS1	RS0	
	—	—	TB	TS1	TS0	IE	TE	DE	
DMAOR	—	—	CMS1	CMS0	—	—	PR1	PR0	
	—	—	—	—	—	AE	NMIF	DME	
DMARS0	C1MID5	C1MID4	C1MID3	C1MID2	C1MID1	C1MID0	C1RID1	C1RID0	
	C0MID5	C0MID4	C0MID3	C0MID2	C0MID1	C0MID0	C0RID1	C0RID0	
DMARS1	C3MID5	C3MID4	C3MID3	C3MID2	C3MID1	C3MID0	C3RID1	C3RID0	
	C2MID5	C2MID4	C2MID3	C2MID2	C2MID1	C2MID0	C2RID1	C2RID0	
UCLKCR	USSCS1	USSCS0	USBEN	—	—	—	—	—	CPG
FRQCR	—	—	—	CKOEN	—	—	STC1	STC0	
	—	—	IFC1	IFC0	—	—	PFC1	PFC0	
WTCNT									WDT
WTCSR	TME	WT/IT	RSTS	WOVF	IOVF	CKS2	CKS1	CKS0	
STBCR	STBY	—	—	STBXTL	—	MSTP2	MSTP1	—	Power-down modes
STBCR2	MSTP10	MSTP9	MSTP8	—	MSTP6	MSTP5	—	—	
STBCR3	MSTP37	—	MSTP35	MSTP34	MSTP33	MSTP32	MSTP31	MSTP30	
TSTR	—	—	—	—	—	STR2	STR1	STR0	TMU
TCOR_0									
TCNT_0									
TCR_0	—	—	—	—	—	—	—	UNF	
	—	—	UNIE	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
TCOR_1									TMU
TCNT_1									
TCR_1	—	—	—	—	—	—	—	UNF	
	—	—	UNIE	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	
TCOR_2									
TCNT_2									
TCR_2	—	—	—	—	—	—	ICPF	UNF	
	ICPE1	ICPE0	UNIE	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	
TCPR_2									
CMSTR	—	—	—	—	—	—	—	—	CMT
	—	—	—	—	—	—	—	STR	
CMCSR	—	—	—	—	—	—	—	—	
	CMF	—	—	CMR	—	—	CKS1	CKS0	
CMCNT									
CMCOR									

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
TSTR	—	—	—	—	—	—	—	—	TPU
	—	—	—	—	CST3	CST2	CST1	CST0	
TCR_0	—	—	—	—	—	—	—	—	
	CCLR2	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	
TMDR_0	—	—	—	—	—	—	—	—	
	—	BFWT	BFB	BFA	—	MD2	MD1	MD0	
TIOR_0	—	—	—	—	—	—	—	—	
	—	—	—	—	—	IOA2	IOA1	IOA0	
TIER_0	—	—	—	—	—	—	—	—	
	—	—	—	TCIEV	TGIED	TGIEC	TGIEB	TGIEA	
TSR_0	—	—	—	—	—	—	—	—	
	—	—	—	TCFV	TGFD	TGFC	TGFB	TGFA	
TCNT_0									
TGRA_0									
TGRB_0									
TGRC_0									
TGRD_0									
TCR_1	—	—	—	—	—	—	—	—	
	CCLR2	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	
TMDR_1	—	—	—	—	—	—	—	—	
	—	BFWT	BFB	BFA	—	MD2	MD1	MD0	
TIOR_1	—	—	—	—	—	—	—	—	
	—	—	—	—	—	IOA2	IOA1	IOA0	
TIER_1	—	—	—	—	—	—	—	—	
	—	—	—	TCIEV	TGIED	TGIEC	TGIEB	TGIEA	
TSR_1	—	—	—	—	—	—	—	—	
	—	—	—	TCFV	TGFD	TGFC	TGFB	TGFA	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
TCNT_1									TPU
TGRA_1									
TGRB_1									
TGRC_1									
TGRD_1									
TCR_2	—	—	—	—	—	—	—	—	
	CCLR2	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	
TMDR_2	—	—	—	—	—	—	—	—	
	—	BFWT	BFB	BFA	—	MD2	MD1	MD0	
TIOR_2	—	—	—	—	—	—	—	—	
	—	—	—	—	—	IOA2	IOA1	IOA0	
TIER_2	—	—	—	—	—	—	—	—	
	—	—	—	TCIEV	TGIED	TGIEC	TGIEB	TGIEA	
TSR_2	—	—	—	—	—	—	—	—	
	—	—	—	TCFV	TGFD	TGFC	TGFB	TGFA	
TCNT_2									
TGRA_2									
TGRB_2									
TGRC_2									
TGRD_2									
TCR_3	—	—	—	—	—	—	—	—	
	CCLR2	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
TMDR_3	—	—	—	—	—	—	—	—	TPU
	—	BFWT	BFB	BFA	—	MD2	MD1	MD0	
TIOR_3	—	—	—	—	—	—	—	—	
	—	—	—	—	—	IOA2	IOA1	IOA0	
TIER_3	—	—	—	—	—	—	—	—	
	—	—	—	TCIEV	TGIED	TGIEC	TGIEB	TGIEA	
TSR_3	—	—	—	—	—	—	—	—	
	—	—	—	TCFV	TGFD	TGFC	TGFB	TGFA	
TCNT_3									
TGRA_3									
TGRB_3									
TGRC_3									
TGRD_3									
R64CNT	—	1Hz	2Hz	4Hz	8Hz	16Hz	32Hz	64Hz	RTC
RSECCNT	—								
RMINCNT	—								
RHRCNT	—	—							
RWKCNT	—	—	—	—	—				
RDAYCNT	—	—							
RMONCNT	—	—	—						
RYRCNT									
RSECAR	ENB								
RMINAR	ENB								
RHRAR	ENB	—							
RWKAR	ENB	—	—	—	—				
RDAYAR	ENB	—							
RMONAR	ENB	—	—						

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
RCR1	CF	—	—	CIE	AIE	—	—	AF	RTC
RCR2	PEF	PES2	PES1	PES0	RTCEN	ADJ	RESET	START	
RYRAR									
RCR3	YAEN	—	—	—	—	—	—	—	
SCSMR_0	—	—	—	—	—	SRC2	SRC1	SRC0	SCIF_0
	C/A	CHR	PE	O/E	STOP	—	CKS1	CKS0	
SCBRR_0	SCBRD7	SCBRD6	SCBRD5	SCBRD4	SCBRD3	SCBRD2	SCBRD1	SCBRD0	
SCSCR_0	—	—	—	—	TSIE	ERIE	BRIE	DRIE	
	TIE	RIE	TE	RE	—	—	CKE1	CKE0	
SCTDSR_0									
SCFER_0	—	—	PER5	PER4	PER3	PER2	PER1	PER0	
	—	—	FER5	FER4	FER3	FER2	FER1	FER0	
SCSSR_0	—	—	—	—	—	—	ORER	TSF	
	ER	TEND	TDFE	BRK	FER	PER	RDF	DR	
SCFCR_0	TSE	TCRST	—	—	—	RSTRG2	RSTRG1	RSTRG0	
	RTRG1	RTRG0	TTRG1	TTRG0	MCE	TFRST	RFRST	LOOP	
SCFDR_0	—	T6	T5	T4	T3	T2	T1	T0	
	—	R6	R5	R4	R3	R2	R1	R0	
SCFTDR_0	SCFTD7	SCFTD6	SCFTD5	SCFTD4	SCFTD3	SCFTD2	SCFTD1	SCFTD0	
SCFRDR_0	SCFRD7	SCFRD6	SCFRD5	SCFRD4	SCFRD3	SCFRD2	SCFRD1	SCFRD0	
SCSMR_2	—	—	—	—	—	SRC2	SRC1	SRC0	SCIF_2
	C/A	CHR	PE	O/E	STOP	—	CKS1	CKS0	
SCBRR_2	SCBRD7	SCBRD6	SCBRD5	SCBRD4	SCBRD3	SCBRD2	SCBRD1	SCBRD0	
SCSCR_2	—	—	—	—	TSIE	ERIE	BRIE	DRIE	
	TIE	RIE	TE	RE	—	—	CKE1	CKE0	
SCTDSR_2									
SCFER_2	—	—	PER5	PER4	PER3	PER2	PER1	PER0	
	—	—	FER5	FER4	FER3	FER2	FER1	FER0	
SCSSR_2	—	—	—	—	—	—	ORER	TSF	
	ER	TEND	TDFE	BRK	FER	PER	RDF	DR	
SCFCR_2	TSE	TCRST	—	—	—	RSTRG2	RSTRG1	RSTRG0	
	RTRG1	RTRG0	TTRG1	TTRG0	MCE	TFRST	RFRST	LOOP	

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SCFDR_2	—	T6	T5	T4	T3	T2	T1	T0	SCIF_2
	—	R6	R5	R4	R3	R2	R1	R0	
SCFTDR_2	SCFTD7	SCFTD6	SCFTD5	SCFTD4	SCFTD3	SCFTD2	SCFTD1	SCFTD0	
SCFRDR_2	SCFRD7	SCFRD6	SCFRD5	SCFRD4	SCFRD3	SCFRD2	SCFRD1	SCFRD0	
SCSMR_Ir	—	—	—	—	—	—	—	—	IrDA
	IRMOD	ICK3	ICK2	ICK1	ICK0	PSEL	—	—	
EPDR0i	D7	D6	D5	D4	D3	D2	D1	D0	USB
EPDR0o	D7	D6	D5	D4	D3	D2	D1	D0	
EPDR0s	D7	D6	D5	D4	D3	D2	D1	D0	
EPDR1	D7	D6	D5	D4	D3	D2	D1	D0	
EPDR2	D7	D6	D5	D4	D3	D2	D1	D0	
EPDR3	D7	D6	D5	D4	D3	D2	D1	D0	
IFR0	BRST	EP1FULL	EP2TR	EP2EMPTY	SETUPTS	EP0oTS	EP0iTR	EP0iTS	
IFR1	—	—	—	—	VBUSMN	EP3TR	EP3TS	VBUS	
TRG	—	EP3PKTE	EP1RDFN	EP2PKTE	—	EP0sRDFN	EP0oRDFN	EP0iPKTE	
FCLR	—	EP3CLR	EP1CLR	EP2CLR	—	—	EP0oCLR	EP0iCLR	
EPSZ0o	D7	D6	D5	D4	D3	D2	D1	D0	
DASTS	—	—	EP3DE	EP2DE	—	—	—	EP0iDE	
EPSTL	—	—	—	—	EP3STL	EP2STL	EP1STL	EP0STL	
IER0	BRST	EP1FULL	EP2TR	EP2EMPTY	SETUPTS	EP0oTS	EP0iTR	EP0iTS	
IER1	—	—	—	—	—	EP3TR	EP3TS	VBUS	
EPSZ1	D7	D6	D5	D4	D3	D2	D1	D0	
DMAR	—	—	—	—	—	—	EP2DMAE	EP1DMAE	
ISR0	BRST	EP1FULL	EP2TR	EP2EMPTY	SETUPTS	EP0oTS	EP0iTR	EP0iTS	
ISR1	—	—	—	—	—	EP3TR	EP3TS	VBUS	
XVERCR	—	—	—	—	—	—	—	XVEROFF	
PACR	PA7MD1	PA7MD0	PA6MD1	PA6MD0	PA5MD1	PA5MD0	PA4MD1	PA4MD0	PFC
	PA3MD1	PA3MD0	PA2MD1	PA2MD0	PA1MD1	PA1MD0	PA0MD1	PA0MD0	
PBCR	PB7MD1	PB7MD0	PB6MD1	PB6MD0	PB5MD1	PB5MD0	PB4MD1	PB4MD0	
	PB3MD1	PB3MD0	PB2MD1	PB2MD0	PB1MD1	PB1MD0	PB0MD1	PB0MD0	
PCCR	PC7MD1	PC7MD0	PC6MD1	PC6MD0	PC5MD1	PC5MD0	PC4MD1	PC4MD0	
	PC3MD1	PC3MD0	PC2MD1	PC2MD0	PC1MD1	PC1MD0	PC0MD1	PC0MD0	

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PDCR	PD7MD1	PD7MD0	PD6MD1	PD6MD0	PD5MD1	PD5MD0	PD4MD1	PD4MD0	PFC
	PD3MD1	PD3MD0	PD2MD1	PD2MD0	PD1MD1	PD1MD0	PD0MD1	PD0MD0	
PECR	PE7MD1	PE7MD0	PE6MD1	PE6MD0	PE5MD1	PE5MD0	PE4MD1	PE4MD0	
	PE3MD1	PE3MD0	PE2MD1	PE2MD0	PE1MD1	PE1MD0	PE0MD1	PE0MD0	
PECR2	—	PE6MD2	PE5MD2	PE4MD2	—	—	—	—	
PFCR	PF7MD1	PF7MD0	PF6MD1	PF6MD0	PF5MD1	PF5MD0	PF4MD1	PF4MD0	
	PF3MD1	PF3MD0	PF2MD1	PF2MD0	PF1MD1	PF1MD0	PF0MD1	PF0MD0	
PFCR2	—	—	—	—	PF3MD2	PF2MD2	PF1MD2	PF0MD2	
PGCR	PG7MD1	PG7MD0	PG6MD1	PG6MD0	PG5MD1	PG5MD0	PG4MD1	PG4MD0	
	PG3MD1	PG3MD0	PG2MD1	PG2MD0	PG1MD1	PG1MD0	PG0MD1	PG0MD0	
PHCR	—	—	PH6MD1	PH6MD0	PH5MD1	PH5MD0	PH4MD1	PH4MD0	
	PH3MD1	PH3MD0	PH2MD1	PH2MD0	PH1MD1	PH1MD0	PH0MD1	PH0MD0	
PJCR	PJ7MD1	PJ7MD0	PJ6MD1	PJ6MD0	PJ5MD1	PJ5MD0	PJ4MD1	PJ4MD0	
	PJ3MD1	PJ3MD0	PJ2MD1	PJ2MD0	PJ1MD1	PJ1MD0	PJ0MD1	PJ0MD0	
PKCR	PK7MD1	PK7MD0	PK6MD1	PK6MD0	PK5MD1	PK5MD0	PK4MD1	PK4MD0	
	PK3MD1	PK3MD0	PK2MD1	PK2MD0	PK1MD1	PK1MD0	PK0MD1	PK0MD0	
PLCR	—	—	—	—	—	—	—	—	
	PL3MD1	PL3MD0	PL2MD1	PL2MD0	PL1MD1	PL1MD0	PL0MD1	PL0MD0	
SCPCR	—	—	—	—	SCP5MD1	SCP5MD0	SCP4MD1	SCP4MD0	
	SCP3MD1	SCP3MD0	SCP2MD1	SCP2MD0	SCP1MD1	SCP1MD0	SCP0MD1	SCP0MD0	
PMCR	—	—	PM6MD1	PM6MD0	—	—	PM4MD1	PM4MD0	
	PM3MD1	PM3MD0	PM2MD1	PM2MD0	PM1MD1	PM1MD0	PM0MD1	PM0MD0	
PNCR	PN7MD1	PN7MD0	PN6MD1	PN6MD0	PN5MD1	PN5MD0	PN4MD1	PN4MD0	
	PN3MD1	PN3MD0	PN2MD1	PN2MD0	PN1MD1	PN1MD0	PN0MD1	PN0MD0	
PNCR2	—	PN6MD2	PN5MD2	PN4MD2	PN3MD2	PN2MD2	PN1MD2	PN0MD2	
PADR	PA7DT	PA6DT	PA5DT	PA4DT	PA3DT	PA2DT	PA1DT	PA0DT	Port
PBDR	PB7DT	PB6DT	PB5DT	PB4DT	PB3DT	PB2DT	PB1DT	PB0DT	
PCDR	PC7DT	PC6DT	PC5DT	PC4DT	PC3DT	PC2DT	PC1DT	PC0DT	
PDDR	PD7DT	PD6DT	PD5DT	PD4DT	PD3DT	PD2DT	PD1DT	PD0DT	
PEDR	PE7DT	PE6DT	PE5DT	PE4DT	PE3DT	PE2DT	PE1DT	PE0DT	
PFDR	PF7DT	PF6DT	PF5DT	PF4DT	PF3DT	PF2DT	PF1DT	PF0DT	
PGDR	PG7DT	PG6DT	PG5DT	PG4DT	PG3DT	PG2DT	PG1DT	PG0DT	

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PHDR	—	PH6DT	PH5DT	PH4DT	PH3DT	PH2DT	PH1DT	PH0DT	Port
PJDR	PJ7DT	PJ6DT	PJ5DT	PJ4DT	PJ3DT	PJ2DT	PJ1DT	PJ0DT	
PKDR	PK7DT	PK6DT	PK5DT	PK4DT	PK3DT	PK2DT	PK1DT	PK0DT	
PLDR	—	—	—	—	PL3DT	PL2DT	PL1DT	PL0DT	
SCPDR	—	—	SCP 5DT	SCP 4DT	SCP 3DT	SCP 2DT	SCP 1DT	SCP 0DT	
PMDR	—	PM6DT	—	PM4DT	PM3DT	PM2DT	PM1DT	PM0DT	
PNDR	PN7DT	PN6DT	PN5DT	PN4DT	PN3DT	PN2DT	PN1DT	PN0DT	
ADDRA									ADC
			—	—	—	—	—	—	
ADDRB									
			—	—	—	—	—	—	
ADDRC									
			—	—	—	—	—	—	
ADDRD									
			—	—	—	—	—	—	
ADCSR	ADF	ADIE	ADST	DMASL	—	—	—	—	
	CKS1	CKS0	MULTI1	MULTI0	—	—	CH1	CH0	
BDRB	BDB31	BDB30	BDB29	BDB28	BDB27	BDB26	BDB25	BDB24	UBC
	BDB23	BDB22	BDB21	BDB20	BDB19	BDB18	BDB17	BDB16	
	BDB15	BDB14	BDB13	BDB12	BDB11	BDB10	BDB9	BDB8	
	BDB7	BDB6	BDB5	BDB4	BDB3	BDB2	BDB1	BDB0	
BDMRB	BDMB31	BDMB30	BDMB29	BDMB28	BDMB27	BDMB26	BDMB25	BDMB24	
	BDMB23	BDMB22	BDMB21	BDMB20	BDMB19	BDMB18	BDMB17	BDMB16	
	BDMB15	BDMB14	BDMB13	BDMB12	BDMB11	BDMB10	BDMB9	BDMB8	
	BDMB7	BDMB6	BDMB5	BDMB4	BDMB3	BDMB2	BDMB1	BDMB0	
BRCR	—	—	—	—	—	—	—	—	
	—	—	BASMA	BASMB	—	—	—	—	
	SCMFCA	SCMFCB	SCMFDA	SCMFDB	PCTE	PCBA	—	—	
	DBEB	PCBB	—	—	SEQ	—	—	ETBE	
BETR	—	—	—	—	BET11	BET10	BET9	BET8	
	BET7	BET6	BET5	BET4	BET3	BET2	BET1	BET0	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
BARB	BAB31	BAB30	BAB29	BAB28	BAB27	BAB26	BAB25	BAB24	UBC
	BAB23	BAB22	BAB21	BAB20	BAB19	BAB18	BAB17	BAB16	
	BAB15	BAB14	BAB13	BAB12	BAB11	BAB10	BAB9	BAB8	
	BAB7	BAB6	BAB5	BAB4	BAB3	BAB2	BAB1	BAB0	
BAMRB	BAMB31	BAMB30	BAMB29	BAMB28	BAMB27	BAMB26	BAMB25	BAMB24	
	BAMB23	BAMB22	BAMB21	BAMB20	BAMB19	BAMB18	BAMB17	BAMB16	
	BAMB15	BAMB14	BAMB13	BAMB12	BAMB11	BAMB10	BAMB9	BAMB8	
	BAMB7	BAMB6	BAMB5	BAMB4	BAMB3	BAMB2	BAMB1	BAMB0	
BBRB	—	—	—	—	—	—	—	—	
	CDB1	CDB0	IDB1	IDB0	RWB1	RWB0	SZB1	SZB0	
BRSR	SVF	—	—	—	BSA27	BSA26	BSA25	BSA24	
	BSA23	BSA22	BSA21	BSA20	BSA19	BSA18	BSA17	BSA16	
	BSA15	BSA14	BSA13	BSA12	BSA11	BSA10	BSA9	BSA8	
	BSA7	BSA6	BSA5	BSA4	BSA3	BSA2	BSA1	BSA0	
BARA	BAA31	BAA30	BAA29	BAA28	BAA27	BAA26	BAA25	BAA24	
	BAA23	BAA22	BAA21	BAA20	BAA19	BAA18	BAA17	BAA16	
	BAA15	BAA14	BAA13	BAA12	BAA11	BAA10	BAA9	BAA8	
	BAA7	BAA6	BAA5	BAA4	BAA3	BAA2	BAA1	BAA0	
BAMRA	BAMA31	BAMA30	BAMA29	BAMA28	BAMA27	BAMA26	BAMA25	BAMA24	
	BAMA23	BAMA22	BAMA21	BAMA20	BAMA19	BAMA18	BAMA17	BAMA16	
	BAMA15	BAMA14	BAMA13	BAMA12	BAMA11	BAMA10	BAMA9	BAMA8	
	BAMA7	BAMA6	BAMA5	BAMA4	BAMA3	BAMA2	BAMA1	BAMA0	
BBRA	—	—	—	—	—	—	—	—	
	CDA1	CDA0	IDA1	IDA0	RWA1	RWA0	SZA1	SZA0	
BRDR	DVF	—	—	—	BDA27	BDA26	BDA25	BDA24	
	BDA23	BDA22	BDA21	BDA20	BDA19	BDA18	BDA17	BDA16	
	BDA15	BDA14	BDA13	BDA12	BDA11	BDA10	BDA9	BDA8	
	BDA7	BDA6	BDA5	BDA4	BDA3	BDA2	BDA1	BDA0	
BASRA	BASA7	BASA6	BASA5	BASA4	BASA3	BASA2	BASA1	BASA0	
BASRB	BASB7	BASB6	BASB5	BASB4	BASB3	BASB2	BASB1	BASB0	

Register Abbreviation	Bit 31/ 23/15/7	Bit 30/ 22/14/6	Bit 29/ 21/13/5	Bit 28/ 20/12/4	Bit 27/ 19/11/3	Bit 26/ 18/10/2	Bit 25/ 17/9/1	Bit 24/ 16/8/0	Module
SDIR	TI7	TI6	TI5	TI4	TI3	TI2	TI1	TI0	H-UDI
	—	—	—	—	—	—	—	—	
SDID/SDIDH	DID31	DID30	DID29	DID28	DID27	DID26	DID25	DID24	
	DID23	DID22	DID21	DID20	DID19	DID18	DID17	DID16	
SDIDL	DID15	DID14	DID13	DID12	DID11	DID10	DID9	DID8	
	DID7	DID6	DID5	DID4	DID3	DID2	DID1	DID0	

24.3 Register States in Each Operating Mode

Register Abbreviation	Power-On Reset	Manual Reset	Software Standby	Module Standby	Sleep	Module
MMUCR	Initialized*[6]	Initialized*[6]	Retained	Retained	Retained	MMU
PTEH	Undefined	Undefined	Retained	Retained	Retained	
PTEL	Undefined	Undefined	Retained	Retained	Retained	
TTB	Undefined	Undefined	Retained	Retained	Retained	
CCR1	Initialized	Initialized	Retained	Retained	Retained	Cache
CCR2	Initialized	Initialized	Retained	Retained	Retained	
CCR3	Initialized	Initialized	Retained	Retained	Retained	
INTEVT2	Undefined	Undefined	Retained	Retained	Retained	Exception handling
TRA	Undefined	Undefined	Retained	Retained	Retained	
EXPEVT	Initialized*[7]	Initialized*[7]	Retained	Retained	Retained	
INTEVT	Undefined	Undefined	Retained	Retained	Retained	
TEA	Undefined	Undefined	Retained	Retained	Retained	
IPRA	Initialized	Initialized	Retained	Retained	Retained	INTC
IPRB	Initialized	Initialized	Retained	Retained	Retained	
IPRC	Initialized	Initialized	Retained	Retained	Retained	
IPRD	Initialized	Initialized	Retained	Retained	Retained	
IPRE	Initialized	Initialized	Retained	Retained	Retained	
IPRF	Initialized	Initialized	Retained	Retained	Retained	
IPRG	Initialized	Initialized	Retained	Retained	Retained	
IPRH	Initialized	Initialized	Retained	Retained	Retained	
ICR0	Initialized*[8]	Initialized*[8]	Retained	Retained	Retained	
ICR1	Initialized	Initialized	Retained	Retained	Retained	
ICR2	Initialized	Initialized	Retained	Retained	Retained	
IRR0	Initialized	Initialized	Retained	Retained	Retained	
IRR1	Initialized	Initialized	Retained	Retained	Retained	
IRR2	Initialized	Initialized	Retained	Retained	Retained	
PINTER	Initialized	Initialized	Retained	Retained	Retained	
CMNCR	Initialized*[9]	Retained	Retained	Retained	Retained	BSC
CS0BCR	Initialized	Retained	Retained	Retained	Retained	
CS2BCR	Initialized	Retained	Retained	Retained	Retained	
CS3BCR	Initialized	Retained	Retained	Retained	Retained	
CS4BCR	Initialized	Retained	Retained	Retained	Retained	

Register Abbreviation	Power-On Reset	Manual Reset	Software Standby	Module Standby	Sleep	Module
CS5ABCR	Initialized	Retained	Retained	Retained	Retained	BSC
CS5BBCR	Initialized	Retained	Retained	Retained	Retained	
CS6ABCR	Initialized	Retained	Retained	Retained	Retained	
CS6BBCR	Initialized	Retained	Retained	Retained	Retained	
CS0WCR	Initialized	Retained	Retained	Retained	Retained	
CS2 WCR	Initialized	Retained	Retained	Retained	Retained	
CS3 WCR	Initialized	Retained	Retained	Retained	Retained	
CS4 WCR	Initialized	Retained	Retained	Retained	Retained	
CS5A WCR	Initialized	Re4ained	Retained	Retained	Retained	
CS5B WCR	Initialized	Retained	Retained	Retained	Retained	
CS6A WCR	Initialized	Retained	Retained	Retained	Retained	
CS6B WCR	Initialized	Retained	Retained	Retained	Retained	
SDCR	Initialized	Retained	Retained	Retained	Retained	
RTCSR	Initialized	Retained	Retained	Retained	Retained	
RTCNT	Initialized	Retained	Retained	Retained	Retained	
RTCOR	Initialized	Retained	Retained	Retained	Retained	
SDMR2	—	—	—	—	—	
SDMR3	—	—	—	—	—	
SAR_0	Undefined	Undefined	Retained	Retained	Retained	DMAC
DAR_0	Undefined	Undefined	Retained	Retained	Retained	
DMATCR_0	Undefined	Undefined	Retained	Retained	Retained	
CHCR_0	Initialized	Initialized	Retained	Retained	Retained	
SAR_1	Undefined	Undefined	Retained	Retained	Retained	
DAR_1	Undefined	Undefined	Retained	Retained	Retained	
DMATCR_1	Undefined	Undefined	Retained	Retained	Retained	
CHCR_1	Initialized	Initialized	Retained	Retained	Retained	
SAR_2	Undefined	Undefined	Retained	Retained	Retained	
DAR_2	Undefined	Undefined	Retained	Retained	Retained	
DMATCR_2	Undefined	Undefined	Retained	Retained	Retained	
CHCR_2	Initialized	Initialized	Retained	Retained	Retained	
SAR_3	Undefined	Undefined	Retained	Retained	Retained	
DAR_3	Undefined	Undefined	Retained	Retained	Retained	

