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H8/3003

Hardware Manual

The revision list can be viewed directly by clicking the title page.

The revision list summarizes the locations of revisions and additions. Details should always be checked by referring to the relevant text.

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Preface

The H8/3003 is a high-performance microcontroller that integrates system supporting functions together with an H8/300H CPU core.

The H8/300H CPU has a 32-bit internal architecture with sixteen 16-bit general registers, and a concise, optimized instruction set designed for speed. It can address a 16-Mbyte linear address space.

The on-chip system supporting functions include RAM, a 16-bit integrated timer unit (ITU), a programmable timing pattern controller (TPC), a watchdog timer (WDT), a serial communication interface (SCI), an A/D converter, I/O ports, a direct memory access controller (DMAC), a refresh controller, and other facilities.

The four operating modes offer a choice of data bus width and address space size, enabling the H8/3003 to adapt quickly and flexibly to a variety of conditions.

This manual describes the H8/3003 hardware. For details of the instruction set, refer to the H8/300H Programming Manual.

Contents

Section 1 Overview 1
1.1 Overview 1
1.2 Block Diagram 5
1.3 Pin Description 6
1.3.1 Pin Arrangement 6
1.3.2 Pin Functions 7
1.4 Pin Functions 11

Section 2 CPU 17
2.1 Overview 17
2.1.1 Features 17
2.1.2 Differences from H8/300 CPU 18
2.2 CPU Operating Modes 19
2.3 Address Space 20
2.4 Register Configuration 21
2.4.1 Overview 21
2.4.2 General Registers 22
2.4.3 Control Registers 23
2.4.4 Initial CPU Register Values 24
2.5 Data Formats 25
2.5.1 General Register Data Formats 25
2.5.2 Memory Data Formats 26
2.6 Instruction Set 28
2.6.1 Instruction Set Overview 28
2.6.2 Instructions and Addressing Modes 29
2.6.3 Tables of Instructions Classified by Function 30
2.6.4 Basic Instruction Formats 40
2.6.5 Notes on Use of Bit Manipulation Instructions 41
2.7 Addressing Modes and Effective Address Calculation 41
2.7.1 Addressing Modes 41
2.7.2 Effective Address Calculation 44
2.8 Processing States 48
2.8.1 Overview 48
2.8.2 Program Execution State 49
2.8.3 Exception-Handling State 49
2.8.4 Exception-Handling Sequences 51
2.8.5 Bus-Released State 52
2.8.6 Reset State 52
2.8.7 Power-Down State 52

2.9 Basic Operational Timing 53
2.9.1 Overview 53
2.9.2 On-Chip Memory Access Timing 53
2.9.3 On-Chip Supporting Module Access Timing 55
2.9.4 Access to External Address Space 56

Section 3 MCU Operating Modes 57
3.1 Overview 57
3.1.1 Operating Mode Selection 57
3.1.2 Register Configuration 58
3.2 Mode Control Register (MDCR) 59
3.3 System Control Register (SYSCR) 60
3.4 Operating Mode Descriptions 62
3.4.1 Mode 1 62
3.4.2 Mode 2 62
3.4.3 Mode 3 62
3.4.4 Mode 4 62
3.5 Pin Functions in Each Operating Mode 63
3.6 Memory Map in Each Operating Mode 63

Section 4 Exception Handling 65
4.1 Overview 65
4.1.1 Exception Handling Types and Priority 65
4.1.2 Exception Handling Operation 65
4.1.3 Exception Vector Table 66
4.2 Reset 67
4.2.1 Overview 67
4.2.2 Reset Sequence 67
4.2.3 Interrupts after Reset 69
4.3 Interrupts 70
4.4 Trap Instruction 71
4.5 Stack Status after Exception Handling 71
4.6 Notes on Stack Usage 72

Section 5 Interrupt Controller 73
5.1 Overview 73
5.1.1 Features 73
5.1.2 Block Diagram 74
5.1.3 Pin Configuration 75
5.1.4 Register Configuration 75

5.2 Register Descriptions 76
5.2.1 System Control Register (SYSCR) 76
5.2.2 Interrupt Priority Registers A and B (IPRA, IPRB) 77
5.2.3 IRQ Status Register (ISR) 84
5.2.4 IRQ Enable Register (IER) 85
5.2.5 IRQ Sense Control Register (ISCR) 86
5.3 Interrupt Sources 87
5.3.1 External Interrupts 87
5.3.2 Internal Interrupts 88
5.3.3 Interrupt Vector Table 88
5.4 Interrupt Operation 91
5.4.1 Interrupt Handling Process 91
5.4.2 Interrupt Sequence 96
5.4.3 Interrupt Response Time 97
5.5 Usage Notes 98
5.5.1 Contention between Interrupt and Interrupt-Disabling Instruction 98
5.5.2 Instructions that Inhibit Interrupts 99
5.5.3 Interrupts during EEPMOV Instruction Execution 99

Section 6 Bus Controller 101
6.1 Overview 101
6.1.1 Features 101
6.1.2 Block Diagram 102
6.1.3 Input/Output Pins 103
6.1.4 Register Configuration 103
6.2 Register Descriptions 104
6.2.1 Bus Width Control Register (ABWCR) 104
6.2.2 Access State Control Register (ASTCR) 105
6.2.3 Wait Control Register (WCR) 106
6.2.4 Wait State Control Enable Register (WCER) 107
6.2.5 Bus Release Control Register (BRCR) 108
6.3 Operation 109
6.3.1 Area Division 109
6.3.2 Chip Select Signals 111
6.3.3 Data Bus 112
6.3.4 Bus Control Signal Timing 113
6.3.5 Wait Modes 121
6.3.6 Interconnections with Memory (Example) 127
6.3.7 Bus Arbiter Operation 129
6.4 Usage Notes 132
6.4.1 Connection to Dynamic RAM and Pseudo-Static RAM 132

6.4.2 Register Write Timing 132
6.4.3 $\overline{\text{BREQ}}$ Input Timing 133

Section 7 Refresh Controller 135
7.1 Overview 135
7.1.1 Features 135
7.1.2 Block Diagram 136
7.1.3 Input/Output Pins 137
7.1.4 Register Configuration 137
7.2 Register Descriptions 138
7.2.1 Refresh Control Register (RFSHCR) 138
7.2.2 Refresh Timer Control/Status Register (RTMCSR) 141
7.2.3 Refresh Timer Counter (RTCNT) 143
7.2.4 Refresh Time Constant Register (RTCOR) 143
7.3 Operation 144
7.3.1 Area Division 144
7.3.2 DRAM Refresh Control 145
7.3.3 Pseudo-Static RAM Refresh Control 160
7.3.4 Interval Timing 165
7.4 Interrupt Source 171
7.5 Usage Notes 171

Section 8 DMA Controller 173
8.1 Overview 173
8.1.1 Features 173
8.1.2 Block Diagram 174
8.1.3 Functional Overview 175
8.1.4 Input/Output Pins 176
8.1.5 Register Configuration 176
8.2 Register Descriptions (1) (Short Address Mode) 179
8.2.1 Memory Address Registers (MAR) 180
8.2.2 I/O Address Registers (IOAR) 181
8.2.3 Execute Transfer Count Registers (ETCR) 181
8.2.4 Data Transfer Control Registers (DTCR) 183
8.3 Register Descriptions (2) (Full Address Mode) 187
8.3.1 Memory Address Registers (MAR) 187
8.3.2 I/O Address Registers (IOAR) 187
8.3.3 Execute Transfer Count Registers (ETCR) 188
8.3.4 Data Transfer Control Registers (DTCR) 190
8.4 Operation 196
8.4.1 Overview 196

8.4.2 I/O Mode ... 198
8.4.3 Idle Mode ... 200
8.4.4 Repeat Mode ... 203
8.4.5 Normal Mode ... 206
8.4.6 Block Transfer Mode ... 209
8.4.7 DMAC Activation ... 214
8.4.8 DMAC Bus Cycle ... 216
8.4.9 Multiple-Channel Operation ... 222
8.4.10 External Bus Requests, Refresh Controller, and DMAC ... 225
8.4.11 NMI Interrupts and DMAC ... 226
8.4.12 Aborting a DMA Transfer ... 227
8.4.13 Exiting Full Address Mode ... 228
8.4.14 DMAC States in Reset State, Standby Modes, and Sleep Mode ... 229
8.5 Interrupts ... 230
8.6 Usage Notes ... 232
8.6.1 Note on Word Data Transfer ... 232
8.6.2 DMAC Self-Access ... 232
8.6.3 Longword Access to Memory Address Registers ... 232
8.6.4 Note on Full Address Mode Setup ... 232
8.6.5 Note on Activating DMAC by Internal Interrupts ... 233
8.6.6 NMI Interrupts and Block Transfer Mode ... 234
8.6.7 Memory and I/O Address Register Values ... 234
8.6.8 Bus Cycle when Transfer is Aborted ... 235

Section 9 I/O Ports ... 237
9.1 Overview ... 237
9.2 Port 4 ... 240
9.2.1 Overview ... 240
9.2.2 Register Descriptions ... 241
9.2.3 Pin Functions in Each Mode ... 243
9.2.4 Input Pull-Up Transistors ... 244
9.3 Port 5 ... 245
9.3.1 Overview ... 245
9.3.2 Register Descriptions ... 245
9.3.3 Pin Functions in Each Mode ... 248
9.3.4 Input Pull-Up Transistors ... 249
9.4 Port 6 ... 250
9.4.1 Overview ... 250
9.4.2 Register Descriptions ... 250
9.4.3 Pin Functions ... 252

9.5 Port 7 252
9.5.1 Overview 252
9.5.2 Register Description 253
9.6 Port 8 254
9.6.1 Overview 254
9.6.2 Register Descriptions 254
9.6.3 Pin Functions 256
9.7 Port 9 257
9.7.1 Overview 257
9.7.2 Register Descriptions 257
9.7.3 Pin Functions 259
9.8 Port A 261
9.8.1 Overview 261
9.8.2 Register Descriptions 261
9.8.3 Pin Functions 263
9.9 Port B 268
9.9.1 Overview 268
9.9.2 Register Descriptions 268
9.9.3 Pin Functions 270
9.10 Port C 276
9.10.1 Overview 276
9.10.2 Register Descriptions 276
9.10.3 Pin Functions 278

Section 10 16-Bit Integrated Timer Unit (ITU) 281
10.1 Overview 281
10.1.1 Features 281
10.1.2 Block Diagrams 284
10.1.3 Input/Output Pins 289
10.1.4 Register Configuration 290
10.2 Register Descriptions 293
10.2.1 Timer Start Register (TSTR) 293
10.2.2 Timer Synchro Register (TSNC) 294
10.2.3 Timer Mode Register (TMDR) 296
10.2.4 Timer Function Control Register (TFCR) 299
10.2.5 Timer Output Master Enable Register (TOER) 301
10.2.6 Timer Output Control Register (TOCR) 304
10.2.7 Timer Counters (TCNT) 305
10.2.8 General Registers (GRA, GRB) 306
10.2.9 Buffer Registers (BRA, BRB) 307
10.2.10 Timer Control Registers (TCR) 308

10.2.11 Timer I/O Control Register (TIOR) ... 310
10.2.12 Timer Status Register (TSR) ... 312
10.2.13 Timer Interrupt Enable Register (TIER) ... 315
10.3 CPU Interface ... 317
10.3.1 16-Bit Accessible Registers ... 317
10.3.2 8-Bit Accessible Registers ... 319
10.4 Operation ... 321
10.4.1 Overview ... 321
10.4.2 Basic Functions ... 322
10.4.3 Synchronization ... 332
10.4.4 PWM Mode ... 334
10.4.5 Reset-Synchronized PWM Mode ... 338
10.4.6 Complementary PWM Mode ... 341
10.4.7 Phase Counting Mode ... 351
10.4.8 Buffering ... 353
10.4.9 ITU Output Timing ... 360
10.5 Interrupts ... 362
10.5.1 Setting of Status Flags ... 362
10.5.2 Clearing of Status Flags ... 364
10.5.3 Interrupt Sources and DMA Controller Activation ... 365
10.6 Usage Notes ... 366

Section 11 Programmable Timing Pattern Controller ... 381
11.1 Overview ... 381
11.1.1 Features ... 381
11.1.2 Block Diagram ... 382
11.1.3 TPC Pins ... 383
11.1.4 Registers ... 384
11.2 Register Descriptions ... 385
11.2.1 Port A Data Direction Register (PADDR) ... 385
11.2.2 Port A Data Register (PADR) ... 385
11.2.3 Port B Data Direction Register (PBDDR) ... 386
11.2.4 Port B Data Register (PBDR) ... 386
11.2.5 Next Data Register A (NDRA) ... 387
11.2.6 Next Data Register B (NDRB) ... 389
11.2.7 Next Data Enable Register A (NDERA) ... 391
11.2.8 Next Data Enable Register B (NDERB) ... 392
11.2.9 TPC Output Control Register (TPCR) ... 393
11.2.10 TPC Output Mode Register (TPMR) ... 396
11.3 Operation ... 398
11.3.1 Overview ... 398

11.3.2 Output Timing ... 399
11.3.3 Normal TPC Output ... 400
11.3.4 Non-Overlapping TPC Output ... 402
11.3.5 TPC Output Triggering by Input Capture ... 404
11.4 Usage Notes ... 405
11.4.1 Operation of TPC Output Pins ... 405
11.4.2 Note on Non-Overlapping Output ... 405

Section 12 Watchdog Timer ... 407
12.1 Overview ... 407
12.1.1 Features ... 407
12.1.2 Block Diagram ... 408
12.1.3 Pin Configuration ... 408
12.1.4 Register Configuration ... 409
12.2 Register Descriptions ... 410
12.2.1 Timer Counter (TCNT) ... 410
12.2.2 Timer Control/Status Register (TCSR) ... 411
12.2.3 Reset Control/Status Register (RSTCSR) ... 413
12.2.4 Notes on Register Access ... 415
12.3 Operation ... 417
12.3.1 Watchdog Timer Operation ... 417
12.3.2 Interval Timer Operation ... 418
12.3.3 Timing of Setting of Overflow Flag (OVF) ... 419
12.3.4 Timing of Setting of Watchdog Timer Reset Bit (WRST) ... 420
12.4 Interrupts ... 421
12.5 Usage Notes ... 421

Section 13 Serial Communication Interface ... 423
13.1 Overview ... 423
13.1.1 Features ... 423
13.1.2 Block Diagram ... 425
13.1.3 Input/Output Pins ... 426
13.1.4 Register Configuration ... 426
13.2 Register Descriptions ... 427
13.2.1 Receive Shift Register (RSR) ... 427
13.2.2 Receive Data Register (RDR) ... 427
13.2.3 Transmit Shift Register (TSR) ... 428
13.2.4 Transmit Data Register (TDR) ... 428
13.2.5 Serial Mode Register (SMR) ... 429
13.2.6 Serial Control Register (SCR) ... 433
13.2.7 Serial Status Register (SSR) ... 437

13.2.8 Bit Rate Register (BRR) 441
13.3 Operation 450
13.3.1 Overview 450
13.3.2 Operation in Asynchronous Mode 452
13.3.3 Multiprocessor Communication 461
13.3.4 Synchronous Operation 468
13.4 SCI Interrupts 477
13.5 Usage Notes 478

Section 14 A/D Converter 483
14.1 Overview 483
14.1.1 Features 483
14.1.2 Block Diagram 484
14.1.3 Input Pins 485
14.1.4 Register Configuration 486
14.2 Register Descriptions 487
14.2.1 A/D Data Registers A to D (ADDRA to ADDRD) 487
14.2.2 A/D Control/Status Register (ADCSR) 488
14.2.3 A/D Control Register (ADCR) 491
14.3 CPU Interface 492
14.4 Operation 493
14.4.1 Single Mode (SCAN = 0) 493
14.4.2 Scan Mode (SCAN = 1) 495
14.4.3 Input Sampling and A/D Conversion Time 497
14.4.4 External Trigger Input Timing 498
14.5 Interrupts 499
14.6 Usage Notes 499

Section 15 RAM 501
15.1 Overview 501
15.1.1 Block Diagram 501
15.1.2 Register Configuration 502
15.2 System Control Register (SYSCR) 503
15.3 Operation 504

Section 16 Clock Pulse Generator 505
16.1 Overview 505
16.1.1 Block Diagram 505
16.2 Oscillator Circuit 506
16.2.1 Connecting a Crystal Resonator 506
16.2.2 External Clock Input 508

16.3 System Clock Divider (Clock-Halving Version) 510
16.4 Duty Adjustment Circuit (1:1 Version) 510
16.5 Prescalers 510

Section 17 Power-Down State 511
17.1 Overview 511
17.2 Register Configuration 512
17.2.1 System Control Register (SYSCR) 512
17.3 Sleep Mode 514
17.3.1 Transition to Sleep Mode 514
17.3.2 Exit from Sleep Mode 514
17.4 Software Standby Mode 515
17.4.1 Transition to Software Standby Mode 515
17.4.2 Exit from Software Standby Mode 515
17.4.3 Selection of Waiting Time for Exit from Software Standby Mode 516
17.4.4 Sample Application of Software Standby Mode 517
17.4.5 Note 517
17.5 Hardware Standby Mode 518
17.5.1 Transition to Hardware Standby Mode 518
17.5.2 Exit from Hardware Standby Mode 518
17.5.3 Timing for Hardware Standby Mode 518

Section 18 Electrical Characteristics 519
18.1 Absolute Maximum Ratings 519
18.2 Electrical Characteristics 520
18.2.1 DC Characteristics 520
18.2.2 AC Characteristics 529
18.2.3 A/D Conversion Characteristics 536
18.3 Operational Timing 537
18.3.1 Bus Timing 537
18.3.2 Refresh Controller Bus Timing 541
18.3.3 Control Signal Timing 546
18.3.4 Clock Timing 548
18.3.5 TPC and I/O Port Timing 548
18.3.6 ITU Timing 549
18.3.7 SCI Input/Output Timing 550
18.3.8 DMAC Timing 551

Appendix A Instruction Set 553
A.1 Instruction List 553
A.2 Operation Code Map 568
A.3 Number of States Required for Execution 571

Appendix B Register Field 580
B.1 Register Addresses and Bit Names 580
B.2 Register Descriptions 589

Appendix C I/O Port Block Diagrams 668
C.1 Port 4 Block Diagram 668
C.2 Port 5 Block Diagram 669
C.3 Port 6 Block Diagrams 670
C.4 Port 7 Block Diagram 673
C.5 Port 8 Block Diagrams 674
C.6 Port 9 Block Diagrams 677
C.7 Port A Block Diagrams 680
C.8 Port B Block Diagrams 683
C.9 Port C Block Diagrams 687

Appendix D Pin States 691
D.1 Port States in Each Mode 691
D.2 Pin States at Reset 693

Appendix E Timing of Transition to and Recovery from Hardware Standby Mode 696

Appendix F Package Dimensions 697

Major Revisions and Additions in This Version

Page	Item		Description
P96	Figure 5-7	Interrupt Sequence (Mode 2, Two-State Access, Stack in External Memory)	Operation timing amended
P97	Table 5-5	Interrupt Response Time	Table values changed
P125	Figure 6-15	Programmable Wait Mode	Operation timing amended
P132	Figure 6-20	ASTCR Write Timing	Operation timing amended
P166	Figure 7-20	Contention between RTCNT Write and Clear	Operation timing amended
P167	Figure 7-21	Contention between RTCNT Write and Increment	Operation timing amended
P168	Figure 7-22	Contention between RTCOR Write and Compare Match	Address bus amended
P175	Table 8-1	DMAC functional overview	Table contents amended
P207	Figure 8-8	Operation in Normal Mode	Signal descriptions amended
P220	Figure 8-17	Timing of DMAC Activation by Low $\overline{\text{DREQ}}$ Level in Normal Mode	Operation timing amended
P270 to P272	Table 9-16	Port B Pin Functions	Table contents amended
P279	Table 9-18	Port C Pin Functions	Table contents amended
P343	Figure 10-34	Clearing Procedure for Complementary PWM Mode	Description added
P408	Table 12-1	WDT Pin	Note deleted
P458 to P459	Figure 13-7	Sample Flowchart for Receiving Serial Data	Flowchart amended
P480	13.5	Usage Notes	Formula amended
P506	Table 16-1	Damping Resistance Value	Values added to table
P507	Table 16-2	Crystal Resonator Parameters	Values added to table
P509	Table 16-3	Clock Timing	Table values changed
P509	Figure 16-6	External Clock Input Timing	Figure amended

Page	Item		Description
P514	17.3.2	Exit from Sleep Mode Exit by Interrupt	Description amended
P529 to P536	Table 18-4 to 18-8	Electrical Characteristics	Condition values amended
P520 to P526	Table 18-2	DC Characteristics	Values changed and added to table
P529 to P531	Table 18-4	Bus Timing	Values changed
P532	Table 18-5	Refresh Controller Bus Timing	Values changed
P536	Table 18-8	A/D Conversion Characteristics	Values changed
P541	Figure 18-7	DRAM Bus Timing (Read/Write): Three-State Access — 2$\overline{WE}$ Mode —	*added
P543	Figure 18-10	DRAM Bus Timing (Read/Write): Three-State Access — 2$\overline{CAS}$ Mode —	*added
P545	Figure 18-13	PSRAM Bus Timing (Read/Write): Three-State Access	*added
P555	Table A-1	Instruction Set MOV. B Rs, @(d:16, ERd)	Operation amended
	Table A-1	Instruction Set MOV. B Rs, @(d:24, ERd)	Operation amended
P556	Table A-1	Instruction Set MOV. W Rs, @(d:16, ERd)	Operation amended
	Table A-1	Instruction Set MOV. W Rs, @(d:24, ERd)	Operation and number of execution states amended
	Table A-1	Instruction Set MOV. L #xx:32, Rd	Number of execution states amended
	Table A-1	Instruction Set POP, L ERn	Number of execution states amended
P557	Table A-1	Instruction Set PUSH. L ERn	Number of execution states amended
P566	Table A-1	Instruction Set STC	Menmonics amended (3 places)
P575	Table A-3	Number of Cycles per Instruction BSRd:16	Internal operation added
P673	Figure C-4	Port 7 Block Diagram (Pin P7n)	Figure amended

Section 1 Overview

1.1 Overview

The H8/3003 is a microcontroller (MCU) that integrates system supporting functions together with an H8/300H CPU core having an original Hitachi architecture.

The H8/300H CPU has a 32-bit internal architecture with sixteen 16-bit general registers, and a concise, optimized instruction set designed for speed. It can address a 16-Mbyte linear address space. Its instruction set is upward-compatible at the object-code level with the H8/300 CPU, enabling easy porting of software from the H8/300 Series.

The on-chip system supporting functions include RAM, a 16-bit integrated timer unit (ITU), a programmable timing pattern controller (TPC), a watchdog timer (WDT), a serial communication interface (SCI), an A/D converter, I/O ports, a direct memory access controller (DMAC), a refresh controller, and other facilities. Four MCU operating modes offer a choice of data bus width and address space size.

Table 1-1 summarizes the H8/3003 features.

Table 1-1 Features

Feature	Description
CPU	Upward-compatible with the H8/300 CPU at the object-code level
	General-register machine
	• Sixteen 16-bit general registers (also useable as sixteen 8-bit registers or eight 32-bit registers)
	High-speed operation
	• Maximum clock rate: 16 MHz • Add/subtract: 125 ns • Multiply/divide: 875 ns
	Two CPU operating modes
	• Normal mode (64-kbyte address space, not available in the H8/3003) • Advanced mode (16-Mbyte address space)
	Instruction features
	• 8/16/32-bit data transfer, arithmetic, and logic instructions • Signed and unsigned multiply instructions (8 bits × 8 bits, 16 bits × 16 bits) • Signed and unsigned divide instructions (16 bits ÷ 8 bits, 32 bits ÷ 16 bits) • Bit accumulator function • Bit manipulation instructions with register-indirect specification of bit positions

Table 1-1 Features (cont)

Feature	Description
Memory	RAM: 512 bytes
Interrupt controller	• Nine external interrupt pins: NMI, $\overline{IRQ_0}$ to $\overline{IRQ_7}$ • 34 internal interrupts • Three selectable interrupt priority levels
Bus controller	• Address space can be partitioned into eight areas, with independent bus specifications in each area • Chip select output available for each area • 8-bit access or 16-bit access selectable for each area • Two-state or three-state access selectable for each area • Selection of four wait modes • Bus arbitration function
Refresh controller	DRAM refresh • Directly connectable to 16-bit-wide DRAM • CAS-before-RAS refresh • Self-refresh mode selectable Pseudo-static RAM refresh • Self-refresh mode selectable Usable as an interval timer
DMA controller (DMAC)	Short address mode • Maximum eight channels available • Selection of I/O mode, idle mode, or repeat mode • Can be activated by compare match/input capture A interrupts from ITU channels 0 to 3, SCI transmit-data-empty and receive-data-full interrupts, or external requests Full address mode • Maximum four channels available • Selection of normal mode or block transfer mode • Can be activated by compare match/input capture A interrupts from ITU channels 0 to 3, external requests, or auto-request

Table 1-1 Features (cont)

Feature	Description
16-bit integrated timer unit (ITU)	• Five 16-bit timer channels, capable of processing up to 12 pulse outputs or 10 pulse inputs • 16-bit timer counter (channels 0 to 4) • Two multiplexed output compare/input capture pins (channels 0 to 4) • Operation can be synchronized (channels 0 to 4) • PWM mode available (channels 0 to 4) • Phase counting mode available (channel 2) • Buffering available (channels 3 and 4) • Reset-synchronized PWM mode available (channels 3 and 4) • Complementary PWM mode available (channels 3 and 4) • DMAC can be activated by compare match/input capture A interrupt (channels 0 to 3)
Programmable timing pattern controller (TPC)	• Maximum 16-bit pulse output, using ITU as time base • Up to four 4-bit pulse output groups (or one 16-bit group, or two 8-bit groups) • Non-overlap mode available • Output data can be transferred by DMAC
Watchdog timer (WDT), 1 channel	• Reset signal can be generated by overflow • Reset signal can be output externally • Usable as an interval timer
Serial communication interface (SCI), 2 channels	• Selection of asynchronous or synchronous mode • Full duplex: can transmit and receive simultaneously • On-chip baud-rate generator
A/D converter	• Resolution: 10 bits • Eight channels, with selection of single or scan mode • Variable analog conversion voltage range • Sample-and-hold function • Can be externally triggered
I/O ports	• 50 input/output pins • 8 input-only pins

Table 1-1 Features (cont)

<table>
<tr><th>Feature</th><th>Description</th></tr>
<tr><td>Operating modes</td><td>Four MCU operating modes
<table>
<tr><th>Mode</th><th>Address Space</th><th>Address Pins</th><th>Initial Bus Width</th><th>Max. Bus Width</th></tr>
<tr><td>Mode 1</td><td>1 Mbyte</td><td>A_0 to A_{19}</td><td>8 bits</td><td>16 bits</td></tr>
<tr><td>Mode 2</td><td>1 Mbyte</td><td>A_0 to A_{19}</td><td>16 bits</td><td>16 bits</td></tr>
<tr><td>Mode 3</td><td>16 Mbyte</td><td>A_0 to A_{23}</td><td>8 bits</td><td>16 bits</td></tr>
<tr><td>Mode 4</td><td>16 Mbyte</td><td>A_0 to A_{23}</td><td>16 bits</td><td>16 bits</td></tr>
</table></td></tr>
<tr><td>Power-down state</td><td>• Sleep mode
• Software standby mode
• Hardware standby mode</td></tr>
<tr><td>Other features</td><td>• On-chip clock oscillator</td></tr>
<tr><td>Product lineup</td><td>
<table>
<tr><th>Model</th><th>Package</th><th>Oscillator</th><th>Power Supply Voltage</th></tr>
<tr><td>HD6413003RF
HD6413003RVF</td><td rowspan="2">112-pin QFP (QFP-112)</td><td rowspan="2">Divide-by-2 oscillator</td><td>5 V ±10%</td></tr>
<tr><td>2.7 V to 5.5 V</td></tr>
<tr><td>HD6413003TF
HD6413003TVF</td><td rowspan="2">1:1 oscillator</td><td>5 V ±10%</td></tr>
<tr><td>2.7 V to 5.5 V</td></tr>
</table></td></tr>
</table>

1.2 Block Diagram

Figure 1-1 shows an internal block diagram.

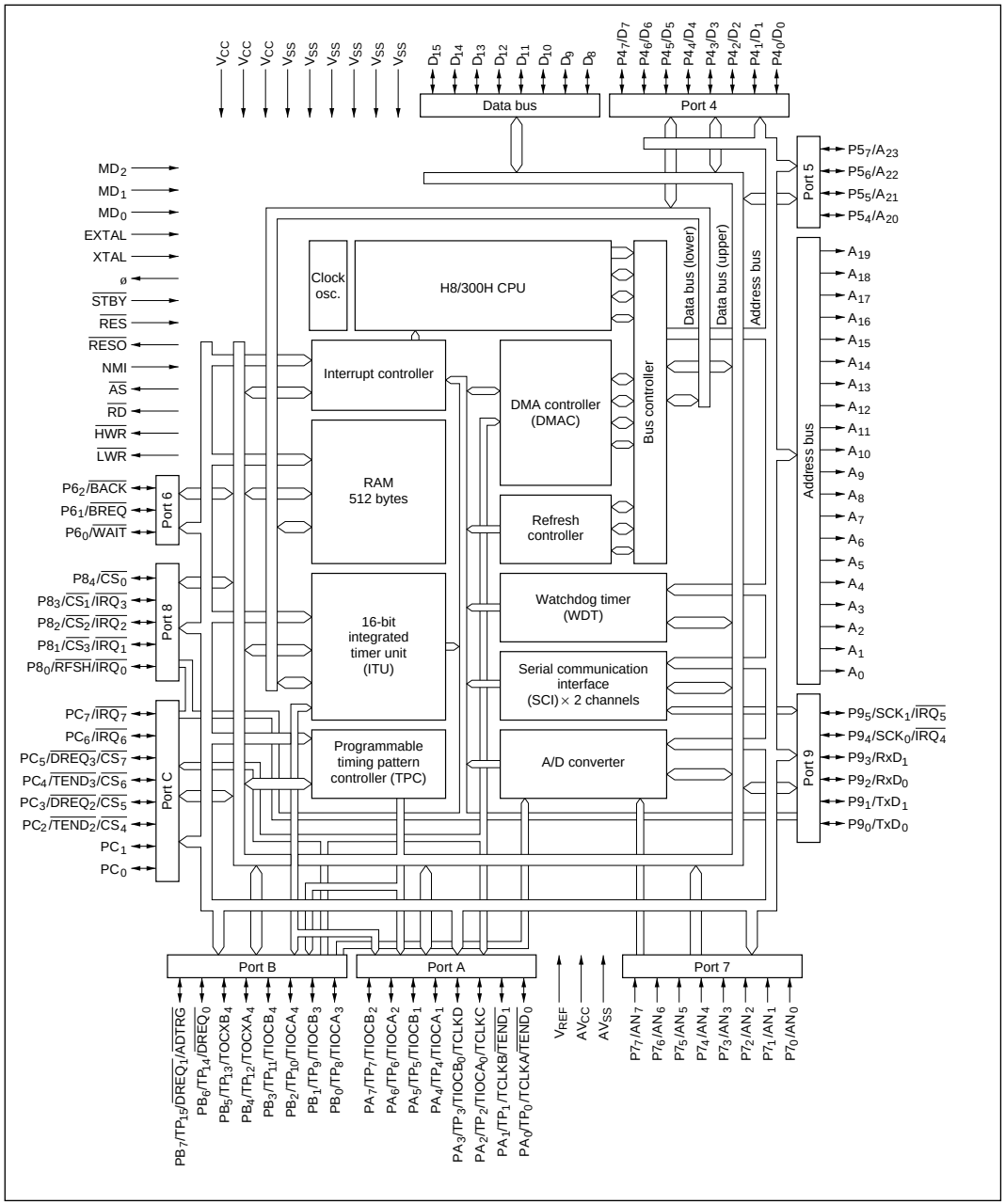


Figure 1-1 Block Diagram

1.3 Pin Description

1.3.1 Pin Arrangement

Figure 1-2 shows the pin arrangement of the H8/3003's QFP-112 package.

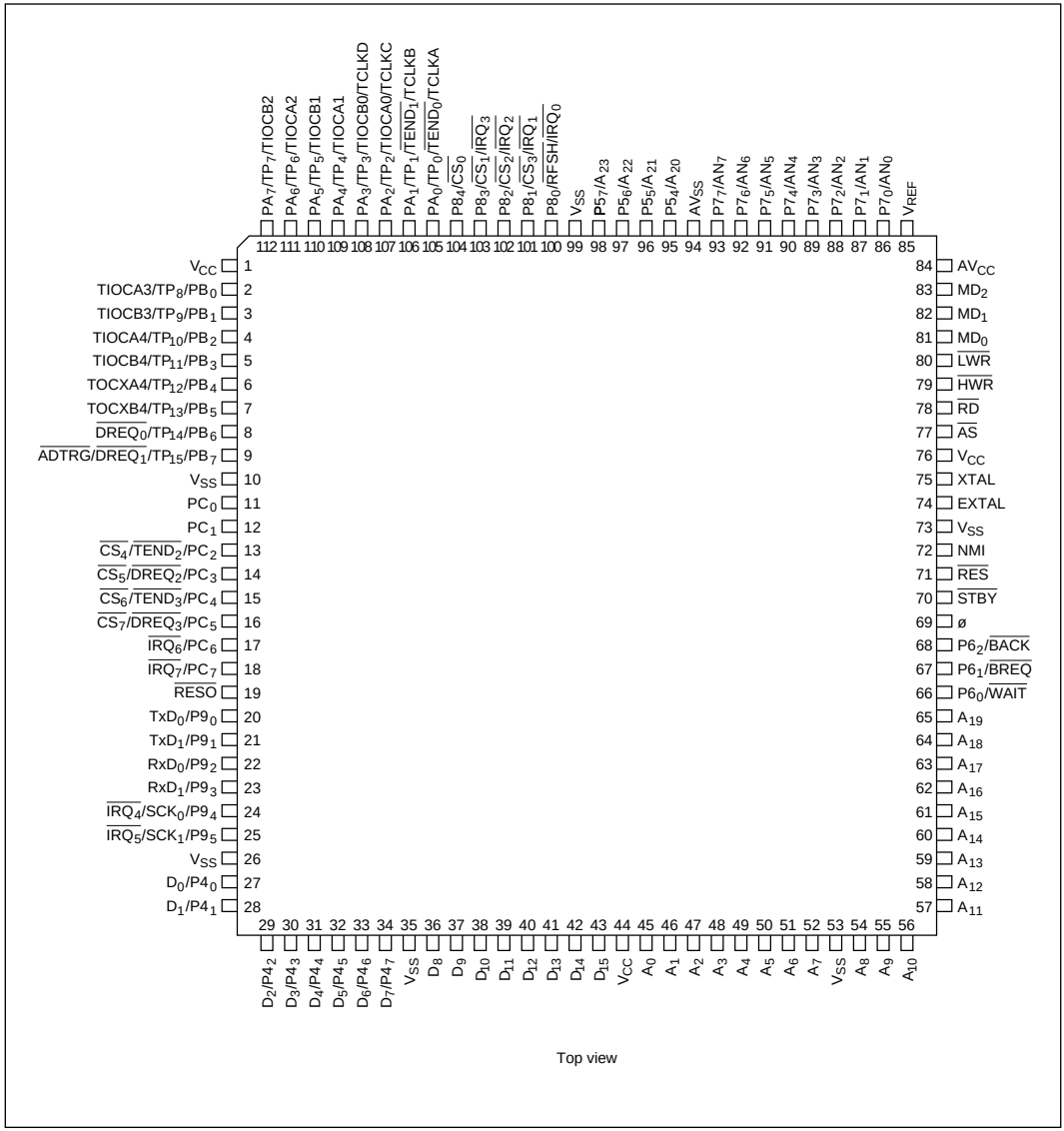


Figure 1-2 Pin Arrangement (QFP-112, Top View)

1.3.2 Pin Functions

Pin Assignments in Each Mode: Table 1-2 lists the QFP-112 pin assignments in each mode.

Table 1-2 QFP-112 Pin Assignments in Each Mode

Pin No.	Pin Name			
	Mode 1	**Mode 2**	**Mode 3**	**Mode 4**
1	V_{CC}	V_{CC}	V_{CC}	V_{CC}
2	$PB_0/TP_8/TIOCA_3$	$PB_0/TP_8/TIOCA_3$	$PB_0/TP_8/TIOCA_3$	$PB_0/TP_8/TIOCA_3$
3	$PB_1/TP_9/TIOCB_3$	$PB_1/TP_9/TIOCB_3$	$PB_1/TP_9/TIOCB_3$	$PB_1/TP_9/TIOCB_3$
4	$PB_2/TP_{10}/TIOCA_4$	$PB_2/TP_{10}/TIOCA_4$	$PB_2/TP_{10}/TIOCA_4$	$PB_2/TP_{10}/TIOCA_4$
5	$PB_3/TP_{11}/TIOCB_4$	$PB_3/TP_{11}/TIOCB_4$	$PB_3/TP_{11}/TIOCB_4$	$PB_3/TP_{11}/TIOCB_4$
6	$PB_4/TP_{12}/TOCXA_4$	$PB_4/TP_{12}/TOCXA_4$	$PB_4/TP_{12}/TOCXA_4$	$PB_4/TP_{12}/TOCXA_4$
7	$PB_5/TP_{13}/TOCXB_4$	$PB_5/TP_{13}/TOCXB_4$	$PB_5/TP_{13}/TOCXB_4$	$PB_5/TP_{13}/TOCXB_4$
8	$PB_6/TP_{14}/\overline{DREQ_0}$	$PB_6/TP_{14}/\overline{DREQ_0}$	$PB_6/TP_{14}/\overline{DREQ_0}$	$PB_6/TP_{14}/\overline{DREQ_0}$
9	$PB_7/TP_{15}/\overline{DREQ_1}/\overline{ADTRG}$	$PB_7/TP_{15}/\overline{DREQ_1}/\overline{ADTRG}$	$PB_7/TP_{15}/\overline{DREQ_1}/\overline{ADTRG}$	$PB_7/TP_{15}/\overline{DREQ_1}/\overline{ADTRG}$
10	V_{SS}	V_{SS}	V_{SS}	V_{SS}
11	PC_0	PC_0	PC_0	PC_0
12	PC_1	PC_1	PC_1	PC_1
13	$PC_2/\overline{TEND_2}/\overline{CS_4}$	$PC_2/\overline{TEND_2}/\overline{CS_4}$	$PC_2/\overline{TEND_2}/\overline{CS_4}$	$PC_2/\overline{TEND_2}/\overline{CS_4}$
14	$PC_3/\overline{DREQ_2}/\overline{CS_5}$	$PC_3/\overline{DREQ_2}/\overline{CS_5}$	$PC_3/\overline{DREQ_2}/\overline{CS_5}$	$PC_3/\overline{DREQ_2}/\overline{CS_5}$
15	$PC_4/\overline{TEND_3}/\overline{CS_6}$	$PC_4/\overline{TEND_3}/\overline{CS_6}$	$PC_4/\overline{TEND_3}/\overline{CS_6}$	$PC_4/\overline{TEND_3}/\overline{CS_6}$
16	$PC_5/\overline{DREQ_3}/\overline{CS_7}$	$PC_5/\overline{DREQ_3}/\overline{CS_7}$	$PC_5/\overline{DREQ_3}/\overline{CS_7}$	$PC_5/\overline{DREQ_3}/\overline{CS_7}$
17	$PC_6/\overline{IRQ_6}$	$PC_6/\overline{IRQ_6}$	$PC_6/\overline{IRQ_6}$	$PC_6/\overline{IRQ_6}$
18	$PC_7/\overline{IRQ_7}$	$PC_7/\overline{IRQ_7}$	$PC_7/\overline{IRQ_7}$	$PC_7/\overline{IRQ_7}$
19	$\overline{RESO}$	$\overline{RESO}$	$\overline{RESO}$	$\overline{RESO}$
20	$P9_0/TxD_0$	$P9_0/TxD_0$	$P9_0/TxD_0$	$P9_0/TxD_0$
21	$P9_1/TxD_1$	$P9_1/TxD_1$	$P9_1/TxD_1$	$P9_1/TxD_1$
22	$P9_2/RxD_0$	$P9_2/RxD_0$	$P9_2/RxD_0$	$P9_2/RxD_0$
23	$P9_3/RxD_1$	$P9_3/RxD_1$	$P9_3/RxD_1$	$P9_3/RxD_1$
24	$P9_4/SCK_0/\overline{IRQ_4}$	$P9_4/SCK_0/\overline{IRQ_4}$	$P9_4/SCK_0/\overline{IRQ_4}$	$P9_4/SCK_0/\overline{IRQ_4}$
25	$P9_5/SCK_1/\overline{IRQ_5}$	$P9_5/SCK_1/\overline{IRQ_5}$	$P9_5/SCK_1/\overline{IRQ_5}$	$P9_5/SCK_1/\overline{IRQ_5}$
26	V_{SS}	V_{SS}	V_{SS}	V_{SS}

Table 1-2 QFP-112 Pin Assignments in Each Mode (cont)

Pin No.	Pin Name Mode 1	Mode 2	Mode 3	Mode 4
27	$P4_0/D_0$*1	$P4_0/D_0$*2	$P4_0/D_0$*	D_0
28	$P4_1/D_1$*1	$P4_1/D_1$*2	$P4_1/D_1$*	D_1
29	$P4_2/D_2$*1	$P4_2/D_2$*2	$P4_2/D_2$*	D_2
30	$P4_3/D_3$*1	$P4_3/D_3$*2	$P4_3/D_3$*	D_3
31	$P4_4/D_4$*1	$P4_4/D_4$*2	$P4_4/D_4$*	D_4
32	$P4_5/D_5$*1	$P4_5/D_5$*2	$P4_5/D_5$*	D_5
33	$P4_6/D_6$*1	$P4_6/D_6$*2	$P4_6/D_6$*	D_6
34	$P4_7/D_7$*1	$P4_7/D_7$*2	$P4_7/D_7$*	D_7
35	V_{SS}	V_{SS}	V_{SS}	V_{SS}
36	D_8	D_8	D_8	D_8
37	D_9	D_9	D_9	D_9
38	D_{10}	D_{10}	D_{10}	D_{10}
39	D_{11}	D_{11}	D_{11}	D_{11}
40	D_{12}	D_{12}	D_{12}	D_{12}
41	D_{13}	D_{13}	D_{13}	D_{13}
42	D_{14}	D_{14}	D_{14}	D_{14}
43	D_{15}	D_{15}	D_{15}	D_{15}
44	V_{CC}	V_{CC}	V_{CC}	V_{CC}
45	A_0	A_0	A_0	A_0
46	A_1	A_1	A_1	A_1
47	A_2	A_2	A_2	A_2
48	A_3	A_3	A_3	A_3
49	A_4	A_4	A_4	A_4
50	A_5	A_5	A_5	A_5
51	A_6	A_6	A_6	A_6
52	A_7	A_7	A_7	A_7
53	V_{SS}	V_{SS}	V_{SS}	V_{SS}
54	A_8	A_8	A_8	A_8
55	A_9	A_9	A_9	A_9

Notes: 1. In modes 1 and 3 the $P4_0$ to $P4_7$ functions of pins $P4_0/D_0$ to $P4_7/D_7$ are selected after a reset, but they can be changed by software.

2. In modes 2 and 4 the D_0 to D_7 functions of pins $P4_0/D_0$ to $D4_7/D_7$ are selected after a reset, but they can be changed by software.

Table 1-2 QFP-112 Pin Assignments in Each Mode (cont)

Pin No.	Pin Name			
	Mode 1	Mode 2	Mode 3	Mode 4
56	A_{10}	A_{10}	A_{10}	A_{10}
57	A_{11}	A_{11}	A_{11}	A_{11}
58	A_{12}	A_{12}	A_{12}	A_{12}
59	A_{13}	A_{13}	A_{13}	A_{13}
60	A_{14}	A_{14}	A_{14}	A_{14}
61	A_{15}	A_{15}	A_{15}	A_{15}
62	A_{16}	A_{16}	A_{16}	A_{16}
63	A_{17}	A_{17}	A_{17}	A_{17}
64	A_{18}	A_{18}	A_{18}	A_{18}
65	A_{19}	A_{19}	A_{19}	A_{19}
66	$P6_0/\overline{WAIT}$	$P6_0/\overline{WAIT}$	$P6_0/\overline{WAIT}$	$P6_0/\overline{WAIT}$
67	$P6_1/\overline{BREQ}$	$P6_1/\overline{BREQ}$	$P6_1/\overline{BREQ}$	$P6_1/\overline{BREQ}$
68	$P6_2/\overline{BACK}$	$P6_2/\overline{BACK}$	$P6_2/\overline{BACK}$	$P6_2/\overline{BACK}$
69	ø	ø	ø	ø
70	$\overline{STBY}$	$\overline{STBY}$	$\overline{STBY}$	$\overline{STBY}$
71	$\overline{RES}$	$\overline{RES}$	$\overline{RES}$	$\overline{RES}$
72	NMI	NMI	NMI	NMI
73	V_{SS}	V_{SS}	V_{SS}	V_{SS}
74	EXTAL	EXTAL	EXTAL	EXTAL
75	XTAL	XTAL	XTAL	XTAL
76	V_{CC}	V_{CC}	V_{CC}	V_{CC}
77	$\overline{AS}$	$\overline{AS}$	$\overline{AS}$	$\overline{AS}$
78	$\overline{RD}$	$\overline{RD}$	$\overline{RD}$	$\overline{RD}$
79	$\overline{HWR}$	$\overline{HWR}$	$\overline{HWR}$	$\overline{HWR}$
80	$\overline{LWR}$	$\overline{LWR}$	$\overline{LWR}$	$\overline{LWR}$
81	MD_0	MD_0	MD_0	MD_0
82	MD_1	MD_1	MD_1	MD_1
83	MD_2	MD_2	MD_2	MD_2

Table 1-2 QFP-112 Pin Assignments in Each Mode (cont)

Pin No.	Pin Name			
	Mode 1	**Mode 2**	**Mode 3**	**Mode 4**
84	AV_{CC}	AV_{CC}	AV_{CC}	AV_{CC}
85	V_{ref}	V_{ref}	V_{ref}	V_{ref}
86	$P7_0/AN_0$	$P7_0/AN_0$	$P7_0/AN_0$	$P7_0/AN_0$
87	$P7_1/AN_1$	$P7_1/AN_1$	$P7_1/AN_1$	$P7_1/AN_1$
88	$P7_2/AN_2$	$P7_2/AN_2$	$P7_2/AN_2$	$P7_2/AN_2$
89	$P7_3/AN_3$	$P7_3/AN_3$	$P7_3/AN_3$	$P7_3/AN_3$
90	$P7_4/AN_4$	$P7_4/AN_4$	$P7_4/AN_4$	$P7_4/AN_4$
91	$P7_5/AN_5$	$P7_5/AN_5$	$P7_5/AN_5$	$P7_5/AN_5$
92	$P7_6/AN_6$	$P7_6/AN_6$	$P7_6/AN_6$	$P7_6/AN_6$
93	$P7_7/AN_7$	$P7_7/AN_7$	$P7_7/AN_7$	$P7_7/AN_7$
94	AV_{SS}	AV_{SS}	AV_{SS}	AV_{SS}
95	$P5_4$	$P5_4$	A_{20}	A_{20}
96	$P5_5$	$P5_5$	A_{21}	A_{21}
97	$P5_6$	$P5_6$	A_{22}	A_{22}
98	$P5_7$	$P5_7$	A_{23}	A_{23}
99	V_{SS}	V_{SS}	V_{SS}	V_{SS}
100	$P8_0/\overline{RFSH}/\overline{IRQ_0}$	$P8_0/\overline{RFSH}/\overline{IRQ_0}$	$P8_0/\overline{RFSH}/\overline{IRQ_0}$	$P8_0/\overline{RFSH}/\overline{IRQ_0}$
101	$P8_1/\overline{CS_3}/\overline{IRQ_1}$	$P8_1/\overline{CS_3}/\overline{IRQ_1}$	$P8_1/\overline{CS_3}/\overline{IRQ_1}$	$P8_1/\overline{CS_3}/\overline{IRQ_1}$
102	$P8_2/\overline{CS_2}/\overline{IRQ_2}$	$P8_2/\overline{CS_2}/\overline{IRQ_2}$	$P8_2/\overline{CS_2}/\overline{IRQ_2}$	$P8_2/\overline{CS_2}/\overline{IRQ_2}$
103	$P8_3/\overline{CS_1}/\overline{IRQ_3}$	$P8_3/\overline{CS_1}/\overline{IRQ_3}$	$P8_3/\overline{CS_1}/\overline{IRQ_3}$	$P8_3/\overline{CS_1}/\overline{IRQ_3}$
104	$P8_4/\overline{CS_0}$	$P8_4/\overline{CS_0}$	$P8_4/\overline{CS_0}$	$P8_4/\overline{CS_0}$
105	$PA_0/TP_0/\overline{TEND_0}$/TCLKA	$PA_0/TP_0/\overline{TEND_0}$/TCLKA	$PA_0/TP_0/\overline{TEND_0}$/TCLKA	$PA_0/TP_0/\overline{TEND_0}$/TCLKA
106	$PA_1/TP_1/\overline{TEND_1}$/TCLKB	$PA_1/TP_1/\overline{TEND_1}$/TCLKB	$PA_1/TP_1/\overline{TEND_1}$/TCLKB	$PA_1/TP_1/\overline{TEND_1}$/TCLKB
107	$PA_2/TP_2/TIOCA_0$/TCLKC	$PA_2/TP_2/TIOCA_0$/TCLKC	$PA_2/TP_2/TIOCA_0$/TCLKC	$PA_2/TP_2/TIOCA_0$/TCLKC
108	$PA_3/TP_3/TIOCB_0$/TCLKD	$PA_3/TP_3/TIOCB_0$/TCLKD	$PA_3/TP_3/TIOCB_0$/TCLKD	$PA_3/TP_3/TIOCB_0$/TCLKD
109	$PA_4/TP_4/TIOCA_1$	$PA_4/TP_4/TIOCA_1$	$PA_4/TP_4/TIOCA_1$	$PA_4/TP_4/TIOCA_1$
110	$PA_5/TP_5/TIOCB_1$	$PA_5/TP_5/TIOCB_1$	$PA_5/TP_5/TIOCB_1$	$PA_5/TP_5/TIOCB_1$
111	$PA_6/TP_6/TIOCA_2$	$PA_6/TP_6/TIOCA_2$	$PA_6/TP_6/TIOCA_2$	$PA_6/TP_6/TIOCA_2$
112	$PA_7/TP_7/TIOCB_2$	$PA_7/TP_7/TIOCB_2$	$PA_7/TP_7/TIOCB_2$	$PA_7/TP_7/TIOCB_2$

1.4 Pin Functions

Table 1-3 summarizes the pin functions.

Table 1-3 Pin Functions

Type	Symbol	Pin No. QFP-112	I/O	Name and Function
Power	V_{CC}	1, 44, 76	Input	**Power:** For connection to the power supply (+5 V). Connect all V_{CC} pins to the +5-V system power supply.
	V_{SS}	10, 26, 35, 53, 73, 99	Input	**Ground:** For connection to ground (0 V). Connect all V_{SS} pins to the 0-V system power supply.
Clock	XTAL	75	Input	For connection to a crystal resonator. For examples of crystal resonator and external clock input, see section 16, Clock Oscillator.
	EXTAL	74	Input	For connection to a crystal resonator or input of an external clock signal. For examples of crystal resonator and external clock input, see section 16, Clock Pulse Generator.
	ø	69	Output	**System clock:** Supplies the system clock to external devices
Operating mode control	MD_2 to MD_0	83 to 81	Input	**Mode 2 to mode 0:** For setting the operating mode, as follows

MD_2	MD_1	MD_0	Operating Mode
0	0	0	—
0	0	1	Mode 1
0	1	0	Mode 2
0	1	1	Mode 3
1	0	0	Mode 4
1	0	1	—
1	1	0	—
1	1	1	—

Table 1-3 Pin Functions (cont)

Type	Symbol	Pin No. QFP-112	I/O	Name and Function
System control	$\overline{RES}$	71	Input	**Reset input:** When driven low, this pin resets the H8/3003
	$\overline{RESO}$	19	Output	**Reset output:** Outputs a reset signal to external devices
	$\overline{STBY}$	70	Input	**Standby:** When driven low, this pin forces a transition to hardware standby mode
	$\overline{BREQ}$	67	Input	**Bus request:** Used by an external bus master to request the bus right from the H8/3003
	$\overline{BACK}$	68	Output	**Bus request acknowledge:** Indicates that the bus has been granted to an external bus master
Interrupts	NMI	72	Input	**Nonmaskable interrupt:** Requests a nonmaskable interrupt
	$\overline{IRQ_7}$ to $\overline{IRQ_0}$	18 to 17, 25 to 24, 103 to 101	Input	**Interrupt request 7 to 0:** Maskable interrupt request pins
Address bus	A_{23} to A_0	98 to 95, 65 to 54, 52 to 45	Output	**Address bus:** Outputs address signals
Data bus	D_{15} to D_0	43 to 36 34 to 27	Input/ output	**Data bus:** Bidirectional data bus
Bus control	$\overline{CS_7}$ to $\overline{CS_0}$	16 to 13 101 to 104	Output	**Chip select:** Select signals for areas 7 to 0
	$\overline{AS}$	77	Output	**Address strobe:** Goes low to indicate valid address output on the address bus
	$\overline{RD}$	78	Output	**Read:** Goes low to indicate reading from the external address space
	$\overline{HWR}$	79	Output	**High write:** Goes low to indicate writing to the external address space; indicates valid data on the upper data bus (D_{15} to D_8).
	$\overline{LWR}$	80	Output	**Low write:** Goes low to indicate writing to the external address space; indicates valid data on the lower data bus (D_7 to D_0).
	$\overline{WAIT}$	66	Input	**Wait:** Requests insertion of wait states in bus cycles during access to the external address space

Table 1-3 Pin Functions (cont)

Type	Symbol	Pin No. QFP-112	I/O	Name and Function
Refresh controller	RFSH	100	Output	**Refresh:** Indicates a refresh cycle
	$\overline{CS_3}$	101	Output	**Row address strobe $\overline{RAS}$:** Row address strobe signal for DRAM connected to area 3
	$\overline{RD}$	78	Output	**Column address strobe $\overline{CAS}$:** Column address strobe signal for bit DRAM connected to area 3; used with 2$\overline{WE}$ DRAM.
				Write enable: Write enable signal for DRAM connected to area 3; used with 2$\overline{CAS}$ DRAM.
	$\overline{HWR}$	79	Output	**Upper write:** Write enable signal for DRAM connected to area 3; used with 2$\overline{WE}$ DRAM.
				Upper column address strobe: Column address strobe signal for DRAM connected to area 3; used with 2$\overline{CAS}$ DRAM.
	$\overline{LWR}$	80	Output	**Lower write:** Write enable signal for DRAM connected to area 3; used with 2$\overline{WE}$ DRAM.
				Lower column address strobe: Column address strobe signal for DRAM connected to area 3; used with 2$\overline{CAS}$ DRAM.
DMA controller (DMAC)	$\overline{DREQ_3}$ to $\overline{DREQ_0}$	16, 14 9, 8	Input	**DMA request 3 to 0:** DMAC activation requests
	$\overline{TEND_3}$ to $\overline{TEND_0}$	15, 13, 106, 105	Output	**Transfer end 3 to 0:** These signals indicate that the DMAC has ended a data transfer
16-bit integrated time unit (ITU)	TCLKD to TCLKA	108 to 105	Input	**Clock input A to D:** External clock inputs
	$TIOCA_4$ to $TIOCA_0$	4, 2, 111, 109, 107	Input/ output	**Input capture/output compare A4 to A0:** GRA4 to GRA0 output compare or input capture, or PWM output
	$TIOCB_4$ to $TIOCB_0$	5, 3, 112, 110, 108	Input/ output	**Input capture/output compare B4 to B0:** GRB4 to GRB0 output compare or input capture, or PWM output
	$TOCXA_4$	6	Output	**Output compare XA4:** PWM output
	$TOCXB_4$	7	Output	**Output compare XB4:** PWM output

Table 1-3 Pin Functions (cont)

Type	Symbol	Pin No. QFP-112	I/O	Name and Function
Programmable timing pattern controller (TPC)	TP_{15} to TP_0	9 to 2 112 to 105	Output	**TPC output 15 to 0:** Pulse output
Serial communication interface (SCI)	TxD_1, TxD_0	21, 20	Output	**Transmit data (channels 0 and 1):** SCI data output
	RxD_1, RxD_0	23, 22	Input	**Receive data (channels 0 and 1):** SCI data input
	SCK_0, SCK_1	25, 24	Input/ output	**Serial clock (channels 0 and 1):** SCI clock input/output
A/D converter	AN_7 to AN_0	93 to 86	Input	**Analog 7 to 0:** Analog input pins
	$\overline{ADTRG}$	9	Input	**A/D trigger:** External trigger input for starting A/D conversion
	AV_{CC}	84	Input	Power supply pin for the A/D converter. Connect to the system power supply (+5 V) when not using the A/D converter.
	AV_{SS}	94	Input	Ground pin for the A/D converter. Connect to system ground (0 V) when not using the A/D converter.
	V_{REF}	85	Input	Reference voltage input pin for the A/D converter. Connect to the system power supply (+5 V) when not using the A/D converter.
I/O ports	$P4_7$ to $P4_0$	34 to 27	Input/ output	**Port 4:** Eight input/output pins. The direction of each pin can be selected in the port 4 data direction register (P4DDR).
	$P5_7$ to $P5_4$	98 to 95	Input/ output	**Port 5:** Four input/output pins. The direction of each pin can be selected in the port 5 data direction register (P5DDR).
	$P6_2$ to $P6_0$	68 to 66	Input/ output	**Port 6:** Three input/output pins. The direction of each pin can be selected in the port 6 data direction register (P6DDR).
	$P7_7$ to $P7_0$	93 to 86	Input	**Port 7:** Eight input pins
	$P8_4$ to $P8_0$	104 to 100	Input/ output	**Port 8:** Five input/output pins. The direction of each pin can be selected in the port 8 data direction register (P8DDR).

Table 1-3 Pin Functions (cont)

Type	Symbol	Pin No. QFP-112	I/O	Name and Function
I/O ports	$P9_5$ to $P9_0$	25 to 20	Input/ output	**Port 9:** Six input/output pins. The direction of each pin can be selected in the port 9 data direction register (P9DDR).
	PA_7 to PA_0	112 to 105	Input/ output	**Port A:** Eight input/output pins. The direction of each pin can be selected in the port A data direction register (PADDR).
	PB_7 to PB_0	9 to 2	Input/ output	**Port B:** Eight input/output pins. The direction of each pin can be selected in the port B data direction register (PBDDR).
	PC_7 to PC_0	18 to 11	Input/ output	**Port C:** Eight input/output pins. The direction of each pin can be selected in the port C data direction register (PCDDR).

Section 2 CPU

2.1 Overview

The H8/300H CPU is a high-speed central processing unit with an internal 32-bit architecture that is upward-compatible with the H8/300 CPU. The H8/300H CPU has sixteen 16-bit general registers, can address a 16-Mbyte linear address space, and is ideal for realtime control.

2.1.1 Features

The H8/300H CPU has the following features.

- Upward compatibility with H8/300 CPU

  Can execute H8/300 series object programs without alteration

- General-register architecture

  Sixteen 16-bit general registers (also usable as sixteen 8-bit registers or eight 32-bit registers)

- Sixty-two basic instructions

  — 8/16/32-bit arithmetic and logic instructions
  — Multiply and divide instructions
  — Powerful bit-manipulation instructions

- Eight addressing modes

  — Register direct [Rn]
  — Register indirect [@ERn]
  — Register indirect with displacement [@(d:16, ERn) or @(d:24, ERn)]
  — Register indirect with post-increment or pre-decrement [@ERn+ or @–ERn]
  — Absolute address [@aa:8, @aa:16, or @aa:24]
  — Immediate [#xx:8, #xx:16, or #xx:32]
  — Program-counter relative [@(d:8, PC) or @(d:16, PC)]
  — Memory indirect [@@aa:8]

- 16-Mbyte linear address space

- High-speed operation

  — All frequently-used instructions execute in two to four states
  — Maximum clock frequency: 16 MHz
  — 8/16/32-bit register-register add/subtract: 125 ns
  — 8 × 8-bit register-register multiply: 875 ns
  — 16 ÷ 8-bit register-register divide: 875 ns
  — 16 × 16-bit register-register multiply: 1.375 µs
  — 32 ÷ 16-bit register-register divide: 1.375 µs

- Two CPU operating modes

  — Normal mode (not available in H8/3003)
  — Advanced mode

- Low-power mode

  Transition to power-down state by SLEEP instruction

2.1.2 Differences from H8/300 CPU

In comparison to the H8/300 CPU, the H8/300H has the following enhancements.

- More general registers

  Eight 16-bit registers have been added.

- Expanded address space

  — Advanced mode supports a maximum 16-Mbyte address space.
  — Normal mode supports the same 64-kbyte address space as the H8/300 CPU.

- Enhanced addressing

  The addressing modes have been enhanced to make effective use of the 16-Mbyte address space.

- Enhanced instructions

  — Data transfer, arithmetic, and logic instructions can operate on 32-bit data.
  — Signed multiply/divide instructions and other instructions have been added.

2.2 CPU Operating Modes

The H8/300H CPU has two operating modes: normal and advanced. Normal mode supports a maximum 64-kbyte address space. Advanced mode supports up to 16 Mbytes. See figure 2-1. The H8/3003 uses only advanced mode.

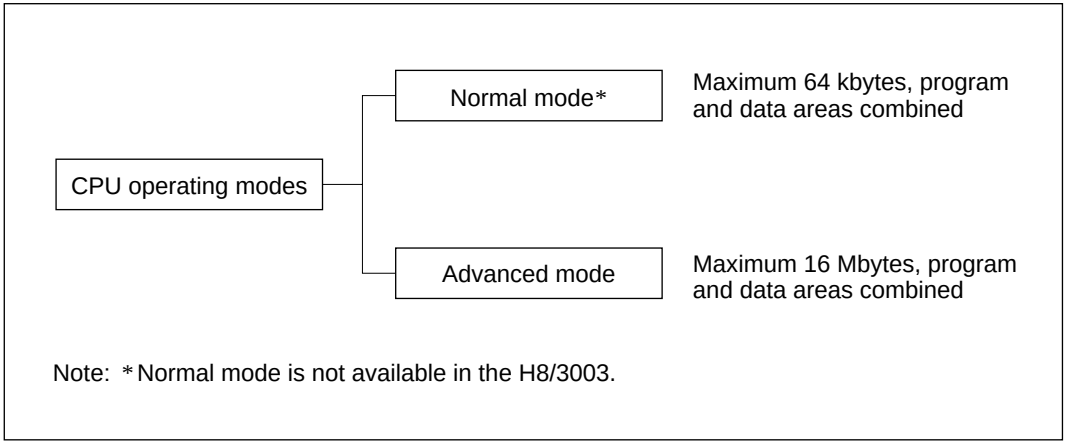


Figure 2-1 CPU Operating Modes

2.3 Address Space

The maximum address space of the H8/300H CPU is 16 Mbytes. The H8/3003 has two operating modes (MCU modes), one providing a 1-Mbyte address space, the other supporting the full 16 Mbytes.

Figure 2-2 shows the H8/3003's address ranges. For further details see section 3.6, Memory Map in Each Operating Mode.

The 1-Mbyte operating mode uses 20-bit addressing. The upper 4 bits of effective addresses are ignored.

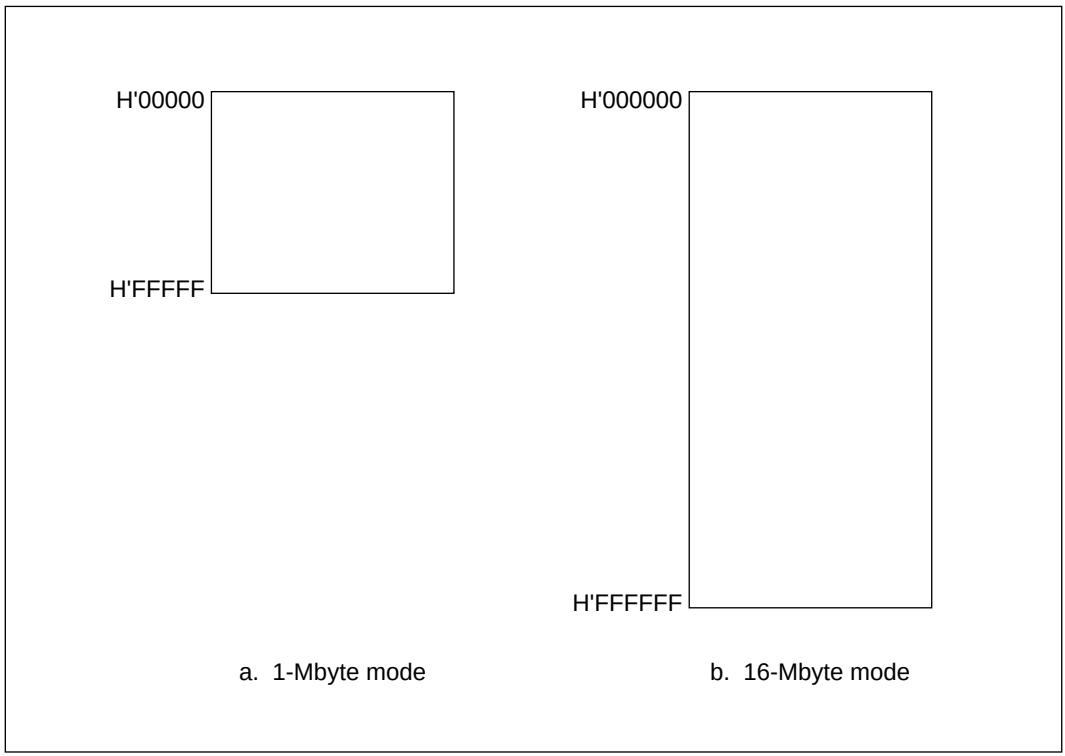


Figure 2-2 Memory Map

2.4 Register Configuration

2.4.1 Overview

The H8/300H CPU has the internal registers shown in figure 2-3. There are two types of registers: general registers and control registers.

General Registers (ERn)

	15 — 0	7 — 0	7 — 0
ER0	E0	R0H	R0L
ER1	E1	R1H	R1L
ER2	E2	R2H	R2L
ER3	E3	R3H	R3L
ER4	E4	R4H	R4L
ER5	E5	R5H	R5L
ER6	E6	R6H	R6L
ER7	E7 (SP)	R7H	R7L

Control Registers (CR)

	23 — 0
PC	

	7	6	5	4	3	2	1	0
CCR	I	UI	H	U	N	Z	V	C

Legend
SP: Stack pointer
PC: Program counter
CCR: Condition code register
I: Interrupt mask bit
UI: User bit or interrupt mask bit
H: Half-carry flag
U: User bit
N: Negative flag
Z: Zero flag
V: Overflow flag
C: Carry flag

Figure 2-3 CPU Registers

2.4.2 General Registers

The H8/300H CPU has eight 32-bit general registers. These general registers are all functionally alike and can be used without distinction between data registers and address registers. When a general register is used as a data register, it can be accessed as a 32-bit, 16-bit, or 8-bit register. When the general registers are used as 32-bit registers or as address registers, they are designated by the letters ER (ER0 to ER7).

The ER registers divide into 16-bit general registers designated by the letters E (E0 to E7) and R (R0 to R7). These registers are functionally equivalent, providing a maximum sixteen 16-bit registers. The E registers (E0 to E7) are also referred to as extended registers.

The R registers divide into 8-bit general registers designated by the letters RH (R0H to R7H) and RL (R0L to R7L). These registers are functionally equivalent, providing a maximum sixteen 8-bit registers.

Figure 2-4 illustrates the usage of the general registers. The usage of each register can be selected independently.

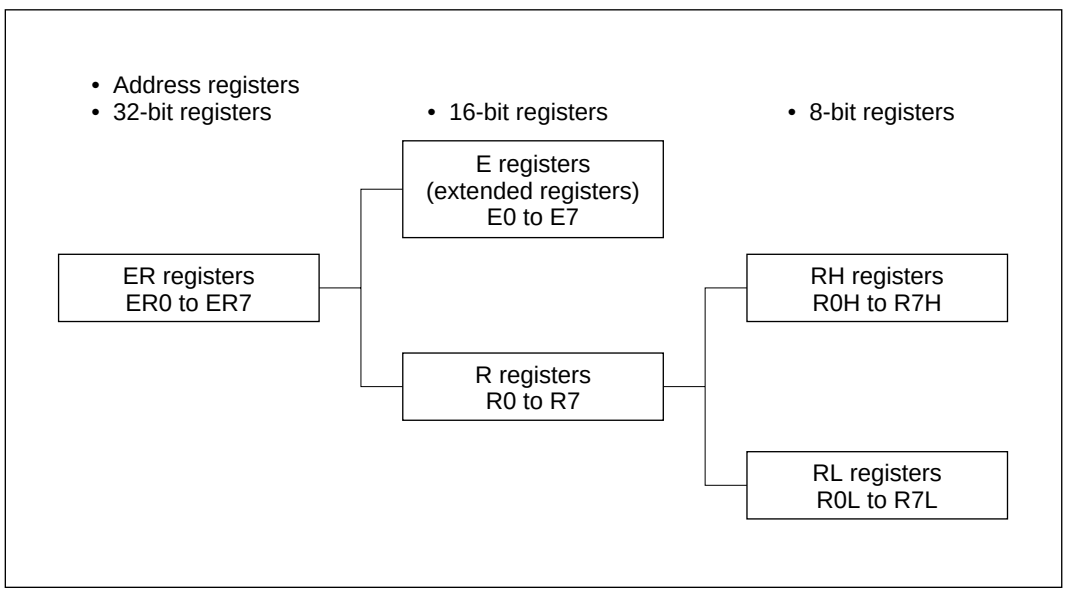


Figure 2-4 Usage of General Registers

General register ER7 has the function of stack pointer (SP) in addition to its general-register function, and is used implicitly in exception handling and subroutine calls. Figure 2-5 shows the stack.

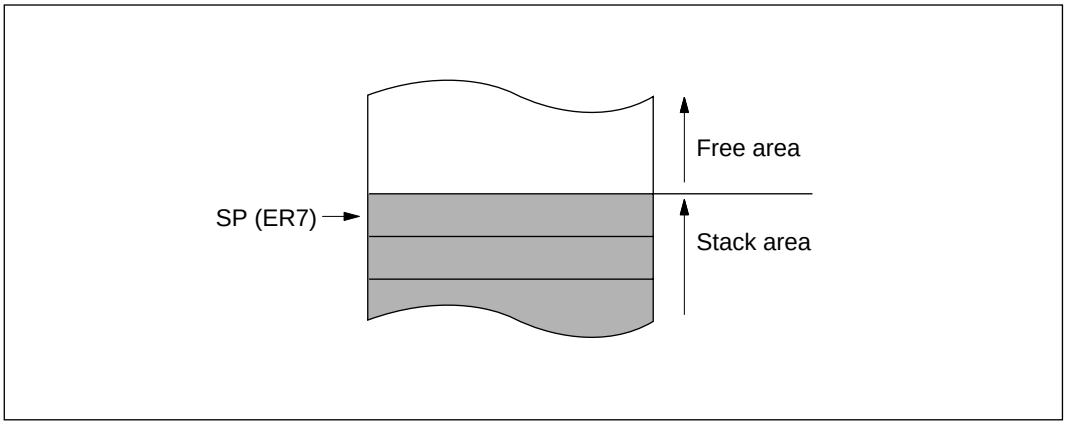


Figure 2-5 Stack

2.4.3 Control Registers

The control registers are the 24-bit program counter (PC) and the 8-bit condition code register (CCR).

Program Counter (PC): This 24-bit counter indicates the address of the next instruction the CPU will execute. The length of all CPU instructions is 2 bytes (one word) or a multiple of 2 bytes, so the least significant PC bit is ignored. When an instruction is fetched, the least significant PC bit is regarded as 0.

Condition Code Register (CCR): This 8-bit register contains internal CPU status information, including the interrupt mask bit (I) and half-carry (H), negative (N), zero (Z), overflow (V), and carry (C) flags.

Bit 7—Interrupt Mask Bit (I): Masks interrupts other than NMI when set to 1. NMI is accepted regardless of the I bit setting. The I bit is set to 1 at the start of an exception-handling sequence.

Bit 6—User Bit or Interrupt Mask Bit (UI): Can be written and read by software using the LDC, STC, ANDC, ORC, and XORC instructions. This bit can also be used as an interrupt mask bit. For details see section 5, Interrupt Controller.

Bit 5—Half-Carry Flag (H): When the ADD.B, ADDX.B, SUB.B, SUBX.B, CMP.B, or NEG.B instruction is executed, this flag is set to 1 if there is a carry or borrow at bit 3, and cleared to 0 otherwise. When the ADD.W, SUB.W, CMP.W, or NEG.W instruction is executed, the H flag is set to 1 if there is a carry or borrow at bit 11, and cleared to 0 otherwise. When the ADD.L, SUB.L, CMP.L, or NEG.L instruction is executed, the H flag is set to 1 if there is a carry or borrow at bit 27, and cleared to 0 otherwise.

Bit 4—User Bit (U): Can be written and read by software using the LDC, STC, ANDC, ORC, and XORC instructions.

Bit 3—Negative Flag (N): Indicates the most significant bit (sign bit) of data.

Bit 2—Zero Flag (Z): Set to 1 to indicate zero data, and cleared to 0 to indicate non-zero data.

Bit 1—Overflow Flag (V): Set to 1 when an arithmetic overflow occurs, and cleared to 0 at other times.

Bit 0—Carry Flag (C): Set to 1 when a carry occurs, and cleared to 0 otherwise. Used by:

- Add instructions, to indicate a carry
- Subtract instructions, to indicate a borrow
- Shift and rotate instructions, to store the value shifted out of the end bit

The carry flag is also used as a bit accumulator by bit manipulation instructions.

Some instructions leave flag bits unchanged. Operations can be performed on CCR by the LDC, STC, ANDC, ORC, and XORC instructions. The N, Z, V, and C flags are used by conditional branch (Bcc) instructions.

For the action of each instruction on the flag bits, see appendix A.1, Instruction List. For the I and UI bits, see section 5, Interrupt Controller.

2.4.4 Initial CPU Register Values

In reset exception handling, PC is initialized to a value loaded from the vector table, and the I bit in CCR is set to 1. The other CCR bits and the general registers are not initialized. In particular, the stack pointer (ER7) is not initialized. The stack pointer must therefore be initialized by an MOV.L instruction executed immediately after a reset.

2.5 Data Formats

The H8/300H CPU can process 1-bit, 4-bit (BCD), 8-bit (byte), 16-bit (word), and 32-bit (longword) data. Bit-manipulation instructions operate on 1-bit data by accessing bit n (n = 0, 1, 2, …, 7) of byte operand data. The DAA and DAS decimal-adjust instructions treat byte data as two digits of 4-bit BCD data.

2.5.1 General Register Data Formats

Figures 2-6 and 2-7 show the data formats in general registers.

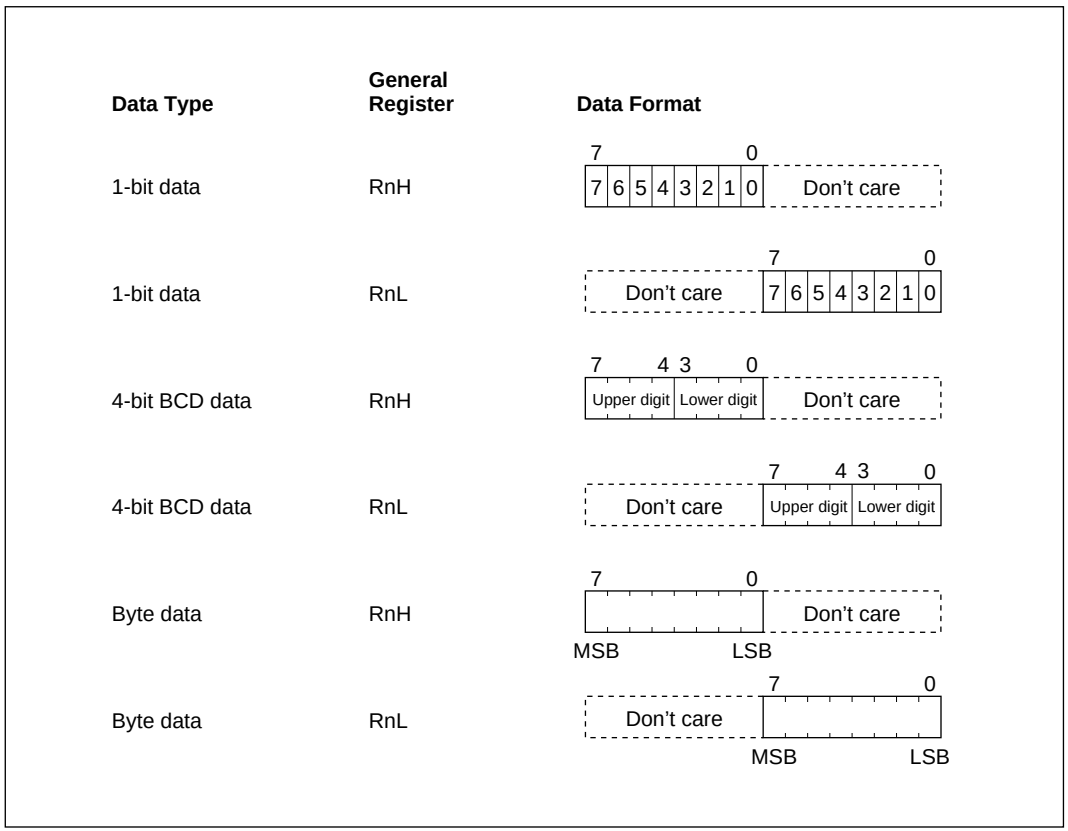


Figure 2-6 General Register Data Formats (1)

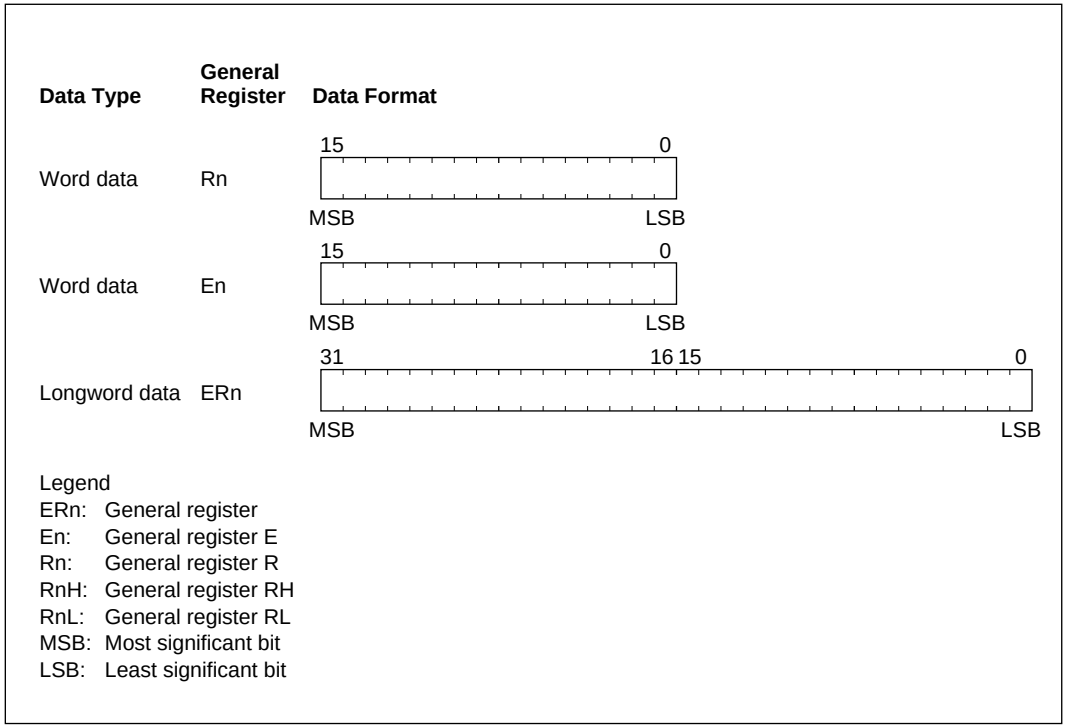


Figure 2-7 General Register Data Formats (2)

2.5.2 Memory Data Formats

Figure 2-8 shows the data formats on memory. The H8/300H CPU can access word data and longword data on memory, but word or longword data must begin at an even address. If an attempt is made to access word or longword data at an odd address, no address error occurs but the least significant bit of the address is regarded as 0, so the access starts at the preceding address. This also applies to instruction fetches.

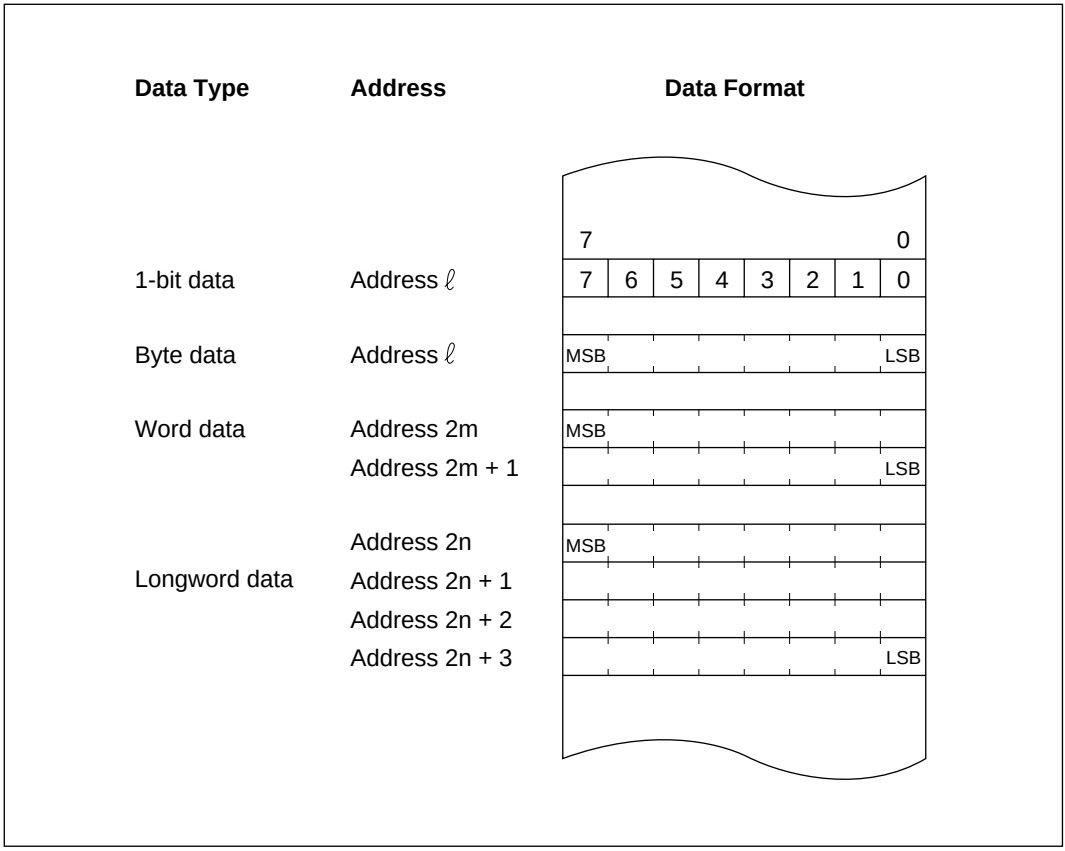


Figure 2-8 Memory Data Formats

When ER7 (SP) is used as an address register to access the stack, the operand size should be word size or longword size.

2.6 Instruction Set

2.6.1 Instruction Set Overview

The H8/300H CPU has 62 types of instructions, which are classified in table 2-1.