Register Abbreviation	Power-On Reset	Manual Reset	Software Standby	Module Standby	Sleep	Module
DMATCR_3	Undefined	Undefined	Retained	Retained	Retained	DMAC
CHCR_3	Initialized	Initialized	Retained	Retained	Retained	
DMAOR	Initialized	Initialized	Retained	Retained	Retained	
DMARS0	Initialized	Initialized	Retained	Retained	Retained	
DMARS1	Initialized	Initialized	Retained	Retained	Retained	
UCLKCR	Initialized	Retained	Retained	Retained	Retained	CPG
FRQCR	Initialized*[5]	Retained	Retained	Retained	Retained	
WTCNT	Initialized*[5]	Retained	Retained	Retained	Retained	WDT
WTCSR	Initialized*[5]	Retained	Retained	Retained	Retained	
STBCR	Initialized	Retained	Retained	Retained	Retained	Power-down modes
STBCR2	Initialized	Retained	Retained	Retained	Retained	
STBCR3	Initialized	Retained	Retained	Retained	Retained	
TSTR	Initialized	Initialized	Initialized	Initialized	Retained	TMU
TCOR_0	Initialized	Initialized	Retained	Retained	Retained	
TCNT_0	Initialized	Initialized	Retained	Retained	Retained	
TCR_0	Initialized	Initialized	Retained	Retained	Retained	
TCOR_1	Initialized	Initialized	Retained	Retained	Retained	
TCNT_1	Initialized	Initialized	Retained	Retained	Retained	
TCR_1	Initialized	Initialized	Retained	Retained	Retained	
TCOR_2	Initialized	Initialized	Retained	Retained	Retained	
TCNT_2	Initialized	Initialized	Retained	Retained	Retained	
TCR_2	Initialized	Initialized	Retained	Retained	Retained	
TCPR_2	Undefined	Undefined	Retained	Retained	Retained	
CMSTR	Initialized	Initialized	Retained	Retained	Retained	CMT
CMCSR	Initialized	Initialized	Retained	Retained	Retained	
CMCNT	Initialized	Initialized	Retained	Retained	Retained	
CMCOR	Initialized	Initialized	Retained	Retained	Retained	

Register Abbreviation	Power-On Reset	Manual Reset	Software Standby	Module Standby	Sleep	Module
TSTR	Initialized	Initialized	Retained	Retained	Retained	TPU
TCR_0	Initialized	Initialized	Retained	Retained	Retained	
TMDR_0	Initialized	Initialized	Retained	Retained	Retained	
TIOR_0	Initialized	Initialized	Retained	Retained	Retained	
TIER_0	Initialized	Initialized	Retained	Retained	Retained	
TSR_0	Initialized	Initialized	Retained	Retained	Retained	
TCNT_0	Initialized	Initialized	Retained	Retained	Retained	
TGRA_0	Initialized	Initialized	Retained	Retained	Retained	
TGRB_0	Initialized	Initialized	Retained	Retained	Retained	
TGRC_0	Initialized	Initialized	Retained	Retained	Retained	
TGRD_0	Initialized	Initialized	Retained	Retained	Retained	
TCR_1	Initialized	Initialized	Retained	Retained	Retained	
TMDR_1	Initialized	Initialized	Retained	Retained	Retained	
TIOR_1	Initialized	Initialized	Retained	Retained	Retained	
TIER_1	Initialized	Initialized	Retained	Retained	Retained	
TSR_1	Initialized	Initialized	Retained	Retained	Retained	
TCNT_1	Initialized	Initialized	Retained	Retained	Retained	
TGRA_1	Initialized	Initialized	Retained	Retained	Retained	
TGRB_1	Initialized	Initialized	Retained	Retained	Retained	
TGRC_1	Initialized	Initialized	Retained	Retained	Retained	
TGRD_1	Initialized	Initialized	Retained	Retained	Retained	
TCR_2	Initialized	Initialized	Retained	Retained	Retained	
TMDR_2	Initialized	Initialized	Retained	Retained	Retained	
TIOR_2	Initialized	Initialized	Retained	Retained	Retained	
TIER_2	Initialized	Initialized	Retained	Retained	Retained	
TSR_2	Initialized	Initialized	Retained	Retained	Retained	
TCNT_2	Initialized	Initialized	Retained	Retained	Retained	
TGRA_2	Initialized	Initialized	Retained	Retained	Retained	
TGRB_2	Initialized	Initialized	Retained	Retained	Retained	
TGRC_2	Initialized	Initialized	Retained	Retained	Retained	
TGRD_2	Initialized	Initialized	Retained	Retained	Retained	

Register Abbreviation	Power-On Reset	Manual Reset	Software Standby	Module Standby	Sleep	Module
TCR_3	Initialized	Initialized	Retained	Retained	Retained	TPU
TMDR_3	Initialized	Initialized	Retained	Retained	Retained	
TIOR_3	Initialized	Initialized	Retained	Retained	Retained	
TIER_3	Initialized	Initialized	Retained	Retained	Retained	
TSR_3	Initialized	Initialized	Retained	Retained	Retained	
TCNT_3	Initialized	Initialized	Retained	Retained	Retained	
TGRA_3	Initialized	Initialized	Retained	Retained	Retained	
TGRB_3	Initialized	Initialized	Retained	Retained	Retained	
TGRC_3	Initialized	Initialized	Retained	Retained	Retained	
TGRD_3	Initialized	Initialized	Retained	Retained	Retained	
R64CNT	Operation continued	Operation continued	Operation continued	Retained	Operation continued	RTC
RSECCNT	Operation continued	Operation continued	Operation continued	Retained	Operation continued	
RMINCNT	Operation continued	Operation continued	Operation continued	Retained	Operation continued	
RHRCNT	Operation continued	Operation continued	Operation continued	Retained	Operation continued	
RWKCNT	Operation continued	Operation continued	Operation continued	Retained	Operation continued	
RDAYCNT	Operation continued	Operation continued	Operation continued	Retained	Operation continued	
RMONCNT	Operation continued	Operation continued	Operation continued	Retained	Operation continued	
RYRCNT	Operation continued	Operation continued	Operation continued	Retained	Operation continued	
RSECAR	Retained*[1]	Retained	Retained	Retained	Retained	
RMINAR	Retained*[1]	Retained	Retained	Retained	Retained	
RHRAR	Retained*[1]	Retained	Retained	Retained	Retained	
RWKAR	Retained*[1]	Retained	Retained	Retained	Retained	
RDAYAR	Retained*[1]	Retained	Retained	Retained	Retained	
RMONAR	Retained*[1]	Retained	Retained	Retained	Retained	
RCR1	Initialized*[2]	Initialized*[2]	Retained	Retained	Retained	
RCR2	Initialized*[10]	Initialized*[10]	Retained	Retained	Retained	
RYRAR	Retained	Retained	Retained	Retained	Retained	
RCR3	Initialized	Retained	Retained	Retained	Retained	

Register Abbreviation	Power-On Reset	Manual Reset	Software Standby	Module Standby	Sleep	Module
SCSMR_0	Initialized	Initialized	Retained	Retained	Retained	SCIF_0
SCBRR_0	Initialized	Initialized	Retained	Retained	Retained	
SCSCR_0	Initialized	Initialized	Retained	Retained	Retained	
SCTDSR_0	Initialized	Initialized	Retained	Retained	Retained	
SCFER_0	Initialized	Initialized	Retained	Retained	Retained	
SCSSR_0	Initialized	Initialized	Retained	Retained	Retained	
SCFCR_0	Initialized	Initialized	Retained	Retained	Retained	
SCFDR_0	Initialized	Initialized	Retained	Retained	Retained	
SCFTDR_0	Undefined	Undefined	Retained	Retained	Retained	
SCFRDR_0	Undefined	Undefined	Retained	Retained	Retained	
SCSMR_2	Initialized	Initialized	Retained	Retained	Retained	SCIF_2
SCBRR_2	Initialized	Initialized	Retained	Retained	Retained	
SCSCR_2	Initialized	Initialized	Retained	Retained	Retained	
SCTDSR_2	Initialized	Initialized	Retained	Retained	Retained	
SCFER_2	Initialized	Initialized	Retained	Retained	Retained	
SCSSR_2	Initialized	Initialized	Retained	Retained	Retained	
SCFCR_2	Initialized	Initialized	Retained	Retained	Retained	
SCFDR_2	Initialized	Initialized	Retained	Retained	Retained	
SCFTDR_2	Undefined	Undefined	Retained	Retained	Retained	
SCFRDR_2	Undefined	Undefined	Retained	Retained	Retained	
SCSMR_Ir	Initialized	Initialized	Retained	Retained	Retained	IrDA
EPDR0i	Undefined	Undefined	Retained	Retained	Retained	USB
EPDR0o	Undefined	Undefined	Retained	Retained	Retained	
EPDR0s	Undefined	Undefined	Retained	Retained	Retained	
EPDR1	Undefined	Undefined	Retained	Retained	Retained	
EPDR2	Undefined	Undefined	Retained	Retained	Retained	
EPDR3	Undefined	Undefined	Retained	Retained	Retained	
IFR0	Initialized	Initialized	Retained	Retained	Retained	
IFR1	Initialized	Initialized	Retained	Retained	Retained	
TRG	Undefined	Undefined	Retained	Retained	Retained	
FCLR	Undefined	Undefined	Retained	Retained	Retained	
EPSZ0o	Initialized	Initialized	Retained	Retained	Retained	
DASTS	Initialized	Initialized	Retained	Retained	Retained	

Register Abbreviation	Power-On Reset	Manual Reset	Software Standby	Module Standby	Sleep	Module
EPSTL	Initialized	Initialized	Retained	Retained	Retained	USB
IER0	Initialized	Initialized	Retained	Retained	Retained	
IER1	Initialized	Initialized	Retained	Retained	Retained	
EPSZ1	Initialized	Initialized	Retained	Retained	Retained	
DMAR	Initialized	Initialized	Retained	Retained	Retained	
ISR0	Initialized	Initialized	Retained	Retained	Retained	
ISR1	Initialized	Initialized	Retained	Retained	Retained	
XVERCR	Initialized	Initialized	Retained	Retained	Retained	
PACR	Initialized	Retained	Retained	Retained	Retained	PFC
PBCR	Initialized	Retained	Retained	Retained	Retained	
PCCR	Initialized	Retained	Retained	Retained	Retained	
PDCR	Initialized	Retained	Retained	Retained	Retained	
PECR	Initialized	Retained	Retained	Retained	Retained	
PECR2	Initialized	Retained	Retained	Retained	Retained	
PFCR	Initialized	Retained	Retained	Retained	Retained	
PFCR2	Initialized	Retained	Retained	Retained	Retained	
PGCR	Initialized	Retained	Retained	Retained	Retained	
PHCR	Initialized	Retained	Retained	Retained	Retained	
PJCR	Initialized	Retained	Retained	Retained	Retained	
PKCR	Initialized	Retained	Retained	Retained	Retained	
PLCR	Initialized	Retained	Retained	Retained	Retained	
SCPCR	Initialized	Retained	Retained	Retained	Retained	
PMCR	Initialized	Retained	Retained	Retained	Retained	
PNCR	Initialized	Retained	Retained	Retained	Retained	
PNCR2	Initialized	Retained	Retained	Retained	Retained	
PADR	Initialized	Retained	Retained	Retained	Retained	Port
PBDR	Initialized	Retained	Retained	Retained	Retained	
PCDR	Initialized	Retained	Retained	Retained	Retained	
PDDR	Initialized	Retained	Retained	Retained	Retained	
PEDR	Initialized	Retained	Retained	Retained	Retained	
PFDR	Initialized	Retained	Retained	Retained	Retained	
PGDR	Initialized	Retained	Retained	Retained	Retained	

Register Abbreviation	Power-On Reset	Manual Reset	Software Standby	Module Standby	Sleep	Module
PHDR	Initialized	Retained	Retained	Retained	Retained	Port
PJDR	Initialized	Retained	Retained	Retained	Retained	
PKDR	Initialized	Retained	Retained	Retained	Retained	
PLDR	Initialized	Retained	Retained	Retained	Retained	
SCPDR	Initialized	Retained	Retained	Retained	Retained	
PMDR	Initialized	Retained	Retained	Retained	Retained	
PNDR	Initialized	Retained	Retained	Retained	Retained	
ADDRA	Initialized	Initialized	Initialized	Initialized	Retained	ADC
ADDRB	Initialized	Initialized	Initialized	Initialized	Retained	
ADDRC	Initialized	Initialized	Initialized	Initialized	Retained	
ADDRD	Initialized	Initialized	Initialized	Initialized	Retained	
ADCSR	Initialized	Initialized	Initialized	Initialized	Retained	
BDRB	Initialized	Retained	Retained	Retained	Retained	UBC
BDMRB	Initialized	Retained	Retained	Retained	Retained	
BRCR	Initialized	Retained	Retained	Retained	Retained	
BETR	Initialized	Retained	Retained	Retained	Retained	
BARB	Initialized	Retained	Retained	Retained	Retained	
BAMRB	Initialized	Retained	Retained	Retained	Retained	
BBRB	Initialized	Retained	Retained	Retained	Retained	
BRSR	Initialized*[3]	Retained	Retained	Retained	Retained	
BARA	Initialized	Retained	Retained	Retained	Retained	
BAMRA	Initialized	Retained	Retained	Retained	Retained	
BBRA	Initialized	Retained	Retained	Retained	Retained	
BRDR	Initialized*[3]	Retained	Retained	Retained	Retained	
BASRA	Undefined	Retained	Retained	Retained	Retained	
BASRB	Undefined	Retained	Retained	Retained	Retained	
SDIR	Retained	Retained	Retained	Retained	Retained	H-UDI
SDID/SDIDH*[4]	—	—	—	—	—	
SDIDL*[4]	—	—	—	—	—	

Notes: *1 The ENB bit is initialized. Other bits are retained.

*2 The CF bit is undefined.

*3 Although the flag is initialized, other bits are not initialized (except the reserved bits).

*4 Values of these resisters are fixed.

*5 These registers are not initialized by a power-on reset caused by the WDT.

*6 The SV bit is undefined.

*7 EXPEVT[11:0] = H′000 at a power-on reset and EXPEVT[11:0] = H′020 at a manual reset.

*8 The NMIL bit = 1 when the NMI input is high, and the NMIL bit = 0 when the NMI input is low.

*9 The ENDIAN bit indicates the MD5 pin input sampled at a power-on reset.

*10 At a power-on reset, this register is initialized to H′09. At a manual reset, bits other than the RTCEN and START bits are initialized.

Section 25 Electrical Characteristics

25.1 Absolute Maximum Ratings

Table 25.1 shows the absolute maximum ratings.

Table 25.1 Absolute Maximum Ratings

Item	Symbol	Rating	Unit
Power supply voltage (I/O)	$V_{CC}Q$ V_{CC}-RTC	–0.3 to 4.2	V
Power supply voltage (internal)	V_{CC} V_{CC}-PLL1 V_{CC}-PLL2	–0.3 to 2.1	V
Input voltage (except port L)	V_{in}	–0.3 to $V_{CC}Q$ + 0.3	V
Input voltage (port L)	V_{in}	–0.3 to AV_{CC} + 0.3	V
Analog power supply voltage (AD)	AV_{CC}	–0.3 to 4.2	V
Analog input voltage (AD)	V_{AN}	–0.3 to AV_{CC} + 0.3	V
Analog power supply voltage (USB)	V_{CC}-USB	–0.3 to 4.2	V
Analog input voltage (USB)	V_{IN}	–0.3 to (V_{CC}-USB) + 0.3	V
Operating temperature	T_{opr}	–20 to 75	°C
Storage temperature	T_{stg}	–55 to 125	°C

Caution:

- Operating the chip in excess of the absolute maximum rating may result in permanent damage.
- Order of turning on 1.5 V power (Vcc, Vcc-PLL1, Vcc-PLL2) and 3.3 V power (VccQ, Vcc-RTC, AVcc, Vcc-USB):
  1. The 3.3 V power and the 1.5 V power should be turned on simultaneously or the 3.3 V power should be tuned on first. When the 3.3 V is turned on first, turn on the 1.5 V power within 1 ms. It is recommended that this interval will be as short as possible.
  2. Until voltage is applied to all power supplies and a low level is input at the $\overline{\text{RESETP}}$ pin, internal circuits remain unsettled, and so pin states are also undefined. The system design must ensure that these undefined states do not cause erroneous system operation.
  3. When the power is turned on, make sure that the voltage of the 1.5 V power is lower than that of the 3.3 V power.

- Power-off order
  1. In the reverse order of powering-on, first turn off the 1.5 V power, then turn off the 3.3 V power within 1 ms. It is recommended that this interval will be as short as possible.
  2. Pin states are undefined while only the 1.5 V power is off. The system design must ensure that these undefined states do not cause erroneous system operation.
  3. When the power is turned off, make sure that the voltage of the 1.5 V power is lower than that of the 3.3 V power.

Waveforms and recommended times at power on/off are shown in figure 25.1.

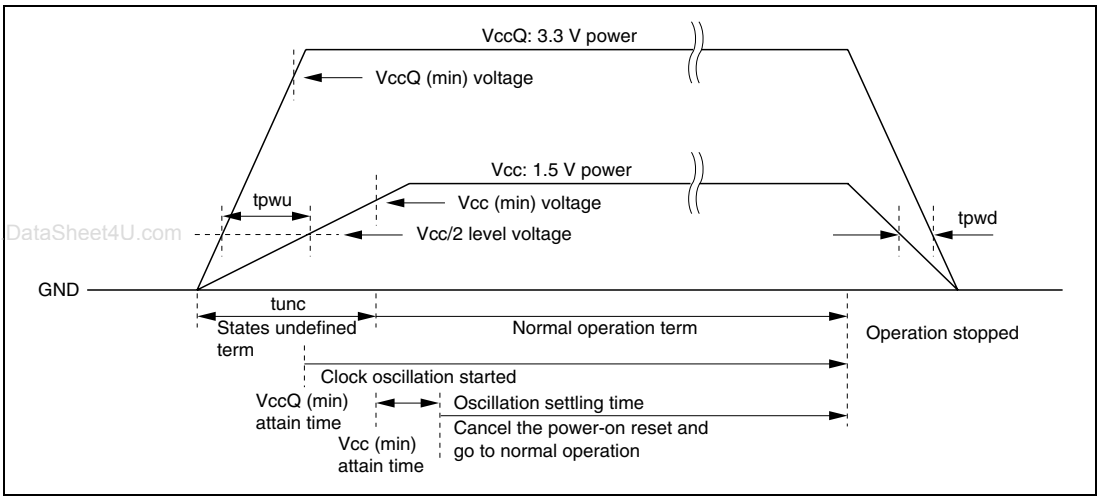


Figure 25.1 Power On/Off Sequence

Recommended Power On/Off Times

Item	Symbol	Max. Permitted Value	Unit
VccQ to Vcc power-on time interval	tpwu	1	ms
VccQ to Vcc power-off time interval	tpwd	1	ms
State undefined term	tunc	10	ms

The recommended times shown above do not require strict settings.

The state undefined term indicates that pins are at the power rising stage. The pin state is stabilized at VccQ (min) attain time. However, a power-on reset ($\overline{\text{RESETP}}$) is accepted successfully only after VccQ (min) attain time and clock oscillation settling time. Set the state undefined term less than 10 ms.

25.2 DC Characteristics

Tables 25.2 and 25.3 list DC characteristics.

Table 25.2 DC Characteristics (1) [Common Items]

(Condition: Ta = –20 to 75°C)

Item		Symbol	Min	Typ	Max	Unit	Measurement Conditions
Power supply voltage		$V_{CC}Q$, V_{CC}-RTC	3.0	3.3	3.6	V	
		V_{CC}, V_{CC}-PLL1 V_{CC}-PLL2	1.4	1.5	1.6		
Current consumption	Normal operation	I_{CC}	—	133	200	mA	V_{CC} = 1.5 V Iϕ = 133 MHz
			—	105	150		V_{CC} = 1.5 V Iϕ = 100 MHz
		$I_{CC}Q$	—	20	40		$V_{CC}Q$ = 3.3 V Bϕ = 33 MHz
	In sleep mode*	I_{CC}	—	25	40	mA	Bϕ = 33 MHz
		$I_{CC}Q$	—	10	20		
	In standby mode	I_{CC}	—	150	500	µA	T_a = 25°C (RTC on)
		$I_{CC}Q$	—	10	30		$V_{CC}Q$ = 3.3 V V_{CC} = 1.5 V
		I_{CC}	—	150	500	µA	T_a = 25°C (RTC off)
		$I_{CC}Q$	—	10	30		$V_{CC}Q$ = 3.3 V V_{CC} = 1.5 V
Input leak current	All input pins	$\lvert I_{in} \rvert$	—	—	1.0	µA	V_{in} = 0.5 to $V_{CC}Q$ – 0.5 V
Three-state leak current	I/O, all output pins (off condition)	$\lvert I_{TSI} \rvert$	—	—	1.0	µA	Vin = 0.5 to $V_{CC}Q$ – 0.5 V
Pull-up resistance	Port pin	R_{pull}	30	60	120	kΩ	

Item		Symbol	Min	Typ	Max	Unit	Measurement Conditions
Pin capacitance	All pins other than the USB transceiver pins (D+, D-) and PTM3 to PTM0	C	—	—	10	pF	
	USB transceiver pins (D+, D–) and PTM3 to PTM0	C_{AN}	—	—	20	pF	
Analog power-supply voltage (AD)		AV_{CC}	3.0	3.3	3.6	V	
Analog power-supply voltage (USB)		V_{CC}-USB	3.0	3.3	3.6	V	
Analog power-supply current (AD)	During A/D conversion	AI_{CC}	—	0.8	2	mA	
	Idle		—	0.01	5.0	µA	

Note: * No external bus cycles except refresh cycles.

Table 25.2 DC Characteristics (2-a) [Excluding USB-Related Pins]

(Condition: Ta = –20 to 75°C)

Item		Symbol	Min	Typ	Max	Unit	Measurement Conditions
Input high voltage	$\overline{\text{RESETP}}$, $\overline{\text{RESETM}}$, NMI IRQ5 to IRQ0, PINT15 to PINT0, RXD0, MD6 to MD0, $\overline{\text{ASEMD0}}$, $\overline{\text{TRST}}$, EXTAL, CKIO, CA	V_{IH}	$V_{CC}Q \times 0.9$	—	$V_{CC}Q + 0.3$	V	
	EXTAL2		—	—	—		When this pin is not connected to the crystal resonator, this pin should be connected to the $V_{CC}Q$ pin (pulled up).
	Port L		2.0	—	$AV_{CC} + 0.3$		
	Other input pins		2.0	—	$V_{CC}Q + 0.3$		
Input low voltage	$\overline{\text{RESETP}}$, $\overline{\text{RESETM}}$, NMI IRQ5 to IRQ0, PINT15 to PINT0, RXD0, MD6 to MD0, $\overline{\text{ASEMD0}}$, $\overline{\text{TRST}}$, EXTAL, CKIO, CA	V_{IL}	–0.3	—	$V_{CC}Q \times 0.1$	V	
	EXTAL2		—	—	—		When this pin is not connected to the crystal resonator, this pin should be connected to the $V_{CC}Q$ pin (pulled up).
	Port L		–0.3	—	$AV_{CC} \times 0.2$		

Item		Symbol	Min	Typ	Max	Unit	Measurement Conditions
Input low voltage	Other input pins	V_{IL}	–0.3	—	$V_{CC}Q \times 0.2$	V	
Output high voltage	All output pins	V_{OH}	2.4	—	—	V	$V_{CC}Q$ = 3.0 V, I_{OH} = –200 µA
			2.0	—	—		$V_{CC}Q$ = 3.0 V, I_{OH} = –2 mA
Output low voltage	All output pins	V_{OL}	—	—	0.55	V	$V_{CC}Q$ = 3.6 V, I_{OL} = 1.6 mA

Notes: 1. Even when the RTC is not used, power must be supplied between V_{CC}-RTC and V_{SS}-RTC.
2. AV_{CC} must satisfy the condition: $V_{CC}Q - 0.2\ V \le AV_{CC} \le V_{CC}Q + 0.2\ V$. Do not leave the AV_{CC} and AV_{SS} pins open if the A/D converter is not used; connect AV_{CC} to $V_{CC}Q$, and AV_{SS} to $V_{SS}Q$.
3. Current consumption values are for V_{IH}min = $V_{CC}Q$ – 0.5 V and V_{IL}max = 0.5 V with all output pins unloaded.

Table 25.2 DC Characteristics (2-b) [USB-Related Pins*]

(Condition: Ta = –20 to 75°C)

Item	Symbol	Min	Typ	Max	Unit	Measurement Conditions
Power supply voltage	$V_{CC}Q$	3.0	3.3	3.6	V	
Input high voltage	V_{IH}	2.0	—	$V_{CC}Q + 0.3$	V	
Input low voltage	V_{IL}	–0.3	—	$V_{CC}Q \times 0.2$	V	
Input high voltage (EXTAL_USB)	V_{IH} (EXTAL_USB)	$V_{CC}Q$ – 0.3	—	$V_{CC}Q + 0.3$	V	
Input low voltage (EXTAL_USB)	V_{IL} (EXTAL_USB)	–0.3	—	$V_{CC}Q \times 0.2$	V	
Output high voltage	V_{OH}	2.4	—	—	V	$V_{CC}Q$ = 3.0 V, I_{OH} = –200 µA
		2.0	—	—		$V_{CC}Q$ = 3.0 V, I_{OH} = –2 mA
Output low voltage	V_{OL}	—	—	0.55	V	$V_{CC}Q$ = 3.6 V, I_{OL} = 1.6 mA

Note: * XVDATA, DPLS, DMNS, TXDPLS, TXDMNS, TXENL, VBUS, SUSPND, and EXTAL_USB pins

Table 25.2 DC Characteristics (2-c) [USB Transceiver-Related Pins*[1]]

(Condition: Ta = –20 to 75°C)

Item	Symbol	Min	Typ	Max	Unit	Measurement Conditions
Power supply voltage*[2]	V_{CC}-USB	3.0	3.3	3.6	V	
Differential input sensitivity	V_{DI}	0.2	—	—	V	|(DP)–(DM)|
Differential common mode range	V_{CM}	0.8	—	2.5	V	
Single ended receiver threshold voltage	V_{SE}	0.8	—	2.0	V	
Output high voltage	V_{OH}	2.8	—	V_{CC}-USB	V	
Output low voltage	V_{OL}	—	—	0.3	V	
Tri-state leak current	I_{LO}	–10	—	10	µA	$0V<V_{IN}<3.3V$

Notes: *1 D+ and D– pins

*2 V_{CC}-USB must satisfy the condition: $V_{CC}Q \leq V_{CC}$-USB. Even when the USB is not used, power must be supplied between V_{CC}-USB and V_{SS}-USB.

Table 25.3 Permitted Output Current Values

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Item	Symbol	Min	Typ	Max	Unit
Output low-level permissible current (per pin)	I_{OL}	—	—	2.0	mA
Output low-level permissible current (total)	$\sum I_{OL}$	—	—	120	mA
Output high-level permissible current (per pin)	$-I_{OH}$	—	—	2.0	mA
Output high-level permissible current (total)	$\sum (-I_{OH})$	—	—	40	mA

Caution: To ensure LSI reliability, do not exceed the value for output current given in table 25.3.

25.3 AC Characteristics

In general, inputting for this LSI should be clock synchronous. Keep the setup and hold times for each input signal unless otherwise specified.

Table 25.4 Maximum Operating Frequencies

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Item		Symbol	Min	Typ	Max	Unit	Remarks
Operating frequency	CPU, cache (Iϕ)	f	20	—	133.34	MHz	133-MHz product
					100		100-MHz product
	External bus (Bϕ)		20	—	66.67		
	Peripheral module (Pϕ)		5	—	33.34		

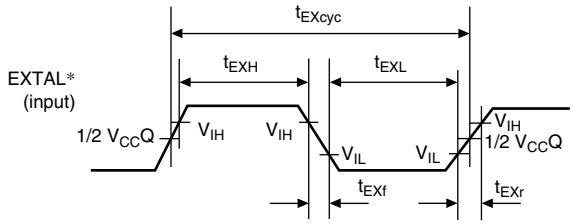
25.3.1 Clock Timing

Table 25.5 Clock Timing

(Condition: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C, Maximum External Bus Operating Frequency: 66.67 MHz)

Item	Symbol	Min	Max	Unit	Figure
EXTAL clock input frequency	f_{EX}	10	66.67	MHz	25.2
EXTAL clock input cycle time	t_{EXcyc}	15	100	ns	
EXTAL clock input low pulse width	t_{EXL}	1.5	—	ns	
EXTAL clock input high pulse width	t_{EXH}	1.5	—	ns	
EXTAL clock input rise time	t_{EXr}	—	6	ns	
EXTAL clock input fall time	t_{EXf}	—	6	ns	
CKIO clock input frequency	f_{CKI}	20	66.67	MHz	25.3
CKIO clock input cycle time	t_{CKICYC}	15	50	ns	
CKIO clock input low pulse width	t_{CKIL}	3	—	ns	
CKIO clock input high pulse width	t_{CKIH}	3	—	ns	
CKIO clock input rise time	t_{CKIR}	—	4	ns	
CKIO clock input fall time	t_{CKIF}	—	4	ns	
CKIO clock output frequency	t_{OP}	20	66.67	MHz	25.4
CKIO clock output cycle time	t_{cyc}	15	50	ns	
CKIO clock output low pulse width	t_{CKOL}	3	—	ns	
CKIO clock output high pulse width	t_{CKOH}	3	—	ns	
CKIO clock output rise time	t_{CKOr}	—	5	ns	
CKIO clock output fall time	t_{CKOf}	—	5	ns	
Power-on oscillation settling time	t_{OSC1}	10	—	ms	25.5
$\overline{\text{RESETP}}$ setup time	t_{RESPS}	20	—	ns	25.5
$\overline{\text{RESETP}}$ assert time	t_{RESPW}	20	—	t_{cyc}	25.5, 25.6
$\overline{\text{RESETM}}$ assert time	t_{RESMW}	20	—	t_{cyc}	25.6
Standby return oscillation settling time 1	t_{OSC2}	10	—	ms	25.6
Standby return oscillation settling time 2	t_{OSC3}	10	—	ms	25.7
Standby return oscillation settling time 3	t_{OSC4}	11	—	ms	25.8

Item	Symbol	Min	Max	Unit	Figure
PLL synchronization settling time 1	t_{PLL1}	100	—	µs	25.9, 25.10
PLL synchronization settling time 2	t_{PLL2}	100	—	µs	25.11
Interrupt determination time (RTC used and standby mode)	t_{IRLSTB}	100	—	µs	25.10



Note: * The clock input from the EXTAL pin.

Figure 25.2 EXTAL Clock Input Timing

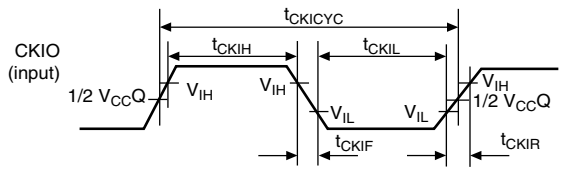


Figure 25.3 CKIO Clock Input Timing

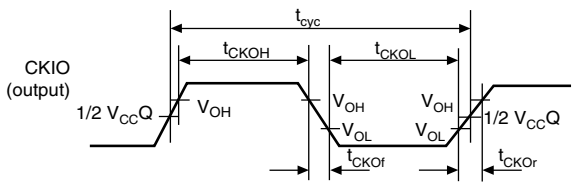
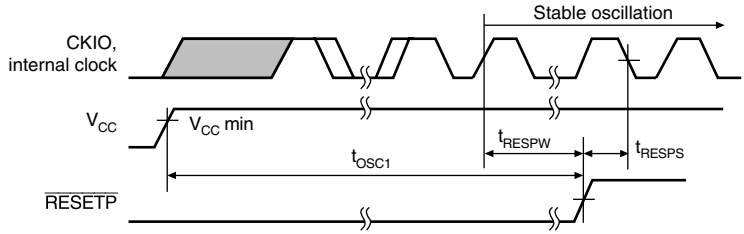
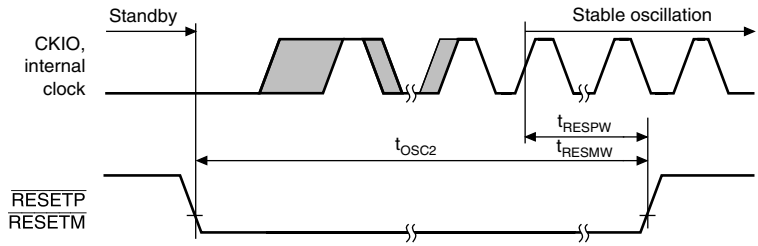


Figure 25.4 CKIO Clock Output Timing



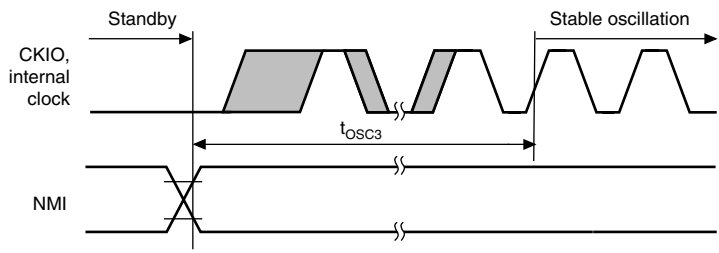
Note: Oscillation settling time when built-in oscillator is used

Figure 25.5 Power-On Oscillation Settling Time



Note: Oscillation settling time when built-in oscillator is used

Figure 25.6 Oscillation Settling Time at Standby Return (Return by Reset)



Note: Oscillation settling time when built-in oscillator is used

Figure 25.7 Oscillation Settling Time at Standby Return (Return by NMI)

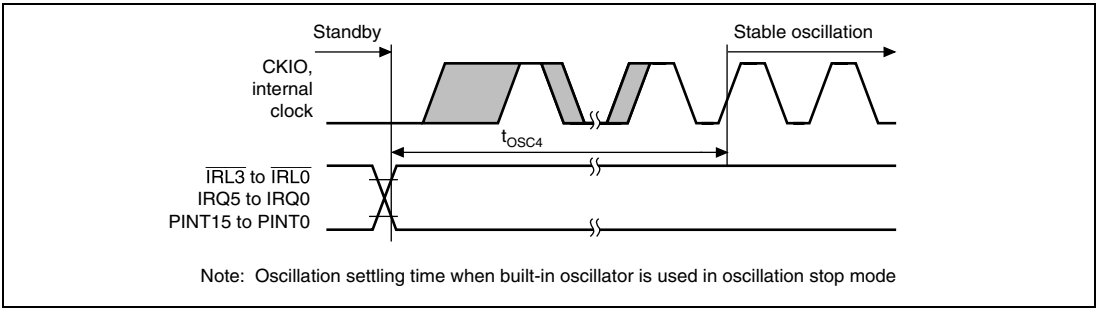


Figure 25.8 Oscillation Settling Time at Standby Return (Return by IRQ5 to IRQ0, PINT15 to PINT0, and $\overline{IRL3}$ to $\overline{IRL0}$)

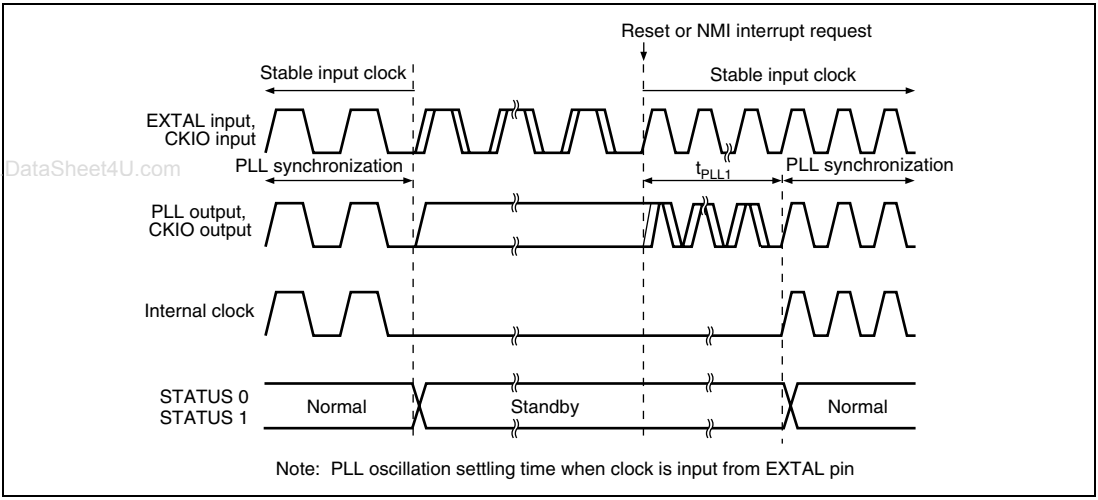


Figure 25.9 PLL Synchronization Settling Time by Reset or NMI

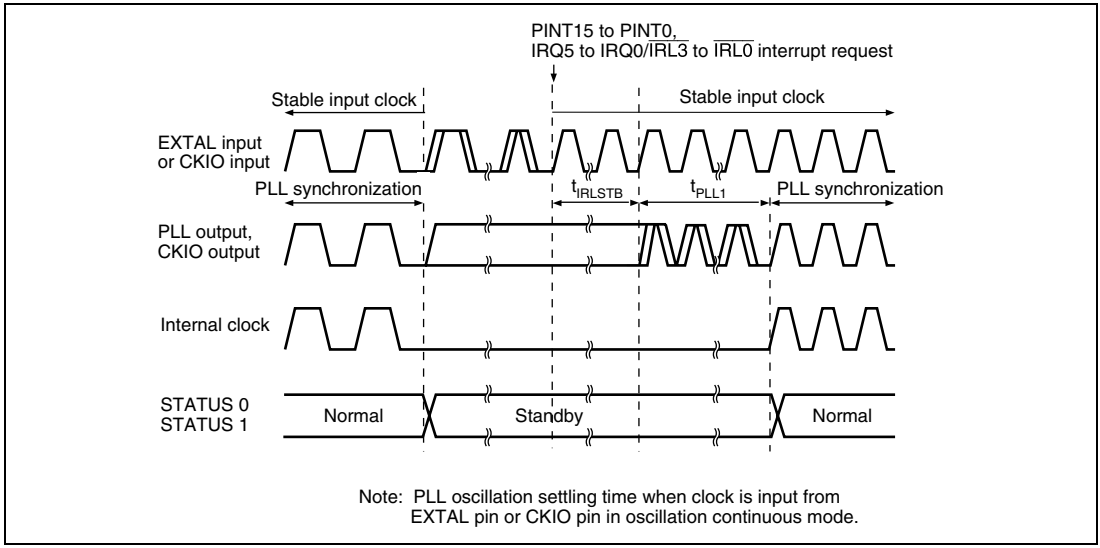


Figure 25.10 PLL Synchronization Settling Time by IRQ/IRL, PINT Interrupts

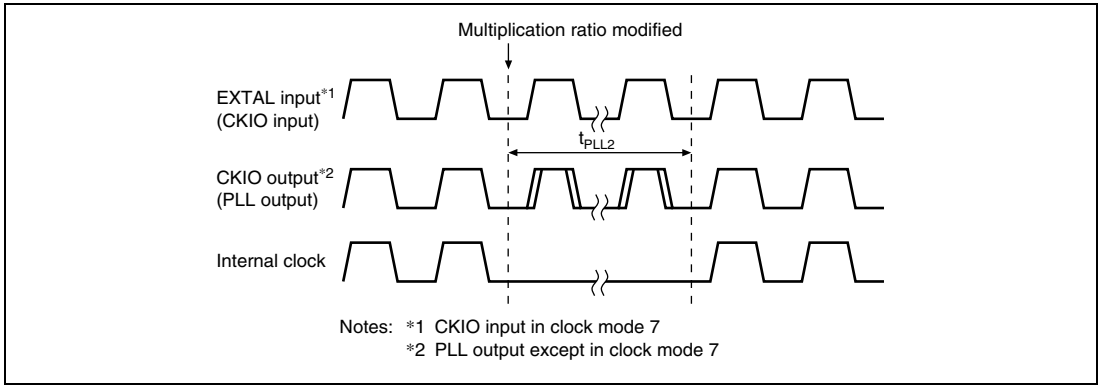


Figure 25.11 PLL Synchronization Settling Time when Frequency Multiplication Ratio Modified

25.3.2 Control Signal Timing

Table 25.6 Control Signal Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

		66.67 MHz*[2]			
Item	**Symbol**	**Min**	**Max**	**Unit**	**Figure**
$\overline{\text{RESETP}}$ pulse width	t_{RESPW}	20*[3]	—	t_{cyc}	25.12
$\overline{\text{RESETP}}$ setup time*[1]	t_{RESPS}	20	—	ns	
$\overline{\text{RESETM}}$ pulse width	t_{RESMW}	20*[4]	—	t_{cyc}	
$\overline{\text{RESETM}}$ setup time	t_{RESMS}	10	—	ns	
$\overline{\text{BREQ}}$ setup time	t_{BREQS}	1/2 t_{cyc}+10	—	ns	25.14
$\overline{\text{BREQ}}$ hold time	t_{BREQH}	1/2 t_{cyc}+3	—	ns	
NMI setup time*[1]	t_{NMIS}	10	—	ns	25.13
NMI hold time	t_{NMIH}	3	—	ns	
IRQ5 to IRQ0 setup time*[1]	t_{IRQS}	10	—	ns	
IRQ5 to IRQ0 hold time	t_{IRQH}	3	—	ns	
$\overline{\text{BACK}}$ delay time	t_{BACKD}	—	1/2 t_{cyc}+13	ns	25.14
STATUS1, STATUS0 delay time	t_{STD}	—	18	ns	25.15
Bus tri-state delay time 1	t_{BOFF1}	0	30	ns	25.14,
Bus tri-state delay time 2	t_{BOFF2}	0	30	ns	25.15
Bus buffer-on time 1	t_{BON1}	0	30	ns	
Bus buffer-on time 2	t_{BON2}	0	30	ns	

Notes: t_{cyc} is the external bus clock cycle (B clock cycle).

*1 $\overline{\text{RESETP}}$, NMI, and IRQ5 to IRQ0 are asynchronous. Changes are detected at the clock rise when the setup shown is kept. When the setup cannot be kept, detection can be delayed until the next clock rises.

*2 The upper limit of the external bus clock is 66.67 MHz.

*3 In standby mode, $t_{RESPW} = t_{OSC2}$ (10 ms). When the crystal oscillation continues or the clock multiplication ratio is changed in standby mode, $t_{RESPW} = t_{PLL1}$ (100 µs).

*4 In standby mode, $t_{RESMW} = t_{OSC2}$ (10 ms). When the crystal oscillation continues or the clock multiplication ratio is changed in standby mode, $\overline{\text{RESETM}}$ must be kept low until STATUS (0-1) changes to reset (HH).

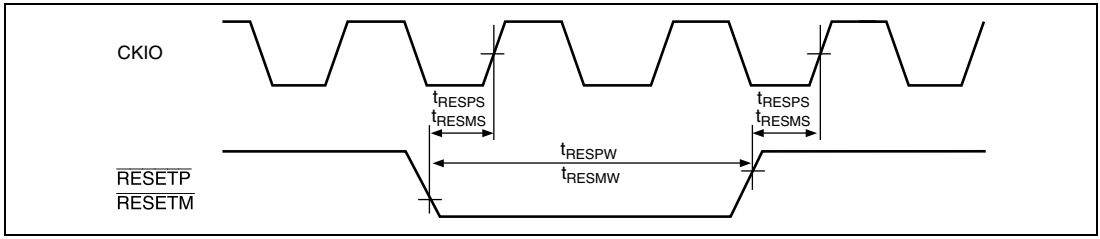


Figure 25.12 Reset Input Timing

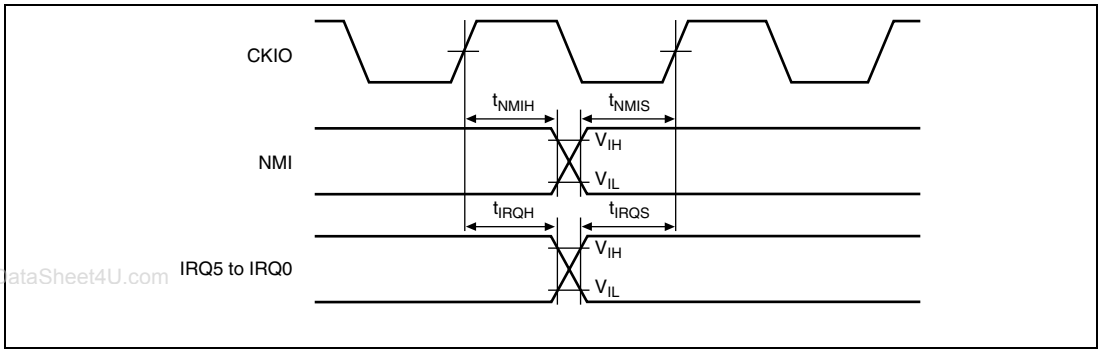


Figure 25.13 Interrupt Signal Input Timing

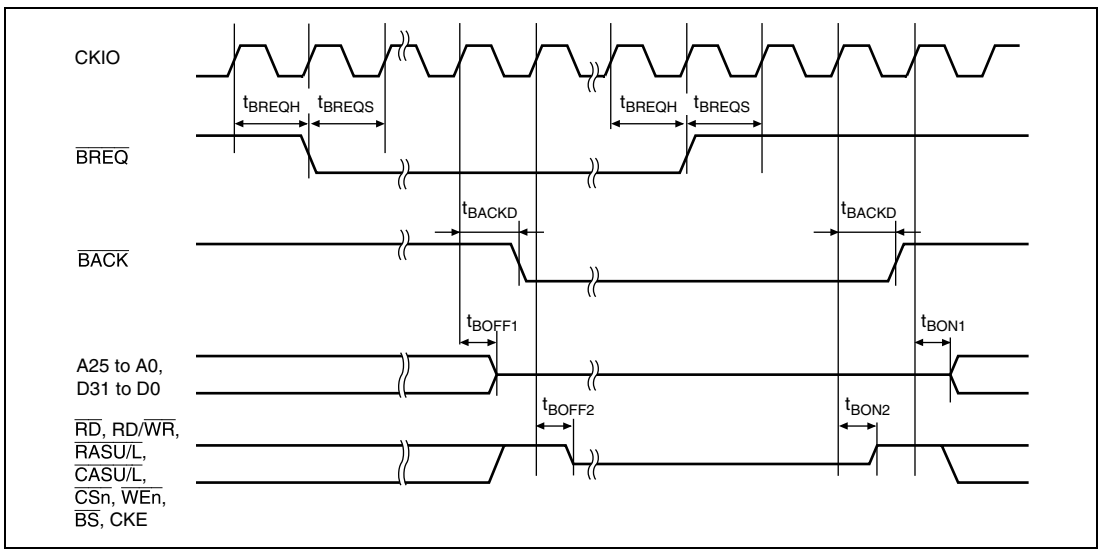


Figure 25.14 Bus Release Timing

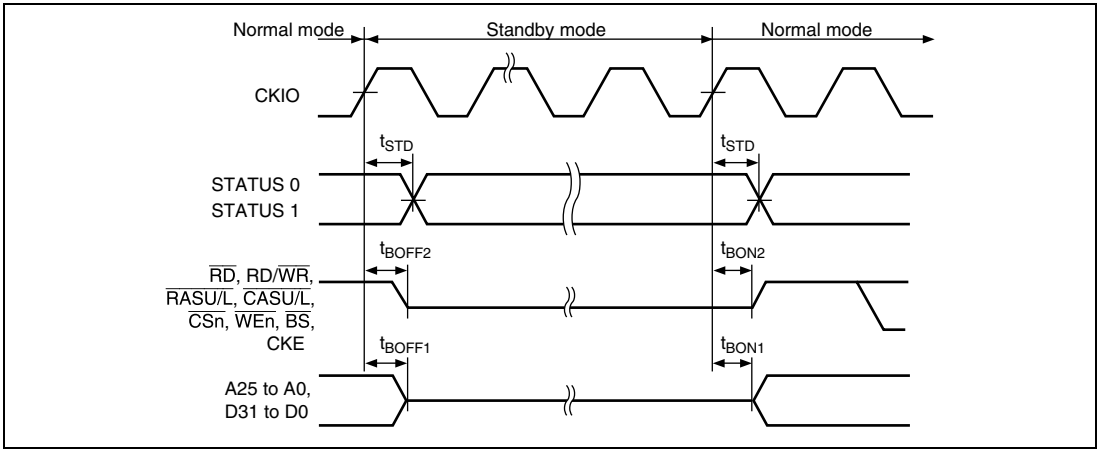


Figure 25.15 Pin Drive Timing at Standby

25.3.3 AC Bus Timing

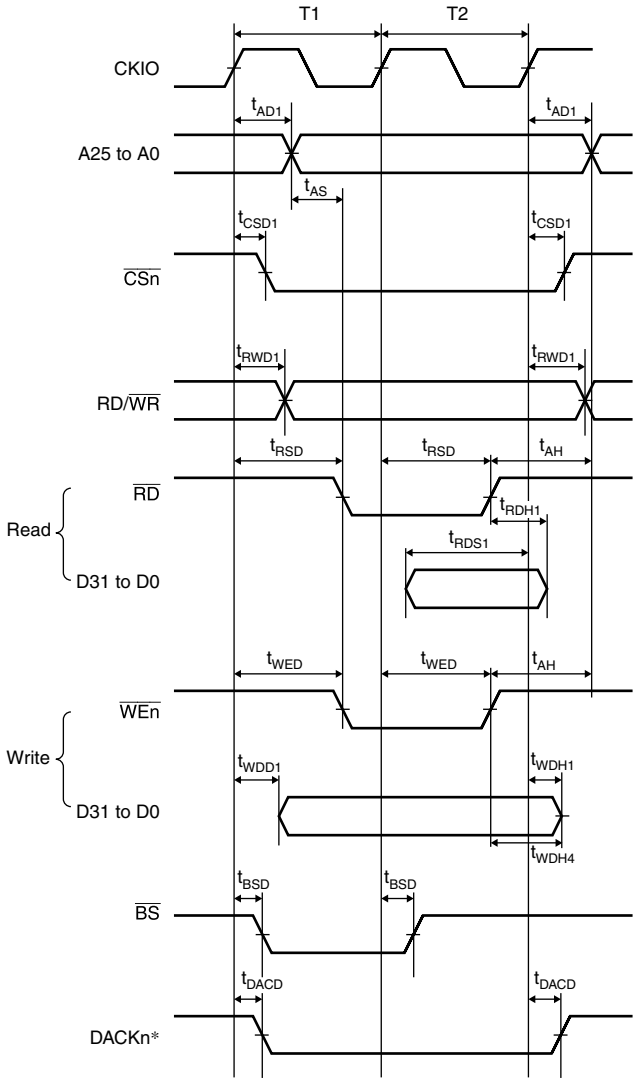
Table 25.7 Bus Timing (1)

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C, Clock mode 0/1/2/4/5/6/7)

		66.67 MHz			
Item	**Symbol**	**Min**	**Max**	**Unit**	**Figure**
Address delay time 1	t_{AD1}	1	12	ns	25.16 to 25.38
Address delay time 2	t_{AD2}	—	1/2 t_{cyc}+12	ns	25.21
Address setup time	t_{AS}	0	—	ns	25.16 to 25.19
Address hold time	t_{AH}	0	—	ns	25.16 to 25.19
$\overline{BS}$ delay time	t_{BSD}	—	10	ns	25.16 to 25.35
$\overline{CS}$ delay time 1	t_{CSD1}	1	10	ns	25.16 to 25.38
Read/write delay time 1	t_{RWD1}	1	10	ns	25.16 to 25.38
Read strobe delay time	t_{RSD}	—	1/2 t_{cyc}+10	ns	25.16 to 25.21
Read data setup time 1	t_{RDS1}	1/2 t_{cyc}+6	—	ns	25.16 to 25.20
Read data setup time 2	t_{RDS2}	6	—	ns	25.22 to 25.25, 25.30 to 25.32
Read data setup time 3	t_{RDS3}	1/2 t_{cyc}+6	—	ns	25.21
Read data hold time 1	t_{RDH1}	0	—	ns	25.16 to 25.20
Read data hold time 2	t_{RDH2}	2	—	ns	25.22 to 25.25, 25.30 to 25.32
Read data hold time 3	t_{RDH3}	0	—	ns	25.21

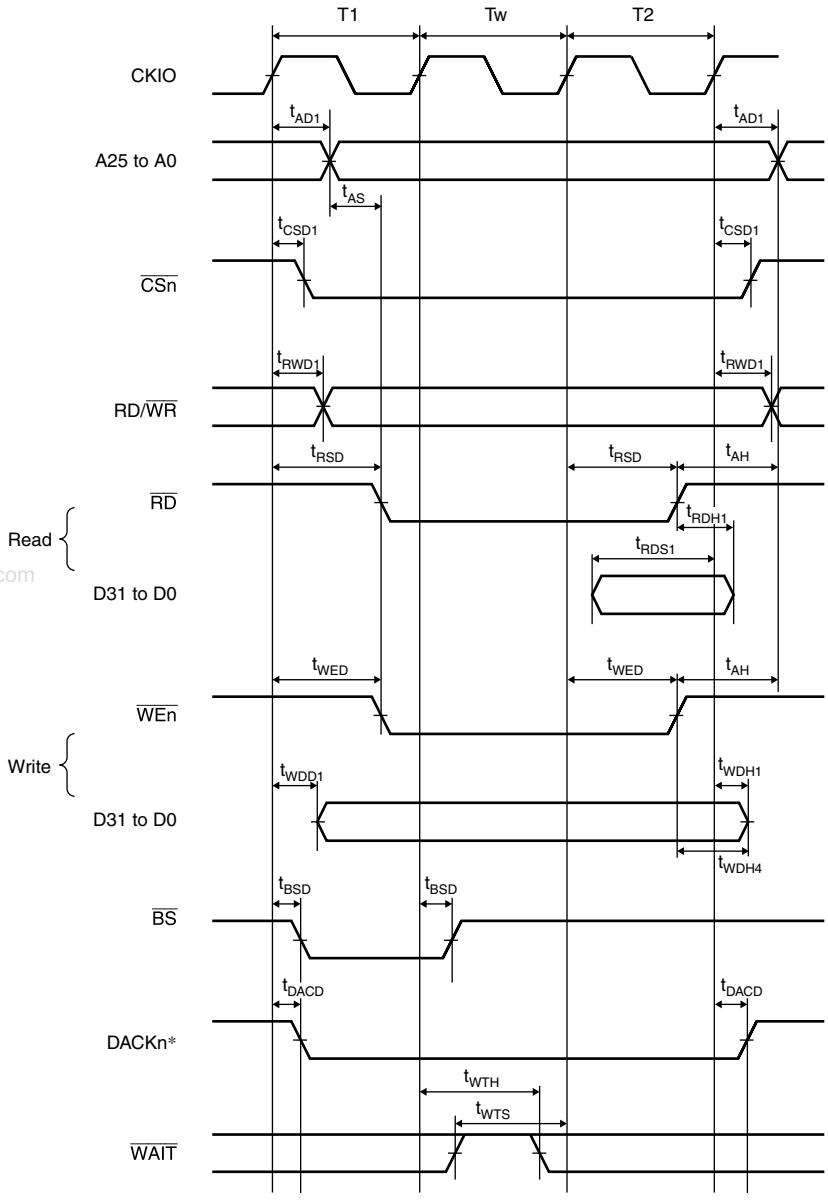
		66.67 MHz			
Item	**Symbol**	**Min**	**Max**	**Unit**	**Figure**
Write enable delay time	t_{WED}	—	1/2 t_{cyc}+10	ns	25.16 to 25.21
Write data delay time 1	t_{WDD1}	—	12	ns	25.16 to 25.20
Write data delay time 2	t_{WDD2}	—	12	ns	25.26 to 25.29, 25.33 to 25.35
Write data hold time 1	t_{WDH1}	1	—	ns	25.16 to 25.20
Write data hold time 2	t_{WDH2}	1	—	ns	25.26 to 25.29, 25.33 to 25.35
Write data hold time 4	t_{WDH4}	0	—	ns	25.16 to 25.19
$\overline{WAIT}$ setup time	t_{WTS}	1/2 t_{cyc}+6	—	ns	25.17 to 25.21
$\overline{WAIT}$ hold time	t_{WTH}	1/2 t_{cyc}+2	—	ns	25.17 to 25.21
$\overline{RAS}$ delay time 1	t_{RASD1}	1	10	ns	25.22 to 25.38
$\overline{CAS}$ delay time 1	t_{CASD1}	1	10	ns	25.22 to 25.38
DQM delay time 1	t_{DQMD1}	1	10	ns	25.22 to 25.35
CKE delay time 1	t_{CKED1}	1	10	ns	25.37
$\overline{AH}$ delay time	t_{AHD}	1/2 t_{cyc}	1/2 t_{cyc}+10	ns	25.20
Multiplex address delay time	t_{MAD}	—	12	ns	25.20
Multiplex address hold time	t_{MAH}	0	—	ns	25.20
DACK delay time	t_{DACD}	—	10	ns	25.16 to 25.35