Table 2-1 Instruction Classification

Function	Instruction	Types
Data transfer	MOV, PUSH*1, POP*1, MOVTPE*2, MOVFPE*2	3
Arithmetic operations	ADD, SUB, ADDX, SUBX, INC, DEC, ADDS, SUBS, DAA, DAS, MULXU, DIVXU, MULXS, DIVXS, CMP, NEG, EXTS, EXTU	18
Logic operations	AND, OR, XOR, NOT	4
Shift operations	SHAL, SHAR, SHLL, SHLR, ROTL, ROTR, ROTXL, ROTXR	8
Bit manipulation	BSET, BCLR, BNOT, BTST, BAND, BIAND, BOR, BIOR, BXOR, BIXOR, BLD, BILD, BST, BIST	14
Branch	Bcc*3, JMP, BSR, JSR, RTS	5
System control	TRAPA, RTE, SLEEP, LDC, STC, ANDC, ORC, XORC, NOP	9
Block data transfer	EEPMOV	1

Total 62 types

Notes: 1. POP.W Rn is identical to MOV.W @SP+, Rn.
PUSH.W Rn is identical to MOV.W Rn, @–SP.
POP.L ERn is identical to MOV.L @SP+, Rn.
PUSH.L ERn is identical to MOV.L Rn, @–SP.
2. They are not available on H8/3003.
3. Bcc is a generic branching instruction.

2.6.2 Instructions and Addressing Modes

Table 2-2 indicates the instructions available in the H8/300H CPU.

Table 2-2 Instructions and Addressing Modes

		Addressing Modes												
Function	**Instruction**	**#xx**	**Rn**	**@ERn**	**@ (d:16, ERn)**	**@ (d:24, ERn)**	**@ERn+/ @–ERn**	**@ aa:8**	**@ aa:16**	**@ aa:24**	**@ (d:8, PC)**	**@ (d:16, PC)**	**@@ aa:8**	**Implied**
Data transfer	MOV	BWL	BWL	BWL	BWL	BWL	BWL	B	BWL	BWL	—	—	—	—
	POP, PUSH	—	—	—	—	—	—	—	—	—	—	—	—	WL
	MOVFPE, MOVTPE	—	—	—	—	—	—	—	B	—	—	—	—	—
Arithmetic operations	ADD, CMP	BWL	BWL	—	—	—	—	—	—	—	—	—	—	—
	SUB	WL	BWL	—	—	—	—	—	—	—	—	—	—	—
	ADDX, SUBX	B	B	—	—	—	—	—	—	—	—	—	—	—
	ADDS, SUBS	—	L	—	—	—	—	—	—	—	—	—	—	—
	INC, DEC	—	BWL	—	—	—	—	—	—	—	—	—	—	—
	DAA, DAS	—	B	—	—	—	—	—	—	—	—	—	—	—
	DIVXU, MULXS, MULXU, DIVXS	—	BW	—	—	—	—	—	—	—	—	—	—	—
	NEG	—	BWL	—	—	—	—	—	—	—	—	—	—	—
	EXTU, EXTS	—	WL	—	—	—	—	—	—	—	—	—	—	—
Logic operations	AND, OR, XOR	BWL	BWL	—	—	—	—	—	—	—	—	—	—	—
	NOT	—	BWL	—	—	—	—	—	—	—	—	—	—	—
Shift instructions		—	BWL	—	—	—	—	—	—	—	—	—	—	—
Bit manipulation		—	B	B	—	—	—	B	—	—	—	—	—	—
Branch	Bcc, BSR	—	—	—	—	—	—	—	—	—	○	○	—	—
	JMP, JSR	—	—	○	—	—	—	—	—	○	—	—	○	—
	RTS	—	—	—	—	—	—	—	—	—	—	—	—	○
System control	TRAPA	—	—	—	—	—	—	—	—	—	—	—	—	○
	RTE	—	—	—	—	—	—	—	—	—	—	—	—	○
	SLEEP	—	—	—	—	—	—	—	—	—	—	—	—	○
	LDC	B	B	W	W	W	W	—	W	W	—	—	—	—
	STC	—	B	W	W	W	W	—	W	W	—	—	—	—
	ANDC, ORC, XORC	B	—	—	—	—	—	—	—	—	—	—	—	—
	NOP	—	—	—	—	—	—	—	—	—	—	—	—	○
Block data transfer		—	—	—	—	—	—	—	—	—	—	—	—	BW

Legend
B: Byte
W: Word
L: Longword

2.6.3 Tables of Instructions Classified by Function

Tables 2-3 to 2-10 summarize the instructions in each functional category. The operation notation used in these tables is defined next.

Operation Notation

Rd	General register (destination)*
Rs	General register (source)*
Rn	General register*
ERn	General register (32-bit register or address register)
(EAd)	Destination operand
(EAs)	Source operand
CCR	Condition code register
N	N (negative) flag of CCR
Z	Z (zero) flag of CCR
V	V (overflow) flag of CCR
C	C (carry) flag of CCR
PC	Program counter
SP	Stack pointer
#IMM	Immediate data
disp	Displacement
+	Addition
–	Subtraction
×	Multiplication
÷	Division
∧	AND logical
∨	OR logical
⊕	Exclusive OR logical
→	Move
¬	NOT (logical complement)
:3/:8/:16/:24	3-, 8-, 16-, or 24-bit length

Note: * General registers include 8-bit registers (R0H to R7H, R0L to R7L), 16-bit registers (R0 to R7, E0 to E7), and 32-bit data or address registers (ER0 to ER7).

Table 2-3 Data Transfer Instructions

Instruction	Size*	Function
MOV	B/W/L	(EAs) → Rd, Rs → (EAd) Moves data between two general registers or between a general register and memory, or moves immediate data to a general register.
MOVFPE	B	(EAs) → Rd Cannot be used in the H8/3003.
MOVTPE	B	Rs → (EAs) Cannot be used in the H8/3003.
POP	W/L	@SP+ → Rn Pops a general register from the stack. POP.W Rn is identical to MOV.W @SP+, Rn. Similarly, POP.L ERn is identical to MOV.L @SP+, ERn.
PUSH	W/L	Rn → @–SP Pushes a general register onto the stack. PUSH.W Rn is identical to MOV.W Rn, @–SP. Similarly, PUSH.L ERn is identical to MOV.L ERn, @–SP.

Note: * Size refers to the operand size.
B: Byte
W: Word
L: Longword

Table 2-4 Arithmetic Operation Instructions

Instruction	Size*	Function
ADD, SUB	B/W/L	Rd ± Rs → Rd, Rd ± #IMM → Rd Performs addition or subtraction on data in two general registers, or on immediate data and data in a general register. (Immediate byte data cannot be subtracted from data in a general register. Use the SUBX or ADD instruction.)
ADDX, SUBX	B	Rd ± Rs ± C → Rd, Rd ± #IMM ± C → Rd Performs addition or subtraction with carry or borrow on data in two general registers, or on immediate data and data in a general register.
INC, DEC	B/W/L	Rd ± 1 → Rd, Rd ± 2 → Rd Increments or decrements a general register by 1 or 2. (Byte operands can be incremented or decremented by 1 only.)
ADDS, SUBS	L	Rd ± 1 → Rd, Rd ± 2 → Rd, Rd ± 4 → Rd Adds or subtracts the value 1, 2, or 4 to or from data in a 32-bit register.
DAA, DAS	B	Rd decimal adjust → Rd Decimal-adjusts an addition or subtraction result in a general register by referring to CCR to produce 4-bit BCD data.
MULXU	B/W	Rd × Rs → Rd Performs unsigned multiplication on data in two general registers: either 8 bits × 8 bits → 16 bits or 16 bits × 16 bits → 32 bits.
MULXS	B/W	Rd × Rs → Rd Performs signed multiplication on data in two general registers: either 8 bits × 8 bits → 16 bits or 16 bits × 16 bits → 32 bits.

Note: * Size refers to the operand size.
B: Byte
W: Word
L: Longword

Table 2-4 Arithmetic Operation Instructions (cont)

Instruction	Size*	Function
DIVXU	B/W	Rd ÷ Rs → Rd Performs unsigned division on data in two general registers: either 16 bits ÷ 8 bits → 8-bit quotient and 8-bit remainder or 32 bits ÷ 16 bits → 16-bit quotient and 16-bit remainder.
DIVXS	B/W	Rd ÷ Rs → Rd Performs signed division on data in two general registers: either 16 bits ÷ 8 bits → 8-bit quotient and 8-bit remainder, or 32 bits ÷ 16 bits → 16-bit quotient and 16-bit remainder.
CMP	B/W/L	Rd – Rs, Rd – #IMM Compares data in a general register with data in another general register or with immediate data, and sets CCR according to the result.
NEG	B/W/L	0 – Rd → Rd Takes the two's complement (arithmetic complement) of data in a general register.
EXTS	W/L	Rd (sign extension) → Rd Extends byte data in the lower 8 bits of a 16-bit register to word data, or extends word data in the lower 16 bits of a 32-bit register to longword data, by extending the sign bit.
EXTU	W/L	Rd (zero extension) → Rd Extends byte data in the lower 8 bits of a 16-bit register to word data, or extends word data in the lower 16 bits of a 32-bit register to longword data, by padding with zeros.

Note: * Size refers to the operand size.
B: Byte
W: Word
L: Longword

Table 2-5 Logic Operation Instructions

Instruction	Size*	Function
AND	B/W/L	Rd $\wedge$ Rs $\rightarrow$ Rd, Rd $\wedge$ #IMM $\rightarrow$ Rd Performs a logical AND operation on a general register and another general register or immediate data.
OR	B/W/L	Rd $\vee$ Rs $\rightarrow$ Rd, Rd $\vee$ #IMM $\rightarrow$ Rd Performs a logical OR operation on a general register and another general register or immediate data.
XOR	B/W/L	Rd $\oplus$ Rs $\rightarrow$ Rd, Rd $\oplus$ #IMM $\rightarrow$ Rd Performs a logical exclusive OR operation on a general register and another general register or immediate data.
NOT	B/W/L	$\neg$ Rd $\rightarrow$ Rd Takes the one's complement of general register contents.

Note: * Size refers to the operand size.
B: Byte
W: Word
L: Longword

Table 2-6 Shift Instructions

Instruction	Size*	Function
SHAL, SHAR	B/W/L	Rd (shift) $\rightarrow$ Rd Performs an arithmetic shift on general register contents.
SHLL, SHLR	B/W/L	Rd (shift) $\rightarrow$ Rd Performs a logical shift on general register contents.
ROTL, ROTR	B/W/L	Rd (rotate) $\rightarrow$ Rd Rotates general register contents.
ROTXL, ROTXR	B/W/L	Rd (rotate) $\rightarrow$ Rd Rotates general register contents through the carry bit.

Note: * Size refers to the operand size.
B: Byte
W: Word
L: Longword

Table 2-7 Bit Manipulation Instructions

Instruction	Size*	Function
BSET	B	1 → (<bit-No.> of <EAd>) Sets a specified bit in a general register or memory operand to 1. The bit number is specified by 3-bit immediate data or the lower 3 bits of a general register.
BCLR	B	0 → (<bit-No.> of <EAd>) Clears a specified bit in a general register or memory operand to 0. The bit number is specified by 3-bit immediate data or the lower 3 bits of a general register.
BNOT	B	¬ (<bit-No.> of <EAd>) → (<bit-No.> of <EAd>) Inverts a specified bit in a general register or memory operand. The bit number is specified by 3-bit immediate data or the lower 3 bits of a general register.
BTST	B	¬ (<bit-No.> of <EAd>) → Z Tests a specified bit in a general register or memory operand and sets or clears the Z flag accordingly. The bit number is specified by 3-bit immediate data or the lower 3 bits of a general register.
BAND	B	C ∧ (<bit-No.> of <EAd>) → C ANDs the carry flag with a specified bit in a general register or memory operand and stores the result in the carry flag.
BIAND	B	C ∧ [¬ (<bit-No.> of <EAd>)] → C ANDs the carry flag with the inverse of a specified bit in a general register or memory operand and stores the result in the carry flag. The bit number is specified by 3-bit immediate data.

Note: * Size refers to the operand size.
B: Byte

Table 2-7 Bit Manipulation Instructions (cont)

Instruction	Size*	Function
BOR	B	C ∨ (<bit-No.> of <EAd>) → C
		ORs the carry flag with a specified bit in a general register or memory operand and stores the result in the carry flag.
BIOR	B	C ∨ [¬ (<bit-No.> of <EAd>)] → C
		ORs the carry flag with the inverse of a specified bit in a general register or memory operand and stores the result in the carry flag.
		The bit number is specified by 3-bit immediate data.
BXOR	B	C ⊕ (<bit-No.> of <EAd>) → C
		Exclusive-ORs the carry flag with a specified bit in a general register or memory operand and stores the result in the carry flag.
BIXOR	B	C ⊕ [¬ (<bit-No.> of <EAd>)] → C
		Exclusive-ORs the carry flag with the inverse of a specified bit in a general register or memory operand and stores the result in the carry flag.
		The bit number is specified by 3-bit immediate data.
BLD	B	(<bit-No.> of <EAd>) → C
		Transfers a specified bit in a general register or memory operand to the carry flag.
BILD	B	¬ (<bit-No.> of <EAd>) → C
		Transfers the inverse of a specified bit in a general register or memory operand to the carry flag.
		The bit number is specified by 3-bit immediate data.
BST	B	C → (<bit-No.> of <EAd>)
		Transfers the carry flag value to a specified bit in a general register or memory operand.
BIST	B	C → ¬ (<bit-No.> of <EAd>)
		Transfers the inverse of the carry flag value to a specified bit in a general register or memory operand.
		The bit number is specified by 3-bit immediate data.

Note: * Size refers to the operand size.
B: Byte

Table 2-8 Branching Instructions

Instruction	Size	Function
Bcc	—	Branches to a specified address if a specified condition is true. The branching conditions are listed below.

Mnemonic	Description	Condition
BRA (BT)	Always (true)	Always
BRN (BF)	Never (false)	Never
BHI	High	$C \vee Z = 0$
BLS	Low or same	$C \vee Z = 1$
Bcc (BHS)	Carry clear (high or same)	$C = 0$
BCS (BLO)	Carry set (low)	$C = 1$
BNE	Not equal	$Z = 0$
BEQ	Equal	$Z = 1$
BVC	Overflow clear	$V = 0$
BVS	Overflow set	$V = 1$
BPL	Plus	$N = 0$
BMI	Minus	$N = 1$
BGE	Greater or equal	$N \oplus V = 0$
BLT	Less than	$N \oplus V = 1$
BGT	Greater than	$Z \vee (N \oplus V) = 0$
BLE	Less or equal	$Z \vee (N \oplus V) = 1$

JMP	—	Branches unconditionally to a specified address
BSR	—	Branches to a subroutine at a specified address
JSR	—	Branches to a subroutine at a specified address
RTS	—	Returns from a subroutine

Table 2-9 System Control Instructions

Instruction	Size*	Function
TRAPA	—	Starts trap-instruction exception handling
RTE	—	Returns from an exception-handling routine
SLEEP	—	Causes a transition to the power-down state
LDC	B/W	(EAs) → CCR Moves the source operand contents to the condition code register. The condition code register size is one byte, but in transfer from memory, data is read by word access.
STC	B/W	CCR → (EAd) Transfers the CCR contents to a destination location. The condition code register size is one byte, but in transfer to memory, data is written by word access.
ANDC	B	CCR ∧ #IMM → CCR Logically ANDs the condition code register with immediate data.
ORC	B	CCR ∨ #IMM → CCR Logically ORs the condition code register with immediate data.
XORC	B	CCR ⊕ #IMM → CCR Logically exclusive-ORs the condition code register with immediate data.
NOP	—	PC + 2 → PC Only increments the program counter.

Note: * Size refers to the operand size.
B: Byte
W: Word

Table 2-10 Block Transfer Instruction

Instruction	Size	Function
EEPMOV.B	—	if R4L ≠ 0 then repeat @ER5+ → @ER6+, R4L – 1 → R4L until R4L = 0 else next;
EEPMOV.W	—	if R4 ≠ 0 then repeat @ER5+ → @ER6+, R4 – 1 → R4 until R4 = 0 else next; Transfers a data block according to parameters set in general registers R4L or R4, ER5, and ER6. R4L or R4: Size of block (bytes) ER5: Starting source address ER6: Starting destination address Execution of the next instruction begins as soon as the transfer is completed.

2.6.4 Basic Instruction Formats

The H8/300H instructions consist of 2-byte (1-word) units. An instruction consists of an operation field (OP field), a register field (r field), an effective address extension (EA field), and a condition field (cc).

Operation Field: Indicates the function of the instruction, the addressing mode, and the operation to be carried out on the operand. The operation field always includes the first 4 bits of the instruction. Some instructions have two operation fields.

Register Field: Specifies a general register. Address registers are specified by 3 bits, data registers by 3 bits or 4 bits. Some instructions have two register fields. Some have no register field.

Effective Address Extension: Eight, 16, or 32 bits specifying immediate data, an absolute address, or a displacement. A 24-bit address or displacement is treated as 32-bit data in which the first 8 bits are 0 (H'00).

Condition Field: Specifies the branching condition of Bcc instructions.

Figure 2-9 shows examples of instruction formats.

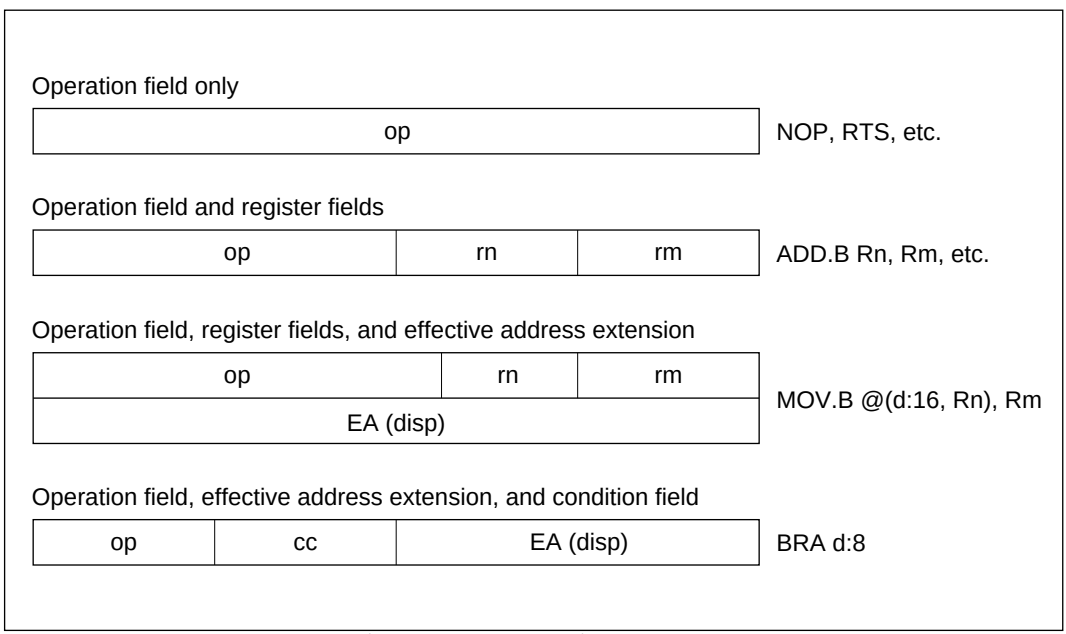


Figure 2-9 Instruction Formats

2.6.5 Notes on Use of Bit Manipulation Instructions

The BSET, BCLR, BNOT, BST, and BIST instructions read a byte of data, modify a bit in the byte, then write the byte back. Care is required when these instructions are used to access registers with write-only bits, or to access ports.

The BCLR instruction can be used to clear flags in the on-chip registers. In an interrupt-handling routine, for example, if it is known that the flag is set to 1, it is not necessary to read the flag ahead of time.

2.7 Addressing Modes and Effective Address Calculation

2.7.1 Addressing Modes

The H8/300H CPU supports the eight addressing modes listed in table 2-11. Each instruction uses a subset of these addressing modes. Arithmetic and logic instructions can use the register direct and immediate modes. Data transfer instructions can use all addressing modes except program-counter relative and memory indirect. Bit manipulation instructions use register direct, register indirect, or absolute (@aa:8) addressing mode to specify an operand, and register direct (BSET, BCLR, BNOT, and BTST instructions) or immediate (3-bit) addressing mode to specify a bit number in the operand.

Table 2-11 Addressing Modes

No.	Addressing Mode	Symbol
1	Register direct	Rn
2	Register indirect	@ERn
3	Register indirect with displacement	@(d:16, ERn)/@d:24, ERn)
4	Register indirect with post-increment Register indirect with pre-decrement	@ERn+ @–ERn
5	Absolute address	@aa:8/@aa:16/@aa:24
6	Immediate	#xx:8/#xx:16/#xx:32
7	Program-counter relative	@(d:8, PC)/@(d:16, PC)
8	Memory indirect	@@aa:8

1 Register Direct—Rn: The register field of the instruction code specifies an 8-, 16-, or 32-bit register containing the operand. R0H to R7H and R0L to R7L can be specified as 8-bit registers. R0 to R7 and E0 to E7 can be specified as 16-bit registers. ER0 to ER7 can be specified as 32-bit registers.

2 Register Indirect—@ERn: The register field of the instruction code specifies an address register (ERn), the lower 24 bits of which contain the address of the operand.

3 Register Indirect with Displacement—@(d:16, ERn) or @(d:24, ERn): A 16-bit or 24-bit displacement contained in the instruction code is added to the contents of an address register (ERn) specified by the register field of the instruction, and the lower 24 bits of the sum specify the address of a memory operand. A 16-bit displacement is sign-extended when added.

4 Register Indirect with Post-Increment or Pre-Decrement—@ERn+ or @–ERn:

- Register indirect with post-increment—@ERn+

  The register field of the instruction code specifies an address register (ERn) the lower 24 bits of which contain the address of a memory operand. After the operand is accessed, 1, 2, or 4 is added to the address register contents (32 bits) and the sum is stored in the address register. The value added is 1 for byte access, 2 for word access, or 4 for longword access. For word or longword access, the register value should be even.

- Register indirect with pre-decrement—@–ERn

  The value 1, 2, or 4 is subtracted from an address register (ERn) specified by the register field in the instruction code, and the lower 24 bits of the result become the address of a memory operand. The result is also stored in the address register. The value subtracted is 1 for byte access, 2 for word access, or 4 for longword access. For word or longword access, the resulting register value should be even.

5 Absolute Address—@aa:8, @aa:16, or @aa:24: The instruction code contains the absolute address of a memory operand. The absolute address may be 8 bits long (@aa:8), 16 bits long (@aa:16), or 24 bits long (@aa:24). For an 8-bit absolute address, the upper 16 bits are all assumed to be 1 (H'FFFF). For a 16-bit absolute address the upper 8 bits are a sign extension. A 24-bit absolute address can access the entire address space. Table 2-12 indicates the accessible address ranges.

Table 2-12 Absolute Address Access Ranges

Absolute Address	1-Mbyte Modes	16-Mbyte Modes
8 bits (@aa:8)	H'FFF00 to H'FFFFF (1048320 to 1048575)	H'FFFF00 to H'FFFFFF (16776960 to 16777215)
16 bits (@aa:16)	H'00000 to H'07FFF, H'F8000 to H'FFFFF (0 to 32767, 1015808 to 1048575)	H'000000 to H'007FFF, H'FF8000 to H'FFFFFF (0 to 32767, 16744448 to 16777215)
24 bits (@aa:24)	H'00000 to H'FFFFF (0 to 1048575)	H'000000 to H'FFFFFF (0 to 16777215)

6 Immediate—#xx:8, #xx:16, or #xx:32: The instruction code contains 8-bit (#xx:8), 16-bit (#xx:16), or 32-bit (#xx:32) immediate data as an operand.

The instruction codes of the ADDS, SUBS, INC, and DEC instructions contain immediate data implicitly. The instruction codes of some bit manipulation instructions contain 3-bit immediate data specifying a bit number. The TRAPA instruction code contains 2-bit immediate data specifying a vector address.

7 Program-Counter Relative—@(d:8, PC) or @(d:16, PC): This mode is used in the Bcc and BSR instructions. An 8-bit or 16-bit displacement contained in the instruction code is sign-extended to 24 bits and added to the 24-bit PC contents to generate a 24-bit branch address. The PC value to which the displacement is added is the address of the first byte of the next instruction, so the possible branching range is –126 to +128 bytes (–63 to +64 words) or –32766 to +32768 bytes (–16383 to +16384 words) from the branch instruction. The resulting value should be an even number.

8 Memory Indirect—@@aa:8: This mode can be used by the JMP and JSR instructions. The instruction code contains an 8-bit absolute address specifying a memory operand. This memory operand contains a branch address. The memory operand is accessed by longword access. The first byte of the memory operand is ignored, generating a 24-bit branch address. See figure 2-10. The upper bits of the 8-bit absolute address are assumed to be 0 (H'0000), so the address range is 0 to 255 (H'000000 to H'0000FF). Note that the first part of this range is also the exception vector area. For further details see section 5, Interrupt Controller.

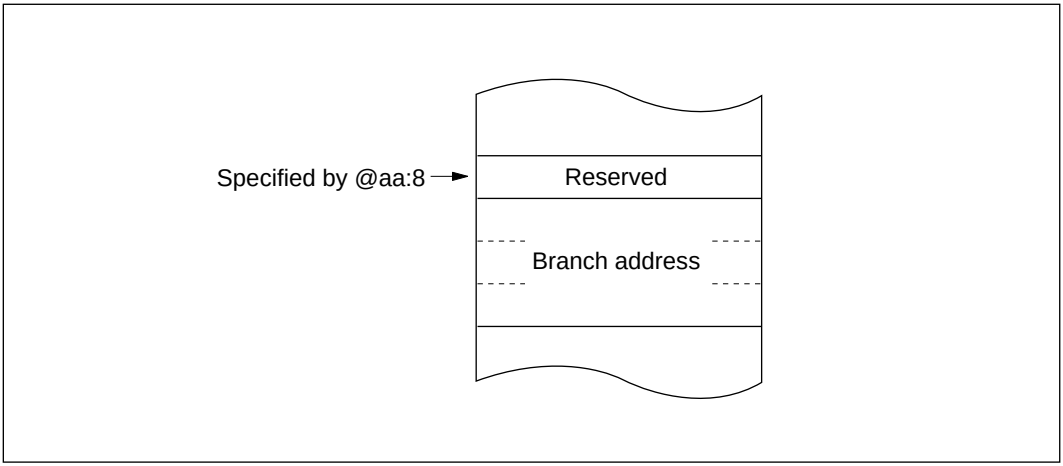


Figure 2-10 Memory-Indirect Branch Address Specification

When a word-size or longword-size memory operand is specified, or when a branch address is specified, if the specified memory address is odd, the least significant bit is regarded as 0. The accessed data or instruction code therefore begins at the preceding address. See section 2.5.2, Memory Data Formats.

2.7.2 Effective Address Calculation

Table 2-13 explains how an effective address is calculated in each addressing mode. In the 1-Mbyte operating modes the upper 4 bits of the calculated address are ignored in order to generate a 20-bit effective address.

Table 2-13 Effective Address Calculation

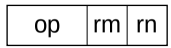
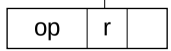
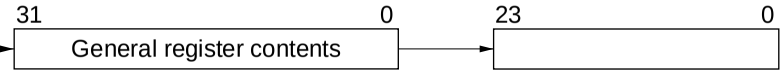
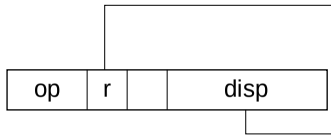
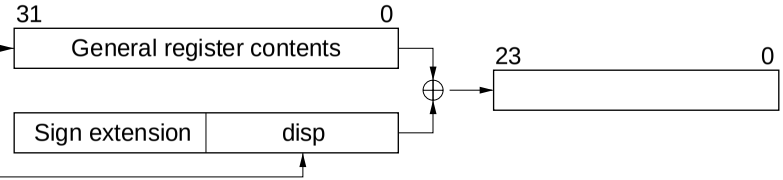
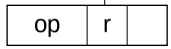
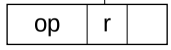
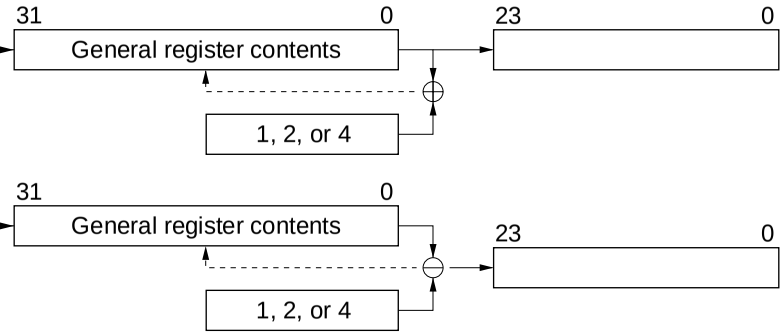
No.	Addressing Mode and Instruction Format	Effective Address Calculation	Effective Address
1	Register direct (Rn) 		Operand is general register contents
2	Register indirect (@ERn) 		
3	Register indirect with displacement @(d:16, ERn)/@(d:24, ERn) 		
4	Register indirect with post-increment or pre-decrement Register indirect with post-increment @ERn+  Register indirect with pre-decrement @–ERn 	 1 for a byte operand, 2 for a word operand, 4 for a longword operand	

Table 2-13 Effective Address Calculation (cont)

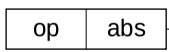
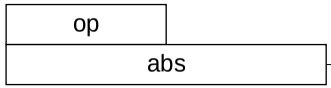
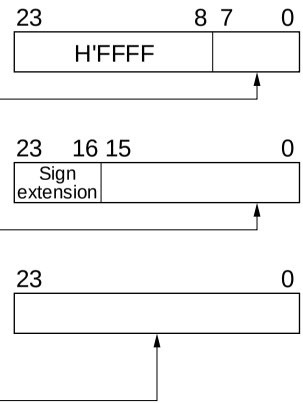
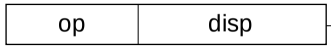
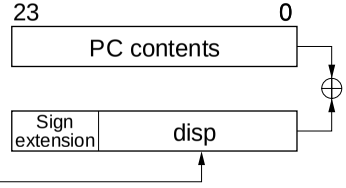
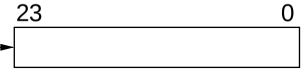
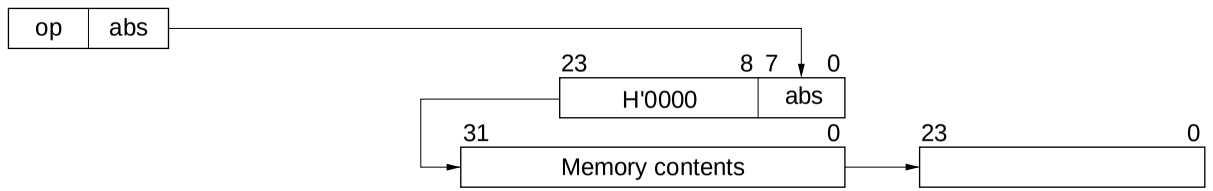
No.	Addressing Mode and Instruction Format	Effective Address Calculation	Effective Address
5	Absolute address @aa:8  @aa:16 @aa:24 		
6	Immediate #xx:8, #xx:16, or #xx:32 		Operand is immediate data
7	Program-counter relative @(d:8, PC) or @(d:16, PC) 		

Table 2-13 Effective Address Calculation (cont)

No.	Addressing Mode and Instruction Format	Effective Address Calculation	Effective Address
8	Memory indirect @@aa:8		

Legend

r, rm, rn:	Register field
op:	Operation field
disp:	Displacement
IMM:	Immediate data
abs:	Absolute address

2.8 Processing States

2.8.1 Overview

The H8/300H CPU has five processing states: the program execution state, exception-handling state, power-down state, reset state, and bus-released state. The power-down state includes sleep mode, software standby mode, and hardware standby mode. Figure 2-11 classifies the processing states. Figure 2-13 indicates the state transitions.

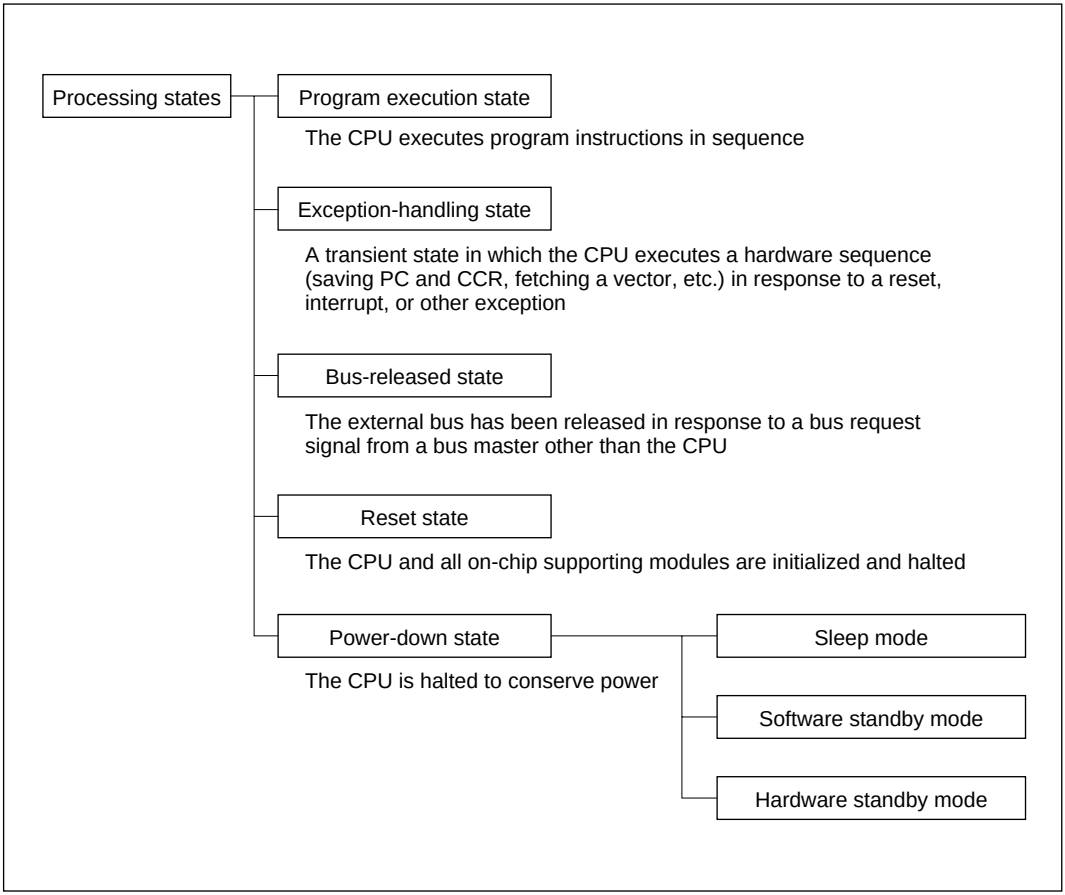


Figure 2-11 Processing States

2.8.2 Program Execution State

In this state the CPU executes program instructions in normal sequence.

2.8.3 Exception-Handling State

The exception-handling state is a transient state that occurs when the CPU alters the normal program flow due to a reset, interrupt, or trap instruction. The CPU fetches a starting address from the exception vector table and branches to that address. In interrupt and trap exception handling the CPU references the stack pointer (ER7) and saves the program counter and condition code register.

Types of Exception Handling and Their Priority: Exception handling is performed for resets, interrupts, and trap instructions. Table 2-14 indicates the types of exception handling and their priority. Trap instruction exceptions are accepted at all times in the program execution state.

Table 2-14 Exception Handling Types and Priority

Priority	Type of Exception	Detection Timing	Start of Exception Handling
High	Reset	Synchronized with clock	Exception handling starts immediately when $\overline{\text{RES}}$ changes from low to high
	Interrupt	End of instruction execution or end of exception handling*	When an interrupt is requested, exception handling starts at the end of the current instruction or current exception-handling sequence
Low	Trap instruction	When TRAPA instruction is executed	Exception handling starts when a trap (TRAPA) instruction is executed

Note: * Interrupts are not detected at the end of the ANDC, ORC, XORC, and LDC instructions, or immediately after reset exception handling.

Figure 2-12 classifies the exception sources. For further details about exception sources, vector numbers, and vector addresses, see section 4, Exception Handling, and section 5, Interrupt Controller.

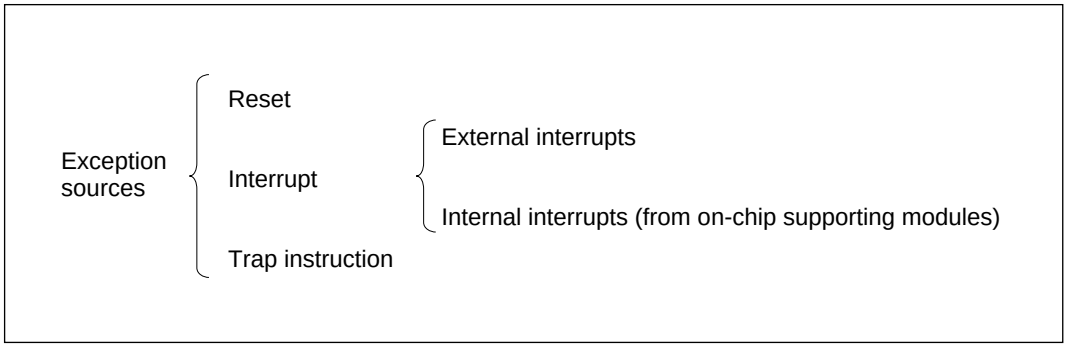
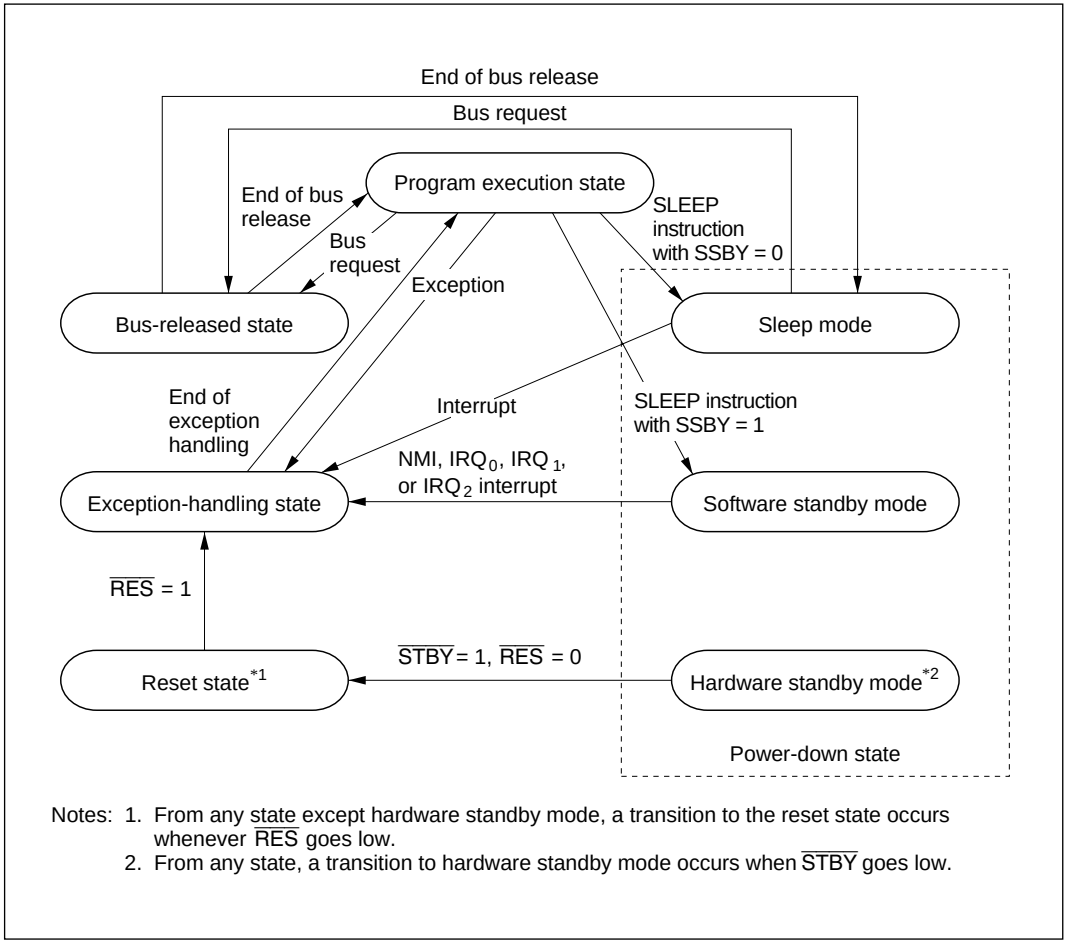


Figure 2-12 Classification of Exception Sources



Notes: 1. From any state except hardware standby mode, a transition to the reset state occurs whenever $\overline{RES}$ goes low.
2. From any state, a transition to hardware standby mode occurs when $\overline{STBY}$ goes low.

Figure 2-13 State Transitions

2.8.4 Exception-Handling Sequences

Reset Exception Handling: Reset exception handling has the highest priority. The reset state is entered when the $\overline{\text{RES}}$ signal goes low. Reset exception handling starts after that, when $\overline{\text{RES}}$ changes from low to high. When reset exception handling starts the CPU fetches a start address from the exception vector table and starts program execution from that address. All interrupts, including NMI, are disabled during the reset exception-handling sequence and immediately after it ends.

Interrupt Exception Handling and Trap Instruction Exception Handling: When these exception-handling sequences begin, the CPU references the stack pointer (ER7) and pushes the program counter and condition code register on the stack. Next, if the UE bit in the system control register (SYSCR) is set to 1, the CPU sets the I bit in the condition code register to 1. If the UE bit is cleared to 0, the CPU sets both the I bit and the UI bit in the condition code register to 1. Then the CPU fetches a start address from the exception vector table and execution branches to that address.

Figure 2-14 shows the stack after the exception-handling sequence.

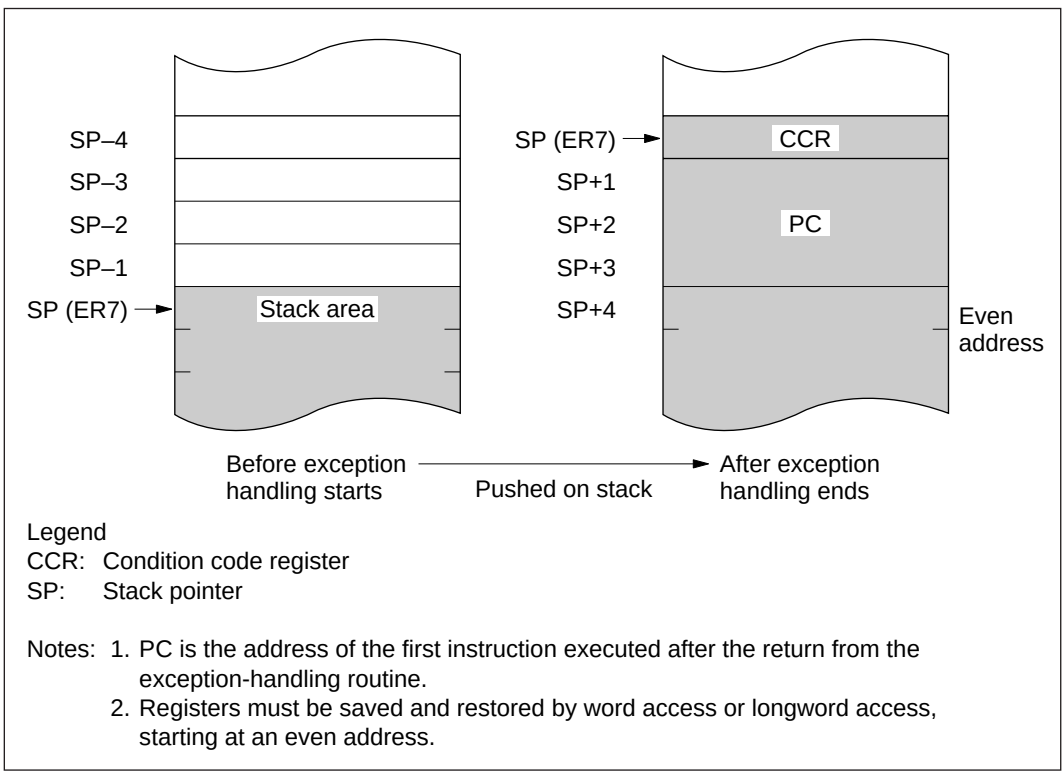


Figure 2-14 Stack Structure after Exception Handling

2.8.5 Bus-Released State

In this state the bus is released to a bus master other than the CPU, in response to a bus request. The bus masters other than the CPU are the DMA controller, the refresh controller, and an external bus master. While the bus is released, the CPU halts except for internal operations. Interrupt requests are not accepted. For details see section 6.3.7, Bus Arbiter Operation

2.8.6 Reset State

When the $\overline{\text{RES}}$ input goes low all current processing stops and the CPU enters the reset state. The I bit in the condition code register is set to 1 by a reset. All interrupts are masked in the reset state. Reset exception handling starts when the $\overline{\text{RES}}$ signal changes from low to high.

The reset state can also be entered by a watchdog timer overflow. For details see section 12, Watchdog Timer.

2.8.7 Power-Down State

In the power-down state the CPU stops operating to conserve power. There are three modes: sleep mode, software standby mode, and hardware standby mode.

Sleep Mode: A transition to sleep mode is made if the SLEEP instruction is executed while the SSBY bit is cleared to 0 in the system control register (SYSCR). CPU operations stop immediately after execution of the SLEEP instruction, but the contents of CPU registers are retained.

Software Standby Mode: A transition to software standby mode is made if the SLEEP instruction is executed while the SSBY bit is set to 1 in SYSCR. The CPU and clock halt and all on-chip supporting modules stop operating. The on-chip supporting modules are reset, but as long as a specified voltage is supplied the contents of CPU registers and on-chip RAM are retained. The I/O ports also remain in their existing states.

Hardware Standby Mode: A transition to hardware standby mode is made when the $\overline{\text{STBY}}$ input goes low. As in software standby mode, the CPU and clock halt and the on-chip supporting modules are reset, but as long as a specified voltage is supplied, on-chip RAM contents are retained.

For further information see section 17, Power-Down State.

2.9 Basic Operational Timing

2.9.1 Overview

The H8/300H CPU operates according to the system clock (ø). The interval from one rise of the system clock to the next rise is referred to as a "state." A memory cycle or bus cycle consists of two or three states. The CPU uses different methods to access on-chip memory, the on-chip supporting modules, and the external address space. Access to the external address space can be controlled by the bus controller.

2.9.2 On-Chip Memory Access Timing

On-chip memory is accessed in two states. The data bus is 16 bits wide, permitting both byte and word access. Figure 2-15 shows the on-chip memory access cycle. Figure 2-16 indicates the pin states.

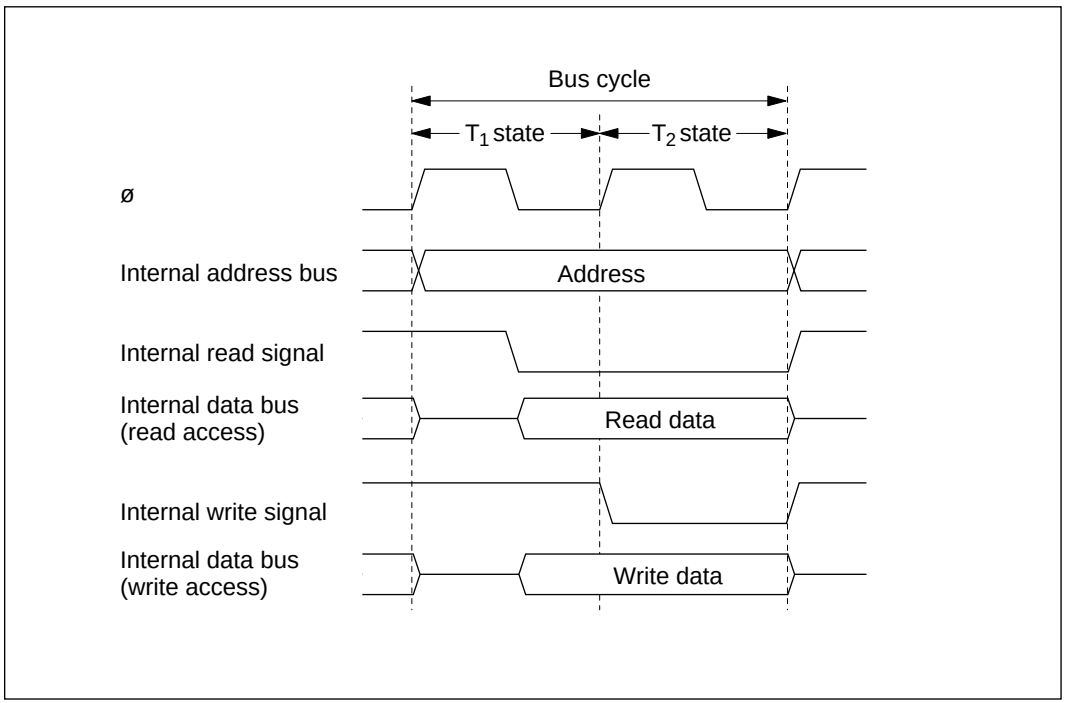


Figure 2-15 On-Chip Memory Access Cycle

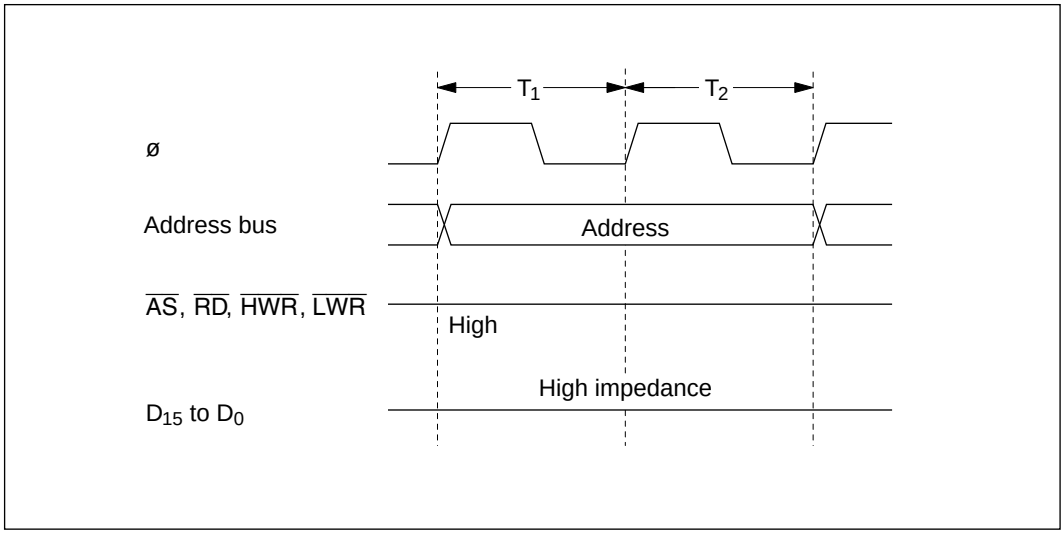


Figure 2-16 Pin States during On-Chip Memory Access

2.9.3 On-Chip Supporting Module Access Timing

The on-chip supporting modules are accessed in three states. The data bus is 8 or 16 bits wide, depending on the register being accessed. Figure 2-17 shows the on-chip supporting module access timing. Figure 2-18 indicates the pin states.

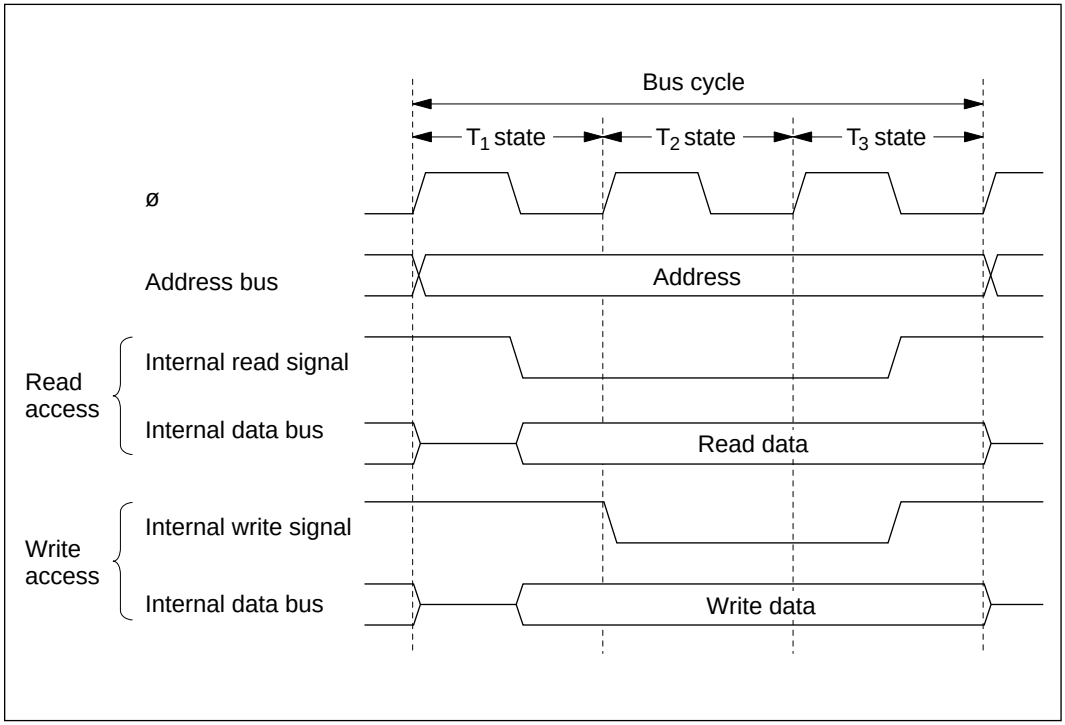


Figure 2-17 Access Cycle for On-Chip Supporting Modules

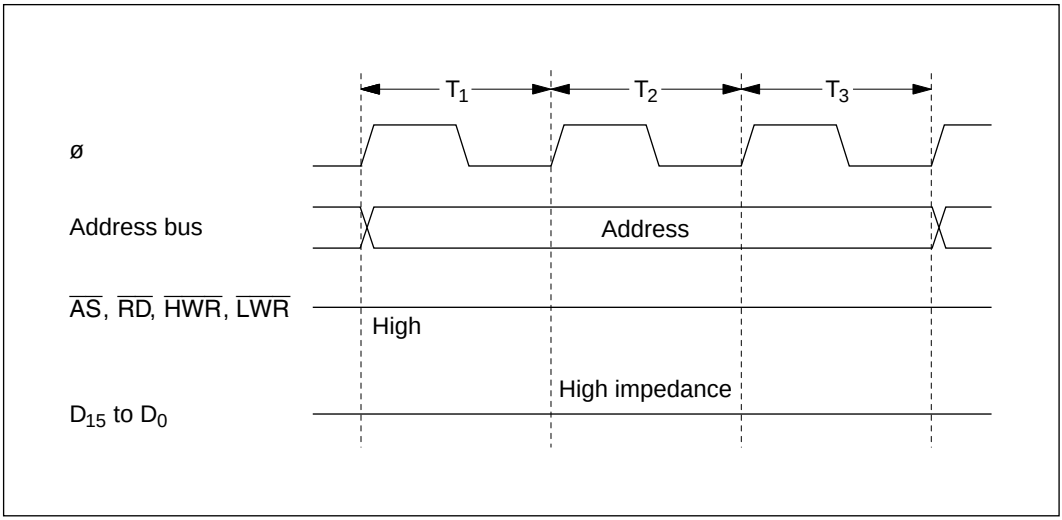


Figure 2-18 Pin States during Access to On-Chip Supporting Modules

2.9.4 Access to External Address Space

The external address space is divided into eight areas (areas 0 to 7). Bus-controller settings determine whether each area is accessed via an 8-bit or 16-bit bus, and whether it is accessed in two or three states. For details see section 6, Bus Controller.

Section 3 MCU Operating Modes

3.1 Overview

3.1.1 Operating Mode Selection

The H8/3003 has four operating modes (modes 1 to 4) that are selected by the mode pins (MD_2 to MD_0) as indicated in table 3-1. The input at these pins determines the size of the address space and the initial bus mode.

Table 3-1 Operating Mode Selection

	Mode Pins			Description		
Operating Mode	**MD_2**	**MD_1**	**MD_0**	**Address Space**	**Initial Bus Mode*1**	**On-Chip RAM**
—	0	0	0	—	—	—
Mode 1	0	0	1	1 Mbyte	8 bits	Enabled*2
Mode 2	0	1	0	1 Mbyte	16 bits	Enabled*2
Mode 3	0	1	1	16 Mbytes	8 bits	Enabled*2
Mode 4	1	0	0	16 Mbytes	16 bits	Enabled*2
—	1	0	1	—	—	—
—	1	1	0	—	—	—
—	1	1	1	—	—	—

Notes: 1. In all modes, an 8-bit or 16-bit data bus can be selected on a per-area basis by settings made in the area bus width control register (ABWCR). For details see section 6, Bus Controller.
2. If the RAM enable bit (RAME) in the system control register (SYSCR) is cleared to 0, these addresses become external addresses.

For the address space size there are two choices: 1 Mbyte or 16 Mbytes. The external data bus is either 8 or 16 bits wide depending on the settings in the area bus width control register (ABWCR). If 8-bit access is selected for all areas, the external data bus is 8 bits wide. For details see section 6, Bus Controller.

Modes 1 to 4 are externally expanded modes that enable access to external memory and peripheral devices. Modes 1 and 2 support a maximum address space of 1 Mbyte. Modes 3 and 4 support a maximum address space of 16 Mbytes.

The H8/3003 can only be used in modes 1 to 4. The inputs at the mode pins must select one of these four modes. The inputs at the mode pins must not be changed during operation.

3.1.2 Register Configuration

The H8/3003 has a mode control register (MDCR) that indicates the inputs at the mode pins (MD_2 to MD_0), and a system control register (SYSCR). Table 3-2 summarizes these registers.

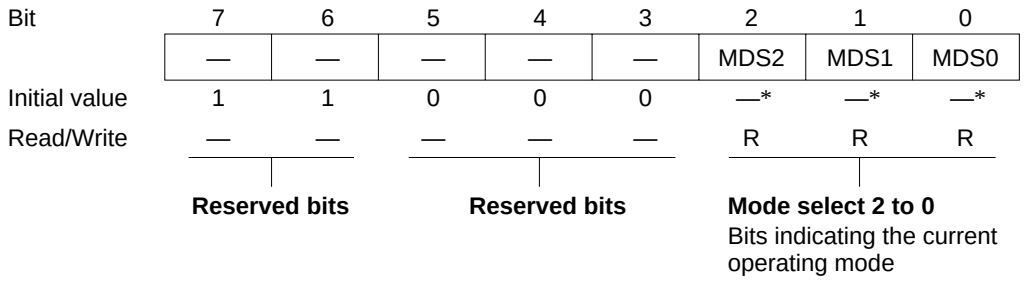
Table 3-2 Registers

Address*	Name	Abbreviation	R/W	Initial Value
H'FFF1	Mode control register	MDCR	R	Undetermined
H'FFF2	System control register	SYSCR	R/W	H'0B

Note: * The lower 16 bits of the address are indicated.

3.2 Mode Control Register (MDCR)

MDCR is an 8-bit read-only register that indicates the current operating mode of the H8/3003.



Note: * Determined by pins MD_2 to MD_0.

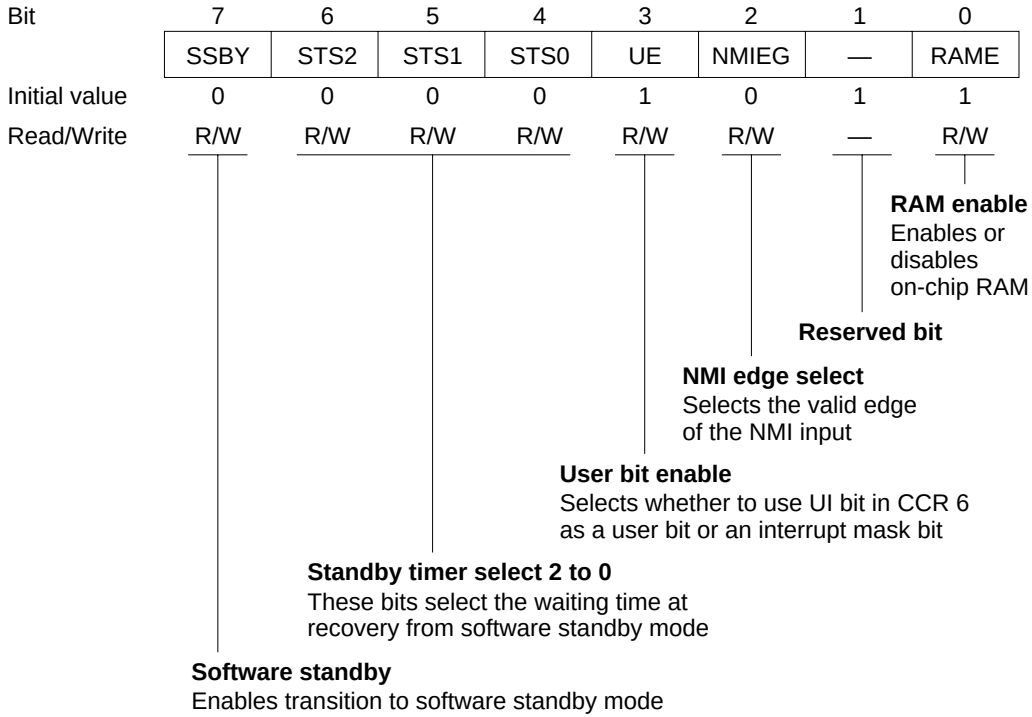
Bits 7 and 6—Reserved: Read-only bits, always read as 1.

Bits 5 to 3—Reserved: Read-only bits, always read as 0.

Bits 2 to 0—Mode Select 2 to 0 (MDS2 to MDS0): These bits indicate the logic levels at pins MD_2 to MD_0 (the current operating mode). MDS2 to MDS0 correspond to MD_2 to MD_0. MDS2 to MDS0 are read-only bits. The mode pin (MD_2 to MD_0) levels are latched when MDCR is read.

3.3 System Control Register (SYSCR)

SYSCR is an 8-bit register that controls the operation of the H8/3003.



Bit 7—Software Standby (SSBY): Enables transition to software standby mode. (For further information about software standby mode see section 17, Power-Down State.)

When software standby mode is exited by an external interrupt, this bit remains set to 1. To clear this bit, write 0.

Bit 7 SSBY	Description	
0	SLEEP instruction causes transition to sleep mode	(Initial value)
1	SLEEP instruction causes transition to software standby mode	

Bits 6 to 4—Standby Timer Select (STS2 to STS0): These bits select the length of time the CPU and on-chip supporting modules wait for the internal clock oscillator to settle when software standby mode is exited by an external interrupt. Set these bits so that the waiting time will be at least 8 ms at the system clock rate. For further information about waiting time selection, see section 17.4.3, Selection of Oscillator Waiting Time after Exit from Software Standby Mode.

Bit 6 STS2	Bit 5 STS1	Bit 4 STS0	Description	
0	0	0	Waiting time = 8192 states	(Initial value)
0	0	1	Waiting time = 16384 states	
0	1	0	Waiting time = 32768 states	
0	1	1	Waiting time = 65536 states	
1	0	—	Waiting time = 131072 states	
1	1	—	Waiting time = 4 states	

Bit 3—User Bit Enable (UE): Selects whether to use the UI bit in the condition code register as a user bit or an interrupt mask bit.

Bit 3 UE	Description	
0	UI bit in CCR is used as an interrupt mask bit	
1	UI bit in CCR is used as a user bit	(Initial value)

Bit 2—NMI Edge Select (NMIEG): Selects the valid edge of the NMI input.

Bit 2 NMIEG	Description	
0	An interrupt is requested at the falling edge of NMI	(Initial value)
1	An interrupt is requested at the rising edge of NMI	

Bit 1—Reserved: Read-only bit, always read as 1.

Bit 0—RAM Enable (RAME): Enables or disables the on-chip RAM. The RAME bit is initialized by the rising edge of the $\overline{\text{RES}}$ signal. It is not initialized in software standby mode.

Bit 0 RAME	Description	
0	On-chip RAM is disabled	
1	On-chip RAM is enabled	(Initial value)

3.4 Operating Mode Descriptions

3.4.1 Mode 1

Address pins A_{19} to A_0 are enabled, permitting access to a maximum 1-Mbyte address space. The initial bus mode after a reset is 8 bits, with 8-bit access to all areas. If at least one area is designated for 16-bit access in ABWCR, the bus mode switches to 16 bits.

3.4.2 Mode 2

Address pins A_{19} to A_0 are enabled, permitting access to a maximum 1-Mbyte address space. The initial bus mode after a reset is 16 bits, with 16-bit access to all areas. If all areas are designated for 8-bit access in ABWCR, the bus mode switches to 8 bits.

3.4.3 Mode 3

Address pins A_{23} to A_0 are enabled, permitting access to a maximum 16-Mbyte address space. The initial bus mode after a reset is 8 bits, with 8-bit access to all areas. If at least one area is designated for 16-bit access in ABWCR, the bus mode switches to 16 bits.

3.4.4 Mode 4

Address pins A_{23} to A_0 are enabled, permitting access to a maximum 16-Mbyte address space. The initial bus mode after a reset is 16 bits, with 16-bit access to all areas. If all areas are designated for 8-bit access in ABWCR, the bus mode switches to 8 bits.

3.5 Pin Functions in Each Operating Mode

The pin functions of ports 4 and 5 vary depending on the operating mode. Table 3-3 indicates their functions in each operating mode.

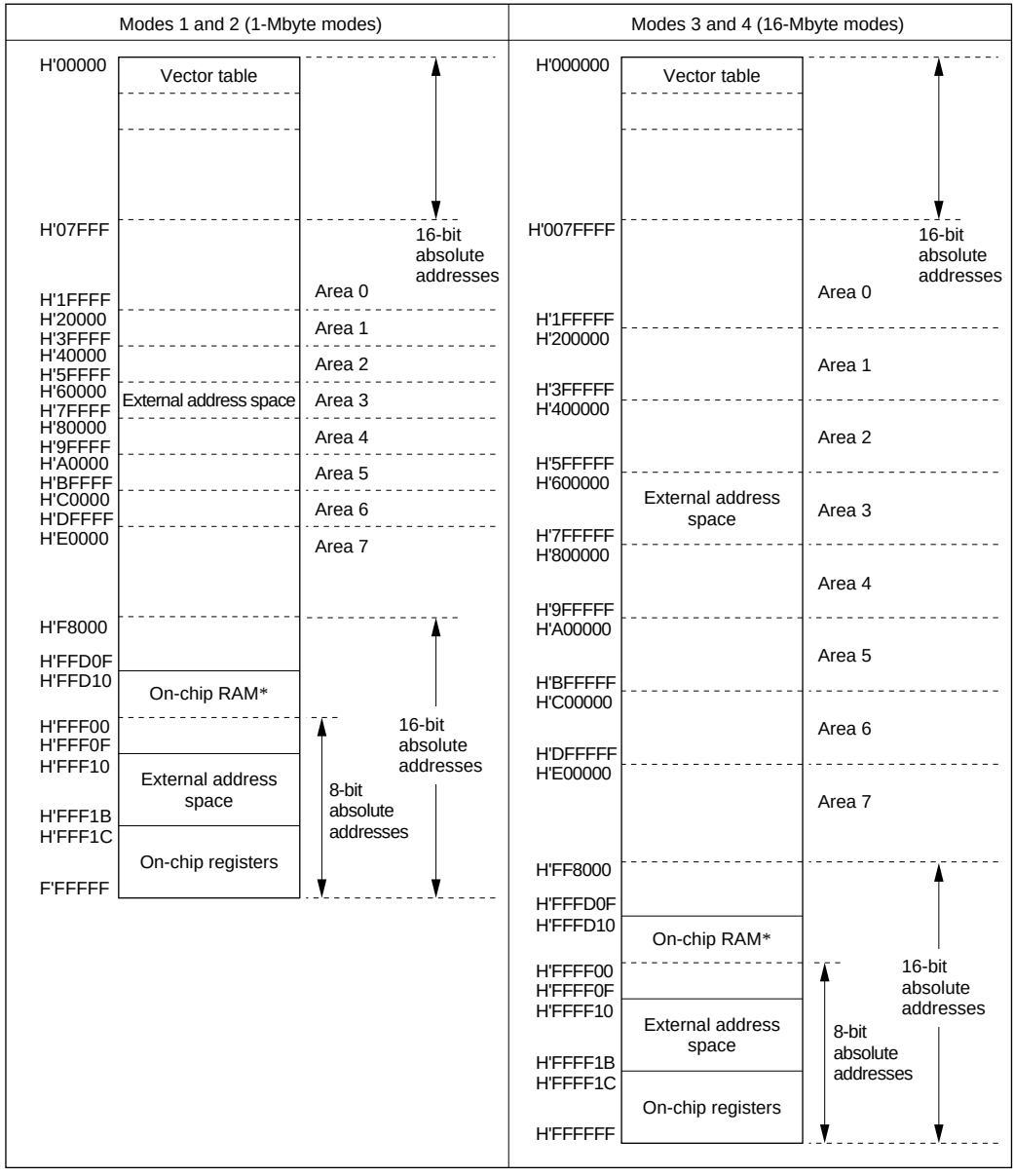
Table 3-3 Pin Functions in Each Mode

Port	Mode 1	Mode 2	Mode 3	Mode 4
Port 4	$P4_7$ to $P4_0$*	D_7 to D_0*	$P4_7$ to $P4_0$*	D_7 to D_0*
Port 5	$P5_7$ to $P5_4$	$P5_7$ to $P5_4$	A_{23} to A_{20}	A_{23} to A_{20}

Note: * Initial state. The bus mode can be switched by settings in ABWCR. These pins function as $P4_7$ to $P4_0$ in 8-bit bus mode, and as D_7 to D_0 in 16-bit bus mode.

3.6 Memory Map in Each Operating Mode

Figure 3-1 shows a memory map for modes 1 to 4. The address space is divided into eight areas. The initial bus mode differs between modes 1 and 2, and also between modes 3 and 4. The address locations of the on-chip RAM and on-chip registers differ between the 1-Mbyte modes (modes 1 and 2) and 16-Mbyte modes (modes 3 and 4). The address range specifiable by the CPU in its 8- and 16-bit absolute addressing modes (@aa:8 and @aa:16) also differs.



Note: * External addresses can be accessed by clearing the RAME bit to 0 in the system control register (SYSCR).

Figure 3-1 Memory Map in Each Operating Mode

Section 4 Exception Handling

4.1 Overview

4.1.1 Exception Handling Types and Priority

As table 4-1 indicates, exception handling may be caused by a reset, trap instruction, or interrupt. Exception handling is prioritized as shown in table 4-1. If two or more exceptions occur simultaneously, they are accepted and processed in priority order. Trap instruction exceptions are accepted at all times in the program execution state.

Table 4-1 Exception Types and Priority

Priority	Exception Type	Start of Exception Handling
High	Reset	Starts immediately after a low-to-high transition at the $\overline{\text{RES}}$ pin
↑	Interrupt	Interrupt requests are handled when execution of the current instruction or handling of the current exception is completed
Low	Trap instruction (TRAPA)	Started by execution of a trap instruction (TRAPA)

4.1.2 Exception Handling Operation

Exceptions originate from various sources. Trap instructions and interrupts are handled as follows.

1. The program counter (PC) and condition code register (CCR) are pushed onto the stack.
2. The CCR interrupt mask bit is set to 1.
3. A vector address corresponding to the exception source is generated, and program execution starts from that address.

For a reset exception, steps 2 and 3 above are carried out.

4.1.3 Exception Vector Table

The exception sources are classified as shown in figure 4-1. Different vectors are assigned to different exception sources. Table 4-2 lists the exception sources and their vector addresses.

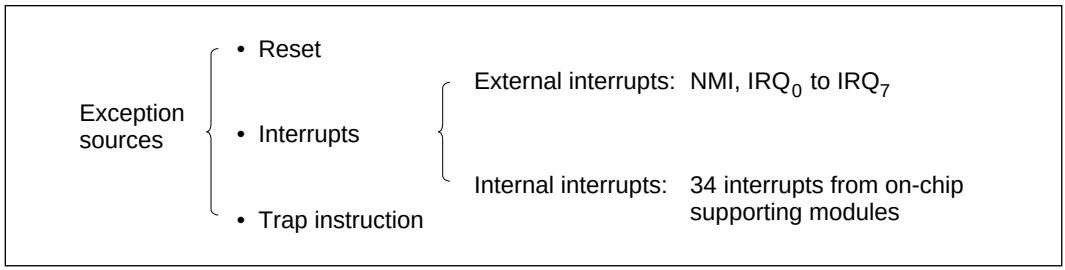


Figure 4-1 Exception Sources

Table 4-2 Exception Vector Table

Exception Source	Vector Number	Vector Address*1
Reset	0	H'0000 to H'0003
Reserved for system use	1	H'0004 to H'0007
	2	H'0008 to H'000B
	3	H'000C to H'000F
	4	H'0010 to H'0013
	5	H'0014 to H'0017
	6	H'0018 to H'001B
External interrupt (NMI)	7	H'001C to H'001F
Trap instruction (4 sources)	8	H'0020 to H'0023
	9	H'0024 to H'0027
	10	H'0028 to H'002B
	11	H'002C to H'002F
External interrupt IRQ_0	12	H'0030 to H'0033
External interrupt IRQ_1	13	H'0034 to H'0037
External interrupt IRQ_2	14	H'0038 to H'003B
External interrupt IRQ_3	15	H'003C to H'003F
External interrupt IRQ_4	16	H'0040 to H'0043
External interrupt IRQ_5	17	H'0044 to H'0047
External interrupt IRQ_6	18	H'0048 to H'004B
External interrupt IRQ_7	19	H'004C to H'004F
Internal interrupts*2	20 to 60	H'0050 to H'0053 to H'00F0 to H'00F3

Notes: 1. Lower 16 bits of the address.
2. For the internal interrupt vectors, see section 5.3.3, Interrupt Vector Table.

4.2 Reset

4.2.1 Overview

A reset is the highest-priority exception. When the $\overline{\text{RES}}$ pin goes low, all processing halts and the H8/3003 enters the reset state. A reset initializes the internal state of the CPU and the registers of the on-chip supporting modules. Reset exception handling begins when the $\overline{\text{RES}}$ pin changes from low to high.

The H8/3003 can also be reset by overflow of the watchdog timer. For details see section 12, Watchdog Timer.

4.2.2 Reset Sequence

The H8/3003 enters the reset state when the $\overline{\text{RES}}$ pin goes low.

To ensure that the H8/3003 is reset, hold the $\overline{\text{RES}}$ pin low for at least 20 ms at power-up. To reset the H8/3003 during operation, hold the $\overline{\text{RES}}$ pin low for at least 10 system clock (ø) cycles. See appendix D.2, Pin States at Reset, for the states of the pins in the reset state.

When the $\overline{\text{RES}}$ pin goes high after being held low for the necessary time, the H8/3003 starts reset exception handling as follows.

- The internal state of the CPU and the registers of the on-chip supporting modules are initialized, and the I bit is set to 1 in CCR.
- The contents of the reset vector address (H'0000 to H'0003) are read, and program execution starts from the address indicated in the vector address.

Figure 4-2 shows the reset sequence in modes 1 and 3. Figure 4-3 shows the reset sequence in modes 2 and 4.

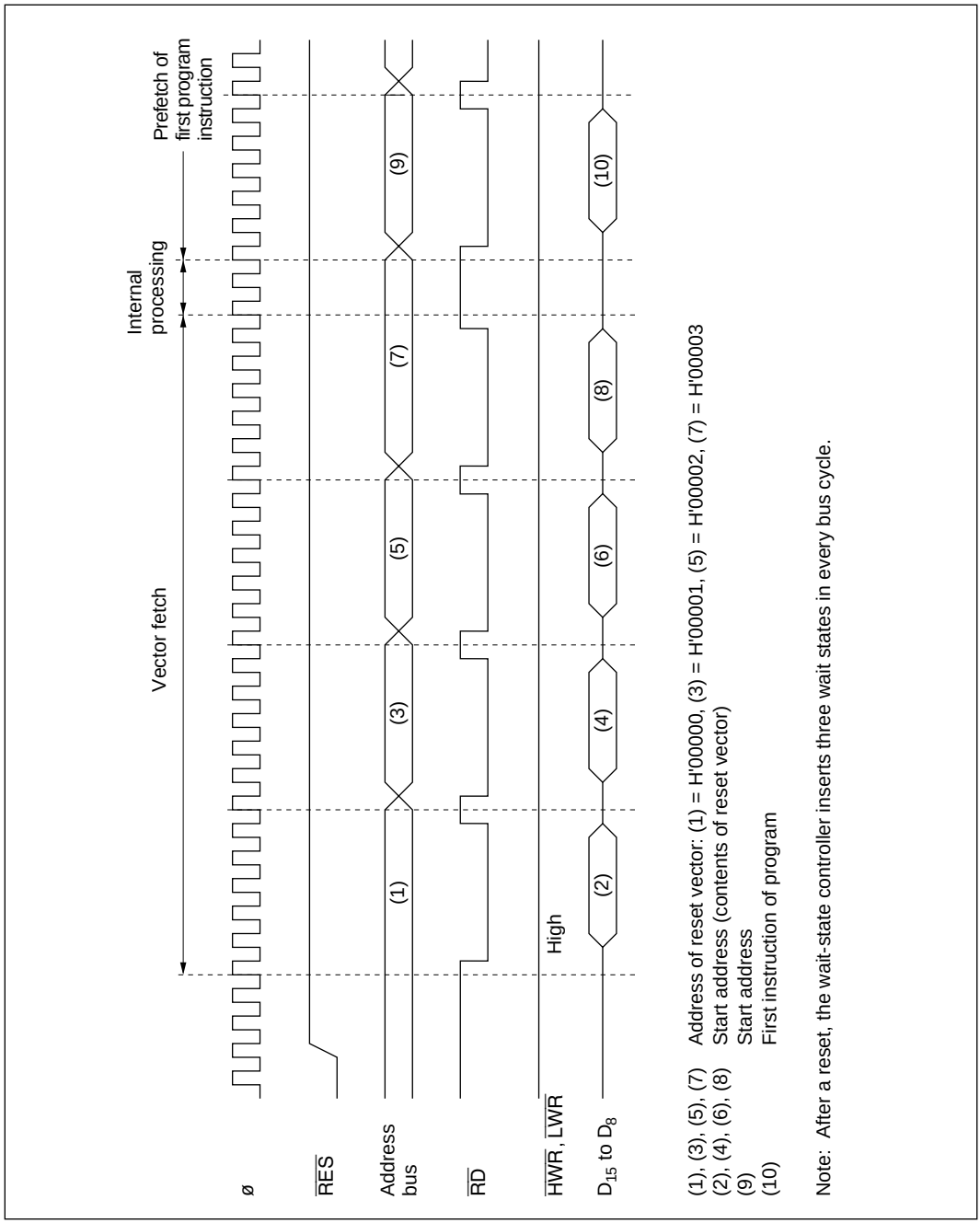
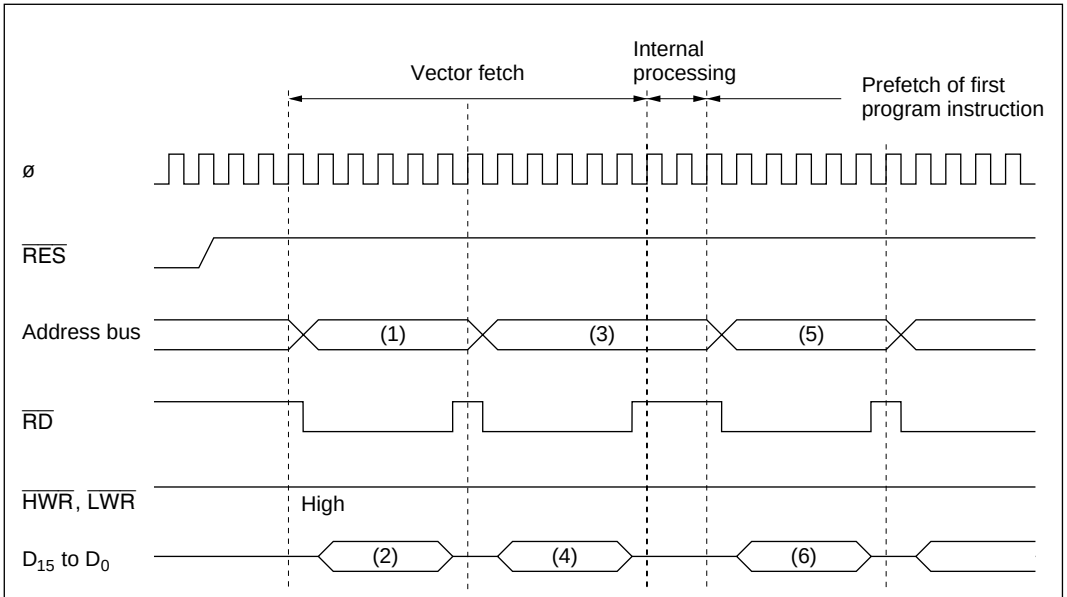


Figure 4-2 Reset Sequence (Modes 1 and 3)



(1), (3) Address of reset vector: (1) = H'00000, (3) = H'00002
(2), (4) Start address (contents of reset vector)
(5) Start address
(6) First instruction of program

Note: After a reset, the wait-state controller inserts three wait states in every bus cycle.

Figure 4-3 Reset Sequence (Modes 2 and 4)

4.2.3 Interrupts after Reset

If an interrupt is accepted after a reset but before the stack pointer (SP) is initialized, PC and CCR will not be saved correctly, leading to a program crash. To prevent this, all interrupt requests, including NMI, are disabled immediately after a reset. The first instruction of the program is always executed immediately after the reset state ends. This instruction should initialize the stack pointer (example: MOV.L #xx:32, SP).

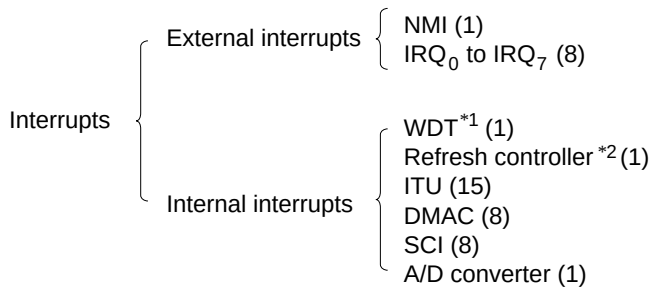
4.3 Interrupts

Interrupt exception handling can be requested by nine external sources (NMI, $\overline{IRQ_0}$ to $\overline{IRQ_7}$) and 34 internal sources in the on-chip supporting modules. Figure 4-4 classifies the interrupt sources and indicates the number of interrupts of each type.

The on-chip supporting modules that can request interrupts are the watchdog timer (WDT), refresh controller, 16-bit integrated timer-pulse unit (ITU), DMA controller (DMAC), serial communication interface (SCI), and A/D converter. Each interrupt source has a separate vector address.

NMI is the highest-priority interrupt and is always accepted. Interrupts are controlled by the interrupt controller. The interrupt controller can assign interrupts other than NMI to two priority levels, and arbitrate between simultaneous interrupts. Interrupt priorities are assigned in interrupt priority registers A and B (IPRA and IPRB) in the interrupt controller.

For details on interrupts see section 5, Interrupt Controller.



Notes: Numbers in parentheses are the number of interrupt sources.
1. When the watchdog timer is used as an interval timer, it generates an interrupt request at every counter overflow.
2. When the refresh controller is used as an interval timer, it generates an interrupt request at compare match.

Figure 4-4 Interrupt Sources and Number of Interrupts

4.4 Trap Instruction

Trap instruction exception handling starts when a TRAPA instruction is executed. If the UE bit is set to 1 in the system control register (SYSCR), the exception handling sequence sets the I bit to 1 in CCR. If the UE bit is 0, the I and UI bits are both set to 1. The TRAPA instruction fetches a start address from a vector table entry corresponding to a vector number from 0 to 3, which is specified in the instruction code.

4.5 Stack Status after Exception Handling

Figure 4-5 shows the stack after completion of trap instruction exception handling and interrupt exception handling.