25.3.4 Basic Timing



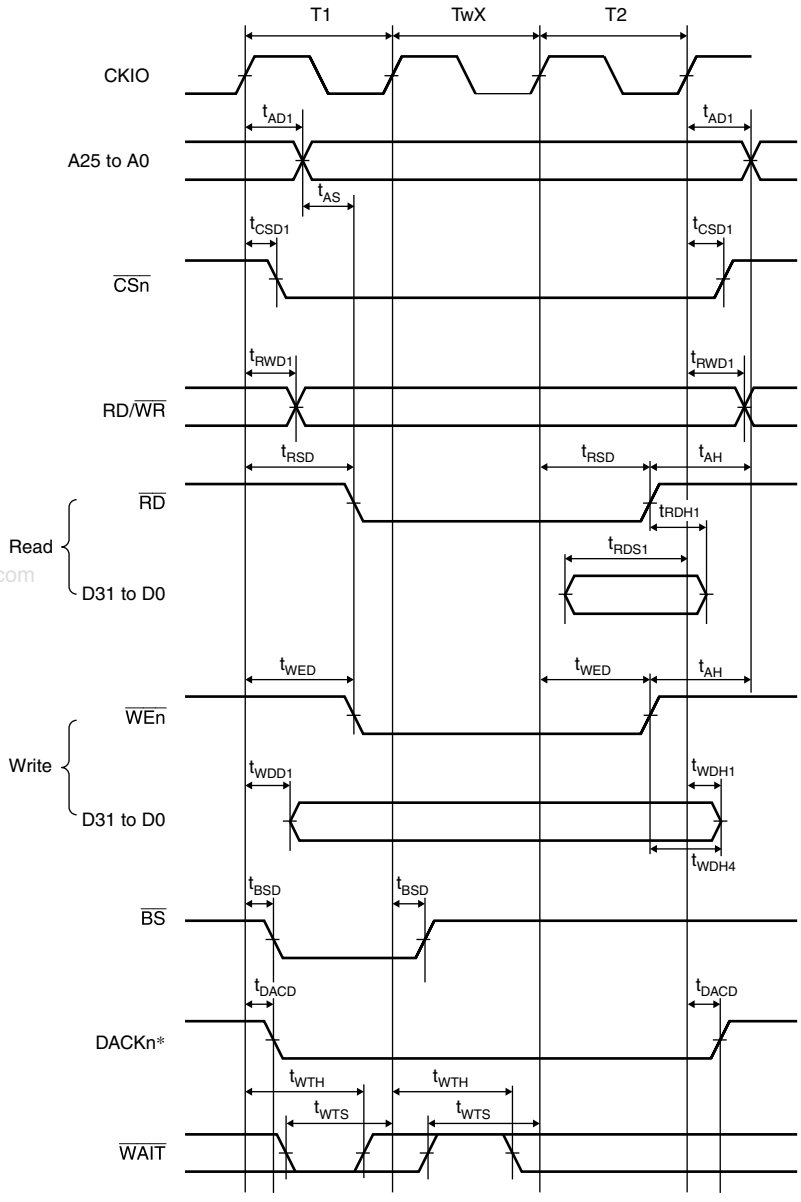
Note: * DACKn is a waveform when active-low is specified.

Figure 25.16 Basic Bus Cycle (No Wait)



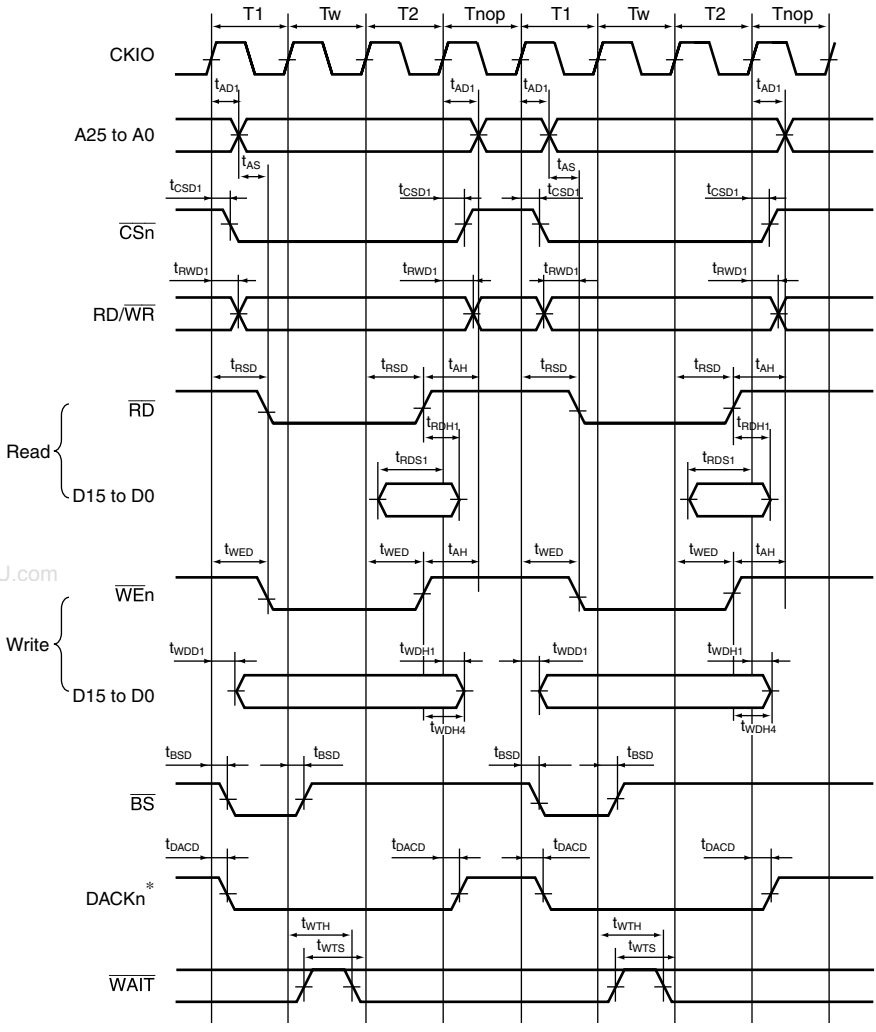
Note: * DACKn is a waveform when active-low is specified.

Figure 25.17 Basic Bus Cycle (One Software Wait)



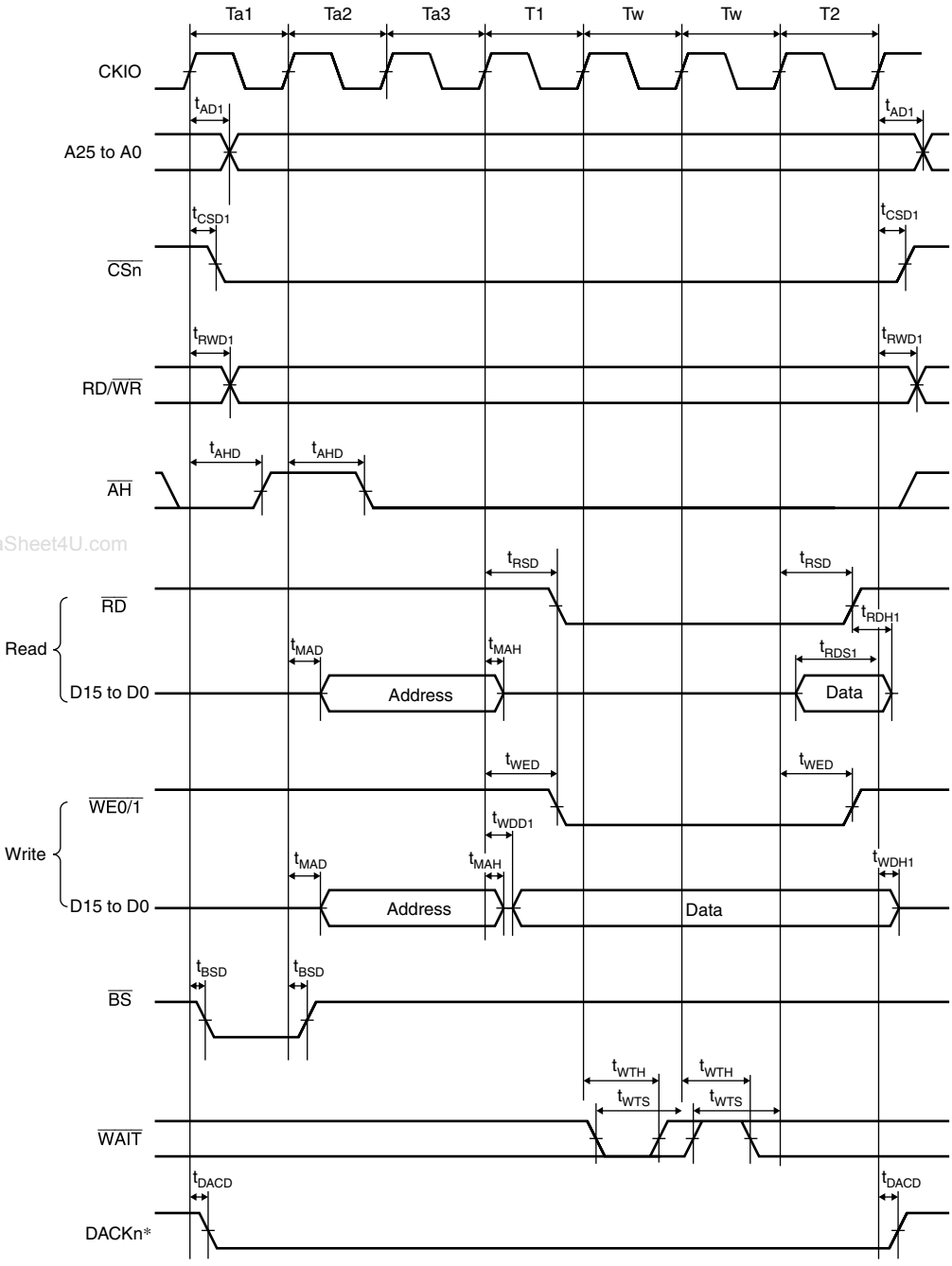
Note: * DACKn is a waveform when active-low is specified.

Figure 25.18 Basic Bus Cycle (One External Wait)



Note: * DACKn is a waveform when active-low is specified.

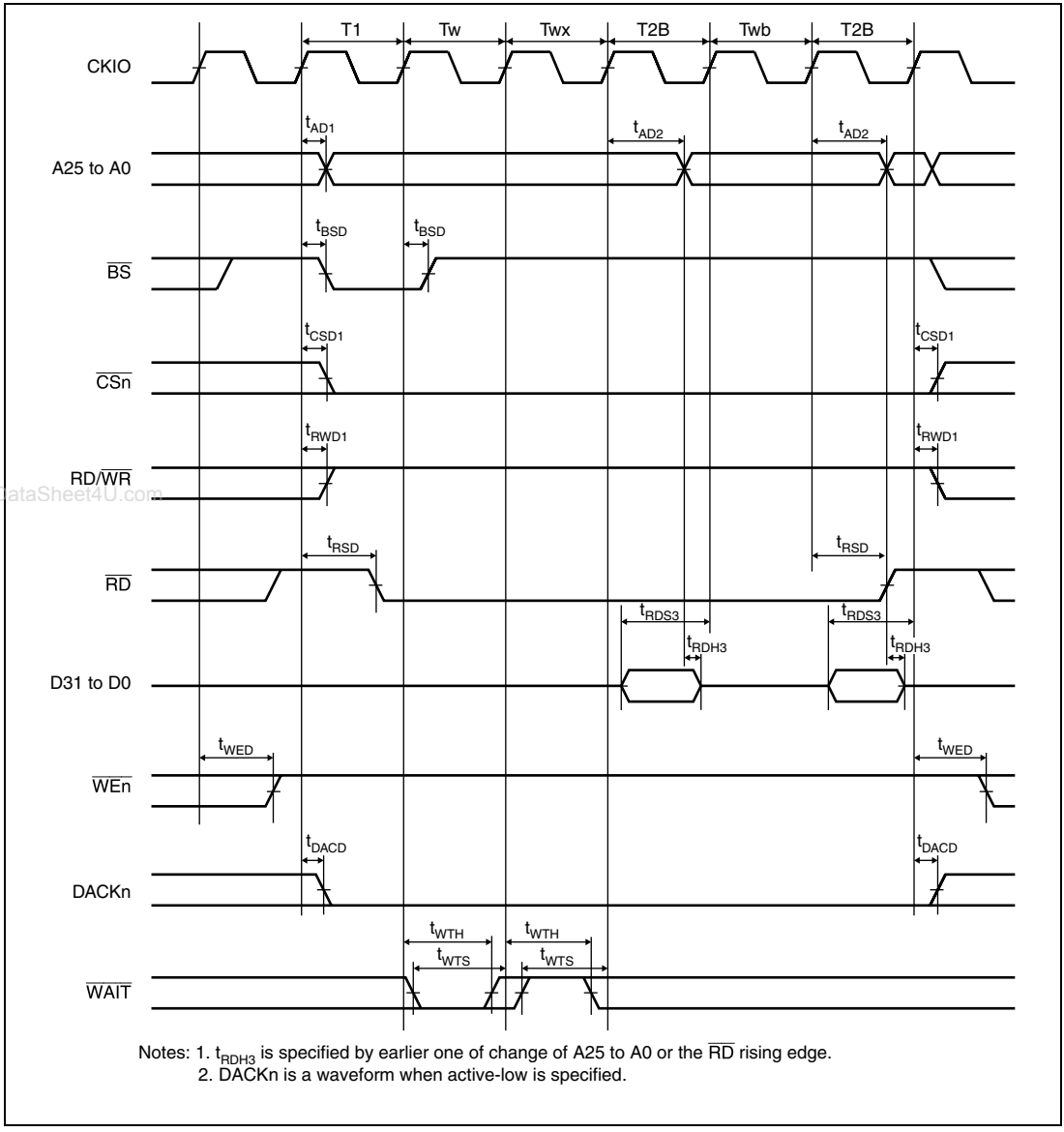
Figure 25.19 Basic Bus Cycle (One Software Wait, External Wait Enabled (WM bit = 0), No Idle Cycle Setting)



Note: * DACKn is a waveform when active-low is specified.

Figure 25.20 Address/Data Multiplex I/O Bus Cycle (Three Address Cycles, One Software Wait, One External Wait)

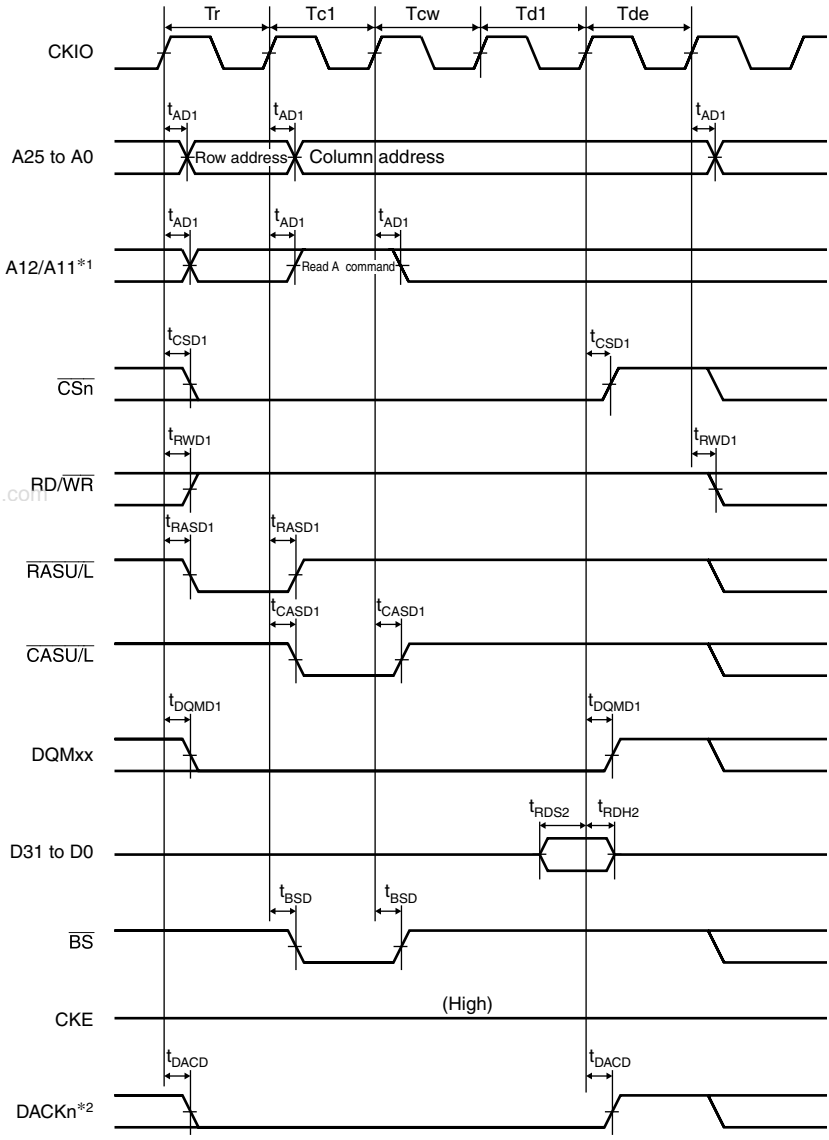
25.3.5 Burst ROM Timing



Notes: 1. t_{RDH3} is specified by earlier one of change of A25 to A0 or the $\overline{RD}$ rising edge.
2. DACKn is a waveform when active-low is specified.

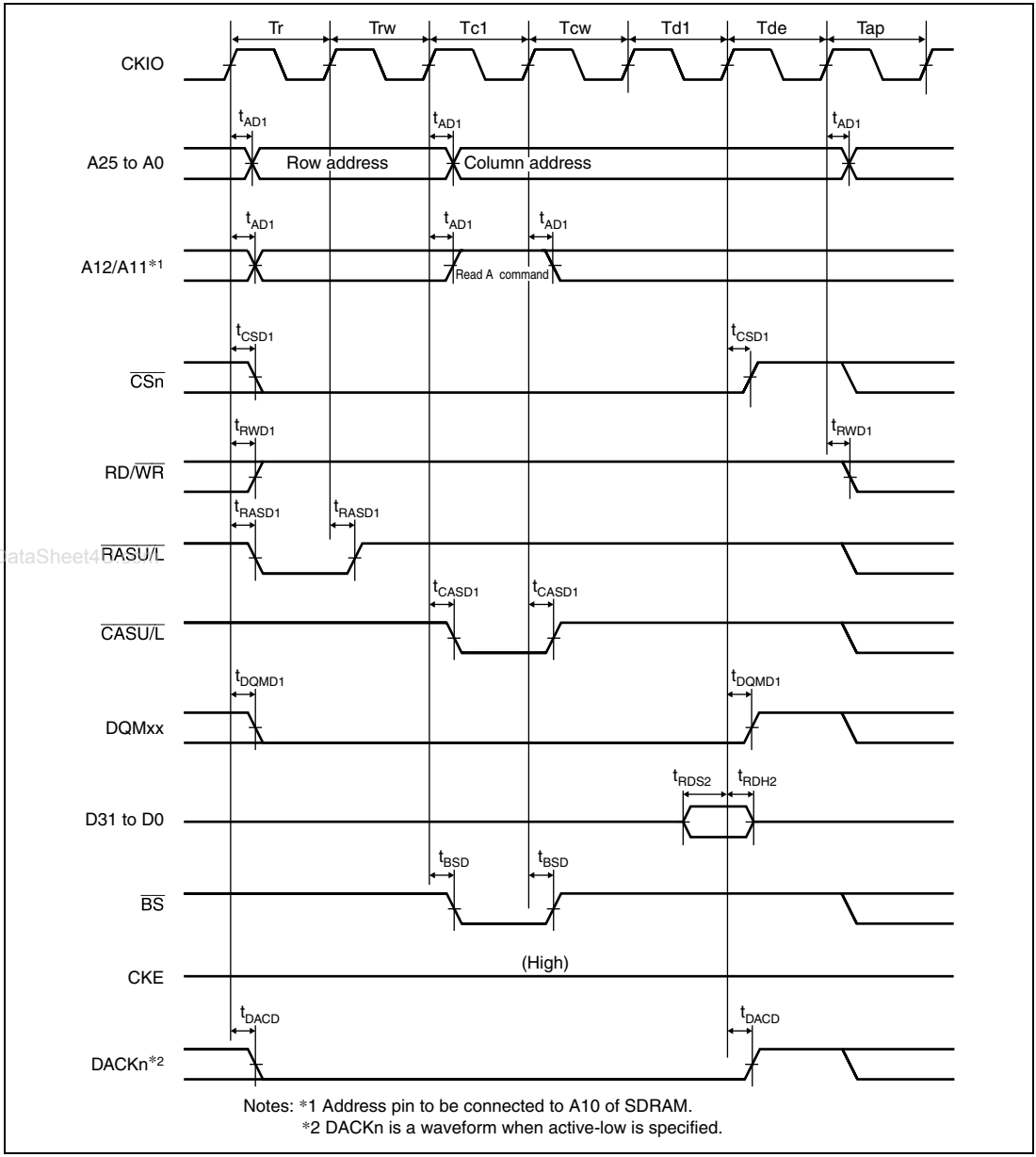
Figure 25.21 Burst ROM Read Cycle (One Access Wait, One External Wait, One Burst Wait, Two Bursts)

25.3.6 Synchronous DRAM Timing



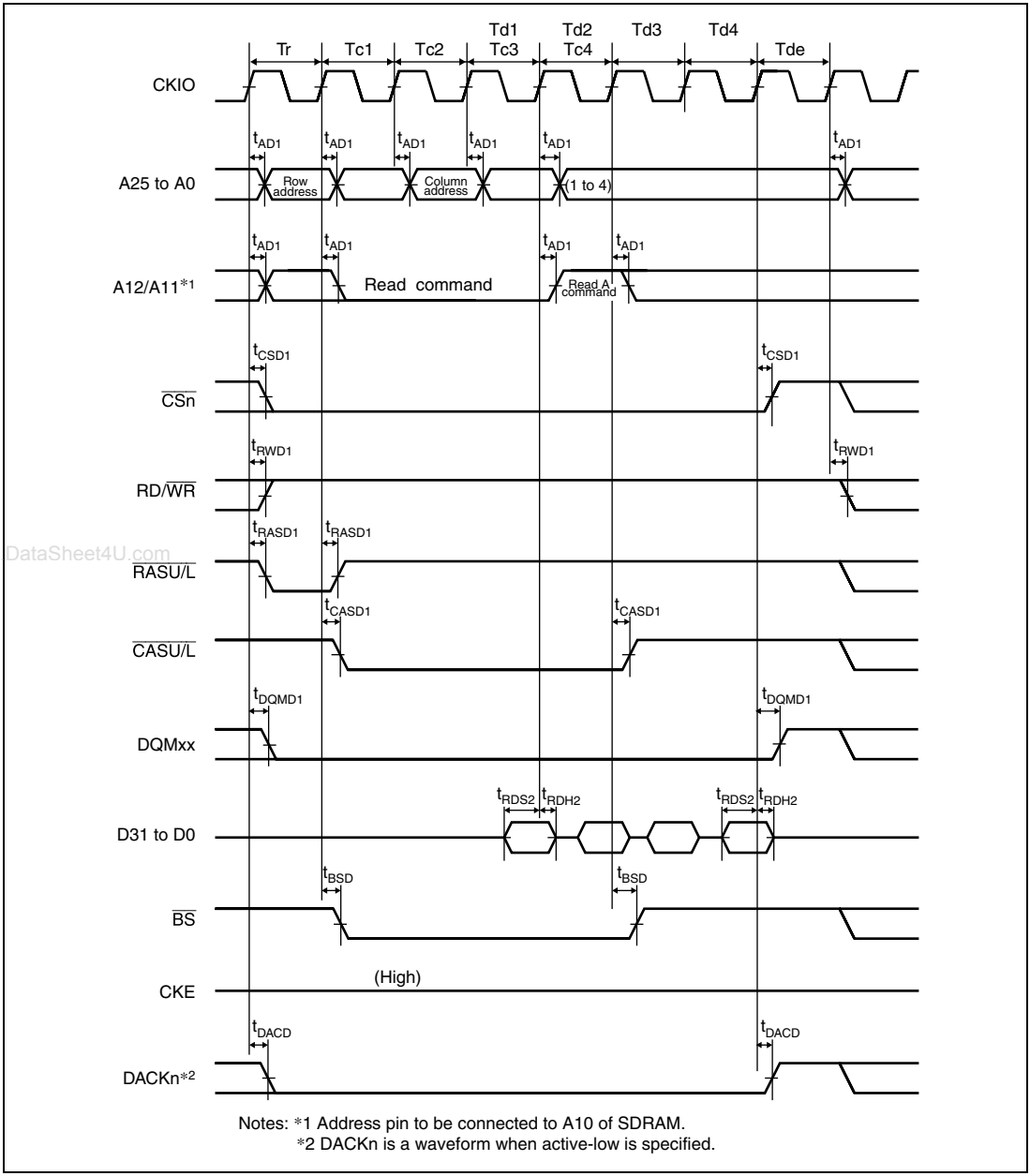
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.22 Synchronous DRAM Single Read Bus Cycle (Auto Precharge, CAS Latency = 2, TRCD = 1 Cycle, TRP = 1 Cycle)



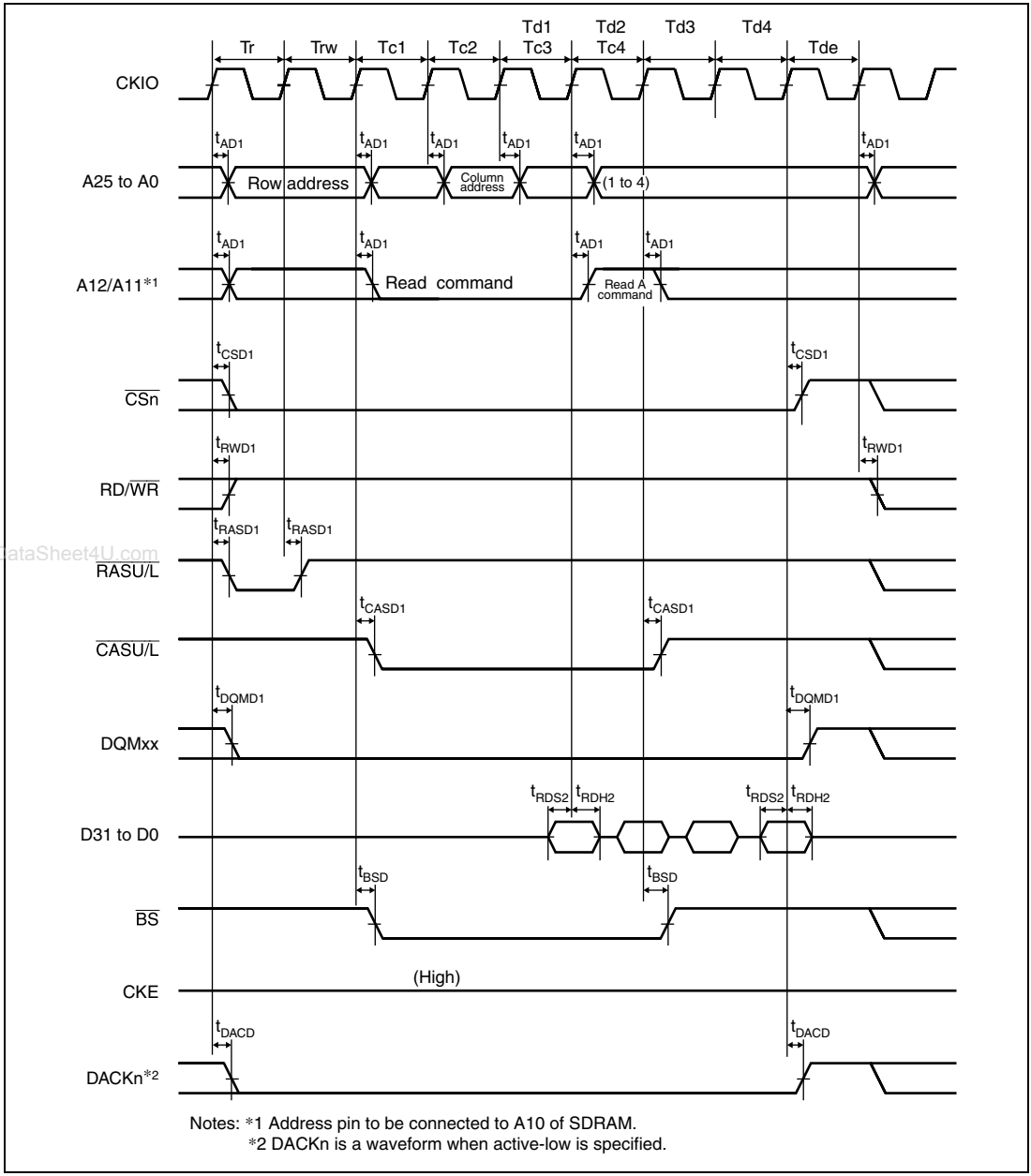
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.23 Synchronous DRAM Single Read Bus Cycle (Auto Precharge, CAS Latency = 2, TRCD = 2 Cycle, TRP = 2 Cycle)



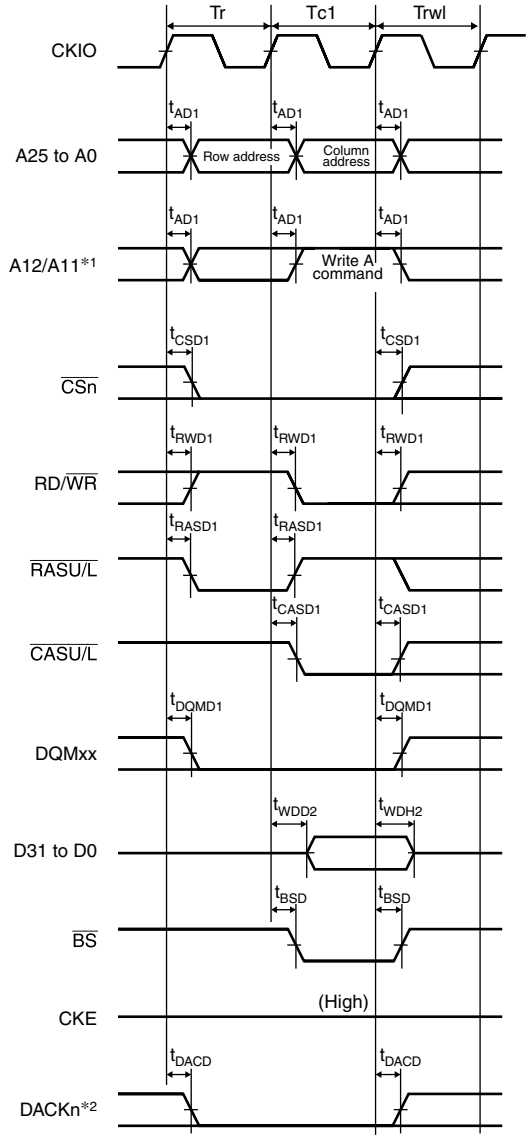
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.24 Synchronous DRAM Burst Read Bus Cycle (Single Read × 4), (Auto Precharge, CAS Latency = 2, TRCD = 1 Cycle, TRP = 2 Cycle)



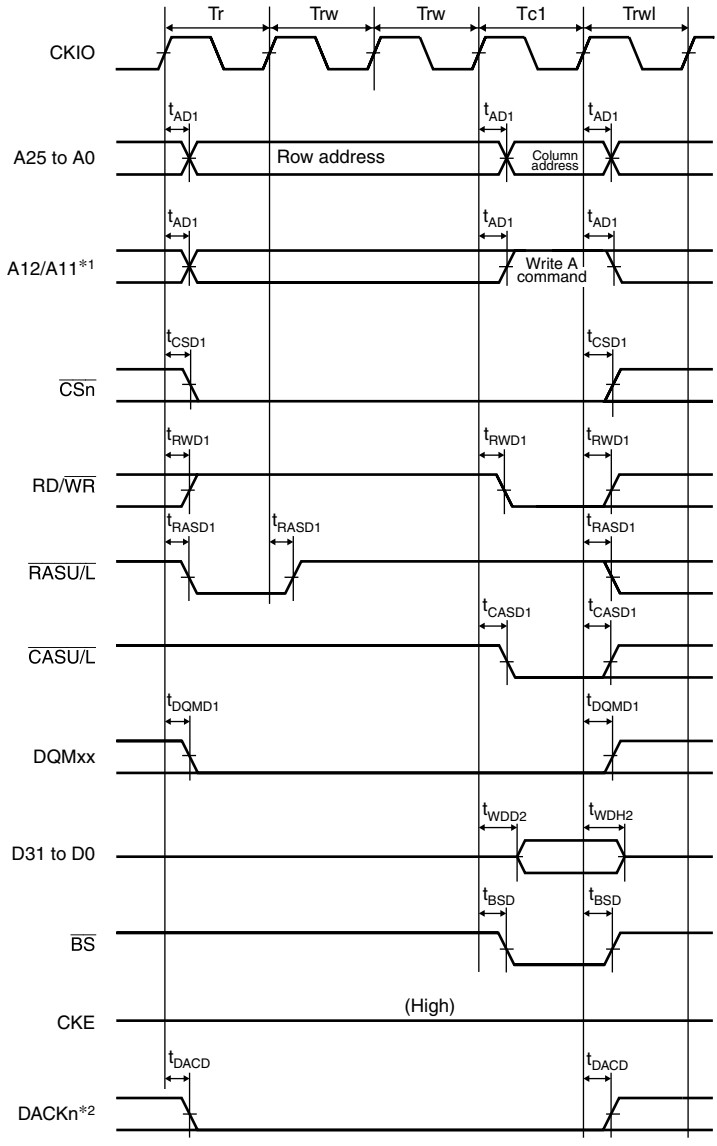
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.25 Synchronous DRAM Burst Read Bus Cycle (Single Read × 4), (Auto Precharge, CAS Latency = 2, TRCD = 2 Cycle, TRP = 1 Cycle)



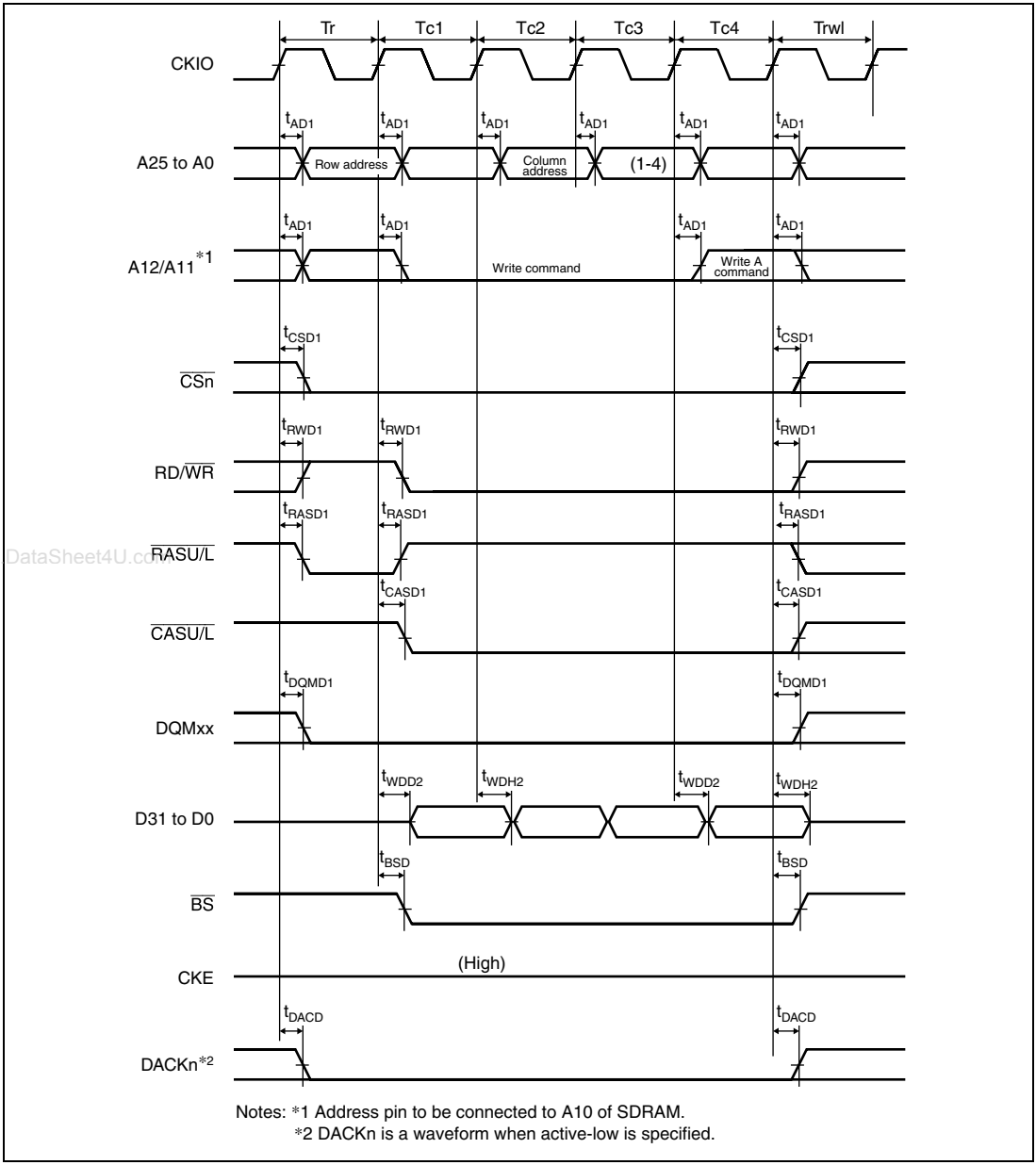
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.26 Synchronous DRAM Single Write Bus Cycle (Auto Precharge, TRWL = 2 Cycle)



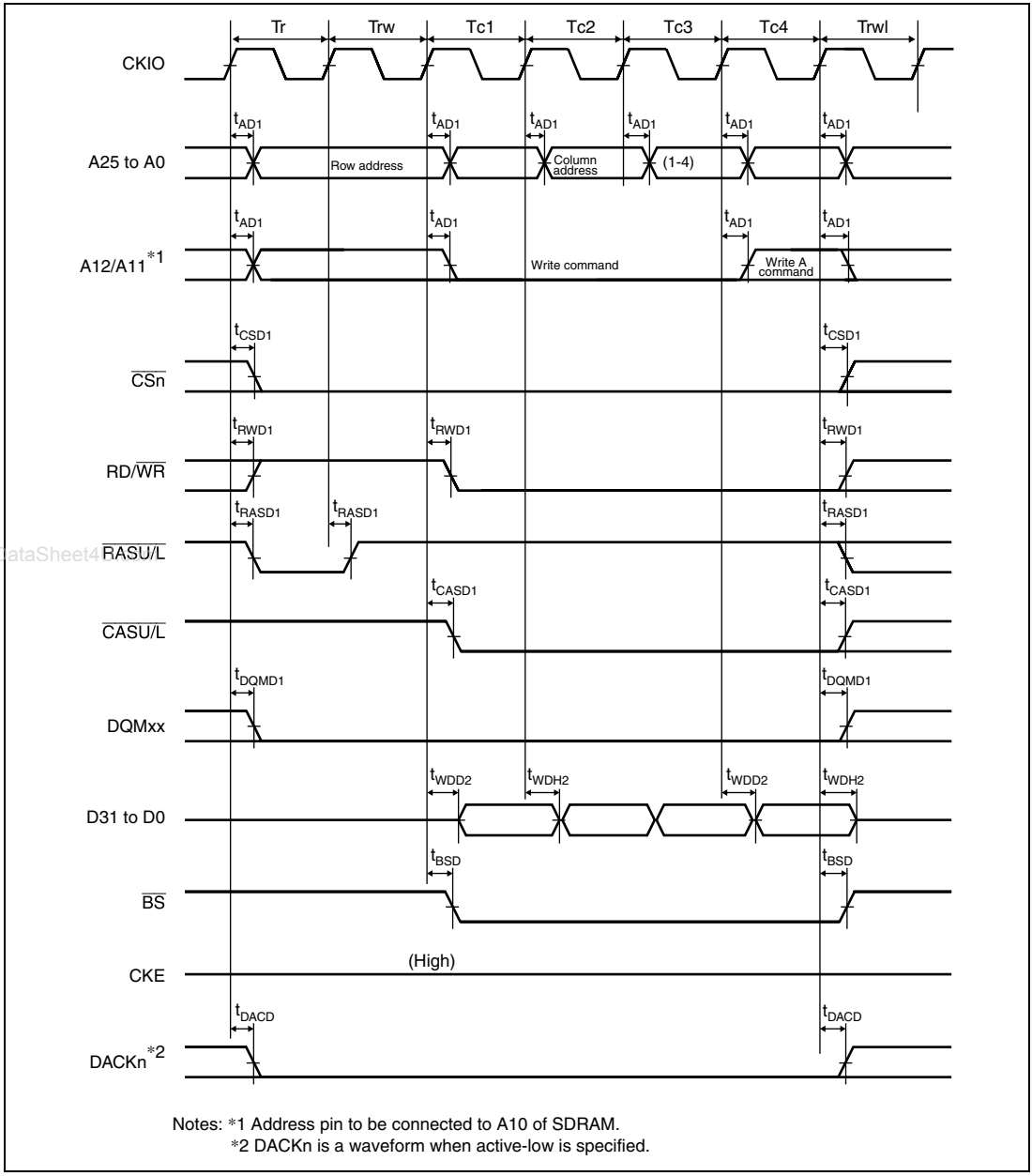
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.27 Synchronous DRAM Single Write Bus Cycle (Auto Precharge, TRCD = 3 Cycle, TRWL = 2 Cycle)



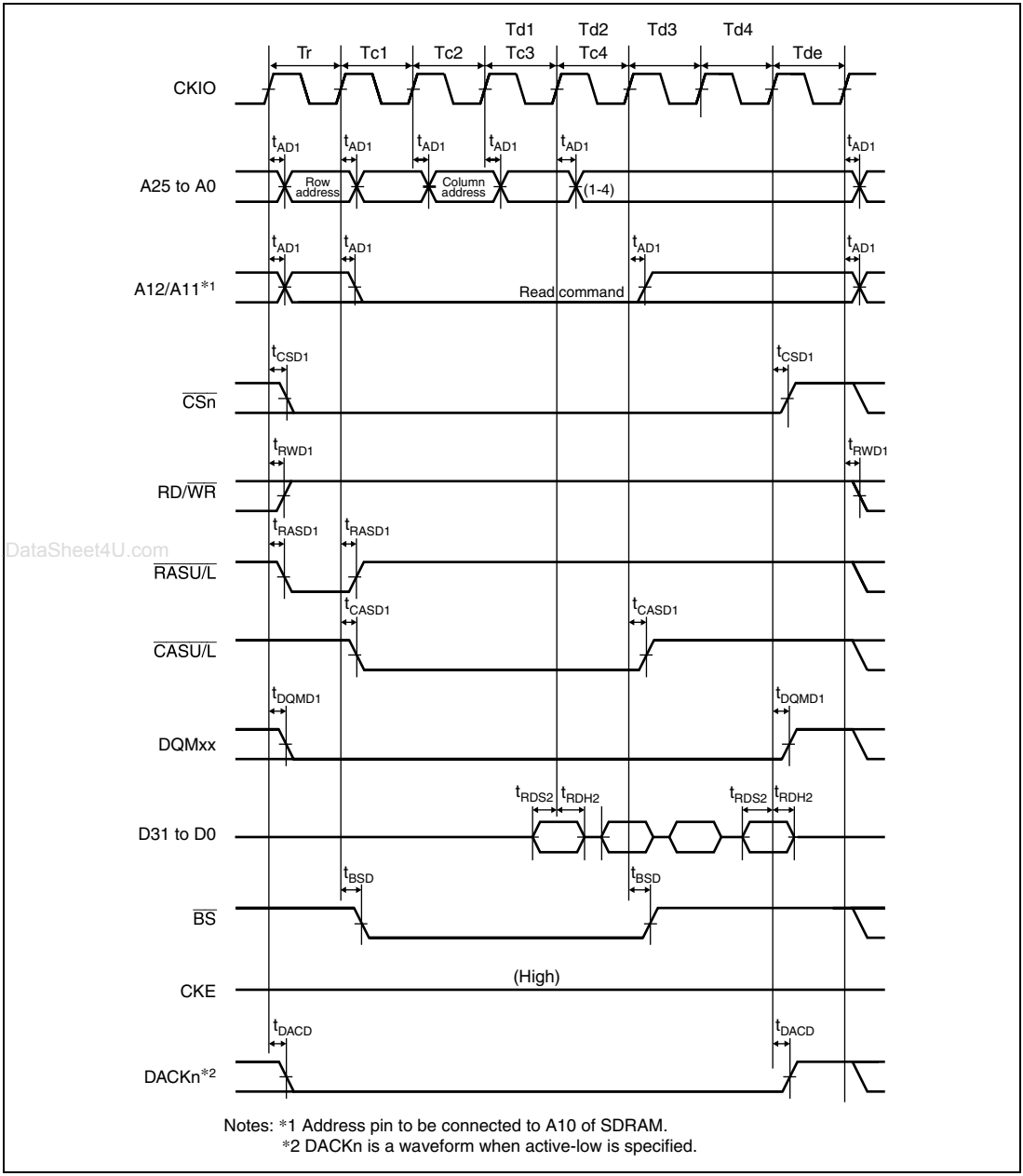
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.28 Synchronous DRAM Burst Write Bus Cycle (Single Write × 4), (Auto Precharge, TRCD = 1 Cycle, TRWL = 2 Cycle)



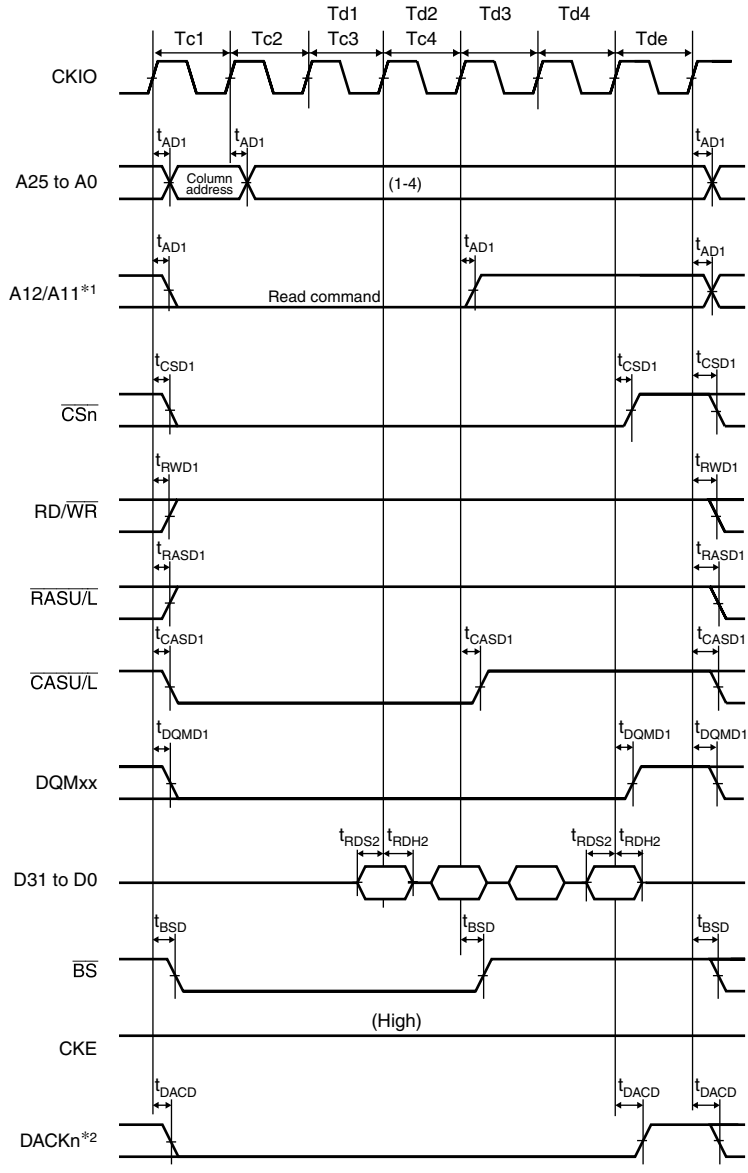
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.29 Synchronous DRAM Burst Write Bus Cycle (Single Write × 4), (Auto Precharge, TRCD = 2 Cycle, TRWL = 2 Cycle)



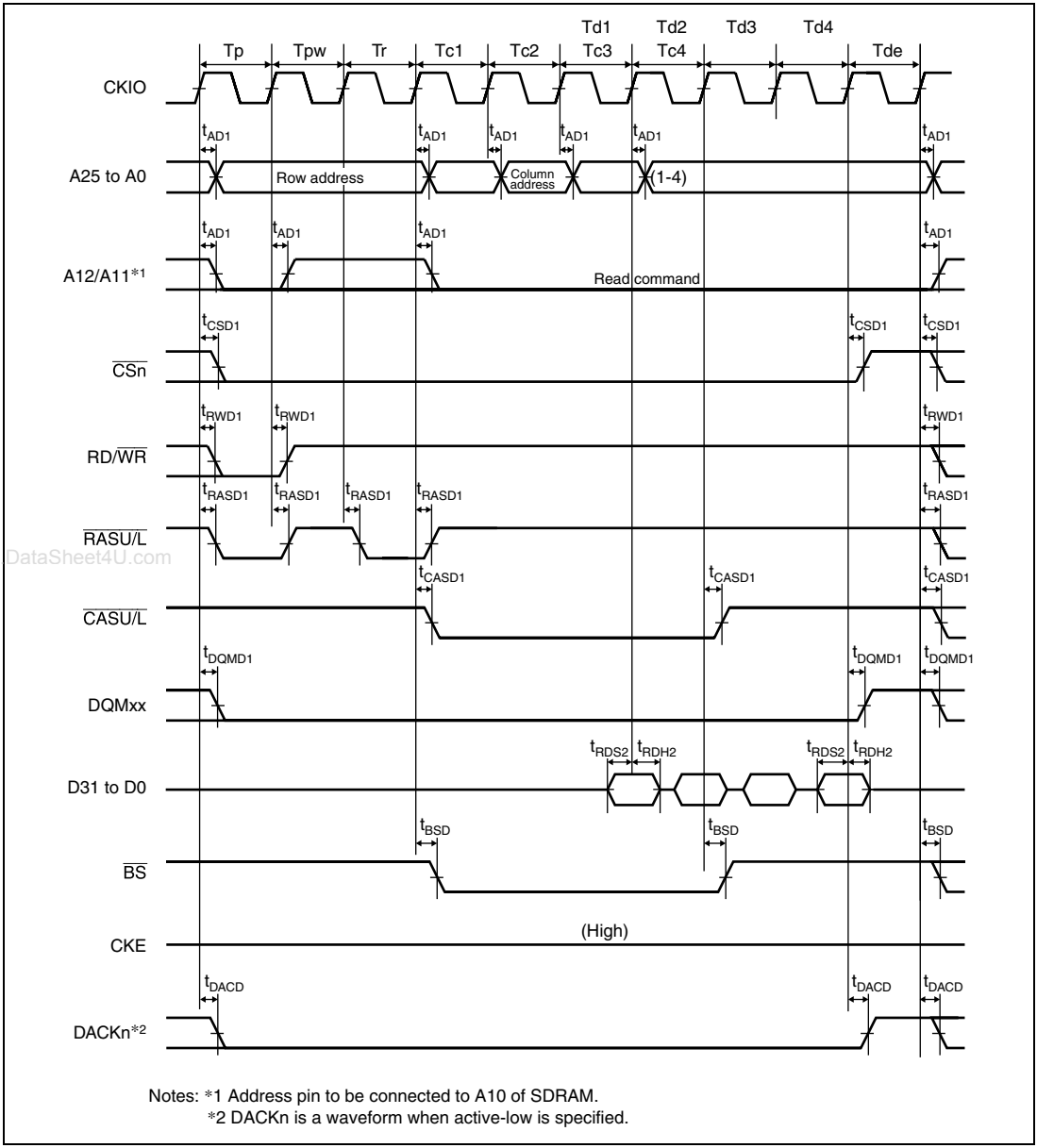
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.30 Synchronous DRAM Burst Read Bus Cycle (Single Read × 4)
(Bank Active Mode: ACTV + READ Commands, CAS Latency = 2, TRCD = 1 Cycle)