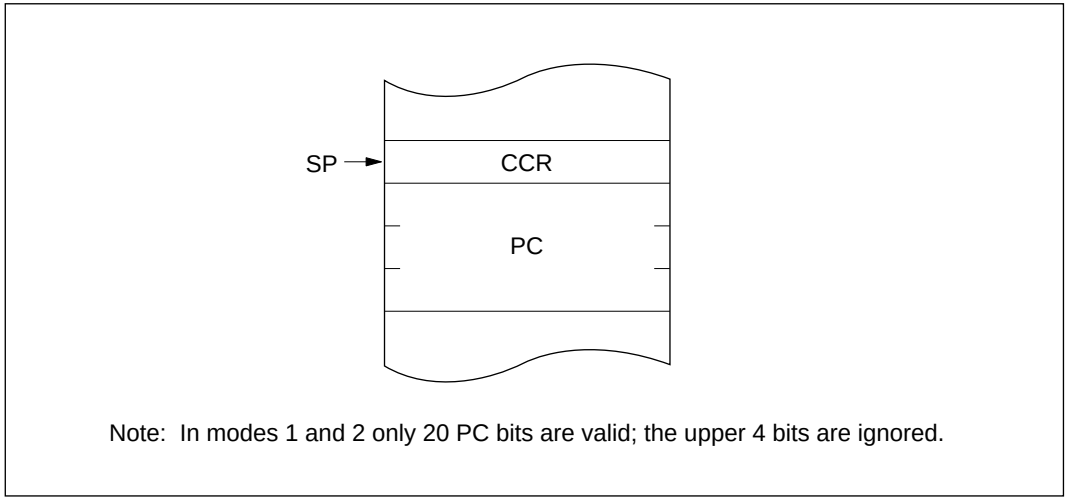


Figure 4-5 Stack after Completion of Exception Handling

4.6 Notes on Stack Usage

When accessing word data or longword data, the H8/3003 regards the lowest address bit as 0. The stack should always be accessed by word access or longword access, and the value of the stack pointer (SP, ER7) should always be kept even. Use the following instructions to save registers:

PUSH.W Rn (or MOV.W Rn, @–SP)
PUSH.L ERn (or MOV.L ERn, @–SP)

Use the following instructions to restore registers:

POP.W Rn (or MOV.W @SP+, Rn)
POP.L ERn (or MOV.L @SP+, ERn)

Setting SP to an odd value may lead to a malfunction. Figure 4-6 shows an example of what happens when the SP value is odd.

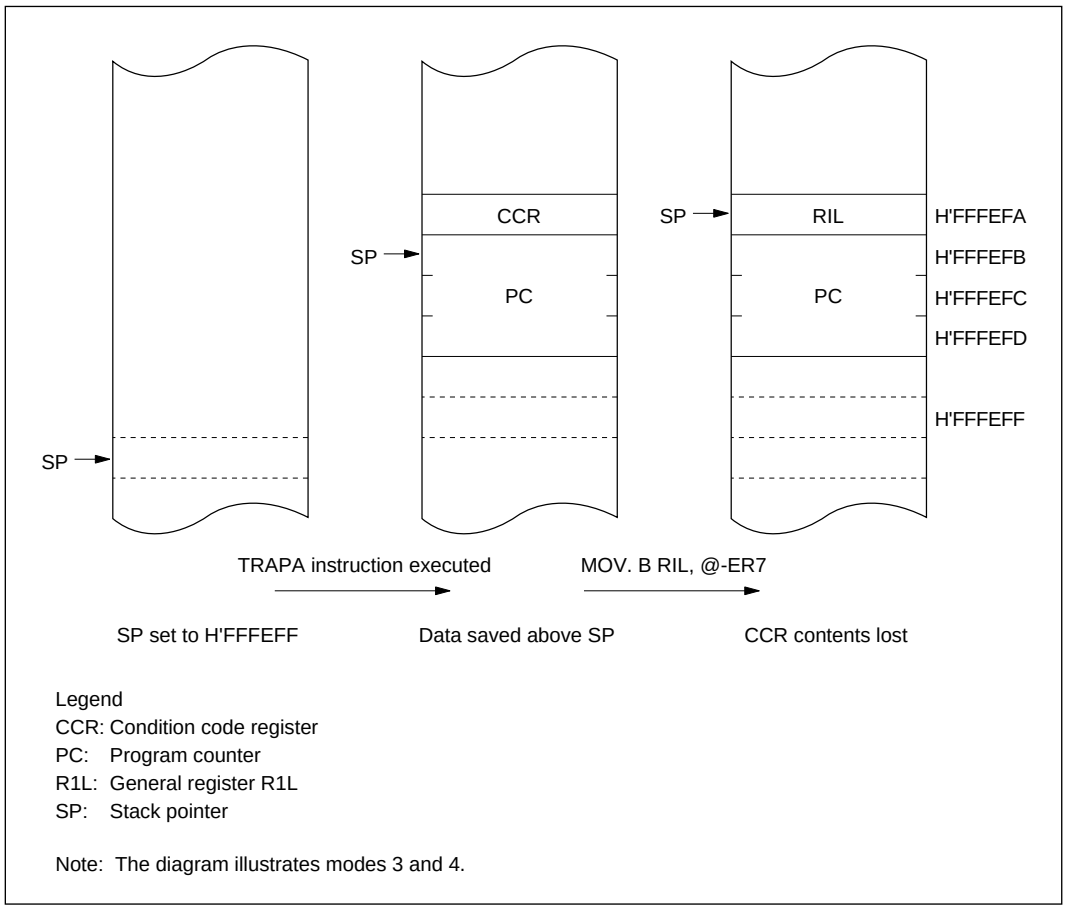


Figure 4-6 Operation when SP Value is Odd

Section 5 Interrupt Controller

5.1 Overview

5.1.1 Features

The interrupt controller has the following features:

- Interrupt priority registers (IPRs) for setting interrupt priorities

  Interrupts other than NMI can be assigned to two priority levels on a module-by-module basis in interrupt priority registers A and B (IPRA and IPRB).

- Three-level masking by the I and UI bits in the CPU condition code register (CCR)

- Independent vector addresses

  All interrupts are independently vectored; the interrupt service routine does not have to identify the interrupt source.

- Nine external interrupt pins

  NMI has the highest priority and is always accepted; either the rising or falling edge can be selected. For each of IRQ_0 to IRQ_7, sensing of the falling edge or level sensing can be selected independently.

5.1.2 Block Diagram

Figure 5-1 shows a block diagram of the interrupt controller.

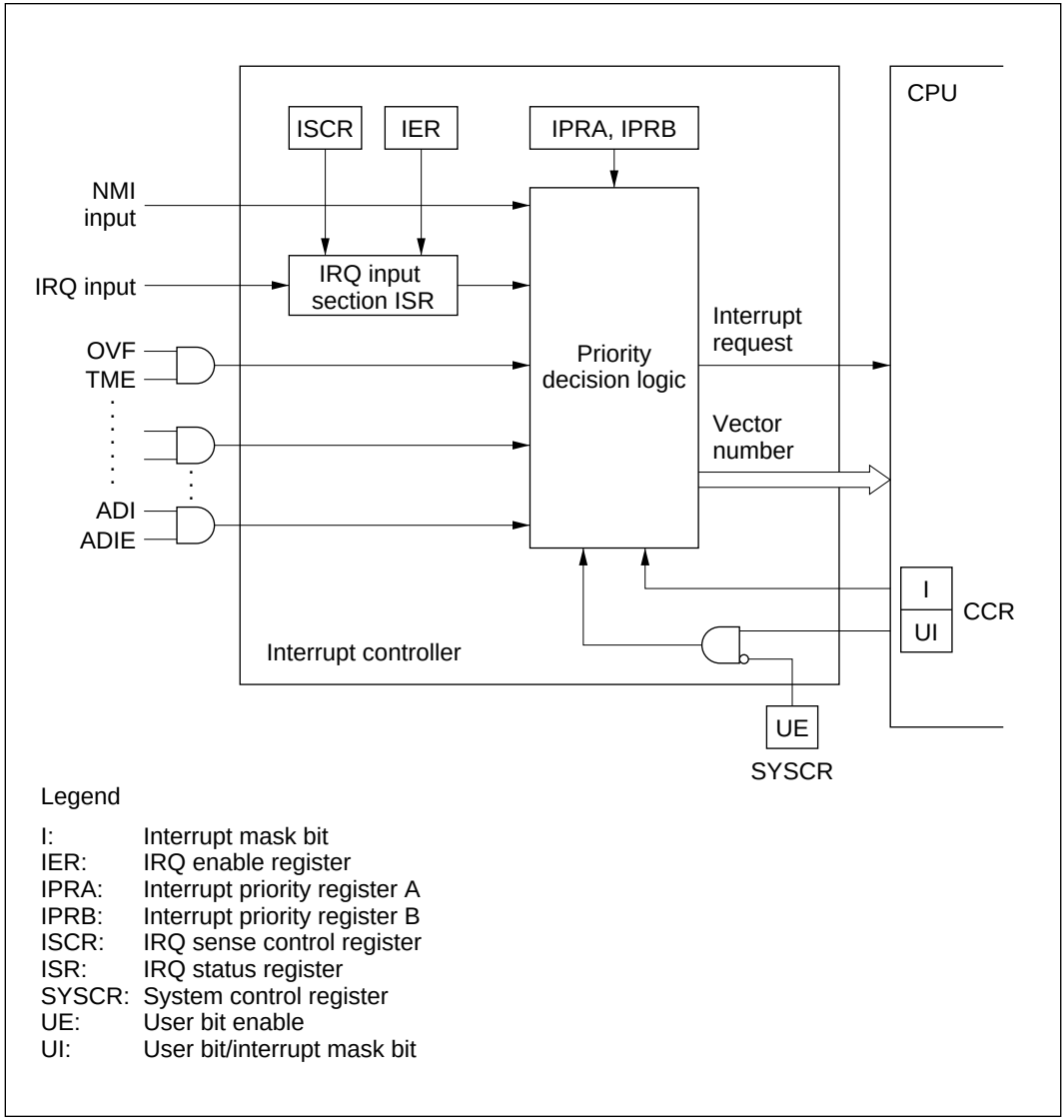


Figure 5-1 Interrupt Controller Block Diagram

5.1.3 Pin Configuration

Table 5-1 lists the interrupt pins.

Table 5-1 Interrupt Pins

Name	Abbreviation	I/O	Function
Nonmaskable interrupt	NMI	Input	Nonmaskable interrupt, rising edge or falling edge selectable
External interrupt request 7 to 0	$\overline{IRQ_7}$ to $\overline{IRQ_0}$	Input	Maskable interrupts, falling edge or level sensing selectable

5.1.4 Register Configuration

Table 5-2 lists the registers of the interrupt controller.

Table 5-2 Interrupt Controller Registers

Address*1	Name	Abbreviation	R/W	Initial Value
H'FFF2	System control register	SYSCR	R/W	H'0B
H'FFF4	IRQ sense control register	ISCR	R/W	H'00
H'FFF5	IRQ enable register	IER	R/W	H'00
H'FFF6	IRQ status register	ISR	R/(W)*2	H'00
H'FFF8	Interrupt priority register A	IPRA	R/W	H'00
H'FFF9	Interrupt priority register B	IPRB	R/W	H'00

Notes: 1. Lower 16 bits of the address.
2. Only 0 can be written, to clear flags.

5.2 Register Descriptions

5.2.1 System Control Register (SYSCR)

SYSCR is an 8-bit readable/writable register that controls software standby mode, selects the action of the UI bit in CCR, selects the NMI edge, and enables or disables the on-chip RAM.

Only bits 3 and 2 are described here. For bits 7 to 4, see section 17.2, Register Configuration. For bit 0, see section 15.2, System Control Register (SYSCR).

SYSCR is initialized to H'0B by a reset and in hardware standby mode. It is not initialized in software standby mode.

Bit	7	6	5	4	3	2	1	0
	SSBY	STS2	STS1	STS0	UE	NMIEG	—	RAME
Initial value	0	0	0	0	1	0	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

RAM enable

Reserved bit

NMI edge select
Selects the NMI input edge

Standby timer select 2 to 0

Software standby

User bit enable
Selects whether to use CCR bit 6 as a user bit or interrupt mask bit

Bit 3—User Bit Enable (UE): Selects whether to use the UI bit in CCR as a user bit or an interrupt mask bit.

Bit 3 UE	Description	
0	UI bit in CCR is used as interrupt mask bit	
1	UI bit in CCR is used as user bit	(Initial value)

Bit 2—NMI Edge Select (NMIEG): Selects the NMI input edge.

Bit 2 NMIEG	Description	
0	Interrupt is requested at falling edge of NMI input	(Initial value)
1	Interrupt is requested at rising edge of NMI input	

5.2.2 Interrupt Priority Registers A and B (IPRA, IPRB)

IPRA and IPRB are 8-bit readable/writable registers that control interrupt priority.

Interrupt Priority Register A (IPRA): IPRA is an 8-bit readable/writable register in which interrupt priority levels can be set.

Bit	7	6	5	4	3	2	1	0
	IPRA7	IPRA6	IPRA5	IPRA4	IPRA3	IPRA2	IPRA1	IPRA0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Priority level A0
Selects the priority level of ITU channel 2 interrupt requests

Priority level A1
Selects the priority level of ITU channel 1 interrupt requests

Priority level A2
Selects the priority level of ITU channel 0 interrupt requests

Priority level A3
Selects the priority level of WDT and refresh controller interrupt requests

Priority level A4
Selects the priority level of IRQ_4 to IRQ_7 interrupt requests

Priority level A5
Selects the priority level of IRQ_2 and IRQ_3 interrupt requests

Priority level A6
Selects the priority level of IRQ_1 interrupt requests

Priority level A7
Selects the priority level of IRQ_0 interrupt requests

IPRA is initialized to H'00 by a reset and in hardware standby mode.

Bit 7—Priority Level A7 (IPRA7): Selects the priority level of IRQ_0 interrupt requests.

Bit 7 IPRA7	Description	
0	IRQ_0 interrupt requests have priority level 0 (low priority)	(Initial value)
1	IRQ_0 interrupt requests have priority level 1 (high priority)	

Bit 6—Priority Level A6 (IPRA6): Selects the priority level of IRQ_1 interrupt requests.

Bit 6 IPRA6	Description	
0	IRQ_1 interrupt requests have priority level 0 (low priority)	(Initial value)
1	IRQ_1 interrupt requests have priority level 1 (high priority)	

Bit 5—Priority Level A5 (IPRA5): Selects the priority level of IRQ_2 and IRQ_3 interrupt requests.

Bit 5 IPRA5	Description	
0	IRQ_2 and IRQ_3 interrupt requests have priority level 0 (low priority)	(Initial value)
1	IRQ_2 and IRQ_3 interrupt requests have priority level 1 (high priority)	

Bit 4—Priority Level A4 (IPRA4): Selects the priority level of IRQ_4 to IRQ_7 interrupt requests.

Bit 4 IPRA4	Description	
0	IRQ_4 to IRQ_7 interrupt requests have priority level 0 (low priority)	(Initial value)
1	IRQ_4 to IRQ_7 interrupt requests have priority level 1 (high priority)	

Bit 3—Priority Level A3 (IPRA3): Selects the priority level of WDT and refresh controller interrupt requests.

Bit 3 IPRA3	Description	
0	WDT and refresh controller interrupt requests have priority level 0 (low priority)	(Initial value)
1	WDT and refresh controller interrupt requests have priority level 1 (high priority)	

Bit 2—Priority Level A2 (IPRA2): Selects the priority level of ITU channel 0 interrupt requests.

Bit 2 IPRA2	Description	
0	ITU channel 0 interrupt requests have priority level 0 (low priority)	(Initial value)
1	ITU channel 0 interrupt requests have priority level 1 (high priority)	

Bit 1—Priority Level A1 (IPRA1): Selects the priority level of ITU channel 1 interrupt requests.

Bit 1 IPRA1	Description	
0	ITU channel 1 interrupt requests have priority level 0 (low priority)	(Initial value)
1	ITU channel 1 interrupt requests have priority level 1 (high priority)	

Bit 0—Priority Level A0 (IPRA0): Selects the priority level of ITU channel 2 interrupt requests.

Bit 0 IPRA0	Description	
0	ITU channel 2 interrupt requests have priority level 0 (low priority)	(Initial value)
1	ITU channel 2 interrupt requests have priority level 1 (high priority)	

Interrupt Priority Register B (IPRB): IPRB is an 8-bit readable/writable register in which interrupt priority levels can be set.

Bit	7	6	5	4	3	2	1	0
	IPRB7	IPRB6	IPRB5	IPRB4	IPRB3	IPRB2	IPRB1	—
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Reserved bit

Priority level B1
Selects the priority level of A/D converter interrupt request

Priority level B2
Selects the priority level of SCI channel 1 interrupt requests

Priority level B3
Selects the priority level of SCI channel 0 interrupt requests

Priority level B4
Selects the priority level of DMAC group 1 interrupt requests (channels 2 and 3)

Priority level B5
Selects the priority level of DMAC group 0 interrupt requests (channels 0 and 1)

Priority level B6
Selects the priority level of ITU channel 4 interrupt requests

Priority level B7
Selects the priority level of ITU channel 3 interrupt requests

IPRB is initialized to H'00 by a reset and in hardware standby mode.

Bit 7—Priority Level B7 (IPRB7): Selects the priority level of ITU channel 3 interrupt requests.

Bit 7 IPRB7	Description	
0	ITU channel 3 interrupt requests have priority level 0 (low priority)	(Initial value)
1	ITU channel 3 interrupt requests have priority level 1 (high priority)	

Bit 6—Priority Level B6 (IPRB6): Selects the priority level of ITU channel 4 interrupt requests.

Bit 6 IPRB6	Description	
0	ITU channel 4 interrupt requests have priority level 0 (low priority)	(Initial value)
1	ITU channel 4 interrupt requests have priority level 1 (high priority)	

Bit 5—Priority Level B5 (IPRB5): Selects the priority level of DMAC group 0 interrupt requests (channels 0 and 1).

Bit 5 IPRB5	Description	
0	DMAC group 0 interrupt requests (channels 0 and 1) have priority level 0 (low priority)	(Initial value)
1	DMAC group 0 interrupt requests (channels 0 and 1) have priority level 1 (high priority)	

Bit 4—Priority Level B4 (IPRB4): Selects the priority level of DMAC group 1 interrupt requests (channels 2 and 3).

Bit 4 IPRB4	Description	
0	DMAC group 1 interrupt requests (channels 2 and 3) have priority level 0 (low priority)	(Initial value)
1	DMAC group 1 interrupt requests (channels 2 and 3) have priority level 1 (high priority)	

Bit 3—Priority Level B3 (IPRB3): Selects the priority level of SCI channel 0 interrupt requests.

Bit 3 IPRB3	Description	
0	SCI0 interrupt requests have priority level 0 (low priority)	(Initial value)
1	SCI0 interrupt requests have priority level 1 (high priority)	

Bit 2—Priority Level B2 (IPRB2): Selects the priority level of SCI channel 1 interrupt requests.

Bit 2 IPRB2	Description	
0	SCI1 interrupt requests have priority level 0 (low priority)	(Initial value)
1	SCI1 interrupt requests have priority level 1 (high priority)	

Bit 1—Priority Level B1 (IPRB1): Selects the priority level of A/D converter interrupt requests.

Bit 1 IPRB1	Description	
0	A/D converter interrupt requests have priority level 0 (low priority)	(Initial value)
1	A/D converter interrupt requests have priority level 1 (high priority)	

Bit 0—Reserved: Although reserved, this bit can be written and read.

5.2.3 IRQ Status Register (ISR)

ISR is an 8-bit readable/writable register that indicates the status of IRQ_0 to IRQ_7 interrupt requests.

Bit	7	6	5	4	3	2	1	0
	IRQ7F	IRQ6F	IRQ5F	IRQ4F	IRQ3F	IRQ2F	IRQ1F	IRQ0F
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*

IRQ_7 to IRQ_0 flags
These bits indicate IRQ_7 to IRQ_0 interrupt request status

Note: * Only 0 can be written, to clear flags.

ISR is initialized to H'00 by a reset and in hardware standby mode.

Bits 7 to 0—IRQ_7 to IRQ_0 Flags (IRQ7F to IRQ0F): These bits indicate the status of IRQ_7 to IRQ_0 interrupt requests.

Bits 7 to 0 IRQ7F to IRQ0F	Description
0	[Clearing conditions] (Initial value) 0 is written in IRQnF after reading the IRQnF flag when IRQnF = 1. IRQnSC = 0, $\overline{IRQn}$ input is high, and interrupt exception handling is carried out. IRQnSC = 1 and IRQn interrupt exception handling is carried out.
1	[Setting conditions] IRQnSC = 0 and $\overline{IRQn}$ input is low. IRQnSC = 1 and $\overline{IRQn}$ input changes from high to low.

Note: n = 7 to 0

5.2.4 IRQ Enable Register (IER)

IER is an 8-bit readable/writable register that enables or disables IRQ_0 to IRQ_7 interrupt requests.

Bit	7	6	5	4	3	2	1	0
	IRQ7E	IRQ6E	IRQ5E	IRQ4E	IRQ3E	IRQ2E	IRQ1E	IRQ0E
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

IRQ_7 to IRQ_0 enable
These bits enable or disable IRQ_7 to IRQ_0 interrupts

IER is initialized to H'00 by a reset and in hardware standby mode.

Bits 7 to 0—IRQ_7 to IRQ_0 Enable (IRQ7E to IRQ0E): These bits enable or disable IRQ_7 to IRQ_0 interrupts.

Bits 7 to 0 IRQ7E to IRQ0E	Description	
0	IRQ_7 to IRQ_0 interrupts are disabled	(Initial value)
1	IRQ_7 to IRQ_0 interrupts are enabled	

5.2.5 IRQ Sense Control Register (ISCR)

ISCR is an 8-bit readable/writable register that selects level sensing or falling-edge sensing of the inputs at pins $\overline{IRQ_7}$ to $\overline{IRQ_0}$.

Bit	7	6	5	4	3	2	1	0
	IRQ7SC	IRQ6SC	IRQ5SC	IRQ4SC	IRQ3SC	IRQ2SC	IRQ1SC	IRQ0SC
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

IRQ_7 to IRQ_0 sense control
These bits select level sensing or falling-edge sensing for IRQ_7 to IRQ_0 interrupts

ISCR is initialized to H'00 by a reset and in hardware standby mode.

Bits 7 to 0—IRQ_7 to IRQ_0 Sense Control (IRQ7SC to IRQ0SC): These bits selects whether interrupts IRQ_7 to IRQ_0 are requested by level sensing of pins $\overline{IRQ_7}$ to $\overline{IRQ_0}$, or by falling-edge sensing.

Bits 7 to 0 IRQ7SC to IRQ0SC	Description	
0	Interrupts are requested when $\overline{IRQ_7}$ to $\overline{IRQ_0}$ inputs are low	(Initial value)
1	Interrupts are requested by falling-edge input at $\overline{IRQ_7}$ to $\overline{IRQ_0}$	

5.3 Interrupt Sources

The interrupt sources include external interrupts (NMI, IRQ_0 to IRQ_7) and 34 internal interrupts.

5.3.1 External Interrupts

There are nine external interrupts: NMI, and IRQ_0 to IRQ_7. Of these, NMI, IRQ_0, IRQ_1, and IRQ_2 can be used to exit software standby mode.

NMI: NMI is the highest-priority interrupt and is always accepted, regardless of the states of the I and UI bits in CCR. The NMIEG bit in SYSCR selects whether an interrupt is requested by the rising or falling edge of the input at the NMI pin. NMI interrupt exception handling has vector number 7.

$\overline{IRQ_0}$ to $\overline{IRQ_7}$ Interrupts: These interrupts are requested by input signals at pins $\overline{IRQ_0}$ to $\overline{IRQ_7}$. The IRQ_0 to IRQ_7 interrupts have the following features.

- ISCR settings can select whether an interrupt is requested by the low level of the input at pins $\overline{IRQ_0}$ to $\overline{IRQ_7}$, or by the falling edge.
- IER settings can enable or disable the IRQ_0 to IRQ_7 interrupts. Interrupt priority levels can be assigned by four bits in IPRA (IPRA7 to IPRA4).
- The status of IRQ_0 to IRQ_7 interrupt requests is indicated in ISR. The ISR flags can be cleared to 0 by software.

Figure 5-2 shows a block diagram of interrupts IRQ_0 to IRQ_7.

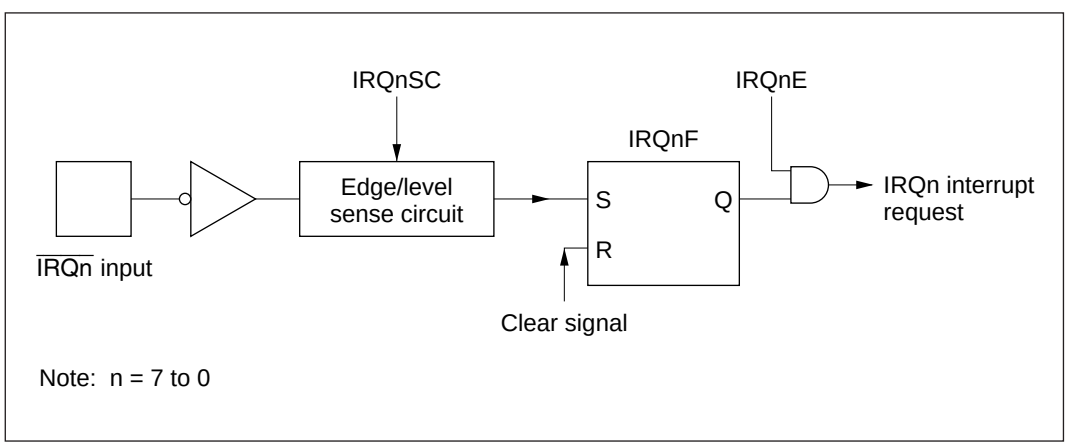


Figure 5-2 Block Diagram of Interrupts IRQ_0 to IRQ_7

Figure 5-3 shows the timing of the setting of the interrupt flags (IRQnF).

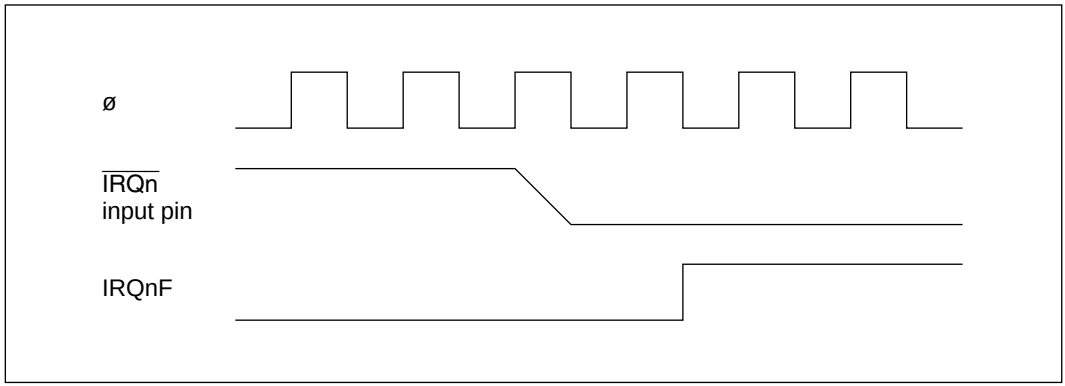


Figure 5-3 Timing of Setting of IRQnF

Interrupts IRQ_0 to IRQ_7 have vector numbers 12 to 19. These interrupts are detected regardless of whether the corresponding pin is set for input or output. When using a pin for external interrupt input, clear its DDR bit to 0 and do not use the pin for chip select output, refresh output, or SCI input or output.

5.3.2 Internal Interrupts

Thirty-four internal interrupts are requested from the on-chip supporting modules.

- Each on-chip supporting module has status flags for indicating interrupt status, and enable bits for enabling or disabling interrupts.
- Interrupt priority levels can be assigned in IPRA and IPRB.
- ITU and SCI interrupt requests can activate the DMAC, in which case no interrupt request is sent to the interrupt controller, and the I and UI bits are disregarded.

5.3.3 Interrupt Vector Table

Table 5-3 lists the interrupt sources, their vector addresses, and their default priority order. In the default priority order, smaller vector numbers have higher priority. The priority of interrupts other than NMI can be changed in IPRA and IPRB. The priority order after a reset is the default order shown in table 5-3.

Table 5-3 Interrupt Sources, Vector Addresses, and Priority

Interrupt Source	Origin	Vector Number	Vector Address*	IPR	Priority
NMI	External pins	7	H'001C to H'001F	—	High
IRQ_0		12	H'0030 to H'0033	IPRA7	
IRQ_1		13	H'0034 to H0037	IPRA6	
IRQ_2		14	H'0038 to H'003B	IPRA5	
IRQ_3		15	H'003C to H'003F		
IRQ_4		16	H'0040 to H'0043	IPRA4	
IRQ_5		17	H'0044 to H'0047		
IRQ_6		18	H'0048 to H'004B		
IRQ_7		19	H'004C to H'004F		
WOVI (interval timer)	Watchdog timer	20	H'0050 to H'0053	IPRA3	
CMI (compare match)	Refresh controller	21	H'0054 to H'0057		
Reserved	—	22	H'0058 to H'005B		
		23	H'005C to H'005F		
IMIA0 (compare match/input capture A0)	ITU channel 0	24	H'0060 to H'0063	IPRA2	
IMIB0 (compare match/input capture B0)		25	H'0064 to H'0067		
OVI0 (overflow 0)		26	H'0068 to H'006B		
Reserved	—	27	H'006C to H'006F		
IMIA1 (compare match/input capture A1)	ITU channel 1	28	H'0070 to H'0073	IPRA1	
IMIB1 (compare match/input capture B1)		29	H'0074 to H'0077		
OVI1 (overflow 1)		30	H'0078 to H'007B		
Reserved	—	31	H'007C to H'007F		
IMIA2 (compare match/input capture A2)	ITU channel 2	32	H'0080 to H'0083	IPRA0	
IMIB2 (compare match/input capture B2)		33	H'0084 to H'0087		
OVI2 (overflow 2)		34	H'0088 to H'008B		
Reserved	—	35	H'008C to H'008F		Low

Note: * Lower 16 bits of the address.

Table 5-3 Interrupt Sources, Vector Addresses, and Priority (cont)

Interrupt Source	Origin	Vector Number	Vector Address*	IPR	Priority
IMIA3 (compare match/input capture A3)	ITU channel 3	36	H'0090 to H'0093	IPRB7	High
IMIB3 (compare match/input capture B3)		37	H'0094 to H'0097		
OVI3 (overflow 3)		38	H'0098 to H'009B		
Reserved	—	39	H'009C to H'009F		
IMIA4 (compare match/input capture A4)	ITU channel 4	40	H'00A0 to H'00A3	IPRB6	
IMIB4 (compare match/input capture B4)		41	H'00A4 to H'00A7		
OVI4 (overflow 4)		42	H'00A8 to H'00AB		
Reserved	—	43	H'00AC to H'00AF		
DEND0A	DMAC group 0	44	H'00B0 to H'00B3	IPRB5	
DEND0B		45	H'00B4 to H'00B7		
DEND1A		46	H'00B8 to H'00BB		
DEND1B		47	H'00BC to H'00BF		
DEND2A	DMAC group 1	48	H'00C0 to H'00C3	IPRB4	
DEND2B		49	H'00C4 to H'00C7		
DEND3A		50	H'00C8 to H'00CB		
DEND3B		51	H'00CC to H'00CF		
ERI0 (receive error 0)	SCI channel 0	52	H'00D0 to H'00D3	IPRB3	
RXI0 (receive data full 0)		53	H'00D4 to H'00D7		
TXI0 (transmit data empty 0)		54	H'00D8 to H'00DB		
TEI0 (transmit end 0)		55	H'00DC to H'00DF		
ERI1 (receive error 1)	SCI channel 1	56	H'00E0 to H'00E3	IPRB2	
RXI1 (receive data full 1)		57	H'00E4 to H'00E7		
TXI1 (transmit data empty 1)		58	H'00E8 to H'00EB		
TEI1 (transmit end 1)		59	H'00EC to H'00EF		
ADI (A/D end)	A/D	60	H'00F0 to H'00F3	IPRB1	Low

Note: * Lower 16 bits of the address.

5.4 Interrupt Operation

5.4.1 Interrupt Handling Process

The H8/3003 handles interrupts differently depending on the setting of the UE bit. When UE = 1, interrupts are controlled by the I bit. When UE = 0, interrupts are controlled by the I and UI bits. Table 5-4 indicates how interrupts are handled for all setting combinations of the UE, I, and UI bits.

NMI interrupts are always accepted except in the reset and hardware standby states. IRQ interrupts and interrupts from the on-chip supporting modules have their own enable bits. Interrupt requests are ignored when the enable bits are cleared to 0.

Table 5-4 UE, I, and UI Bit Settings and Interrupt Handling

SYSCR	CCR		
UE	**I**	**UI**	**Description**
1	0	—	All interrupts are accepted. Interrupts with priority level 1 have higher priority.
	1	—	No interrupts are accepted except NMI.
0	0	—	All interrupts are accepted. Interrupts with priority level 1 have higher priority.
	1	0	NMI and interrupts with priority level 1 are accepted.
		1	No interrupts are accepted except NMI.

UE = 1: Interrupts IRQ_0 to IRQ_7 and interrupts from the on-chip supporting modules can all be masked by the I bit in the CPU's CCR. Interrupts are masked when the I bit is set to 1, and unmasked when the I bit is cleared to 0. Interrupts with priority level 1 have higher priority. Figure 5-4 is a flowchart showing how interrupts are accepted when UE = 1.

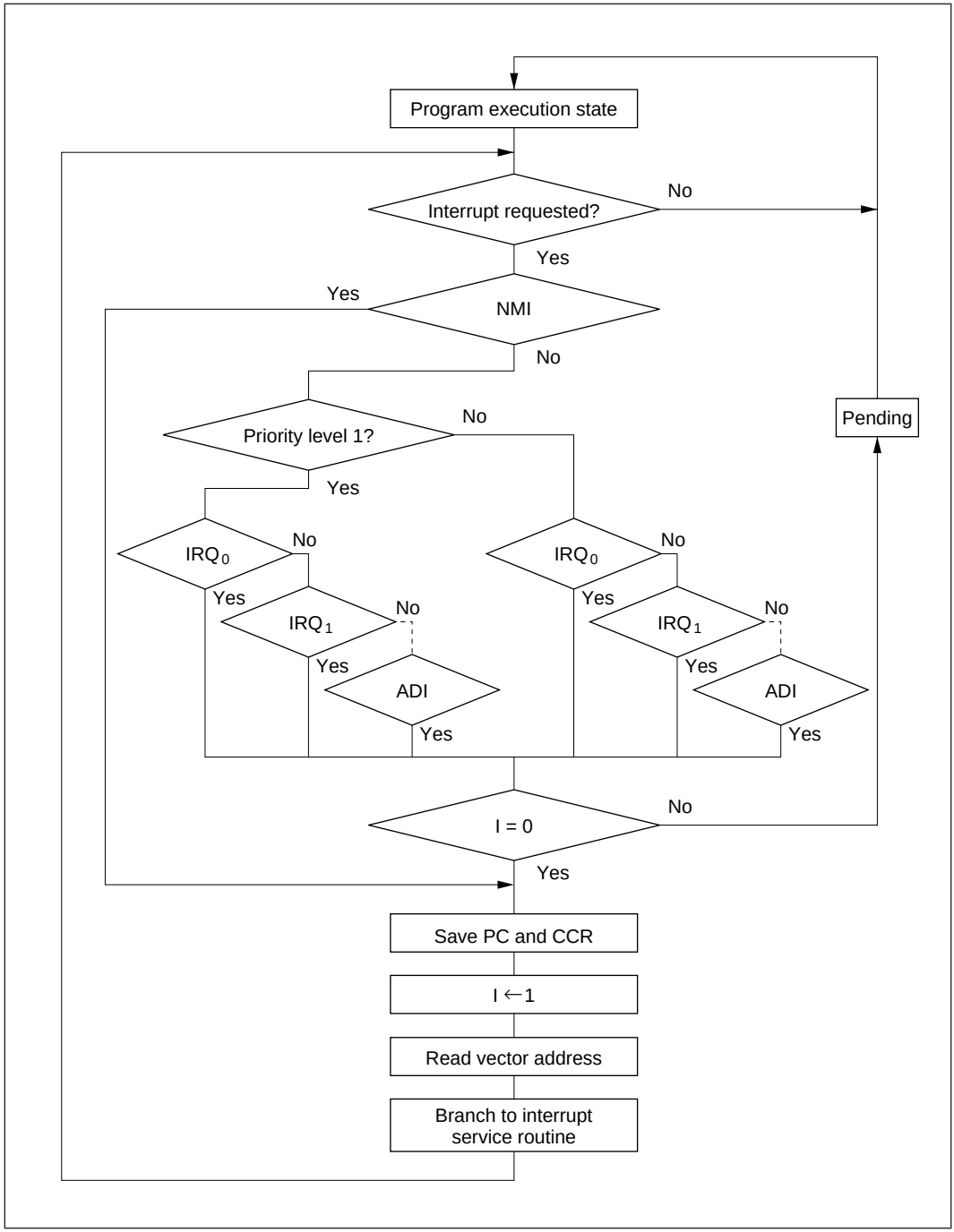


Figure 5-4 Process Up to Interrupt Acceptance when UE = 1

- If an interrupt condition occurs and the corresponding interrupt enable bit is set to 1, an interrupt request is sent to the interrupt controller.
- When the interrupt controller receives one or more interrupt requests, it selects the highest-priority request, following the IPR interrupt priority settings, and holds other requests pending. If two or more interrupts with the same IPR setting are requested simultaneously, the interrupt controller follows the priority order shown in table 5-3.
- The interrupt controller checks the I bit. If the I bit is cleared to 0, the selected interrupt request is accepted. If the I bit is set to 1, only NMI is accepted; other interrupt requests are held pending.
- When an interrupt request is accepted, interrupt exception handling starts after execution of the current instruction has been completed.
- In interrupt exception handling, PC and CCR are saved to the stack area. The PC value that is saved indicates the address of the first instruction that will be executed after the return from the interrupt service routine.
- Next the I bit is set to 1 in CCR, masking all interrupts except NMI.
- The vector address of the accepted interrupt is generated, and the interrupt service routine starts executing from the address indicated by the contents of the vector address.

UE = 0: The I and UI bits in the CPU's CCR and the IPR bits enable three-level masking of IRQ_0 to IRQ_7 interrupts and interrupts from the on-chip supporting modules.

- Interrupt requests with priority level 0 are masked when the I bit is set to 1, and are unmasked when the I bit is cleared to 0.
- Interrupt requests with priority level 1 are masked when the I and UI bits are both set to 1, and are unmasked when either the I bit or the UI bit is cleared to 0.

  For example, if the interrupt enable bits of all interrupt requests are set to 1, IPRA is set to H'20, and IPRB is set to H'00 (giving IRQ_2 and IRQ_3 interrupt requests priority over other interrupts), interrupts are masked as follows:

  a. If I = 0, all interrupts are unmasked (priority order: NMI > IRQ_2 > IRQ_3 >IRQ_0 …).
  b. If I = 1 and UI = 0, only NMI, IRQ_2, and IRQ_3 are unmasked.
  c. If I = 1 and UI = 1, all interrupts are masked except NMI.

Figure 5-5 shows the transitions among the above states.

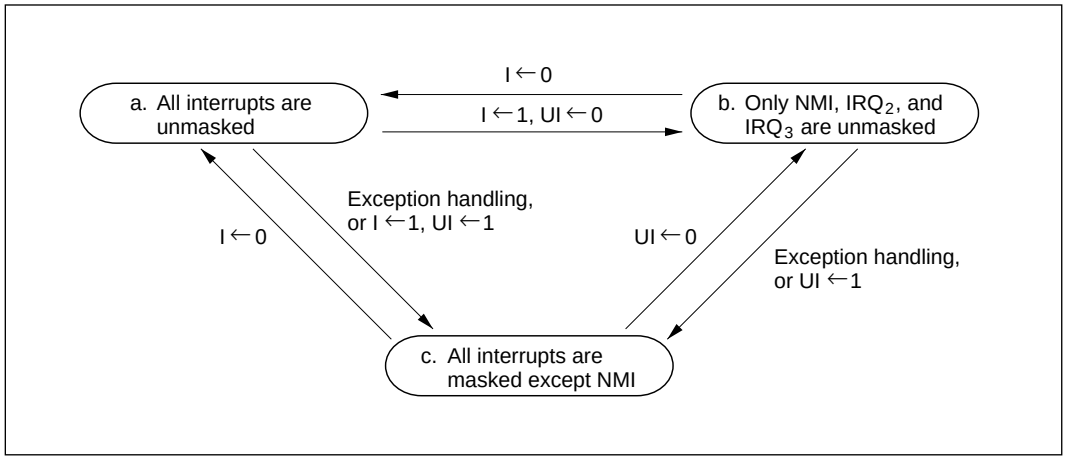


Figure 5-5 Interrupt Masking State Transitions (Example)

Figure 5-6 is a flowchart showing how interrupts are accepted when UE = 0.

- If an interrupt condition occurs and the corresponding interrupt enable bit is set to 1, an interrupt request is sent to the interrupt controller.
- When the interrupt controller receives one or more interrupt requests, it selects the highest-priority request, following the IPR interrupt priority settings, and holds other requests pending. If two or more interrupts with the same IPR setting are requested simultaneously, the interrupt controller follows the priority order shown in table 5-3.
- The interrupt controller checks the I bit. If the I bit is cleared to 0, the selected interrupt request is accepted regardless of its IPR setting, and regardless of the UI bit. If the I bit is set to 1 and the UI bit is cleared to 0, only NMI and interrupts with priority level 1 are accepted; interrupt requests with priority level 0 are held pending. If the I bit and UI bit are both set to 1, only NMI is accepted; all other interrupt requests are held pending.
- When an interrupt request is accepted, interrupt exception handling starts after execution of the current instruction has been completed.
- In interrupt exception handling, PC and CCR are saved to the stack area. The PC value that is saved indicates the address of the first instruction that will be executed after the return from the interrupt service routine.
- The I and UI bits are set to 1 in CCR, masking all interrupts except NMI.
- The vector address of the accepted interrupt is generated, and the interrupt service routine starts executing from the address indicated by the contents of the vector address.

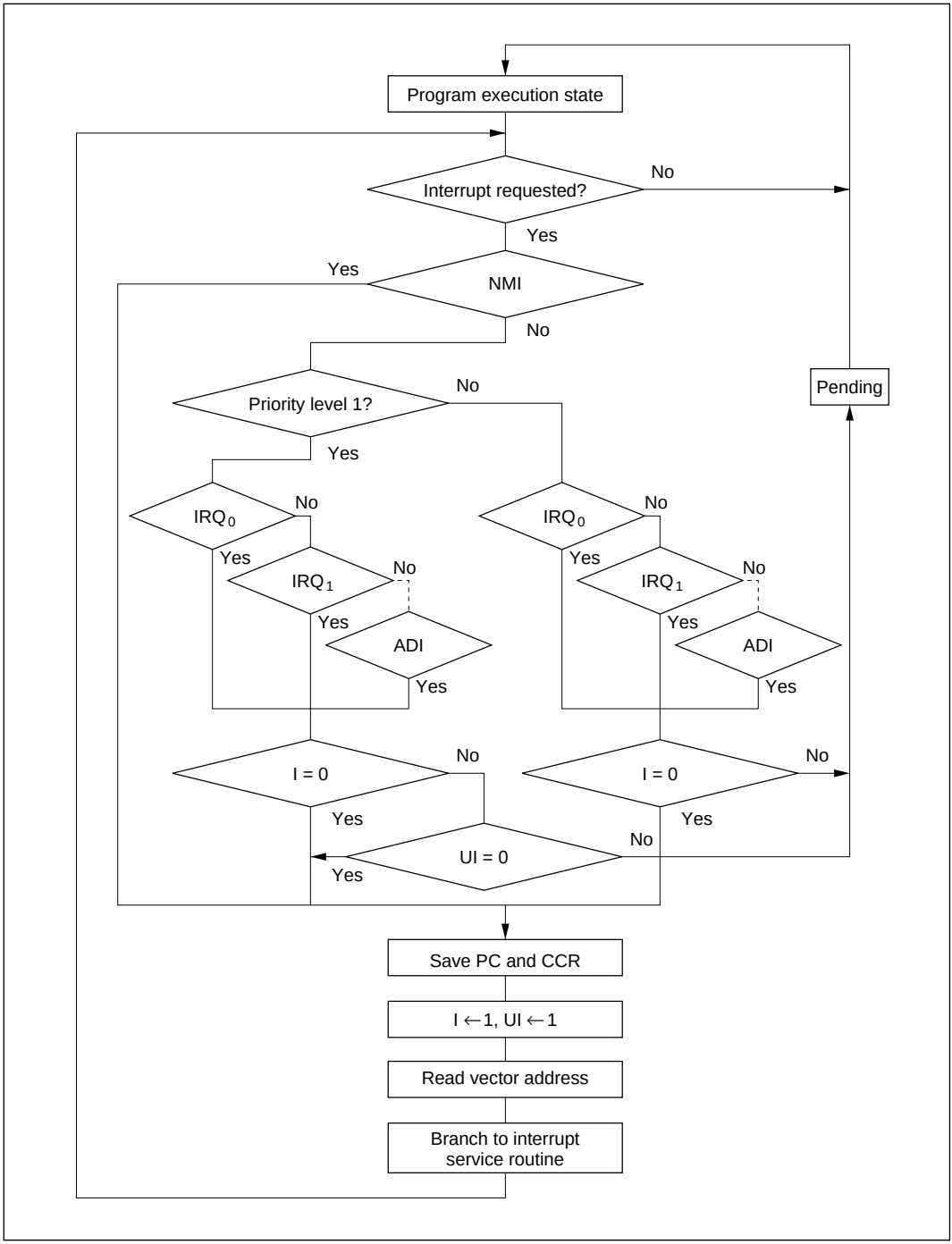


Figure 5-6 Process Up to Interrupt Acceptance when UE = 0

5.4.2 Interrupt Sequence

Figure 5-7 shows the interrupt sequence in mode 2 when the program code and stack are in an external memory area accessed in two states via a 16-bit bus.

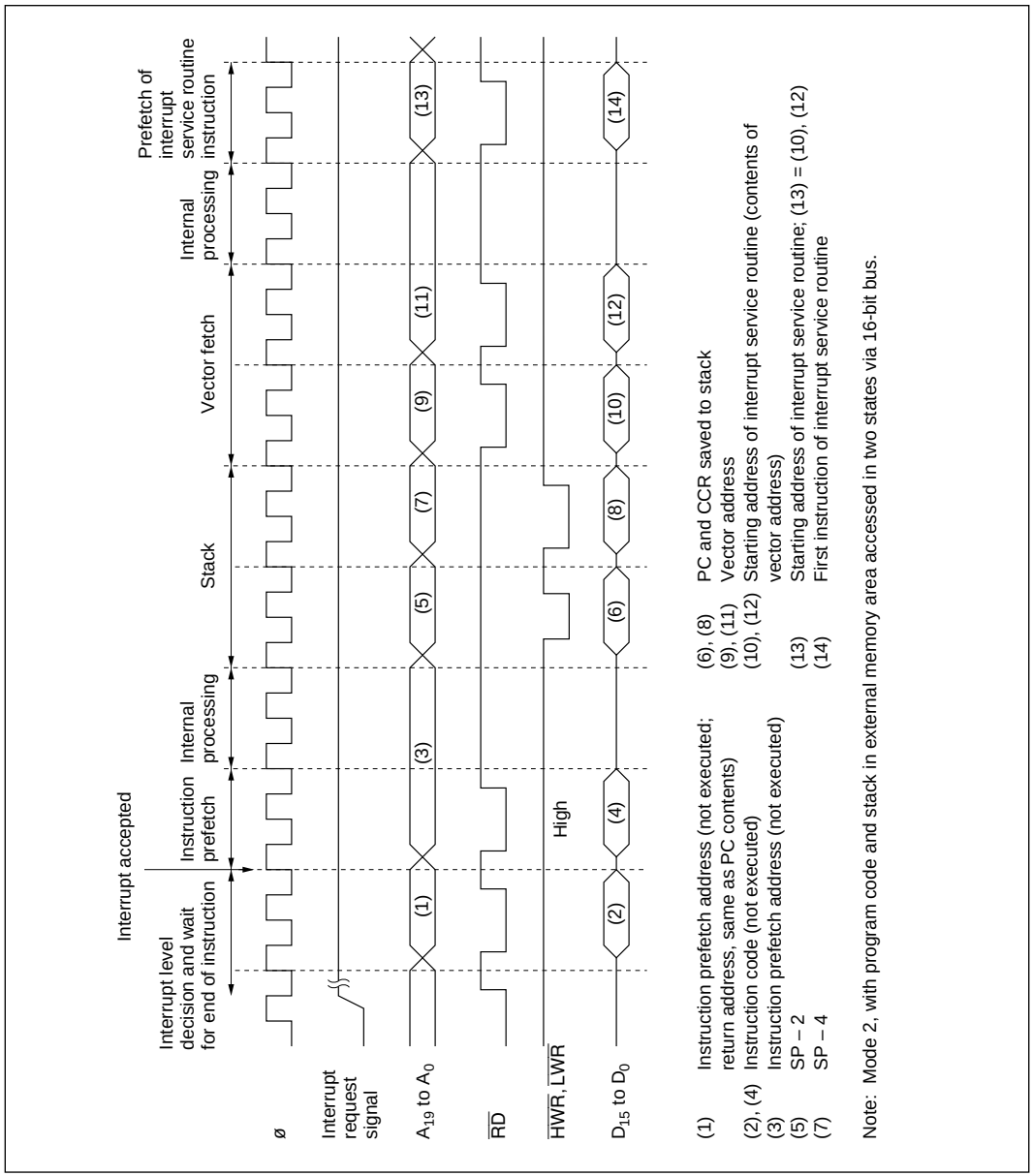


Figure 5-7 Interrupt Sequence (Mode 2, Two-State Access, Stack in External Memory)

5.4.3 Interrupt Response Time

Table 5-5 indicates the interrupt response time from the occurrence of an interrupt request until the first instruction of the interrupt service routine is executed.

Table 5-5 Interrupt Response Time

No.	Item	On-Chip Memory	External Memory			
			8-Bit Bus		16-Bit Bus	
			2 States	3 States	2 States	3 States
1	Interrupt priority decision	2*1	2*1	2*1	2*1	2*1
2	Maximum number of states until end of current instruction	1 to 23	1 to 27	1 to 31*4	1 to 23	1 to 25*4
3	Saving PC and CCR to stack	4	8	12*4	4	6*4
4	Vector fetch	4	8	12*4	4	6*4
5	Instruction prefetch*2	4	8	12*4	4	6*4
6	Internal processing*3	4	4	4	4	4
Total		19 to 41	31 to 57	43 to 73	19 to 41	25 to 49

Notes: 1. 1 state for internal interrupts.
2. Prefetch after the interrupt is accepted and prefetch of the first instruction in the interrupt service routine.
3. Internal processing after the interrupt is accepted and internal processing after prefetch.
4. The number of states increases if wait states are inserted in external memory access.

5.5 Usage Notes

5.5.1 Contention between Interrupt and Interrupt-Disabling Instruction

When an instruction clears an interrupt enable bit to 0 to disable the interrupt, the interrupt is not disabled until after execution of the instruction is completed. If an interrupt occurs while a BCLR, MOV, or other instruction is being executed to clear its interrupt enable bit to 0, at the instant when execution of the instruction ends the interrupt is still enabled, so its interrupt exception handling is carried out. If a higher-priority interrupt is also requested, however, interrupt exception handling for the higher-priority interrupt is carried out, and the lower-priority interrupt is ignored. This also applies to the clearing of an interrupt flag.

Figure 5-8 shows an example in which an IMIEA bit is cleared to 0 in the ITU.

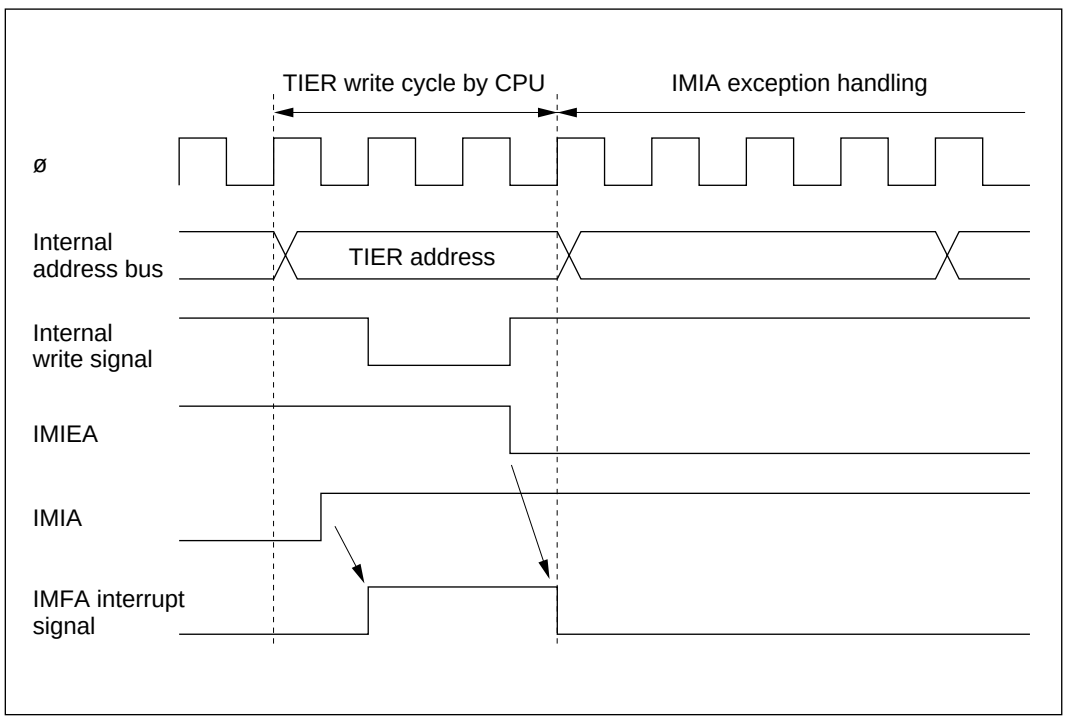


Figure 5-8 Contention between Interrupt and Interrupt-Disabling Instruction

This type of contention will not occur if the interrupt is masked when the interrupt enable bit or flag is cleared to 0.

5.5.2 Instructions that Inhibit Interrupts

The LDC, ANDC, ORC, and XORC instructions inhibit interrupts. When an interrupt occurs, after determining the interrupt priority, the interrupt controller requests a CPU interrupt. If the CPU is currently executing one of these interrupt-inhibiting instructions, however, when the instruction is completed the CPU always continues by executing the next instruction.

5.5.3 Interrupts during EEPMOV Instruction Execution

The EEPMOV.B and EEPMOV.W instructions differ in their reaction to interrupt requests.

When the EEPMOV.B instruction is executing a transfer, no interrupts are accepted until the transfer is completed, not even NMI.

When the EEPMOV.W instruction is executing a transfer, interrupt requests other than NMI are not accepted until the transfer is completed. If NMI is requested, NMI exception handling starts at a transfer cycle boundary. The PC value saved on the stack is the address of the next instruction. Programs should be coded as follows to allow for NMI interrupts during EEPMOV.W execution:

```
L1:  EEPMOV.W
     MOV.W R4,R4
     BNE  L1
```

Section 6 Bus Controller

6.1 Overview

The H8/3003 has an on-chip bus controller that divides the address space into eight areas and can assign different bus specifications to each. This enables different types of memory to be connected easily.

A bus arbitration function of the bus controller controls the operation of the DMA controller (DMAC) and refresh controller. The bus controller can also release the bus to an external device.

6.1.1 Features

Features of the bus controller are listed below.

- Independent settings for address areas 0 to 7
  - — 128-kbyte areas in 1-Mbyte modes; 2-Mbyte areas in 16-Mbyte modes.
  - — Chip select signals ($\overline{CS}_0$ to $\overline{CS}_7$) can be output for areas 0 to 7.
  - — Areas can be designated for 8-bit or 16-bit access.
  - — Areas can be designated for two-state or three-state access.
- Four wait modes
  - — Programmable wait mode, pin auto-wait mode, and pin wait modes 0 and 1 can be selected.
  - — Zero to three wait states can be inserted automatically.
- Bus arbitration function
  - — A built-in bus arbiter grants the bus right to the CPU, DMAC, refresh controller, or an external bus master.

6.1.2 Block Diagram

Figure 6-1 shows a block diagram of the bus controller.

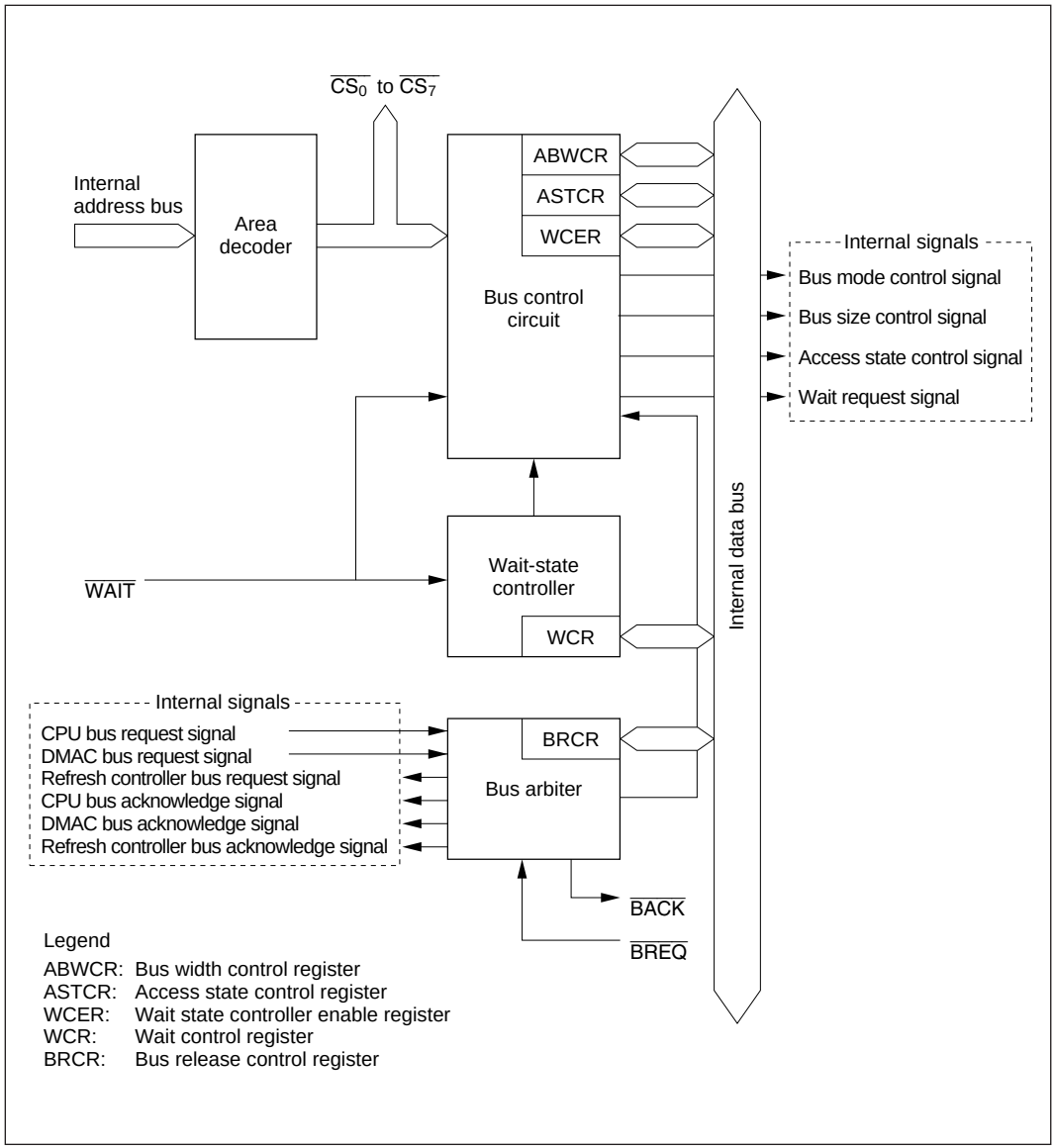


Figure 6-1 Block Diagram of Bus Controller

6.1.3 Input/Output Pins

Table 6-1 summarizes the bus controller's input/output pins.

Table 6-1 Bus Controller Pins

Name	Abbreviation	I/O	Function
Chip select 0 to 7	$\overline{CS_0}$ to $\overline{CS_7}$	Output	Strobe signals selecting areas 0 to 7
Address strobe	$\overline{AS}$	Output	Strobe signal indicating valid address output on the address bus
Read	$\overline{RD}$	Output	Strobe signal indicating reading from the external address space
High write	$\overline{HWR}$	Output	Strobe signal indicating writing to the external address space, with valid data on the upper data bus (D_{15} to D_8)
Low write	$\overline{LWR}$	Output	Strobe signal indicating writing to the external address space, with valid data on the lower data bus (D_7 to D_0)
Wait	$\overline{WAIT}$	Input	Wait request signal for access to external three-state-access areas
Bus request	$\overline{BREQ}$	Input	Request signal for releasing the bus to an external device
Bus acknowledge	$\overline{BACK}$	Output	Acknowledge signal indicating the bus is released to an external device

6.1.4 Register Configuration

Table 6-2 summarizes the bus controller's registers.

Table 6-2 Bus Controller Registers

Address*	Name	Abbreviation	R/W	Initial Value	
				Modes 1 & 3	Modes 2 & 4
H'FFEC	Bus width control register	ABWCR	R/W	H'FF	H'00
H'FFED	Access state control register	ASTCR	R/W	H'FF	H'FF
H'FFEE	Wait control register	WCR	R/W	H'F3	H'F3
H'FFEF	Wait state controller enable register	WCER	R/W	H'FF	H'FF
H'FFF3	Bus release control register	BRCR	R/W	H'FE	H'FE

Note: * Lower 16 bits of the address.

6.2 Register Descriptions

6.2.1 Bus Width Control Register (ABWCR)

ABWCR is an 8-bit readable/writable register that selects 8-bit or 16-bit access for each area.

Bit		7	6	5	4	3	2	1	0
		ABW7	ABW6	ABW5	ABW4	ABW3	ABW2	ABW1	ABW0
Initial value	Mode 1, 3	1	1	1	1	1	1	1	1
	Mode 2, 4	0	0	0	0	0	0	0	0
Read/Write		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Bits selecting bus width for each area

When ABWCR contains H'FF (selecting 8-bit access for all areas), the H8/3003 operates in 8-bit bus mode: the upper data bus (D_{15} to D_8) is valid, and port 4 is an input/output port. When at least one bit is cleared to 0 in ABWCR, the H8/3003 operates in 16-bit bus mode with a 16-bit data bus (D_{15} to D_0). In modes 1 and 3, ABWCR is initialized to H'FF by a reset and in hardware standby mode. In modes 2 and 4, ABWCR is initialized to H'00 by a reset and in hardware standby mode. ABWCR is not initialized in software standby mode.

Bits 7 to 0—Area 7 to 0 Bus Width Control (ABW7 to ABW0): These bits select 8-bit access or 16-bit access to the corresponding address areas.

Bits 7 to 0 ABW7 to ABW0	Description
0	Areas 7 to 0 are 16-bit access areas
1	Areas 7 to 0 are 8-bit access areas

ABWCR specifies the bus width of external memory areas. The bus width of on-chip memory and registers is fixed and does not depend on ABWCR settings.

6.2.2 Access State Control Register (ASTCR)

ASTCR is an 8-bit readable/writable register that selects whether each area is accessed in two states or three states.

Bit	7	6	5	4	3	2	1	0
	AST7	AST6	AST5	AST4	AST3	AST2	AST1	AST0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Bits selecting number of states for access to each area

ASTCR is initialized to H'FF by a reset and in hardware standby mode. It is not initialized in software standby mode.

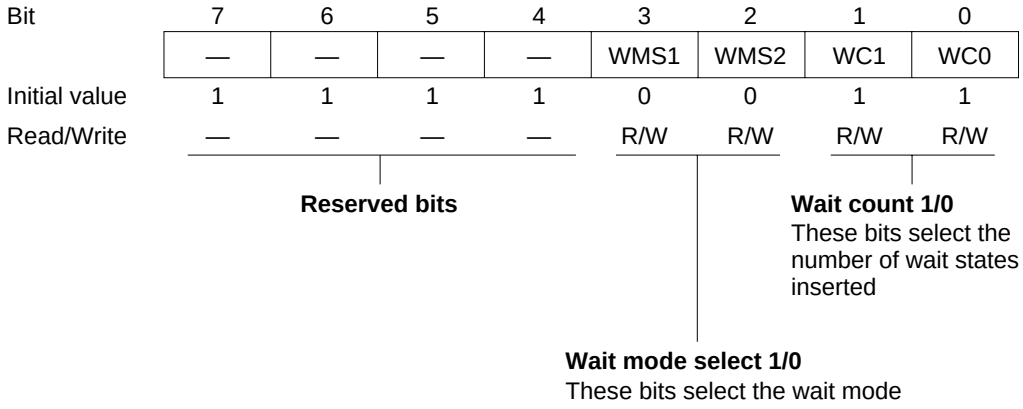
Bits 7 to 0—Area 7 to 0 Access State Control (AST7 to AST0): These bits select whether the corresponding area is accessed in two or three states.

Bits 7 to 0 AST7 to AST0	Description	
0	Areas 7 to 0 are accessed in two states	
1	Areas 7 to 0 are accessed in three states	(Initial value)

ASTCR specifies the number of states in which external areas are accessed. On-chip memory and registers are accessed in a fixed number of states that does not depend on ASTCR settings.

6.2.3 Wait Control Register (WCR)

WCR is an 8-bit readable/writable register that selects the wait mode for the wait-state controller (WSC) and specifies the number of wait states.



WCR is initialized to H'F3 by a reset and in hardware standby mode. It is not initialized in software standby mode.

Bits 7 to 4—Reserved: Read-only bits, always read as 1.

Bits 3 and 2—Wait Mode Select 1 and 0 (WMS1/0): These bits select the wait mode.

Bit 3 WMS1	Bit 2 WMS0	Description	
0	0	Programmable wait mode	(Initial value)
	1	No wait states inserted by wait-state controller	
1	0	Pin wait mode 1	
	1	Pin auto-wait mode	

Bits 1 and 0—Wait Count 1 and 0 (WC1/0): These bits select the number of wait states inserted in access to external three-state-access areas.

Bit 1 WC1	Bit 0 WC0	Description
0	0	No wait states inserted by wait-state controller
	1	1 state inserted
1	0	2 states inserted
	1	3 states inserted (Initial value)

6.2.4 Wait State Control Enable Register (WCER)

WCER is an 8-bit readable/writable register that enables or disables wait-state control of external three-state-access areas by the wait-state controller.

Bit	7	6	5	4	3	2	1	0
	WCE7	WCE6	WCE5	WCE4	WCE3	WCE2	WCE1	WCE0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Wait state controller enable 7 to 0
These bits enable or disable wait-state control

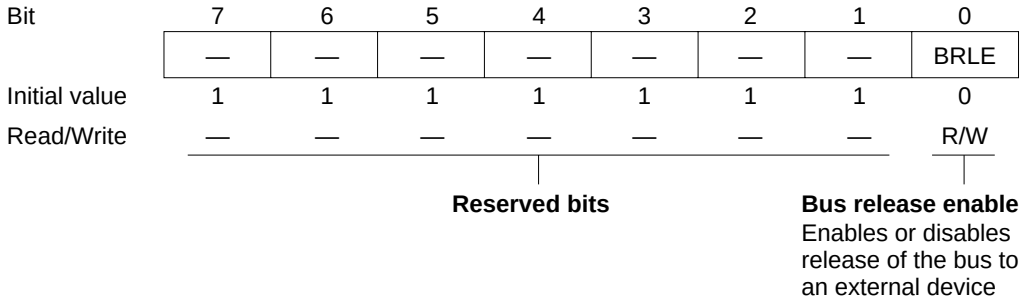
WCER is initialized to H'FF by a reset and in hardware standby mode. It is not initialized in software standby mode.

Bits 7 to 0—Wait-State Control Enable 7 to 0 (WCE7 to WCE0): These bits enable or disable wait-state control of external three-state-access areas.

Bits 7 to 0 WCE7 to WCE0	Description
0	Wait-state control disabled (pin wait mode 0)
1	Wait-state control enabled (Initial value)

6.2.5 Bus Release Control Register (BRCR)

BRCR is an 8-bit readable/writable register that enables or disables release of the bus to an external device.



BRCR is initialized to H'FE by a reset and in hardware standby mode. It is not initialized in software standby mode.

Bits 7 to 1—Reserved: Read-only bits, always read as 1.

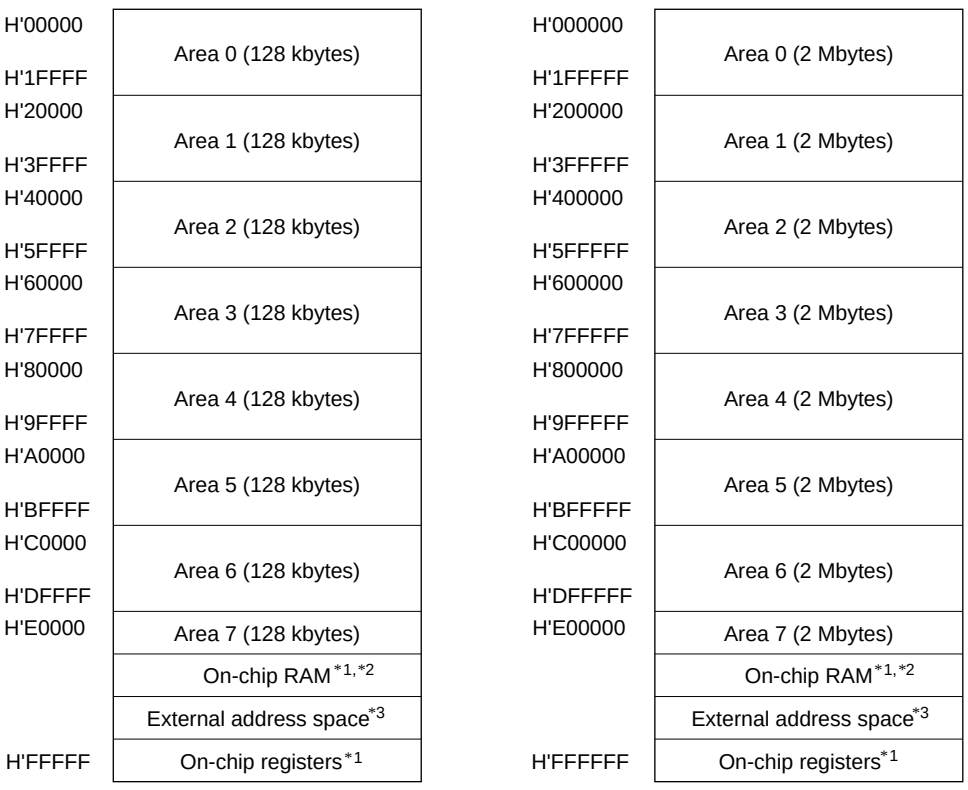
Bit 0—Bus Release Enable (BRLE): Enables or disables release of the bus to an external device.

Bit 0 BRLE	Description	
0	The bus cannot be released to an external device; $\overline{\text{BREQ}}$ and $\overline{\text{BACK}}$ can be used as input/output pins	(Initial value)
1	The bus can be released to an external device	

6.3 Operation

6.3.1 Area Division

The external address space is divided into areas 0 to 7. Each area has a size of 128 kbytes in the 1-Mbyte modes, or 2 Mbytes in the 16-Mbyte modes. Figure 6-2 shows a general view of the memory map.



a. 1-Mbyte modes (modes 1 and 2)

b. 16-Mbyte modes (modes 3 and 4)

Notes: 1. The on-chip RAM and on-chip registers have a fixed bus width and are accessed in a fixed number of states.
2. When the RAME bit is cleared to 0 in SYSCR, this area conforms to the specifications of area 7.
3. The 12-byte external address space conforms to the specifications of area 7.

Figure 6-2 Access Area Map for Modes 1 to 4

Chip select signals ($\overline{CS_0}$ to $\overline{CS_7}$) can be output for each area. The bus specifications for each area can be selected in ABWCR, ASTCR, WCER, and WCR as shown in table 6-3.

Table 6-3 Bus Specifications

ABWCR	ASTCR	WCER	WCR		Bus Specifications		
ABWn	ASTn	WCEn	WMS1	WMS0	Bus Width	Access States	Wait Mode
0	0	—	—	—	16	2	Disabled
	1	0	—	—	16	3	Pin wait mode 0
		1	0	0	16	3	Programmable wait mode
				1	16	3	Disabled
			1	0	16	3	Pin wait mode 1
				1	16	3	Pin auto-wait mode
1	0	—	—	—	8	2	Disabled
	1	0	—	—	8	3	Pin wait mode 0
		1	0	0	8	3	Programmable wait mode
				1	8	3	Disabled
			1	0	8	3	Pin wait mode 1
				1	8	3	Pin auto-wait mode

Note: n = 0 to 7

6.3.2 Chip Select Signals

For each of areas 0 to 7, the H8/3003 can output a chip select signal ($\overline{CS_0}$ to $\overline{CS_7}$) that goes low to indicate when the area is selected. Figure 6-3 shows the output timing of a $\overline{CSn}$ signal.

Output of the $\overline{CS_n}$ signal is enabled or disabled in the data direction register (DDR) of the corresponding port. A reset leaves pin $\overline{CS_0}$ in the output state and pins $\overline{CS_1}$ to $\overline{CS_7}$ in the input state. To output chip select signals $\overline{CS_1}$ to $\overline{CS_7}$, the corresponding DDR bits must be set to 1. For details see section 9, I/O Ports.

When the on-chip RAM and on-chip registers are accessed, $\overline{CS_7}$ goes low but the $\overline{AS}$, $\overline{RD}$, $\overline{HWR}$, and $\overline{LWR}$ signals remain high. The $\overline{CS_n}$ signals are decoded from the address signals. They can be used as chip select signals for SRAM and other devices.

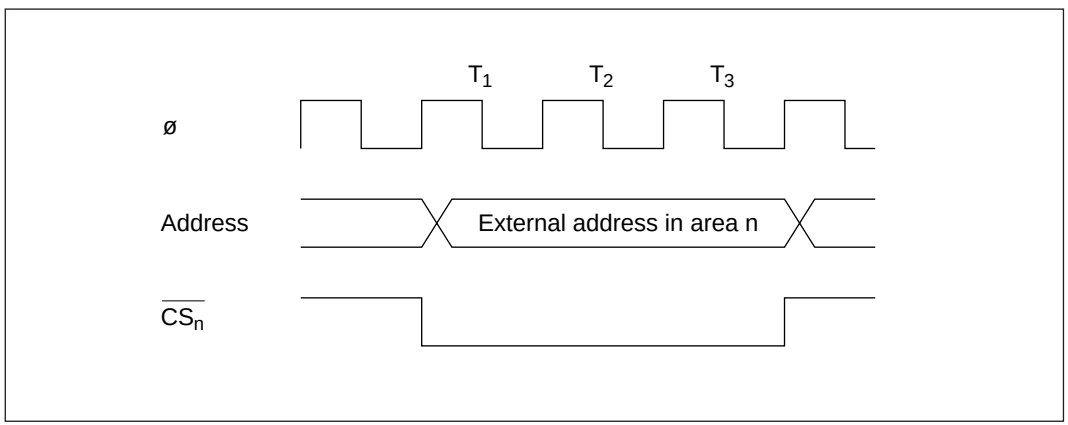


Figure 6-3 $\overline{CS_n}$ Output Timing

6.3.3 Data Bus

The H8/3003 allows either 8-bit access or 16-bit access to be designated for each of areas 0 to 7. An 8-bit-access area uses the upper data bus (D_{15} to D_8). A 16-bit-access area uses both the upper data bus (D_{15} to D_8) and lower data bus (D_7 to D_0).

In read access the $\overline{RD}$ signal applies without distinction to both the upper and lower data bus. In write access the $\overline{HWR}$ signal applies to the upper data bus, and the $\overline{LWR}$ signal applies to the lower data bus.

Table 6-4 indicates how the two parts of the data bus are used under different access conditions.

Table 6-4 Access Conditions and Data Bus Usage

Area	Access Size	Read/ Write	Address	Valid Strobe	Upper Data Bus (D_{15} to D_8)	Lower Data Bus (D_7 to D_0)
8-bit-access area	—	Read	—	$\overline{RD}$	Valid	Invalid
		Write	—	$\overline{HWR}$		Undetermined data
16-bit-access area	Byte	Read	Even	$\overline{RD}$	Valid	Invalid
			Odd		Invalid	Valid
		Write	Even	$\overline{HWR}$	Valid	Undetermined data
			Odd	$\overline{LWR}$	Undetermined data	Valid
	Word	Read	—	$\overline{RD}$	Valid	Valid
		Write	—	$\overline{HWR}$, $\overline{LWR}$	Valid	Valid

Note: Undetermined data means that unpredictable data is output.
Invalid means that the bus is in the input state and the input is ignored.

6.3.4 Bus Control Signal Timing

8-Bit, Three-State-Access Areas: Figure 6-4 shows the timing of bus control signals for an 8-bit, three-state-access area. The upper address bus (D_{15} to D_8) is used to access these areas. The $\overline{LWR}$ pin is always high. Wait states can be inserted.

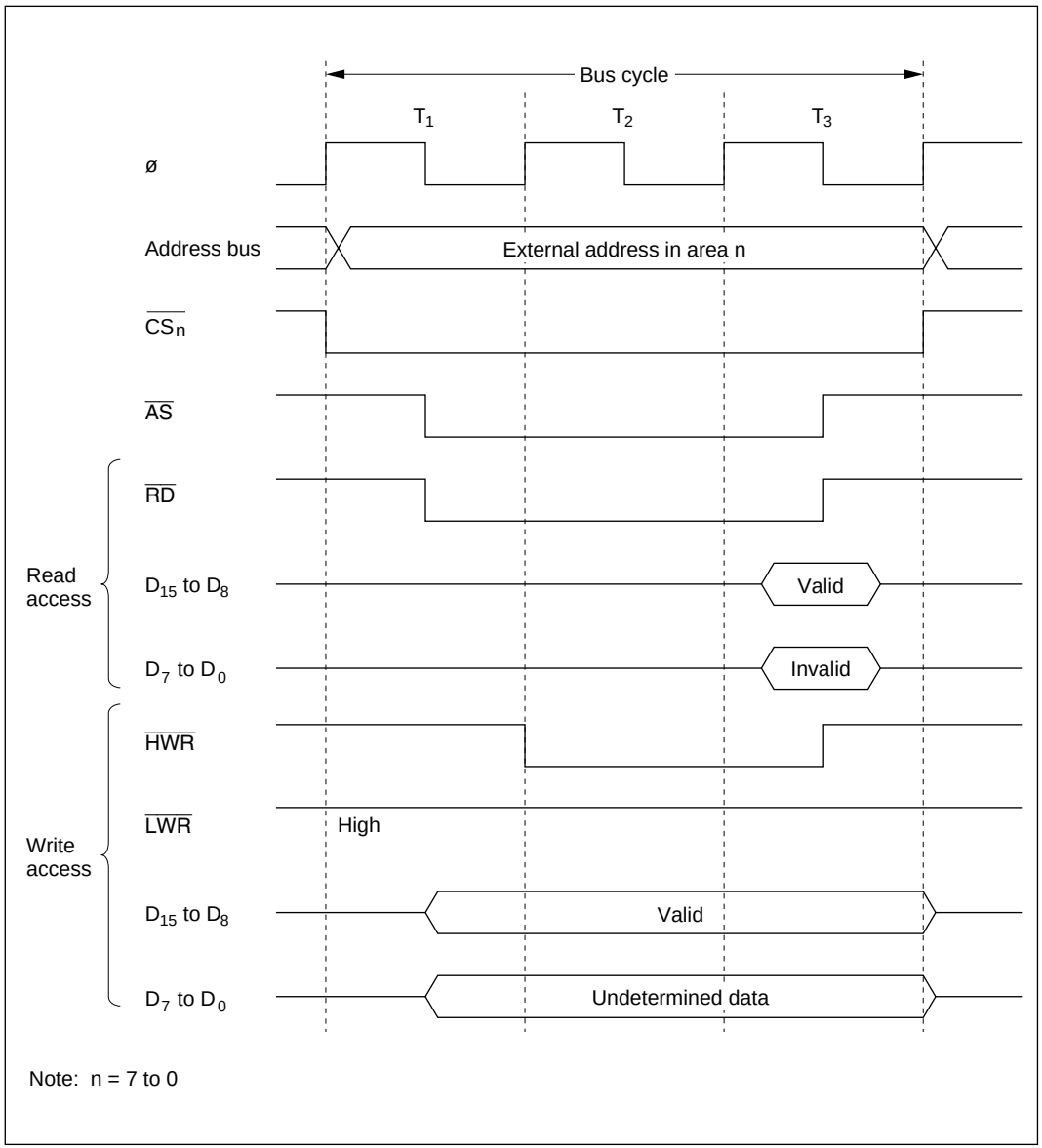


Figure 6-4 Bus Control Signal Timing for 8-Bit, Three-State-Access Area

8-Bit, Two-State-Access Areas: Figure 6-5 shows the timing of bus control signals for an 8-bit, two-state-access area. The upper address bus (D_{15} to D_8) is used to access these areas. The $\overline{LWR}$ pin is always high. Wait states cannot be inserted.

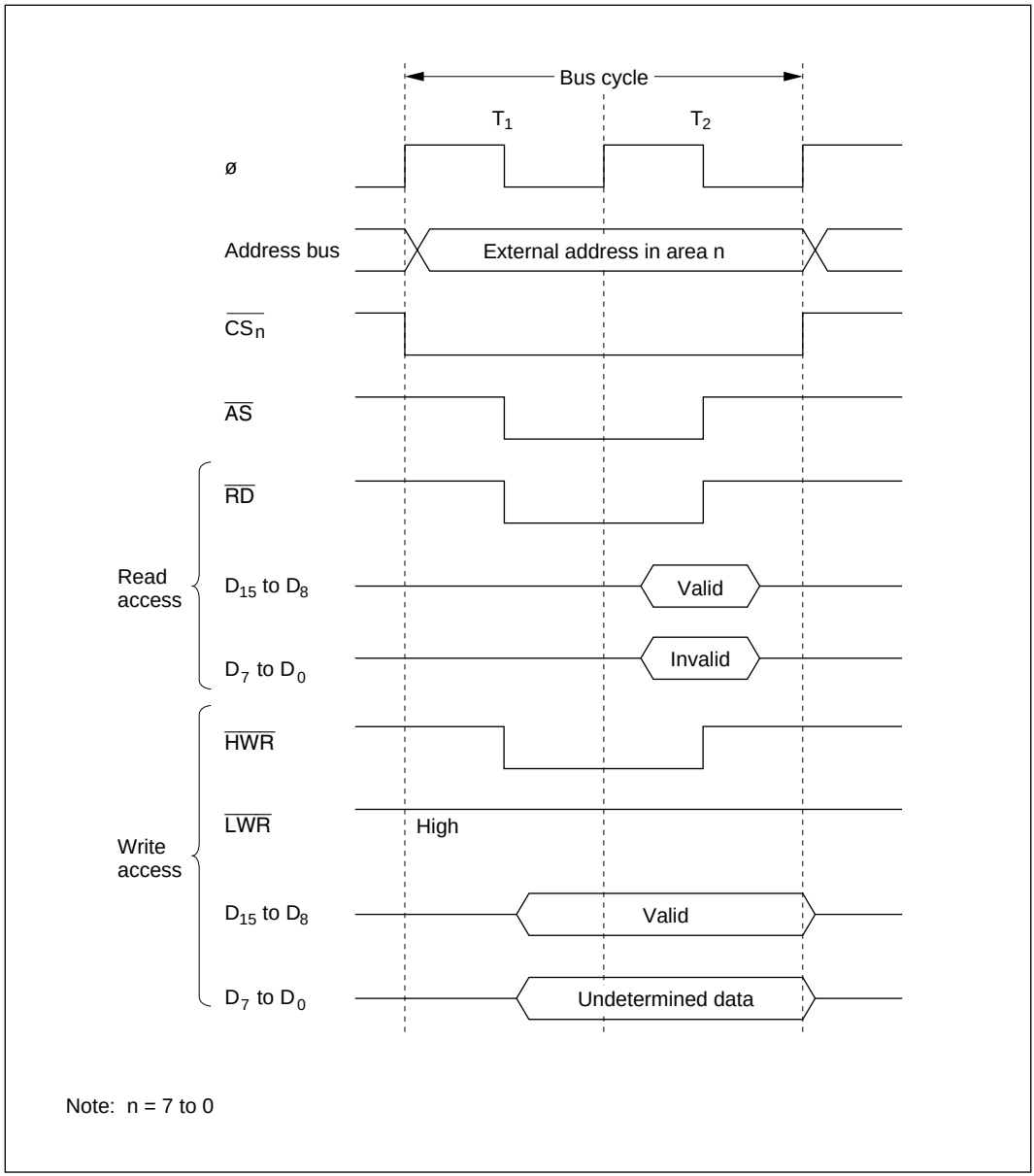


Figure 6-5 Bus Control Signal Timing for 8-Bit, Two-State-Access Area

16-Bit, Three-State-Access Areas: Figures 6-6 to 6-8 show the timing of bus control signals for a 16-bit, three-state-access area. In these areas, the upper address bus (D_{15} to D_8) is used to access even addresses and the lower address bus (D_7 to D_0) is used to access odd addresses. Wait states can be inserted.