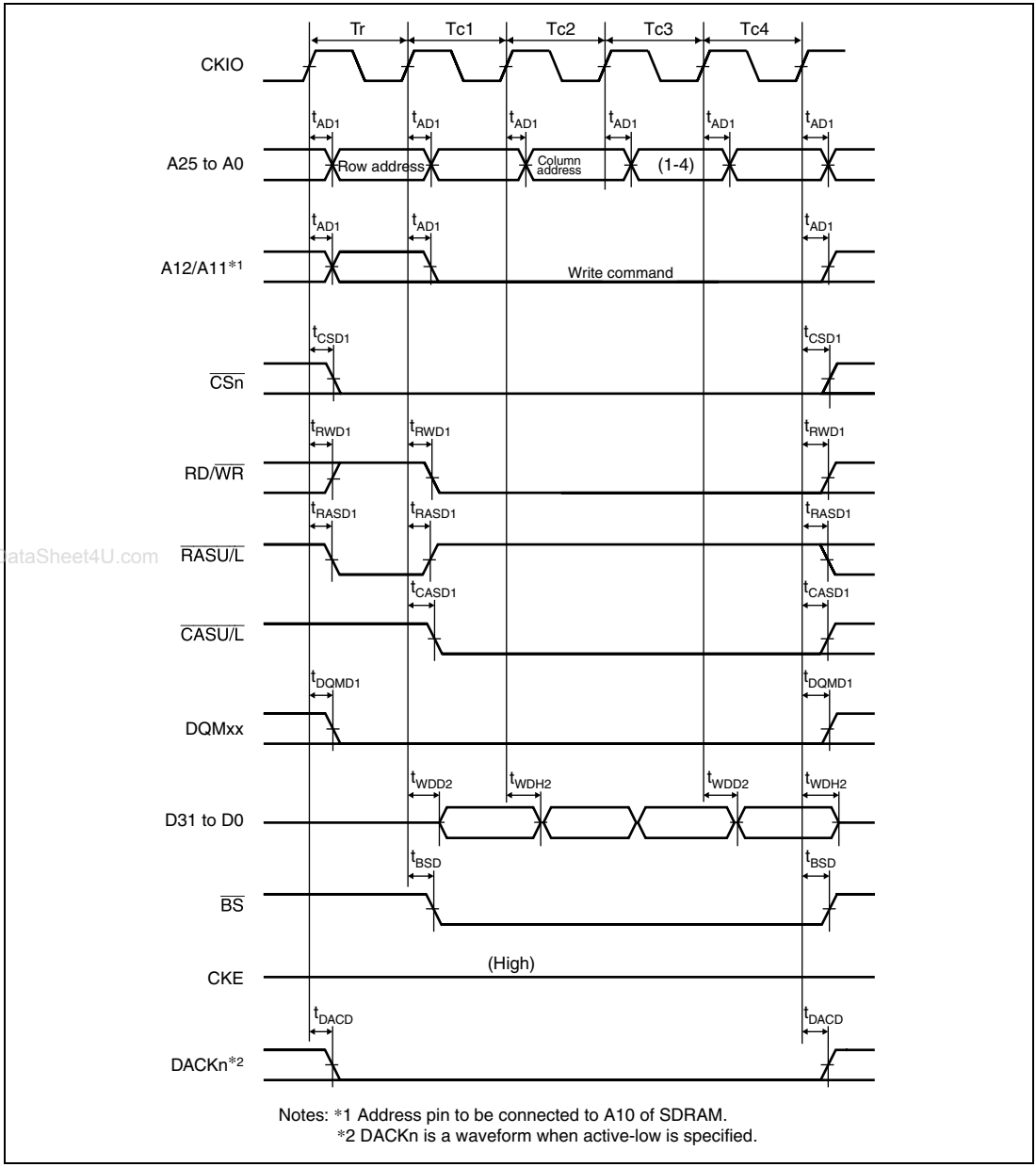
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.31 Synchronous DRAM Burst Read Bus Cycle (Single Read × 4)
(Bank Active Mode: READ Command, Same Row Address,
CAS Latency = 2, TRCD = 1 Cycle)



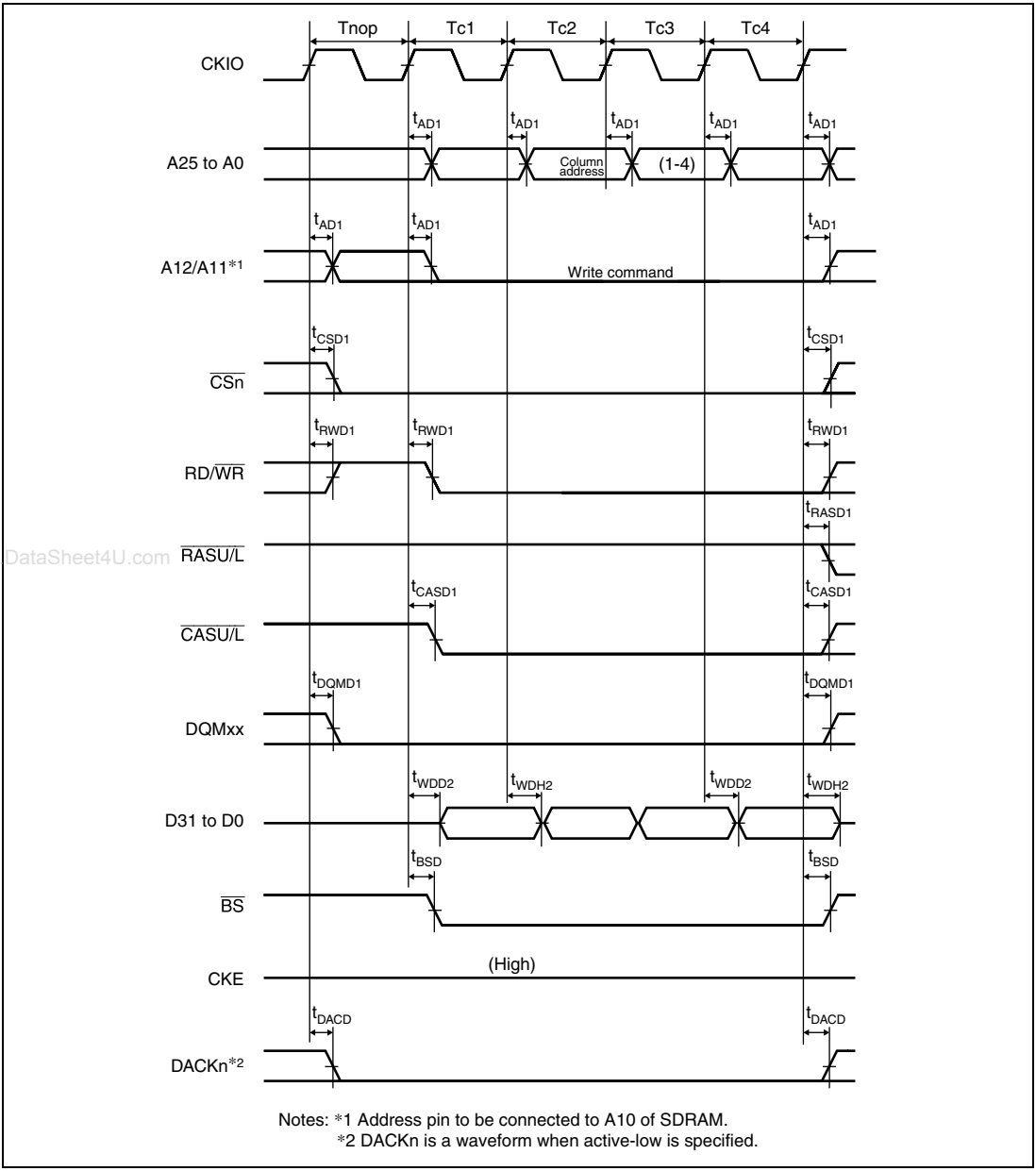
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.32 Synchronous DRAM Burst Read Bus Cycle (Single Read × 4)
(Bank Active Mode: PRE + ACTV + READ Commands,
Different Row Address, CAS Latency = 2, TRCD = 1 Cycle)



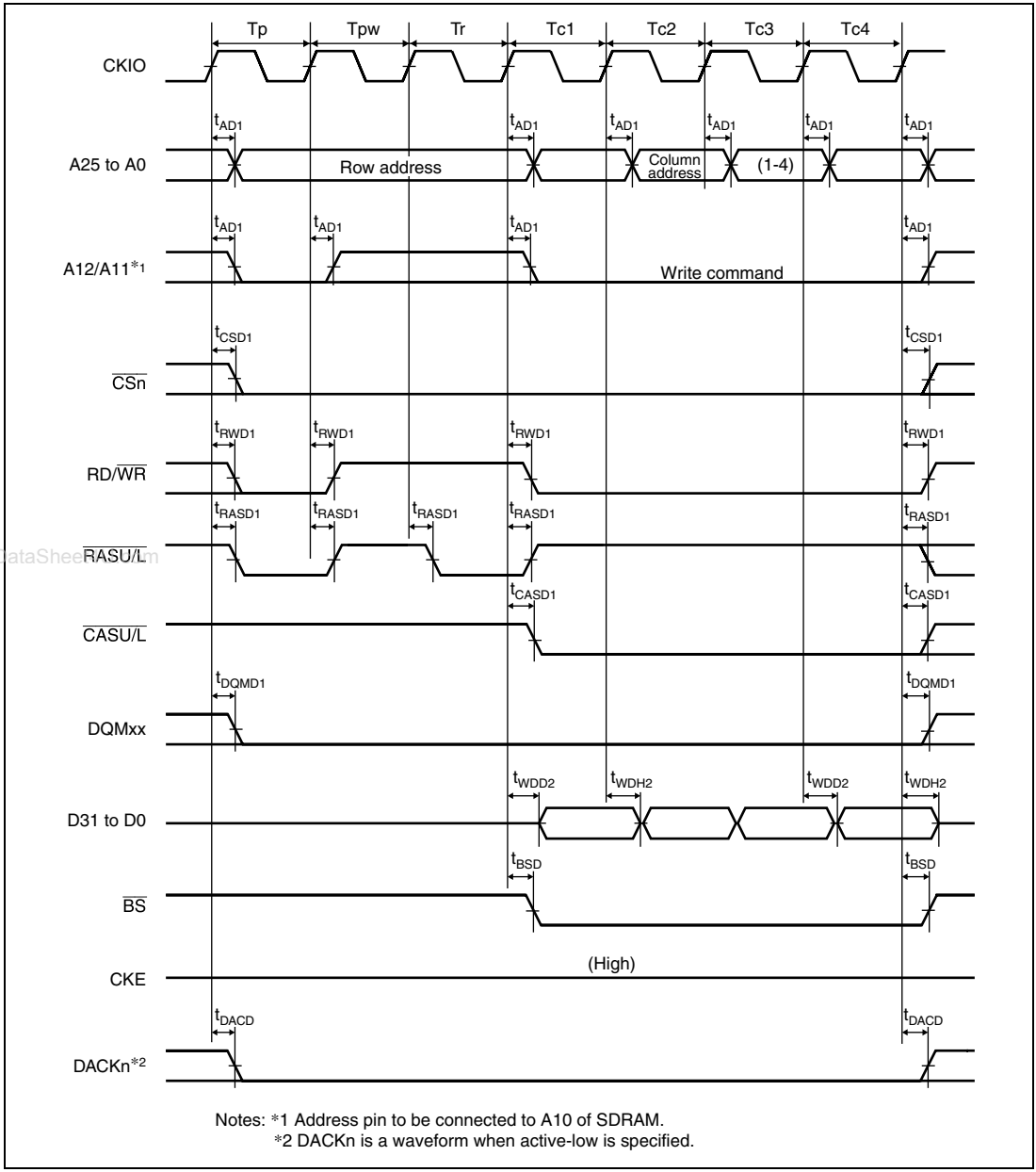
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.33 Synchronous DRAM Burst Write Bus Cycle (Single Write × 4)
(Bank Active Mode: ACTV + WRITE Commands, TRCD = 1 Cycle, TRWL = 1 Cycle)



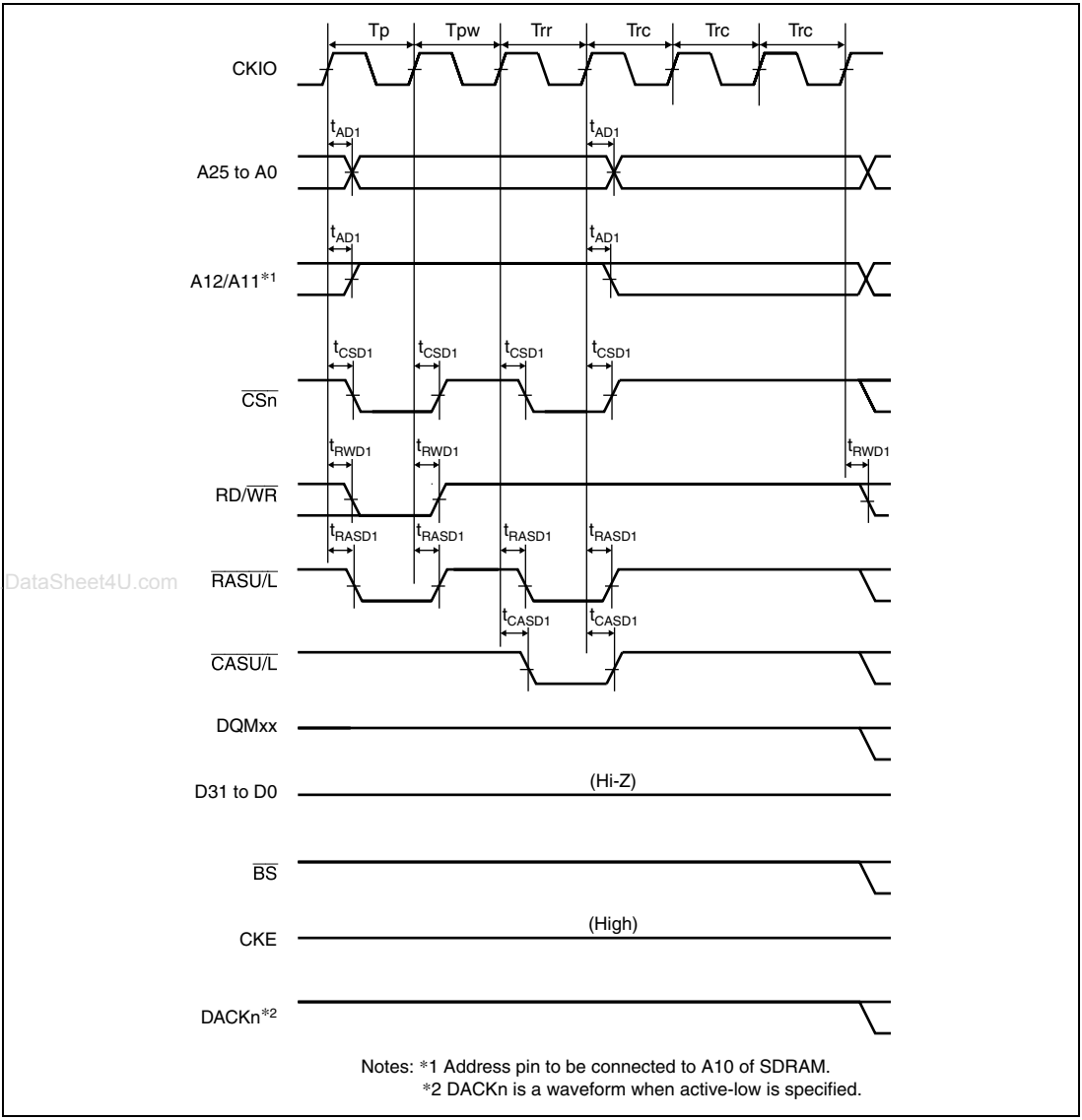
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.34 Synchronous DRAM Burst Write Bus Cycle (Single Write × 4)
(Bank Active Mode: WRITE Command, Same Row Address,
TRCD = 1 Cycle, TRWL = 1 Cycle)



Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.35 Synchronous DRAM Burst Write Bus Cycle (Single Write × 4)
(Bank Active Mode: PRE + ACTV + WRITE Commands,
Different Row Address, TRCD = 1 Cycle, TRWL = 1 Cycle)



Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.36 Synchronous DRAM Auto-Refresh Timing (TRP = 2 Cycle)

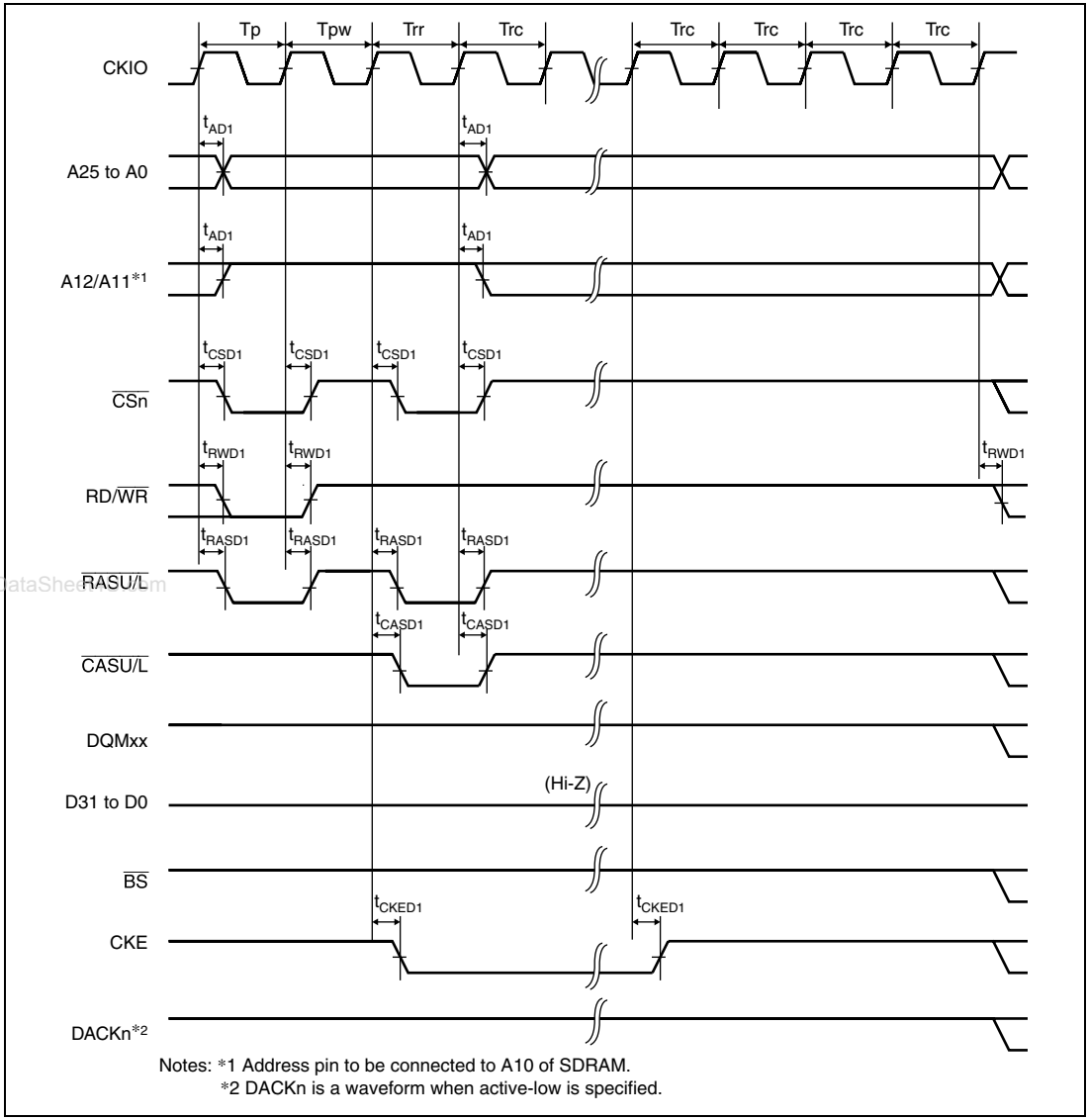
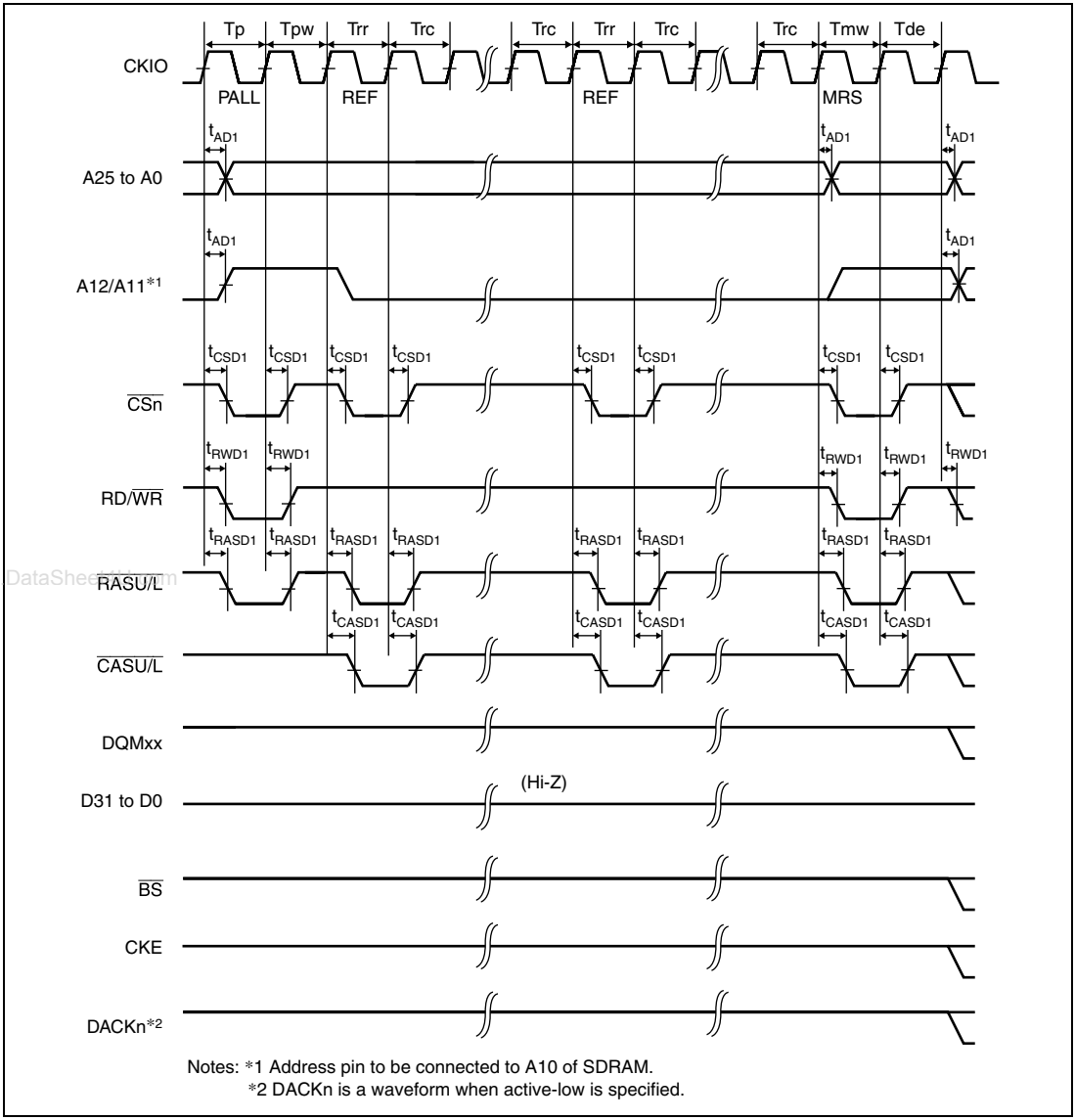


Figure 25.37 Synchronous DRAM Self-Refresh Timing (TRP = 2 Cycle)



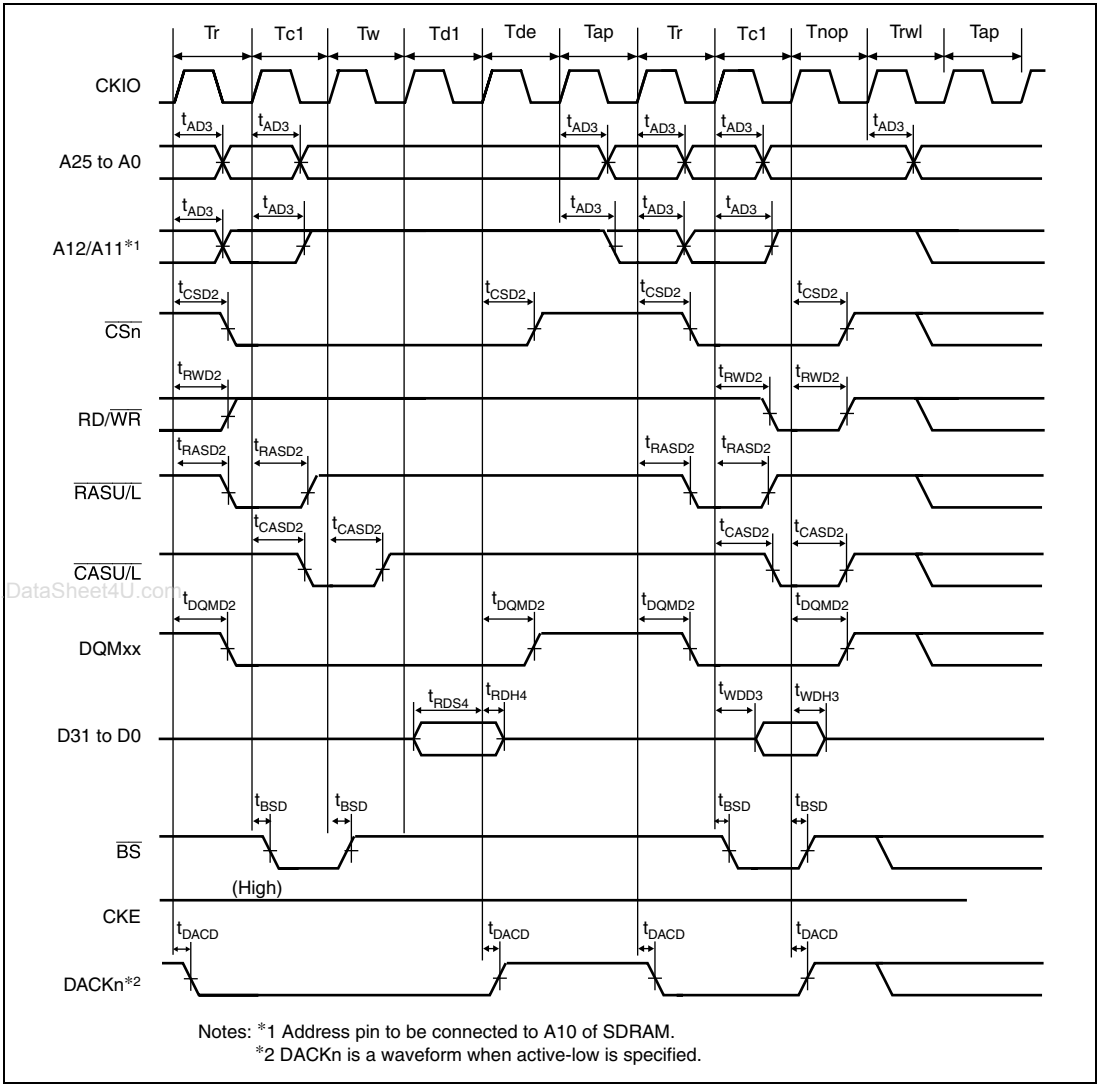
Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.38 Synchronous DRAM Mode Register Write Timing (TRP = 2 Cycle)

Table 25.8 Bus Timing (2)

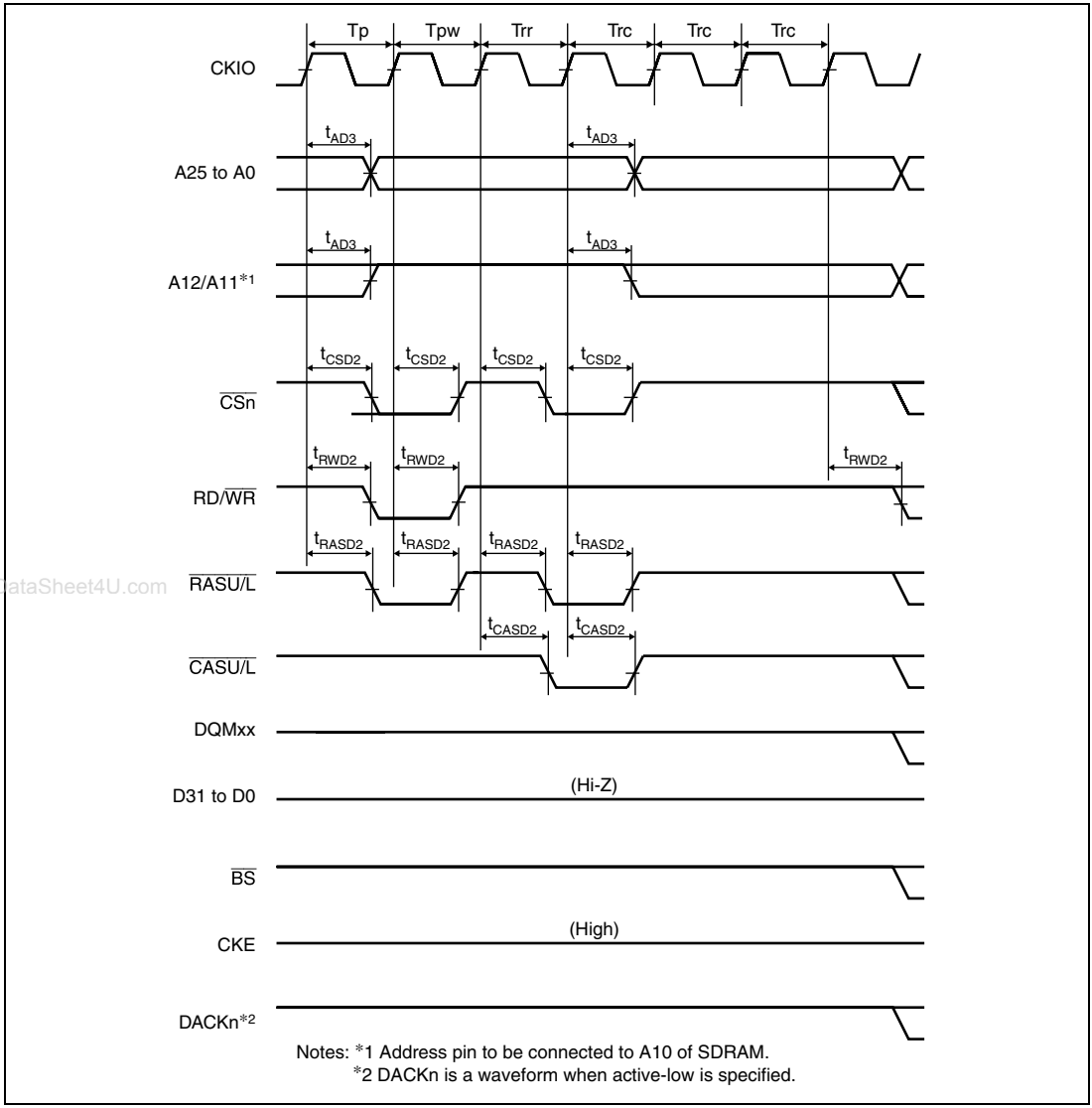
(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C, Clock mode 0/1/2/4/5/6/7)

Item	Symbol	Min	Max	Unit	Figure
Address delay time 3	t_{AD3}	1/2 t_{cyc}	1/2 t_{cyc}+12	ns	25.39 to 25.42
$\overline{CS}$ delay time 2	t_{CSD2}	1/2 t_{cyc}	1/2 t_{cyc}+10	ns	25.39 to 25.42
Read/write delay time 2	t_{RWD2}	1/2 t_{cyc}	1/2 t_{cyc}+10	ns	25.39 to 25.42
Read data setup time 4	t_{RDS4}	1/2 t_{cyc}+6	—	ns	25.39
Read data hold time 4	t_{RDH4}	0	—	ns	25.39
Write data delay time 3	t_{WDD3}	—	1/2 t_{cyc}+12	ns	25.39
Write data hold time 3	t_{WDH3}	1/2 t_{cyc}	—	ns	25.39
$\overline{RAS}$ delay time 2	t_{RASD2}	1/2 t_{cyc}	1/2 t_{cyc}+10	ns	25.39 to 25.42
$\overline{CAS}$ delay time 2	t_{CASD2}	1/2 t_{cyc}	1/2 t_{cyc}+10	ns	25.39 to 25.42
DQM delay time 2	t_{DQMD2}	1/2 t_{cyc}	1/2 t_{cyc}+10	ns	25.39
CKE delay time 2	t_{CKED2}	1/2 t_{cyc}	1/2 t_{cyc}+10	ns	25.41



Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.39 Access Timing in Low-Frequency Mode (Auto Precharge)



Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.40 Synchronous DRAM Auto-Refresh Timing (TRP = 2 Cycle, Low-Frequency Mode)

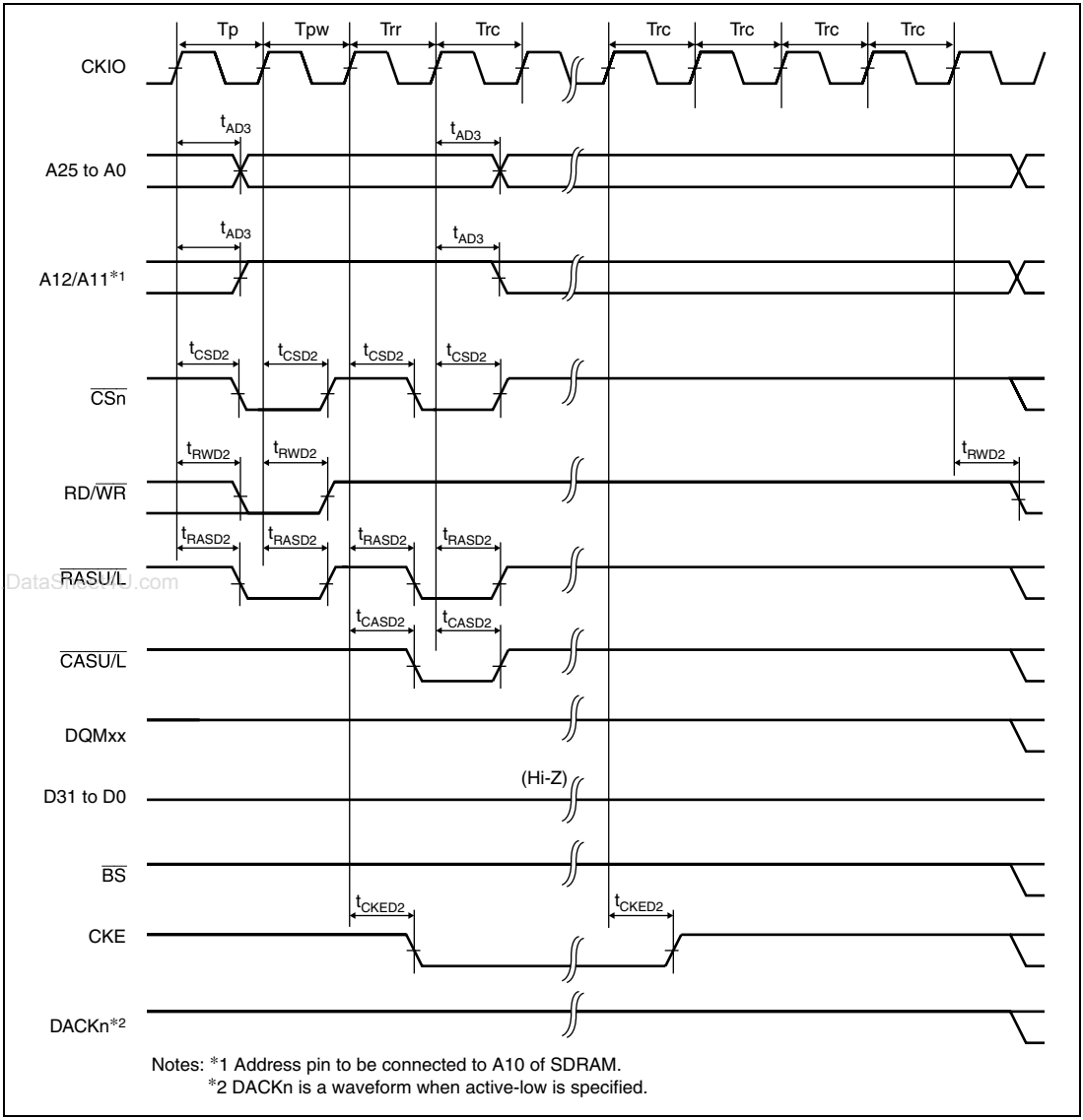
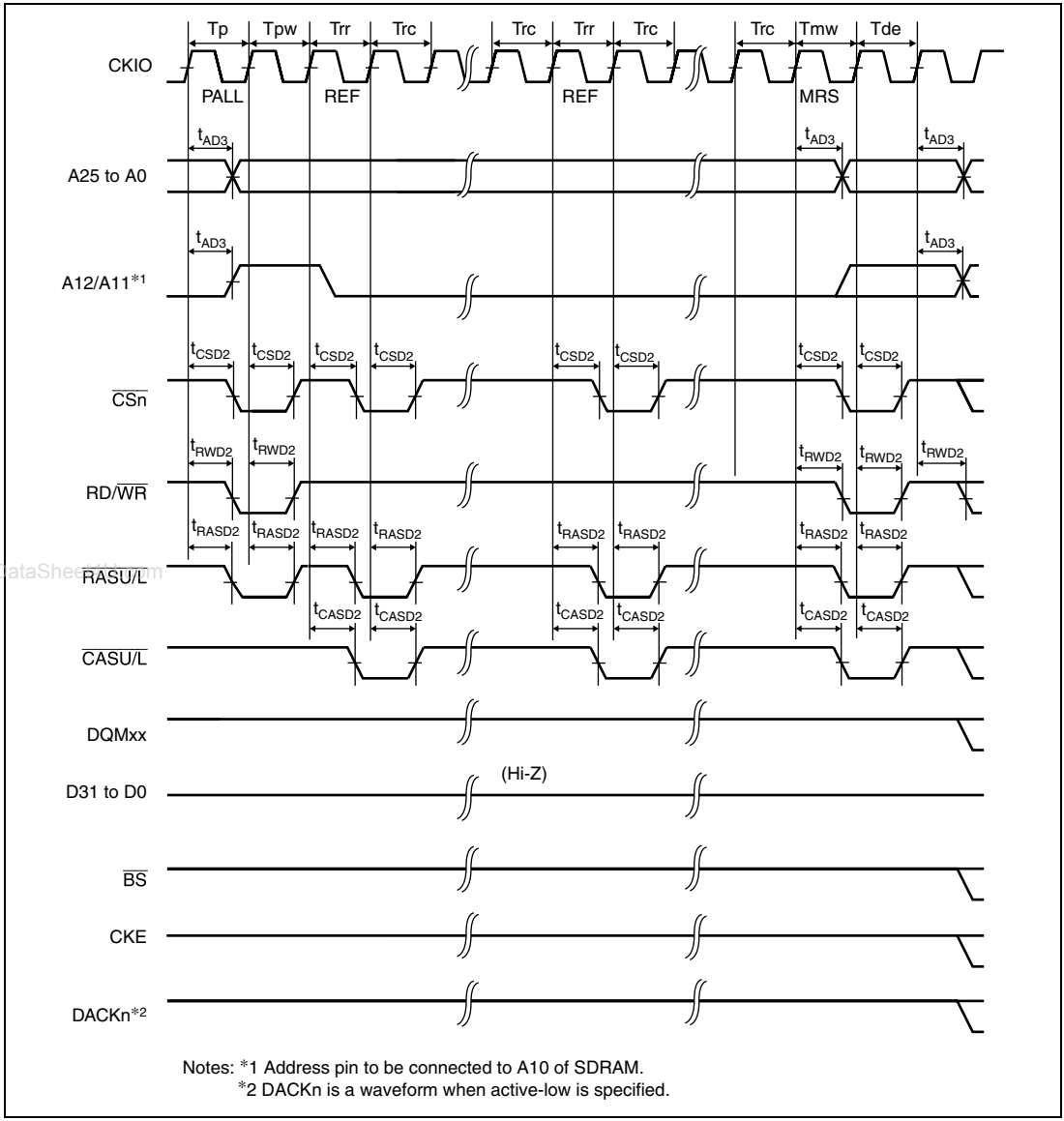


Figure 25.41 Synchronous DRAM Self-Refresh Timing (TRP = 2 Cycle, Low-Frequency Mode)



Notes: *1 Address pin to be connected to A10 of SDRAM.
*2 DACKn is a waveform when active-low is specified.

Figure 25.42 Synchronous DRAM Mode Register Write Timing (TRP = 2 Cycle, Low-Frequency Mode)

25.3.7 DMAC Signal Timing

Table 25.9 DMAC Signal Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Module	Item	Symbol	Min	Max	Unit	Figure
DMAC	DREQ setup time	t_{DRQS}	10	—	ns	25.43
	DREQ hold time	t_{DRQH}	3	—		
	DACK, TEND delay time	t_{DACD}	—	10		25.44

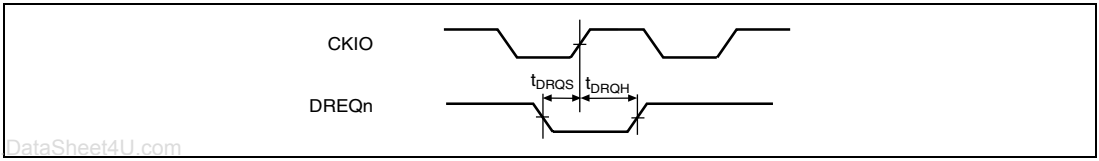


Figure 25.43 DREQ Input Timing

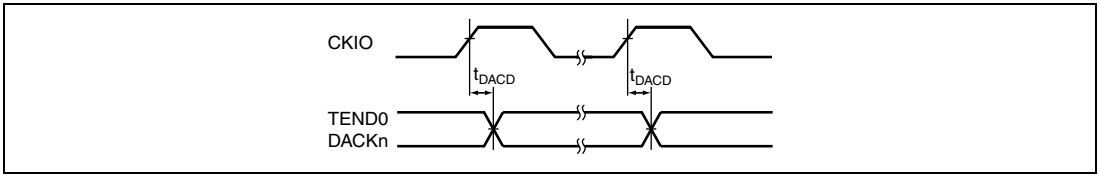


Figure 25.44 DACK, TEND Output Timing

25.3.8 TMU Signal Timing

Table 25.10 TMU Signal Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Module	Item		Symbol	Min	Max	Unit	Figure
TMU	Timer input setup time	B:P clock ratio = 1:1	t_{TCLKS}	15	—	ns	25.45
		B:P clock ratio = 2:1		t_{cyc}+15	—		
		B:P clock ratio = 4:1		$3 \times t_{cyc}$+15	—		
	Timer clock input setup time		t_{TCKS}	15	—		25.46
	Timer clock pulse width	Edge specification	$t_{TCKWH/L}$	2.0	—	t_{pcyc}*	
		Both edge specification	$t_{TCKWH/L}$	3.0	—		

Note: * t_{pcyc} indicates a peripheral clock (Pϕ) cycle.

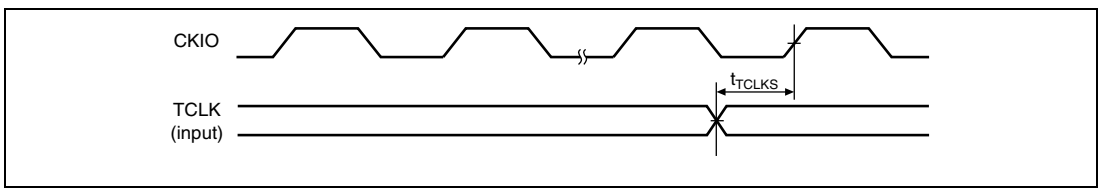


Figure 25.45 TCLK Input Timing

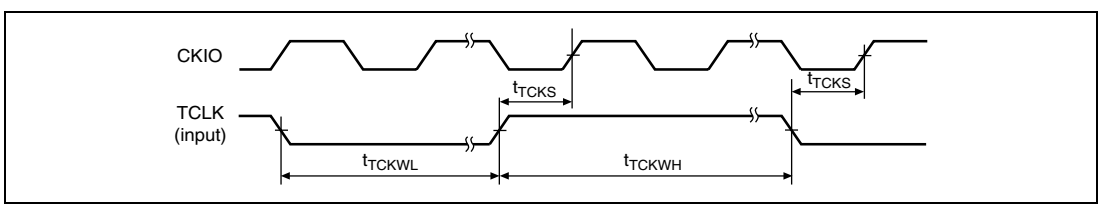


Figure 25.46 TCLK Clock Input Timing

25.3.9 RTC Signal Timing

Table 25.11 RTC Signal Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Module	Item	Symbol	Min	Max	Unit	Figure
RTC	Oscillation settling time	t_{ROSC}	3	—	s	25.47

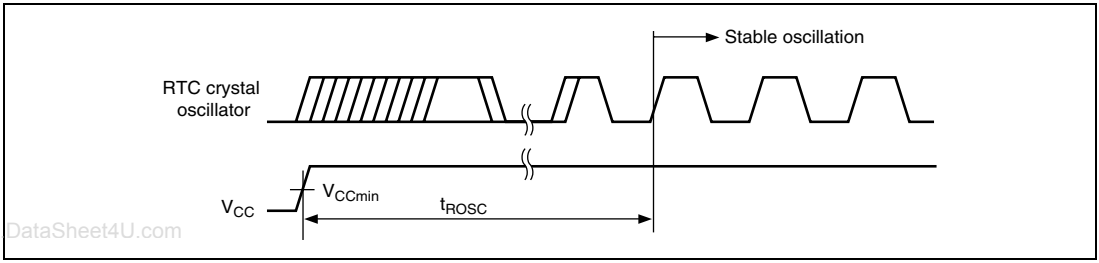


Figure 25.47 Oscillation Settling Time when RTC Crystal Oscillator is Turned On

25.3.10 16-Bit Timer Pulse Unit (TPU) Signal Timing

Table 25.12 16-Bit Timer Pulse Unit (TPU) Signal Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Item	Symbol	Min	Max	Unit	Figure
Timer output delay time	t_{TOD}	—	15	ns	25.48

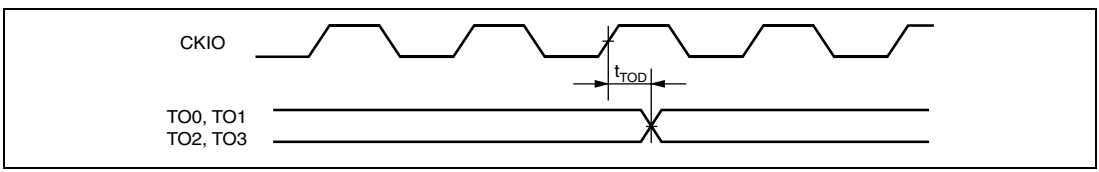


Figure 25.48 TPU Output Timing

25.3.11 SCIF Module Signal Timing

Table 25.13 SCIF Module Signal Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Module	Item		Symbol	Min	Max	Unit	Figure
SCIF0, SCIF2	Input clock cycle	Clock synchronization	t_{Scyc}	12	—	t_{pcyc}	25.49 25.50
		Asynchroniza-tion		4	—		
	Input clock rise time		t_{SCKr}	—	1.5		25.49
	Input clock fall time		t_{SCKf}	—	1.5		
	Input clock pulse width		t_{SCKW}	0.4	0.6	t_{scyc}	
	Transmission data delay time		t_{TXD}	—	3 t_{pcyc}* + 50	ns	25.50
	Receive data setup time (clock synchronization)		t_{RXS}	2 t_{pcyc}*	—		
	Receive data hold time (clock synchronization)		t_{RXH}	2 t_{pcyc}*	—		
	$\overline{RTS}$ delay time		t_{RTSD}	—	100		
	$\overline{CTS}$ setup time (clock synchronization)		t_{CTSS}	100	—		
	$\overline{CTS}$ hold time (clock synchronization)		t_{CTSH}	100	—		

Note: * t_{pcyc} indicates a peripheral clock (Pϕ) cycle.

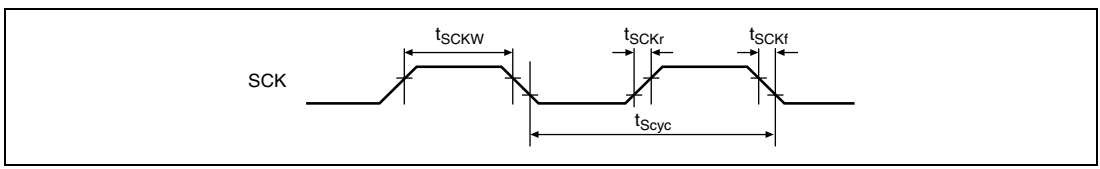


Figure 25.49 SCK Input Clock Timing

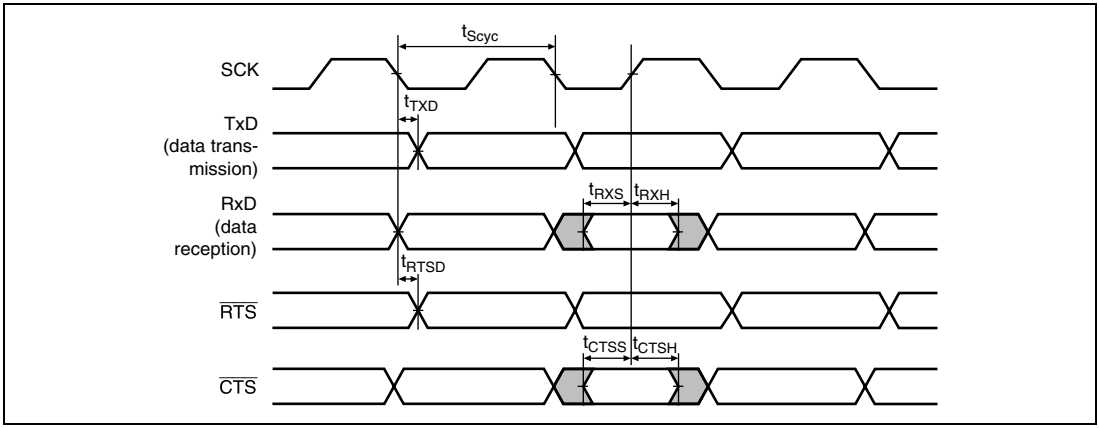


Figure 25.50 SCIF Input/Output Timing in Clock Synchronous Mode

25.3.12 USB Module Signal Timing

Table 25.14 USB Module Clock Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Item	Symbol	Min	Max	Unit	Figure
Frequency (48 MHz)*	t_{FREQ}	47.9	48.1	MHz	25.51
Clock rise time*	t_{R48}	—	4	ns	
Clock fall time*	t_{F48}	—	4	ns	
Duty (t_{HIGH}/t_{LOW})*	t_{DUTY}	90	110	%	
Oscillation settling time	t_{UOSC}	10	—	ms	25.52

Note: *When the USB is operated by supplying a clock to the EXTAL_USB pin from off-chip, the supplied clock must satisfy the above clock specifications.

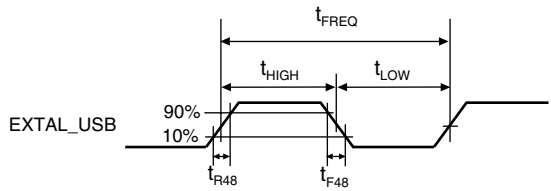


Figure 25.51 USB Clock Timing

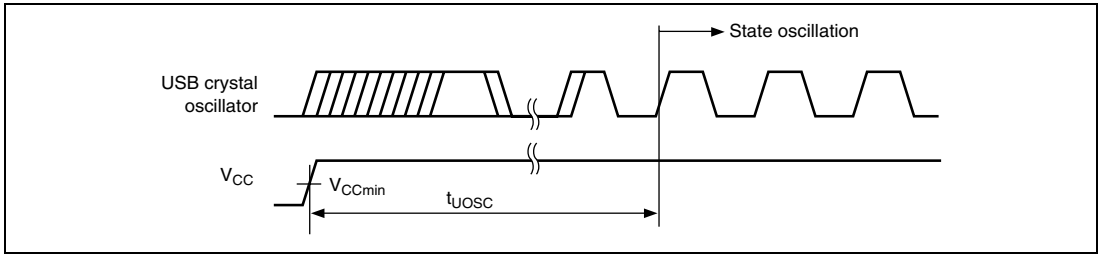


Figure 25.52 Oscillation Settling Time when USB Crystal Oscillator is Turned On

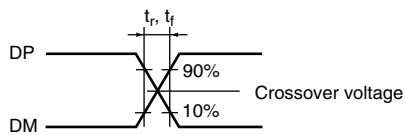
25.3.13 USB Transceiver Timing

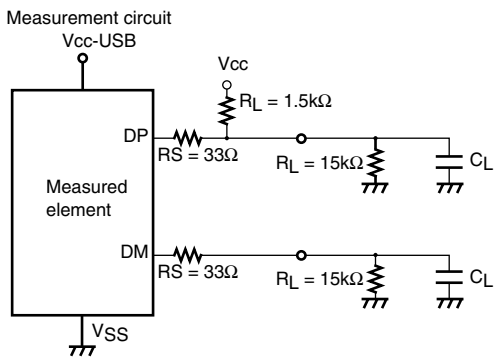
Table 25.15 USB Transceiver Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Item	Symbol	Min	Typ	Max	Unit	Measurement Condition
Rising time	t_r	4	—	20	ns	C_L = 50pF
Falling time	t_f	4	—	20	ns	C_L = 50pF
Rising/falling time ratio	t_r / t_f	90	—	110	%	
Output signal crossover voltage	V_{CRS}	1.3	—	2.0	V	C_L = 50pF

Note: This transceiver complies with the full-speed specifications.





1. t_r and t_f are judged by the time taken for the transitions between 10% and 90% amplitude.
2. The electrostatic capacitance, C_L, includes the floating capacitance of the wiring connection and the input capacitance of the probe.