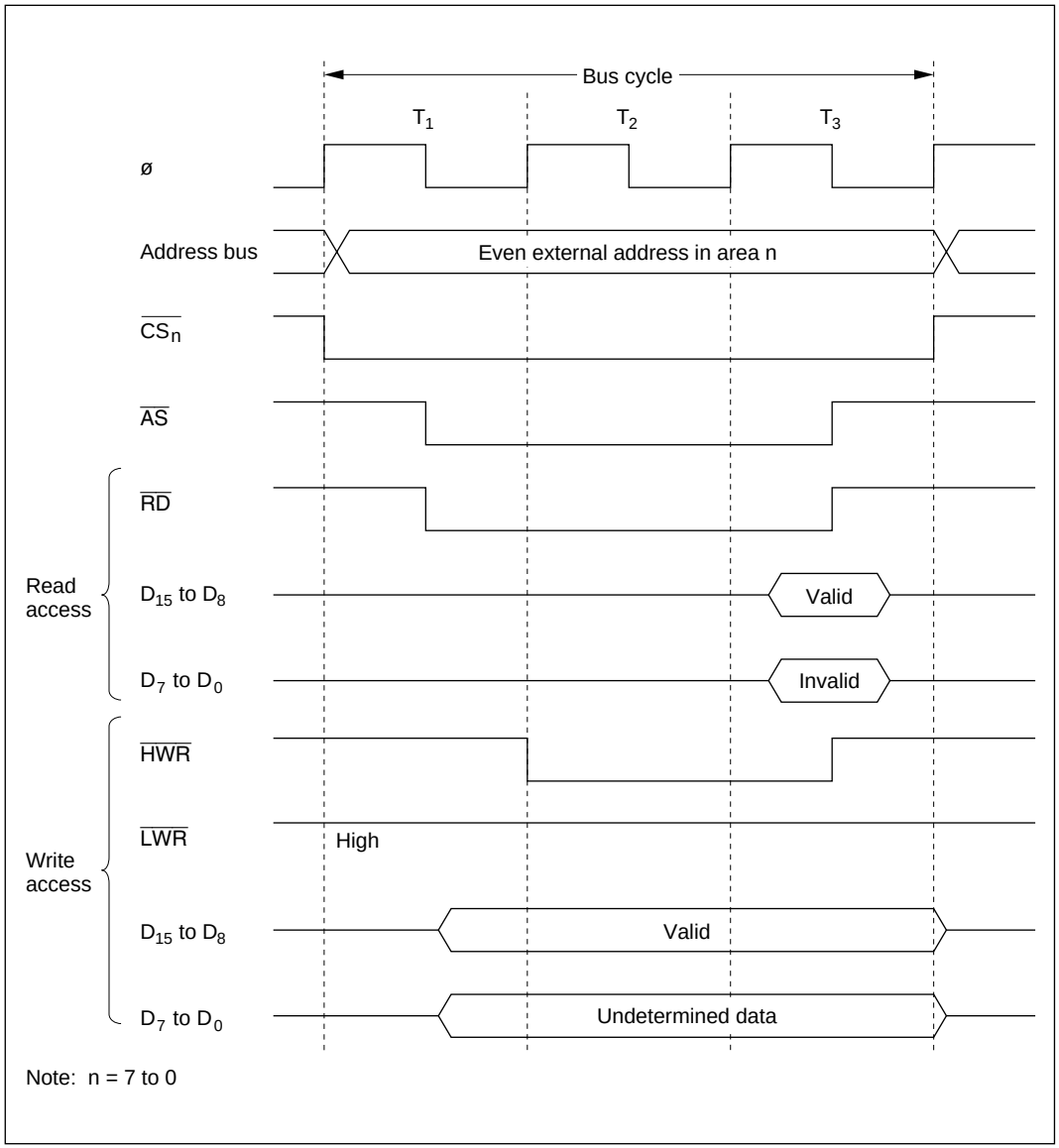


Figure 6-6 Bus Control Signal Timing for 16-Bit, Three-State-Access Area (1) (Byte Access to Even Address)

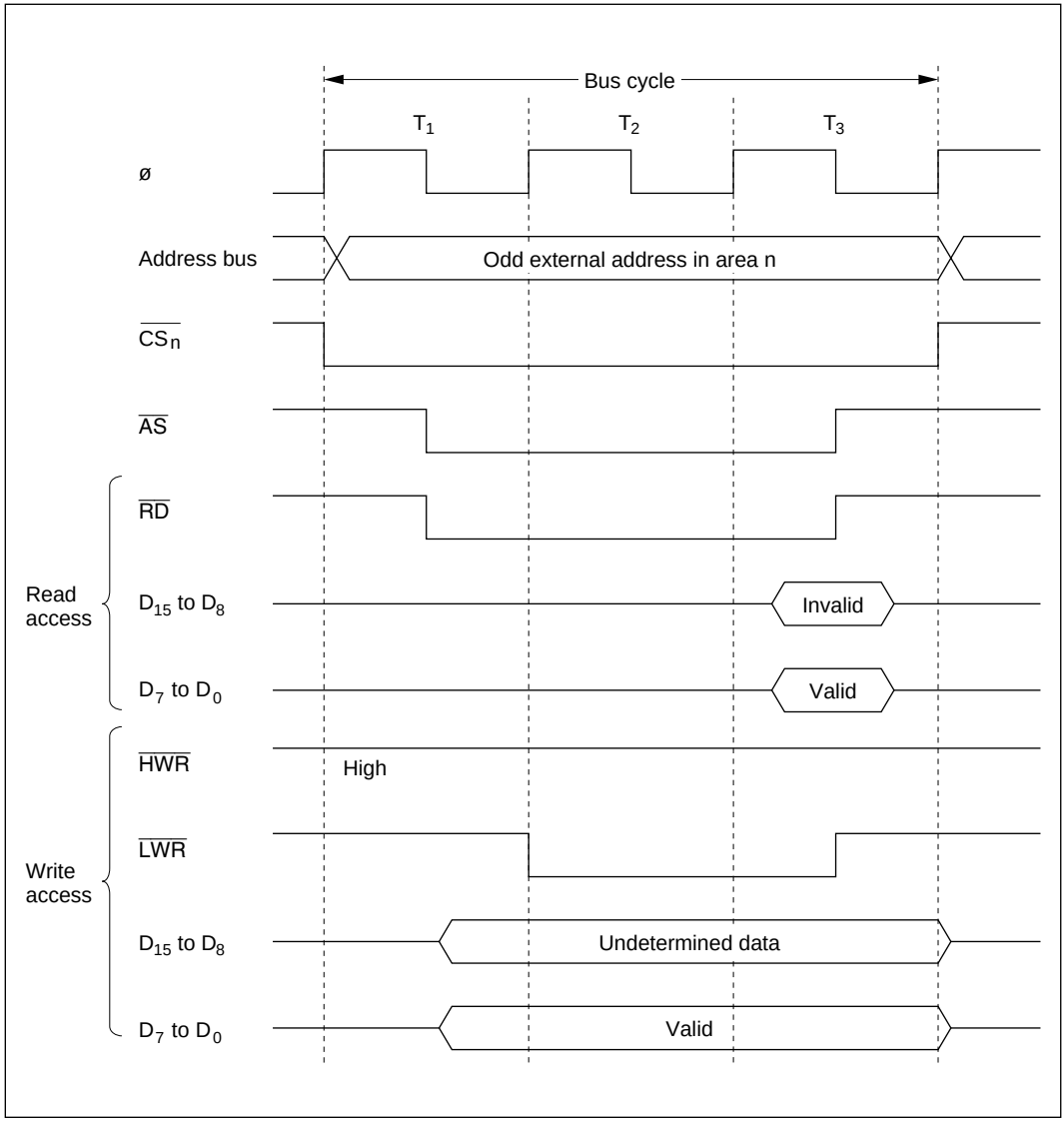


Figure 6-7 Bus Control Signal Timing for 16-Bit, Three-State-Access Area (2) (Byte Access to Odd Address)

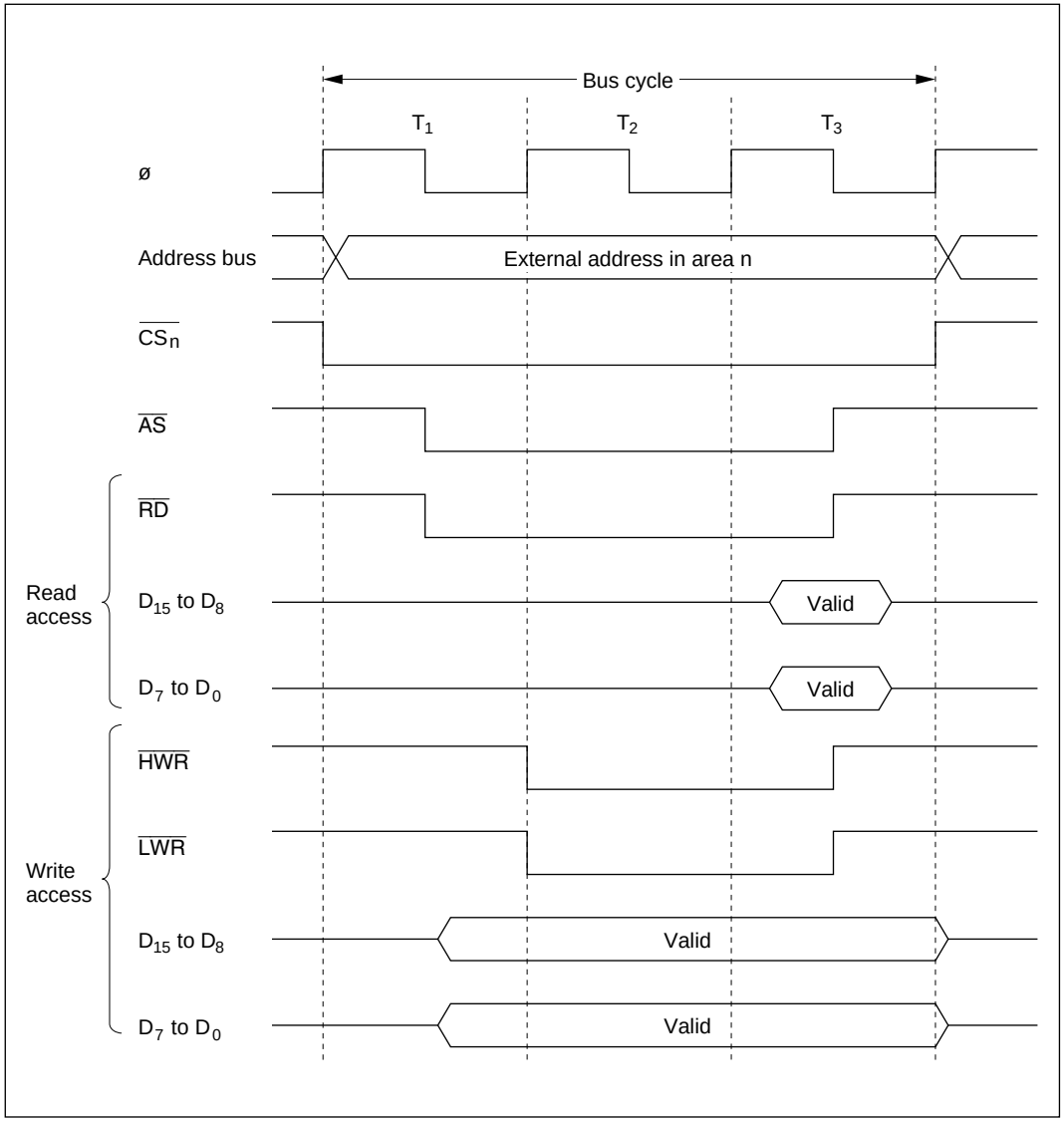


Figure 6-8 Bus Control Signal Timing for 16-Bit, Three-State-Access Area (3) (Word Access)

16-Bit, Two-State-Access Areas: Figures 6-9 to 6-11 show the timing of bus control signals for a 16-bit, two-state-access area. In these areas, the upper address bus (D_{15} to D_8) is used to access even addresses and the lower address bus (D_7 to D_0) is used to access odd addresses. Wait states cannot be inserted.

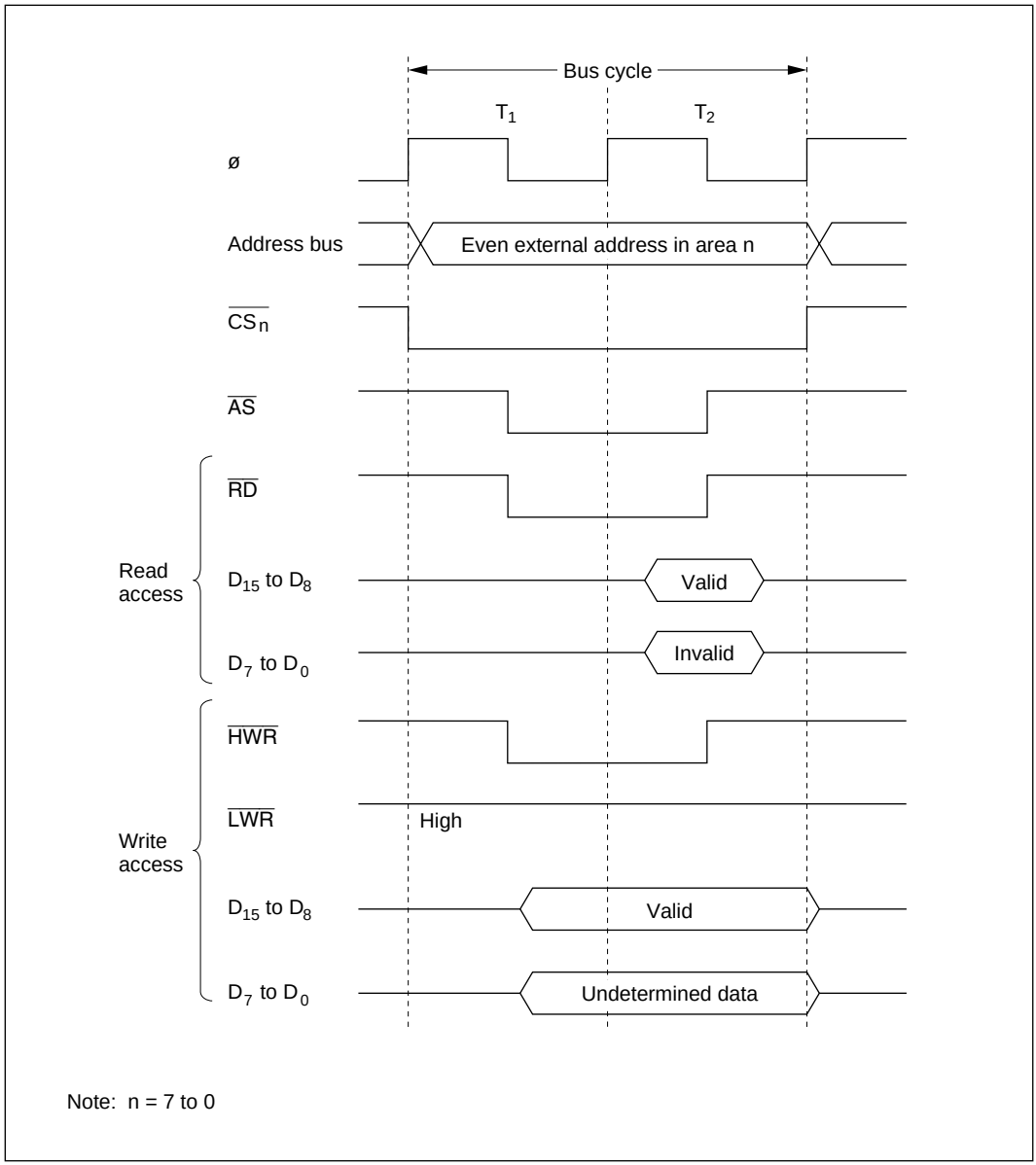


Figure 6-9 Bus Control Signal Timing for 16-Bit, Two-State-Access Area (1) (Byte Access to Even Address)

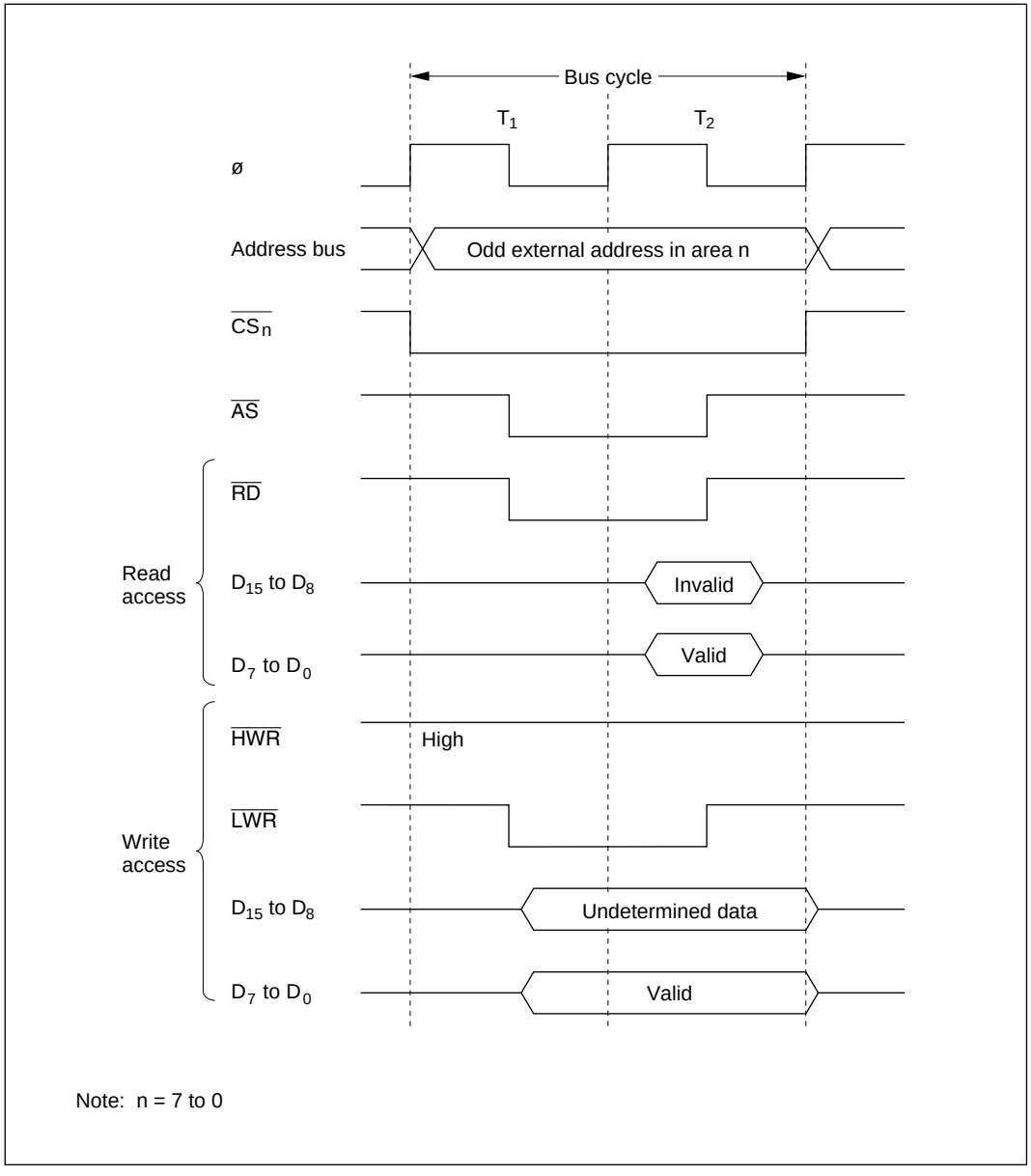


Figure 6-10 Bus Control Signal Timing for 16-Bit, Two-State-Access Area (2) (Byte Access to Odd Address)

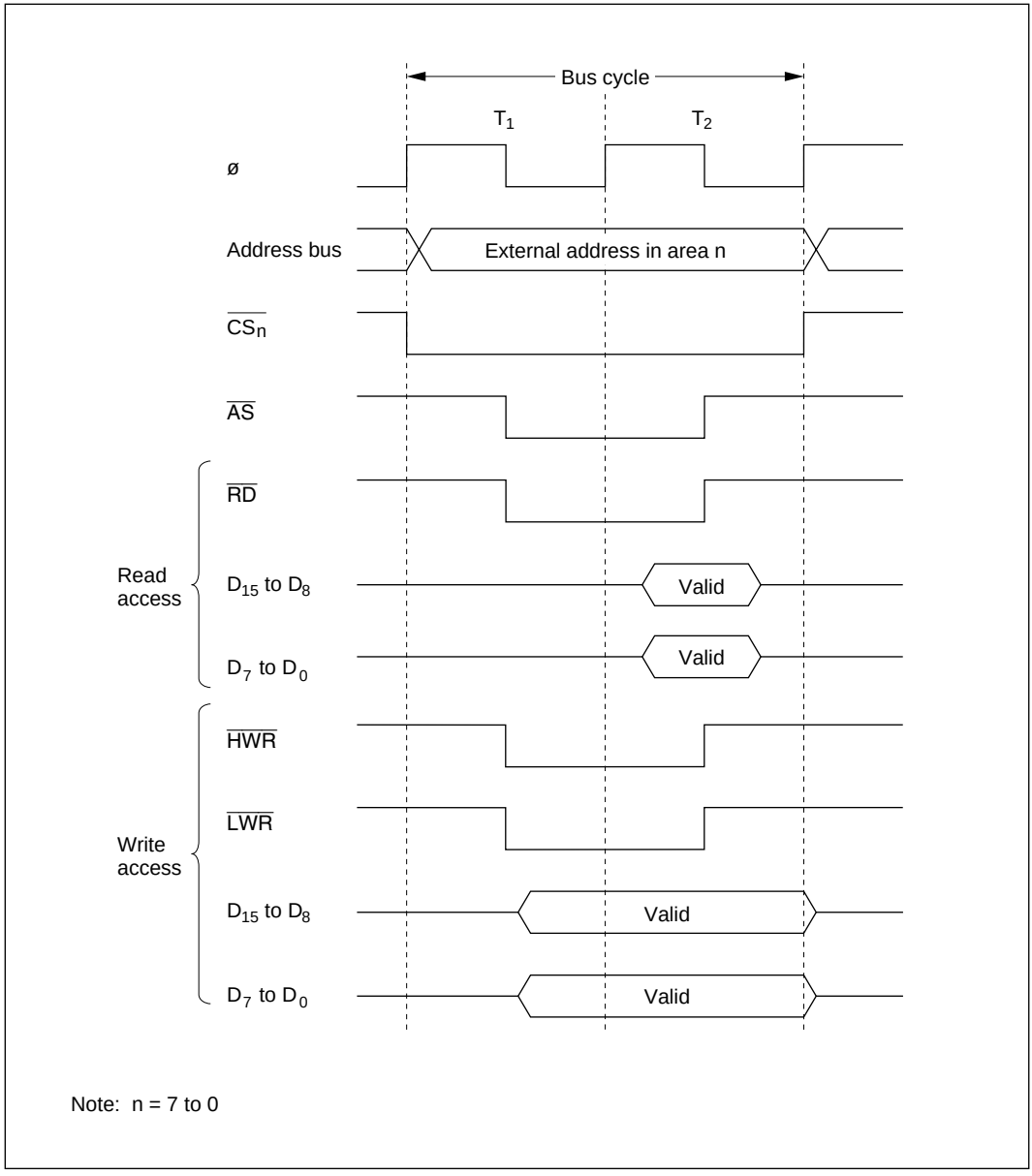


Figure 6-11 Bus Control Signal Timing for 16-Bit, Two-State-Access Area (3) (Word Access)

6.3.5 Wait Modes

Four wait modes can be selected for each area as shown in table 6-5.

Table 6-5 Wait Mode Selection

ASTCR	WCER	WCR			
ASTn Bit	WCEn Bit	WMS1 Bit	WMS0 Bit	WSC Control	Wait Mode
0	—	—	—	Disabled	No wait states
1	0	—	—	Disabled	Pin wait mode 0
	1	0	0	Enabled	Programmable wait mode
			1	Enabled	No wait states
		1	0	Enabled	Pin wait mode 1
			1	Enabled	Pin auto-wait mode

Note: n = 7 to 0

The ASTn and WCEn bits can be set independently for each area. Bits WMS1 and WMS0 apply to all areas. All areas for which WSC control is enabled operate in the same wait mode.

Pin Wait Mode 0: The wait state controller is disabled. Wait states can only be inserted by $\overline{\text{WAIT}}$ pin control. During access to an external three-state-access area, if the $\overline{\text{WAIT}}$ pin is low at the fall of the system clock (ø) in the T_2 state, a wait state (T_W) is inserted. If the $\overline{\text{WAIT}}$ pin remains low, wait states continue to be inserted until the $\overline{\text{WAIT}}$ signal goes high. Figure 6-12 shows the timing.

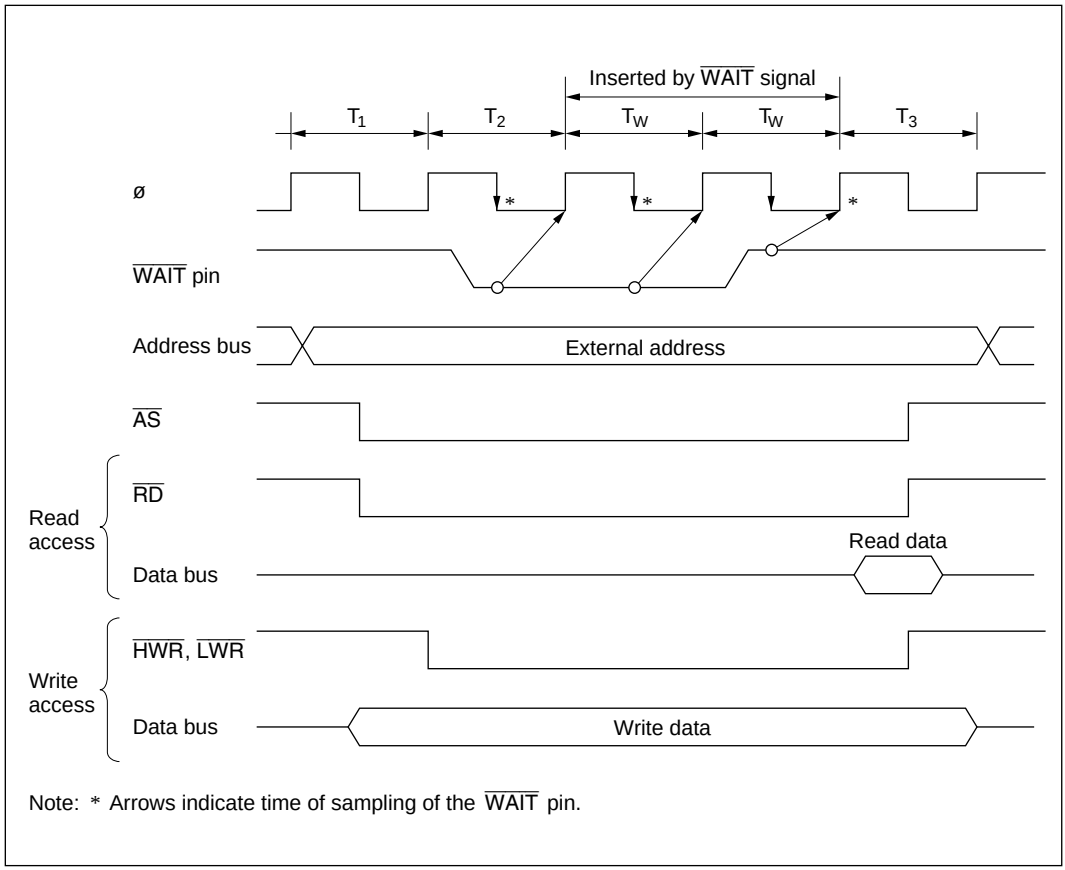


Figure 6-12 Pin Wait Mode 0

Pin Wait Mode 1: In all accesses to external three-state-access areas, the number of wait states (T_W) selected by bits WC1 and WC0 are inserted. If the $\overline{\text{WAIT}}$ pin is low at the fall of the system clock (ø) in the last of these wait states, an additional wait state is inserted. If the $\overline{\text{WAIT}}$ pin remains low, wait states continue to be inserted until the $\overline{\text{WAIT}}$ signal goes high.

Pin wait mode 1 is useful for inserting four or more wait states, or for inserting different numbers of wait states for different external devices.

If the wait count is 0, this mode operates in the same way as pin wait mode 0.

Figure 6-13 shows the timing when the wait count is 1 (WC1 = 0, WC0 = 1) and one additional wait state is inserted by $\overline{\text{WAIT}}$ input.

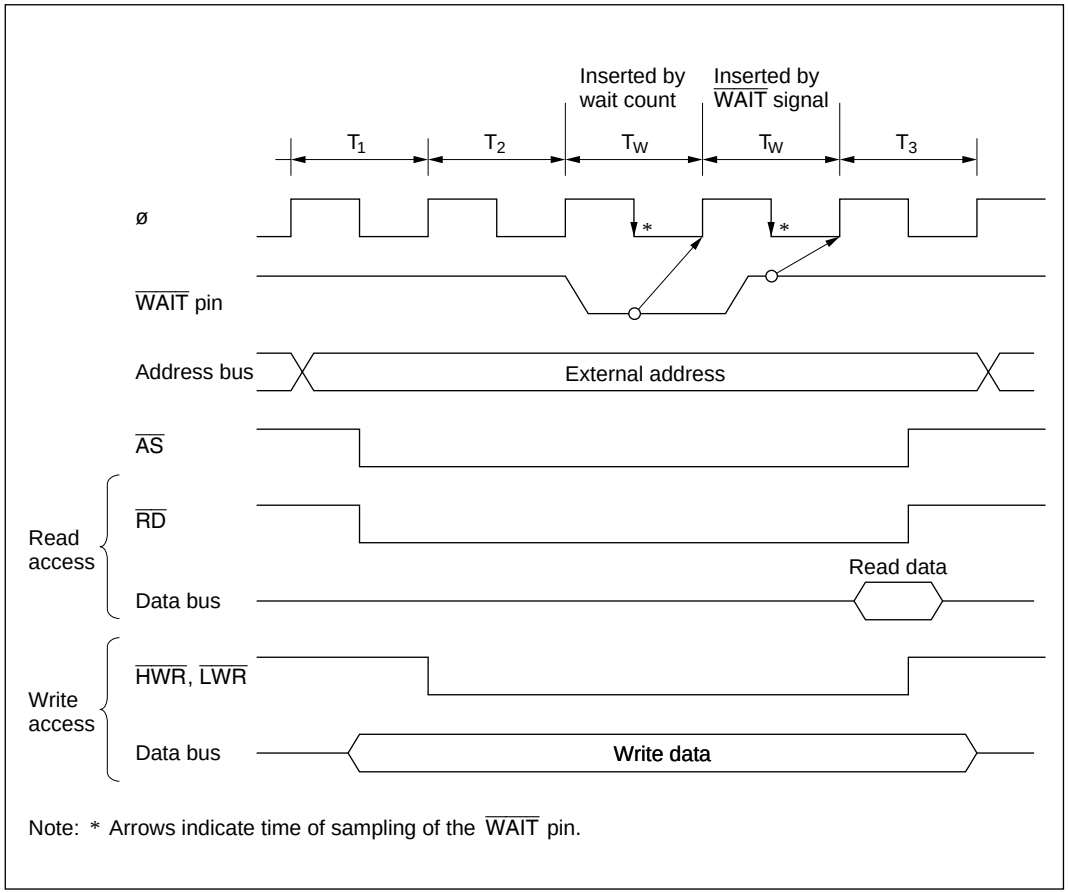


Figure 6-13 Pin Wait Mode 1

Pin Auto-Wait Mode: If the $\overline{\text{WAIT}}$ pin is low, the number of wait states (T_W) selected by bits WC1 and WC0 are inserted.

In pin auto-wait mode, if the $\overline{\text{WAIT}}$ pin is low at the fall of the system clock (ø) in the T_2 state, the number of wait states (T_W) selected by bits WC1 and WC0 are inserted. No additional wait states are inserted even if the $\overline{\text{WAIT}}$ pin remains low. Pin auto-wait mode can be used for an easy interface to low-speed memory, simply by routing the chip select signal to the $\overline{\text{WAIT}}$ pin.

Figure 6-14 shows the timing when the wait count is 1.

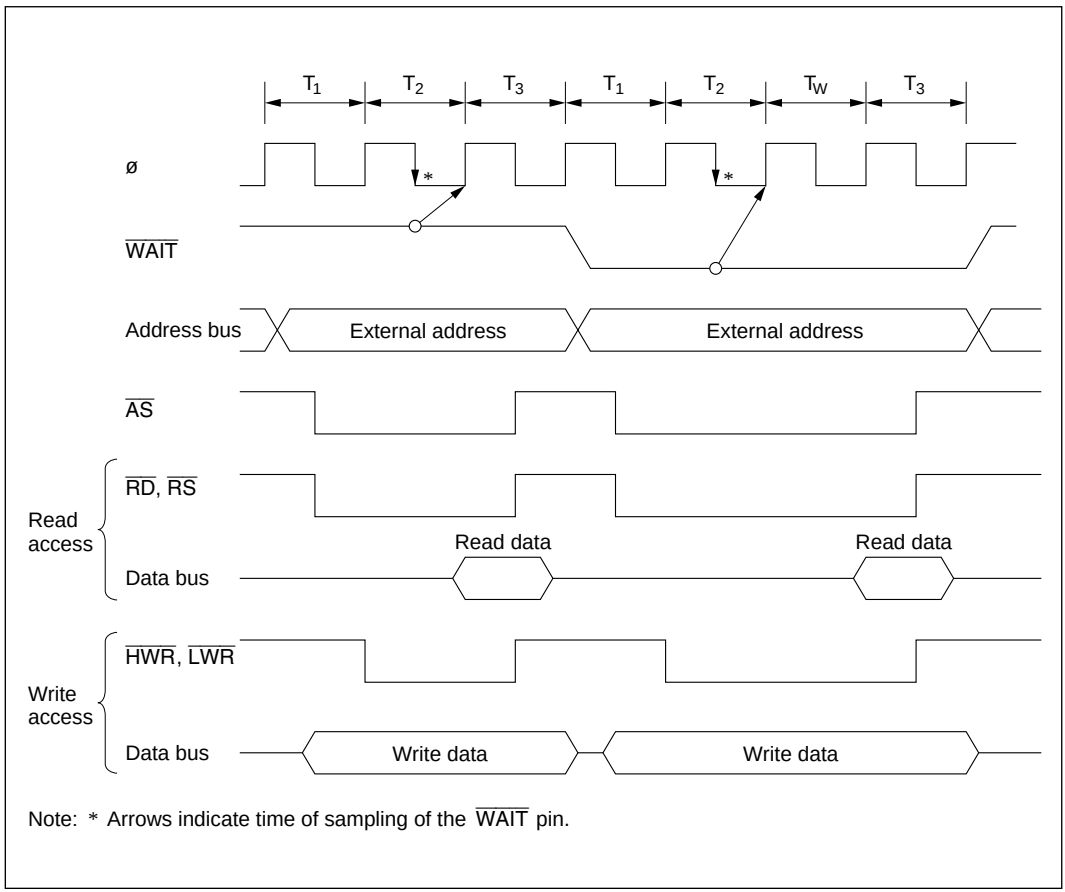


Figure 6-14 Pin Auto-Wait Mode

Programmable Wait Mode: The number of wait states (T_W) selected by bits WC1 and WC0 are inserted in all accesses to external three-state-access areas. Figure 6-15 shows the timing when the wait count is 1 (WC1 = 0, WC0 = 1).

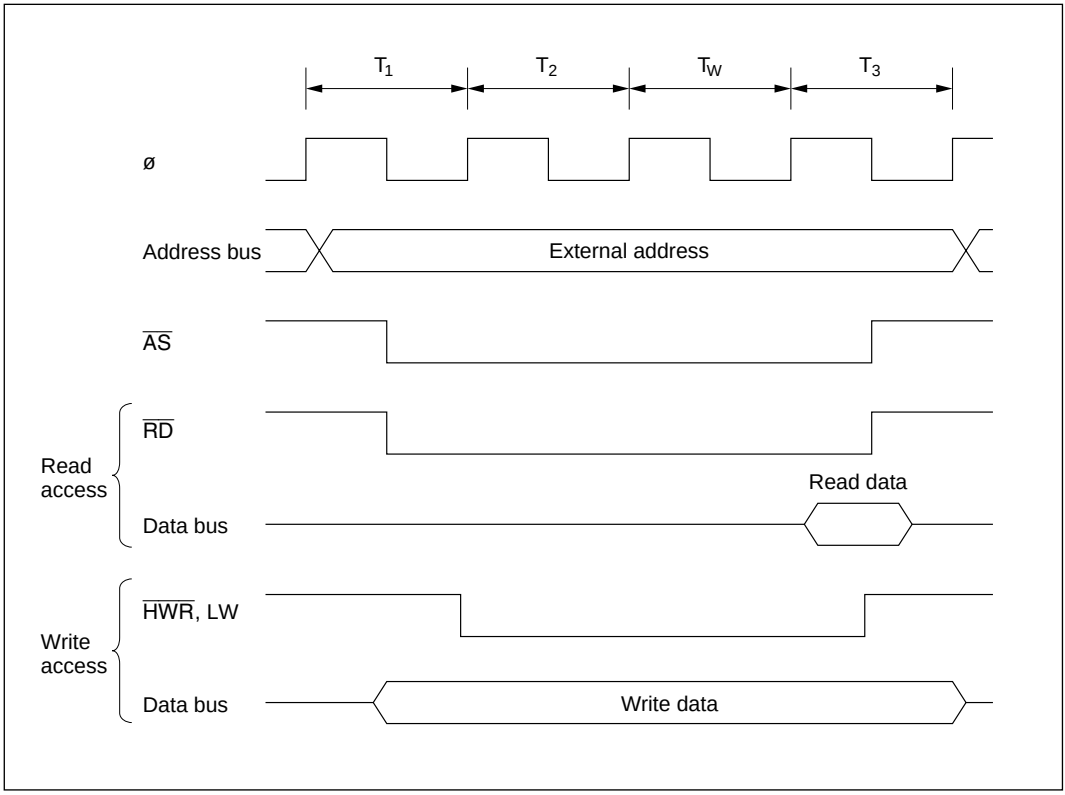
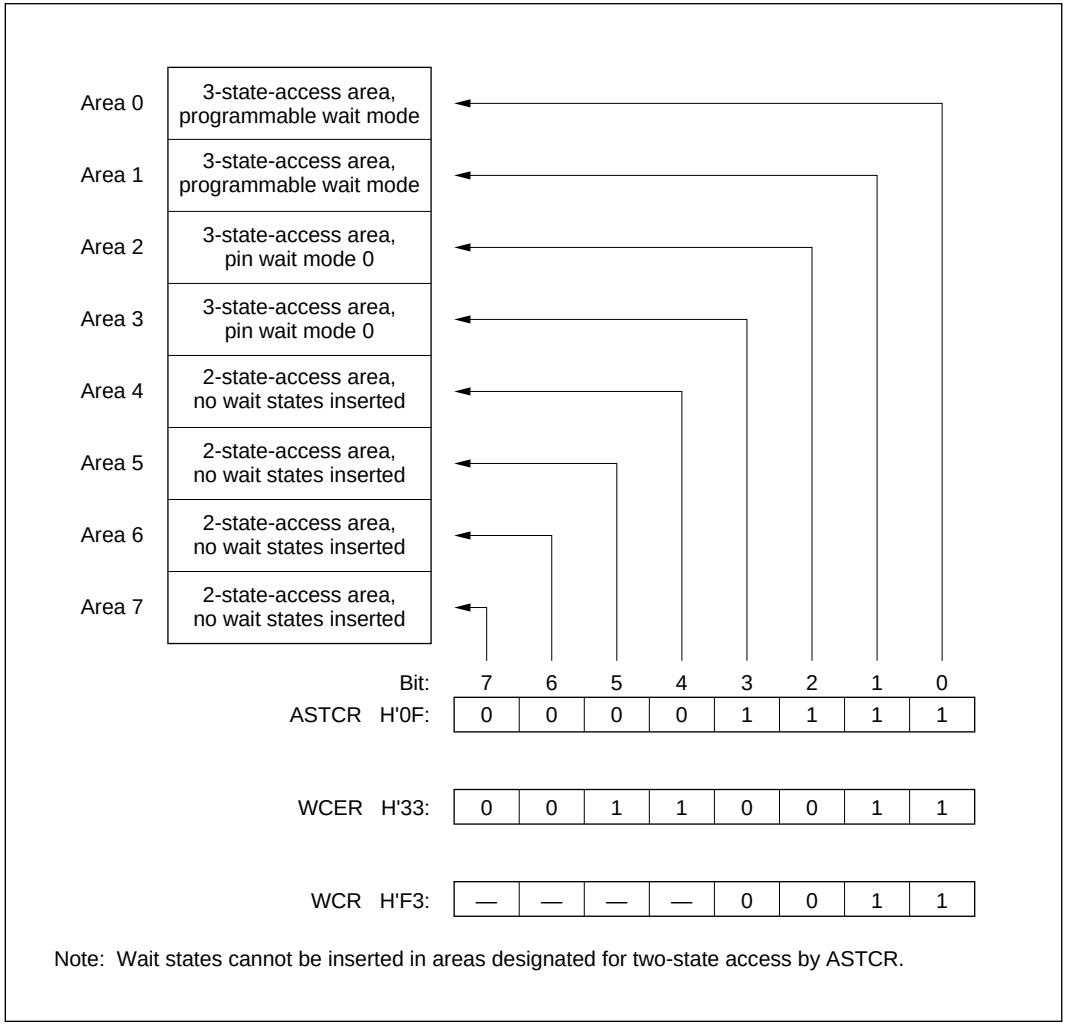


Figure 6-15 Programmable Wait Mode

Example of Wait State Control Settings: A reset initializes ASTCR and WCER to H'FF and WCR to H'F3, selecting programmable wait mode and three wait states for all areas. Software can select other wait modes for individual areas by modifying the ASTCR, WCER, and WCR settings. Figure 6-16 shows an example of wait mode settings.



Note: Wait states cannot be inserted in areas designated for two-state access by ASTCR.

Figure 6-16 Wait Mode Settings (Example)

6.3.6 Interconnections with Memory (Example)

For each area, the bus controller can select two- or three-state access and an 8- or 16-bit data bus width. In three-state-access areas, wait states can be inserted in a variety of modes, simplifying the connection of both high-speed and low-speed devices.

Figure 6-18 shows an example of interconnections between the H8/3003 and memory. Figure 6-17 shows a memory map for this example.

A 256-kword × 16-bit EPROM is connected to area 0. This device is accessed in three states via a 16-bit bus.

Two 32-kword × 8-bit SRAM devices (SRAM1 and SRAM2) are connected to area 1. These devices are accessed in two states via a 16-bit bus.

One 32-kword × 8-bit SRAM (SRAM3) is connected to area 7. This device is accessed via an 8-bit bus, using three-state access with an additional wait state inserted in pin auto-wait mode.

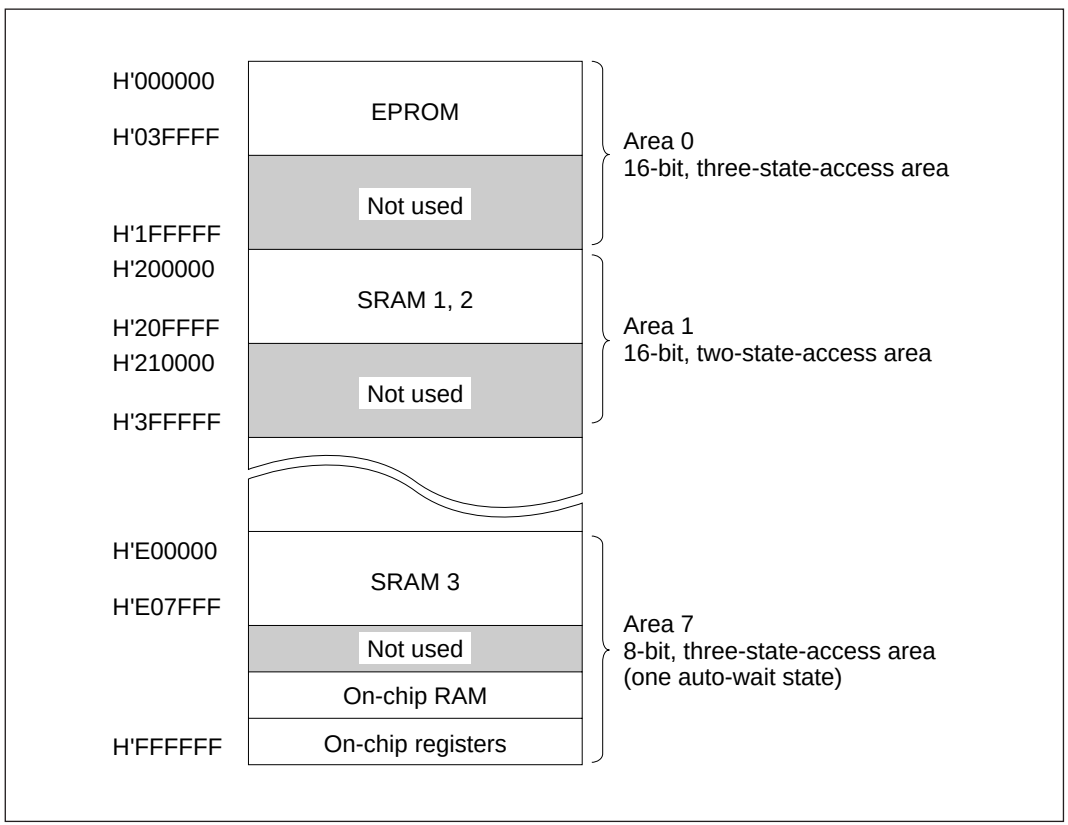


Figure 6-17 Memory Map (Example)

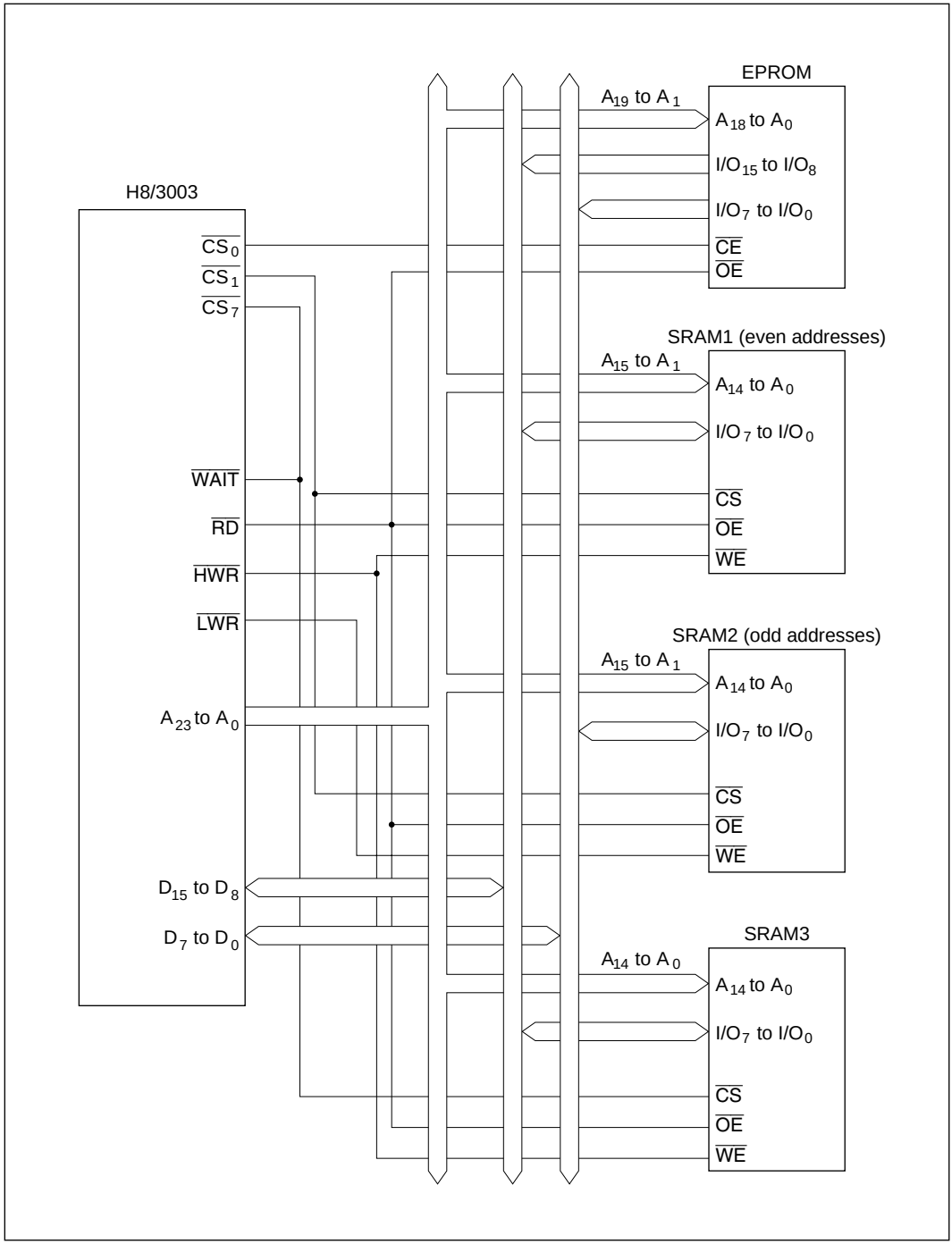


Figure 6-18 Interconnections between H8/3003 and Memory (Example)

6.3.7 Bus Arbiter Operation

The bus controller has a built-in bus arbiter that arbitrates between different bus masters. There are four bus masters: the CPU, DMA controller (DMAC), refresh controller, and an external bus master. When a bus master has the bus right it can carry out read, write, or refresh access. Each bus master uses a bus request signal to request the bus right. At fixed times the bus arbiter determines priority and uses a bus acknowledge signal to grant the bus to a bus master, which can then operate using the bus.

The bus arbiter checks whether the bus request signal from a bus master is active or inactive, and returns an acknowledge signal to the bus master if the bus request signal is active. When two or more bus masters request the bus, the highest-priority bus master receives an acknowledge signal. The bus master that receives an acknowledge signal can continue to use the bus until the acknowledge signal is deactivated.

The bus master priority order is:

(High) External bus master > refresh controller > DMAC > CPU (Low)

The bus arbiter samples the bus request signals and determines priority at all times, but it does not always grant the bus immediately, even when it receives a bus request from a bus master with higher priority than the current bus master. Each bus master has certain times at which it can release the bus to a higher-priority bus master.

CPU: The CPU is the lowest-priority bus master. If the DMAC, refresh controller, or an external bus master requests the bus while the CPU has the bus right, the bus arbiter transfers the bus right to the bus master that requested it. The bus right is transferred at the following times:

- The bus right is transferred at the boundary of a bus cycle. If word data is accessed by two consecutive byte accesses, however, the bus right is not transferred between the two byte accesses.
- If another bus master requests the bus while the CPU is performing internal operations, such as executing a multiply or divide instruction, the bus right is transferred immediately. The CPU continues its internal operations.
- If another bus master requests the bus while the CPU is in sleep mode, the bus right is transferred immediately.

DMAC: When the DMAC receives an activation request, it requests the bus right from the bus arbiter. If DMAC is a bus master and the refresh controller or an external bus master requests the bus, the bus arbiter transfers the bus right from the DMAC to the bus master that requested the bus. The bus right is transferred at the following times.

The bus right is transferred when the DMAC finishes transferring 1 byte or 1 word. A DMAC transfer cycle consists of a read cycle and a write cycle. The bus right is not transferred between the read cycle and the write cycle.

There is a priority order among the DMAC channels. For details see section 8.4.9, Multiple-Channel Operation.

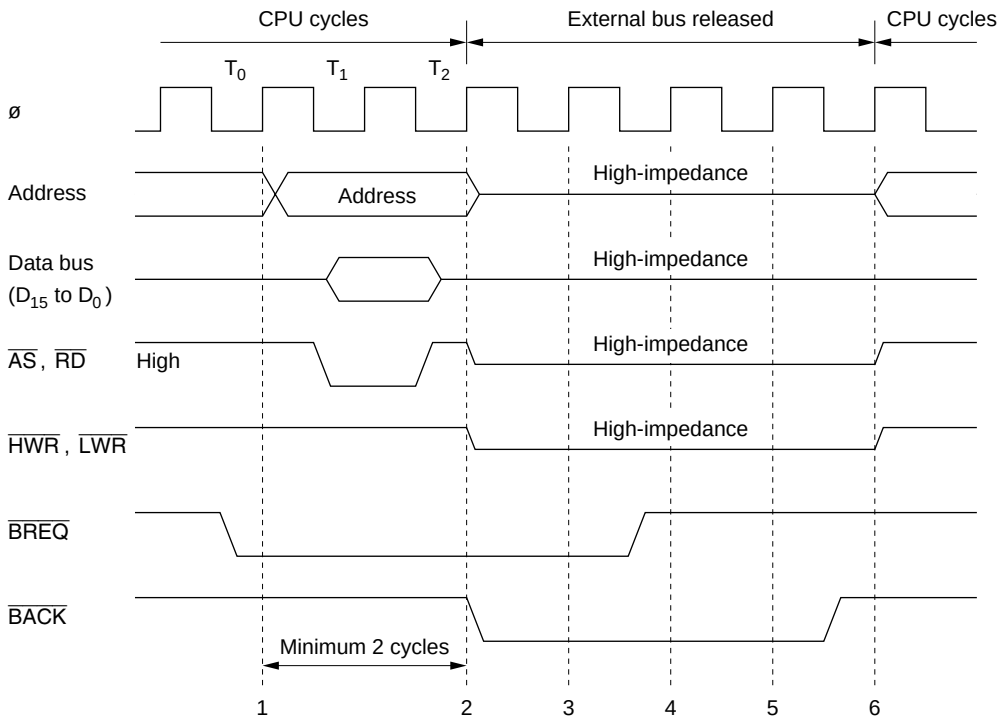
Refresh Controller: When a refresh cycle is requested, the refresh controller requests the bus right from the bus arbiter. When the refresh cycle is completed, the refresh controller releases the bus. For details see section 7, Refresh Controller.

External Bus Master: When the BRLE bit is set to 1 in BRCR, the bus can be released to an external bus master. The external bus master has highest priority, and requests the bus right from the bus arbiter by driving the $\overline{\text{BREQ}}$ signal low. Once the external bus master gets the bus, it keeps the bus right until the $\overline{\text{BREQ}}$ signal goes high. While the bus is released to an external bus master, the H8/3003 holds the address bus and data bus control signals ($\overline{\text{AS}}$, $\overline{\text{RD}}$, $\overline{\text{HWR}}$, and $\overline{\text{LWR}}$) in the high-impedance state, and holds the $\overline{\text{BACK}}$ pin in the low output state.

The bus arbiter samples the $\overline{\text{BREQ}}$ pin at the rise of the system clock (ø). If $\overline{\text{BREQ}}$ is low, the bus is released to the external bus master at the appropriate opportunity. The $\overline{\text{BREQ}}$ signal should be held low until the $\overline{\text{BACK}}$ signal goes low.

When the $\overline{\text{BREQ}}$ pin is high in two consecutive samples, the $\overline{\text{BACK}}$ signal is driven high to end the bus-release cycle.

Figure 6-19 shows the timing when the bus right is requested by an external bus master during a read cycle in a two-state-access area. There is a minimum interval of two states from when the $\overline{\text{BREQ}}$ signal goes low until the bus is released.



1 Low $\overline{\text{BREQ}}$ signal is sampled at rise of T_0 state.
2 $\overline{\text{BACK}}$ signal goes low at end of CPU read cycle, releasing bus right to external bus master.
3 $\overline{\text{BREQ}}$ pin continues to be sampled while bus is released to external bus master.
4, 5 High $\overline{\text{BREQ}}$ signal is sampled twice consecutively.
6 $\overline{\text{BREQ}}$ signal goes high, ending bus-release cycle.

Figure 6-19 External-Bus-Released State (Two-State-Access Area, During Read Cycle)

6.4 Usage Notes

6.4.1 Connection to Dynamic RAM and Pseudo-Static RAM

A different bus control signal timing applies when dynamic RAM or pseudo-static RAM is connected to area 3. For details see section 7, Refresh Controller.

6.4.2 Register Write Timing

ABWCR, ASTCR, and WCER Write Timing: Data written to ABWCR, ASTCR, or WCER takes effect starting from the next bus cycle. Figure 6-20 shows the timing when an instruction fetched from area 0 changes area 0 from three-state access to two-state access.

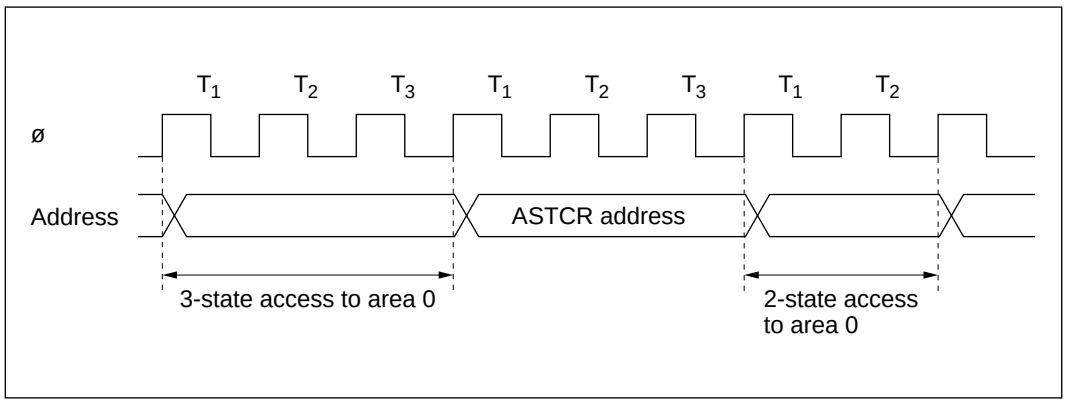


Figure 6-20 ASTCR Write Timing

DDR Write Timing: Data written to a data direction register (DDR) to change a $\overline{CS_n}$ pin from $\overline{CS_n}$ output to generic input, or vice versa, takes effect starting from the T_3 state of the DDR write cycle. Figure 6-21 shows the timing when the $\overline{CS_1}$ pin is changed from generic input to $\overline{CS_1}$ output.

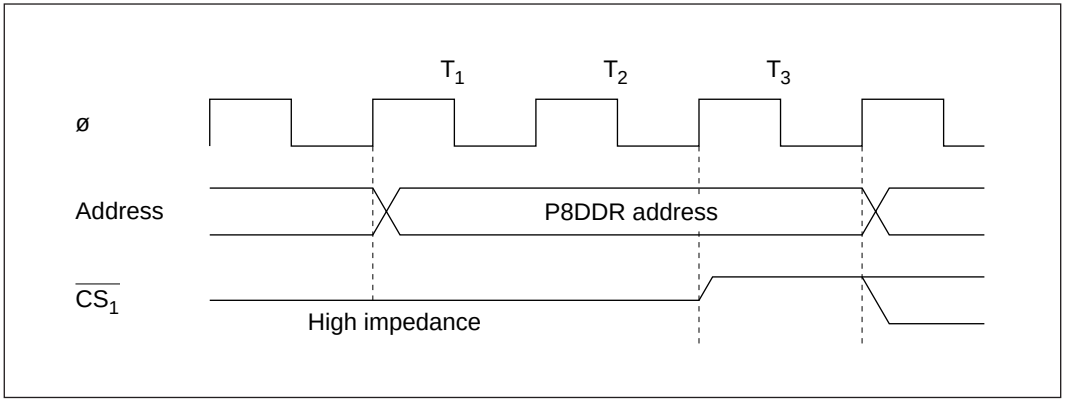


Figure 6-21 DDR Write Timing

6.4.3 $\overline{BREQ}$ Input Timing

After driving the $\overline{BREQ}$ pin low, hold it low until $\overline{BACK}$ goes low. If $\overline{BREQ}$ returns to the high level before $\overline{BACK}$ goes low, the bus arbiter may operate incorrectly.

To terminate the external-bus-released state, hold the $\overline{BREQ}$ signal high for at least three states. If $\overline{BREQ}$ is high for too short an interval, the bus arbiter may operate incorrectly.

Section 7 Refresh Controller

7.1 Overview

The H8/3003 has an on-chip refresh controller that enables direct connection of 16-bit-wide DRAM or pseudo-static RAM (PSRAM).

DRAM or pseudo-static RAM can be directly connected to area 3 of the external address space. A maximum 128 kbytes can be connected in modes 1 and 2 (1-Mbyte modes). A maximum 2 Mbytes can be connected in modes 3 and 4 (16-Mbyte modes).

Systems that do not need to refresh DRAM or pseudo-static RAM can use the refresh controller as an 8-bit interval timer.

7.1.1 Features

The refresh controller can be used for one of three functions: DRAM refresh control, pseudo-static RAM refresh control, or 8-bit interval timing. Features of the refresh controller are listed below.

Features as a DRAM Refresh Controller

- Enables direct connection of 16-bit-wide DRAM
- Selection of 2$\overline{\text{CAS}}$ or 2$\overline{\text{WE}}$ mode
- Selection of 8-bit or 9-bit column address multiplexing for DRAM address input

  Examples:

  — 1-Mbit DRAM: 8-bit row address × 8-bit column address
  — 4-Mbit DRAM: 9-bit row address × 9-bit column address
  — 4-Mbit DRAM: 10-bit row address × 8-bit column address
- $\overline{\text{CAS}}$-before-$\overline{\text{RAS}}$ refresh control
- Software-selectable refresh interval
- Software-selectable self-refresh mode
- Wait states can be inserted

Features as a Pseudo-Static RAM Refresh Controller

- $\overline{\text{RFSH}}$ signal output for refresh control
- Software-selectable refresh interval
- Software-selectable self-refresh mode
- Wait states can be inserted

Features as an Interval Timer

- Refresh timer counter (RTCNT) can be used as an 8-bit up-counter
- Selection of seven counter clock sources: ø/2, ø/8, ø/32, ø/128, ø/512, ø/2048, ø/4096
- Interrupts can be generated by compare match between RTCNT and the refresh time constant register (RTCOR)

7.1.2 Block Diagram

Figure 7-1 shows a block diagram of the refresh controller.

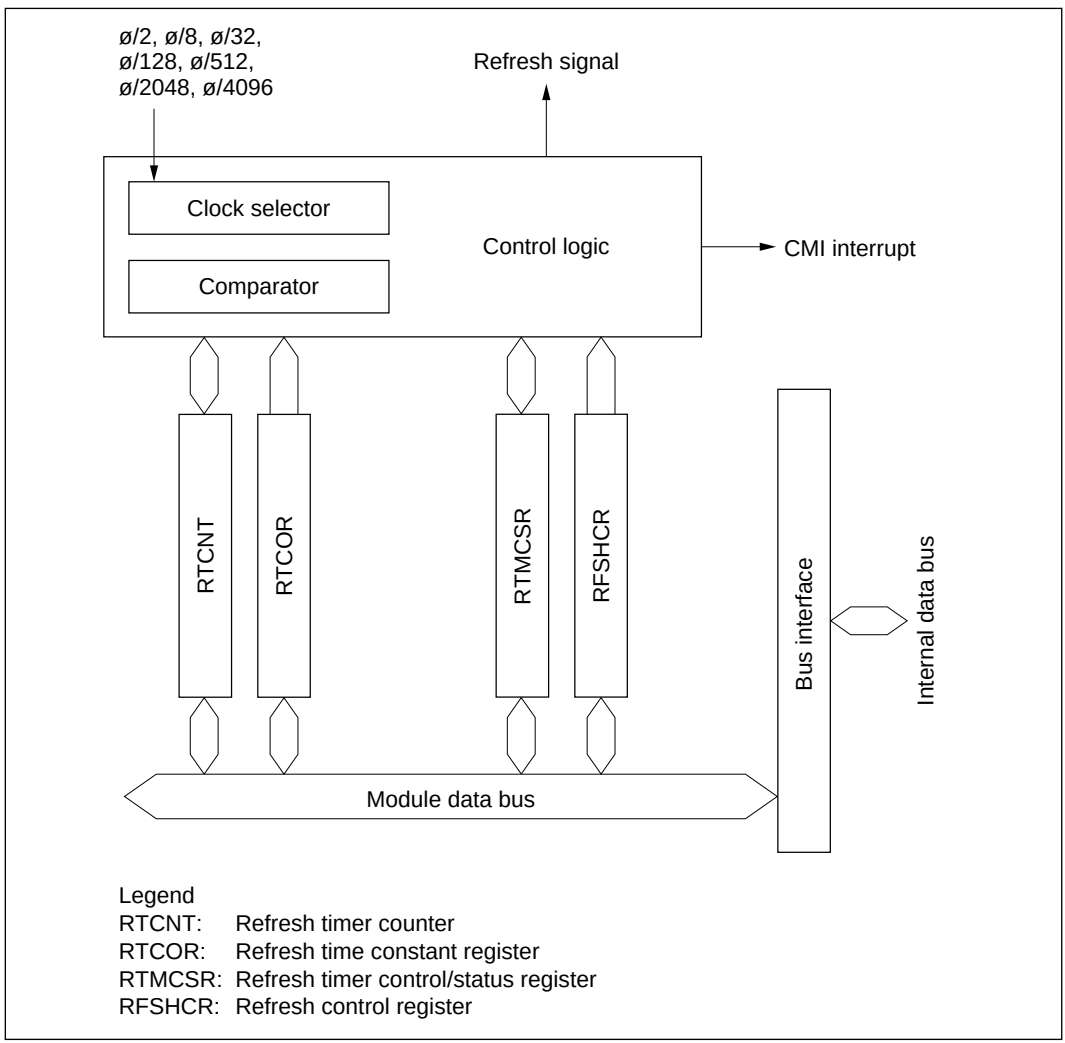


Figure 7-1 Block Diagram of Refresh Controller

7.1.3 Input/Output Pins

Table 7-1 summarizes the refresh controller's input/output pins.

Table 7-1 Refresh Controller Pins

Pin	Signal		I/O	Function
	Name	Abbr.		
$\overline{\text{RFSH}}$	Refresh	$\overline{\text{RFSH}}$	Output	Goes low during refresh cycles; used to refresh DRAM and PSRAM
$\overline{\text{HWR}}$	Upper write/upper column address strobe	$\overline{\text{UW}}$/$\overline{\text{UCAS}}$	Output	Connects to the $\overline{\text{UW}}$ pin of 2$\overline{\text{WE}}$ DRAM or $\overline{\text{UCAS}}$ pin of 2$\overline{\text{CAS}}$ DRAM
$\overline{\text{LWR}}$	Lower write/lower column address strobe	$\overline{\text{LW}}$/$\overline{\text{LCAS}}$	Output	Connects to the $\overline{\text{LW}}$ pin of 2$\overline{\text{WE}}$ DRAM or $\overline{\text{LCAS}}$ pin of 2$\overline{\text{CAS}}$ DRAM
$\overline{\text{RD}}$	Column address strobe/ write enable	$\overline{\text{CAS}}$/$\overline{\text{WE}}$	Output	Connects to the $\overline{\text{CAS}}$ pin of 2$\overline{\text{WE}}$ DRAM or $\overline{\text{WE}}$ pin of 2$\overline{\text{CAS}}$ DRAM
$\overline{\text{CS}_3}$	Row address strobe	$\overline{\text{RAS}}$	Output	Connects to the $\overline{\text{RAS}}$ pin of DRAM

7.1.4 Register Configuration

Table 7-2 summarizes the refresh controller's registers.

Table 7-2 Refresh Controller Registers

Address*	Name	Abbreviation	R/W	Initial Value
H'FFAC	Refresh control register	RFSHCR	R/W	H'02
H'FFAD	Refresh timer control/status register	RTMCSR	R/W	H'07
H'FFAE	Refresh timer counter	RTCNT	R/W	H'00
H'FFAF	Refresh time constant register	RTCOR	R/W	H'FF

Note: * Lower 16 bits of the address.

7.2 Register Descriptions

7.2.1 Refresh Control Register (RFSHCR)

RFSHCR is an 8-bit readable/writable register that selects the operating mode of the refresh controller.

Bit	7	6	5	4	3	2	1	0
	SRFMD	PSRAME	DRAME	CAS/$\overline{\text{WE}}$	M9/$\overline{\text{M8}}$	RFSHE	—	RCYCE
Initial value	0	0	0	0	0	0	1	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	—	R/W

Refresh cycle enable
Enables or disables insertion of refresh cycles

Reserved bit

Refresh pin enable
Enables refresh signal output from the refresh pin

Address multiplex mode select
Selects the number of column address bits

Strobe mode select
Selects 2$\overline{\text{CAS}}$ or 2$\overline{\text{WE}}$ strobing of DRAM

PSRAM enable and DRAM enable
These bits enable or disable connection of pseudo-static RAM and DRAM

Self-refresh mode
Selects self-refresh mode

RFSHCR is initialized to H'02 by a reset and in hardware standby mode.

Bit 7—Self-Refresh Mode (SRFMD): Specifies DRAM or pseudo-static RAM self-refresh during software standby mode. When PSRAME = 1 and DRAME = 0, after the SRFMD bit is set to 1, pseudo-static RAM can be self-refreshed when the H8/3003 enters software standby mode. When PSRAME = 0 and DRAME = 1, after the SRFMD bit is set to 1, DRAM can be self-refreshed when the H8/3003 enters software standby mode. In either case, the normal access state resumes on exit from software standby mode.

Bit 7 SRFMD	Description	
0	DRAM or PSRAM self-refresh is disabled in software standby mode	(Initial value)
1	DRAM or PSRAM self-refresh is enabled in software standby mode	

Bit 6—PSRAM Enable (PSRAME) and Bit 5—DRAM Enable (DRAME): These bits enable or disable connection of pseudo-static RAM and DRAM to area 3 of the external address space.

When DRAM or pseudo-static RAM is connected, the bus cycle and refresh cycle of area 3 consist of three states, regardless of the setting in the access state control register (ASTCR). If AST3 = 0 in ASTCR, wait states cannot be inserted.

When the PSRAME or DRAME bit is set to 1, bits 0, 2, 3, and 4 in RFSHCR and registers RTMCSR, RTCNT, and RTCOR are write-disabled, except that the CMF flag in RTMCSR can be cleared by writing 0.

Bit 6 PSRAME	Bit 5 DRAME	Description	
0	0	Can be used as an interval timer	(Initial value)
	1	DRAM can be connected	
1	0	PSRAM can be connected	
	1	Illegal setting	

Bit 4—Strobe Mode Select (CAS/$\overline{WE}$): Selects 2$\overline{CAS}$ or 2$\overline{WE}$ mode. The setting of this bit is valid when PSRAME = 0 and DRAME = 1. This bit is write-disabled when the PSRAME or DRAME bit is set to 1.

Bit 4 CAS/$\overline{WE}$	Description	
0	2$\overline{WE}$ mode	(Initial value)
1	2$\overline{CAS}$ mode	

Bit 3—Address Multiplex Mode Select (M9/$\overline{M8}$): Selects 8-bit or 9-bit column addressing. The setting of this bit is valid when PSRAME = 0 and DRAME = 1. This bit is write-disabled when the PSRAME or DRAME bit is set to 1.

Bit 3 M9/$\overline{M8}$	Description	
0	8-bit column address mode	(Initial value)
1	9-bit column address mode	

Bit 2—Refresh Pin Enable (RFSHE): Enables or disables refresh signal output from the $\overline{RFSH}$ pin. This bit is write-disabled when the PSRAME or DRAME bit is set to 1.

Bit 2 RFSHE	Description	
0	Refresh signal output at the $\overline{RFSH}$ pin is disabled (the $\overline{RFSH}$ pin can be used as a generic input/output port)	(Initial value)
1	Refresh signal output at the $\overline{RFSH}$ pin is enabled	

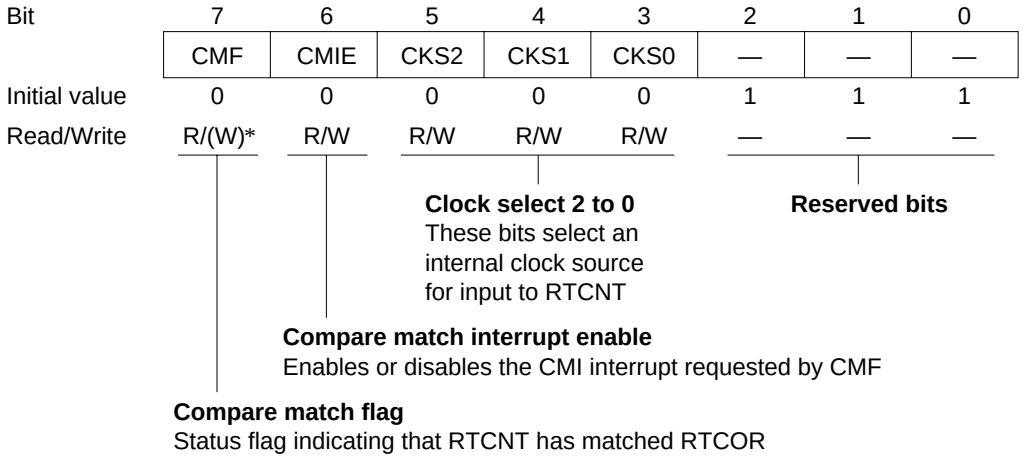
Bit 1—Reserved: Read-only bit, always read as 1.

Bit 0—Refresh Cycle Enable (RCYCE): Enables or disables insertion of refresh cycles. The setting of this bit is valid when PSRAME = 1 or DRAME = 1. When PSRAME = 0 and DRAME = 0, refresh cycles are not inserted regardless of the setting of this bit.

Bit 0 RCYCE	Description	
0	Refresh cycles are disabled	(Initial value)
1	Refresh cycles are enabled for area 3	

7.2.2 Refresh Timer Control/Status Register (RTMCSR)

RTMCSR is an 8-bit readable/writable register that selects the clock source for RTCNT. It also enables or disables interrupt requests when the refresh controller is used as an interval timer.



Note: * Only 0 can be written, to clear the flag.

Bits 7 and 6 are initialized by a reset and in standby mode. Bits 5 to 3 are initialized by a reset and in hardware standby mode, but retain their previous values on transition to software standby mode.

Bit 7—Compare Match Flag (CMF): This status flag indicates that the RTCNT and RTCOR values have matched.

Bit 7 CMF	Description
0	[Clearing condition] Cleared by reading CMF when CMF = 1, then writing 0 in CMF
1	[Setting condition] When RTCNT = RTCOR

Bit 6—Compare Match Interrupt Enable (CMIE): Enables or disables the CMI interrupt requested when the CMF flag is set to 1 in RTMCSR. The CMIE bit is always cleared to 0 when PSRAME = 1 or DRAME = 1.

Bit 6 CMIE	Description	
0	The CMI interrupt requested by CMF is disabled	(Initial value)
1	The CMI interrupt requested by CMF is enabled	

Bits 5 to 3—Clock Select 2 to 0 (CKS2 to CKS0): These bits select an internal clock source for input to RTCNT. When used for refresh control, the refresh controller outputs a refresh request at periodic intervals determined by compare match between RTCNT and RTCOR. When used as an interval timer, the refresh controller generates CMI interrupts at periodic intervals determined by compare match. These bits are write-disabled when the PSRAME bit or DRAME bit is set to 1.

Bit 5 CKS2	Bit 4 CKS1	Bit 3 CKS0	Description	
0	0	0	Clock input is disabled	(Initial value)
		1	ø/2 clock source	
	1	0	ø/8 clock source	
		1	ø/32 clock source	
1	0	0	ø/128 clock source	
		1	ø/512 clock source	
	1	0	ø/2048 clock source	
		1	ø/4096 clock source	

Bits 2 to 0—Reserved: Read-only bits, always read as 1.

7.2.3 Refresh Timer Counter (RTCNT)

RTCNT is an 8-bit readable/writable up-counter.

Bit	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

RTCNT is an up-counter that is incremented by an internal clock selected by bits CKS2 to CKS0 in RTMCSR. When RTCNT matches RTCOR (compare match), the CMF flag is set to 1 and RTCNT is cleared to H'00.

RTCNT is write-disabled when the PSRAME bit or DRAME bit is set to 1. RTCNT is initialized to H'00 by a reset and in standby mode.

7.2.4 Refresh Time Constant Register (RTCOR)

RTCOR is an 8-bit readable/writable register that determines the interval at which RTCNT is cleared.

Bit	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

RTCOR and RTCNT are constantly compared. When their values match, the CMF flag is set to 1 in RTMCSR, and RTCNT is simultaneously cleared to H'00.

RTCOR is write-disabled when the PSRAME bit or DRAME bit is set to 1. RTCOR is initialized to H'FF by a reset and in hardware standby mode. In software standby mode it retains its previous value.

7.3 Operation

7.3.1 Area Division

One of three functions can be selected for the H8/3003 refresh controller: interfacing to DRAM connected to area 3, interfacing to pseudo-static RAM connected to area 3, or interval timing. Table 7-3 summarizes the register settings when these three functions are used.

Table 7-3 Refresh Controller Settings

		Usage		
Register Settings		**DRAM Interface**	**PSRAM Interface**	**Interval Timer**
RFSHCR	SRFMD	Selects self-refresh mode		Cleared to 0
	PSRAME	Cleared to 0	Set to 1	Cleared to 0
	DRAME	Set to 1	Cleared to 0	Cleared to 0
	CAS/WE	Selects 2$\overline{CAS}$ or 2$\overline{WE}$ mode	—	—
	M9/$\overline{M8}$	Selects column addressing mode	—	—
	RFSHE	Selects $\overline{RFSH}$ signal output		Cleared to 0
	RCYCE	Selects insertion of refresh cycles		—
RTCOR		Refresh interval setting		Interrupt interval setting
RTMCSR	CKS2 to CKS0			
	CMF	Set to 1 when RTCNT = RTCOR		
	CMIE	Cleared to 0		Enables or disables interrupt requests
P8DDR	P8$_1$DDR	Set to 1 ($\overline{CS_3}$ output)		Set to 0 or 1
ABWCR	ABW3	Cleared to 0		—

DRAM Interface: To set up area 3 for connection to 16-bit-wide DRAM, initialize RTCOR, RTMCSR, and RFSHCR in that order, clearing bit PSRAME to 0 and setting bit DRAME to 1. Set bit P8$_1$DDR to 1 in the port 8 data direction register (P8DDR) to enable $\overline{CS_3}$ output. In ABWCR, make area 3 a 16-bit-access area.

Pseudo-Static RAM Interface: To set up area 3 for connection to pseudo-static RAM, initialize RTCOR, RTMCSR, and RFSHCR in that order, setting bit PSRAME to 1 and clearing bit DRAME to 0. Set bit P8$_1$DDR to 1 in P8DDR to enable $\overline{CS_3}$ output.

Interval Timer: When PSRAME = 0 and DRAME = 0, the refresh controller operates as an interval timer. After setting RTCOR, select an input clock in RTMCSR and set the CMIE bit to 1. CMI interrupts will be requested at compare match intervals determined by RTCOR and bits CKS2 to CKS0 in RTMCSR.

When setting RTCOR, RTMCSR, and RFSHCR, make sure that PSRAME = 0 and DRAME = 0. Writing is disabled when either of these bits is set to 1.

7.3.2 DRAM Refresh Control

Refresh Request Interval and Refresh Cycle Execution: The refresh request interval is determined by the settings of RTCOR and bits CKS2 to CKS0 in RTMCSR. Figure 7-2 illustrates the refresh request interval.

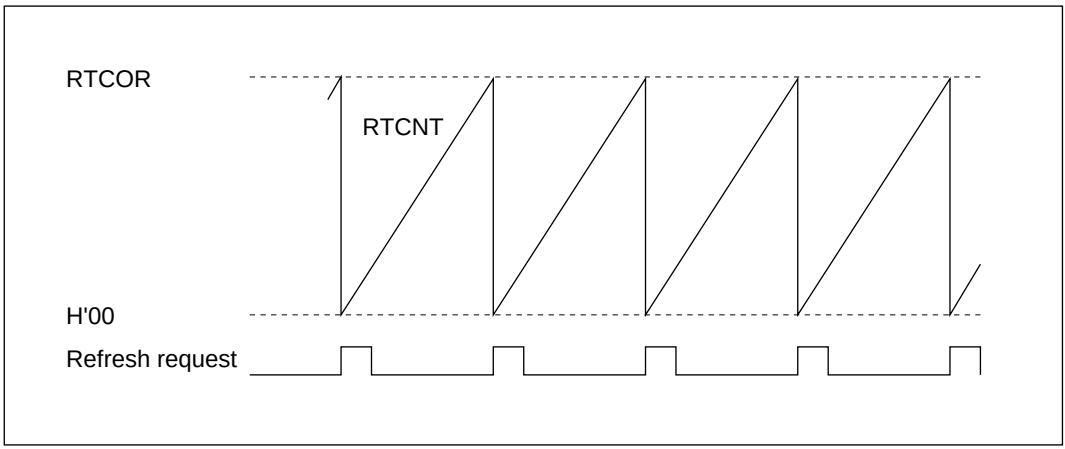


Figure 7-2 Refresh Request Interval (RCYCE = 1)

Refresh requests are generated at regular intervals as shown in figure 7-2, but the refresh cycle is not actually executed until the refresh controller gets the bus right.

Table 7-4 summarizes the relationship among area 3 settings, DRAM read/write cycles, and refresh cycles.

Table 7-4 Area 3 Settings, DRAM Access Cycles, and Refresh Cycles

Area 3 Settings	Read/Write Cycle by CPU or DMAC	Refresh Cycle
2-state-access area (AST3 = 0)	• 3 states • Wait states cannot be inserted	• 3 states • Wait states cannot be inserted
3-state-access area (AST3 = 1)	• 3 states • Wait states can be inserted	• 3 states • Wait states can be inserted

To insert refresh cycles, set the RCYCE bit to 1 in RFSHCR. Figure 7-3 shows the state transitions for execution of refresh cycles.

When the first refresh request occurs after exit from the reset state or standby mode, the refresh controller does not execute a refresh cycle, but goes into the refresh request pending state. Note this point when using a DRAM that requires a refresh cycle for initialization.

When a refresh request occurs in the refresh request pending state, the refresh controller acquires the bus right, then executes a refresh cycle. If another refresh request occurs during execution of the refresh cycle, it is ignored.

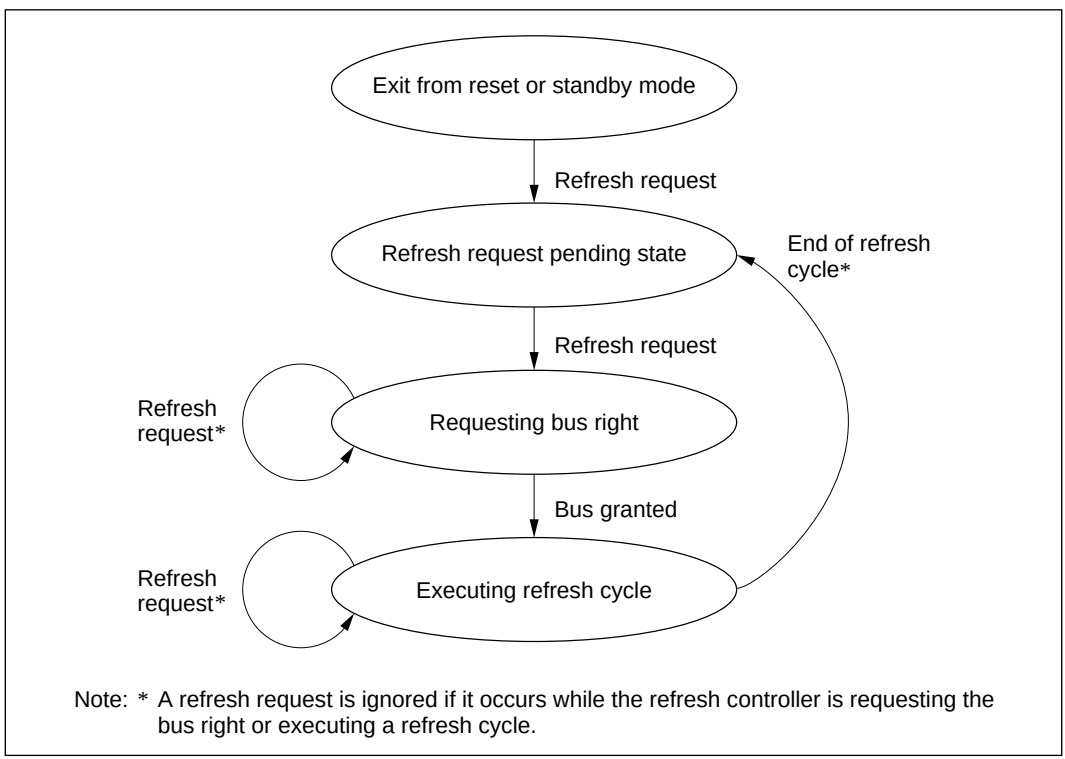


Figure 7-3 State Transitions for Refresh Cycle Execution

Address Multiplexing: Address multiplexing depends on the setting of the M9/$\overline{M8}$ bit in RFSHCR, as described in table 7-5. Figure 7-4 shows the address output timing. Address output is multiplexed only in area 3.

Table 7-5 Address Multiplexing

Address Pins		A_{23} to A_{10}	A_9	A_8	A_7	A_6	A_5	A_4	A_3	A_2	A_1	A_0
Address signals during row address output		A_{23} to A_{10}	A_9	A_8	A_7	A_6	A_5	A_4	A_3	A_2	A_1	A_0
Address signals during column address output	M9/$\overline{M8}$ = 0	A_{23} to A_{10}	A_9	A_9	A_{16}	A_{15}	A_{14}	A_{13}	A_{12}	A_{11}	A_{10}	A_0
	M9/$\overline{M8}$ = 1	A_{23} to A_{10}	A_{18}	A_{17}	A_{16}	A_{15}	A_{14}	A_{13}	A_{12}	A_{11}	A_{10}	A_0

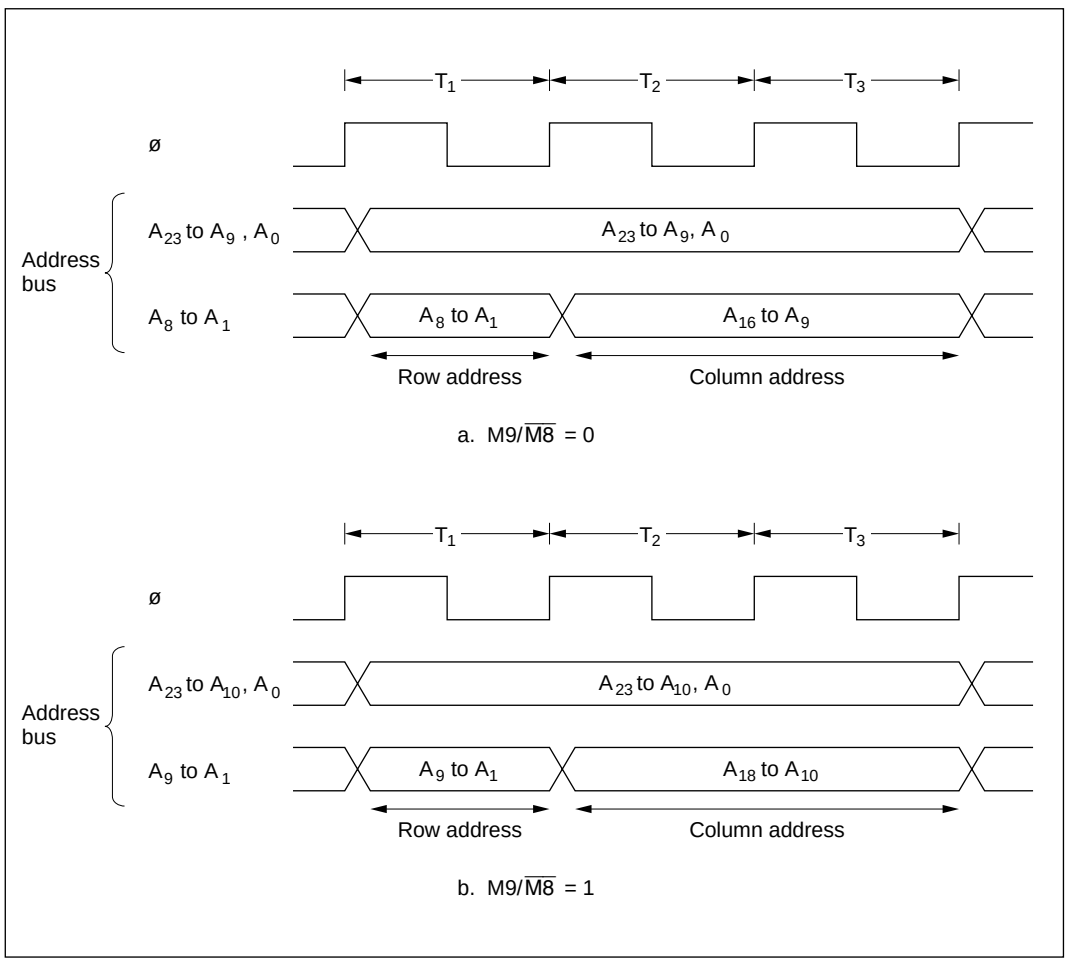


Figure 7-4 Multiplexed Address Output (Example without Wait States)

2$\overline{\text{CAS}}$ and 2$\overline{\text{WE}}$ Modes: The CAS/$\overline{\text{WE}}$ bit in RFSHCR can select two control modes for 16-bit-wide DRAM: one using $\overline{\text{UCAS}}$ and $\overline{\text{LCAS}}$; the other using $\overline{\text{UW}}$ and $\overline{\text{LW}}$. These DRAM pins correspond to H8/3003 pins as shown in table 7-6.

Table 7-6 DRAM Pins and H8/3003 Pins

	DRAM Pin	
H8/3003 Pin	**CAS/$\overline{\text{WE}}$ = 0 (2$\overline{\text{WE}}$ mode)**	**CAS/$\overline{\text{WE}}$ = 1 (2$\overline{\text{CAS}}$ mode)**
$\overline{\text{HWR}}$	$\overline{\text{UW}}$	$\overline{\text{UCAS}}$
$\overline{\text{LWR}}$	$\overline{\text{LW}}$	$\overline{\text{LCAS}}$
$\overline{\text{RD}}$	$\overline{\text{CAS}}$	$\overline{\text{WE}}$
$\overline{\text{CS}_3}$	$\overline{\text{RAS}}$	$\overline{\text{RAS}}$

Figure 7-5 (1) shows the interface timing for 2$\overline{\text{WE}}$ DRAM. Figure 7-5 (2) shows the interface timing for 2$\overline{\text{CAS}}$ DRAM.

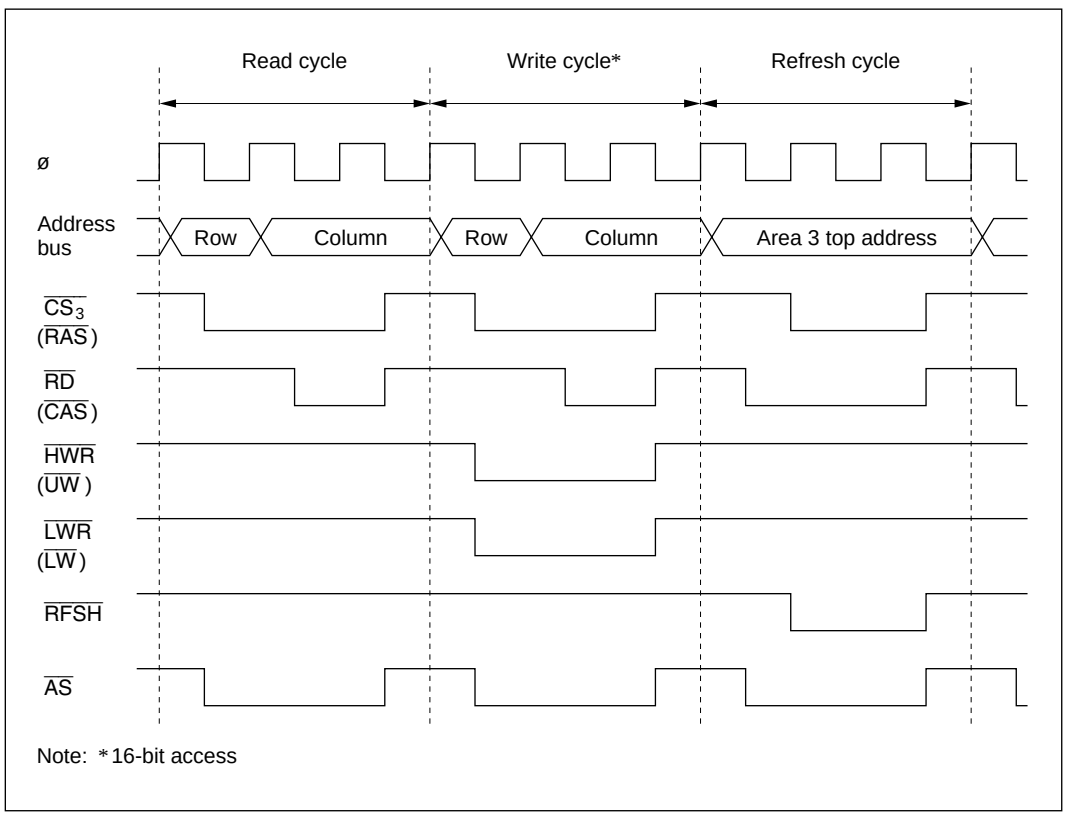


Figure 7-5 DRAM Control Signal Output Timing (1) (2$\overline{\text{WE}}$ Mode)

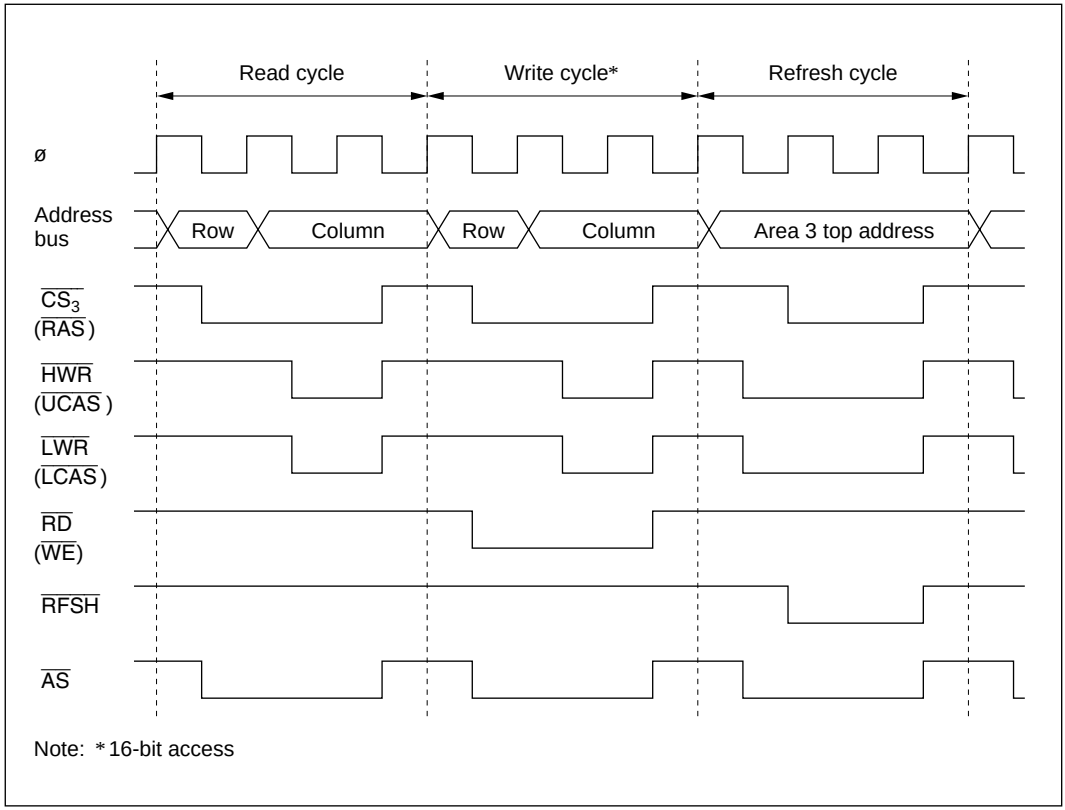


Figure 7-5 DRAM Control Signal Output Timing (2) (2$\overline{CAS}$ Mode)

Refresh Cycle Priority Order: When there are simultaneous bus requests, the priority order is:

(High) External bus master > refresh controller > DMA controller > CPU (Low)

For details see section 6.3.7, Bus Arbiter Operation.

Wait State Insertion: When bit AST3 is set to 1 in ASTCR, bus controller settings can cause wait states to be inserted into bus cycles and refresh cycles. For details see section 6.3.5, Wait Modes.

Self-Refresh Mode: Some DRAM devices have a self-refresh function. After the SRFMD bit is set to 1 in RFSHCR, when a transition to software standby mode occurs, the $\overline{CAS}$ and $\overline{RAS}$ outputs go low in that order so that the DRAM self-refresh function can be used. On exit from software standby mode, the $\overline{CAS}$ and $\overline{RAS}$ outputs both go high.

Table 7-7 shows the pin states in software standby mode. Figure 7-6 shows the signal output timing.

Table 7-7 Pin States in Software Standby Mode (1) (PSRAME = 0, DRAME = 1)

	Software Standby Mode			
	SRFMD = 0		SRFMD = 1 (self-refresh mode)	
Signal	**CAS/$\overline{WE}$ = 0**	**CAS/$\overline{WE}$ = 1**	**CAS/$\overline{WE}$ = 0**	**CAS/$\overline{WE}$ = 1**
$\overline{HWR}$	High-impedance	High-impedance	High	Low
$\overline{LWR}$	High-impedance	High-impedance	High	Low
$\overline{RD}$	High-impedance	High-impedance	Low	High
$\overline{CS_3}$	High	High	Low	Low
$\overline{RFSH}$	High	High	Low	Low

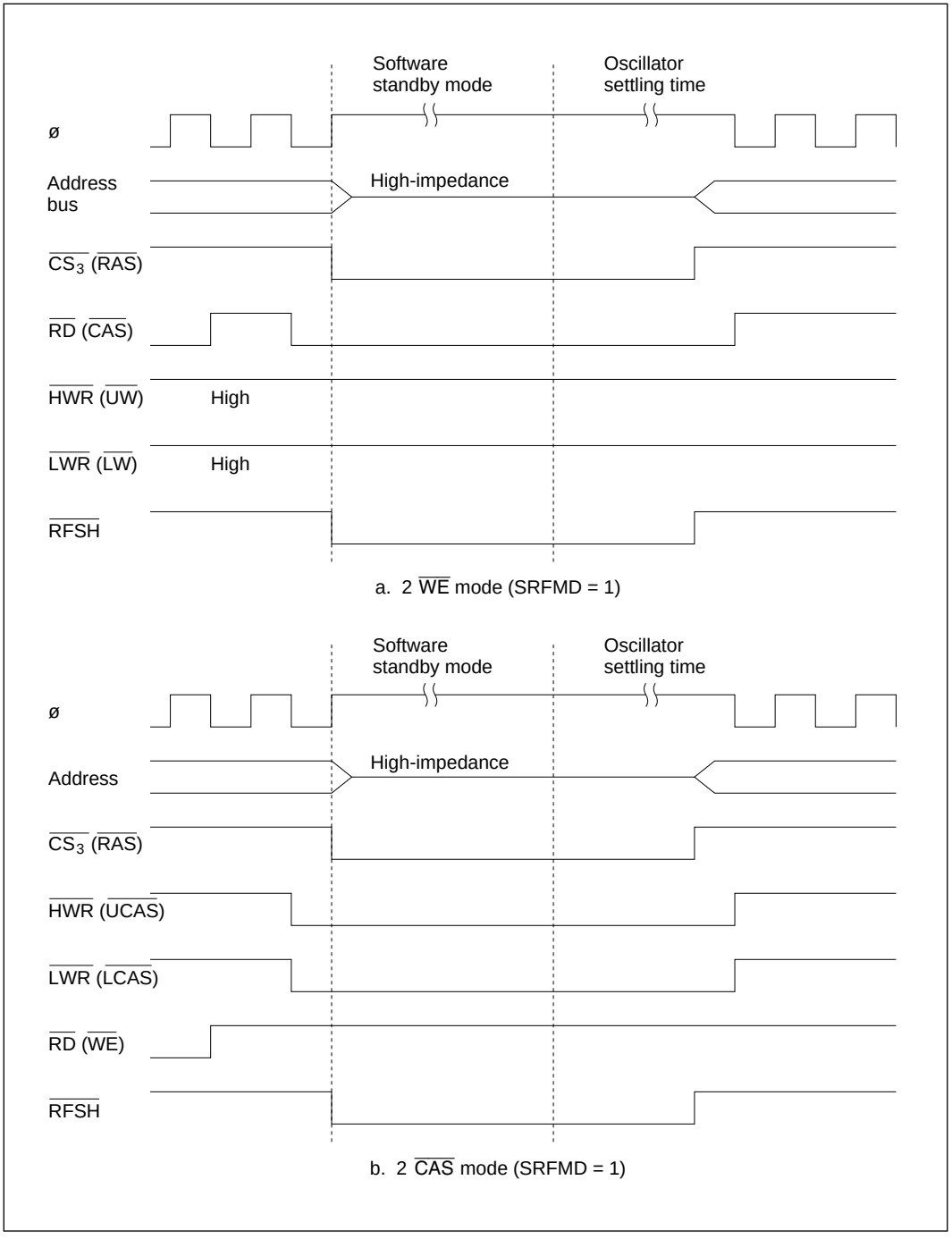


Figure 7-6 Signal Output Timing in Self-Refresh Mode (PSRAME = 0, DRAME = 1)

Operation in Power-Down State: The refresh controller operates in sleep mode. It does not operate in hardware standby mode. In software standby mode RTCNT is initialized, but RFSHCR, RTMCSR bits 5 to 3, and RTCOR retain their settings prior to the transition to software standby mode.

Example 1: Connection to 2$\overline{\text{WE}}$ 1-Mbit DRAM (1-Mbyte Mode): Figure 7-7 shows typical interconnections to a 2$\overline{\text{WE}}$ 1-Mbit DRAM, and the corresponding address map. Figure 7-8 shows a setup procedure to be followed by a program for this example. After power-up the DRAM must be refreshed to initialize its internal state. Initialization takes a certain length of time, which can be measured by using an interrupt from another timer module, or by counting the number of times RTMCSR bit 7 (CMF) is set. Note that no refresh cycle is executed for the first refresh request after exit from the reset state or standby mode (the first time the CMF flag is set; see figure 7-3). When using this example, check the DRAM device characteristics carefully and use a procedure that fits them.

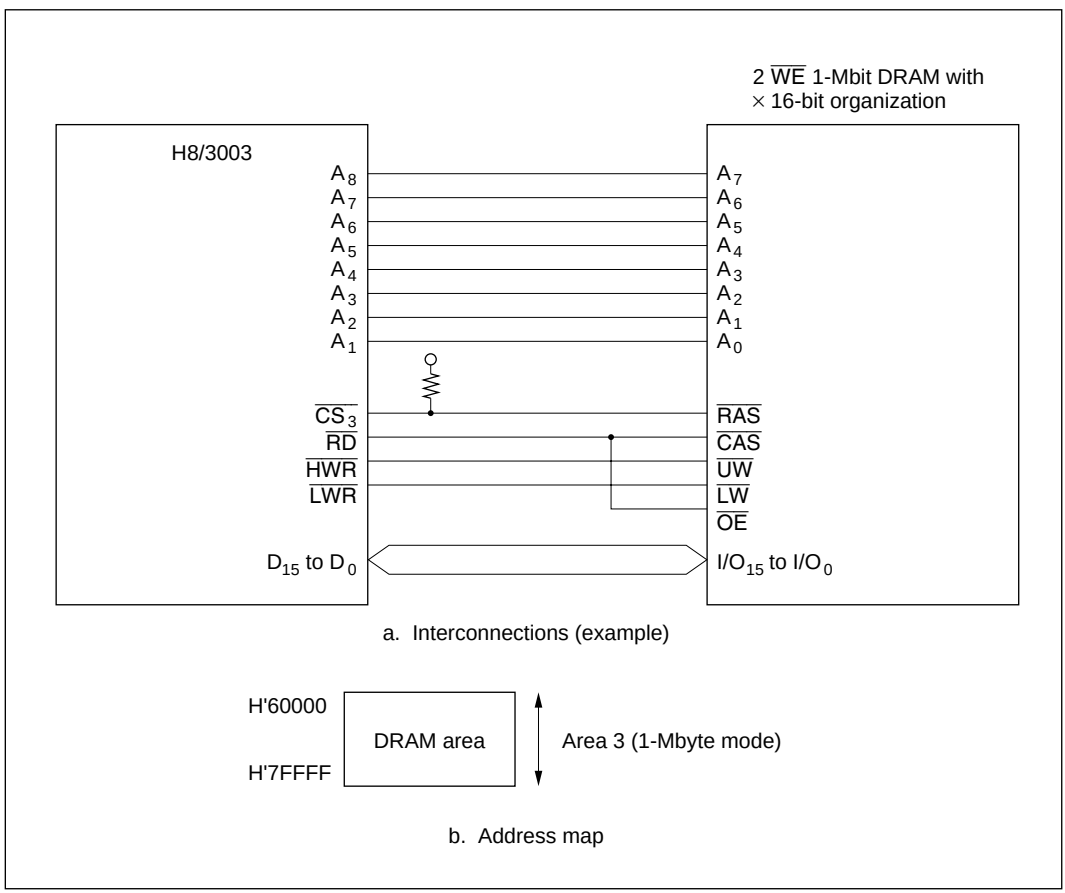


Figure 7-7 Interconnections and Address Map for 2$\overline{\text{WE}}$ 1-Mbit DRAM (Example)

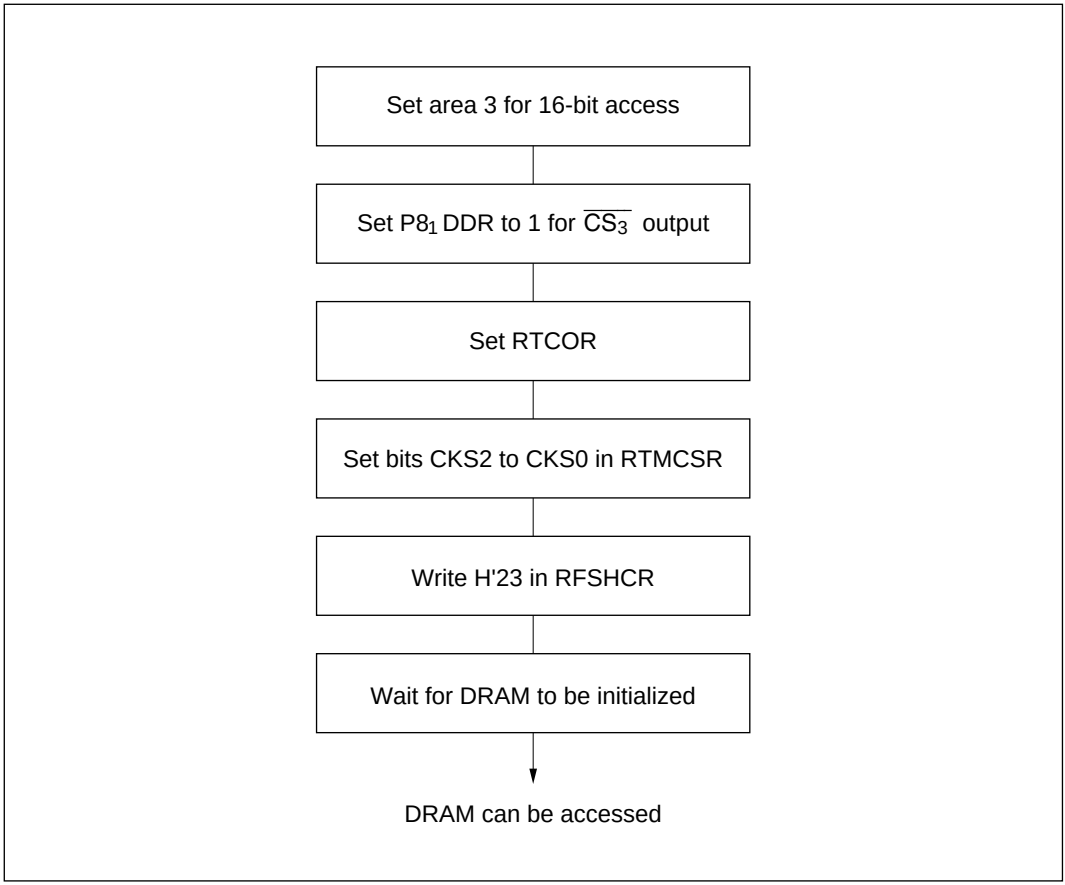


Figure 7-8 Setup Procedure for 2$\overline{WE}$ 1-Mbit DRAM (1-Mbyte Mode)

Example 2: Connection to 2$\overline{WE}$ 4-Mbit DRAM (16-Mbyte Mode): Figure 7-9 shows typical interconnections to a single 2$\overline{WE}$ 4-Mbit DRAM, and the corresponding address map. Figure 7-10 shows a setup procedure to be followed by a program for this example.

The DRAM in this example has 10-bit row addresses and 8-bit column addresses. Its address area is H'600000 to H'67FFFF.

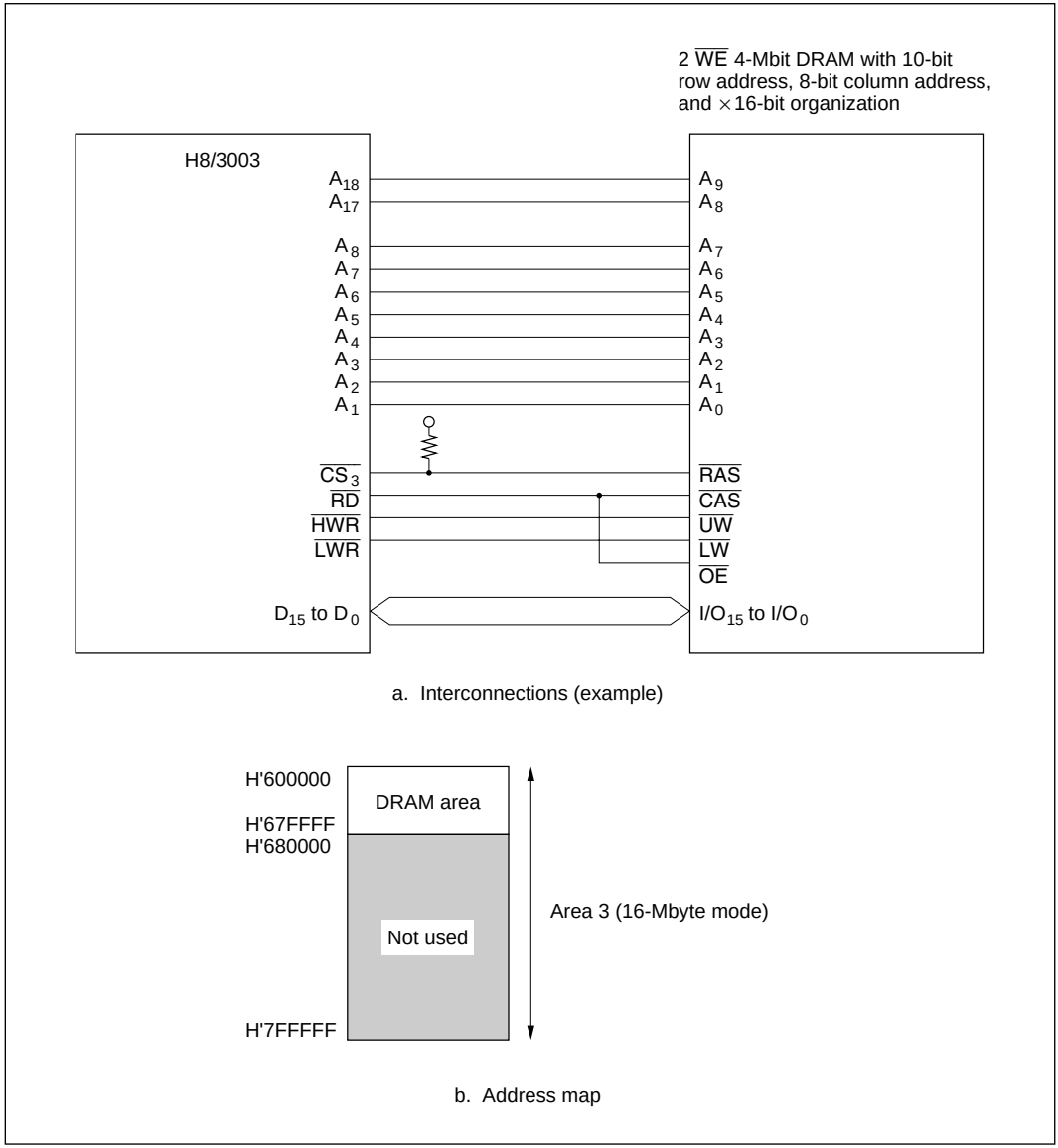


Figure 7-9 Interconnections and Address Map for 2$\overline{WE}$ 4-Mbit DRAM (Example)

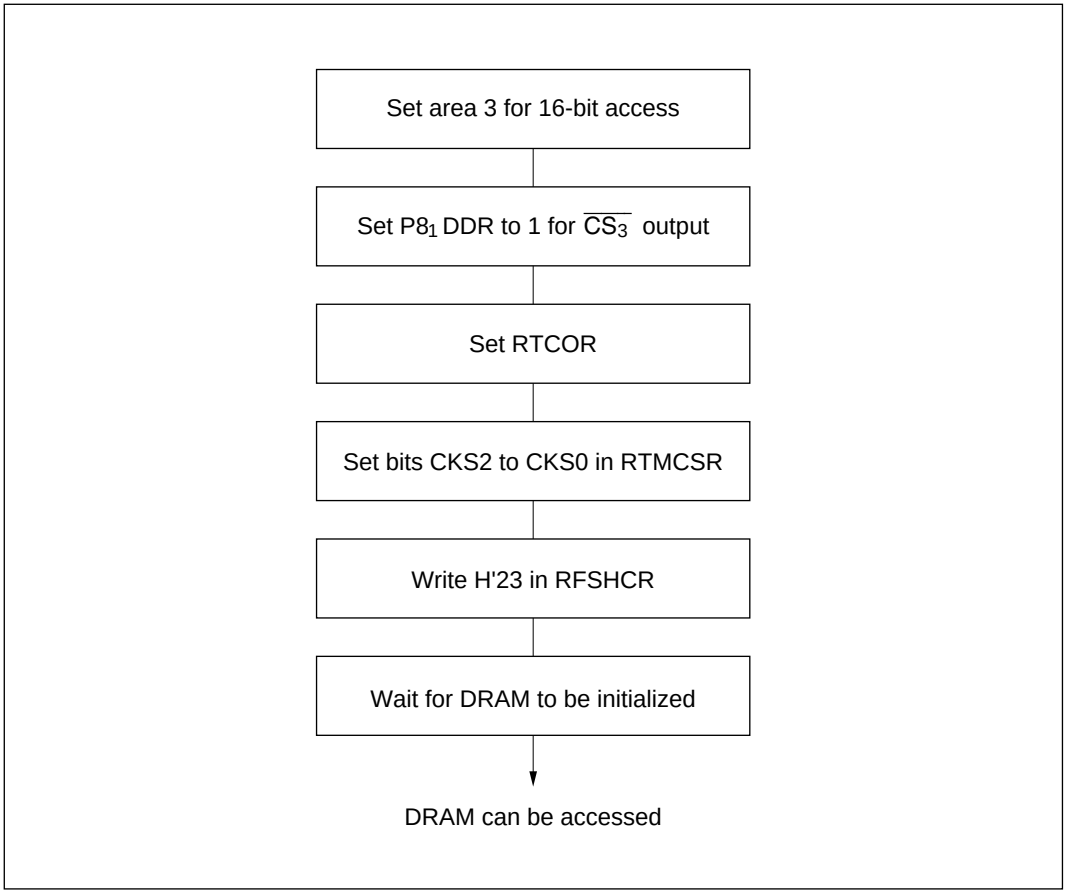


Figure 7-10 Setup Procedure for 2$\overline{WE}$ 4-Mbit DRAM with 10-Bit Row Address and 8-Bit Column Address (16-Mbyte Mode)

Example 3: Connection to 2$\overline{\text{CAS}}$ 4-Mbit DRAM (16-Mbyte Mode): Figure 7-11 shows typical interconnections to a single 2$\overline{\text{CAS}}$ 4-Mbit DRAM, and the corresponding address map. Figure 7-12 shows a setup procedure to be followed by a program for this example.

The DRAM in this example has 9-bit row addresses and 9-bit column addresses. Its address area is H'600000 to H'67FFFF.

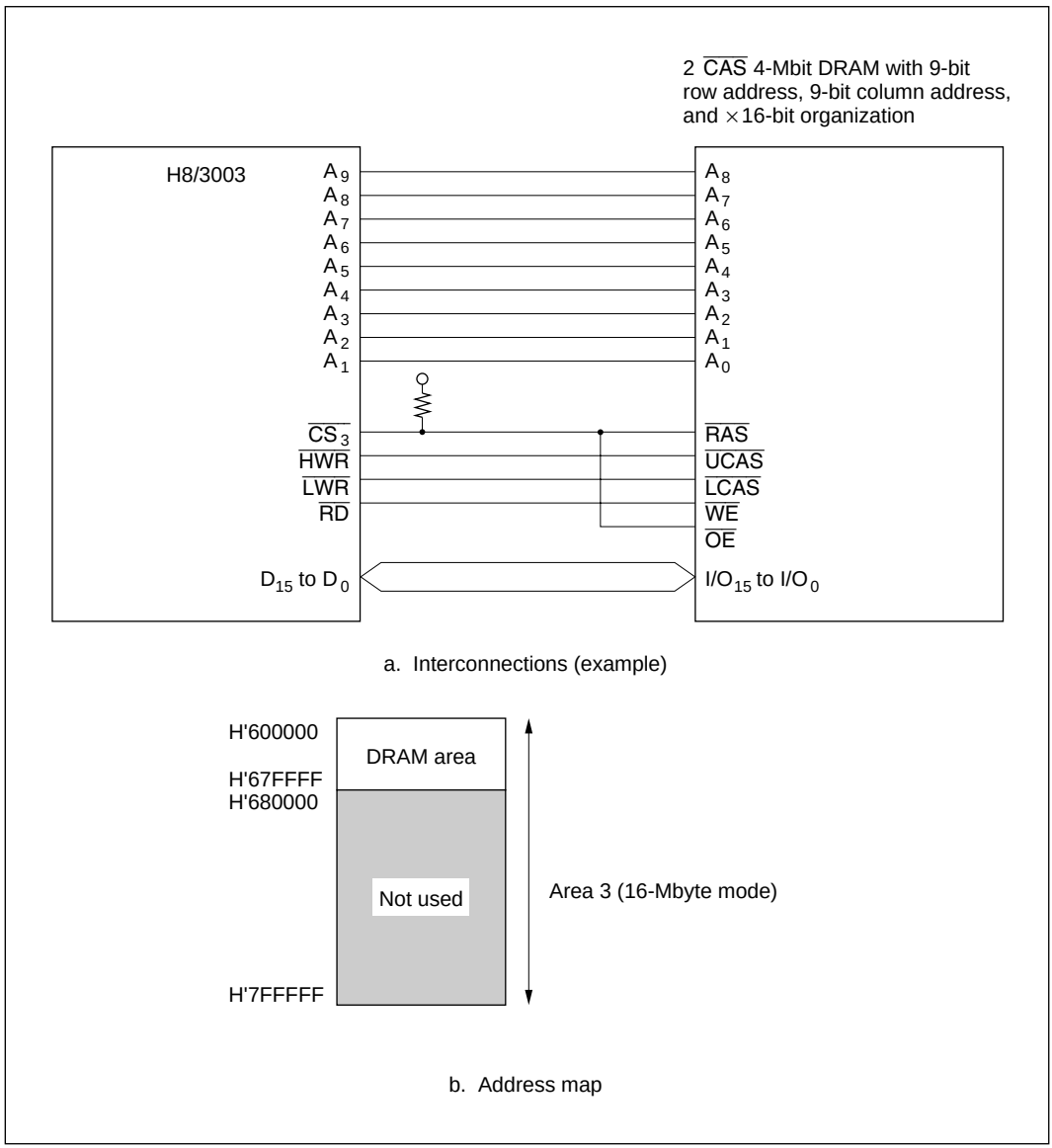


Figure 7-11 Interconnections and Address Map for 2$\overline{\text{CAS}}$ 4-Mbit DRAM (Example)

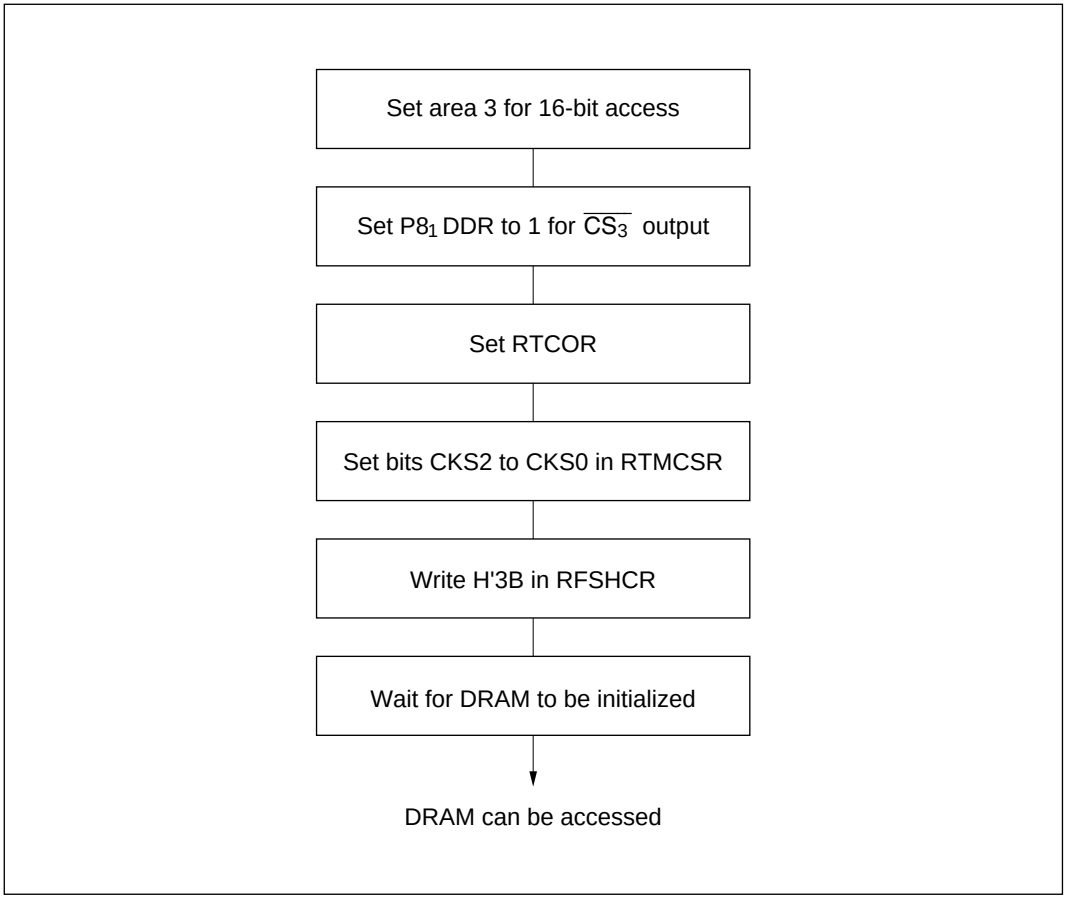


Figure 7-12 Setup Procedure for 2$\overline{CAS}$ 4-Mbit DRAM with 9-Bit Row Address and 9-Bit Column Address (16-Mbyte Mode)

Example 4: Connection to Two 4-Mbit DRAM Chips (16-Mbyte Mode): Figure 7-13 shows an example of interconnections to two 2$\overline{\text{CAS}}$ 4-Mbit DRAM chips, and the corresponding address map. Up to four DRAM chips can be connected to area 3 by decoding upper address bits A_{19} and A_{20}.

Figure 7-14 shows a setup procedure to be followed by a program for this example. The DRAM in this example has 9-bit row addresses and 9-bit column addresses. Both chips must be refreshed simultaneously, so the $\overline{\text{RFSH}}$ pin must be used.

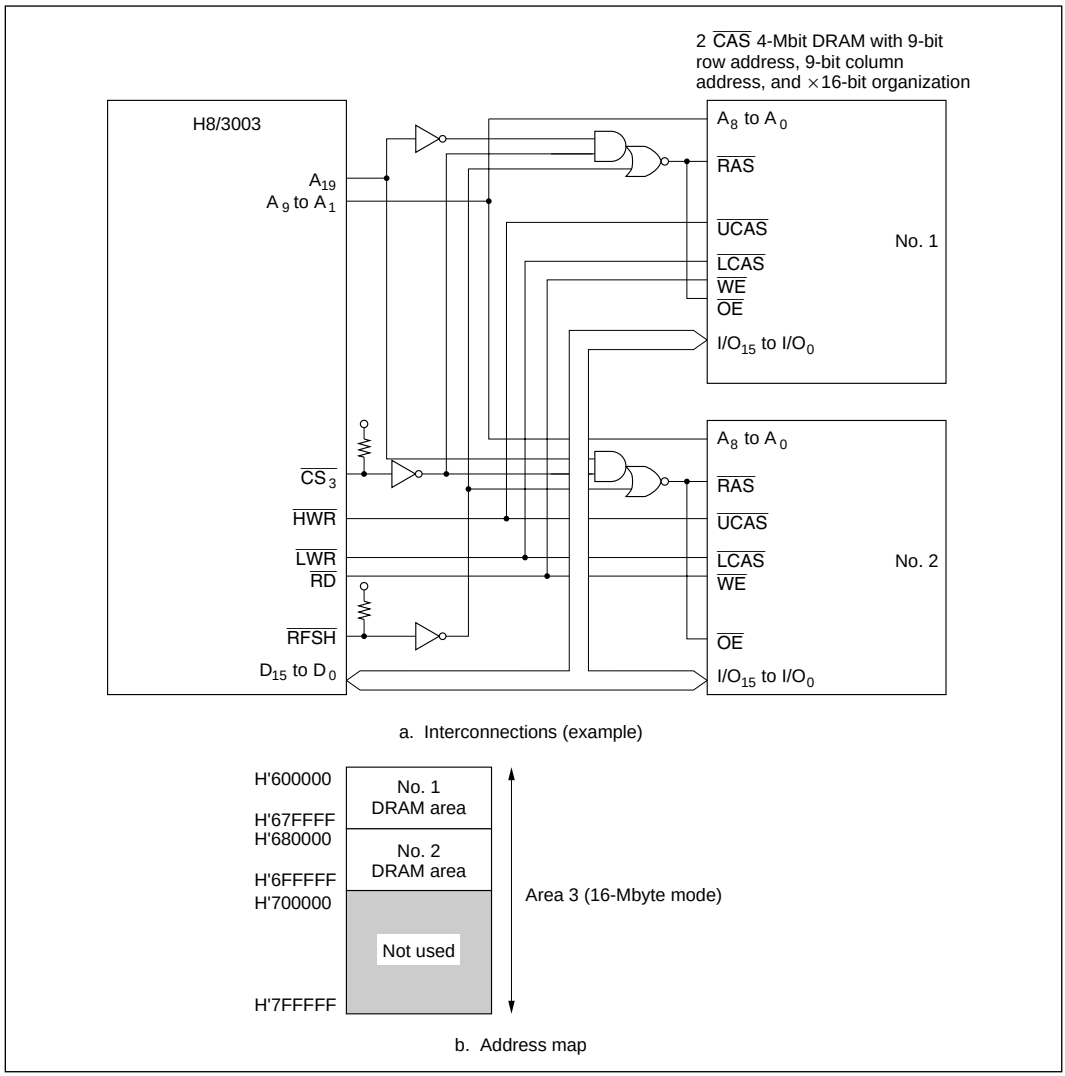


Figure 7-13 Interconnections and Address Map for Multiple 2$\overline{\text{CAS}}$ 4-Mbit DRAM Chips (Example)

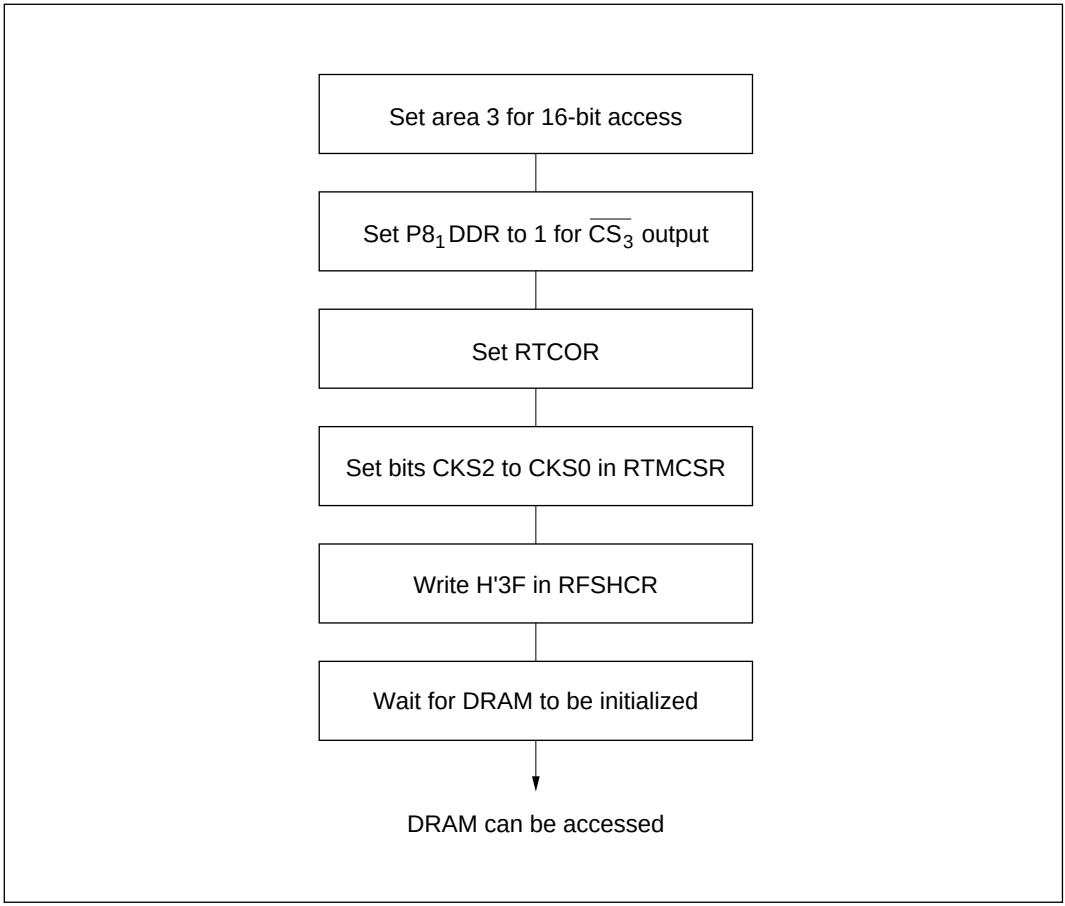


Figure 7-14 Setup Procedure for Multiple 2$\overline{CAS}$ 4-Mbit DRAM Chips with 9-Bit Row Address and 9-Bit Column Address (16-Mbyte Mode)

7.3.3 Pseudo-Static RAM Refresh Control

Refresh Request Interval and Refresh Cycle Execution: The refresh request interval is determined as in a DRAM interface, by the settings of RTCOR and bits CKS2 to CKS0 in RTMCSR. The numbers of states required for pseudo-static RAM read/write cycles and refresh cycles are the same as for DRAM (see table 7-4). The state transitions are as shown in figure 7-3.

Pseudo-Static RAM Control Signals: Figure 7-15 shows the control signals for pseudo-static RAM read, write, and refresh cycles.

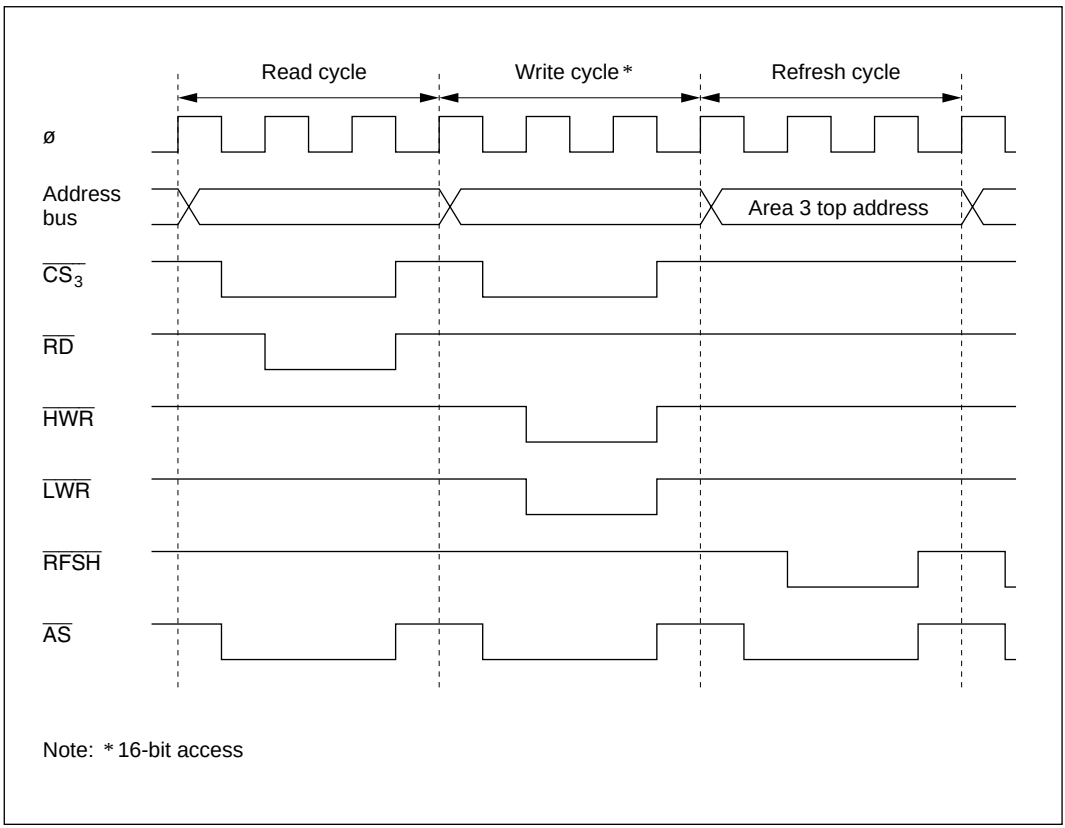


Figure 7-15 Pseudo-Static RAM Control Signal Output Timing

Refresh Cycle Priority Order: When there are simultaneous bus requests, the priority order is:

(High) External bus master > refresh controller > DMA controller > CPU (Low)

For details see section 6.3.7, Bus Arbiter Operation.

Wait State Insertion: When bit AST3 is set to 1 in ASTCR, the wait state controller (WSC) can insert wait states into bus cycles and refresh cycles. For details see section 6.3.5, Wait Modes.

Self-Refresh Mode: Some pseudo-static RAM devices have a self-refresh function. After the SRFMD bit is set to 1 in RFSHCR, when a transition to software standby mode occurs, the H8/3003's $\overline{CS_3}$ output goes high and its $\overline{RFSH}$ output goes low so that the pseudo-static RAM self-refresh function can be used. On exit from software standby mode, the $\overline{RFSH}$ output goes high.

Table 7-8 shows the pin states in software standby mode. Figure 7-16 shows the signal output timing.

Table 7-8 Pin States in Software Standby Mode (2) (PSRAME = 1, DRAME = 0)

	Software Standby Mode	
Signal	**SRFMD = 0**	**SRFMD = 1 (self-refresh mode)**
$\overline{CS_3}$	High	High
$\overline{RD}$	High-impedance	High-impedance
$\overline{HWR}$	High-impedance	High-impedance
$\overline{LWR}$	High-impedance	High-impedance
$\overline{RFSF}$	High	Low

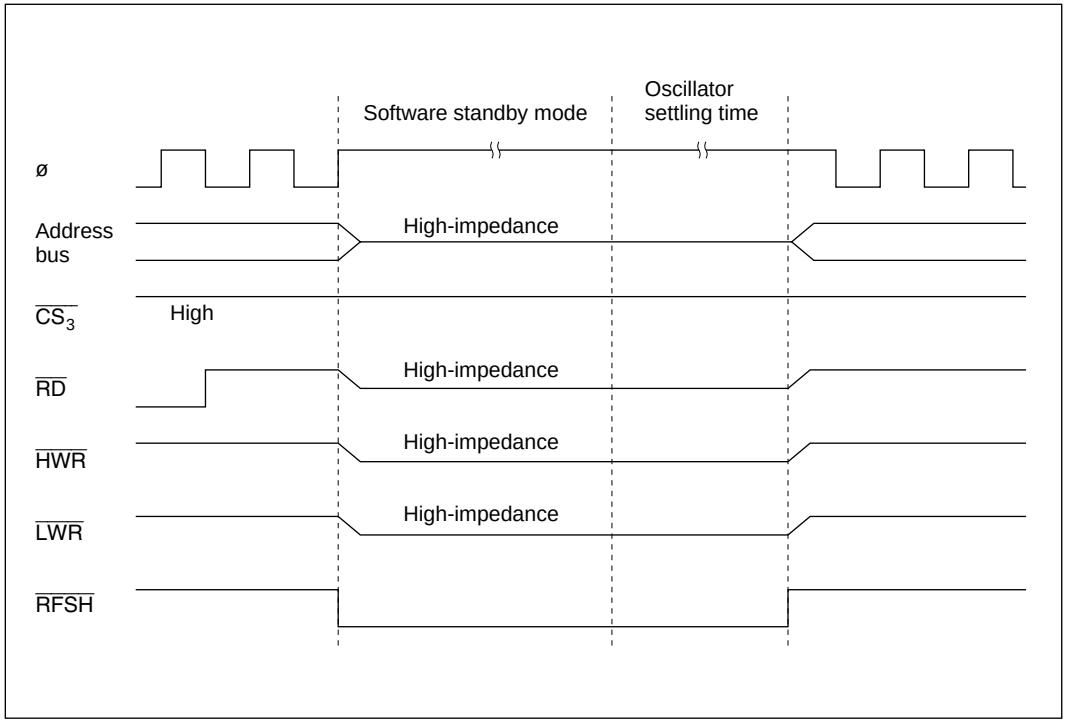


Figure 7-16 Signal Output Timing in Self-Refresh Mode (PSRAME = 1, DRAME = 0)

Operation in Power-Down State: The refresh controller operates in sleep mode. It does not operate in hardware standby mode. In software standby mode RTCNT is initialized, but RFSHCR, RTMCSR bits 5 to 3, and RTCOR retain their settings prior to the transition to software standby mode.

Example: Pseudo-static RAM may have separate $\overline{OE}$ and $\overline{RFSH}$ pins, or these may be combined into a single $\overline{OE}/\overline{RFSH}$ pin. Figure 7-17 shows an example of a circuit for generating an $\overline{OE}/\overline{RFSH}$ signal. Check the device characteristics carefully, and design a circuit that fits them. Figure 7-18 shows a setup procedure to be followed by a program.

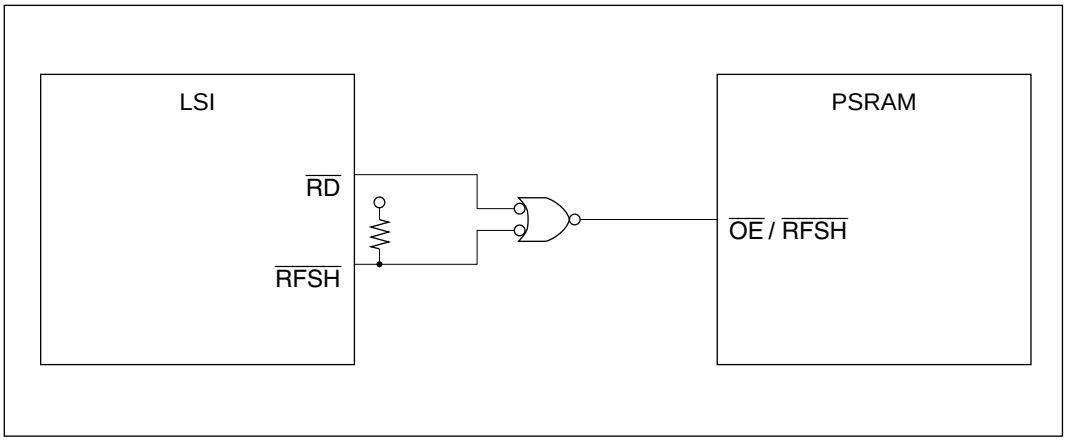


Figure 7-17 Interconnection to Pseudo-Static RAM with $\overline{OE}/\overline{RFSH}$ Signal (Example)

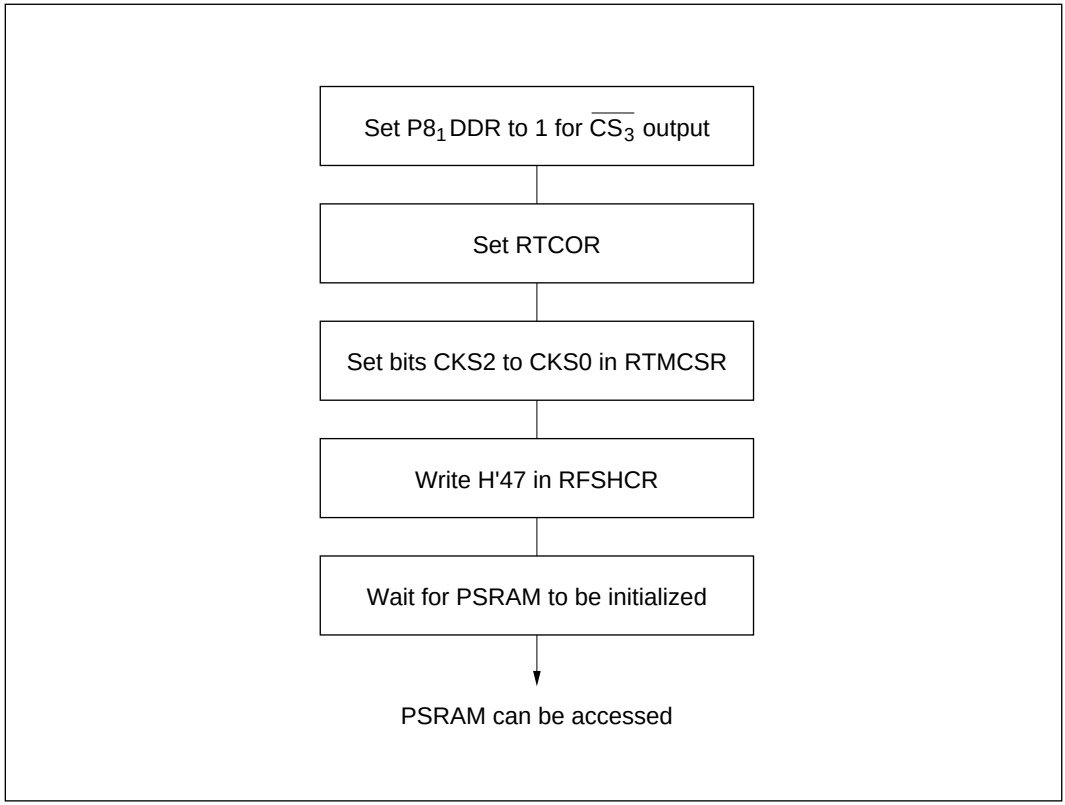


Figure 7-18 Setup Procedure for Pseudo-Static RAM

7.3.4 Interval Timing

To use the refresh controller as an interval timer, clear the PSRAME and DRAME both to 0. After setting RTCOR, select a clock source with bits CKS2 to CKS0 in RTMCSR, and set the CMIE bit to 1.

Timing of Setting of Compare Match Flag and Clearing by Compare Match: The CMF flag in RTCSR is set to 1 by a compare match signal output when the RTCOR and RTCNT values match. The compare match signal is generated in the last state in which the values match (when RTCNT is updated from the matching value to a new value). Accordingly, when RTCNT and RTCOR match, the compare match signal is not generated until the next counter clock pulse. Figure 7-19 shows the timing.

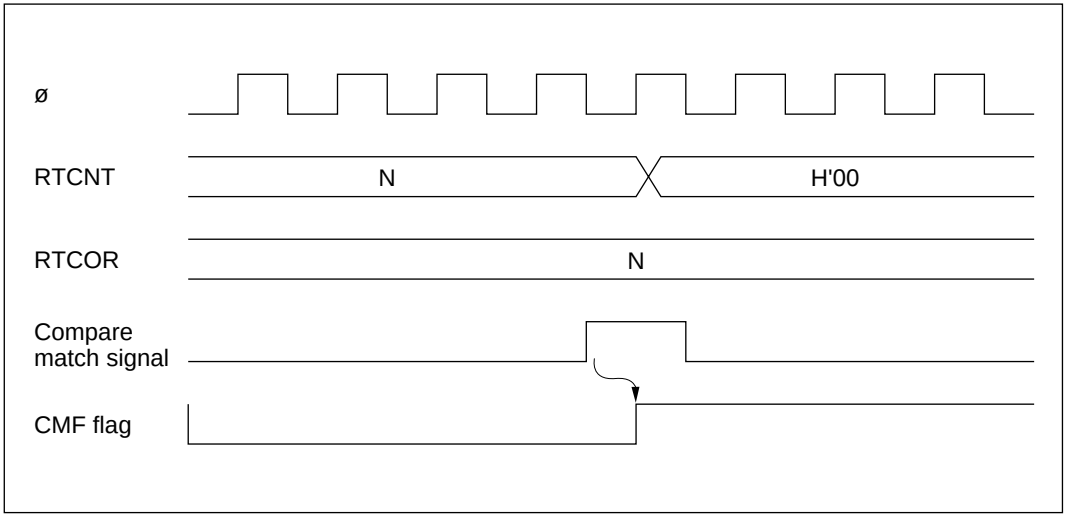


Figure 7-19 Timing of Setting of CMF Flag

Operation in Power-Down State: The interval timer function operates in sleep mode. It does not operate in hardware standby mode. In software standby mode RTCNT and RTMCSR bits 7 and 6 are initialized, but RTMCSR bits 5 to 3 and RTCOR retain their settings prior to the transition to software standby mode.

Contention between RTCNT Write and Counter Clear: If a counter clear signal occurs in the T_3 state of an RTCNT write cycle, clearing of the counter takes priority and the write is not performed. See figure 7-20.

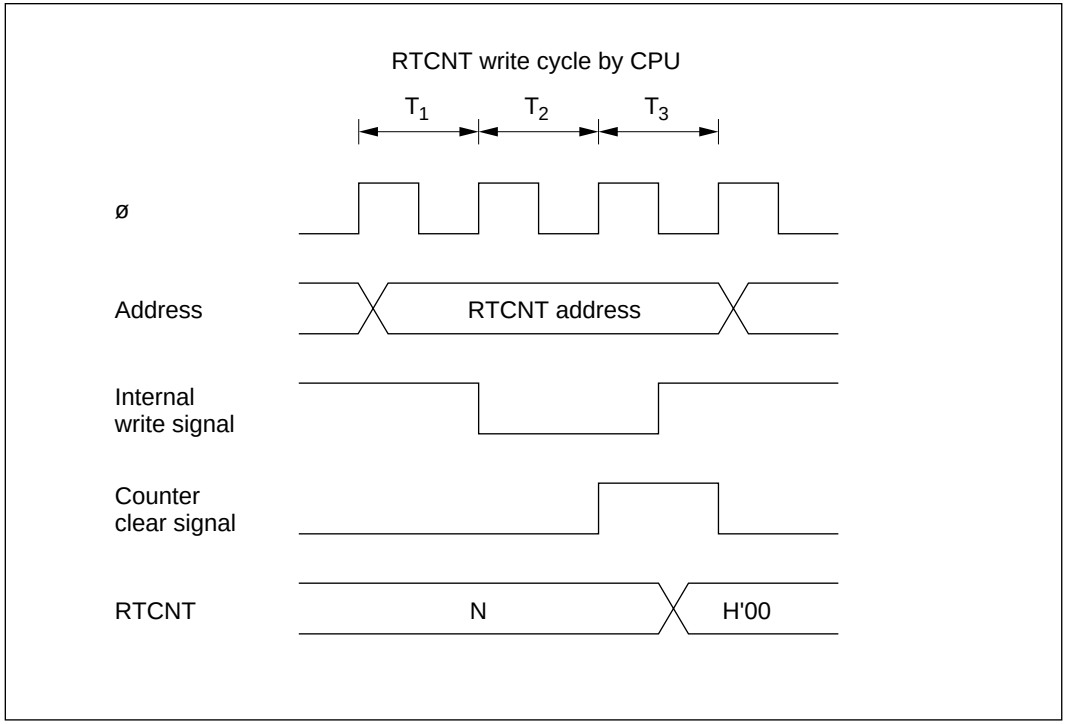


Figure 7-20 Contention between RTCNT Write and Clear

Contention between RTCNT Write and Increment: If an increment pulse occurs in the T_3 state of an RTCNT write cycle, writing takes priority and RTCNT is not incremented. See figure 7-21.

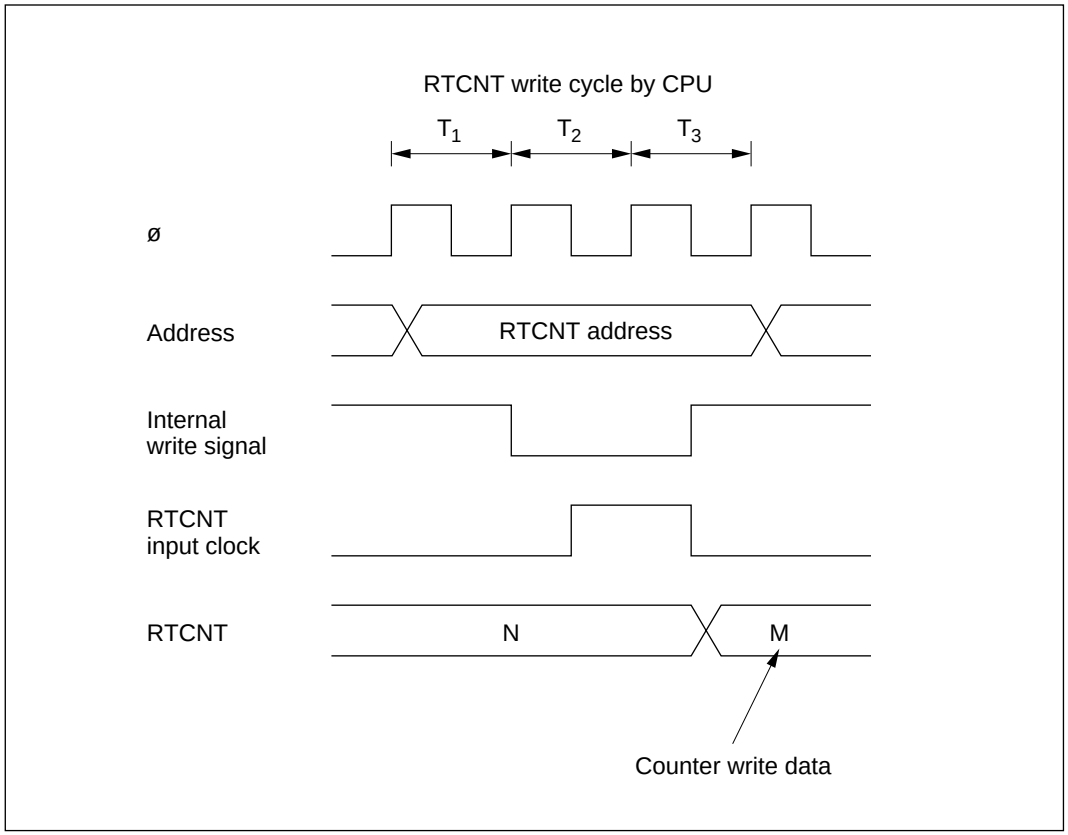


Figure 7-21 Contention between RTCNT Write and Increment

Contention between RTCOR Write and Compare Match: If a compare match occurs in the T_3 state of an RTCOR write cycle, writing takes priority and the compare match signal is inhibited. See figure 7-22.

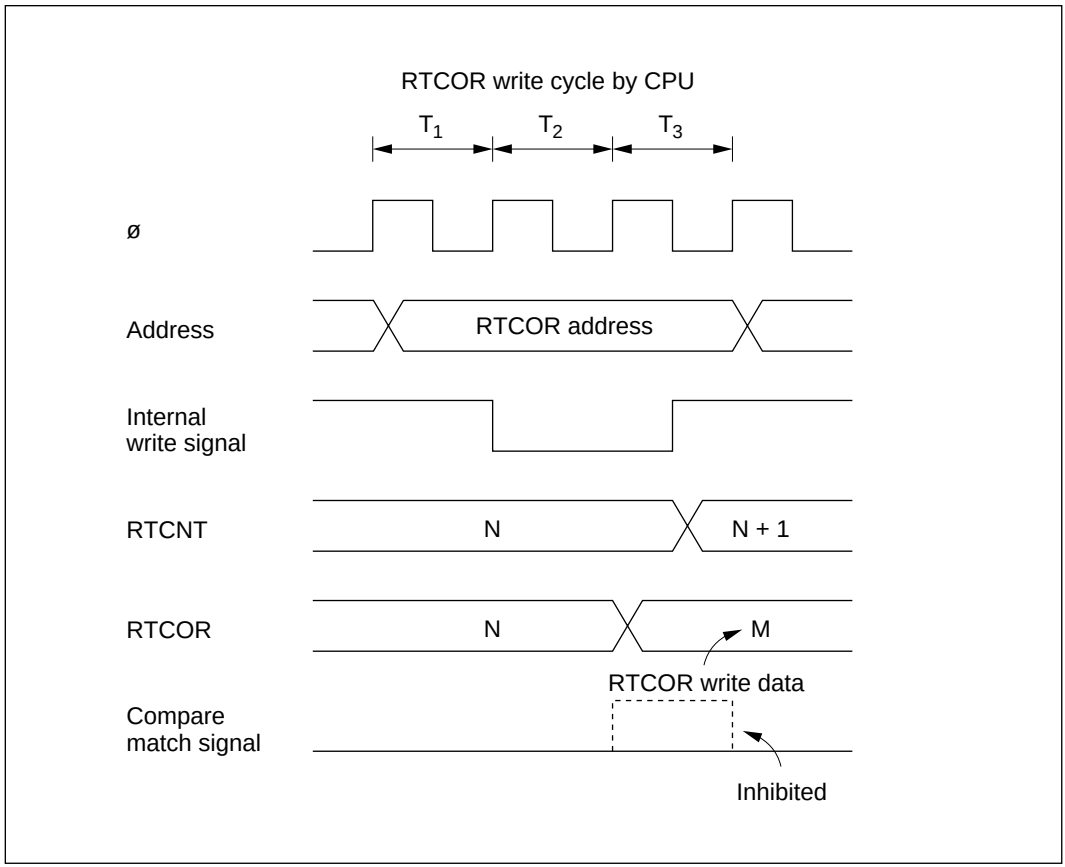
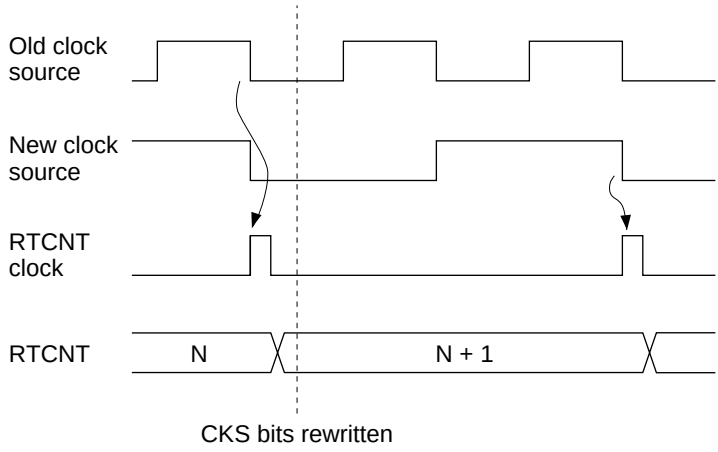
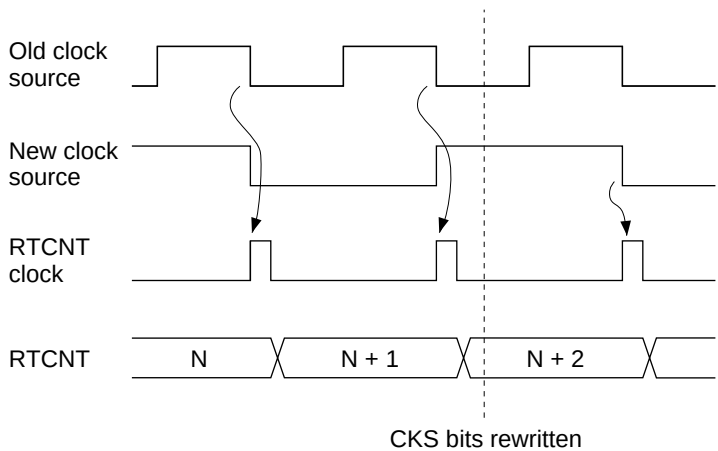


Figure 7-22 Contention between RTCOR Write and Compare Match

RTCNT Operation at Internal Clock Source Switchover: Switching internal clock sources may cause RTCNT to increment, depending on the switchover timing. Table 7-9 shows the relation between the time of the switchover (by writing to bits CKS2 to CKS0) and the operation of RTCNT.

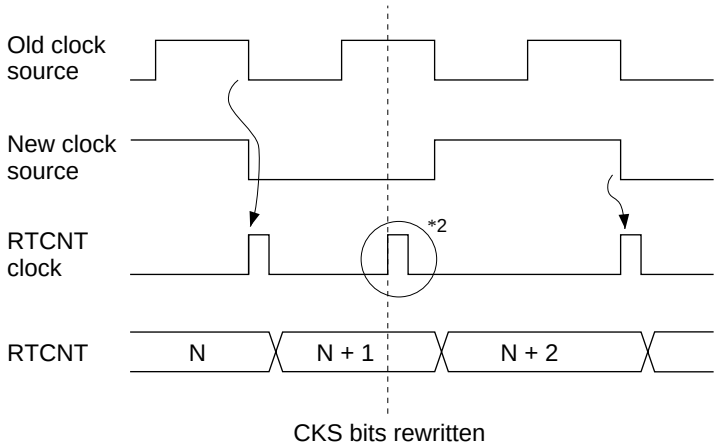
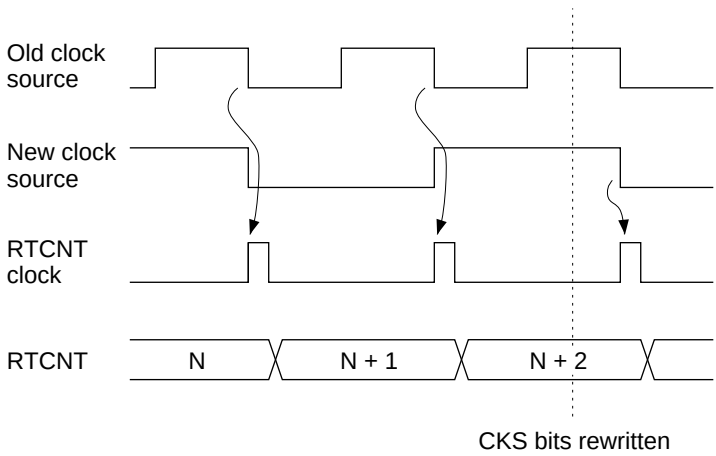
The RTCNT input clock is generated from the internal clock source by detecting the falling edge of the internal clock. If a switchover is made from a high clock source to a low clock source, as in case No. 3 in table 7-9, the switchover will be regarded as a falling edge, an RTCNT clock pulse will be generated, and RTCNT will be incremented.

Table 7-9 Internal Clock Switchover and RTCNT Operation

No.	CKS2 to CKS0 Write Timing	RTCNT Operation
1	Low → low switchover*1	
2	Low → high switchover*2	

Notes: 1. Including switchovers from a low clock source to the halted state, and from the halted state to a low clock source.
2. Including switchover from the halted state to a high clock source.

Table 7-9 Internal Clock Switchover and RTCNT Operation (cont)

No.	CKS2 to CKS0 Write Timing	RTCNT Operation
3	High → low switchover*1	
4	High → high switchover	

Notes: 1. Including switchover from a high clock source to the halted state.
2. The switchover is regarded as a falling edge, causing RTCNT to increment.

7.4 Interrupt Source

Compare match interrupts (CMI) can be generated when the refresh controller is used as an interval timer. Compare match interrupt requests are masked/unmasked with the CMIE bit of RTMCSR.

7.5 Usage Notes

When using the DRAM or pseudo-static RAM refresh function, note the following points:

- Refresh cycles are not executed while the bus is released, during software standby mode, and when a bus cycle is greatly prolonged by insertion of wait states. When these conditions occur, other means of refreshing are required.
- If refresh requests occur while the bus is released, the first request is held and one refresh cycle is executed after the bus-released state ends. Figure 7-23 shows the bus cycles in this case.

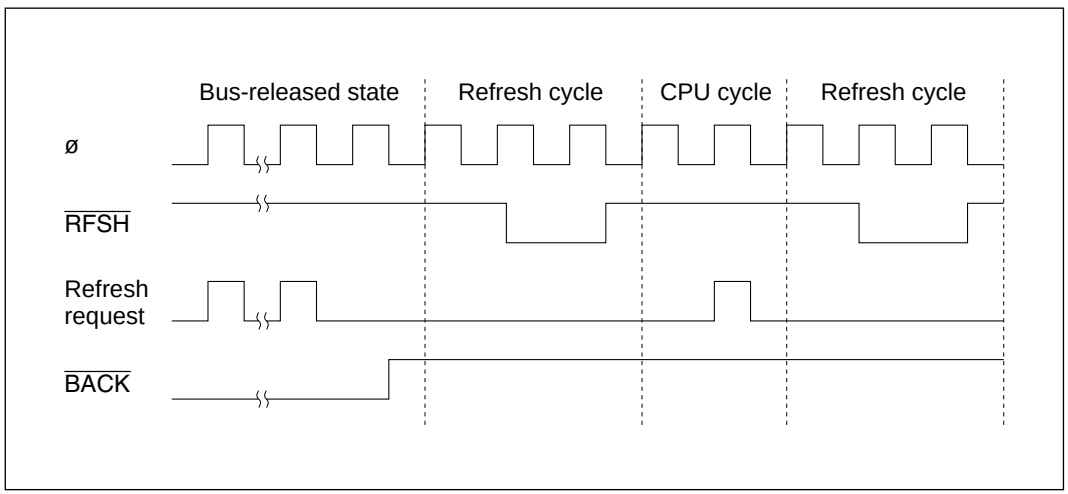


Figure 7-23 Refresh Cycles when Bus is Released

- If a bus cycle is prolonged by insertion of wait states, the first refresh request is held, as in the bus-released state.
- If contention occurs between a transition to software standby mode and a bus request from an external bus master, the bus may be released for one state just before the transition to software standby mode (see figure 7-24). When using software standby mode, clear the BRLE bit to 0 in BRCR before executing the SLEEP instruction.

  If similar contention occurs in a transition to self-refresh mode, strobe waveforms may not be output correctly. This can also be prevented by clearing the BRLE bit to 0 in BRCR.

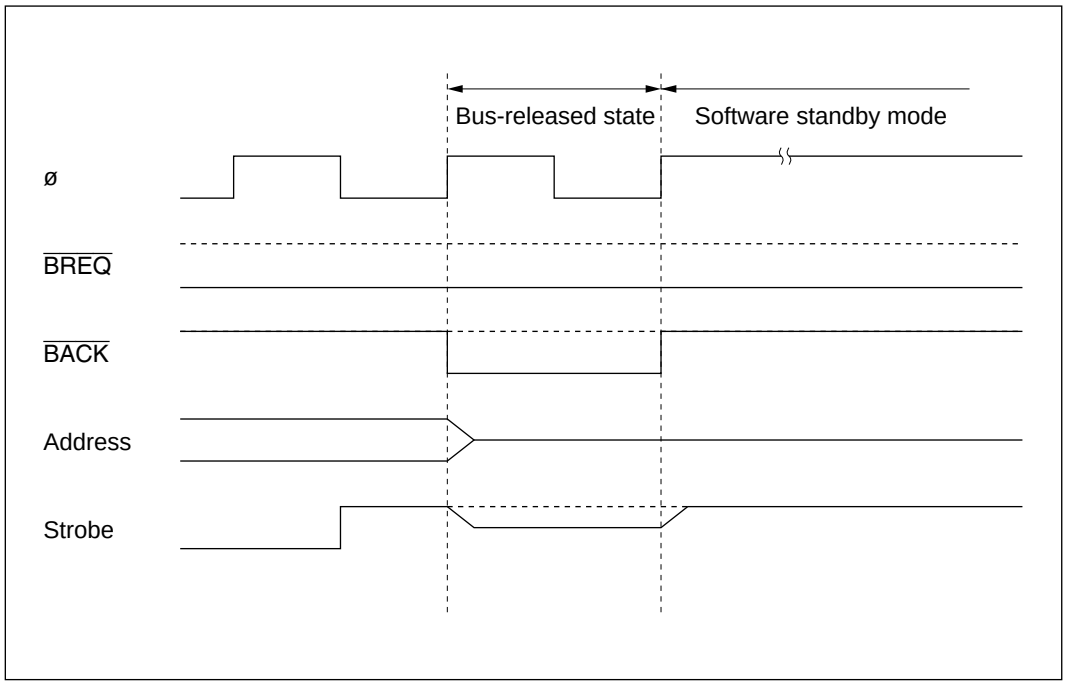


Figure 7-24 Contention between Bus-Released State and Software Standby Mode

Section 8 DMA Controller

8.1 Overview

The H8/3003 has an on-chip DMA controller (DMAC) that can transfer data on up to eight channels.

8.1.1 Features

DMAC features are listed below.

- Selection of short address mode or full address mode

  Short address mode

  — 8-bit source address and 24-bit destination address, or vice versa
  — Maximum eight channels available
  — Selection of I/O mode, idle mode, or repeat mode

  Full address mode

  — 24-bit source and destination addresses
  — Maximum four channels available
  — Selection of normal mode or block transfer mode

- Directly addressable 16-Mbyte address space
- Selection of byte or word transfer
- Activation by internal interrupts, external requests, or auto-request (depending on transfer mode)

  — ITU compare match/input capture interrupts (four)
  — SCI transmit-data-empty/receive-data-full interrupts
  — External requests
  — Auto-request

8.1.2 Block Diagram

Figure 8-1 shows a DMAC block diagram. The DMAC is divided into two groups (group 0 and group 1) of four channels each.