25.3.14 Port Input/Output Timing

Table 25.16 Port Input/Output Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Module	Item		Symbol	Min	Max	Unit	Figure
Port	Output data delay time		t_{PORTD}	—	17	ns	25.53
	Input data setup time	B:P clock ratio = 1:1	t_{PORTS}	15	—		
		B:P clock ratio = 2:1		t_{cyc}+15	—		
		B:P clock ratio = 4:1		$3 \times t_{cyc}$+15	—		
	Input data hold time		t_{PORTH}	8	—		

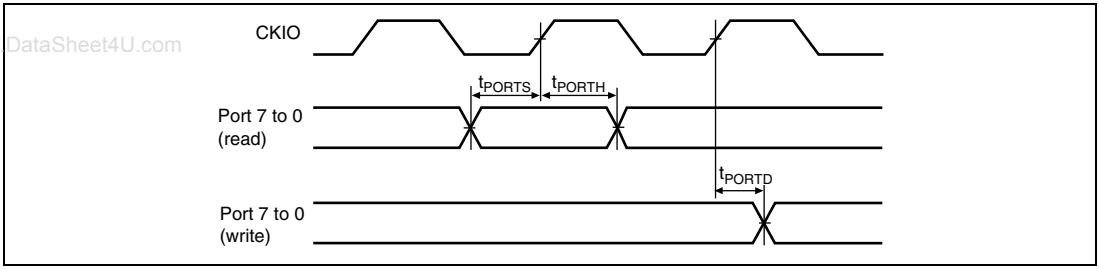


Figure 25.53 I/O Port Timing

25.3.15 H-UDI Related Pin Timing

Table 25.17 H-UDI Related Pin Timing

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Item	Symbol	Min	Max	Unit	Figure
TCK cycle time	t_{TCKcyc}	50	—	ns	25.54, 25.56
TCK high-pulse width	t_{TCKH}	12	—	ns	25.54
TCK low-pulse width	t_{TCKL}	12	—	ns	
TCK rise/fall time	t_{TCKf}	—	4	ns	
$\overline{TRST}$ setup time	t_{TRSTS}	12	—	ns	25.55
$\overline{TRST}$ hold time	t_{TRSTH}	50	—	t_{cyc}	
TDI setup time	t_{TDIS}	10	—	ns	25.56
TDI hold time	t_{TDIH}	10	—	ns	
TMS setup time	t_{TMSS}	10	—	ns	
TMS hold time	t_{TMSH}	10	—	ns	
TDO delay time	t_{TDOD}	—	15	ns	
$\overline{ASEMD0}$ setup time	$t_{ASEMD0S}$	12	—	ns	25.57
$\overline{ASEMD0}$ hold time	$t_{ASEMD0H}$	12	—	ns	

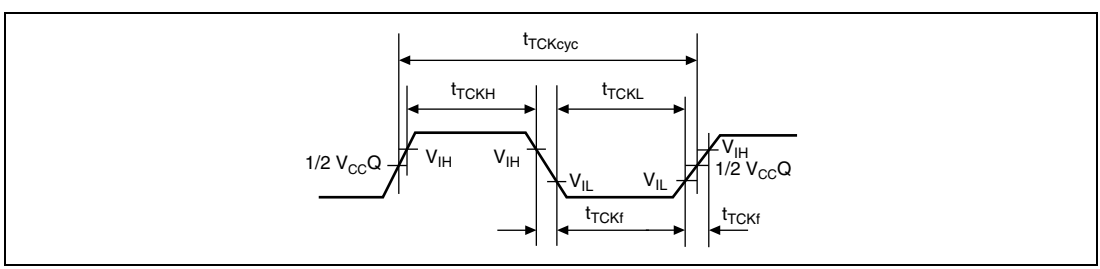


Figure 25.54 TCK Input Timing

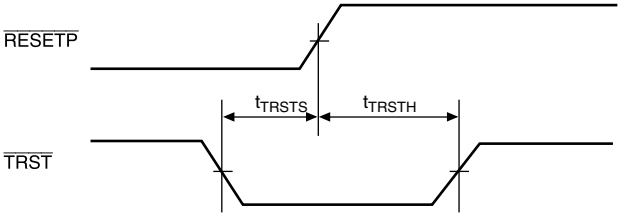


Figure 25.55 $\overline{\text{TRST}}$ Input Timing (Reset Hold)

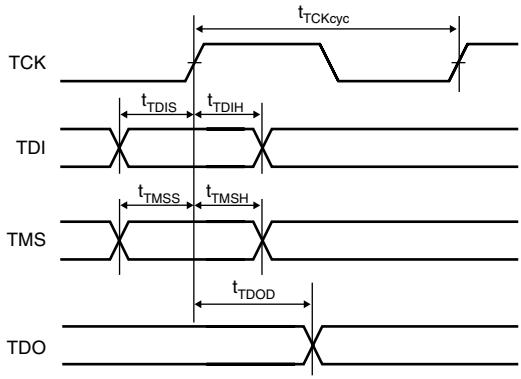


Figure 25.56 H-UDI Data Transfer Timing

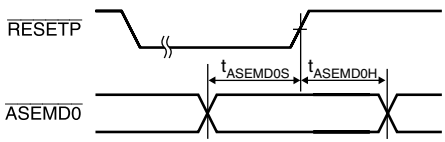
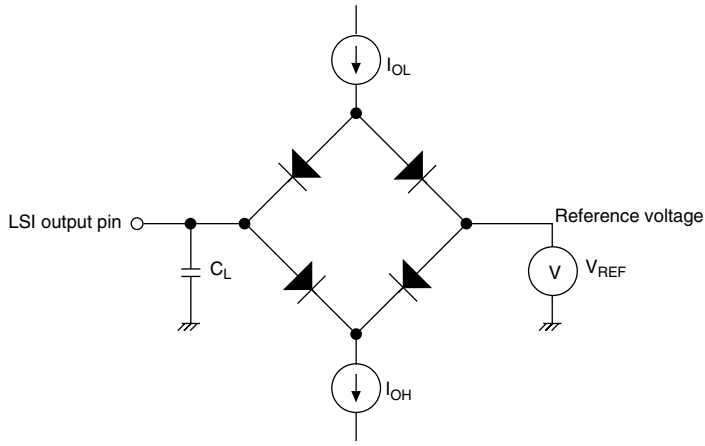


Figure 25.57 $\overline{\text{ASEMD0}}$ Input Timing

25.3.16 AC Characteristics Measurement Conditions

- I/O signal reference level: $V_{CC}Q/2$ ($V_{CC}Q$ = 3.0 to 3.6 V, V_{CC} = 1.4 to 1.6 V)
- Input pulse level: $V_{SS}Q$ to 3.0 V (where $\overline{\text{RESETP}}$, $\overline{\text{RESETM}}$, $\overline{\text{ASEMD0}}$, NMI, IRQ5 to IRQ0, CKIO, and MD6 to MD0 are within $V_{SS}Q$ to $V_{CC}Q$)
- Input rise and fall times: 1 ns



Notes: 1. C_L is the total value that includes the capacitance of measurement instruments, etc., and is set as follows for each pin.
30 pF: CKIO, $\overline{\text{RASU/L}}$, $\overline{\text{CASU/L}}$, $\overline{\text{CS0}}$, $\overline{\text{CS2}}$ to $\overline{\text{CS6B}}$, $\overline{\text{BACK}}$
50 pF: All other pins
2. I_{OL} =1.6 mA, I_{OH} = –200µA

Figure 25.58 Output Load Circuit

25.4 A/D Converter Characteristics

Table 25.18 lists the A/D converter characteristics.

Table 25.18 A/D Converter Characteristics

(Conditions: $V_{CC}Q = V_{CC}$-RTC = V_{CC}-USB = 3.0 to 3.6 V, $V_{CC} = V_{CC}$-PLL1 = V_{CC}-PLL2 = 1.4 to 1.6 V, AV_{CC} = 3.0 to 3.6 V, $V_{SS}Q = V_{SS} = V_{SS}$-RTC = V_{SS}-USB = V_{SS}-PLL1 = V_{SS}-PLL2 = AV_{SS} = 0 V, T_a = –20 to 75°C)

Item	Min	Typ	Max	Unit
Resolution	10	10	10	bits
Conversion time	8.5	—	—	µs
Analog input capacitance	—	—	20	pF
Permissible signal-source impedance (single-source)	—	—	5	kΩ
Nonlinearity error	—	—	±3.0	LSB
Offset error	—	—	±2.0	LSB
Full-scale error	—	—	±2.0	LSB
Quantization error	—	—	±0.5	LSB
Absolute accuracy	—	—	±4.0	LSB

Appendix

A. I/O Port States in Each Processing State

Table A.1 I/O Port States in Each Processing State

		Reset		Power-Down States		Bus		
Category	Pin	Power-on Reset	Manual Reset	Software Standby	Sleep	Mastership Released	I/O	Handling of Unused Pins
Clock	EXTAL	I	I	I	I	I	I	Pull-up
	XTAL	O	O	O	O	O	O	Open
	EXTAL2	I	I	I	I	I	I	Pull-up
	XTAL2	O	O	O	O	O	O	Open
	CKIO	I O*1	I O*1	I O*1	I O*1	I O*1	I O	Open
System control	$\overline{\text{RESETP}}$	I	I	I	I	I	I	Must be used
	$\overline{\text{RESETM}}$	I	I	I	I	I	I	Pull-up
	$\overline{\text{BREQ}}$/PTG[6]	Z	i P*2	i K*3	I P*2	I	I/IO	Pull-up
	$\overline{\text{BACK}}$/PTG[5]	O	O P*2	O K*3	O P*2	L P*2	O/IO	Open
	MD6	I	i	Z	i	i	I	Pull-down
	MD[2:0]	I	i	i	i	i	I	Must be used
	MD[5:3]	I	i	Z	i	i	I	Must be used
	CA	I	I	I	I	I	I	Pull-up
	STATUS0/ PTE[4]/$\overline{\text{RTS0}}$	H	H P*2 Z*6	H K*3 Z*6	L P*2 O	L P*2 O	O/IO/ O	Open
	STATUS1/ PTE[5]/$\overline{\text{CTS0}}$	H	H P*2 Z*6	L K*3 Z*7	H P*2 I	L P*2 I	O/IO/ I	Open
Interrupt	IRQ[3:0]/ $\overline{\text{IRL[3:0]}}$/ PTH[3:0]	Z	I P*2	I K*3	I P*2	I P*2	I/I/IO	Pull-up
	IRQ4/PTH[4]	Z	I P*2	I K*3	I P*2	I P*2	I/IO	Pull-up
	IRQ5/PTE[2]	Z	I P*2	I K*3	I P*2	I P*2	I/IO	Pull-up
	NMI	I	I	I	I	I	I	Pull-up
Address	A[25:19,0]/ PTK[7:0]	O	O P*2	ZO*8K*3	O P*2	Z P*2	O/IO	Open
	A[18:1]	O	O	ZO*8	O	Z	O	Open

Category	Pin	Reset		Power-Down States		Bus Mastership Released	I/O	Handling of Unused Pins
		Power-on Reset	Manual Reset	Software Standby	Sleep			
Data	D[15:0]	Z	Z	Z	IO	Z	IO	Pull-up
	D[23:16]/ PTA[7:0]/ PINT[7:0]	Z	Z P*[2]	Z P*[2]	IO P*[2]	Z P*[2]	IO/IO /I	Pull-up
	D[31:24]/ PTB[7:0]/ PINT[15:8]	Z	Z P*[2]	Z P*[2]	IO P*[2]	Z P*[2]	IO/IO /I	Pull-up
Bus control	$\overline{CS0}$	H	O	ZH*[6]	O	Z	O	Open
	$\overline{CS2}$/PTC[3]	H	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/IO	Open
	$\overline{CS3}$/PTC[4]	H	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/IO	Open
	$\overline{CS4}$/PTC[5]	H	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/IO	Open
	$\overline{CS5A}$/PTC[6]	Z	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/IO	Pull-up
	$\overline{CS5B}$/PTD[6]	Z	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/IO	Pull-up
	$\overline{CS6A}$/PTC[7]	Z	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/IO	Pull-up
	$\overline{CS6B}$/PTD[7]	Z	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/IO	Pull-up
	$\overline{BS}$/PTC[0]	H	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/IO	Open
	$\overline{RASL}$/PTD[0]	H	O P*[2]	ZH*[6] K*[3]	O P*[2]	ZH*[6] P*[2]	O/IO	Open
	$\overline{RASU}$/PTD[1]	Z	O P*[2]	ZH*[6] K*[3]	O P*[2]	ZH*[6] P*[2]	O/IO	Pull-up
	$\overline{CASL}$/PTD[2]	H	O P*[2]	ZH*[6] K*[3]	O P*[2]	ZH*[6] P*[2]	O/IO	Open
	$\overline{CASU}$/PTD[3]	Z	O P*[2]	ZH*[6] K*[3]	O P*[2]	ZH*[6] P*[2]	O/IO	Pull-up
	$\overline{WE0}$/DQMLL	H	O	ZH*[6]	O	Z	O/O	Open
	$\overline{WE1}$/DQMLU	H	O	ZH*[6]	O	Z	O/O	Open
	$\overline{WE2}$/DQMUL/ PTC[1]	H	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/O/I O	Open
	$\overline{WE3}$/DQMUU/ $\overline{AH}$/PTC[2]	H	O P*[2]	ZH*[6] K*[3]	O P*[2]	Z P*[2]	O/O/ O/IO	Open
	RD/$\overline{WR}$	H	O	ZH*[6]	O	Z	O	Open
	$\overline{RD}$	H	O	ZH*[6]	O	Z	O	Open
	CKE/PTD[4]	H	O P*[2]	OK*[3]	O P*[2]	OP*[2]	O/IO	Open
	$\overline{WAIT}$/PTG[7]	I	I P*[2]	I K*[3]	I P*[2]	I P*[2]	I/IO	Pull-up

Category	Pin	Reset		Power-Down States		Bus Mastership Released	I/O	Handling of Unused Pins
		Power-on Reset	Manual Reset	Software Standby	Sleep			
DMAC	DREQ0/ PTH[5]	Z	Z P*2	Z K*3	I P*2	I P*2	I/IO	Pull-up
	DACK0/ PTE[0]	V	O P*2	Z K*3	O P*2	O P*2	O/IO	Open
	TEND0/ PTE[3]	V	O P*2	Z K*3	O P*2	O P*2	O/IO	Open
	DREQ1/ PTH[6]	Z	Z P*2	Z K*3	I P*2	I P*2	I/IO	Pull-up
	DACK1/ PTE[1]	V	O P*2	Z K*3	O P*2	O P*2	O/IO	Open
Timer	TCLK/PTE[6]	V	I P*2	Z K*3	I P*2	I P*2	I/IO	Open
SCIF	RxD0/ SCPT[0]/IrRX	Z	Z I*4	Z	I	I	I/I/I	Pull-up
	TxD0/ SCPT[0]/IrTX	Z	Z O*5	Z O*5	O	O	O/O/ O	Open
	SCK0/ SCPT[1]	Z	Z P*2	Z K*3	IO P*2	IO P*2	IO/IO	Pull-up
	RxD2/ SCPT[2]	Z	Z I*4	Z	I	I	I/I	Pull-up
	TxD2/ SCPT[2]	Z	Z O*5	Z O*5	O	O	O/O	Open
	SCK2/ SCPT[3]	Z	Z P*2	Z K*3	IO P*2	IO P*2	IO/IO	Pull-up
	$\overline{\text{RTS2}}$/ SCPT[4]	V	Z P*2	Z K*3	O P	O P	O/IO	Open
	$\overline{\text{CTS2}}$/ SCPT[5]	Z	Z P*2	Z K*3	I P*2	I P*2	I/IO	Pull-up
Analog	AN[3:0]/ PTL[3:0]	i	Z I*4	i	I	I	I/I	Open
USB	VBUS/ PTM[6]	V	I P*2	Z K*2	I P*2	I P*2	I/IO	Open
	SUSPND/ PTN[0]	V	O P*2	O K*3	O P*2	O P*2	O/IO	Open
	TXENL/ PTN[1]	V	O P*2	O K*3	O P*2	O P*2	O/IO	Open
	XVDATA/ PTN[2]	V	I P*2	V K*3	I P*2	I P*2	I/IO	Open

Category	Pin	Reset		Power-Down States		Bus Mastership Released	I/O	Handling of Unused Pins
		Power-on Reset	Manual Reset	Software Standby	Sleep			
USB	TXDMNS/ PTN[3]	V	O P*2	O K*3	O P*2	O P*2	O/IO	Open
	TXDPLS/ PTN[4]	V	O P*2	O K*3	O P*2	O P*2	O/IO	Open
	DMNS/ PTN[5]	V	I P*2	V K*3	I P*2	I P*2	I/IO	Open
	DPLS/PTN[6]	V	I P*2	V K*3	I P*2	I P*2	I/IO	Open
	EXTAL_USB	I	I	i	I	I	I	Pull-up
	XTAL_USB	O	O	O	O	O	O	Open
	D+	Z	IO*9	Z	IO*9	IO*9	IO	Open
	D-	Z	IO*9	Z	IO*9	IO*9	IO	Open
Port	NF/PTD[5]	I	I	Z	I	I	I/I	Pull-up
	PTE[7]	V	P	K	P	P	IO	Open
	NF/PTJ[7]	L	O	O	O	O	O/O	Open
	NF/PTJ[6:0]	H	O	O	O	O	O/O	Open
	NF/PTM[4]	I	I	Z	I	I	I/I	Pull-up
	PTM[3:0]	V	P	K	P	P	IO	Open
	PTN[7]	V	P	K	P	P	IO	Open
Advanced user debugger	AUDSYNC/ PTF[4]	V/V*10	O P*2	O K*3	O P*2	O P*2	O/IO	Open
	AUDATA[3:0]/ PTF[3:0]/ TO[3:0]	V/V*10	O P*2 Z*8	O K*3 Z*8	O P*2	O P*2	O/IO/ O	Open
	AUDCK/ PTG[4]	O/V*10	O P*2	O K*3	O P*2	O P*2	O/IO	Open
Hitachi user debugg-ing interface	TDI/PTG[0]	I*11	I*11 P*2	i*11 K*3	I*11 P*2	I*11 P*2	I/IO	Open
	TCK/PTG[1]	I*11	I*11 P*2	i*11 K*3	I*11 P*2	I*11 P*2	I/IO	Open
	TMS/PTG[2]	I*11	I*11 P*2	i*11 K*3	I*11 P*2	I*11 P*2	I/IO	Open
	$\overline{\text{TRST}}$/PTG[3]	I*11	I*11 P*2	i*11 K*3	I*11 P*2	I*11 P*2	I/IO	Must be used
	TDO/PTF[5]	OZ	O P*2	Z K*3	O P*2	O P*2	O/IO	Open
	$\overline{\text{ASEBRKAK}}$/ PTF[6]	V/V*10	O P*2	O K*3	O P*2	O P*2	O/IO	Open
	$\overline{\text{ASEMD0}}$/ PTF[7]	I*11	I*11 P*2	V K*3	I*11 P*2	I*11 P*2	I/IO	Must be used

Category	Pin	Reset		Power-Down States		Bus Mastership Released	I/O	Handling of Unused Pins
		Power-on Reset	Manual Reset	Software Standby	Sleep			
Power supply voltage	Vcc_USB	—	—	—	—	—	—	VccQ
	Vss_USB	—	—	—	—	—	—	VssQ
	Vcc-RTC	—	—	—	—	—	—	VccQ
	Vss-RTC	—	—	—	—	—	—	VssQ
	AVcc	—	—	—	—	—	—	VccQ
	AVss	—	—	—	—	—	—	VssQ
	VccQ	—	—	—	—	—	—	VccQ
	VssQ	—	—	—	—	—	—	VssQ
	Vcc-PLL1	—	—	—	—	—	—	Vcc*[12]
	Vss-PLL1	—	—	—	—	—	—	Vss*[12]
	Vcc-PLL2	—	—	—	—	—	—	Vcc*[12]
	Vss-PLL2	—	—	—	—	—	—	Vss*[12]
	Vcc	—	—	—	—	—	—	Vcc
	Vss	—	—	—	—	—	—	Vss

Legend:

I : Input state

i : Input state (however, input is fixed by the internal logic.)

O : Output state (high or low, undefined)

L : Low-level output

H : High-level output

Z : High impedance (input/output buffer off)

V : Input/output buffer off, pull-up on

K : The high-level output or low-level output/input becomes high impedance.

P : Input or output depending on the register settings.

Notes:

*1 Depends on clock mode.

*2 The state is P when the port function is used.

*3 The state is K when the port function is used.

*4 The state is I when the port function is used.

*5 The state is O when the port function is used.

*6 The state is Z or H depending on the register settings.

*7 The state is Z or L depending on the register settings.

*8 The state is Z or O depending on the register settings.

*9 The state is i when the USB is not used.

*10 The initial value (power-on reset) changes depending on the input level of the $\overline{\text{ASEMD0}}$ pin. First, this list shows the value when the $\overline{\text{ASEMD0}}$ pin is 0, then the value when the $\overline{\text{ASEMD0}}$ pin is 1.

*11 Pull-up MOS open

*12 To avoid the power friction, Vcc-PLL1, Vcc-PLL2, and Vss-PLL1, Vss-PLL2, and other digital Vcc, Vss should be arranged in three independent patterns from the board power-supply source.

Connect the pull-up pins shown in table A.1 to 3.3 V power through the pull-up resistor.

B. Package Dimensions

Figures B.1 and B.2 show the package dimensions.

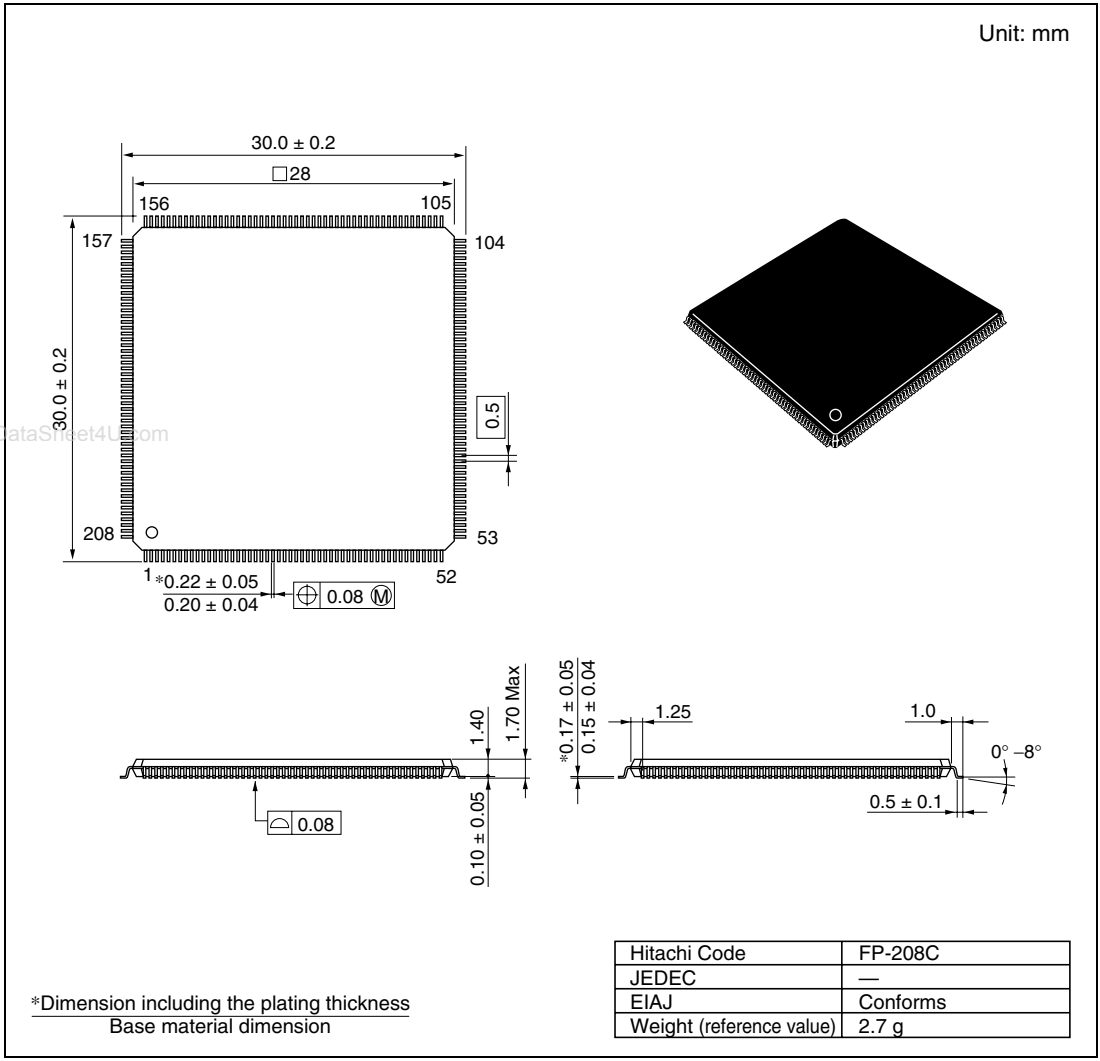


Figure B.1 Package Dimensions (FP-208C)

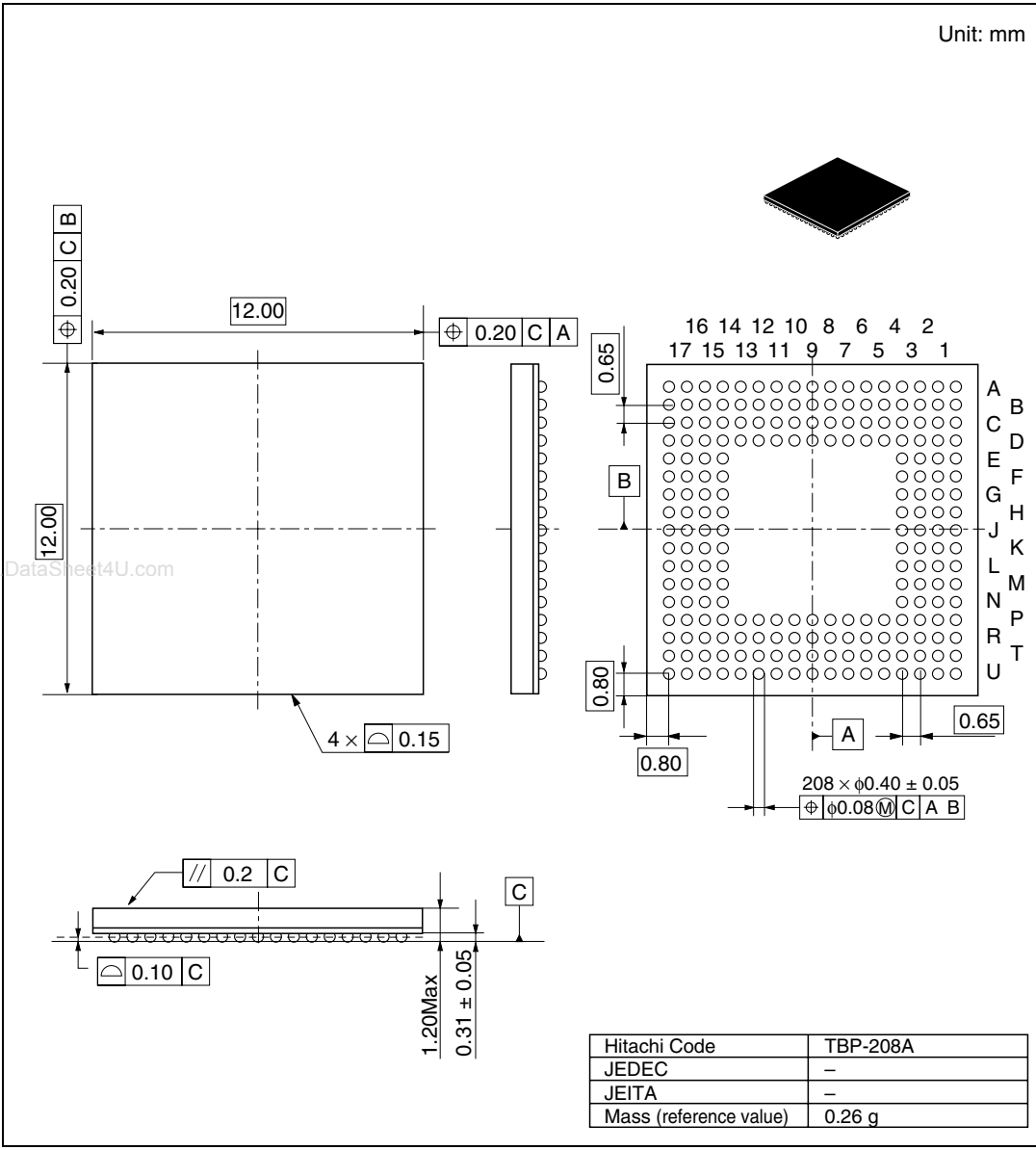


Figure B.2 Package Dimensions (TBP-208A)

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