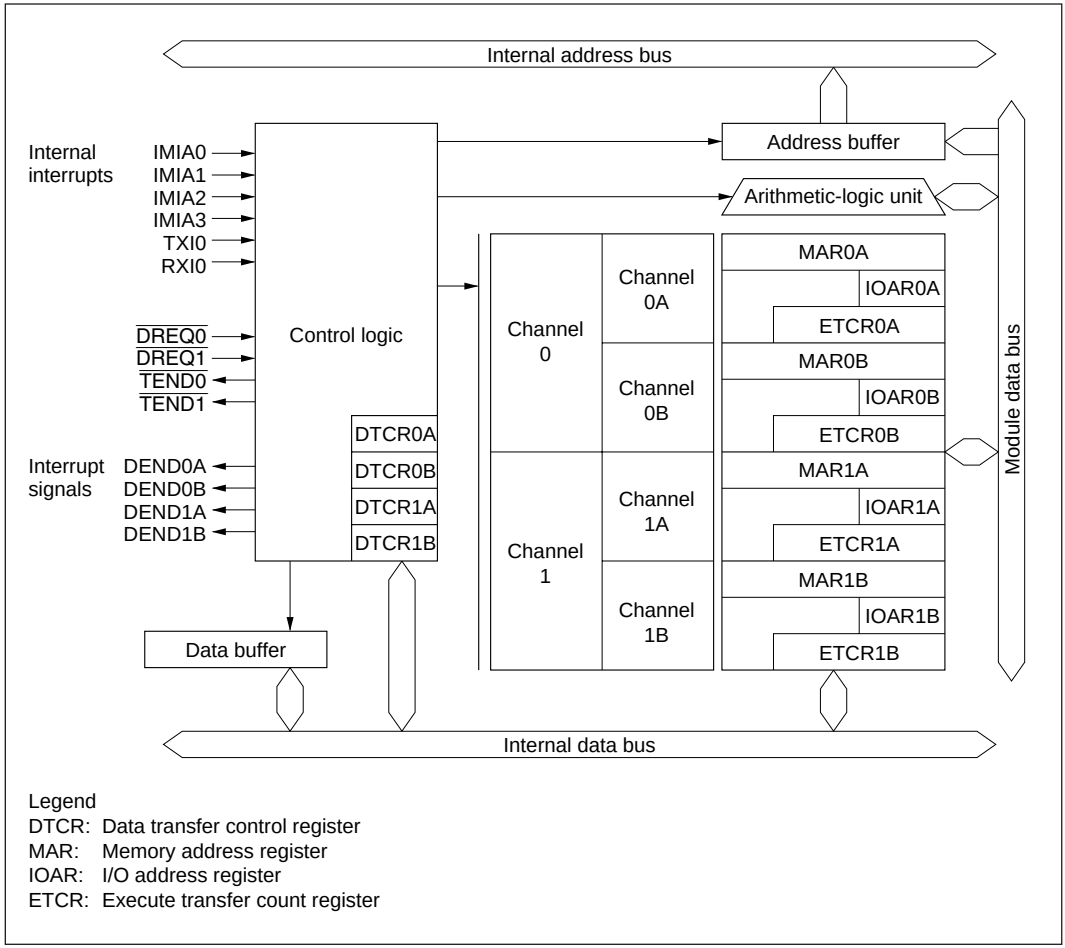


Figure 8-1 Block Diagram of DMA Controller (Group 0: Four Channels)

8.1.3 Functional Overview

Table 8-1 gives an overview of the DMAC functions.

Table 8-1 DMAC Functional Overview

Transfer Mode		Activation	Address Reg. Length	
			Source	Destination
Short address mode	I/O mode • Transfers one byte or one word per request • Increments or decrements the memory address by 1 or 2 • Executes 1 to 65,536 transfers Idle mode • Transfers one byte or one word per request • Holds the memory address fixed • Executes 1 to 65,536 transfers Repeat mode • Transfers one byte or one word per request • Increments or decrements the memory address by 1 or 2 • Executes a specified number (1 to 255) of transfers, then returns to the initial state and continues	• Compare match/input capture A interrupts from ITU channels 0 to 3 • Transmit-data-empty interrupt from serial communication interface	24	8
		• Receive-data-full interrupt from serial communication interface	8	24
		• External request	24	8
Full address mode	Normal mode • Auto-request — Retains the transfer request internally — Executes a specified number (1 to 65,536) of transfers continuously — Selection of burst mode or cycle-steal mode • External request — Transfers one byte or one word per request — Executes 1 to 65,536 transfers	• Auto-request • External request	24	24
	Block transfer • Transfers one block of a specified size per request • Executes 1 to 65,536 transfers • Allows either the source or destination to be a fixed block area • Block size can be 1 to 255 bytes or words	• Compare match/ input capture A interrupts from ITU channels 0 to 3 • External request	24	24

8.1.4 Input/Output Pins

Table 8-2 lists the DMAC pins.

Table 8-2 DMAC Pins

Group	Channel	Name	Abbreviation	Input/ Output	Function
0	0	DMA request 0	$\overline{DREQ_0}$	Input	External request for DMAC channel 0
		Transfer end 0	$\overline{TEND_0}$	Output	Transfer end on DMAC channel 0
	1	DMA request 1	$\overline{DREQ_1}$	Input	External request for DMAC channel 1
		Transfer end 1	$\overline{TEND_1}$	Output	Transfer end on DMAC channel 1
1	2	DMA request 2	$\overline{DREQ_2}$	Input	External request for DMAC channel 2
		Transfer end 2	$\overline{TEND_2}$	Output	Transfer end on DMAC channel 2
	3	DMA request 3	$\overline{DREQ_3}$	Input	External request for DMAC channel 3
		Transfer end 3	$\overline{TEND_3}$	Output	Transfer end on DMAC channel 3

Note: External requests cannot be made to channel A in short address mode.

8.1.5 Register Configuration

Table 8-3 lists the DMAC registers.

Table 8-3 DMAC Registers

Group	Channel	Address*	Name	Abbreviation	R/W	Initial Value
0	0	H'FF20	Memory address register 0AR	MAR0AR	R/W	Undetermined
		H'FF21	Memory address register 0AE	MAR0AE	R/W	Undetermined
		H'FF22	Memory address register 0AH	MAR0AH	R/W	Undetermined
		H'FF23	Memory address register 0AL	MAR0AL	R/W	Undetermined
		H'FF26	I/O address register 0A	IOAR0A	R/W	Undetermined
		H'FF24	Execute transfer count register 0AH	ETCR0AH	R/W	Undetermined
		H'FF25	Execute transfer count register 0AL	ETCR0AL	R/W	Undetermined
		H'FF27	Data transfer control register 0A	DTCR0A	R/W	H'00
		H'FF28	Memory address register 0BR	MAR0BR	R/W	Undetermined
		H'FF29	Memory address register 0BE	MAR0BE	R/W	Undetermined
		H'FF2A	Memory address register 0BH	MAR0BH	R/W	Undetermined
		H'FF2B	Memory address register 0BL	MAR0BL	R/W	Undetermined
		H'FF2E	I/O address register 0B	IOAR0B	R/W	Undetermined
		H'FF2C	Execute transfer count register 0BH	ETCR0BH	R/W	Undetermined
		H'FF2D	Execute transfer count register 0BL	ETCR0BL	R/W	Undetermined
		H'FF2F	Data transfer control register 0B	DTCR0B	R/W	H'00
	1	H'FF30	Memory address register 1AR	MAR1AR	R/W	Undetermined
		H'FF31	Memory address register 1AE	MAR1AE	R/W	Undetermined
		H'FF32	Memory address register 1AH	MAR1AH	R/W	Undetermined
		H'FF33	Memory address register 1AL	MAR1AL	R/W	Undetermined
		H'FF36	I/O address register 1A	IOAR1A	R/W	Undetermined
		H'FF34	Execute transfer count register 1AH	ETCR1AH	R/W	Undetermined
		H'FF35	Execute transfer count register 1AL	ETCR1AL	R/W	Undetermined
		H'FF37	Data transfer control register 1A	DTCR1A	R/W	H'00
		H'FF38	Memory address register 1BR	MAR1BR	R/W	Undetermined
		H'FF39	Memory address register 1BE	MAR1BE	R/W	Undetermined
		H'FF3A	Memory address register 1BH	MAR1BH	R/W	Undetermined
		H'FF3B	Memory address register 1BL	MAR1BL	R/W	Undetermined
		H'FF3E	I/O address register 1B	IOAR1B	R/W	Undetermined
		H'FF3C	Execute transfer count register 1BH	ETCR1BH	R/W	Undetermined
		H'FF3D	Execute transfer count register 1BL	ETCR1BL	R/W	Undetermined
		H'FF3F	Data transfer control register 1B	DTCR1B	R/W	H'00

Note: * The lower 16 bits of the address are indicated.

Table 8-3 DMAC Registers (cont)

Group	Channel	Address*	Name	Abbreviation	R/W	Initial Value
1	2	H'FF40	Memory address register 2AR	MAR2AR	R/W	Undetermined
		H'FF41	Memory address register 2AE	MAR2AE	R/W	Undetermined
		H'FF42	Memory address register 2AH	MAR2AH	R/W	Undetermined
		H'FF43	Memory address register 2AL	MAR2AL	R/W	Undetermined
		H'FF46	I/O address register 2A	IOAR2A	R/W	Undetermined
		H'FF44	Execute transfer count register 2AH	ETCR2AH	R/W	Undetermined
		H'FF45	Execute transfer count register 2AL	ETCR2AL	R/W	Undetermined
		H'FF47	Data transfer control register 2A	DTCR2A	R/W	H'00
		H'FF48	Memory address register 2BR	MAR2BR	R/W	Undetermined
		H'FF49	Memory address register 2BE	MAR2BE	R/W	Undetermined
		H'FF4A	Memory address register 2BH	MAR2BH	R/W	Undetermined
		H'FF4B	Memory address register 2BL	MAR2BL	R/W	Undetermined
		H'FF4E	I/O address register 2B	IOAR2B	R/W	Undetermined
		H'FF4C	Execute transfer count register 2BH	ETCR2BH	R/W	Undetermined
		H'FF4D	Execute transfer count register 2BL	ETCR2BL	R/W	Undetermined
		H'FF4F	Data transfer control register 2B	DTCR2B	R/W	H'00
	3	H'FF50	Memory address register 3AR	MAR3AR	R/W	Undetermined
		H'FF51	Memory address register 3AE	MAR3AE	R/W	Undetermined
		H'FF52	Memory address register 3AH	MAR3AH	R/W	Undetermined
		H'FF53	Memory address register 3AL	MAR3AL	R/W	Undetermined
		H'FF56	I/O address register 3A	IOAR3A	R/W	Undetermined
		H'FF54	Execute transfer count register 3AH	ETCR3AH	R/W	Undetermined
		H'FF55	Execute transfer count register 3AL	ETCR3AL	R/W	Undetermined
		H'FF57	Data transfer control register 3A	DTCR3A	R/W	H'00
		H'FF58	Memory address register 3BR	MAR3BR	R/W	Undetermined
		H'FF59	Memory address register 3BE	MAR3BE	R/W	Undetermined
		H'FF5A	Memory address register 3BH	MAR3BH	R/W	Undetermined
		H'FF5B	Memory address register 3BL	MAR3BL	R/W	Undetermined
		H'FF5E	I/O address register 3B	IOAR3B	R/W	Undetermined
		H'FF5C	Execute transfer count register 3BH	ETCR3BH	R/W	Undetermined
		H'FF5D	Execute transfer count register 3BL	ETCR3BL	R/W	Undetermined
		H'FF5F	Data transfer control register 3B	DTCR3B	R/W	H'00

Note: * The lower 16 bits of the address are indicated.

8.2 Register Descriptions (1) (Short Address Mode)

In short address mode, transfers can be carried out independently on channels A and B. Short address mode is selected by bits DTS2A and DTS1A in data transfer control register A (DTCRA) as indicated in table 8-4.

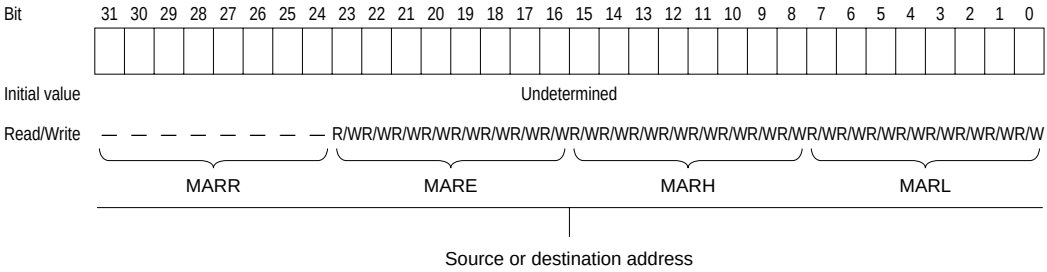
Table 8-4 Selection of Short and Full Address Modes

Channel	Bit 2 DTS2A	Bit 1 DTS1A	Description
0	1	1	DMAC channel 0 operates as one channel in full address mode
	Other than above		DMAC channels 0A and 0B operate as two independent channels in short address mode
1	1	1	DMAC channel 1 operates as one channel in full address mode
	Other than above		DMAC channels 1A and 1B operate as two independent channels in short address mode
2	1	1	DMAC channel 2 operates as one channel in full address mode
	Other than above		DMAC channels 2A and 2B operate as two independent channels in short address mode
3	1	1	DMAC channel 3 operates as one channel in full address mode
	Other than above		DMAC channels 3A and 3B operate as two independent channels in short address mode

8.2.1 Memory Address Registers (MAR)

A memory address register (MAR) is a 32-bit readable/writable register that specifies a source or destination address. The transfer direction is determined automatically from the activation source.

An MAR consists of four 8-bit registers designated MARR, MARE, MARH, and MARL. All bits of MARR are reserved: they cannot be modified and always read 1.



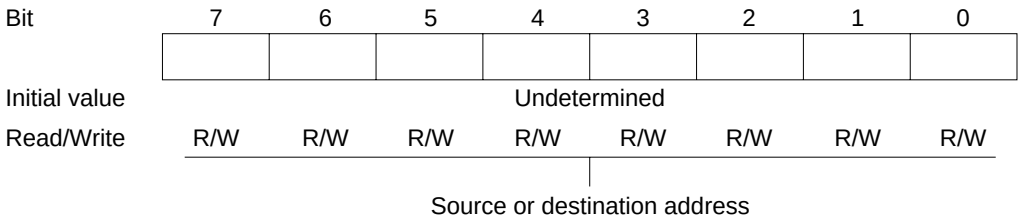
An MAR functions as a source or destination address register depending on how the DMAC is activated: as a destination address register if activation is by a receive-data-full interrupt from the serial communication interface (SCI), and as a source address register otherwise.

The MAR value is incremented or decremented each time one byte or word is transferred, automatically updating the source or destination memory address. For details, see section 8.2.4, Data Transfer Control Registers (DTCR).

The MARs are not initialized by a reset or in standby mode.

8.2.2 I/O Address Registers (IOAR)

An I/O address register (IOAR) is an 8-bit readable/writable register that specifies a source or destination address. The IOAR value is the lower 8 bits of the address. The upper 16 address bits are all 1 (H'FFFF).



An IOAR functions as a source or destination address register depending on how the DMAC is activated: as a source address register if activation is by a receive-data-full interrupt from the SCI, and as a destination address register otherwise.

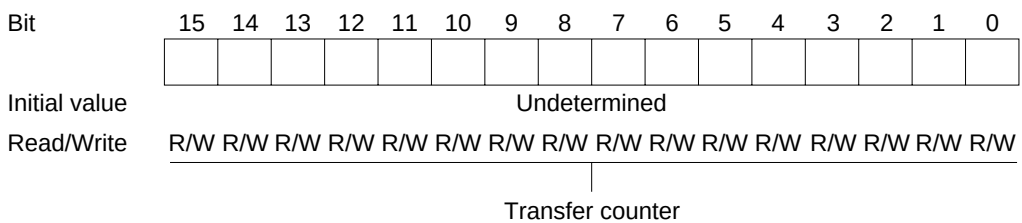
The IOAR value is held fixed. It is not incremented or decremented when a transfer is executed.

The IOARs are not initialized by a reset or in standby mode.

8.2.3 Execute Transfer Count Registers (ETCR)

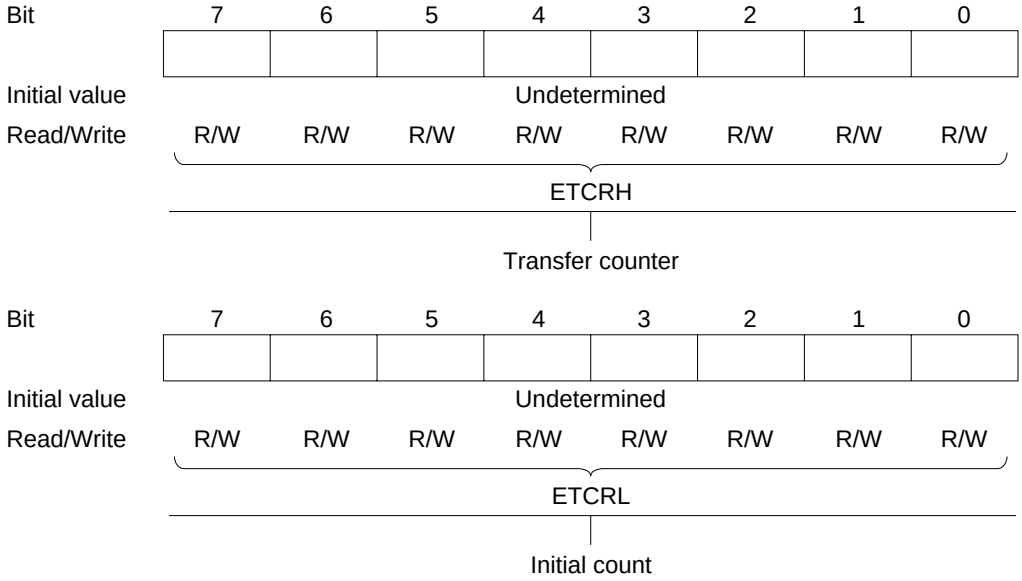
An execute transfer count register (ETCR) is a 16-bit readable/writable register that specifies the number of transfers to be executed. These registers function in one way in I/O mode and idle mode, and another way in repeat mode.

- I/O mode and idle mode



In I/O mode and idle mode, ETCR functions as a 16-bit counter. The count is decremented by 1 each time one transfer is executed. The transfer ends when the count reaches H'0000.

- Repeat mode

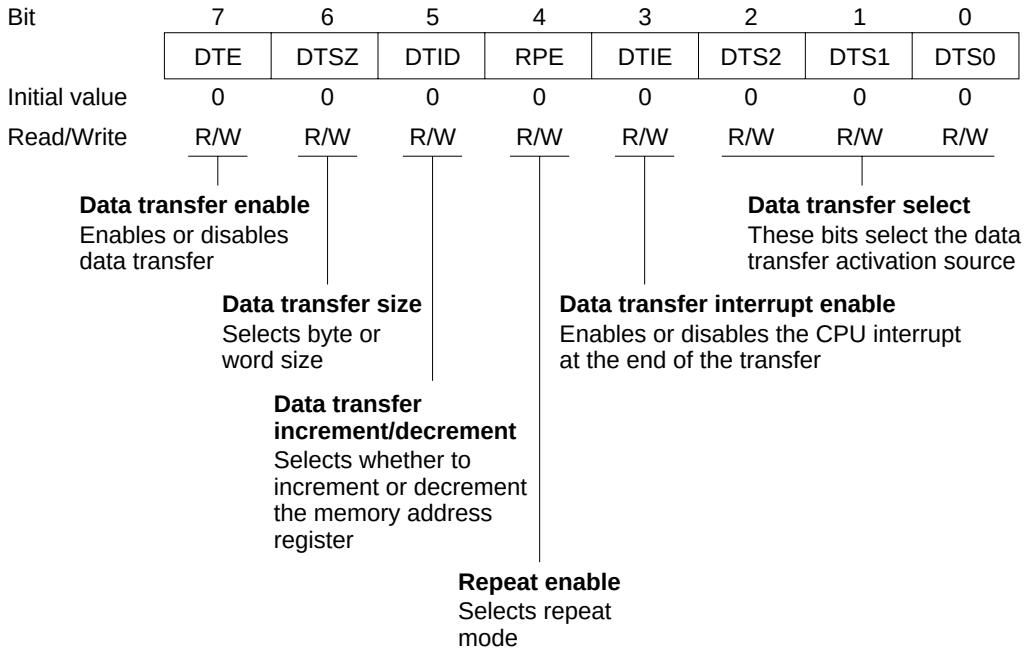


In repeat mode, ETCRH functions as an 8-bit transfer counter and ETCRL holds the initial transfer count. ETCRH is decremented by 1 each time one transfer is executed. When ETCRH reaches H'00, the value in ETCRL is reloaded into ETCRH and the same operation is repeated.

The ETCRs are not initialized by a reset or in standby mode.

8.2.4 Data Transfer Control Registers (DTCR)

A data transfer control register (DTCR) is an 8-bit readable/writable register that controls the operation of one DMAC channel.



The DTCRs are initialized to H'00 by a reset and in standby mode.

Bit 7—Data Transfer Enable (DTE): Enables or disables data transfer on a channel. When the DTE bit is set to 1, the channel waits for a transfer to be requested, and executes the transfer when activated as specified by bits DTS2 to DTS0 . When DTE is 0, the channel is disabled and does not accept transfer requests. DTE is set to 1 by reading the register when DTE is 0, then writing 1.

Bit 7 DTE	Description	
0	Data transfer is disabled. In I/O mode or idle mode, DTE is cleared to 0 when the specified number of transfers have been completed.	(Initial value)
1	Data transfer is enabled	

If DTIE is set to 1, a CPU interrupt is requested when DTE is cleared to 0.

Bit 6—Data Transfer Size (DTSZ): Selects the data size of each transfer.

Bit 6 DTSZ	Description	
0	Byte-size transfer	(Initial value)
1	Word-size transfer	

Bit 5—Data Transfer Increment/Decrement (DTID): Selects whether to increment or decrement the memory address register (MAR) after a data transfer in I/O mode or repeat mode.

Bit 5 DTID	Description	
0	MAR is incremented after each data transfer • If DTSZ = 0, MAR is incremented by 1 after each transfer • If DTSZ = 1, MAR is incremented by 2 after each transfer	(Initial value)
1	MAR is decremented after each data transfer • If DTSZ = 0, MAR is decremented by 1 after each transfer • If DTSZ = 1, MAR is decremented by 2 after each transfer	

MAR is not incremented or decremented in idle mode.

Bit 4—Repeat Enable (RPE): Selects whether to transfer data in I/O mode, idle mode, or repeat mode.

Bit 4 RPE	Bit 3 DTIE	Description	
0	0	I/O mode	(Initial value)
	1		
1	0	Repeat mode	
	1	Idle mode	

Operations in these modes are described in sections 8.4.2, I/O Mode, 8.4.3, Idle Mode, and 8.4.4, Repeat Mode.

Bit 3—Data Transfer Interrupt Enable (DTIE): Enables or disables the CPU interrupt (DEND) requested when the DTE bit is cleared to 0.

Bit 3 DTIE	Description	
0	The DEND interrupt requested by DTE is disabled	(Initial value)
1	The DEND interrupt requested by DTE is enabled	

Bits 2 to 0—Data Transfer Select (DTS2, DTS1, DTS0): These bits select the data transfer activation source. Some of the selectable sources differ between channels A and B.

Channel A

Bit 2 DTS2A	Bit 1 DTS1A	Bit 0 DTS0A	Description	
0	0	0	Compare match/input capture A interrupt from ITU channel 0	(Initial value)
		1	Compare match/input capture A interrupt from ITU channel 1	
	1	0	Compare match/input capture A interrupt from ITU channel 2	
		1	Compare match/input capture A interrupt from ITU channel 3	
1	0	0	Transmit-data-empty interrupt from SCI channel 0 or 1*2	
		1	Receive-data-full interrupt from SCI channel 0 or 1*2	
	1	—*1	Transfer in full address mode	

Notes: 1. See section 8.3.4, Data Transfer Control Register (DTCR).
2. DMAC channels 0 and 1 accept transmit-data-empty and receive-data-full interrupts from SCI channel 0. DMAC channels 2 and 3 accept transmit-data-empty and receive-data-full interrupts from SCI channel 1.

Channel B

Bit 2 DTS2B	Bit 1 DTS1B	Bit 0 DTS0B	Description
0	0	0	Compare match/input capture A interrupt from ITU channel 0 (Initial value)
		1	Compare match/input capture A interrupt from ITU channel 1
	1	0	Compare match/input capture A interrupt from ITU channel 2
		1	Compare match/input capture A interrupt from ITU channel 3
1	0	0	Transmit-data-empty interrupt from SCI channel 0 or 1*
		1	Receive-data-full interrupt from SCI channel 0 or 1*
	1	0	Falling edge of $\overline{\text{DREQ}}$ input
		1	Low level of $\overline{\text{DREQ}}$ input

Note: * DMAC channels 0 and 1 accept transmit-data-empty and receive-data-full interrupts from SCI channel 0. DMAC channels 2 and 3 accept transmit-data-empty and receive-data-full interrupts from SCI channel 1.

The same internal interrupt can be selected as an activation source for two or more channels at once. In that case the channels are activated in a priority order, highest-priority channel first. For the priority order, see section 8.4.9, Multiple-Channel Operation.

When a channel is enabled (DTE = 1), its selected DMAC activation source cannot generate a CPU interrupt.

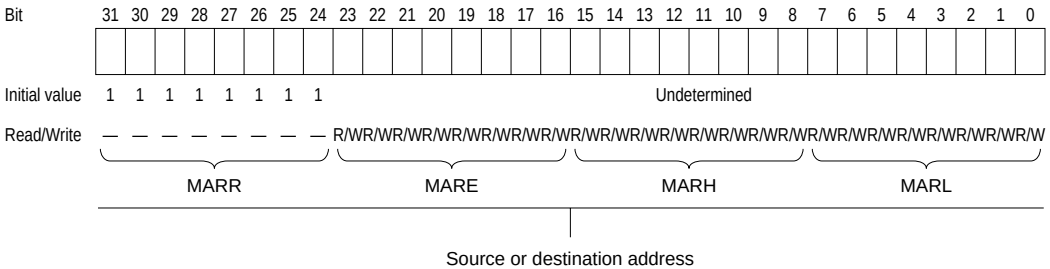
8.3 Register Descriptions (2) (Full Address Mode)

In full address mode the A and B channels operate together. Full address mode is selected as indicated in table 8-4.

8.3.1 Memory Address Registers (MAR)

A memory address register (MAR) is a 32-bit readable/writable register. MARA functions as the source address register of the transfer, and MARB as the destination address register.

An MAR consists of four 8-bit registers designated MARR, MARE, MARH, and MARL. All bits of MARR are reserved: they cannot be modified and always read 1.



The MAR value is incremented or decremented each time one byte or word is transferred, automatically updating the source or destination memory address. For details, see section 8.3.4, Data Transfer Control Registers (DTCR).

The MARs are not initialized by a reset or in standby mode.

8.3.2 I/O Address Registers (IOAR)

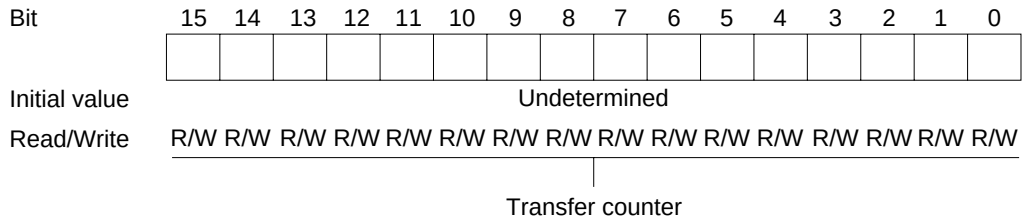
The I/O address registers (IOARs) are not used in full address mode.

8.3.3 Execute Transfer Count Registers (ETCR)

An execute transfer count register (ETCR) is a 16-bit readable/writable register that specifies the number of transfers to be executed. The functions of these registers differ between normal mode and block transfer mode.

- Normal mode

ETCRA

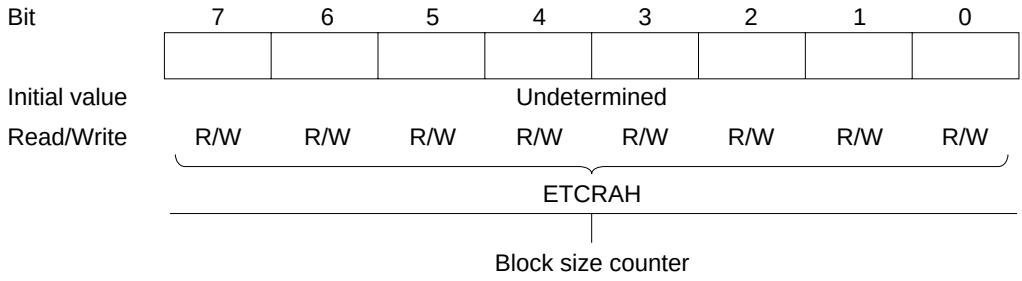


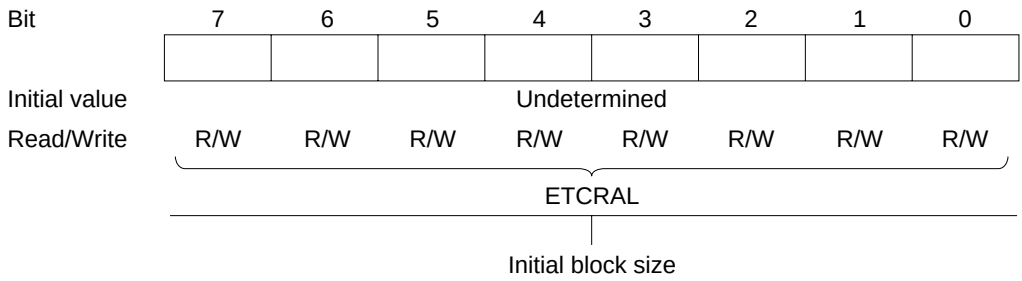
ETCRB: Is not used in normal mode.

In normal mode ETCRA functions as a 16-bit transfer counter. The count is decremented by 1 each time one transfer is executed. The transfer ends when the count reaches H'0000. ETCRB is not used.

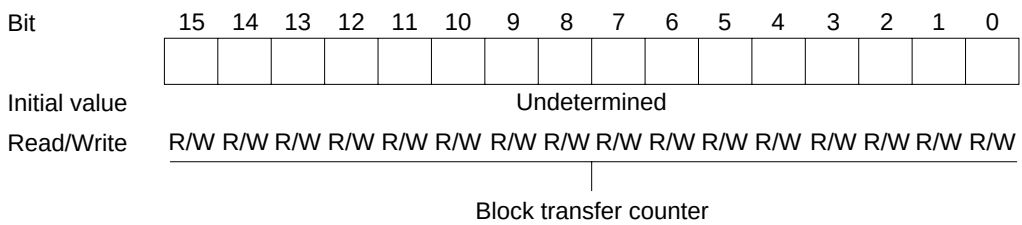
- Block mode

ETCRA





ETCRB



In block transfer mode, ETCRAH functions as an 8-bit block size counter. ETCRAL holds the initial block size. ETCRAH is decremented by 1 each time one byte or word is transferred. When the count reaches H'00, ETCRAH is reloaded from ETCRAL. Blocks consisting of an arbitrary number of bytes or words can be transferred repeatedly by setting the same initial block size value in ETCRAH and ETCRAL.

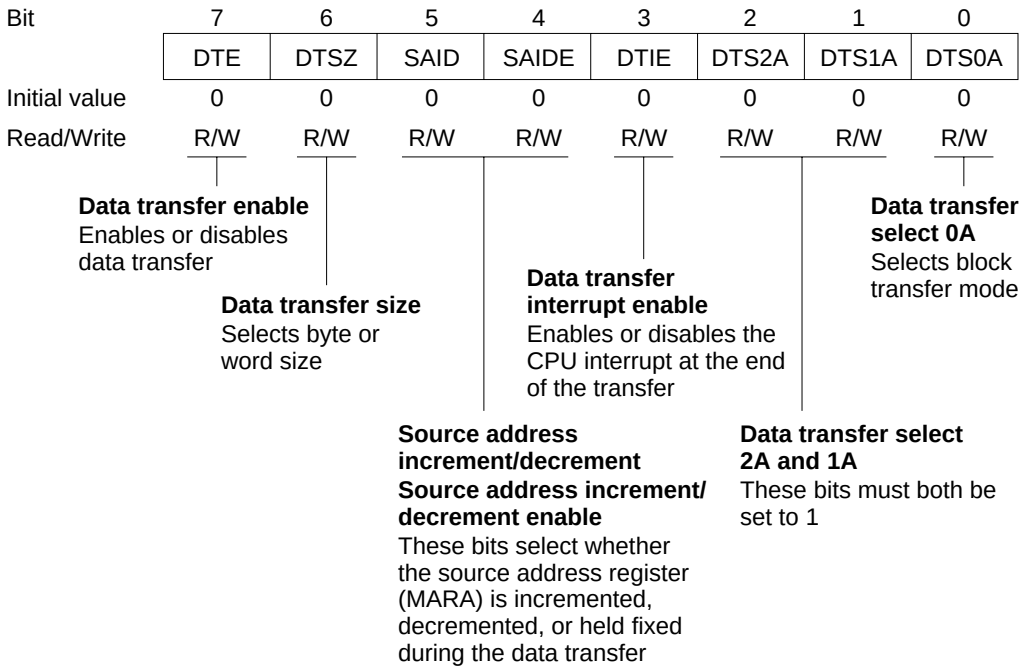
In block transfer mode ETCRB functions as a 16-bit block transfer counter. ETCRB is decremented by 1 each time one block is transferred. The transfer ends when the count reaches H'0000.

The ETCRs are not initialized by a reset or in standby mode.

8.3.4 Data Transfer Control Registers (DTCR)

The data transfer control registers (DTCRs) are 8-bit readable/writable registers that control the operation of the DMAC channels. A channel operates in full address mode when bits DTS2A and DTS1A are both set to 1 in DTCRA. DTCRA and DTCRB have different functions in full address mode.

DTCRA



DTCRA is initialized to H'00 by a reset and in standby mode.

Bit 7—Data Transfer Enable (DTE): Together with the DTME bit in DTCRB, this bit enables or disables data transfer on the channel. When the DTME and DTE bits are both set to 1, the channel is enabled. If auto-request is specified, data transfer begins immediately. Otherwise, the channel waits for transfers to be requested. When the specified number of transfers have been completed, the DTE bit is automatically cleared to 0. When DTE is 0, the channel is disabled and does not accept transfer requests. DTE is set to 1 by reading the register when DTE is 0, then writing 1.

Bit 7 DTE	Description	
0	Data transfer is disabled (DTE is cleared to 0 when the specified number of transfers have been completed)	(Initial value)
1	Data transfer is enabled	

If DTIE is set to 1, a CPU interrupt is requested when DTE is cleared to 0.

Bit 6—Data Transfer Size (DTSZ): Selects the data size of each transfer.

Bit 6 DTSZ	Description	
0	Byte-size transfer	(Initial value)
1	Word-size transfer	

Bit 5—Source Address Increment/Decrement (SAID) and Bit 4—Source Address Increment/Decrement Enable (SAIDE): These bits select whether the source address register (MARA) is incremented, decremented, or held fixed during the data transfer.

Bit 5 SAID	Bit 4 SAIDE	Description	
0	0	MARA is held fixed	(Initial value)
	1	MARA is incremented after each data transfer • If DTSZ = 0, MARA is incremented by 1 after each transfer • If DTSZ = 1, MARA is incremented by 2 after each transfer	
1	0	MARA is held fixed	
	1	MARA is decremented after each data transfer • If DTSZ = 0, MARA is decremented by 1 after each transfer • If DTSZ = 1, MARA is decremented by 2 after each transfer	

Bit 3—Data Transfer Interrupt Enable (DTIE): Enables or disables the CPU interrupt (DEND) requested when the DTE bit is cleared to 0.

Bit 3 DTIE	Description	
0	The DEND interrupt requested by DTE is disabled	(Initial value)
1	The DEND interrupt requested by DTE is enabled	

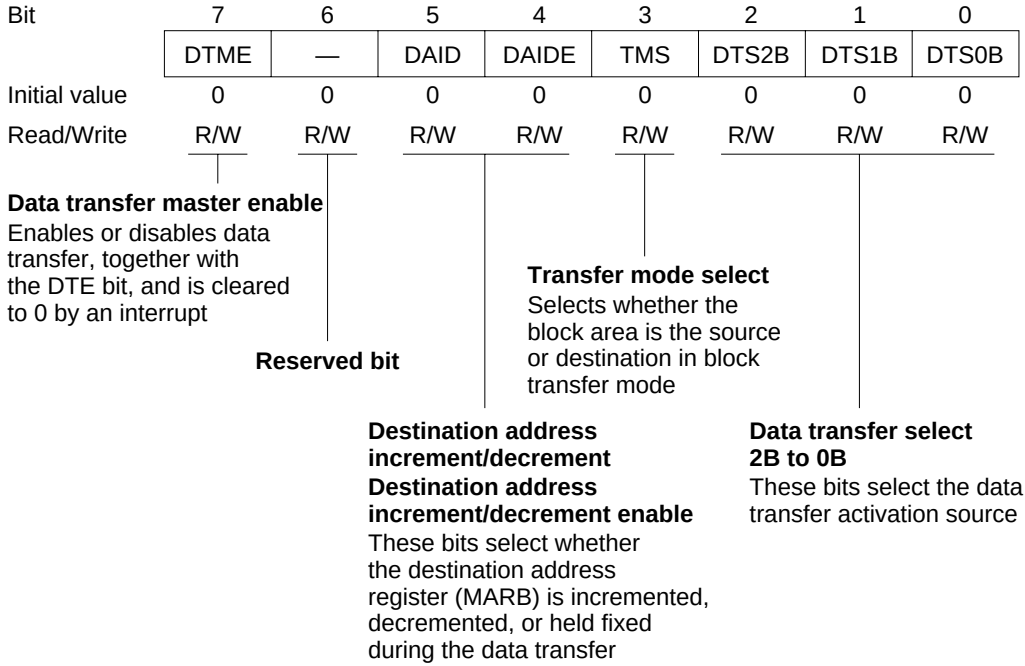
Bits 2 and 1—Data Transfer Select 2A and 1A (DTS2A, DTS1A): A channel operates in full address mode when DTS2A and DTS1A are both set to 1.

Bit 0—Data Transfer Select 0A (DTS0A): Selects normal mode or block transfer mode.

Bit 0 DTS0A	Description	
0	Normal mode	(Initial value)
1	Block transfer mode	

Operations in these modes are described in sections 8.4.5, Normal Mode, and 8.4.6, Block Transfer Mode.

DTCRB



DTCRB is initialized to H'00 by a reset and in standby mode.

Bit 7—Data Transfer Master Enable (DTME): Together with the DTE bit in DTCRA, this bit enables or disables data transfer. When the DTME and DTE bits are both set to 1, the channel is enabled. When an NMI interrupt occurs DTME is cleared to 0, suspending the transfer so that the CPU can use the bus. The suspended transfer resumes when DTME is set to 1 again. For further information on operation in block transfer mode, see section 8.6.6, NMI Interrupts and Block Transfer Mode.

DTME is set to 1 by reading the register while DTME = 0, then writing 1.

Bit 7 DTME	Description	
0	Data transfer is disabled (DTME is cleared to 0 when an NMI interrupt occurs)	(Initial value)
1	Data transfer is enabled	

Bit 6—Reserved: Although reserved, this bit can be written and read.

Bit 5—Destination Address Increment/Decrement (DAID) and Bit 4—Destination Address Increment/Decrement Enable (DAIDE): These bits select whether the destination address register (MARB), is incremented, decremented, or held fixed during the data transfer.

Bit 5 DAID	Bit 4 DAIDE	Description	
0	0	MARB is held fixed	(Initial value)
	1	MARB is incremented after each data transfer • If DTSZ = 0, MARB is incremented by 1 after each data transfer • If DTSZ = 1, MARB is incremented by 2 after each data transfer	
1	0	MARB is held fixed	
	1	MARB is decremented after each data transfer • If DTSZ = 0, MARB is decremented by 1 after each data transfer • If DTSZ = 1, MARB is decremented by 2 after each data transfer	

Bit 3—Transfer Mode Select (TMS): Selects whether the source or destination is the block area in block transfer mode.

Bit 3 TMS	Description	
0	Destination is the block area in block transfer mode	(Initial value)
1	Source is the block area in block transfer mode	

Bits 2 to 0—Data Transfer Select (DTS2B, DTS1B, DTS0B): These bits select the data transfer activation source. The selectable activation sources differ between normal mode and block transfer mode.

Normal mode

Bit 2 DTS2B	Bit 1 DTS1B	Bit 0 DTS0B	Description	
0	0	0	Auto-request (burst mode)	(Initial value)
		1	*	
	1	0	Auto-request (cycle-steal mode)	
		1	*	
1	0	0	*	
		1	*	
	1	0	Falling edge of $\overline{\text{DREQ}}$	
		1	Low level input at $\overline{\text{DREQ}}$	

Note: Settings marked with asterisks (*) cannot be used.

Block transfer mode

Bit 2 DTS2B	Bit 1 DTS1B	Bit 0 DTS0B	Description	
0	0	0	Compare match/input capture A interrupt from ITU channel 0	(Initial value)
		1	Compare match/input capture A interrupt from ITU channel 1	
	1	0	Compare match/input capture A interrupt from ITU channel 2	
		1	Compare match/input capture A interrupt from ITU channel 3	
1	0	0	*	
		1	*	
	1	0	Falling edge of $\overline{\text{DREQ}}$	
		1	*	

Note: Settings marked with asterisks (*) cannot be used.

The same internal interrupt can be selected to activate two or more channels. The channels are activated in a priority order, highest priority first. For the priority order, see section 8.4.9, Multiple-Channel Operation.

8.4 Operation

8.4.1 Overview

Table 8-5 summarizes the DMAC modes.

Table 8-5 DMAC Modes

Transfer Mode	Activation	Notes	
Short address mode	I/O mode Idle mode Repeat mode	Compare match/input capture A interrupt from ITU channels 0 to 3	• Up to eight channels can operate independently • Only the B channels support external requests
		SCI transmit-data-empty and receive-data-full interrupts	
		External request	
Full address mode	Normal mode	Auto-request	• A and B channels are paired; up to four channels are available • Burst mode or cycle-steal mode can be selected for auto-requests
		External request	
	Block transfer mode	Compare match/input capture A interrupt from ITU channels 0 to 3	
		External request	

A summary of operations in these modes follows.

I/O Mode: One byte or word is transferred per request. A designated number of these transfers are executed. A CPU interrupt can be requested at completion of the designated number of transfers. One 24-bit address and one 8-bit address are specified. The transfer direction is determined automatically from the activation source.

Idle Mode: One byte or word is transferred per request. A designated number of these transfers are executed. A CPU interrupt can be requested at completion of the designated number of transfers. One 24-bit address and one 8-bit address are specified. The addresses are held fixed. The transfer direction is determined automatically from the activation source.

Repeat Mode: One byte or word is transferred per request. A designated number of these transfers are executed. When the designated number of transfers are completed, the initial address and counter value are restored and operation continues. No CPU interrupt is requested. One 24-bit address and one 8-bit address are specified. The transfer direction is determined automatically from the activation source.

Normal Mode

- Auto-request

  The DMAC is activated by register setup alone, and continues executing transfers until the designated number of transfers have been completed. A CPU interrupt can be requested at completion of the transfers. Both addresses are 24-bit addresses.

  — Cycle-steal mode

    The bus is released to another bus master after each byte or word is transferred.

  — Burst mode

    Unless requested by a higher-priority bus master, the bus is not released until the designated number of transfers have been completed.

- External request

  One byte or word is transferred per request. A designated number of these transfers are executed. A CPU interrupt can be requested at completion of the designated number of transfers. Both addresses are 24-bit addresses.

Block Transfer Mode: One block of a specified size is transferred per request. A designated number of block transfers are executed. At the end of each block transfer, one address is restored to its initial value. When the designated number of blocks have been transferred, a CPU interrupt can be requested. Both addresses are 24-bit addresses.

8.4.2 I/O Mode

I/O mode can be selected independently for each channel.

One byte or word is transferred at each transfer request in I/O mode. A designated number of these transfers are executed. One address is specified in the memory address register (MAR), the other in the I/O address register (IOAR). The direction of transfer is determined automatically from the activation source. The transfer is from the address specified in IOAR to the address specified in MAR if activated by an SCI receive-data-full interrupt, and from the address specified in MAR to the address specified in IOAR otherwise.

Table 8-6 indicates the register functions in I/O mode.

Table 8-6 Register Functions in I/O Mode

	Function			
Register	**Activated by SCI Receive-Data-Full Interrupt**	**Other Activation**	**Initial Setting**	**Operation**
23 MAR 0	Destination address register	Source address register	Destination or source address	Incremented or decremented once per transfer
23 All 1s 7 IOAR 0	Source address register	Destination address register	Source or destination address	Held fixed
15 ETCR 0	Transfer counter	Number of	Decremented transfers	once per transfer until H'0000 is reached and transfer ends

Legend
MAR: Memory address register
IOAR: I/O address register
ETCR: Execute transfer count register

MAR and IOAR specify the source and destination addresses. MAR specifies a 24-bit source or destination address, which is incremented or decremented as each byte or word is transferred. IOAR specifies the lower 8 bits of a fixed address. The upper 16 bits are all 1s. IOAR is not incremented or decremented.

Figure 8-2 illustrates how I/O mode operates.

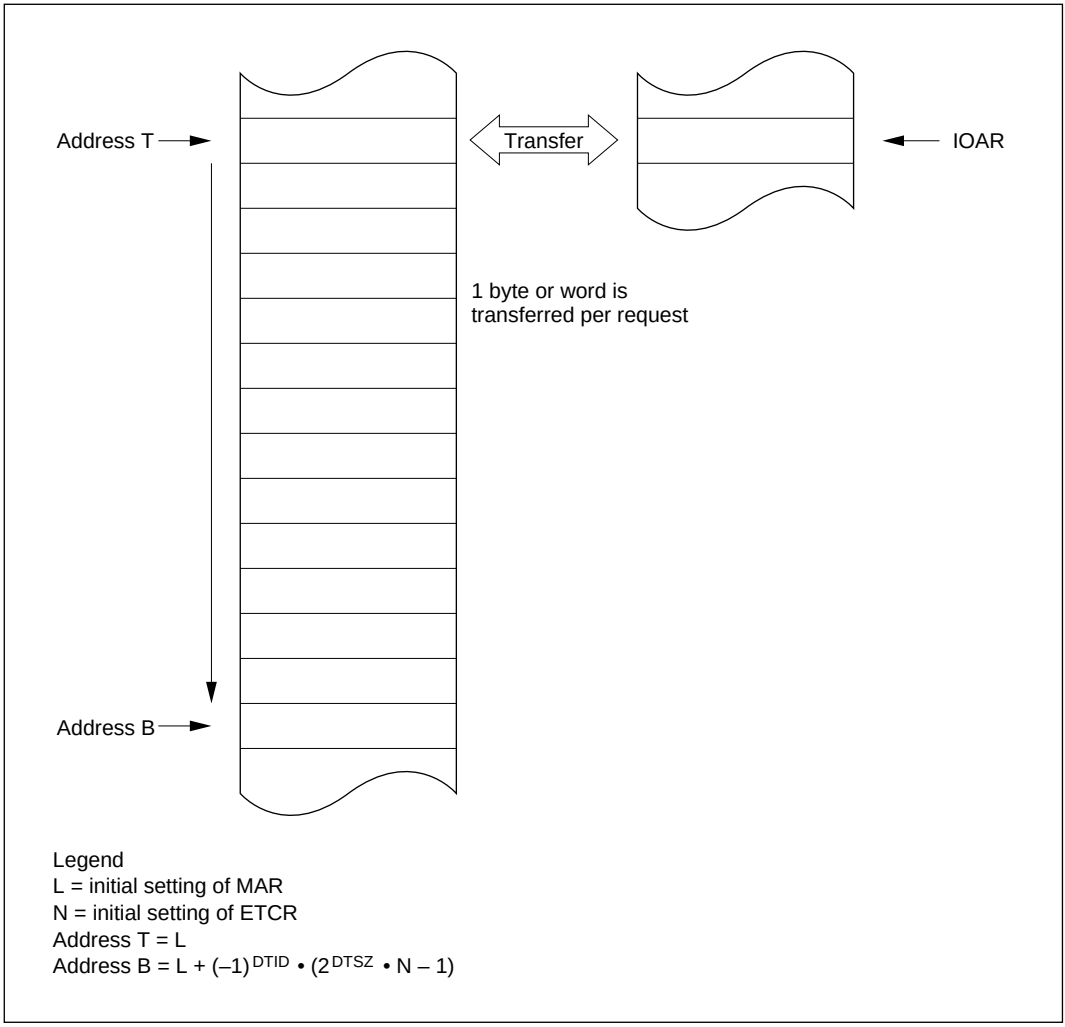


Figure 8-2 Operation in I/O Mode

The transfer count is specified as a 16-bit value in ETCR. The ETCR value is decremented by 1 at each transfer. When the ETCR value reaches H'0000, the DTE bit is cleared and the transfer ends. If the DTIE bit is set to 1, a CPU interrupt is requested at this time. The maximum transfer count is 65,536, obtained by setting ETCR to H'0000.

Transfers can be requested (activated) by compare match/input capture A interrupts from ITU channels 0 to 3, SCI transmit-data-empty and receive-data-full interrupts, and external request signals.

For the detailed settings see section 8.2.4, Data Transfer Control Registers (DTCR).

Figure 8-3 shows a sample setup procedure for I/O mode.

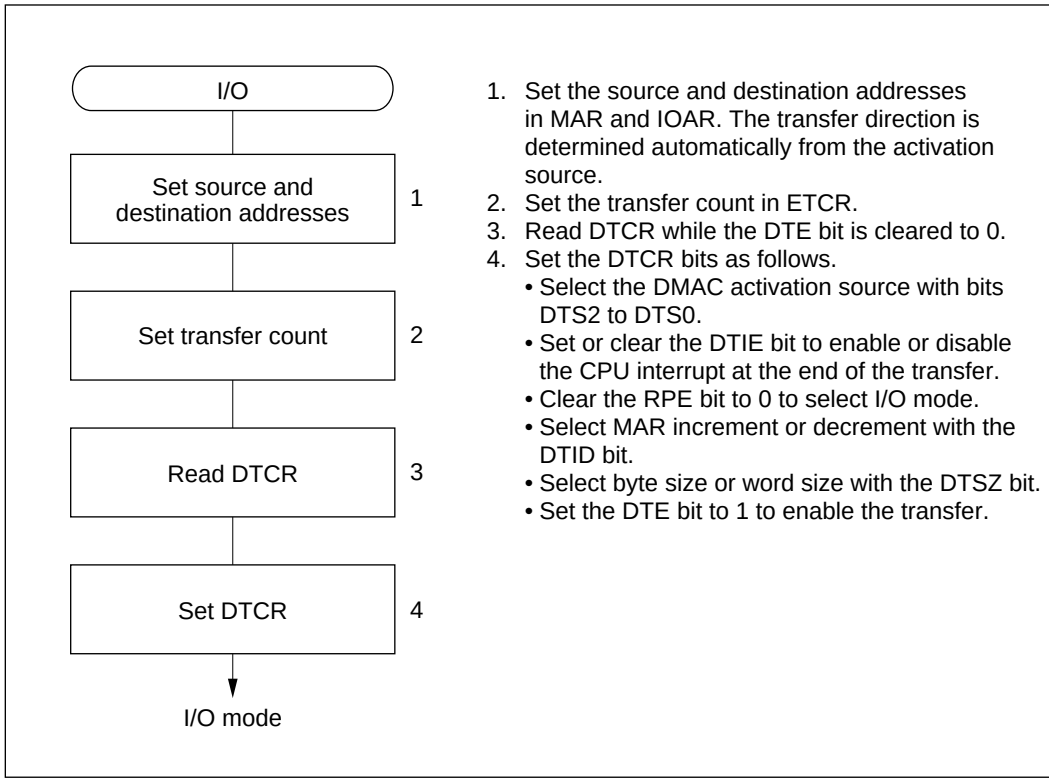


Figure 8-3 I/O Mode Setup Procedure (Example)

8.4.3 Idle Mode

Idle mode can be selected independently for each channel.

One byte or word is transferred at each transfer request in idle mode. A designated number of these transfers are executed. One address is specified in the memory address register (MAR), the other in the I/O address register (IOAR). The direction of transfer is determined automatically from the activation source. The transfer is from the address specified in IOAR to the address specified in MAR if activated by an SCI receive-data-full interrupt, and from the address specified in MAR to the address specified in IOAR otherwise.

Table 8-7 indicates the register functions in idle mode.

Table 8-7 Register Functions in Idle Mode

Register	Function: Activated by SCI Receive-Data-Full Interrupt	Function: Other Activation	Initial Setting	Operation
23 MAR 0	Destination address register	Source address register	Destination or source address	Held fixed
23 All 1s 7 IOAR 0	Source address register	Destination address register	Source or destination address	Held fixed
15 ETCR 0	Transfer counter	Number of	Decremented transfers	once per transfer until H'0000 is reached and transfer ends

Legend
MAR: Memory address register
IOAR: I/O address register
ETCR: Execute transfer count register

MAR and IOAR specify the source and destination addresses. MAR specifies a 24-bit source or destination address. IOAR specifies the lower 8 bits of a fixed address. The upper 16 bits are all 1s. MAR and IOAR are not incremented or decremented.

Figure 8-4 illustrates how idle mode operates.

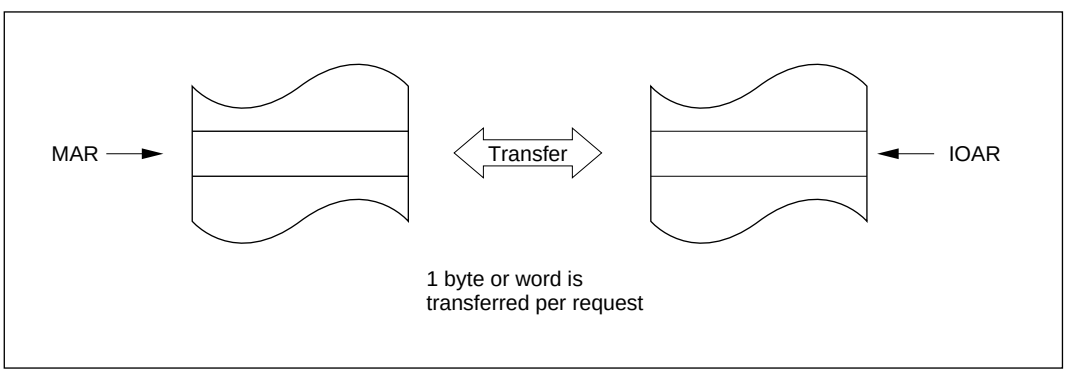


Figure 8-4 Operation in Idle Mode

The transfer count is specified as a 16-bit value in ETCR. The ETCR value is decremented by 1 at each transfer. When the ETCR value reaches H'0000, the DTE bit is cleared, the transfer ends, and a CPU interrupt is requested. The maximum transfer count is 65,536, obtained by setting ETCR to H'0000.

Transfers can be requested (activated) by compare match/input capture A interrupts from ITU channels 0 to 3, SCI transmit-data-empty and receive-data-full interrupts, and external request signals.

For the detailed settings see section 8.2.4, Data Transfer Control Registers (DTCR).

Figure 8-5 shows a sample setup procedure for idle mode.

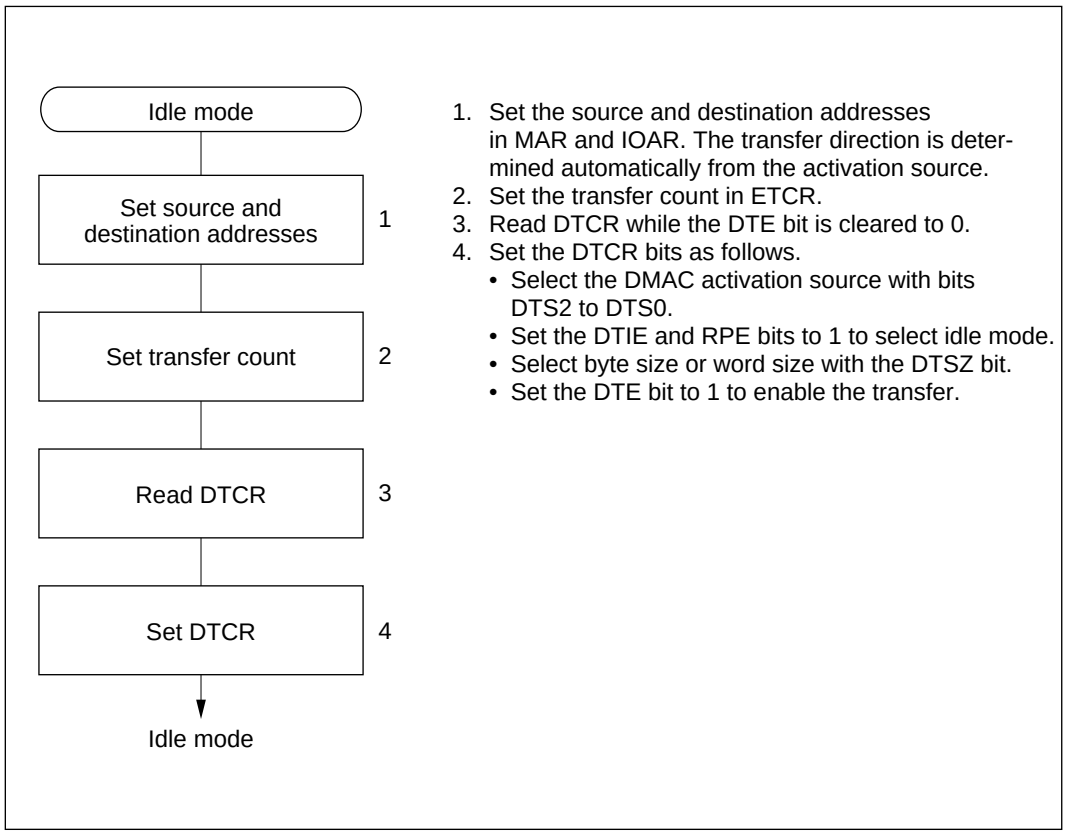


Figure 8-5 Idle Mode Setup Procedure (Example)

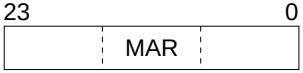
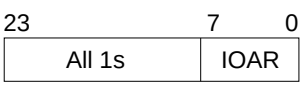
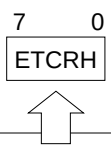
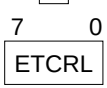
8.4.4 Repeat Mode

Repeat mode is useful for cyclically transferring a bit pattern from a table to the programmable timing pattern controller (TPC) in synchronization, for example, with ITU compare match. Repeat mode can be selected for each channel independently.

One byte or word is transferred per request in repeat mode, as in I/O mode. A designated number of these transfers are executed. One address is specified in the memory address register (MAR), the other in the I/O address register (IOAR). At the end of the designated number of transfers, MAR and ETCR are restored to their original values and operation continues. The direction of transfer is determined automatically from the activation source. The transfer is from the address specified in IOAR to the address specified in MAR if activated by an SCI receive-data-full interrupt, and from the address specified in MAR to the address specified in IOAR otherwise.

Table 8-8 indicates the register functions in repeat mode.

Table 8-8 Register Functions in Repeat Mode

	Function			
Register	**Activated by SCI Receive-Data-Full Interrupt**	**Other Activation**	**Initial Setting**	**Operation**
	Destination address register	Source address register	Destination or source address	Incremented or decremented at each transfer until ETCRH reaches H'0000, then restored to initial value
	Source address register	Destination address register	Source or destination address	Held fixed
	Transfer counter		Number of transfers	Decremented once per transfer unti H'0000 is reached, then reloaded from ETCRL
	Initial transfer count		Number of transfers	Held fixed

Legend
MAR: Memory address register
IOAR: I/O address register
ETCR: Execute transfer count register

In repeat mode ETCRH is used as the transfer counter while ETCRL holds the initial transfer count. ETCRH is decremented by 1 at each transfer until it reaches H'00, then is reloaded from ETCRL. MAR is also restored to its initial value, which is calculated from the DTSZ and DTID bits in DTCR. Specifically, MAR is restored as follows:

$$MAR \leftarrow MAR - (-1)^{DTID} \cdot 2^{DTSZ} \cdot ETCRL$$

ETCRH and ETCRL should be initially set to the same value.

In repeat mode transfers continue until the CPU clears the DTE bit to 0. After DTE is cleared to 0, if the CPU sets DTE to 1 again, transfers resume from the state at which DTE was cleared. No CPU interrupt is requested.

As in I/O mode, MAR and IOAR specify the source and destination addresses. MAR specifies a 24-bit source or destination address. IOAR specifies the lower 8 bits of a fixed address. The upper 16 bits are all 1s. IOAR is not incremented or decremented.

Figure 8-6 illustrates how repeat mode operates.

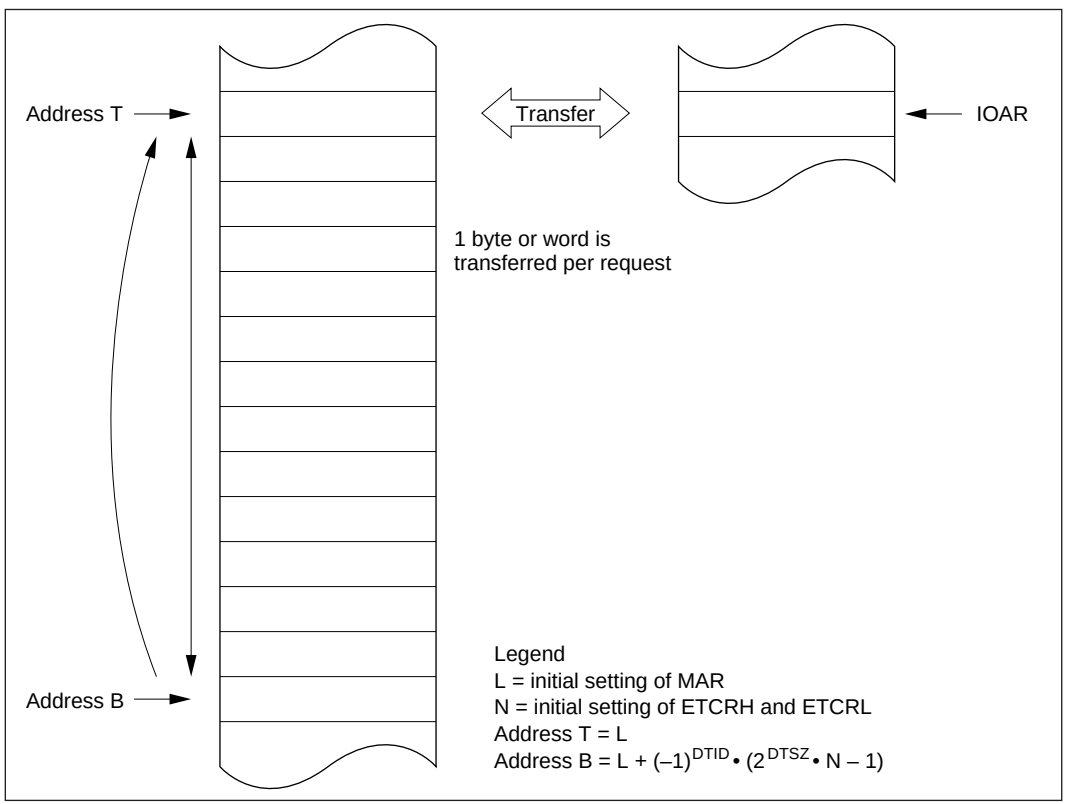


Figure 8-6 Operation in Repeat Mode

The transfer count is specified as an 8-bit value in ETCRH and ETCRL. The maximum transfer count is 255, obtained by setting both ETCRH and ETCRL to H'FF.

Transfers can be requested (activated) by compare match/input capture A interrupts from ITU channels 0 to 3, SCI transmit-data-empty and receive-data-full interrupts, and external request signals.

For the detailed settings see section 8.2.4, Data Transfer Control Registers (DTCR).

Figure 8-7 shows a sample setup procedure for repeat mode.

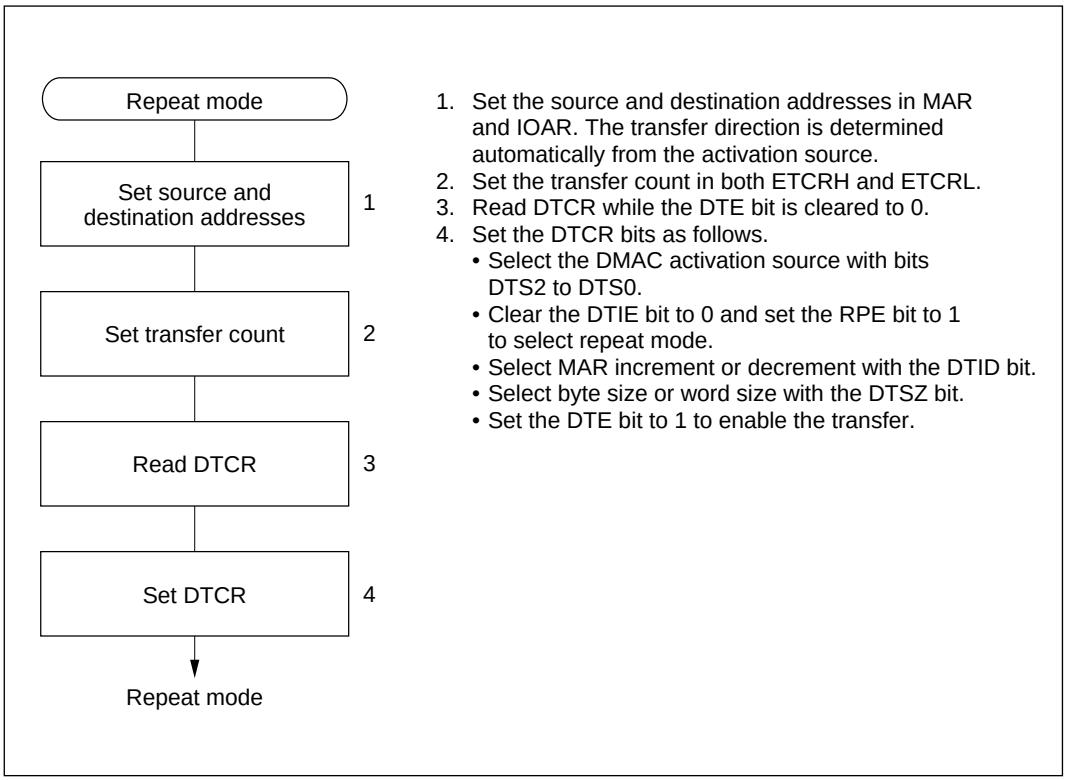


Figure 8-7 Repeat Mode Setup Procedure (Example)

8.4.5 Normal Mode

In normal mode the A and B channels are combined. One byte or word is transferred per request. A designated number of these transfers are executed. Addresses are specified in MARA and MARB. Table 8-9 indicates the register functions in I/O mode.

Table 8-9 Register Functions in Normal Mode

Register	Function	Initial Setting	Operation
23 MARA 0	Source address register	Source address	Incremented or decremented once per transfer, or held fixed
23 MARB 0	Destination address register	Destination address	Incremented or decremented once per transfer, or held fixed
15 ETCRA 0	Transfer counter	Number of transfers	Decremented once per transfer

Legend
MARA: Memory address register A
MARB: Memory address register B
ETCRA: Execute transfer count register A

The source and destination addresses are both 24-bit addresses. MARA specifies the source address. MARB specifies the destination address. MARA and MARB can be independently incremented, decremented, or held fixed as data is transferred.

The transfer count is specified as a 16-bit value in ETCRA. The ETCRA value is decremented by 1 at each transfer. When the ETCRA value reaches H'0000, the DTE bit is cleared and the transfer ends. If the DTIE bit is set, a CPU interrupt is requested at this time. The maximum transfer count is 65,536, obtained by setting ETCRA to H'0000.

Figure 8-8 illustrates how normal mode operates.

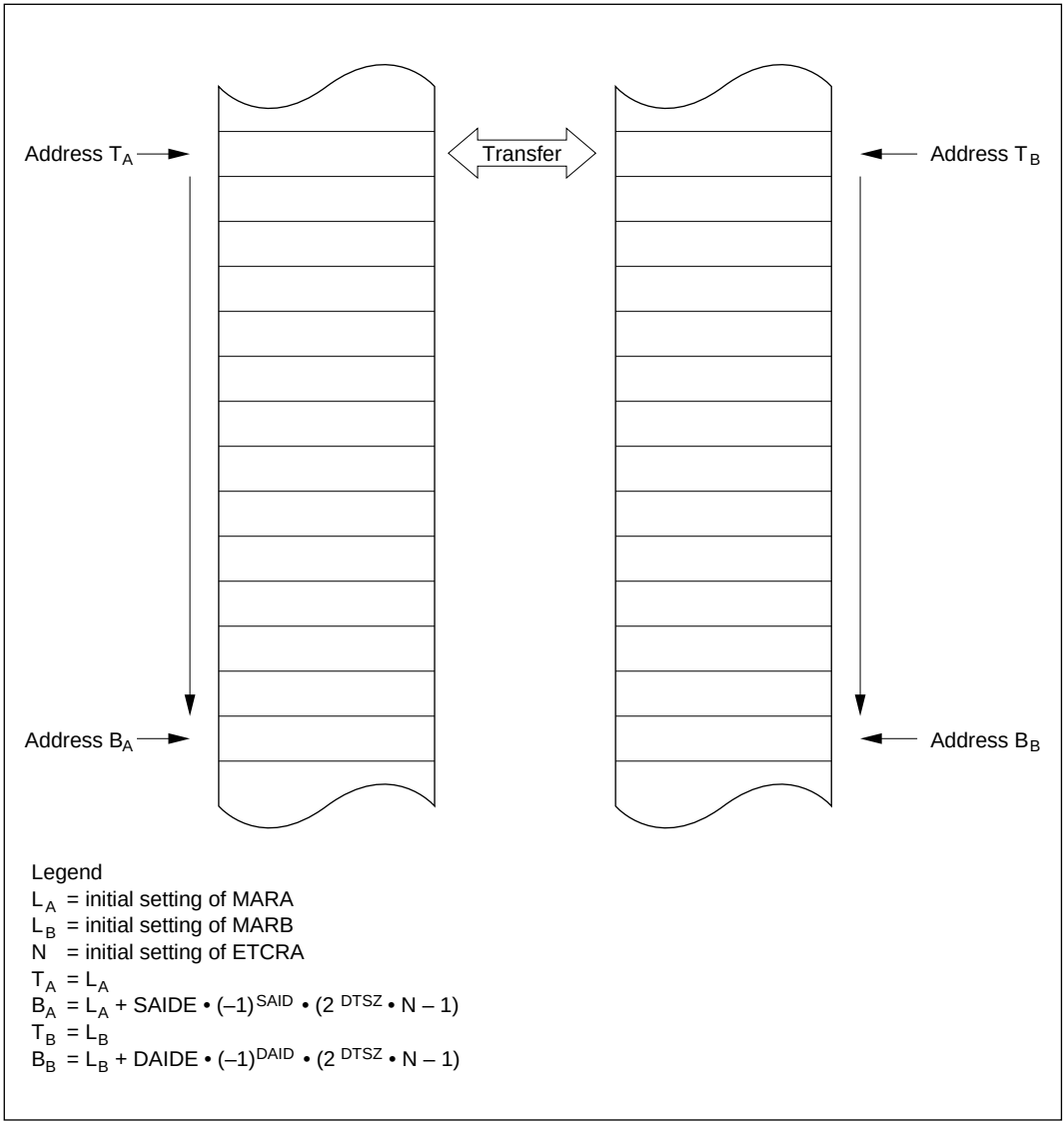
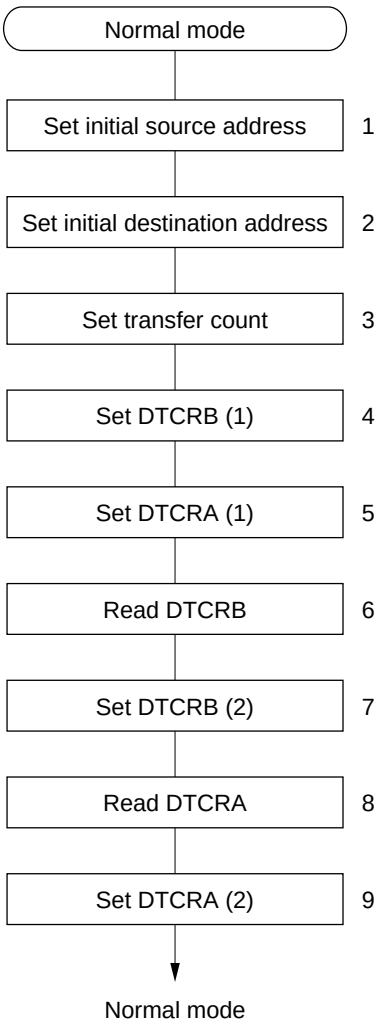


Figure 8-8 Operation in Normal Mode

Transfers can be requested (activated) by an external request or auto-request. An auto-requested transfer is activated by the register settings alone. The designated number of transfers are executed automatically. Either cycle-steal or burst mode can be selected. In cycle-steal mode the DMAC releases the bus temporarily after each transfer. In burst mode the DMAC keeps the bus until the transfers are completed, unless there is a bus request from a higher-priority bus master.

For the detailed settings see section 8.3.4, Data Transfer Control Registers (DTCR).

Figure 8-9 shows a sample setup procedure for normal mode.



1. Set the initial source address in MARA.
2. Set the initial destination address in MARB.
3. Set the transfer count in ETCRA.
4. Set the DTCRB bits as follows.
   - Clear the DTME bit to 0.
   - Set the DAID and DAIDE bits to select whether MARB is incremented, decremented, or held fixed.
   - Select the DMAC activation source with bits DTS2B to DTS0B.
5. Set the DTCRA bits as follows.
   - Clear the DTE bit to 0.
   - Select byte or word size with the DTSZ bit.
   - Set the SAID and SAIDE bits to select whether MARA is incremented, decremented, or held fixed.
   - Set or clear the DTIE bit to enable or disable the CPU interrupt at the end of the transfer.
   - Clear the DTS0A bit to 0 and set the DTS2A and DTS1A bits to 1 to select normal mode.
6. Read DTCRB with DTME cleared to 0.
7. Set the DTME bit to 1 in DTCRB.
8. Read DTCRA with DTE cleared to 0.
9. Set the DTE bit to 1 in DTCRA to enable the transfer.

Note: * Carry out settings 1 to 9 with the DEND interrupt masked in the CPU.

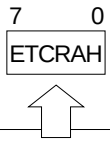
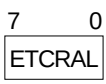
Figure 8-9 Normal Mode Setup Procedure (Example)

8.4.6 Block Transfer Mode

In block transfer mode the A and B channels are combined. One block of a specified size is transferred per request. A designated number of block transfers are executed. Addresses are specified in MARA and MARB. The block area address can be either held fixed or cycled.

Table 8-10 indicates the register functions in block transfer mode.

Table 8-10 Register Functions in Block Transfer Mode

Register	Function	Initial Setting	Operation
	Source address register	Source address	Incremented or decremented once per transfer, or held fixed
	Destination address register	Destination address	Incremented or decremented once per transfer, or held fixed
	Block size counter	Block size	Decremented once per transfer until H'00 is reached, then reloaded from ETCRAL
	Initial block size	Block size	Held fixed
	Block transfer counter	Number of block transfers	Decremented once per block transfer until H'0000 is reached and the transfer ends

Legend
MARA: Memory address register A
MARB: Memory address register B
ETCRA: Execute transfer count register A
ETCRB: Execute transfer count register B

The source and destination addresses are both 24-bit addresses. MARA specifies the source address. MARB specifies the destination address. MARA and MARB can be independently incremented, decremented, or held fixed as data is transferred. One of these registers operates as a block area register: even if it is incremented or decremented, it is restored to its initial value at the end of each block transfer. The TMS bit in DTCRB selects whether the block area is the source or destination.

If M (1 to 255) is the size of the block transferred at each request and N (1 to 65,536) is the number of blocks to be transferred, then ETCRAH and ETCRAL should initially be set to M and ETCRB should initially be set to N.

Figure 8-10 illustrates how block transfer mode operates. In this figure, bit TMS is cleared to 0, meaning the block area is the destination.

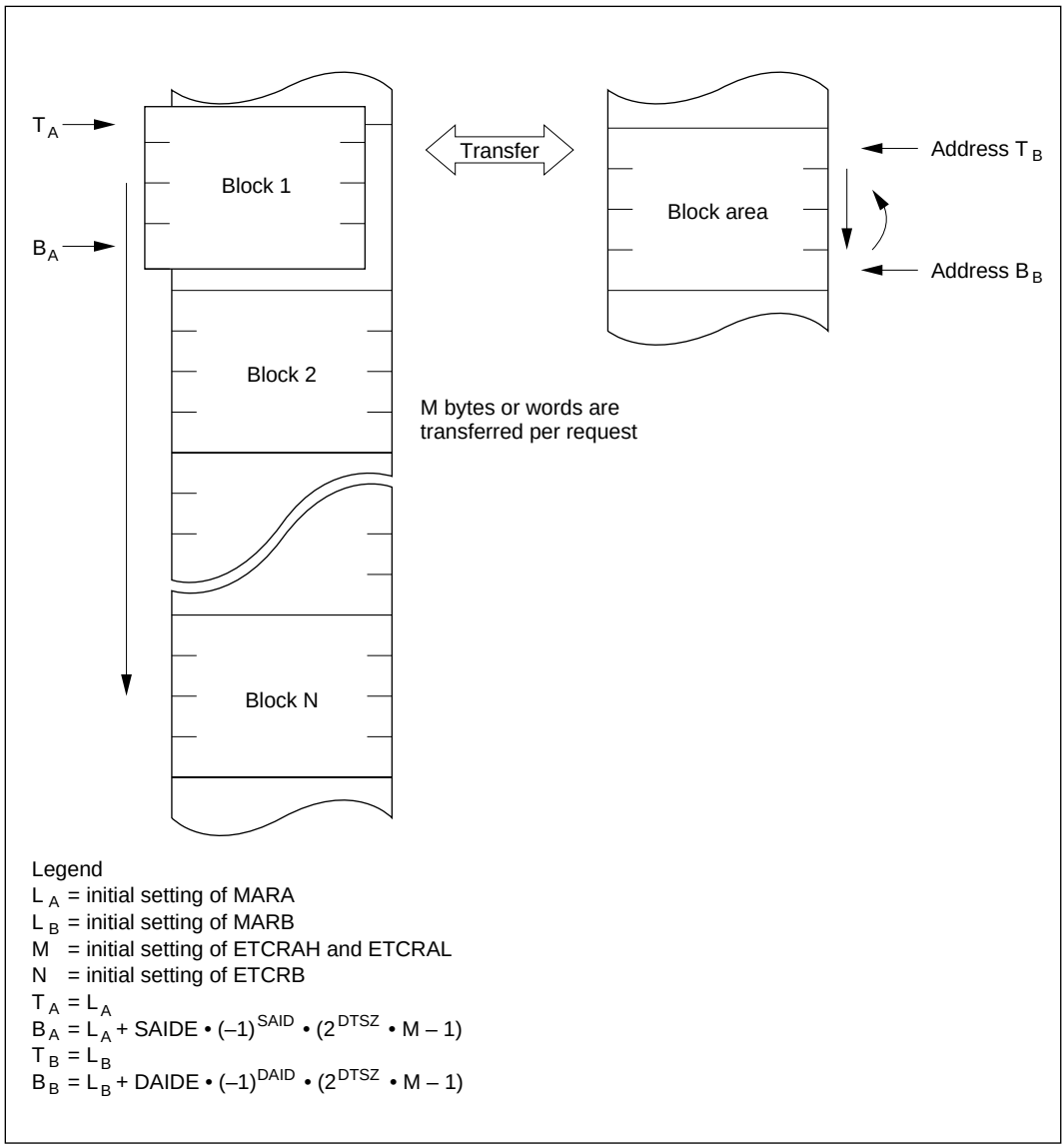


Figure 8-10 Operation in Block Transfer Mode

When activated by a transfer request, the DMAC executes a burst transfer. During the transfer MARA and MARB are updated according to the DTCR settings, and ETCRAH is decremented. When ETCRAH reaches H'00, it is reloaded from ETCRAL to restore the initial value. The memory address register of the block area is also restored to its initial value, and ETCRB is decremented. If ETCRB is not H'0000, the DMAC then waits for the next transfer request. ETCRAH and ETCRAL should be initially set to the same value.

The above operation is repeated until ETCRB reaches H'0000, at which point the DTE bit is cleared to 0 and the transfer ends. If the DTIE bit is set to 1, a CPU interrupt is requested at this time.

Figure 8-11 shows examples of a block transfer with byte data size when the block area is the destination. In (a) the block area address is cycled. In (b) the block area address is held fixed.

Transfers can be requested (activated) by compare match/input capture A interrupts from ITU channels 0 to 3, and by external request signals.

For the detailed settings see section 8.3.4, Data Transfer Control Registers (DTCR).

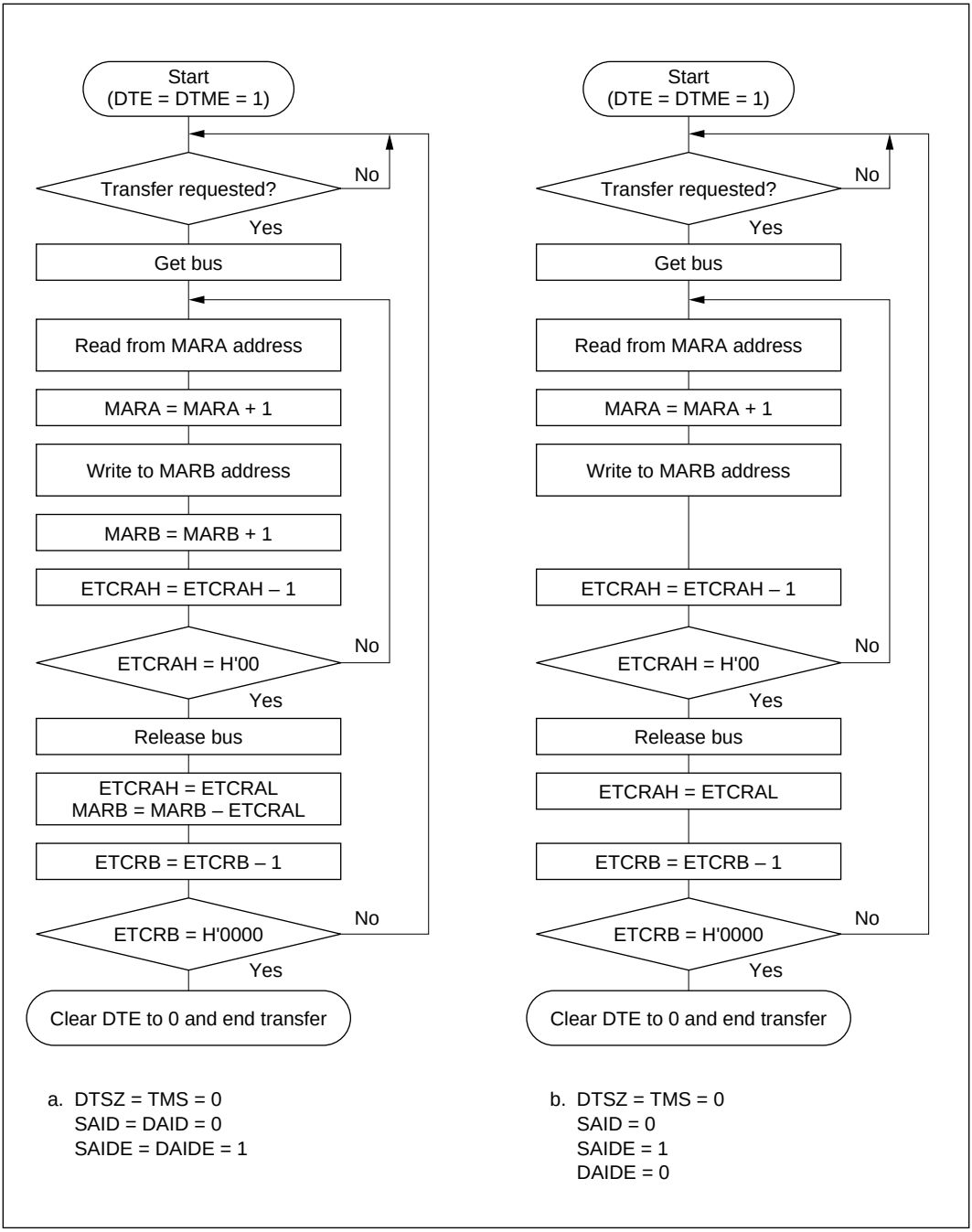
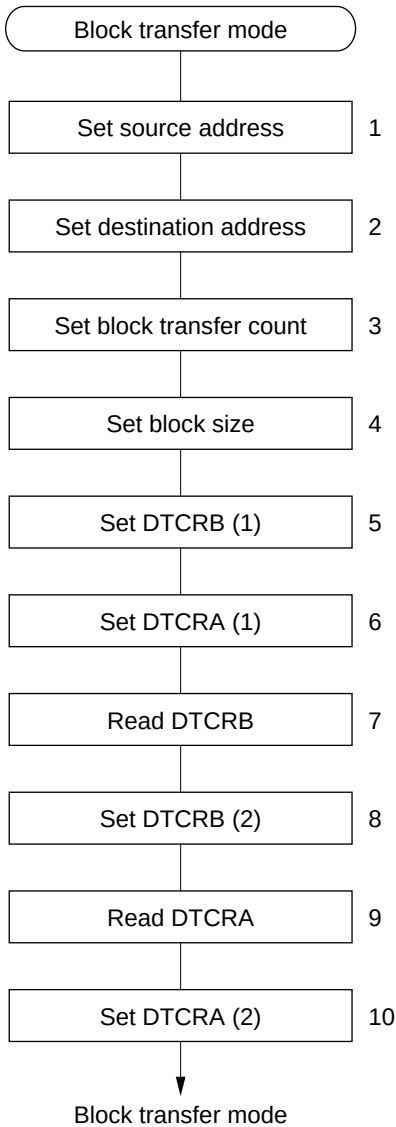


Figure 8-11 Block Transfer Mode Flowcharts (Examples)

Figure 8-12 shows a sample setup procedure for block transfer mode.



1. Set the source address in MARA.
2. Set the destination address in MARB.
3. Set the block transfer count in ETCRB.
4. Set the block size (number of bytes or words) in both ETCRAH and ETCRAL.
5. Set the DTCRB bits as follows.
   - Clear the DTME bit to 0.
   - Set the DAID and DAIDE bits to select whether MARB is incremented, decremented, or held fixed.
   - Set or clear the TMS bit to make the block area the source or destination.
   - Select the DMAC activation source with bits DTS2B to DTS0B.
6. Set the DTCRA bits as follows.
   - Clear the DTE to 0.
   - Select byte size or word size with the DTSZ bit.
   - Set the SAID and SAIDE bits to select whether MARA is incremented, decremented, or held fixed.
   - Set or clear the DTIE bit to enable or disable the CPU interrupt at the end of the transfer.
   - Set bits DTS2A to DTS0A all to 1 to select block transfer mode.
7. Read DTCRB with DTME cleared to 0.
8. Set the DTME bit to 1 in DTCRB.
9. Read DTCRA with DTE cleared to 0.
10. Set the DTE bit to 1 in DTCRA to enable the transfer.

Note: * Carry out settings 1 to 10 with the DEND interrupt masked in the CPU.

Figure 8-12 Block Transfer Mode Setup Procedure (Example)

8.4.7 DMAC Activation

The DMAC can be activated by an internal interrupt, external request, or auto-request. The available activation sources differ depending on the transfer mode and channel as indicated in table 8-11.

Table 8-11 DMAC Activation Sources

Activation Source		Short Address Mode				Full Address Mode	
		Channels 0A and 1A	Channels 0B and 1B	Channels 2A and 3A	Channels 2B and 3B	Normal	Block
Internal interrupts	IMIA0	○	○	○	○	×	○
	IMIA1	○	○	○	○	×	○
	IMIA2	○	○	○	○	×	○
	IMIA3	○	○	○	○	×	○
	TXI0	○	○	×	×	×	×
	RXI0	○	○	×	×	×	×
	TXI1	×	×	○	○	×	×
	RXI1	×	×	○	○	×	×
External requests	Falling edge of $\overline{\text{DREQ}}$	×	○	×	○	○	○
	Low input at $\overline{\text{DREQ}}$	×	○	×	○	○	×
Auto-request		×	×	×	×	○	×

Activation by Internal Interrupts: When an interrupt request is selected as a DMAC activation source and the DTE bit is set to 1, that interrupt request is not sent to the CPU. It is not possible for an interrupt request to activate the DMAC and simultaneously generate a CPU interrupt.

When the DMAC is activated by an interrupt request, the interrupt request flag is cleared automatically. If the same interrupt is selected to activate two or more channels, the interrupt request flag is cleared when the highest-priority channel is activated, but the transfer request is held pending on the other channels in the DMAC, which are activated in their priority order.

Activation by External Request: If an external request ($\overline{\text{DREQ}}$ pin) is selected as an activation source, the $\overline{\text{DREQ}}$ pin becomes an input pin and the corresponding $\overline{\text{TEND}}$ pin becomes an output pin, regardless of the port data direction register (DDR) settings. The $\overline{\text{DREQ}}$ input can be level-sensitive or edge-sensitive.

In short address mode and normal mode, an external request operates as follows. If edge sensing is selected, one byte or word is transferred each time a high-to-low transition of the $\overline{\text{DREQ}}$ input is detected. If the next edge is input before the transfer is completed, the next transfer may not be executed. If level sensing is selected, the transfer continues while $\overline{\text{DREQ}}$ is low, until the transfer is completed. The bus is released temporarily after each byte or word has been transferred, however. If the $\overline{\text{DREQ}}$ input goes high during a transfer, the transfer is suspended after the current byte or word has been transferred. When $\overline{\text{DREQ}}$ goes low, the request is held internally until one byte or word has been transferred. The $\overline{\text{TEND}}$ signal goes low during the last write cycle.

In block transfer mode, an external request operates as follows. Only edge-sensitive transfer requests are possible in block transfer mode. Each time a high-to-low transition of the $\overline{\text{DREQ}}$ input is detected, a block of the specified size is transferred. The $\overline{\text{TEND}}$ signal goes low during the last write cycle in each block.

Activation by Auto-Request: The transfer starts as soon as enabled by register setup, and continues until completed. Cycle-steal mode or burst mode can be selected.

In cycle-steal mode the DMAC releases the bus temporarily after transferring each byte or word. Normally, DMAC cycles alternate with CPU cycles.

In burst mode the DMAC keeps the bus until the transfer is completed, unless there is a higher-priority bus request. If there is a higher-priority bus request, the bus is released after the current byte or word has been transferred.

8.4.8 DMAC Bus Cycle

Figure 8-13 shows an example of the timing of the basic DMAC bus cycle. This example shows a word-size transfer from a 16-bit two-state access area to an 8-bit three-state access area. When the DMAC gets the bus from the CPU, after one dead cycle (T_d), it reads from the source address and writes to the destination address. During these read and write operations the bus is not released even if there is another bus request. DMAC cycles comply with bus controller settings in the same way as CPU cycles.

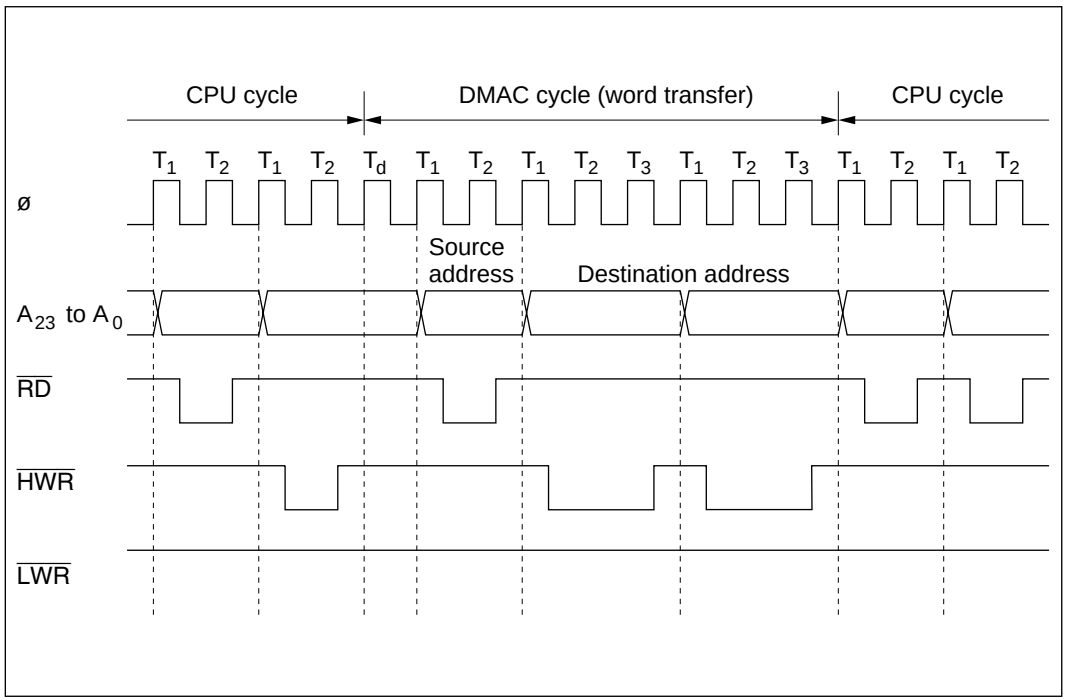


Figure 8-13 DMA Transfer Bus Timing (Example)

Figure 8-14 shows the timing when the DMAC is activated by low input at a $\overline{\text{DREQ}}$ pin. This example shows a word-size transfer from a 16-bit two-state access area to another 16-bit two-state access area. The DMAC continues the transfer while the $\overline{\text{DREQ}}$ pin is held low.

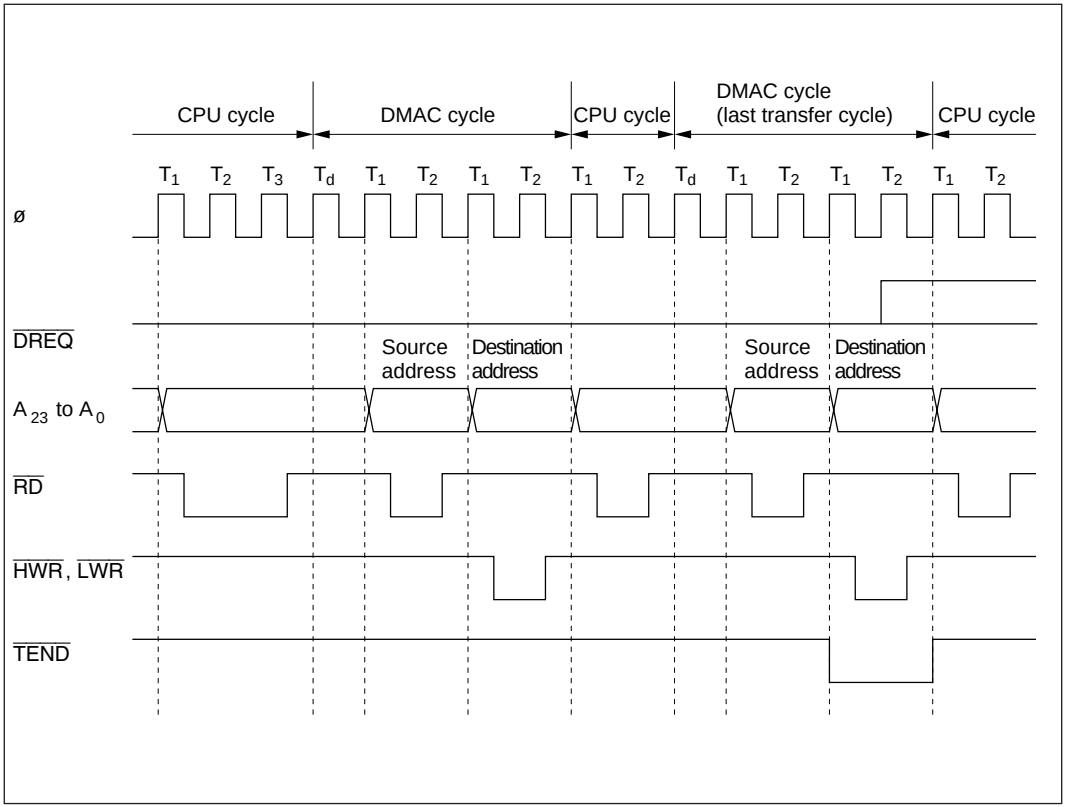


Figure 8-14 Bus Timing of DMA Transfer Requested by Low $\overline{\text{DREQ}}$ Input

Figure 8-15 shows an auto-requested burst-mode transfer. This example shows a transfer of three words from a 16-bit two-state access area to another 16-bit two-state access area.

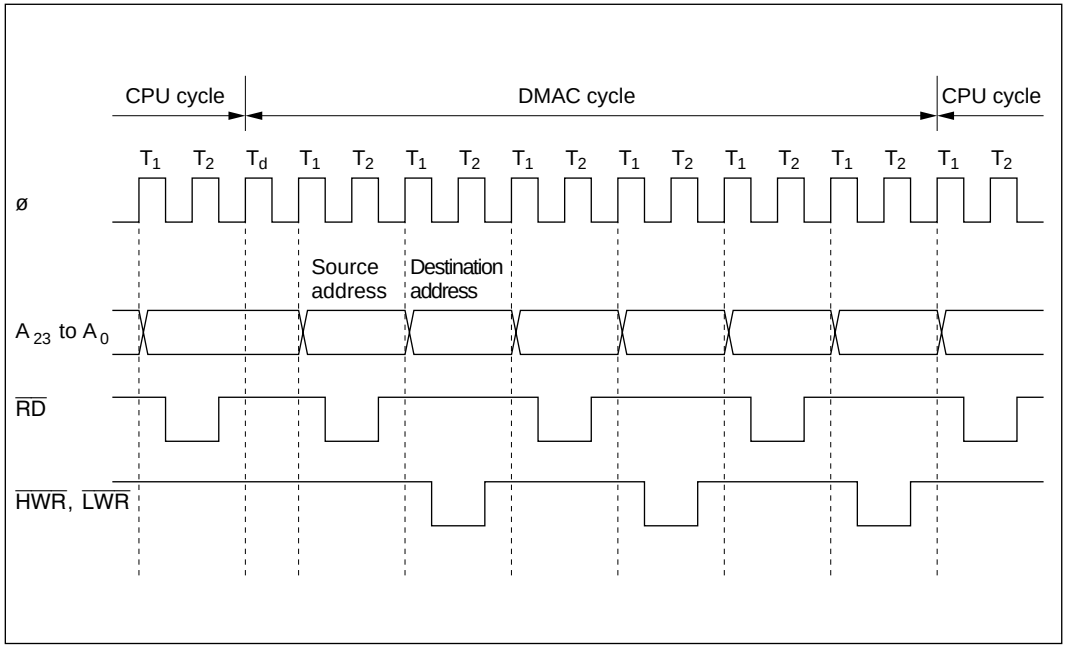


Figure 8-15 Burst DMA Bus Timing

When the DMAC is activated from a $\overline{\text{DREQ}}$ pin there is a minimum interval of four states from when the transfer is requested until the DMAC starts operating. The $\overline{\text{DREQ}}$ pin is not sampled during the time between the transfer request and the start of the transfer. In short address mode and normal mode, the pin is next sampled at the end of the read cycle. In block transfer mode, the pin is next sampled at the end of one block transfer.

Figure 8-16 shows the timing when the DMAC is activated by the falling edge of $\overline{\text{DREQ}}$ in normal mode.

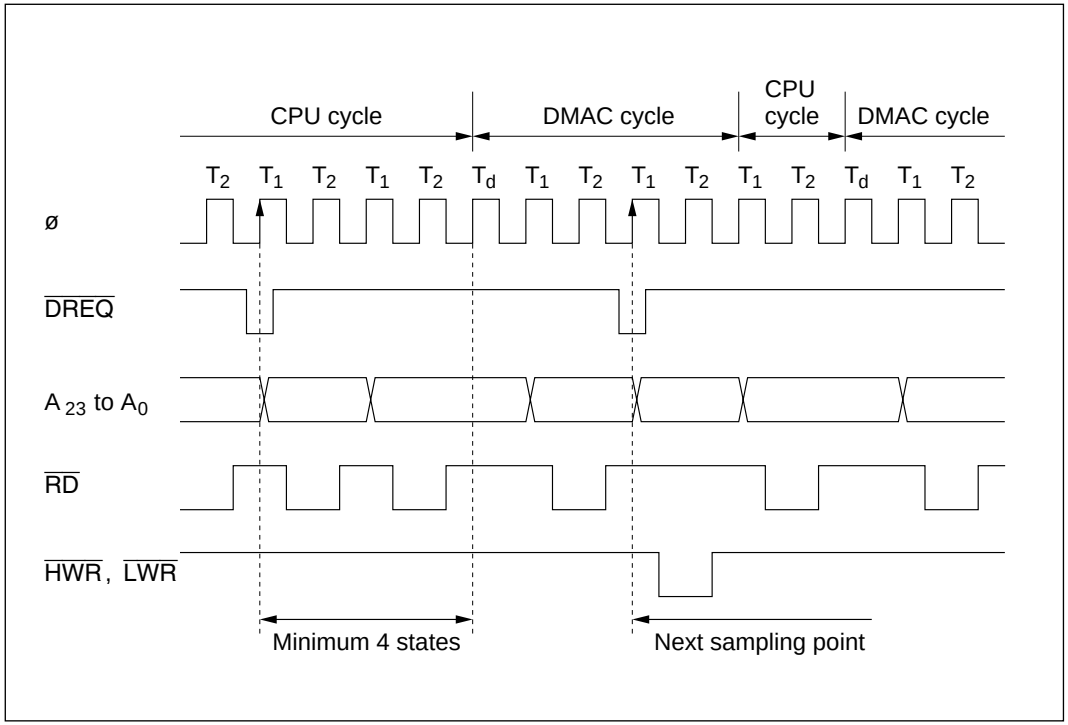


Figure 8-16 Timing of DMAC Activation by Falling Edge of $\overline{\text{DREQ}}$ in Normal Mode

Figure 8-17 shows the timing when the DMAC is activated by level-sensitive low $\overline{\text{DREQ}}$ input in normal mode.

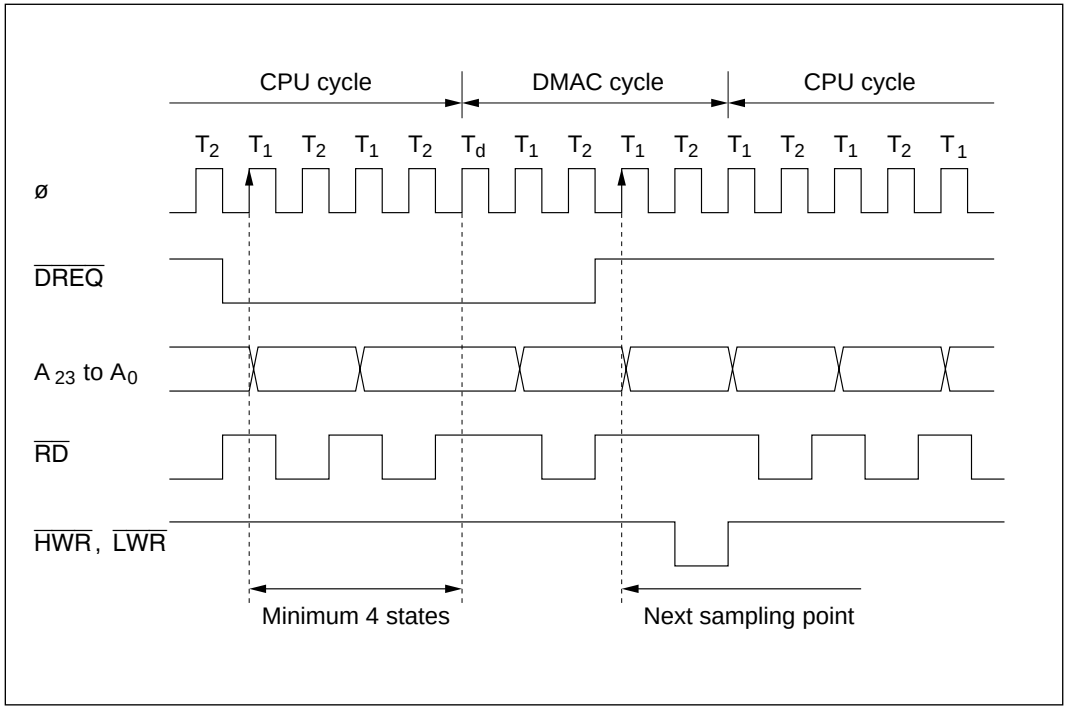


Figure 8-17 Timing of DMAC Activation by Low $\overline{\text{DREQ}}$ Level in Normal Mode

Figure 8-18 shows the timing when the DMAC is activated by the falling edge of $\overline{\text{DREQ}}$ in block transfer mode.

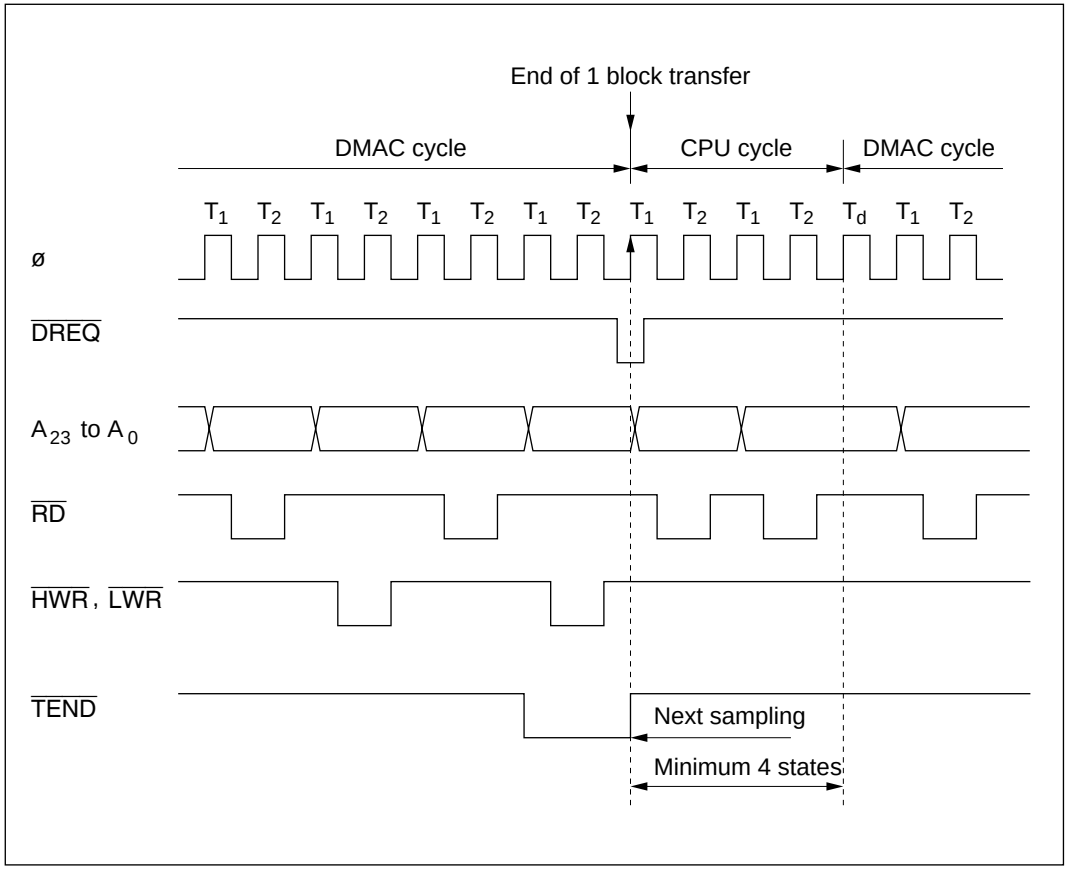


Figure 8-18 Timing of DMAC Activation by Falling Edge of $\overline{\text{DREQ}}$ in Block Transfer Mode

8.4.9 Multiple-Channel Operation

The DMAC channel priority order is: channel 0 > channel 1 > channel 2 > channel 3, and channel A > channel B. Table 8-12 shows the complete priority order. Group 0 and group 1 operate as two independent bus masters.

Table 8-12 Channel Priority Order

Bus Master	Short Address Mode	Full Address Mode	Priority
Group 0	Channel 0A	Channel 0	High
	Channel 0B		
	Channel 1A	Channel 1	
	Channel 1B		
Group 1	Channel 2A	Channel 2	
	Channel 2B		
	Channel 3A	Channel 3	
	Channel 3B		Low

Multiple-Channel Operation in the Same Group: If transfers are requested on two or more channels simultaneously in the same group, or if a transfer on one channel is requested during a transfer on another channel in the same group, the DMAC operates as follows.

- When a transfer is requested, the DMAC requests the bus right. When it gets the bus right, it starts a transfer on the highest-priority channel at that time.
- Once a transfer starts on one channel, requests to other channels in the same group are held pending until that channel releases the bus.
- After each transfer in short address mode, and each externally-requested or cycle-steal transfer in normal mode, the DMAC releases the bus and returns to step 1. After releasing the bus, if there is a transfer request for another channel in the same group, the DMAC requests the bus again.
- After completion of a burst-mode transfer, or after transfer of one block in block transfer mode, the DMAC releases the bus and returns to step 1. If there is a transfer request for a higher-priority channel or a bus request from a higher-priority bus master, however, the DMAC releases the bus after completing the transfer of the current byte or word. After releasing the bus, if there is a transfer request for another channel in the same group, the DMAC requests the bus again.

Figure 8-19 shows the timing when channel 0A is set up for I/O mode and channel 1 for burst mode, and a transfer request for channel 0A is received while channel 1 is active.

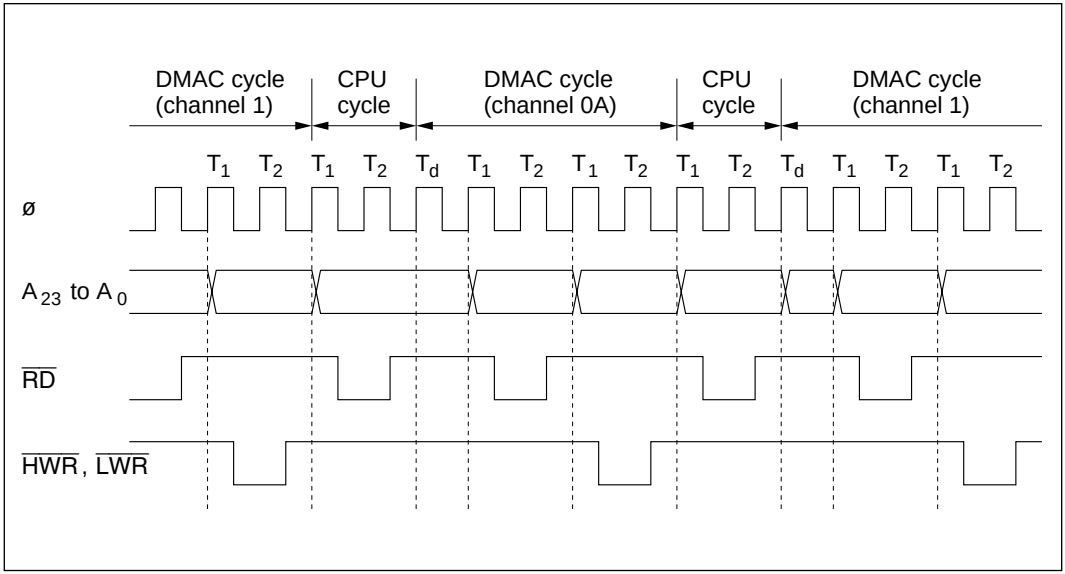


Figure 8-19 Timing of Multiple-Channel Operations in the Same Group

Multiple-Channel Operation in Different Groups: If transfers are requested on channels in groups 0 and 1 simultaneously, or if a transfer in one group is requested during a transfer in the other group, the DMAC operates as follows.

- When a transfer is requested, the DMAC requests the bus right. When it gets the bus right, it activates the highest-priority channel at that time. If there are transfer requests for both DMAC groups 0 and 1, a channel in group 0 is activated.
- Once a transfer starts on a channel in one group, requests to other channels are held pending until that channel releases the bus.
- After each transfer in short address mode, and each externally-requested or cycle-steal transfer in normal mode, the DMAC releases the bus and returns to step 1. If there is a transfer request for a channel in the other group, that channel is activated immediately.
- After completion of a burst-mode transfer, or after transfer of one block in block transfer mode, the DMAC releases the bus and returns to step 1. If there is a transfer request for a group-0 channel while a group-1 channel is active, however, the group-1 channel releases the bus after completing the transfer of the current byte or word. When the bus is released, if there is a transfer request for a channel in the other group, the DMAC is activated immediately.

Figure 8-20 shows the timing when channel 0A is set up for I/O mode and channel 2 for burst mode, and a transfer request for channel 0A is received while channel 2 is active.

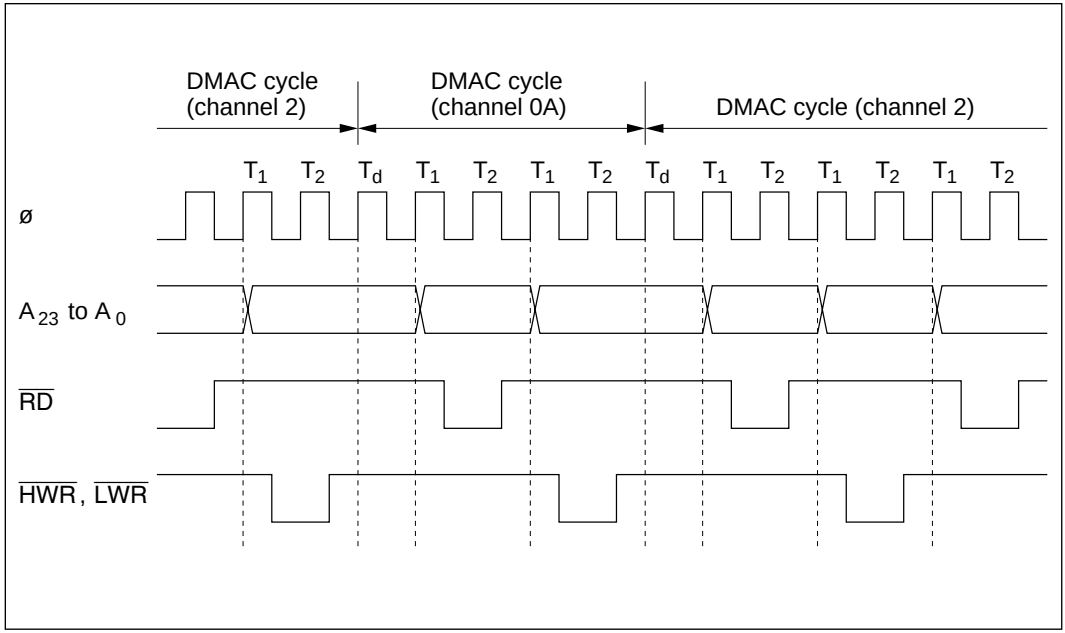


Figure 8-20 Timing of Multiple-Channel Operations in Different Groups

If cycle-steal mode is selected in both groups 0 and 1, the DMAC may activate channels in these two groups alternately without passing the bus right to the CPU.

8.4.10 External Bus Requests, Refresh Controller, and DMAC

During a DMA transfer, if the bus right is requested by an external bus request signal ($\overline{\text{BREQ}}$) or by the refresh controller, the DMAC releases the bus after completing the transfer of the current byte or word. If there is a transfer request at this point, the DMAC requests the bus right again. Figure 8-21 shows an example of the timing of insertion of a refresh cycle during a burst transfer on channel 0.

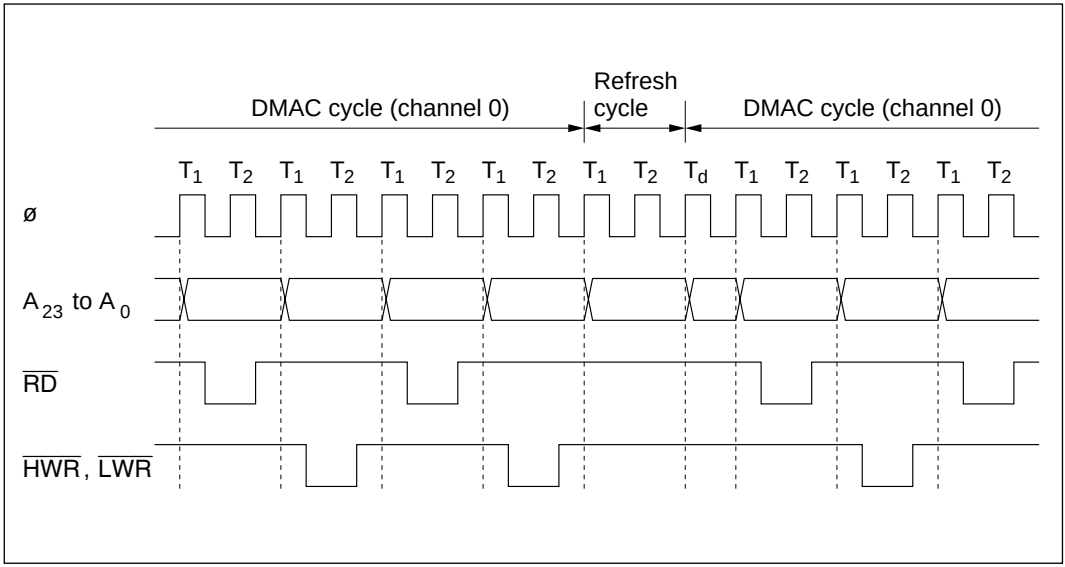


Figure 8-21 Bus Timing of Refresh Controller and DMAC

8.4.11 NMI Interrupts and DMAC

NMI interrupts do not affect DMAC operations in short address mode.

If an NMI interrupt occurs during a transfer in full address mode, the DMAC suspends operations. In full address mode, a channel is enabled when its DTE and DTME bits are both set to 1. NMI input clears the DTME bit to 0. After transferring the current byte or word, the DMAC releases the bus to the CPU. In normal mode, the suspended transfer resumes when the CPU sets the DTME bit to 1 again. Check that the DTE bit is set to 1 and the DTME bit is cleared to 0 before setting the DTME bit to 1.

Figure 8-22 shows the procedure for resuming a DMA transfer in normal mode on channel 0 after the transfer was halted by NMI input.

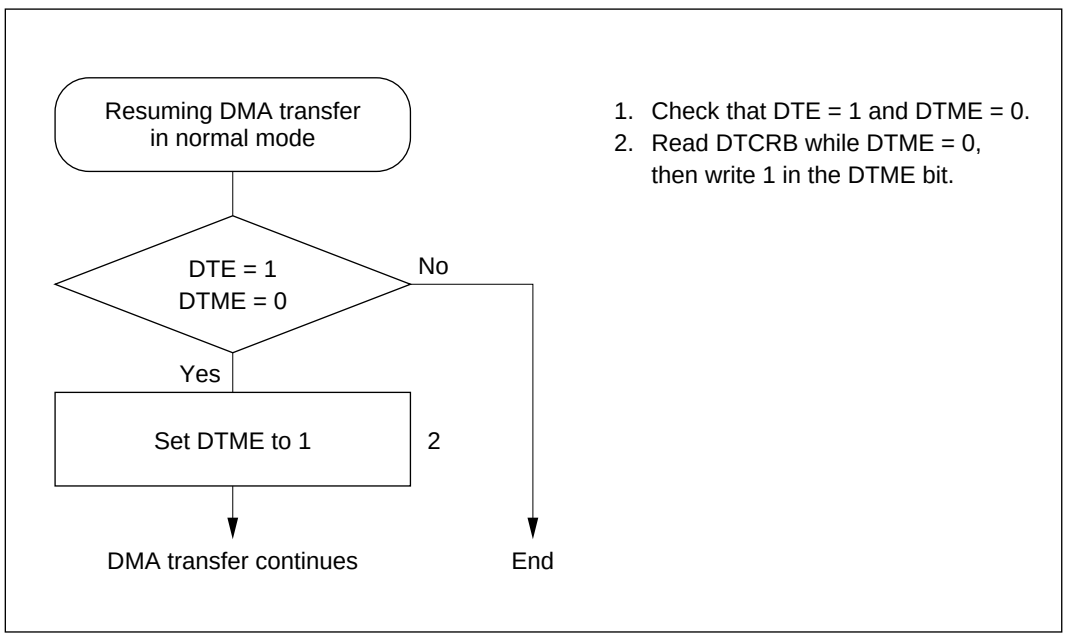


Figure 8-22 Procedure for Resuming a DMA Transfer Halted by NMI (Example)

For information about NMI interrupts in block transfer mode, see section 8.6.6, NMI Interrupts and Block Transfer Mode.

8.4.12 Aborting a DMA Transfer

When the DTE bit in an active channel is cleared to 0, the DMAC halts after transferring the current byte or word. The DMAC starts again when the DTE bit is set to 1. In full address mode, the DTME bit can be used for the same purpose. Figure 8-23 shows the procedure for aborting a DMA transfer by software.

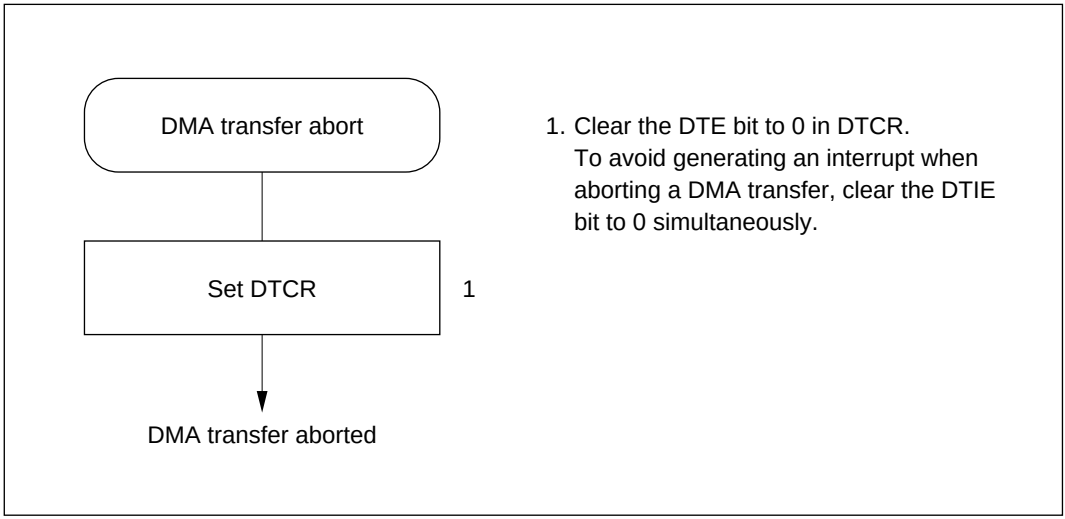


Figure 8-23 Procedure for Aborting a DMA Transfer

8.4.13 Exiting Full Address Mode

Figure 8-24 shows the procedure for exiting full address mode and initializing the pair of channels. To set the channels up in another mode after exiting full address mode, follow the setup procedure for the relevant mode.

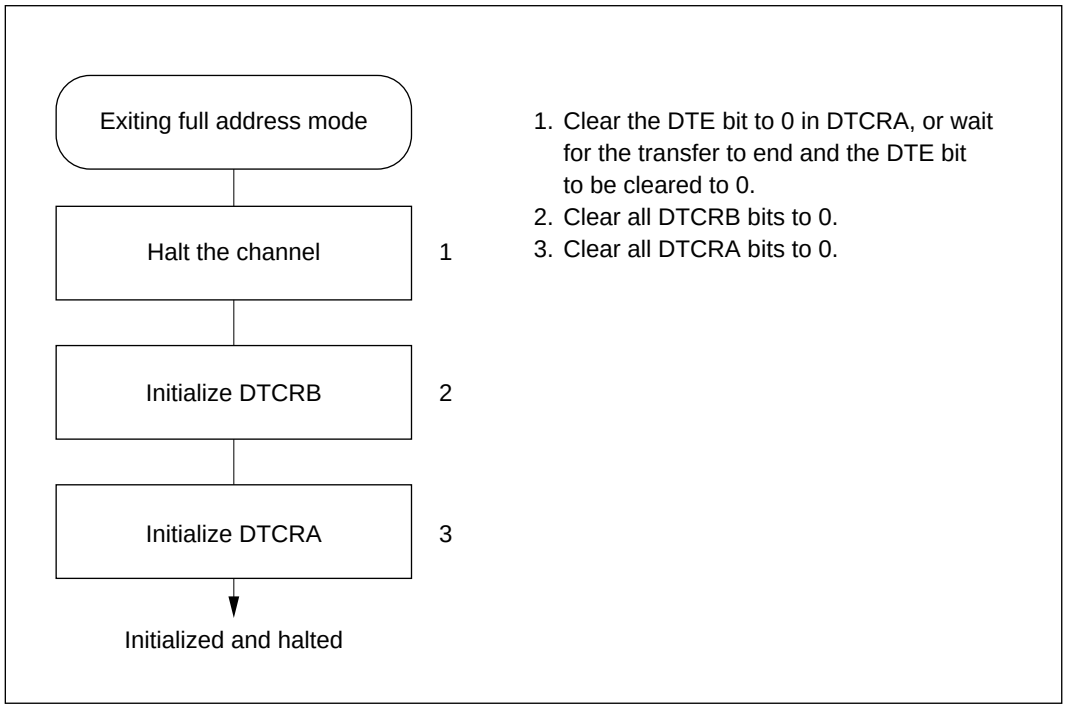


Figure 8-24 Procedure for Exiting Full Address Mode (Example)

8.4.14 DMAC States in Reset State, Standby Modes, and Sleep Mode

When the chip is reset or enters hardware or software standby mode, the DMAC is initialized. DMAC operations continue in sleep mode. Figure 8-25 shows the timing of a cycle-steal transfer in sleep mode.

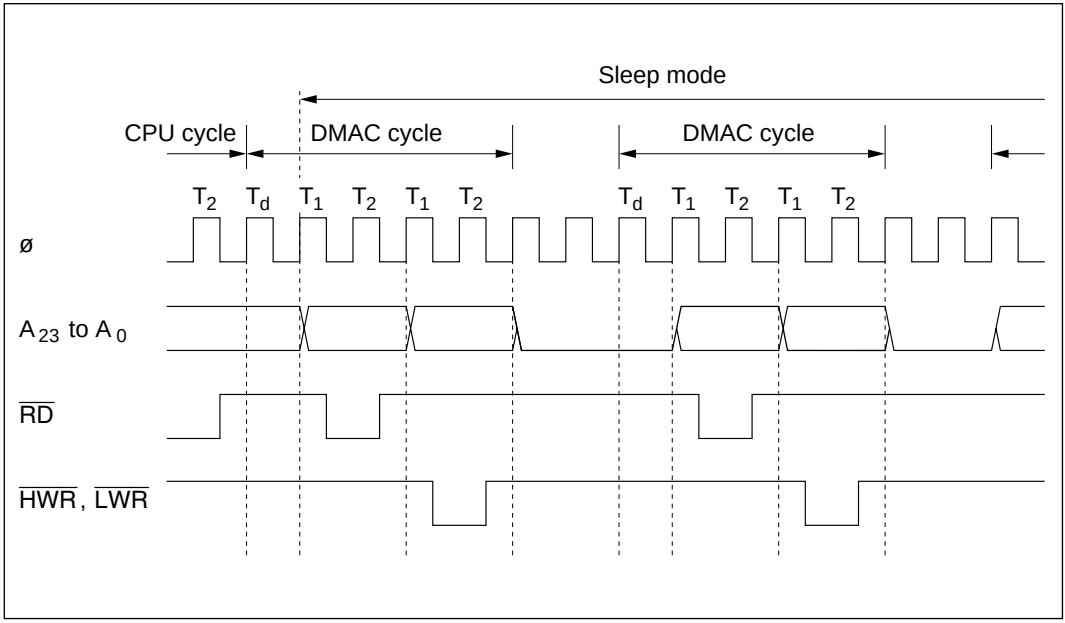


Figure 8-25 Timing of Cycle-Steal Transfer in Sleep Mode

8.5 Interrupts

The DMAC generates only DMA-end interrupts. Table 8-13 lists the interrupts and their priority.

Table 8-13 DMAC Interrupts

		Description		
Group	**Interrupt**	**Short Address Mode**	**Full Address Mode**	**Interrupt Priority**
0	DEND0A	End of transfer on channel 0A	End of transfer on channel 0	High
	DEND0B	End of transfer on channel 0B	—	
	DEND1A	End of transfer on channel 1A	End of transfer on channel 1	
	DEND1B	End of transfer on channel 1B	—	
1	DEND2A	End of transfer on channel 2A	End of transfer on channel 2	
	DEND2B	End of transfer on channel 2B	—	
	DEND3A	End of transfer on channel 3A	End of transfer on channel 3	
	DEND3B	End of transfer on channel 3B	—	Low

Each interrupt is enabled or disabled by the DTIE bit in the corresponding data transfer control register (DTCR). Separate interrupt signals are sent to the interrupt controller.

The interrupt priority order among channels is channel 0 > channel 1 > channel 2 > channel 3, and channel A > channel B. The interrupt priority order between groups can be modified in interrupt priority register B (IPRB).

Figure 8-26 shows the DMA-end interrupt logic. An interrupt is requested whenever DTE = 0 and DTIE = 1.

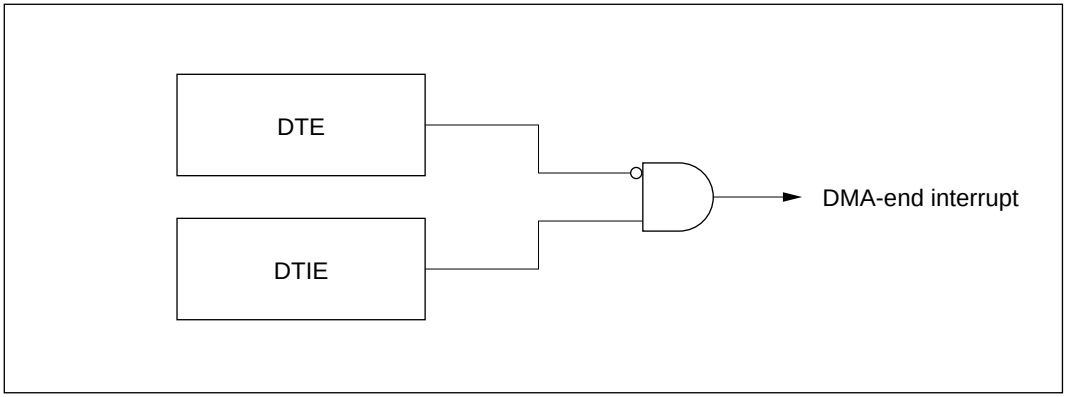


Figure 8-26 DMA-End Interrupt Logic

The DMA-end interrupt for the B channels (DENDB) is unavailable in full address mode. The DTME bit does not affect interrupt operations.

8.6 Usage Notes

8.6.1 Note on Word Data Transfer

Word data cannot be accessed starting at an odd address. When word-size transfer is selected, set even values in the memory and I/O address registers (MAR and IOAR).

8.6.2 DMAC Self-Access

The DMAC itself cannot be accessed during a DMAC cycle. DMAC registers cannot be specified as source or destination addresses.

8.6.3 Longword Access to Memory Address Registers

A memory address register can be accessed as longword data at the MARR address.

Example

```
MOV.L    #LBL, ER0
MOV.L    ER0, @MARR
```

Four byte accesses are performed. Note that the CPU may release the bus between the second byte (MARE) and third byte (MARH).

Memory address registers should be written and read only when the DMAC is halted.

8.6.4 Note on Full Address Mode Setup

Full address mode is controlled by two registers: DTCRA and DTCRB. Care must be taken to prevent the B channel from operating in short address mode during the register setup. The enable bits (DTE and DTME) should not be set to 1 until the end of the setup procedure.

8.6.5 Note on Activating DMAC by Internal Interrupts

When using an internal interrupt to activate the DMAC, make sure that the interrupt selected as the activating source does not occur during the interval after it has been selected but before the DMAC has been enabled. The on-chip supporting module that will generate the interrupt should not be activated until the DMAC has been enabled. If the DMAC must be enabled while the on-chip supporting module is active, follow the procedure in figure 8-27.

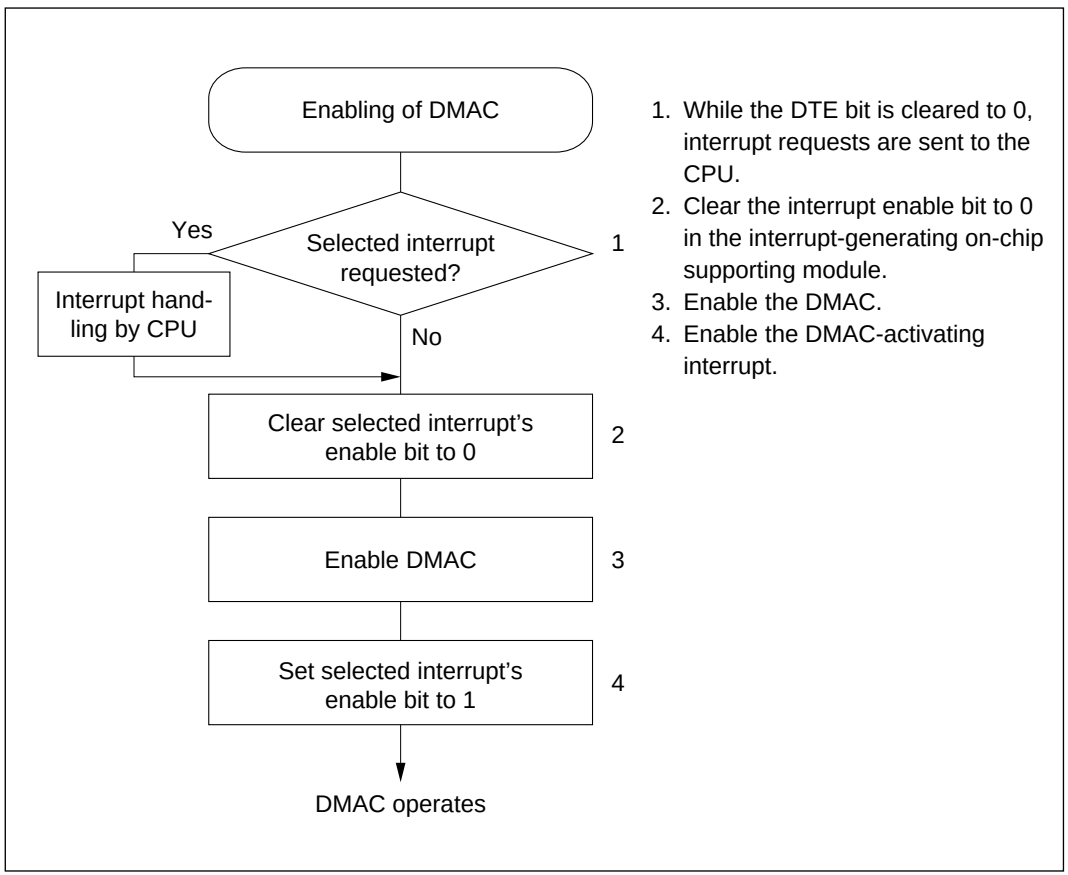


Figure 8-27 Procedure for Enabling DMAC while On-Chip Supporting Module is Operating (Example)

If the DTE bit is set to 1 but the DTME bit is cleared to 0, the DMAC is halted and the selected activating source cannot generate a CPU interrupt. If the DMAC is halted by an NMI interrupt, for example, the selected activating source cannot generate CPU interrupts. To terminate DMAC operations in this state, clear the DTE bit to 0 to allow CPU interrupts to be requested. To continue DMAC operations, carry out steps 2 and 4 in figure 8-27 before and after setting the DTME bit to 1.

When an ITU interrupt activates the DMAC, make sure the next interrupt does not occur before the DMA transfer ends. If one ITU interrupt activates two or more channels, make sure the next interrupt does not occur before the DMA transfers end on all the activated channels. If the next interrupt occurs before a transfer ends, the channel or channels for which that interrupt was selected may fail to accept further activation requests.

8.6.6 NMI Interrupts and Block Transfer Mode

If an NMI interrupt occurs in block transfer mode, the DMAC operates as follows.

- When the NMI interrupt occurs, the DMAC finishes transferring the current byte or word, then clears the DTME bit to 0 and halts. The halt may occur in the middle of a block.

  It is possible to find whether a transfer was halted in the middle of a block by checking the block size counter. If the block size counter does not have its initial value, the transfer was halted in the middle of a block.

- If the transfer is halted in the middle of a block, the activating interrupt flag is cleared to 0. The activation request is not held pending.

- While the DTE bit is set to 1 and the DTME bit is cleared to 0, the DMAC is halted and does not accept activating interrupt requests. If an activating interrupt occurs in this state, the DMAC does not operate and does not hold the transfer request pending internally. Neither is a CPU interrupt requested.

  For this reason, before setting the DTME bit to 1, first clear the enable bit of the activating interrupt to 0. Then, after setting the DTME bit to 1, set the interrupt enable bit to 1 again. See section 8.6.5, Note on Activating DMAC by Internal Interrupts.

- When the DTME bit is set to 1, the DMAC waits for the next transfer request. If it was halted in the middle of a block transfer, the rest of the block is transferred when the next transfer request occurs. Otherwise, the next block is transferred when the next transfer request occurs.

8.6.7 Memory and I/O Address Register Values

Table 8-14 indicates the address ranges that can be specified in the memory and I/O address registers (MAR and IOAR).

Table 8-14 Address Ranges Specifiable in MAR and IOAR

	1-Mbyte Mode	16-Mbyte Mode
MAR	H'00000 to H'FFFFF (0 to 1048575)	H'000000 to H'FFFFFF (0 to 16777215)
IOAR	H'FFF00 to H'FFFFF (1048320 to 1048575)	H'FFFF00 to H'FFFFFF (16776960 to 16777215)

MAR bits 23 to 20 are ignored in 1-Mbyte mode.

8.6.8 Bus Cycle when Transfer is Aborted

When a transfer is aborted by clearing the DTE bit or suspended by an NMI that clears the DTME bit, if this halts a channel for which the DMAC has a transfer request pending internally, a dead cycle occurs. This dead cycle does not update the halted channel's address register or counter value. Figure 8-28 shows an example in which an auto-requested transfer in cycle-steal mode on channel 0 is aborted by clearing the DTE bit in channel 0.

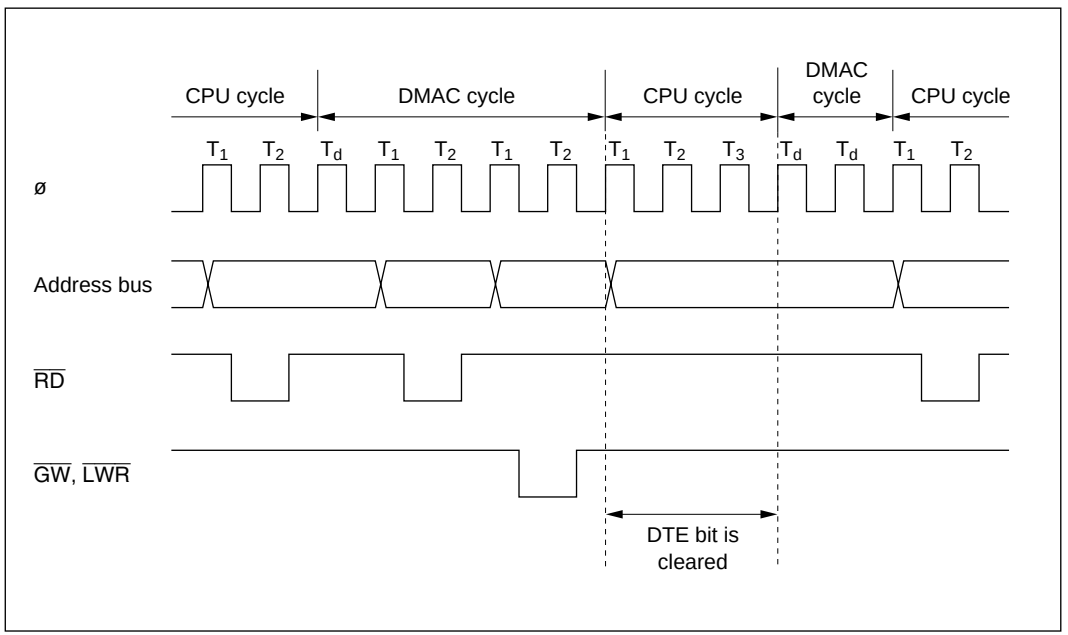


Figure 8-28 Bus Timing at Abort of DMA Transfer in Cycle-Steal Mode

Section 9 I/O Ports

9.1 Overview

The H8/3003 has eight input/output ports (ports 4, 5, 6, 8, 9, A, B, and C) and one input port (port 7). Table 9-1 summarizes the port functions. The pins in each port are multiplexed as shown in table 9-1.

Each port has a data direction register (DDR) for selecting input or output, and a data register (DR) for storing output data. In addition to their DDR and DR, ports 4 and 5 have an input pull-up control register (PCR) for switching input pull-up transistors on and off.

Ports 4, 5, 6, 8, and C can drive one TTL load and a 90-pF capacitive load. Ports 9, A, and B can drive one TTL load and a 30-pF capacitive load. Ports 4 to 6 and 8 to C can drive a Darlington pair. Ports 5 and B can drive LEDs (with 10-mA current sink). Ports $P8_2$ to $P8_0$, PA_7 to PA_0, and PB_3 to PB_0 have Schmitt-trigger input circuits.

For block diagrams of the ports see appendix C, I/O Port Block Diagrams.

Table 9-1 Port Functions

Port	Description	Pins	Mode 1 Mode 2 Mode 3 Mode 4
Port 4	8-bit I/O port Input pull-up	$P4_7$ to $P4_0$/D_7 to D_0	Data bus (D_7 to D_0) and 8-bit generic input/output 8-bit bus mode: generic input/output 16-bit bus mode: data bus
Port 5	4-bit I/O port Input pull-up Can drive LEDs	$P5_7$ to $P5_4$/A_{23} to A_{20}	Generic input/output Address output
Port 6	3-bit I/O port	$P6_2$/$\overline{BACK}$ $P6_1$/$\overline{BREQ}$ $P6_0$/$\overline{WAIT}$	Bus control signal input/output ($\overline{BACK}$, $\overline{BREQ}$, $\overline{WAIT}$) and 3-bit generic input/output
Port 7	8-bit input port	$P7_7$ to $P7_0$/AN_7 to AN_0	Analog input (AN_7 to AN_0) to A/D converter, and 8-bit generic input
Port 8	5-bit I/O port $P8_2$ to $P8_0$ have Schmitt inputs	$P8_4$/$\overline{CS_0}$	DDR = 0: generic input DDR = 1 (reset value): $\overline{CS_0}$ output
		$P8_3$/$\overline{CS_1}$/$\overline{IRQ_3}$ $P8_2$/$\overline{CS_2}$/$\overline{IRQ_2}$ $P8_1$/$\overline{CS_3}$/$\overline{IRQ_1}$	$\overline{IRQ_3}$ to $\overline{IRQ_1}$ input, $\overline{CS_1}$ to $\overline{CS_3}$ output, and generic input DDR = 0 (reset value): generic input DDR = 1: $\overline{CS_1}$ to $\overline{CS_3}$ output
		$P8_0$/$\overline{RFSH}$/$\overline{IRQ_0}$	$\overline{IRQ_0}$ input, $\overline{RFSH}$ output, and generic input/output
Port 9	6-bit I/O port	$P9_5$/SCK_1/$\overline{IRQ_5}$ $P9_4$/SCK_0/$\overline{IRQ_4}$ $P9_3$/RxD_1 $P9_2$/RxD_0 $P9_1$/TxD_1 $P9_0$/TxD_0	Input and output (SCK_1, SCK_0, RxD_1, RxD_0, TxD_1, TxD_0) for serial communication interfaces 1 and 0 (SCI1/0), $\overline{IRQ_5}$ and $\overline{IRQ_4}$ input, and 6-bit generic input/output

Table 9-1 Port Functions (cont)

Port	Description	Pins	Mode 1 Mode 2 Mode 3 Mode 4
Port A	8-bit I/O port Schmitt inputs	$PA_7/TP_7/TIOCB_2$ $PA_6/TP_6/TIOCA_2$ $PA_5/TP_5/TIOCB_1$ $PA_4/TP_4/TIOCA_1$ $PA_3/TP_3/TIOCB_0/TCLKD$ $PA_2/TP_2/TIOCA_0/TCLKC$ $PA_1/TP_1/\overline{TEND_1}/TCLKB$ $PA_0/TP_0/\overline{TEND_0}/TCLKA$	Output (TP_7 to TP_0) from programmable timing pattern controller (TPC), output ($\overline{TEND_1}$, $\overline{TEND_0}$) from DMA controller (DMAC), input and output (TCLKD, TCLKC, TCLKB, TCLKA, $TIOCB_2$, $TIOCA_2$, $TIOCB_1$, $TIOCA_1$, $TIOCB_0$, $TIOCA_0$) for 16-bit integrated timer unit (ITU), and 8-bit generic input/output
Port B	8-bit I/O port Can drive LEDs PB_3 to PB_0 have Schmitt inputs	$PB_7/TP_{15}/\overline{DREQ_1}/\overline{ADTRG}$ $PB_6/TP_{14}/\overline{DREQ_0}$ $PB_5/TP_{13}/TOCXB_4$ $PB_4/TP_{12}/TOCXA_4$ $PB_3/TP_{11}/TIOCB_4$ $PB_2/TP_{10}/TIOCA_4$ $PB_1/TP_9/TIOCB_3$ $PB_0/TP_8/TIOCB_3$	Output (TP_{15} to TP_8) from TPC, input ($\overline{DREQ_1}$ and $\overline{DREQ_0}$) to DMAC, trigger input ($\overline{ADTRG}$) to A/D converter, ITU input and output ($TOCXB_4$, $TOCXA_4$, $TIOCB_4$, $TIOCA_4$, $TIOCB_3$, $TIOCA_3$), and 8-bit generic input/output
Port C	8-bit I/O port	$PC_7/\overline{IRQ_7}$ $PC_6/\overline{IRQ_6}$ $PC_5/\overline{DREQ_3}/\overline{CS_7}$ $PC_4/\overline{TEND_3}/\overline{CS_6}$ $PC_3/\overline{DREQ_2}/\overline{CS_5}$ $PC_2/\overline{TEND_2}/\overline{CS_4}$ PC_1 PC_0	$\overline{IRQ_7}$ and $\overline{IRQ_6}$ input, $\overline{CS_7}$ to $\overline{CS_4}$ output, DMAC input and output ($\overline{DREQ_3}$, $\overline{TEND_3}$, $\overline{DREQ_2}$, $\overline{TEND_2}$), and 8-bit generic input/output

9.2 Port 4

9.2.1 Overview

Port 4 is an 8-bit input/output port with the pin configuration shown in figure 9-1. The pin functions differ between the 8-bit and 16-bit bus modes.

When the bus width control register (ABWCR) designates areas 0 to 7 all as 8-bit-access areas, the H8/3003 operates in 8-bit bus mode and port 4 is a generic input/output port. When at least one of areas 0 to 7 is designated as a 16-bit-access area, the H8/3003 operates in 16-bit bus mode and port 4 becomes the lower data bus.

Port 4 has software-programmable built-in pull-up transistors.

Pins in port 4 can drive one TTL load and a 90-pF capacitive load. They can also drive a darlington transistor pair.

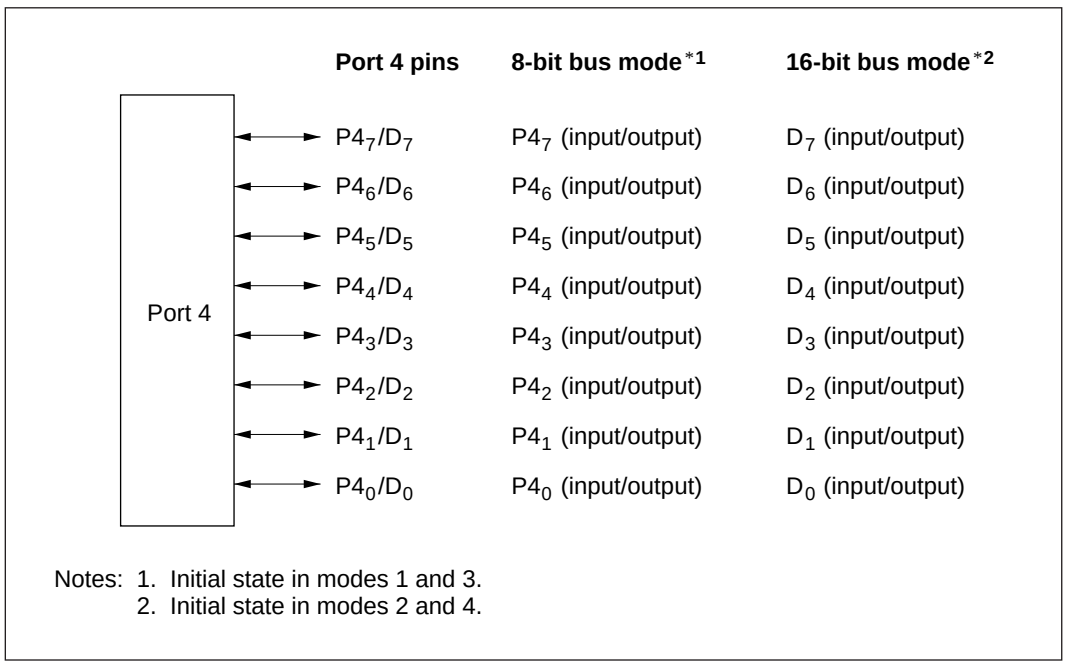


Figure 9-1 Port 4 Pin Configuration

9.2.2 Register Descriptions

Table 9-2 summarizes the registers of port 4.

Table 9-2 Port 4 Registers

Address*	Name	Abbreviation	R/W	Initial Value
H'FFC5	Port 4 data direction register	P4DDR	W	H'00
H'FFC7	Port 4 data register	P4DR	R/W	H'00
H'FFDA	Port 4 input pull-up control register	P4PCR	R/W	H'00

Note: * Lower 16 bits of the address.

Port 4 Data Direction Register (P4DDR): P4DDR is an 8-bit write-only register that can select input or output for each pin in port 4.

Bit	7	6	5	4	3	2	1	0
	$P4_7DDR$	$P4_6DDR$	$P4_5DDR$	$P4_4DDR$	$P4_3DDR$	$P4_2DDR$	$P4_1DDR$	$P4_0DDR$
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port 4 data direction 7 to 0
These bits select input or output for port 4 pins

8-Bit Bus Mode: When all areas are designated as 8-bit-access areas, selecting 8-bit bus mode, port 4 functions as a generic input/output port. A pin in port 4 becomes an output pin if the corresponding P4DDR bit is set to 1, and an input pin if this bit is cleared to 0.

16-Bit Bus Mode: When at least one area is designated as a 16-bit-access area, selecting 16-bit bus mode, port 4 functions as the lower data bus.

P4DDR is a write-only register. Its value cannot be read. All bits return 1 when read.

P4DDR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

ABWCR and P4DDR are not initialized in software standby mode. When port 4 functions as a generic input/output port, if a P4DDR bit is set to 1, the corresponding pin maintains its output state in software standby mode.

Port 4 Data Register (P4DR): P4DR is an 8-bit readable/writable register that stores data for pins $P4_7$ to $P4_0$.

Bit	7	6	5	4	3	2	1	0
	$P4_7DR$	$P4_6DR$	$P4_5DR$	$P4_4DR$	$P4_3DR$	$P4_2DR$	$P4_1DR$	$P4_0DR$
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Port 4 data 7 to 0
These bits store data for port 4 pins

When a bit in P4DDR is set to 1, if port 4 is read the value of the corresponding P4DR bit is returned directly, regardless of the actual state of the pin. When a bit in P4DDR is cleared to 0, if port 4 is read the corresponding pin level is read. This applies in both 8-bit and 16-bit bus modes.

P4DR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

Port 4 Input Pull-Up Control Register (P4PCR): P4PCR is an 8-bit readable/writable register that controls the MOS input pull-up transistors in port 4.

Bit	7	6	5	4	3	2	1	0
	$P4_7PCR$	$P4_6PCR$	$P4_5PCR$	$P4_4PCR$	$P4_3PCR$	$P4_2PCR$	$P4_1PCR$	$P4_0PCR$
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Port 4 input pull-up control 7 to 0
These bits control input pull-up transistors built into port 4

In 8-bit bus mode, when a P4DDR bit is cleared to 0 (selecting generic input), if the corresponding P4PCR bit is set to 1, the input pull-up transistor is turned on.

P4PCR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

9.2.3 Pin Functions in Each Mode

The functions of port 4 differ depending on whether 8-bit or 16-bit bus mode is selected by ABWCR settings. The pin functions in each mode are described below.

8-Bit Bus Mode: Input or output can be selected separately for each pin in port 4. A pin becomes an output pin if the corresponding P4DDR bit is set to 1 and an input pin if this bit is cleared to 0. Figure 9-2 shows the pin functions in 8-bit bus mode. This is the initial state in modes 1 and 3.

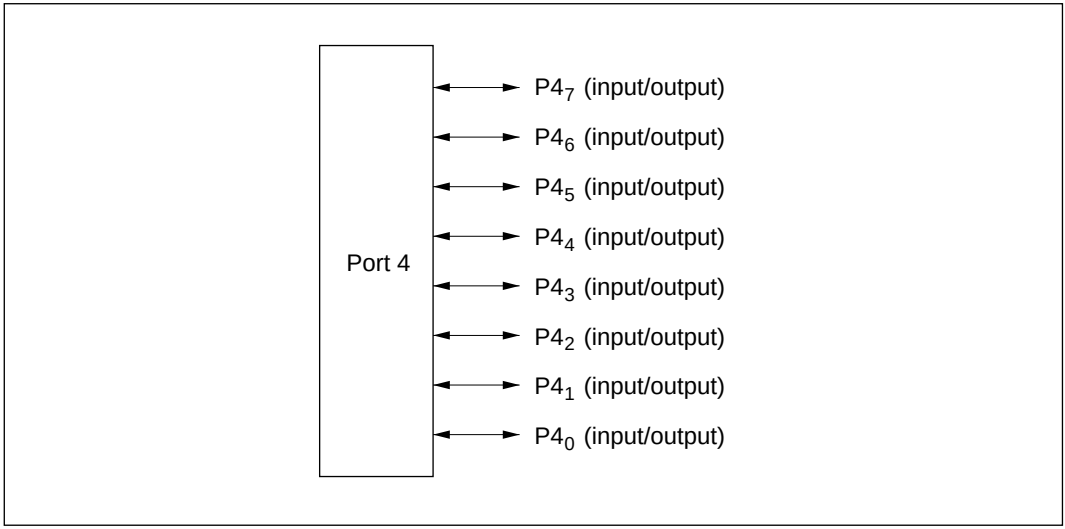


Figure 9-2 Pin Functions in 8-Bit Bus Mode (Port 4)

16-Bit Bus Mode: The input/output settings in P4DDR are ignored. Port 4 automatically becomes a bidirectional data bus. Figure 9-3 shows the pin functions in 16-bit bus mode. This is the initial state in modes 2 and 4.

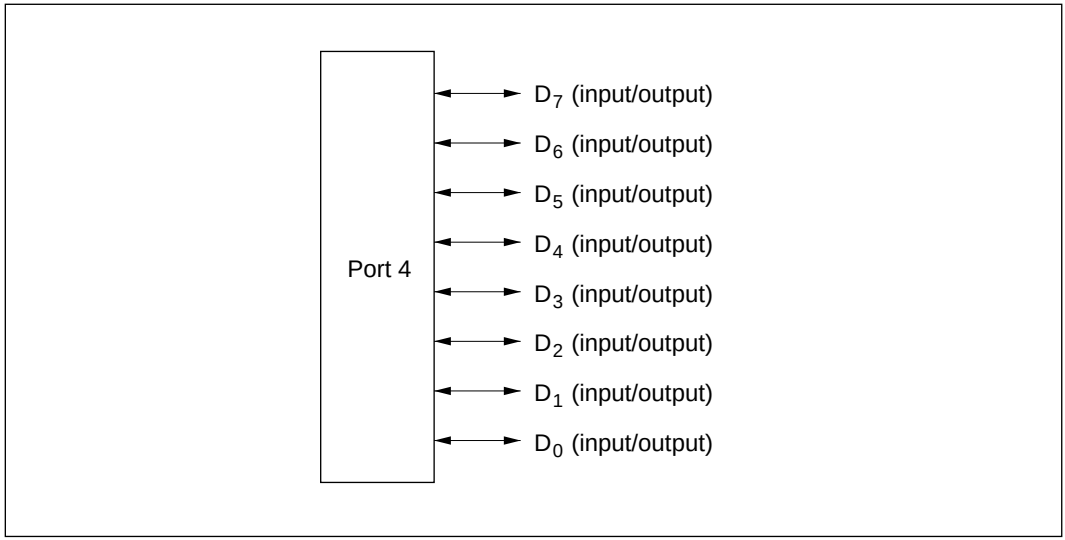


Figure 9-3 Pin Functions in 16-Bit Bus Mode (Port 4)

9.2.4 Input Pull-Up Transistors

Port 4 has built-in MOS input pull-up transistors that can be controlled by software. These input pull-up transistors can be used in 8-bit bus mode. They can be turned on and off individually.

In 8-bit bus mode, when a P4PCR bit is set to 1 and the corresponding P4DDR bit is cleared to 0, the input pull-up transistor is turned on.

The input pull-up transistors are turned off by a reset and in hardware standby mode. In software standby mode they retain their previous state.

Table 9-3 summarizes the states of the input pull-ups in the 8-bit and 16-bit bus modes.

Table 9-3 Input Pull-Up Transistor States (Port 4)

Mode	Reset	Hardware Standby Mode	Software Standby Mode	Other Modes
8-bit bus mode	Off		On/off	
16-bit bus mode			Off	

Legend
Off: The input pull-up transistor is always off.
On/off: The input pull-up transistor is on if P4PCR = 1 and P4DDR = 0. Otherwise, it is off.

9.3 Port 5

9.3.1 Overview

Port 5 is a 4-bit input/output port with the pin configuration shown in figure 9-4. The pin functions differ depending on the operating mode.

In modes 1 and 2, port 5 is a generic input/output port. In modes 3 and 4, port 5 is used for address output.

Port 5 has software-programmable built-in pull-up transistors.

Pins in port 5 can drive one TTL load and a 90-pF capacitive load. They can also drive an LED or a darlington transistor pair.

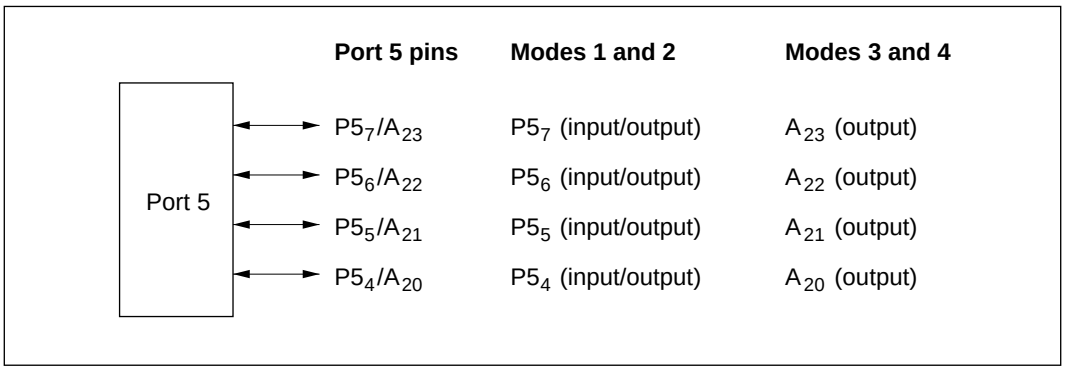


Figure 9-4 Port 5 Pin Configuration

9.3.2 Register Descriptions

Table 9-4 summarizes the registers of port 5.

Table 9-4 Port 5 Registers

				Initial Value	
Address*	**Name**	**Abbreviation**	**R/W**	**Mode 1/2**	**Mode 3/4**
H'FFC8	Port 5 data direction register	P5DDR	W	H'0F	H'FF
H'FFCA	Port 5 data register	P5DR	R/W	H'00	
H'FFDB	Port 5 input pull-up control register	P5PCR	R/W	H'00	

Note: * Lower 16 bits of the address.

Port 5 Data Direction Register (P5DDR): P5DDR is an 8-bit write-only register that can select input or output for each pin in port 5.

Bit		7	6	5	4	3	2	1	0
		$P5_7DDR$	$P5_6DDR$	$P5_5DDR$	$P5_4DDR$	$P5_3DDR$	$P5_2DDR$	$P5_1DDR$	$P5_0DDR$
Mode 1/2	Initial value	0	0	0	0	1	1	1	1
	Read/Write	W	W	W	W	—	—	—	—
Mode 3/4	Initial value	1	1	1	1	1	1	1	1
	Read/Write	—	—	—	—	—	—	—	—

Port 5 data direction 7 to 4
These bits select input or output for port 5 pins

Reserved bits

Modes 1 and 2 (1-Mbyte Modes): Port 5 functions as a generic input/output port. A pin in port 5 becomes an output pin if the corresponding P5DDR bit is set to 1, and an input pin if this bit is cleared to 0.

Modes 3 and 4 (16-Mbyte Modes): All P5DDR bits are fixed at 1 and port 5 functions as part of the address bus. Bits $P5_3DDR$ to $P5_0DDR$ are reserved and are also fixed at 1. No bit values can be modified.

In modes 1 and 2, P5DDR is a write-only register. Its value cannot be read. All bits return 1 when read.

P5DDR is initialized to H'0F by a reset and in hardware standby mode. In software standby mode it retains its previous setting, so if a P5DDR bit is set to 1, the corresponding pin maintains its output state in software standby mode.

Port 5 Data Register (P5DR): P5DR is an 8-bit readable/writable register that stores data for pins $P5_7$ to $P5_4$.

Bit	7	6	5	4	3	2	1	0
	$P5_7$	$P5_6$	$P5_5$	$P5_4$	$P5_3$	$P5_2$	$P5_1$	$P5_0$
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Port 5 data 7 to 4
These bits store data for port 5 pins

Reserved bits

When a bit in P5DDR is set to 1, if port 5 is read the value of the corresponding P5DR bit is returned directly, regardless of the actual state of the pin. When a bit in P5DDR is cleared to 0, if port 5 is read the corresponding pin level is read.

Bits $P5_3$ to $P5_0$ are reserved. They can be written and read, but they cannot be used for port input or output.

P5DR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

Port 5 Input Pull-Up Control Register (P5PCR): P5PCR is an 8-bit readable/writable register that controls the MOS input pull-up transistors in port 5.

Bit	7	6	5	4	3	2	1	0
	$P5_7$PCR	$P5_6$PCR	$P5_5$PCR	$P5_4$PCR	$P5_3$PCR	$P5_2$PCR	$P5_1$PCR	$P5_0$PCR
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Port 5 input pull-up control 7 to 4
These bits control input pull-up transistors built into port 5

Reserved bits

In modes 1 and 2, when a P5DDR bit is cleared to 0 (selecting generic input), if the corresponding bit from $P5_7$PCR to $P5_4$PCR is set to 1, the input pull-up transistor is turned on.

Bits $P5_3$PCR to $P5_0$PCR are reserved. They can be written and read, but they do not control input pull-up transistors.

P5PCR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

9.3.3 Pin Functions in Each Mode

The functions of port 5 differ between modes 1 and 2 (1-Mbytes modes) and modes 3 and 4 (16-Mbyte modes). The pin functions in each mode are described below.

Pin Functions in Modes 1 and 2 (1-Mbytes Modes): Input or output can be selected separately for each pin in port 5. A pin becomes an output pin if the corresponding P5DDR bit is set to 1 and an input pin if this bit is cleared to 0. Figure 9-5 shows the pin functions in modes 1 and 2.

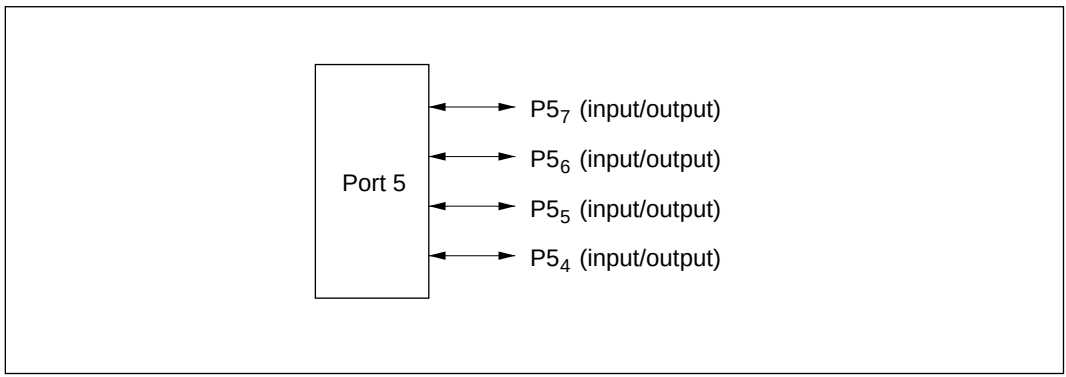


Figure 9-5 Pin Functions in Modes 1 and 2 (Port 5)

Pin Functions in Modes 3 and 4 (16-Mbytes Modes): The pins in port 5 are automatically used for address output. Figure 9-6 shows the pin functions in modes 3 and 4.

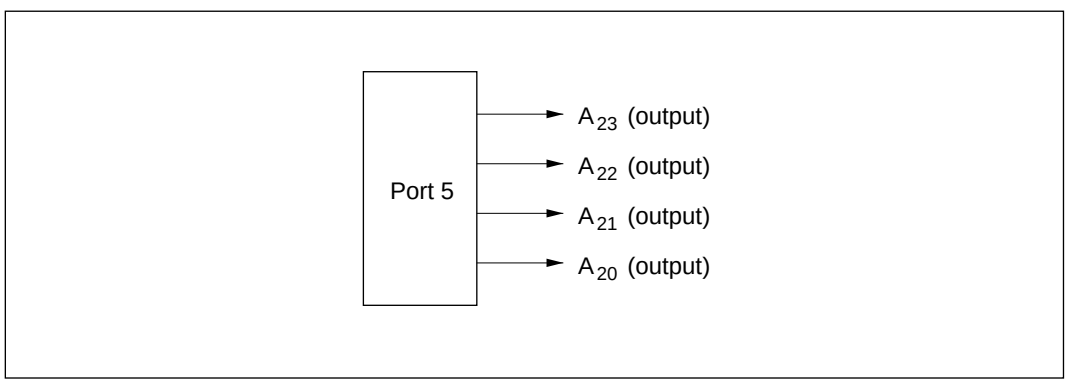


Figure 9-6 Pin Functions in Modes 3 and 4 (Port 5)

9.3.4 Input Pull-Up Transistors

Port 5 has built-in MOS pull-up transistors that can be controlled by software. These input pull-up transistors can be used in modes 1 and 2. They can be turned on and off individually.

In modes 1 and 2, when a P5PCR bit is set to 1 and the corresponding P5DDR bit is cleared to 0, the input pull-up transistor is turned on.

The input pull-up transistors are turned off by a reset and in hardware standby mode. In software standby mode they retain their previous state.

Table 9-5 summarizes the states of the input pull-ups in each mode.

Table 9-5 Input Pull-Up Transistor States (Port 5)

Mode	Reset	Hardware Standby Mode	Software Standby Mode	Other Modes
1 2	Off		On/off	
3 4			Off	

Legend
Off: The input pull-up transistor is always off.
On/off: The input pull-up transistor is on if P5PCR = 1 and P5DDR = 0. Otherwise, it is off.

9.4 Port 6

9.4.1 Overview

Port 6 is a 3-bit input/output port that is also used for input and output of bus control signals ($\overline{\text{BACK}}$, $\overline{\text{BREQ}}$, and $\overline{\text{WAIT}}$). Port 6 has the same set of pin functions in all operating modes. Figure 9-7 shows the pin configuration of port 6.

Pins in port 6 can drive one TTL load and a 90-pF capacitive load. They can also drive a darlington transistor pair.

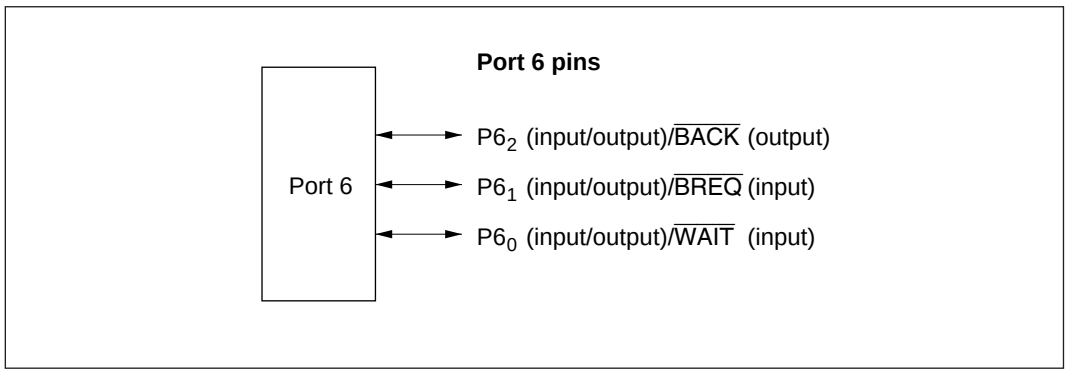


Figure 9-7 Port 6 Pin Configuration

9.4.2 Register Descriptions

Table 9-6 summarizes the registers of port 6.

Table 9-6 Port 6 Registers

Address*	Name	Abbreviation	R/W	Initial Value
H'FFC9	Port 6 data direction register	P6DDR	W	H'80
H'FFCB	Port 6 data register	P6DR	R/W	H'80

Note: * Lower 16 bits of the address.

Port 6 Data Direction Register (P6DDR): P6DDR is an 8-bit write-only register that can select input or output for each pin in port 6.

Bit	7	6	5	4	3	2	1	0
	—	$P6_6DDR$	$P6_5DDR$	$P6_4DDR$	$P6_3DDR$	$P6_2DDR$	$P6_1DDR$	$P6_0DDR$
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	W	W	W	W	W	W	W

Reserved bits

Port 6 data direction 2 to 0
These bits select input or output for port 6 pins

A pin in port 6 becomes an output pin if the corresponding P6DDR bit is set to 1, and an input pin if this bit is cleared to 0. Bits 7 to 3 are reserved.

P6DDR is a write-only register. Its value cannot be read. All bits return 1 when read.

P6DDR is initialized to H'80 by a reset and in hardware standby mode. In software standby mode it retains its previous setting, so if a P6DDR bit is set to 1, the corresponding pin maintains its output state in software standby mode.

Port 6 Data Register (P6DR): P6DR is an 8-bit readable/writable register that stores data for pins $P6_2$ to $P6_0$.

Bit	7	6	5	4	3	2	1	0
	—	$P6_6$	$P6_5$	$P6_4$	$P6_3$	$P6_2$	$P6_1$	$P6_0$
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Reserved bits

Port 6 data 2 to 0
These bits store data for port 6 pins

When a bit in P6DDR is set to 1, if port 6 is read the value of the corresponding P6DR bit is returned directly. When a bit in P6DDR is cleared to 0, if port 6 is read the corresponding pin level is read. In this case bit 7 reads 1 and bits 6 to 3 have undetermined values. Bits 7 to 3 are reserved. Bits 6 to 3 can be written and read, but they cannot be used for port input or output.
Bit 7 cannot be modified and always reads 1.

P6DR is initialized to H'80 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

9.4.3 Pin Functions

The port 6 pins are also used for $\overline{\text{BACK}}$ output and $\overline{\text{BREQ}}$ and $\overline{\text{WAIT}}$ input. Table 9-7 describes the selection of pin functions.

Table 9-7 Port 6 Pin Functions

<table>
<tr><th>Pin</th><th>Pin Functions and Selection Method</th></tr>
<tr><td>P6₂/$\overline{\text{BACK}}$</td><td>Bit BRLE in BRCR and bit P6₂DDR select the pin function as follows
<table>
<tr><td>BRLE</td><td colspan="2">0</td><td>1</td></tr>
<tr><td>P6₂DDR</td><td>0</td><td>1</td><td>—</td></tr>
<tr><td>Pin function</td><td>P6₂ input</td><td>P6₂ output</td><td>$\overline{\text{BACK}}$ output</td></tr>
</table></td></tr>
<tr><td>P6₁/$\overline{\text{BREQ}}$</td><td>Bit BRLE in BRCR and bit P6₁DDR select the pin function as follows
<table>
<tr><td>BRLE</td><td colspan="2">0</td><td>1</td></tr>
<tr><td>P6₁DDR</td><td>0</td><td>1</td><td>—</td></tr>
<tr><td>Pin function</td><td>P6₁ input</td><td>P6₁ output</td><td>$\overline{\text{BREQ}}$ input</td></tr>
</table></td></tr>
<tr><td>P6₀/$\overline{\text{WAIT}}$</td><td>Bits WCE7 to WCE0 in WCER, bit WMS1 in WCR, and bit P6₀DDR select the pin function as follows
<table>
<tr><td>WCER</td><td colspan="2">All 1s</td><td colspan="2">Not all 1s</td></tr>
<tr><td>WMS1</td><td colspan="2">0</td><td>1</td><td>—</td></tr>
<tr><td>P6₀DDR</td><td>0</td><td>1</td><td>0*</td><td>0*</td></tr>
<tr><td>Pin function</td><td>P6₀ input</td><td>P6₀ output</td><td colspan="2">$\overline{\text{WAIT}}$ input</td></tr>
</table></td></tr>
</table>

Note: * Do not set bit P6₀DDR to 1.

9.5 Port 7

9.5.1 Overview

Port 7 is an 8-bit input port that is also used for analog input to the A/D converter. Port 7 has the same set of pin functions in all operating modes. Figure 9-8 shows the pin configuration of port 7.

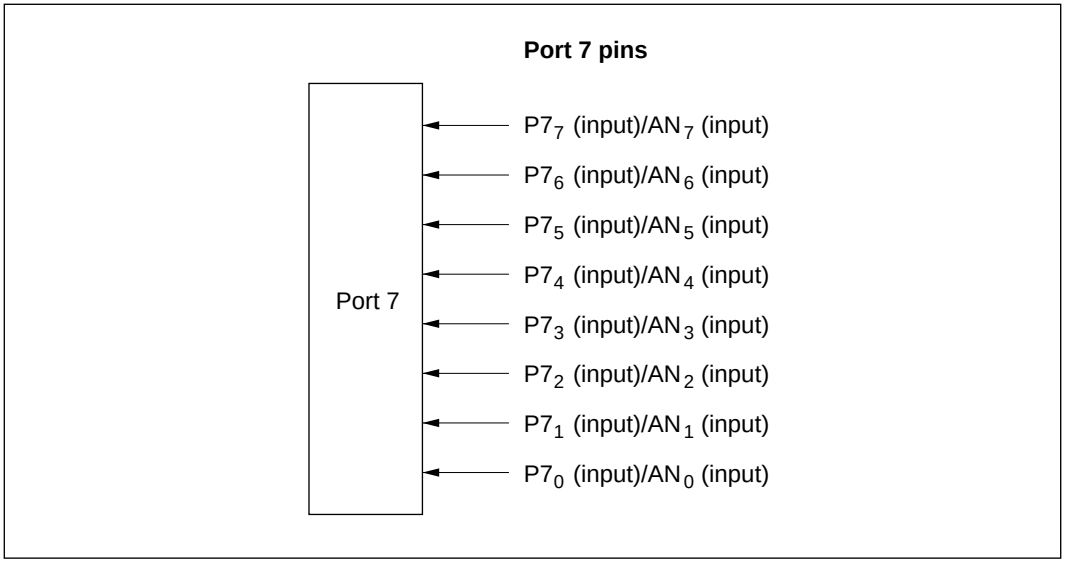


Figure 9-8 Port 7 Pin Configuration

9.5.2 Register Description

Table 9-8 summarizes the port 7 register. Port 7 is an input-only port, so it has no data direction register.

Table 9-8 Port 7 Register

Address*	Name	Abbreviation	R/W	Initial Value
H'FFCE	Port 7 data register	P7DR	R	Undetermined

Note: * Lower 16 bits of the address.

Port 7 Data Register (P7DR)

Bit	7	6	5	4	3	2	1	0
	P7$_7$	P7$_6$	P7$_5$	P7$_4$	P7$_3$	P7$_2$	P7$_1$	P7$_0$
Initial value	—*	—*	—*	—*	—*	—*	—*	—*
Read/Write	R	R	R	R	R	R	R	R

Note: * Determined by pins P7$_7$ to P7$_0$.

When port 7 is read, the pin levels are always read.

9.6 Port 8

9.6.1 Overview

Port 8 is a 5-bit input/output port that is also used for $\overline{CS_3}$ to $\overline{CS_0}$ output, $\overline{RFSH}$ output, and $\overline{IRQ_3}$ to $\overline{IRQ_0}$ input. Port 8 has the same set of pin functions in all operating modes. Figure 9-9 shows the pin configuration of port 8.

Pins in port 8 can drive one TTL load and a 90-pF capacitive load. They can also drive a darlington transistor pair. Pins $P8_2$ to $P8_0$ have Schmitt-trigger inputs.

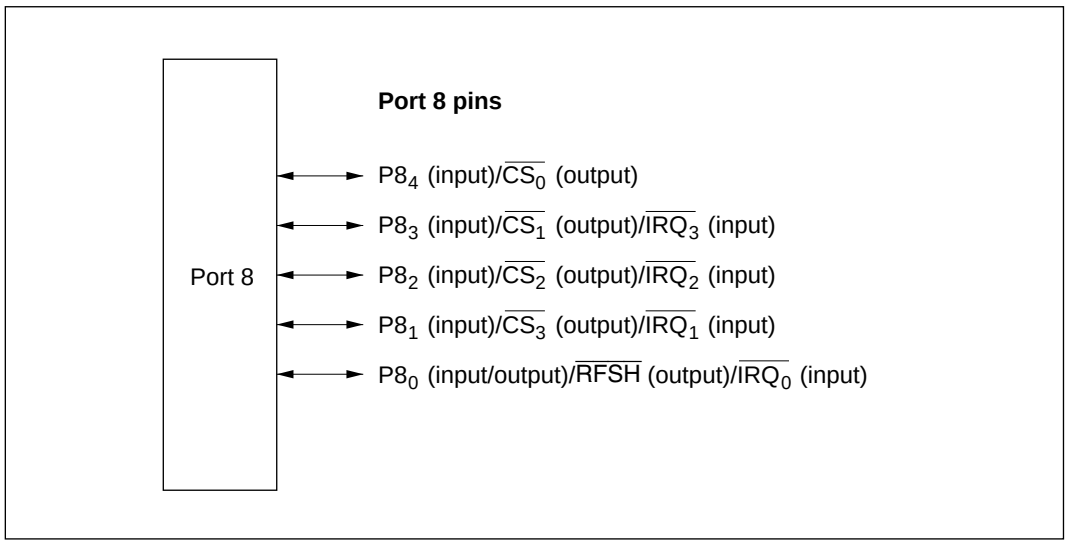


Figure 9-9 Port 8 Pin Configuration

9.6.2 Register Descriptions

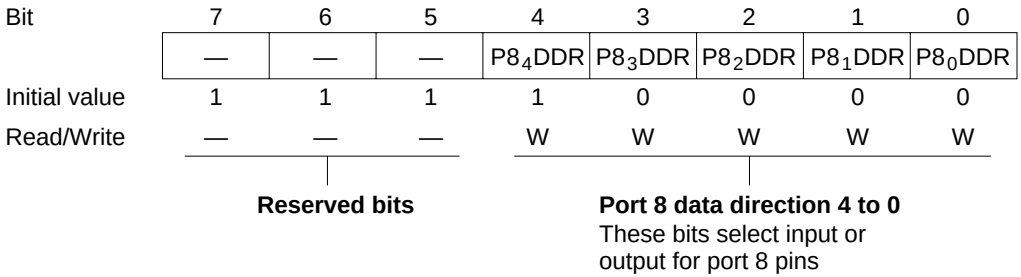
Table 9-9 summarizes the registers of port 8.

Table 9-9 Port 8 Registers

Address*	Name	Abbreviation	R/W	Initial Value
H'FFCD	Port 8 data direction register	P8DDR	W	H'F0
H'FFCF	Port 8 data register	P8DR	R/W	H'E0

Note: * Lower 16 bits of the address.

Port 8 Data Direction Register (P8DDR): P8DDR is an 8-bit write-only register that can select input or output for each pin in port 8.

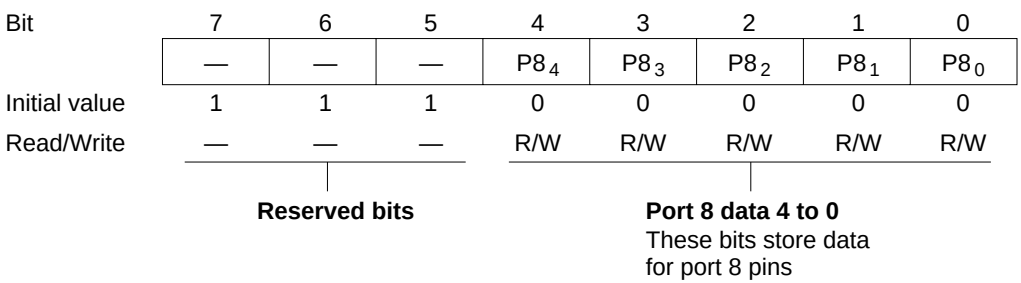


When bits in P8DDR bit are set to 1, $P8_4$ to $P8_1$ become $\overline{CS_0}$ to $\overline{CS_3}$ output pins and $P8_0$ becomes a generic output pin. When bits in P8DDR are cleared to 0, the corresponding pins become input pins.

P8DDR is a write-only register. Its value cannot be read. All bits return 1 when read.

P8DDR is initialized to H'F0 by a reset and in hardware standby mode. In software standby mode it retains its previous setting, so if a P8DDR bit is set to 1, the corresponding pin maintains its output state in software standby mode.

Port 8 Data Register (P8DR): P8DR is an 8-bit readable/writable register that stores data for pins $P8_4$ to $P8_0$.



When a bit in P8DDR is set to 1, if port 8 is read the value of the corresponding P8DR bit is returned directly. When a bit in P8DDR is cleared to 0, if port 8 is read the corresponding pin level is read.

Bits 7 to 5 are reserved. They cannot be modified and always read 1.

P8DR is initialized to H'E0 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

9.6.3 Pin Functions

The port 8 pins are also used for $\overline{CS_3}$ to $\overline{CS_0}$ and $\overline{RFSH}$ output and $\overline{IRQ_3}$ to $\overline{IRQ_0}$ input. Table 9-10 describes the selection of pin functions.

Table 9-10 Port 8 Pin Functions

Pin	Pin Functions and Selection Method
$P8_4/\overline{CS_0}$	Bit $P8_4$DDR selects the pin function as follows

$P8_4$DDR	0	1
Pin function	$P8_4$ input	$\overline{CS_0}$ output

$P8_3/\overline{CS_1}/\overline{IRQ_3}$	Bit $P8_3$DDR selects the pin function as follows

$P8_3$DDR	0	1
Pin function	$P8_3$ input	$\overline{CS_1}$ output
	$\overline{IRQ_3}$ input	

$P8_2/\overline{CS_2}/\overline{IRQ_2}$	Bit $P8_2$DDR selects the pin function as follows

$P8_2$DDR	0	1
Pin function	$P8_2$ input	$\overline{CS_2}$ output
	$\overline{IRQ_2}$ input	

$P8_1/\overline{CS_3}/\overline{IRQ_1}$	Bit $P8_1$DDR selects the pin function as follows

$P8_1$DDR	0	1
Pin function	$P8_1$ input	$\overline{CS_3}$ output
	$\overline{IRQ_1}$ input	

$P8_0/\overline{RFSH}/\overline{IRQ_0}$	Bit RFSHE in RFSHCR and bit $P8_0$DDR select the pin function as follows

RFSHE	0		1
$P8_0$DDR	0	1	—
Pin function	$P8_0$ input	$P8_0$ output	$\overline{RFSH}$ output
	$\overline{IRQ_0}$ input		

9.7 Port 9

9.7.1 Overview

Port 9 is a 6-bit input/output port that is also used for input and output (TxD_0, TxD_1, RxD_0, RxD_1, SCK_0, SCK_1) by serial communication interface channels 0 and 1 (SCI_0 and SCI_1), and for $\overline{IRQ_5}$ and $\overline{IRQ_4}$ input. Port 9 has the same set of pin functions in all operating modes. Figure 9-10 shows the pin configuration of port 9.

Pins in port 9 can drive one TTL load and a 30-pF capacitive load. They can also drive a darlington transistor pair.

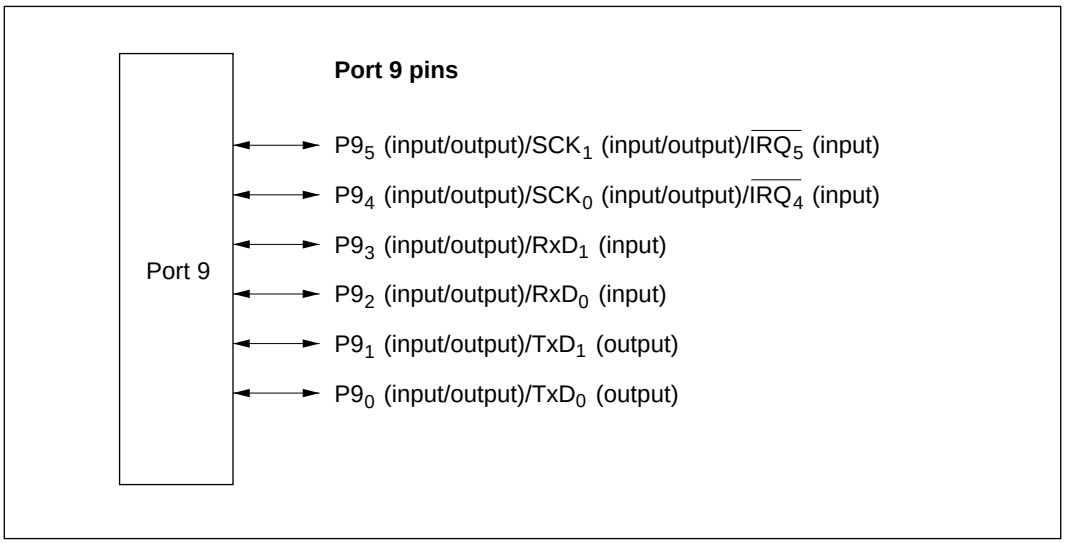


Figure 9-10 Port 9 Pin Configuration

9.7.2 Register Descriptions

Table 9-11 summarizes the registers of port 9.

Table 9-11 Port 9 Registers

Address*	Name	Abbreviation	R/W	Initial Value
H'FFD0	Port 9 data direction register	P9DDR	W	H'C0
H'FFD2	Port 9 data register	P9DR	R/W	H'C0

Note: * Lower 16 bits of the address.

Port 9 Data Direction Register (P9DDR): P9DDR is an 8-bit write-only register that can select input or output for each pin in port 9.

Bit	7	6	5	4	3	2	1	0
	—	—	$P9_5DDR$	$P9_4DDR$	$P9_3DDR$	$P9_2DDR$	$P9_1DDR$	$P9_0DDR$
Initial value	1	1	0	0	0	0	0	0
Read/Write	—	—	W	W	W	W	W	W

Reserved bits

Port 9 data direction 5 to 0
These bits select input or output for port 9 pins

A pin in port 9 becomes an output pin if the corresponding P9DDR bit is set to 1, and an input pin if this bit is cleared to 0.

P9DDR is a write-only register. Its value cannot be read. All bits return 1 when read.

P9DDR is initialized to H'C0 by a reset and in hardware standby mode. In software standby mode it retains its previous setting, so if a P9DDR bit is set to 1, the corresponding pin maintains its output state in software standby mode.

Port 9 Data Register (P9DR): P9DR is an 8-bit readable/writable register that stores data for pins $P9_5$ to $P9_0$.

Bit	7	6	5	4	3	2	1	0
	—	—	$P9_5$	$P9_4$	$P9_3$	$P9_2$	$P9_1$	$P9_0$
Initial value	1	1	0	0	0	0	0	0
Read/Write	—	—	R/W	R/W	R/W	R/W	R/W	R/W

Reserved bits

Port 9 data 5 to 0
These bits store data for port 9 pins

When a bit in P9DDR is set to 1, if port 9 is read the value of the corresponding P9DR bit is returned directly. When a bit in P9DDR is cleared to 0, if port 9 is read the corresponding pin level is read.

Bits 7 and 6 are reserved. They cannot be modified and always read 1.

P9DR is initialized to H'C0 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

9.7.3 Pin Functions

The port 9 pins are also used for SCI0 and SCI1 input and output (TxD_0, RxD_0, SCK_0, TxD_1, RxD_1, SCK_1), and for $\overline{IRQ_5}$ and $\overline{IRQ_4}$ input. Table 9-12 describes the selection of pin functions.

Table 9-12 Port 9 Pin Functions

Pin	Pin Functions and Selection Method
$P9_5/SCK_1/\overline{IRQ_5}$	Bit C/$\overline{A}$ in SMR of SCI1, bits CKE0 and CKE1 in SCR of SCI1, and bit $P9_5$DDR select the pin function as follows

CKE1	0				1
C/$\overline{A}$	0			1	—
CKE0	0		1	—	—
$P9_5$DDR	0	1	—	—	—
Pin function	$P9_5$ input	$P9_5$ output	SCK_1 output	SCK_1 output	SCK_1 input
	$\overline{IRQ_5}$ input				

$P9_4/SCK_0/\overline{IRQ_4}$	Bit C/$\overline{A}$ in SMR of SCI0, bits CKE0 and CKE1 in SCR of SCI0, and bit $P9_4$DDR select the pin function as follows

CKE1	0				1
C/$\overline{A}$	0			1	—
CKE0	0		1	—	—
$P9_4$DDR	0	1	—	—	—
Pin function	$P9_4$ input	$P9_4$ output	SCK_0 output	SCK_0 output	SCK_0 input
	$\overline{IRQ_4}$ input				

Table 9-12 Port 9 Pin Functions (cont)

Pin	Pin Functions and Selection Method
$P9_3/RxD_1$	Bit RE in SCR of SCI1 and bit $P9_3$DDR select the pin function as follows

RE	0		1
$P9_3$DDR	0	1	—
Pin function	$P9_3$ input	$P9_3$ output	RxD_1 input

$P9_2/RxD_0$	Bit RE in SCR of SCI0 and bit $P9_2$DDR select the pin function as follows

RE	0		1
$P9_2$DDR	0	1	—
Pin function	$P9_2$ input	$P9_2$ output	RxD_0 input

$P9_1/TxD_1$	Bit TE in SCR of SCI1 and bit $P9_1$DDR select the pin function as follows

TE	0		1
$P9_1$DDR	0	1	—
Pin function	$P9_1$ input	$P9_1$ output	TxD_1 output

$P9_0/TxD_0$	Bit TE in SCR of SCI0 and bit $P9_0$DDR select the pin function as follows

TE	0		1
$P9_0$DDR	0	1	—
Pin function	$P9_0$ input	$P9_0$ output	TxD_0 output

9.8 Port A

9.8.1 Overview

Port A is an 8-bit input/output port that is also used for output (TP_7 to TP_0) from the programmable timing pattern controller (TPC), input and output ($TIOCB_2$, $TIOCA_2$, $TIOCB_1$, $TIOCA_1$, $TIOCB_0$, $TIOCA_0$, TCLKD, TCLKC, TCLKB, TCLKA) by the 16-bit integrated timer-pulse unit (ITU), and output ($\overline{TEND_1}$, $\overline{TEND_0}$) from the DMA controller (DMAC). Port A has the same set of pin functions in all operating modes. Figure 9-11 shows the pin configuration of port A.

Pins in port A can drive one TTL load and a 30-pF capacitive load. They can also drive a darlington transistor pair. Port A has Schmitt-trigger inputs.

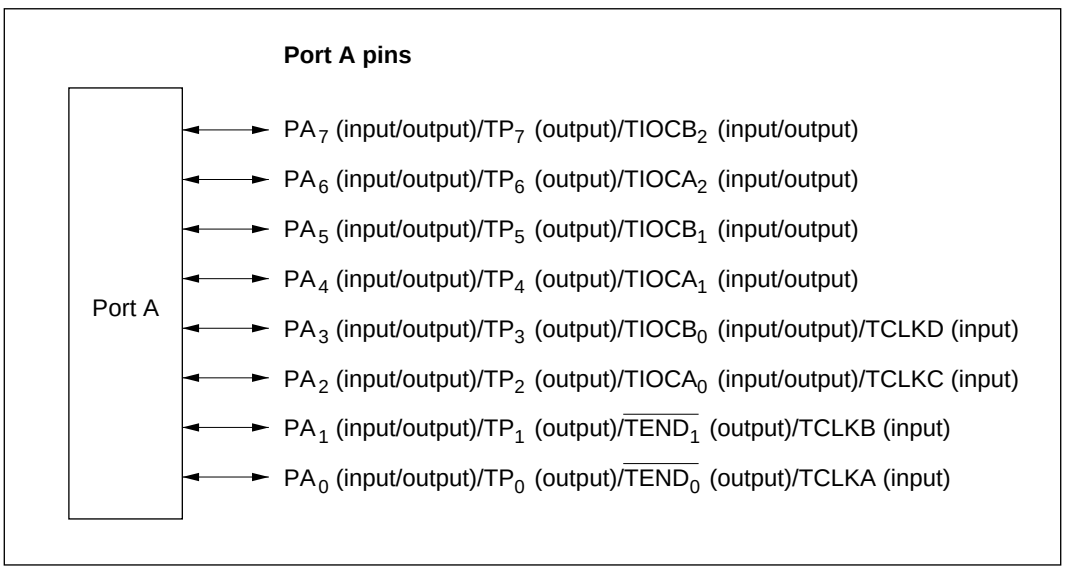


Figure 9-11 Port A Pin Configuration

9.8.2 Register Descriptions

Table 9-13 summarizes the registers of port A.

Table 9-13 Port A Registers

Address*	Name	Abbreviation	R/W	Initial Value
H'FFD1	Port A data direction register	PADDR	W	H'00
H'FFD3	Port A data register	PADR	R/W	H'00

Note: * Lower 16 bits of the address.

Port A Data Direction Register (PADDR): PADDR is an 8-bit write-only register that can select input or output for each pin in port A.

Bit	7	6	5	4	3	2	1	0
	PA_7DDR	PA_6DDR	PA_5DDR	PA_4DDR	PA_3DDR	PA_2DDR	PA_1DDR	PA_0DDR
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port A data direction 7 to 0
These bits select input or output for port A pins

A pin in port A becomes an output pin if the corresponding PADDR bit is set to 1, and an input pin if this bit is cleared to 0.

PADDR is a write-only register. Its value cannot be read. All bits return 1 when read.

PADDR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting, so if a PADDR bit is set to 1, the corresponding pin maintains its output state in software standby mode.

Port A Data Register (PADR): PADR is an 8-bit readable/writable register that stores data for pins PA_7 to PA_0.

Bit	7	6	5	4	3	2	1	0
	PA_7	PA_6	PA_5	PA_4	PA_3	PA_2	PA_1	PA_0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Port A data 7 to 0
These bits store data for port A pins

When a bit in PADDR is set to 1, if port A is read the value of the corresponding PADR bit is returned directly. When a bit in PADDR is cleared to 0, if port A is read the corresponding pin level is read.

PADR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

9.8.3 Pin Functions

The port A pins are also used for TPC output (TP_7 to TP_0), ITU input/output ($TIOCB_2$ to $TIOCB_0$, $TIOCA_2$ to $TIOCA_0$) and input (TCLKD, TCLKC, TCLKB, TCLKA), and DMAC output ($\overline{TEND_1}$, $\overline{TEND_0}$). Table 9-14 describes the selection of pin functions.

Table 9-14 Port A Pin Functions

<table>
<tr><th>Pin</th><th>Pin Functions and Selection Method</th></tr>
<tr><td>$PA_7/TP_7/TIOCB_2$</td><td>ITU channel 2 settings (bit PWM2 in TMDR and bits IOB2 to IOB0 in TIOR2), bit NDER7 in NDERA, and bit PA_7DDR in PADDR select the pin function as follows
<table>
<tr><td>ITU channel 2 settings</td><td>1 in table below</td><td colspan="3">2 in table below</td></tr>
<tr><td>PA_7DDR</td><td>—</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>NDER7</td><td>—</td><td>—</td><td>0</td><td>1</td></tr>
<tr><td rowspan="2">Pin function</td><td rowspan="2">$TIOCB_2$ output</td><td>PA_7 input</td><td>PA_7 output</td><td>TP_7 output</td></tr>
<tr><td colspan="3">$TIOCB_2$ input*</td></tr>
</table>
Note: * $TIOCB_2$ input when IOB2 = 1 and PWM2 = 0.
<table>
<tr><td>ITU channel 2 settings</td><td>2</td><td colspan="2">1</td><td>2</td></tr>
<tr><td>IOB2</td><td colspan="3">0</td><td>1</td></tr>
<tr><td>IOB1</td><td>0</td><td>0</td><td>1</td><td>—</td></tr>
<tr><td>IOB0</td><td>0</td><td>1</td><td>—</td><td>—</td></tr>
</table>
</td></tr>
</table>

Table 9-14 Port A Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PA_6/TP_6/TIOCA_2$	ITU channel 2 settings (bit PWM2 in TMDR and bits IOA2 to IOA0 in TIOR2), bit NDER6 in NDERA, and bit PA_6DDR in PADDR select the pin function as follows

ITU channel 2 settings	1 in table below	2 in table below		
PA_6DDR	—	0	1	1
NDER6	—	—	0	1
Pin function	$TIOCA_2$ output	PA_6 input	PA_6 output	TP_6 output
		$TIOCA_2$ input*		

Note: * $TIOCA_2$ input when IOA2 = 1.

ITU channel 2 settings	2	1		2	1
PWM2	0				1
IOA2	0			1	—
IOA1	0	0	1	—	—
IOA0	0	1	—	—	—

$PA_5/TP_5/TIOCB_1$	ITU channel 1 settings (bit PWM1 in TMDR and bits IOB2 to IOB0 in TIOR1), bit NDER5 in NDERA, and bit PA_5DDR in PADDR select the pin function as follows

ITU channel 2 settings	1 in table below	2 in table below		
PA_5DDR	—	0	1	1
NDER5	—	—	0	1
Pin function	$TIOCB_1$ output	PA_5 input	PA_5 output	TP_5 output
		$TIOCB_1$ input*		

Note: * $TIOCB_1$ input when IOB2 = 1 and PWM1 = 0.

ITU channel 1 settings	2	1		2
IOB2	0			1
IOB1	0	0	1	—
IOB0	0	1	—	—

Table 9-14 Port A Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PA_4/TP_4/TIOCA_1$	ITU channel 1 settings (bit PWM1 in TMDR and bits IOA2 to IOA0 in TIOR1), bit NDER4 in NDERA, and bit PA_4DDR in PADDR select the pin function as follows

ITU channel 1 settings	1 in table below	2 in table below		
PA_4DDR	—	0	1	1
NDER4	—	—	0	1
Pin function	$TIOCA_1$ output	PA_4 input	PA_4 output	TP_4 output
		$TIOCA_1$ input*		

Note: * $TIOCA_1$ input when IOA2 = 1.

ITU channel 1 settings	2	1		2	1
PWM1	0				1
IOA2	0			1	—
IOA1	0	0	1	—	—
IOA0	0	1	—	—	—

$PA_3/TP_3/TIOCB_0$/ TCLKD	ITU channel 0 settings (bit PWM0 in TMDR and bits IOB2 to IOB0 in TIOR0), bits TPSC2 to TPSC0 in timer control registers 4 to 0 (TCR4 to TCR0), bit NDER3 in NDERA, and bit PA_3DDR in PADDR select the pin function as follows

ITU channel 0 settings	1 in table below	2 in table below		
PA_3DDR	—	0	1	1
NDER3	—	—	0	1
Pin function	$TIOCB_0$ output	PA_3 input	PA_3 output	TP_3 output
		$TIOCB_0$ input*1		
	TCLKD input*2			

Notes: 1. $TIOCB_0$ input when IOB2 = 1 and PWM0 = 0.
2. TCLKD input when TPSC2 = TPSC1 = TPSC0 = 1 in any of TCR4 to TCR0.

ITU channel 0 settings	2	1		2
IOB2	0			1
IOB1	0	0	1	—
IOB0	0	1	—	—

Table 9-14 Port A Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PA_2/TP_2/TIOCA_0$/ TCLKC	ITU channel 0 settings (bit PWM0 in TMDR and bits IOA2 to IOA0 in TIOR0), bits TPSC2 to TPSC0 in TCR4 to TCR0, bit NDER2 in NDERA, and bit PA_2DDR in PADDR select the pin function as follows

ITU channel 0 settings	1 in table below	2 in table below		
PA_2DDR	—	0	1	1
NDER2	—	—	0	1
Pin function	$TIOCA_0$ output	PA_2 input	PA_2 output	TP_2 output
	$TIOCA_0$ input*1 and TCLKC input*2			

Notes: 1. $TIOCA_0$ input when IOA2 = 1.
2. TCLKC input when TPSC2 = TPSC1 = 1 and TPSC0 = 0 in any of TCR4 to TCR0.

ITU channel 0 settings	2	1		2	1
PWM0	0				1
IOA2	0			1	—
IOA1	0	0	1	—	—
IOA0	0	1	—	—	—

Table 9-14 Port A Pin Functions (cont)

Pin	Pin Functions and Selection Method
$\overline{PA_1/TP_1}$/TCLKB/ $\overline{TEND_1}$	DMAC channel 1 settings (bits DTS2/1/0A and DTS2/1/0B in DTCR1A and DTCR1B), bit NDER1 in NDERA, and bit PA_1DDR in PADDR select the pin function as follows

DMAC channel 1 settings	1 in table below	2 in table below		
PA_1DDR	—	0	1	1
NDER1	—	—	0	1
Pin function	$\overline{TEND_1}$ output	PA_1 input	PA_1 output	TP_1 output
	TCLKB input*			

Note: * TCLKB input when MDF = 1 in TMDR, or when TPSC2 = 1, TPSC1 = 0, and TPSC0 = 1 in any of TCR4 to TCR0.

DMAC channel 1 settings	2		1	2	1	2		1
DTS2A, DTS1A	Not both 1			Both 1				
DTS0A	—			0	0	1	1	1
DTS2B	0	1	1	0	1	0	1	1
DTS1B	—	0	1	—	—	—	0	1

$\overline{PA_0/TP_0}$/TCLKA/ $\overline{TEND_0}$	DMAC channel 0 settings (bits DTS2/1/0A and DTS2/1/0B in DTCR0A and DTCR0B), bit NDER0 in NDERA, and bit PA_0DDR in PADDR select the pin function as follows

DMAC channel 0 settings	1 in table below	2 in table below		
PA_0DDR	—	0	1	1
NDER0	—	—	0	1
Pin function	$\overline{TEND_0}$ output	PA_0 input	PA_0 output	TP_0 output
	TCLKA input*			

Note: * TCLKA input when MDF = 1 in TMDR, or when TPSC2 = 1 and TPSC1 = 0 in any of TCR4 to TCR0.

DMAC channel 0 settings	2		1	2	1	2		1
DTS2A, DTS1A	Not both 1			Both 1				
DTS0A	—			0	0	1	1	1
DTS2B	0	1	1	0	1	0	1	1
DTS1B	—	0	1	—	—	—	0	1

9.9 Port B

9.9.1 Overview

Port B is an 8-bit input/output port that is also used for output (TP_{15} to TP_8) from the programmable timing pattern controller (TPC), input/output ($TIOCB_4$, $TIOCB_3$, $TIOCA_4$, $TIOCA_3$) and output ($TOCXB_4$, $TOCXA_4$) by the 16-bit integrated timer-pulse unit (ITU), input ($\overline{DREQ_1}$, $\overline{DREQ_0}$) to the DMA controller (DMAC), and $\overline{ADTRG}$ input to the A/D converter. Port B has the same set of pin functions in all operating modes. Figure 9-12 shows the pin configuration of port B.

Pins in port B can drive one TTL load and a 30-pF capacitive load. They can also drive a darlington transistor pair. Pins PB_3 to PB_0 have Schmitt-trigger inputs.

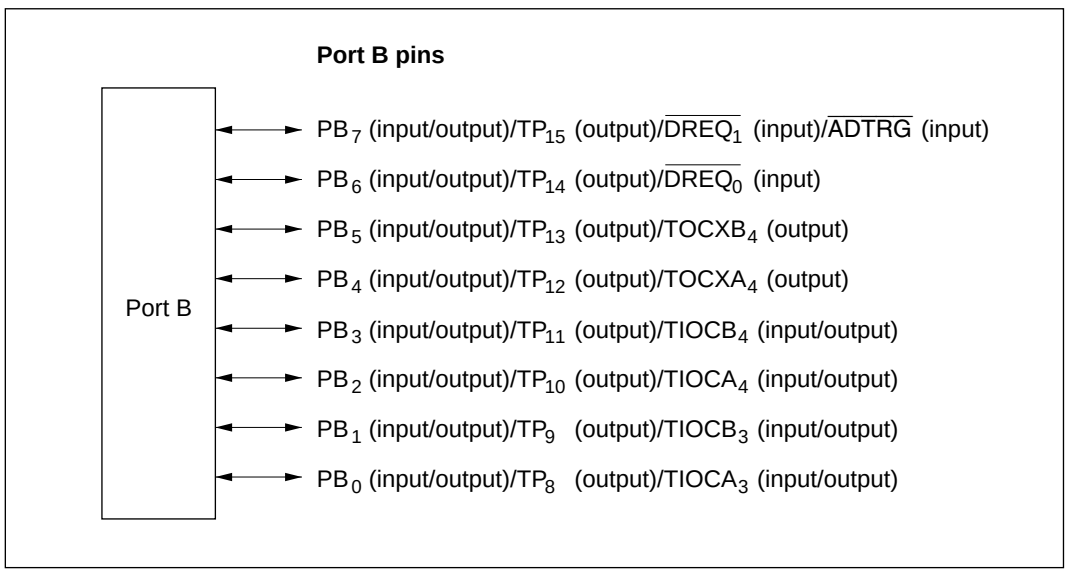


Figure 9-12 Port B Pin Configuration

9.9.2 Register Descriptions

Table 9-15 summarizes the registers of port B.

Table 9-15 Port B Registers

Address*	Name	Abbreviation	R/W	Initial Value
H'FFD4	Port B data direction register	PBDDR	W	H'00
H'FFD6	Port B data register	PBDR	R/W	H'00

Note: * Lower 16 bits of the address.

Port B Data Direction Register (PBDDR): PBDDR is an 8-bit write-only register that can select input or output for each pin in port B.

Bit	7	6	5	4	3	2	1	0
	PB_7DDR	PB_6DDR	PB_5DDR	PB_4DDR	PB_3DDR	PB_2DDR	PB_1DDR	PB_0DDR
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port B data direction 7 to 0
These bits select input or output for port B pins

A pin in port B becomes an output pin if the corresponding PBDDR bit is set to 1, and an input pin if this bit is cleared to 0.

PBDDR is a write-only register. Its value cannot be read. All bits return 1 when read.

PBDDR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting, so if a PBDDR bit is set to 1, the corresponding pin maintains its output state in software standby mode.

Port B Data Register (PBDR): PBDR is an 8-bit readable/writable register that stores data for pins PB_7 to PB_0.

Bit	7	6	5	4	3	2	1	0
	PB_7	PB_6	PB_5	PB_4	PB_3	PB_2	PB_1	PB_0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Port B data 7 to 0
These bits store data for port B pins

When a bit in PBDDR is set to 1, if port B is read the value of the corresponding PBDR bit is returned directly. When a bit in PBDDR is cleared to 0, if port B is read the corresponding pin level is read.

PBDR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

9.9.3 Pin Functions

The port B pins are also used for TPC output (TP_{15} to TP_8), ITU input/output ($TIOCB_4$, $TIOCB_3$, $TIOCA_4$, $TIOCA_3$) and output ($TOCXB_4$, $TOCXA_4$), DMAC input ($\overline{DREQ_1}$, $\overline{DREQ_0}$), and $\overline{ADTRG}$ input. Table 9-16 describes the selection of pin functions.

Table 9-16 Port B Pin Functions

Pin	Pin Functions and Selection Method
$PB_7/TP_{15}/\overline{DREQ_1}/\overline{ADTRG}$	DMAC channel 1 settings (bits DTS2/1/0A and DTS2/1/0B in DTCR1A and DTCR1B), bit TRGE in ADCR, bit NDER15 in NDERB, and bit PB_7DDR in PBDDR select the pin function as follows

PB_7DDR	0	1	1
NDER15	—	0	1
Pin function	PB_7 input	PB_7 output	TP_{15} output
	$\overline{DREQ_1}$ input*1		
	$\overline{ADTRG}$ input*2		

Notes: 1. $\overline{DREQ_1}$ input under DMAC channel 1 settings 1 in the table below.
2. $\overline{ADTRG}$ input when TRGE = 1.

DMAC channel 1 settings	2		1	2	1	2	2	1
DTS2A, DTS1A	Not both 1			Both 1				
DTS0A	—			0	0	1	1	1
DTS2B	0	1	1	0	1	0	1	1
DTS1B	—	0	1	—	—	—	0	1

Table 9-16 Port B Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PB_6/TP_{14}/\overline{DREQ_0}$	DMAC channel 0 settings (bits DTS2/1/0A and DTS2/1/0B in DTCR0A and DTCR0B), bit NDER14 in NDERB, and bit PB_6DDR in PBDDR select the pin function as follows

PB_6DDR	0	1	1
NDER14	—	0	1
Pin function	PB_6 input	PB_6 output	TP_{14} output
	$\overline{DREQ_0}$ input*		

Note: * $\overline{DREQ_0}$ input under DMAC channel 0 settings 1 in the table below.

DMAC channel 0 settings	2		1	2	1	2	2	1
DTS2A, DTS1A	Not both 1			Both 1				
DTS0A	—			0	0	1	1	1
DTS2B	0	1	1	0	1	0	1	1
DTS1B	—	0	1	—	—	—	0	1

$PB_5/TP_{13}/TOCXB_4$	ITU channel 4 settings (bit CMD1 in TFCR and bit EXB4 in TOER), bit NDER13 in NDERB, and bit PB_5DDR in PBDDR select the pin function as follows

EXB4, CMD1	Not both 1			Both 1
PB_5DDR	0	1	1	—
NDER13	—	0	1	—
Pin function	PB_5 input	PB_5 output	TP_{13} output	$TOCXB_4$ output

$PB_4/TP_{12}/TOCXA_4$	ITU channel 4 settings (bit CMD1 in TFCR and bit EXA4 in TOER), bit NDER12 in NDERB, and bit PB_4DDR in PBDDR select the pin function as follows

EXA4, CMD1	Not both 1			Both 1
PB_4DDR	0	1	1	—
NDER12	—	0	1	—
Pin function	PB_4 input	PB_4 output	TP_{12} output	$TOCXA_4$ output

Table 9-16 Port B Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PB_3/TP_{11}/TIOCB_4$	ITU channel 4 settings (bit PWM4 in TMDR, bit CMD1 in TFCR, bit EB4 in TOER, and bits IOB2 to IOB0 in TIOR4), bit NDER11 in NDERB, and bit PB_3DDR in PBDDR select the pin function as follows

ITU channel 4 settings	1 in table below	2 in table below		
PB_3DDR	—	0	1	1
NDER11	—	—	0	1
Pin function	$TIOCB_4$ output	PB_3 input	PB_3 output	TP_{11} output
		$TIOCB_4$ input*		

Note: * $TIOCB_4$ input when CMD1 = PWM4 = 0 and IOB2 = 1.

ITU channel 4 settings	2	2	1		2	1
EB4	0	1				
CMD1	—	0				1
IOB2	—	0	0	0	1	—
IOB1	—	0	0	1	—	—
IOB0	—	0	1	—	—	—

Table 9-16 Port B Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PB_2/TP_{10}/TIOCA_4$	ITU channel 4 settings (bit CMD1 in TFCR, bit EA4 in TOER, bit PWM4 in TMDR, and bits IOA2 to IOA0 in TIOR4), bit NDER10 in NDERB, and bit PB_2DDR in PBDDR select the pin function as follows

ITU channel 4 settings	1 in table below	2 in table below		
PB_2DDR	—	0	1	1
NDER10	—	—	0	1
Pin function	$TIOCA_4$ output	PB_2 input	PB_2 output	TP_{10} output
		$TIOCA_4$ input*		

Note: * $TIOCA_4$ input when CMD1 = PWM4 = 0 and IOA2 = 1.

ITU channel 4 settings	2	2	1		2	1	
EA4	0	1					
CMD1	—	0					1
PWM4	—	0				1	—
IOA2	—	0	0	0	1	—	—
IOA1	—	0	0	1	—	—	—
IOA0	—	0	1	—	—	—	—

Table 9-16 Port B Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PB_1/TP_9/TIOCB_3$	ITU channel 3 settings (bit PWM3 in TMDR, bit CMD1 in TFCR, bit EB3 in TOER, and bits IOB2 to IOB0 in TIOR3), bit NDER9 in NDERB, and bit PB_1DDR in PBDDR select the pin function as follows

ITU channel 3 settings	1 in table below	2 in table below		
PB_1DDR	—	0	1	1
NDER9	—	—	0	1
Pin function	$TIOCB_3$ output	PB_1 input	PB_1 output	TP_9 output
		$TIOCB_3$ input*		

Note: * $TIOCB_3$ input when CMD1 = PWM3 = 0 and IOB2 = 1.

ITU channel 3 settings	2	2	1		2	1
EB3	0	1				
CMD1	—	0				1
IOB2	—	0	0	0	1	—
IOB1	—	0	0	1	—	—
IOB0	—	0	1	—	—	—

Table 9-16 Port B Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PB_0/TP_8/TIOCA_3$	ITU channel 3 settings (bit CMD1 in TFCR, bit EA3 in TOER, bit PWM3 in TMDR, and bits IOA2 to IOA0 in TIOR3), bit NDER8 in NDERB, and bit PB_0DDR in PBDDR select the pin function as follows

ITU channel 3 settings	1 in table below	2 in table below		
PB_0DDR	—	0	1	1
NDER8	—	—	0	1
Pin function	$TIOCA_3$ output	PB_0 input	PB_0 output	TP_8 output
		$TIOCA_3$ input*		

Note: * $TIOCA_3$ input when CMD1 = PWM3 = 0 and IOA2 = 1.

ITU channel 3 settings	2	2	1		2	1	
EA3	0	1					
CMD1	—	0					1
PWM3	—	0				1	—
IOA2	—	0	0	0	1	—	—
IOA1	—	0	0	1	—	—	—
IOA0	—	0	1	—	—	—	—

9.10 Port C

9.10.1 Overview

Port C is an 8-bit input/output port that is also used for DMAC input and output ($\overline{DREQ_3}$, $DREQ_2$, $\overline{TEND_3}$, $\overline{TEND_2}$), $\overline{CS_7}$ to $\overline{CS_4}$ output, and IRQ_7 and $\overline{IRQ_6}$ input. Port C has the same set of pin functions in all operating modes. Figure 9-13 shows the pin configuration of port C.

Pins in port C can drive one TTL load and a 90-pF capacitive load. They can also drive a darlington transistor pair.

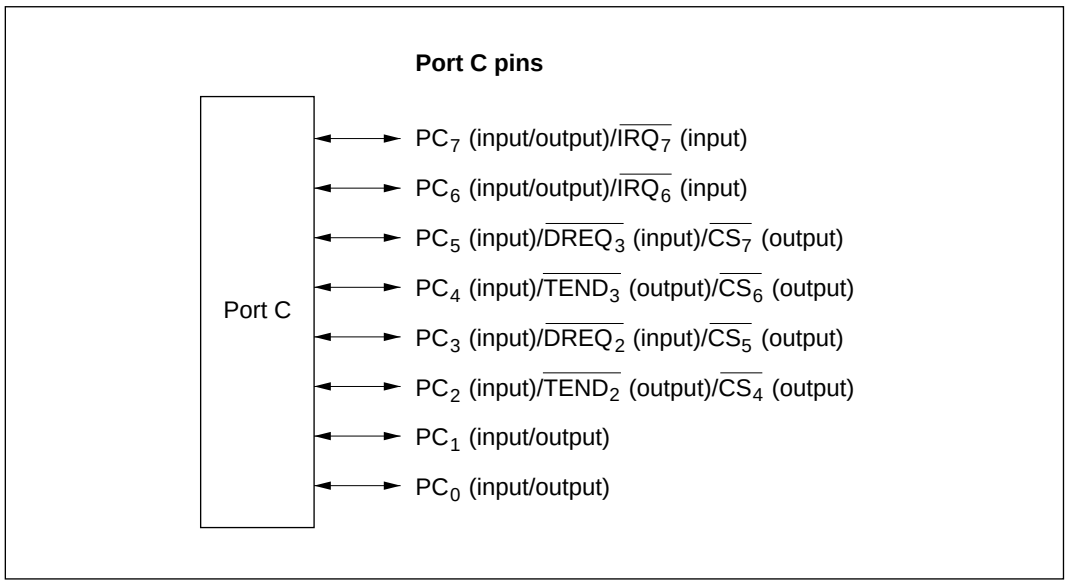


Figure 9-13 Port C Pin Configuration

9.10.2 Register Descriptions

Table 9-17 summarizes the registers of port C.

Table 9-17 Port C Registers

Address*	Name	Abbreviation	R/W	Initial Value
H'FFD5	Port C data direction register	PCDDR	W	H'00
H'FFD7	Port C data register	PCDR	R/W	H'00

Note: * Lower 16 bits of the address.

Port C Data Direction Register (PCDDR): PCDDR is an 8-bit write-only register that can select input or output for each pin in port C.

Bit	7	6	5	4	3	2	1	0
	PC_7DDR	PC_6DDR	PC_5DDR	PC_4DDR	PC_3DDR	PC_2DDR	PC_1DDR	PC_0DDR
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port C data direction 7 to 0
These bits select input or output for port C pins

When bits in PCDDR are set to 1, pins PC_7, PC_6, PC_1, and PC_0 become generic output pins and pins PC_5 to PC_2 become $\overline{CS_7}$ to $\overline{CS_4}$ output pins. When bits in PCDDR are cleared to 0, the corresponding pins become input pins.

PCDDR is a write-only register. Its value cannot be read. All bits return 1 when read.

PCDDR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting, so if a PCDDR bit is set to 1, the corresponding pin maintains its output state in software standby mode.

Port C Data Register (PCDR): PCDR is an 8-bit readable/writable register that stores data for pins PC_7 to PC_0.

Bit	7	6	5	4	3	2	1	0
	PC_7	PC_6	PC_5	PC_4	PC_3	PC_2	PC_1	PC_0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Port C data 7 to 0
These bits store data for port C pins

When a bit in PCDDR is set to 1, if port C is read the value of the corresponding PCDR bit is returned directly. When a bit in PCDDR is cleared to 0, if port C is read the corresponding pin level is read.

PCDR is initialized to H'00 by a reset and in hardware standby mode. In software standby mode it retains its previous setting.

9.10.3 Pin Functions

The port C pins are also used for DMA controller input and output ($\overline{DREQ_3}$, $\overline{TEND_3}$, $\overline{DREQ_2}$, $\overline{TEND_2}$), $\overline{CS_7}$ to $\overline{CS_4}$ output, and $\overline{IRQ_7}$ and $\overline{IRQ_6}$ input. Table 9-18 describes the selection of functions of pins PC_7 to PC_2.

Table 9-18 Port C Pin Functions

<table>
<tr><th>Pin</th><th>Pin Functions and Selection Method</th></tr>
<tr><td>$PC_7/\overline{IRQ_7}$</td><td>Bit PC_7DDR selects the pin function as follows
<table>
<tr><td>PC_7DDR</td><td>0</td><td>1</td></tr>
<tr><td>Pin function</td><td>PC_7 input</td><td>PC_7 output</td></tr>
<tr><td></td><td colspan="2">$\overline{IRQ_7}$ input</td></tr>
</table></td></tr>
<tr><td>$PC_6/\overline{IRQ_6}$</td><td>Bit PC_6DDR selects the pin function as follows
<table>
<tr><td>PC_6DDR</td><td>0</td><td>1</td></tr>
<tr><td>Pin function</td><td>PC_6 input</td><td>PC_6 output</td></tr>
<tr><td></td><td colspan="2">$\overline{IRQ_6}$ input</td></tr>
</table></td></tr>
<tr><td>$PC_5/\overline{DREQ_3}/\overline{CS_7}$</td><td>DMAC channel 3 settings (bits DTS2/1/0A and DTS2/1/0B in DTCR3A and DTCR3B) and bit PC_5DDR in PCDDR select the pin function as follows
<table>
<tr><td>PC_5DDR</td><td>0</td><td>1</td></tr>
<tr><td>Pin function</td><td>PC_5 input</td><td>$\overline{CS_7}$ output</td></tr>
<tr><td></td><td colspan="2">$\overline{DREQ_3}$ input*</td></tr>
</table>
Note: * $\overline{DREQ_3}$ input under DMAC channel 3 settings 1 in the table below.
<table>
<tr><td>DMAC channel 3 settings</td><td colspan="2">2</td><td>1</td><td>2</td><td>1</td><td colspan="2">2</td><td>1</td></tr>
<tr><td>DTS2A, DTS1A</td><td colspan="3">Not both 1</td><td colspan="5">Both 1</td></tr>
<tr><td>DTS0A</td><td colspan="3">—</td><td>0</td><td>0</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>DTS2B</td><td>0</td><td>1</td><td>1</td><td>0</td><td>1</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>DTS1B</td><td>—</td><td>0</td><td>1</td><td>—</td><td>—</td><td>—</td><td>0</td><td>1</td></tr>
</table></td></tr>
</table>

Table 9-18 Port C Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PC_4/\overline{TEND_3}/\overline{CS_6}$	DMAC channel 3 settings (bits DTS2/1/0A and DTS2/1/0B in DTCR3A and DTCR3B) and bit PC_4DDR in PCDDR select the pin function as follows

DMAC channel 3 settings	1 in table below	2 in table below		3 in table below
PC_4DDR	—	0	1	—
Pin function	$\overline{TEND_3}$ output	PC_4 input	$\overline{CS_6}$ output	Not usable

DMAC channel 3 settings	2		1	2	3	1	2		1
DTS2A, DTS1A	Not both 1			Both 1					
DTS0A	—			0	0		1	1	1
DTS2B	0	1	1	0	1		0	1	1
DTS1B	—	0	1	—	0	1	—	0	1

$PC_3/\overline{DREQ_2}/\overline{CS_5}$	DMAC channel 2 settings (bits DTS2/1/0A and DTS2/1/0B in DTCR2A and DTCR2B) and bit PC_3DDR in PCDDR select the pin function as follows

PC_3DDR	0	1
Pin function	PC_3 input	$\overline{CS_5}$ output
	$\overline{DREQ_2}$ input*	

Note: * $\overline{DREQ_2}$ input under DMAC channel 2 settings 1 in the table below.

DMAC channel 2 settings	2		1	2	1	2		1
DTS2A, DTS1A	Not both 1			Both 1				
DTS0A	—			0	0	1	1	1
DTS2B	0	1	1	0	1	0	1	1
DTS1B	—	0	1	—	—	—	0	1

Table 9-18 Port C Pin Functions (cont)

Pin	Pin Functions and Selection Method
$PC_2/\overline{TEND_2}/\overline{CS_4}$	DMAC channel 2 settings (bits DTS2/1/0A and DTS2/1/0B in DTCR2A and DTCR2B) and bit PC_2DDR in PCDDR select the pin function as follows

DMAC channel 2 settings	1 in table below	2 in table below	
PC_2DDR	—	0	1
Pin function	$\overline{TEND_2}$ output	PC_2 input	$\overline{CS_4}$ output

DMAC channel 2 settings	2		1	2	1	2		1
DTS2A, DTS1A	Not both 1			Both 1				
DTS0A	—			0	0	1	1	1
DTS2B	0	1	1	0	1	0	1	1
DTS1B	—	0	1	—	—	—	0	1

Section 10 16-Bit Integrated Timer Unit (ITU)

10.1 Overview

The H8/3003 has a built-in 16-bit integrated timer unit (ITU) with five 16-bit timer channels.

10.1.1 Features

ITU features are listed below.

- Capability to process up to 12 pulse outputs or 10 pulse inputs
- Ten general registers (GRs, two per channel) with independently-assignable output compare or input capture functions
- Selection of eight counter clock sources for each channel:

  Internal clocks: ø, ø/2, ø/4, ø/8
  External clocks: TCLKA, TCLKB, TCLKC, TCLKD
- Five operating modes selectable in all channels:
  - — Waveform output by compare match

    Selection of 0 output, 1 output, or toggle output (only 0 or 1 output in channel 2)
  - — Input capture function

    Rising edge, falling edge, or both edges (selectable)
  - — Counter clearing function

    Counters can be cleared by compare match or input capture
  - — Synchronization

    Two or more timer counters (TCNTs) can be preset simultaneously, or cleared simultaneously by compare match or input capture. Counter synchronization enables synchronous register input and output.

— PWM mode

PWM output can be provided with an arbitrary duty cycle. With synchronization, up to five-phase PWM output is possible

- Phase counting mode selectable in channel 2

  Two-phase encoder output can be counted automatically.

- Three additional modes selectable in channels 3 and 4

  — Reset-synchronized PWM mode

  If channels 3 and 4 are combined, three-phase PWM output is possible with three pairs of complementary waveforms.

  — Complementary PWM mode

  If channels 3 and 4 are combined, three-phase PWM output is possible with three pairs of non-overlapping complementary waveforms.

  — Buffering

  Input capture registers can be double-buffered. Output compare registers can be updated automatically.

- High-speed access via internal 16-bit bus

  The 16-bit timer counters, general registers, and buffer registers can be accessed at high speed via a 16-bit bus.

- Fifteen interrupt sources

  Each channel has two compare match/input capture interrupts and an overflow interrupt. All interrupts can be requested independently.

- Activation of DMA controller (DMAC)

  Four of the compare match/input capture interrupts from channels 0 to 3 can start the DMAC.

- Output triggering of programmable pattern controller (TPC)

  Compare match/input capture signals from channels 0 to 3 can be used as TPC output triggers.

Table 10-1 summarizes the ITU functions.

Table 10-1 ITU Functions

Item		Channel 0	Channel 1	Channel 2	Channel 3	Channel 4
Clock sources		Internal clocks: ø, ø/2, ø/4, ø/8 External clocks: TCLKA, TCLKB, TCLKC, TCLKD, selectable independently				
General registers (output compare/input capture registers)		GRA0, GRB0	GRA1, GRB1	GRA2, GRB2	GRA3, GRB3	GRA4, GRB4
Buffer registers		—	—	—	BRA3, BRB3	BRA4, BRB4
Input/output pins		$TIOCA_0$, $TIOCB_0$	$TIOCA_1$, $TIOCB_1$	$TIOCA_2$, $TIOCB_2$	$TIOCA_3$, $TIOCB_3$	$TIOCA_4$, $TIOCB_4$
Output pins		—	—	—	—	$TOCXA_4$, TOCXB4
Counter clearing function		GRA0/GRB0 compare match or input capture	GRA1/GRB1 compare match or input capture	GRA2/GRB2 compare match or input capture	GRA3/GRB3 compare match or input capture	GRA4/GRB4 compare match or input capture
Compare match output	0	○	○	○	○	○
	1	○	○	○	○	○
	Toggle	○	○	—	○	○
Input capture function		○	○	○	○	○
Synchronization		○	○	○	○	○
PWM mode		○	○	○	○	○
Reset-synchronized PWM mode		—	—	—	○	○
Complementary PWM mode		—	—	—	○	○
Phase counting mode		—	—	○	—	—
Buffering		—	—	—	○	○
DMAC activation		GRA0 compare match or input capture	GRA1 compare match or input capture	GRA2 compare match or input capture	GRA3 compare match or input capture	—
Interrupt sources		Three sources • Compare match/input capture A0 • Compare match/input capture B0 • Overflow	Three sources • Compare match/input capture A1 • Compare match/input capture B1 • Overflow	Three sources • Compare match/input capture A2 • Compare match/input capture B2 • Overflow	Three sources • Compare match/input capture A3 • Compare match/input capture B3 • Overflow	Three sources • Compare match/input capture A4 • Compare match/input capture B4 • Overflow

Legend
○: Available
—: Not available

10.1.2 Block Diagrams

ITU Block Diagram (overall): Figure 10-1 is a block diagram of the ITU.

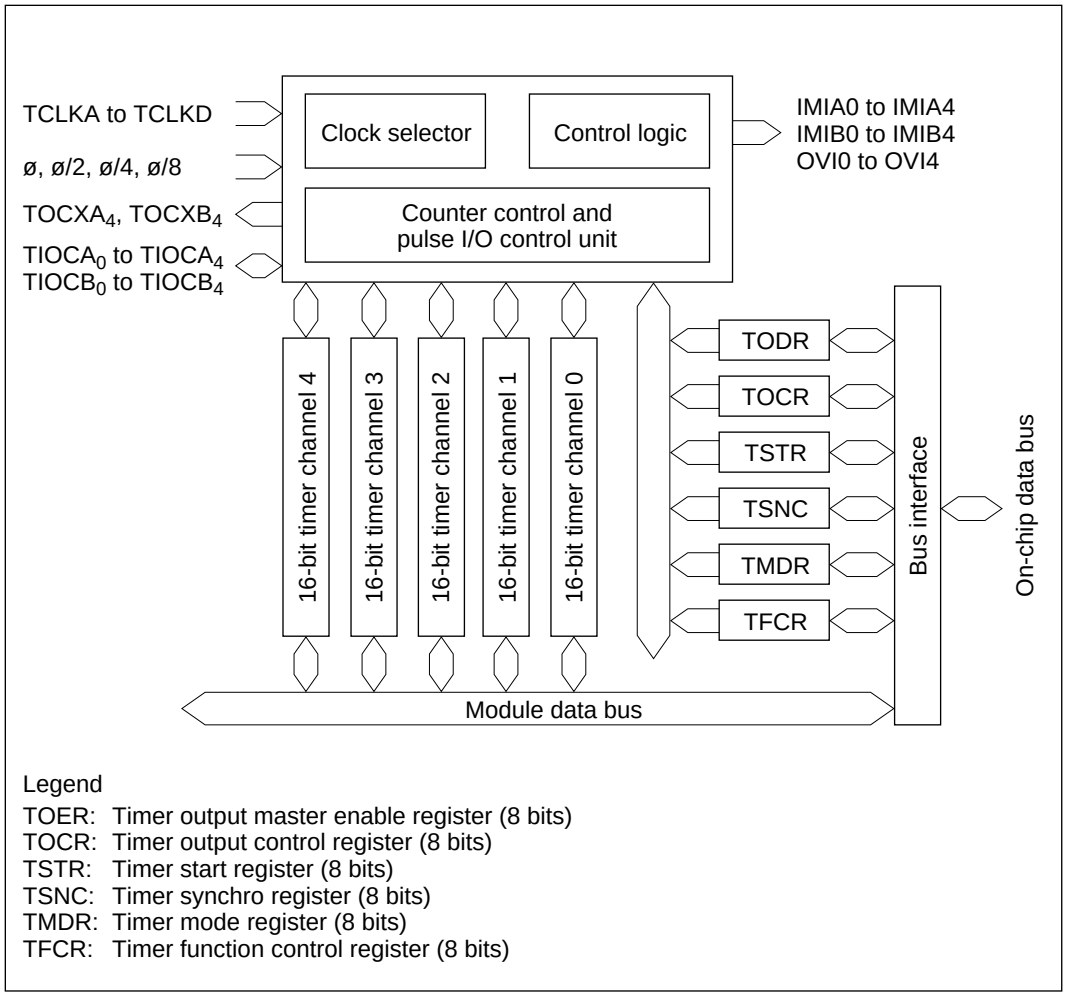


Figure 10-1 ITU Block Diagram (Overall)

Block Diagram of Channels 0 and 1: ITU channels 0 and 1 are functionally identical. Both have the structure shown in figure 10-2.

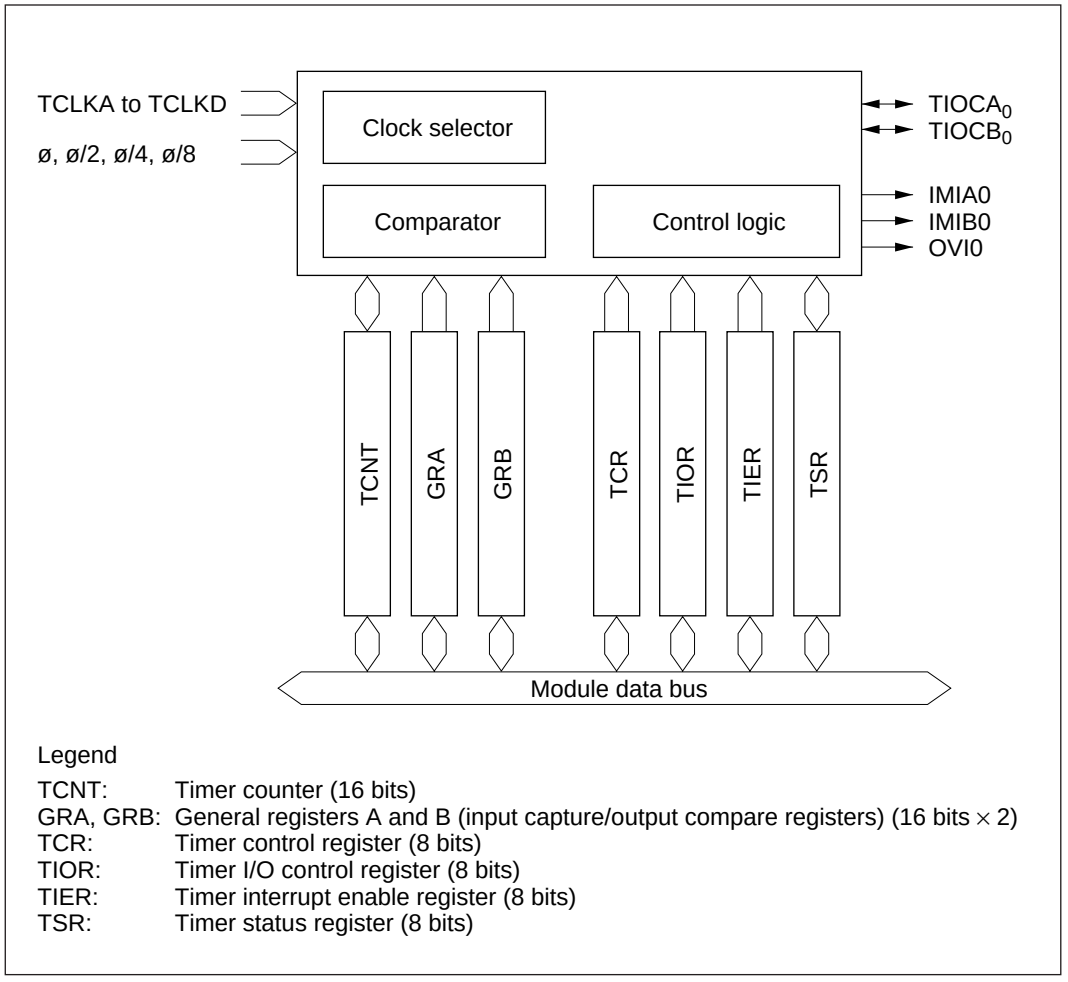
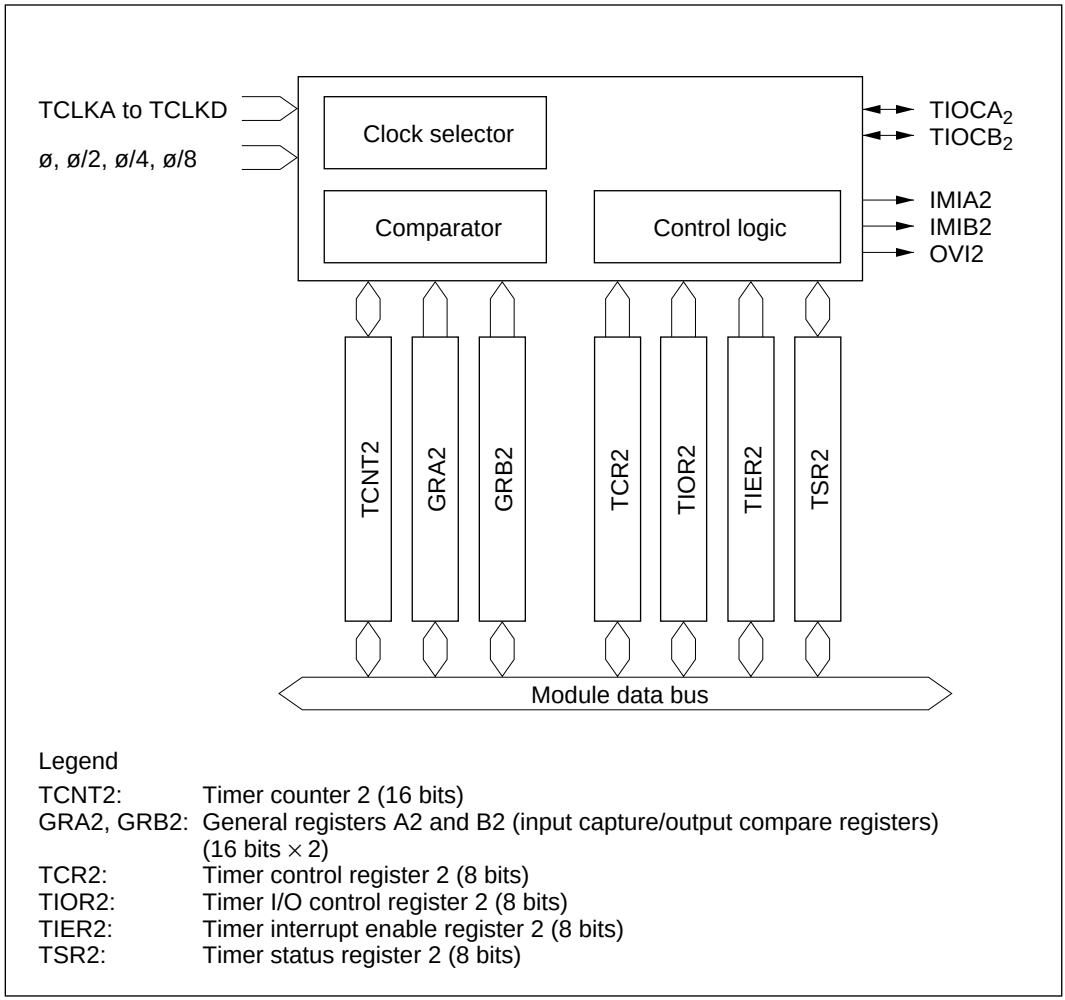


Figure 10-2 Block Diagram of Channels 0 and 1 (for Channel 0)

Block Diagram of Channel 2: Figure 10-3 is a block diagram of channel 2. This is the channel that provides only 0 output and 1 output.

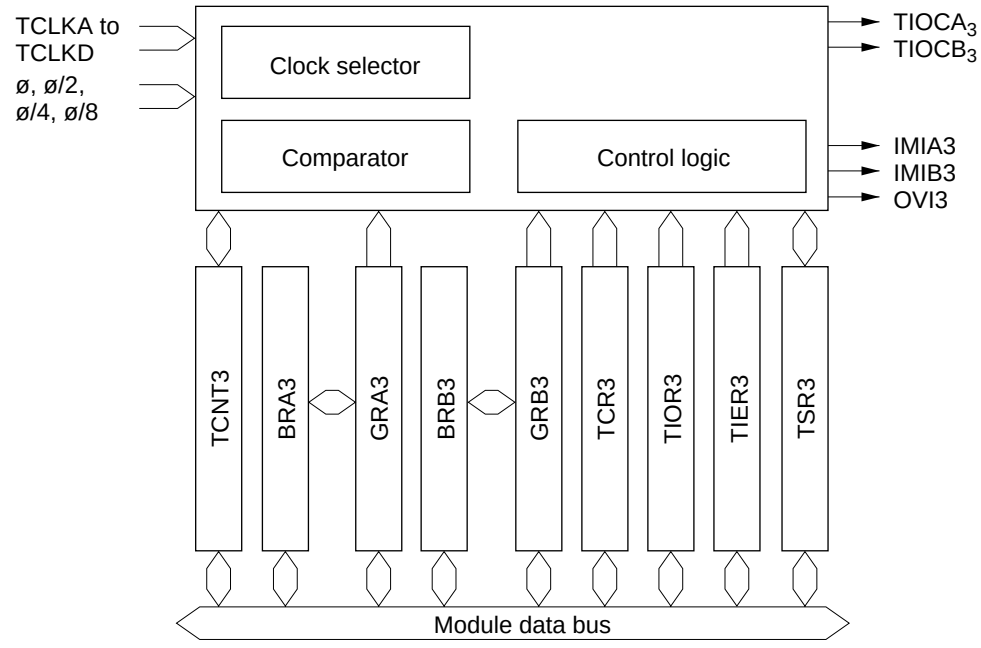


Legend

TCNT2:	Timer counter 2 (16 bits)
GRA2, GRB2:	General registers A2 and B2 (input capture/output compare registers) (16 bits × 2)
TCR2:	Timer control register 2 (8 bits)
TIOR2:	Timer I/O control register 2 (8 bits)
TIER2:	Timer interrupt enable register 2 (8 bits)
TSR2:	Timer status register 2 (8 bits)

Figure 10-3 Block Diagram of Channel 2

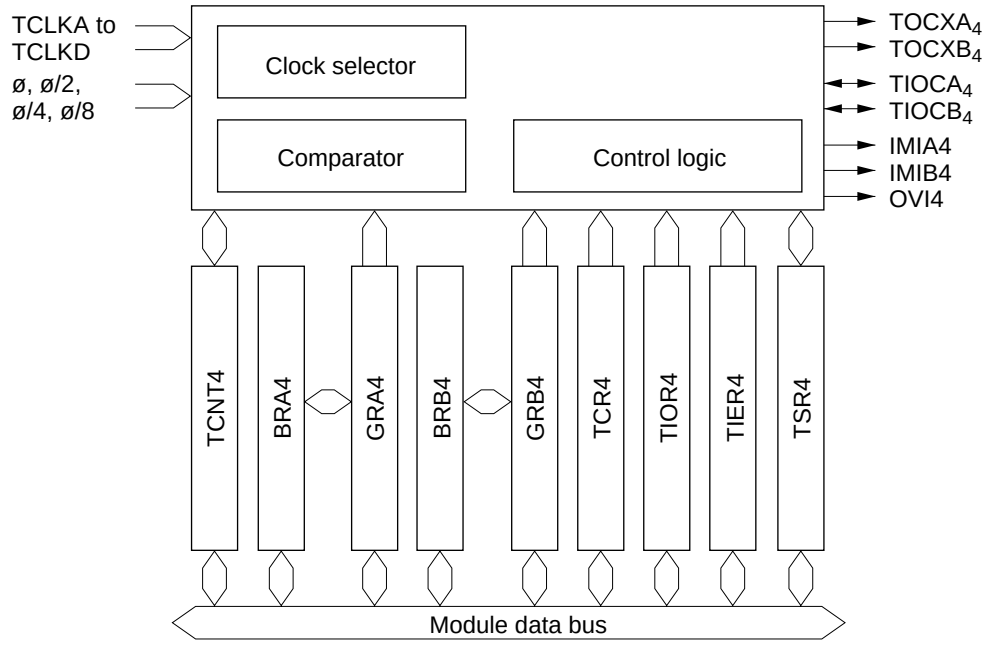
Block Diagrams of Channels 3 and 4: Figure 10-4 is a block diagram of channel 3. Figure 10-5 is a block diagram of channel 4.



Legend

TCNT3:	Timer counter 3 (16 bits)
GRA3, GRB3:	General registers A3 and B3 (input capture/output compare registers) (16 bits × 2)
BRA3, BRB3:	Buffer registers A3 and B3 (input capture/output compare buffer registers) (16 bits × 2)
TCR3:	Timer control register 3 (8 bits)
TIOR3:	Timer I/O control register 3 (8 bits)
TIER3:	Timer interrupt enable register 3 (8 bits)
TSR3:	Timer status register 3 (8 bits)

Figure 10-4 Block Diagram of Channel 3



Legend

TCNT4:	Timer counter 4 (16 bits)
GRA4, GRB4:	General registers A4 and B4 (input capture/output compare registers) (16 bits × 2)
BRA4, BRB4:	Buffer registers A4 and B4 (input capture/output compare buffer registers) (16 bits × 2)
TCR4:	Timer control register 4 (8 bits)
TIOR4:	Timer I/O control register 4 (8 bits)
TIER4:	Timer interrupt enable register 4 (8 bits)
TSR4:	Timer status register 4 (8 bits)

Figure 10-5 Block Diagram of Channel 4

10.1.3 Input/Output Pins

Table 10-2 summarizes the ITU pins.

Table 10-2 ITU Pins

Channel	Name	Abbre-viation	Input/ Output	Function
Common	Clock input A	TCLKA	Input	External clock A input pin (phase-A input pin in phase counting mode)
	Clock input B	TCLKB	Input	External clock B input pin (phase-B input pin in phase counting mode)
	Clock input C	TCLKC	Input	External clock C input pin
	Clock input D	TCLKD	Input	External clock D input pin
0	Input capture/output compare A0	$TIOCA_0$	Input/ output	GRA0 output compare or input capture pin PWM output pin in PWM mode
	Input capture/output compare B0	$TIOCB_0$	Input/ output	GRB0 output compare or input capture pin
1	Input capture/output compare A1	$TIOCA_1$	Input/ output	GRA1 output compare or input capture pin PWM output pin in PWM mode
	Input capture/output compare B1	$TIOCB_1$	Input/ output	GRB1 output compare or input capture pin
2	Input capture/output compare A2	$TIOCA_2$	Input/ output	GRA2 output compare or input capture pin PWM output pin in PWM mode
	Input capture/output compare B2	$TIOCB_2$	Input/ output	GRB2 output compare or input capture pin
3	Input capture/output compare A3	$TIOCA_3$	Input/ output	GRA3 output compare or input capture pin PWM output pin in PWM mode, complementary PWM mode, or reset-synchronized PWM mode
	Input capture/output compare B3	$TIOCB_3$	Input/ output	GRB3 output compare or input capture pin PWM output pin in complementary PWM mode or reset-synchronized PWM mode
4	Input capture/output compare A4	$TIOCA_4$	Input/ output	GRA4 output compare or input capture pin PWM output pin in PWM mode, complementary PWM mode, or reset-synchronized PWM mode
	Input capture/output compare B4	$TIOCB_4$	Input/ output	GRB4 output compare or input capture pin PWM output pin in complementary PWM mode or reset-synchronized PWM mode
	Output compare XA4	$TOCXA_4$	Output	PWM output pin in complementary PWM mode or reset-synchronized PWM mode
	Output compare XB4	$TOCXB_4$	Output	PWM output pin in complementary PWM mode or reset-synchronized PWM mode

10.1.4 Register Configuration

Table 10-3 summarizes the ITU registers.

Table 10-3 ITU Registers

Channel	Address*1	Name	Abbre-viation	R/W	Initial Value
Common	H'FF60	Timer start register	TSTR	R/W	H'E0
	H'FF61	Timer synchro register	TSNC	R/W	H'E0
	H'FF62	Timer mode register	TMDR	R/W	H'80
	H'FF63	Timer function control register	TFCR	R/W	H'C0
	H'FF90	Timer output master enable register	TOER	R/W	H'FF
	H'FF91	Timer output control register	TOCR	R/W	H'FF
0	H'FF64	Timer control register 0	TCR0	R/W	H'80
	H'FF65	Timer I/O control register 0	TIOR0	R/W	H'88
	H'FF66	Timer interrupt enable register 0	TIER0	R/W	H'F8
	H'FF67	Timer status register 0	TSR0	R/(W)*2	H'F8
	H'FF68	Timer counter 0 (high)	TCNT0H	R/W	H'00
	H'FF69	Timer counter 0 (low)	TCNT0L	R/W	H'00
	H'FF6A	General register A0 (high)	GRA0H	R/W	H'FF
	H'FF6B	General register A0 (low)	GRA0L	R/W	H'FF
	H'FF6C	General register B0 (high)	GRB0H	R/W	H'FF
	H'FF6D	General register B0 (low)	GRB0L	R/W	H'FF
1	H'FF6E	Timer control register 1	TCR1	R/W	H'80
	H'FF6F	Timer I/O control register 1	TIOR1	R/W	H'88
	H'FF70	Timer interrupt enable register 1	TIER1	R/W	H'F8
	H'FF71	Timer status register 1	TSR1	R/(W)*2	H'F8
	H'FF72	Timer counter 1 (high)	TCNT1H	R/W	H'00
	H'FF73	Timer counter 1 (low)	TCNT1L	R/W	H'00
	H'FF74	General register A1 (high)	GRA1H	R/W	H'FF
	H'FF75	General register A1 (low)	GRA1L	R/W	H'FF
	H'FF76	General register B1 (high)	GRB1H	R/W	H'FF
	H'FF77	General register B1 (low)	GRB1L	R/W	H'FF

Notes: 1. The lower 16 bits of the address are indicated.
2. Only 0 can be written, to clear flags.

Table 10-3 ITU Registers (cont)

Channel	Address*1	Name	Abbre-viation	R/W	Initial Value
2	H'FF78	Timer control register 2	TCR2	R/W	H'80
	H'FF79	Timer I/O control register 2	TIOR2	R/W	H'88
	H'FF7A	Timer interrupt enable register 2	TIER2	R/W	H'F8
	H'FF7B	Timer status register 2	TSR2	R/(W)*2	H'F8
	H'FF7C	Timer counter 2 (high)	TCNT2H	R/W	H'00
	H'FF7D	Timer counter 2 (low)	TCNT2L	R/W	H'00
	H'FF7E	General register A2 (high)	GRA2H	R/W	H'FF
	H'FF7F	General register A2 (low)	GRA2L	R/W	H'FF
	H'FF80	General register B2 (high)	GRB2H	R/W	H'FF
	H'FF81	General register B2 (low)	GRB2L	R/W	H'FF
3	H'FF82	Timer control register 3	TCR3	R/W	H'80
	H'FF83	Timer I/O control register 3	TIOR3	R/W	H'88
	H'FF84	Timer interrupt enable register 3	TIER3	R/W	H'F8
	H'FF85	Timer status register 3	TSR3	R/(W)*2	H'F8
	H'FF86	Timer counter 3 (high)	TCNT3H	R/W	H'00
	H'FF87	Timer counter 3 (low)	TCNT3L	R/W	H'00
	H'FF88	General register A3 (high)	GRA3H	R/W	H'FF
	H'FF89	General register A3 (low)	GRA3L	R/W	H'FF
	H'FF8A	General register B3 (high)	GRB3H	R/W	H'FF
	H'FF8B	General register B3 (low)	GRB3L	R/W	H'FF
	H'FF8C	Buffer register A3 (high)	BRA3H	R/W	H'FF
	H'FF8D	Buffer register A3 (low)	BRA3L	R/W	H'FF
	H'FF8E	Buffer register B3 (high)	BRB3H	R/W	H'FF
	H'FF8F	Buffer register B3 (low)	BRB3L	R/W	H'FF

Notes: 1. The lower 16 bits of the address are indicated.
2. Only 0 can be written, to clear flags.

Table 10-3 ITU Registers (cont)

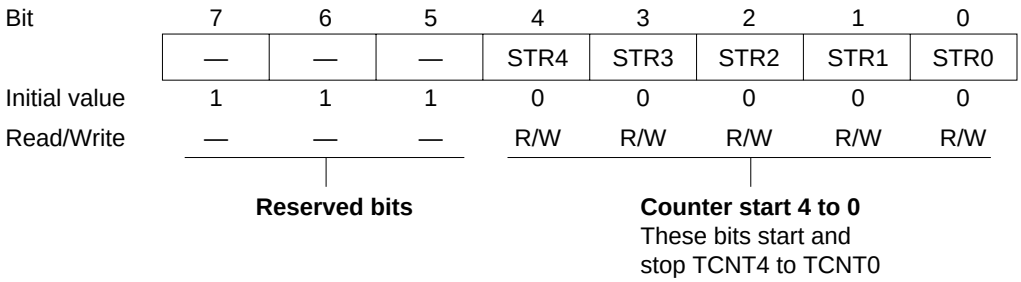
Channel	Address*1	Name	Abbre-viation	R/W	Initial Value
4	H'FF92	Timer control register 4	TCR4	R/W	H'80
	H'FF93	Timer I/O control register 4	TIOR4	R/W	H'88
	H'FF94	Timer interrupt enable register 4	TIER4	R/W	H'F8
	H'FF95	Timer status register 4	TSR4	R/(W)*2	H'F8
	H'FF96	Timer counter 4 (high)	TCNT4H	R/W	H'00
	H'FF97	Timer counter 4 (low)	TCNT4L	R/W	H'00
	H'FF98	General register A4 (high)	GRA4H	R/W	H'FF
	H'FF99	General register A4 (low)	GRA4L	R/W	H'FF
	H'FF9A	General register B4 (high)	GRB4H	R/W	H'FF
	H'FF9B	General register B4 (low)	GRB4L	R/W	H'FF
	H'FF9C	Buffer register A4 (high)	BRA4H	R/W	H'FF
	H'FF9D	Buffer register A4 (low)	BRA4L	R/W	H'FF
	H'FF9E	Buffer register B4 (high)	BRB4H	R/W	H'FF
	H'FF9F	Buffer register B4 (low)	BRB4L	R/W	H'FF

Notes: 1. The lower 16 bits of the address are indicated.
2. Only 0 can be written, to clear flags.

10.2 Register Descriptions

10.2.1 Timer Start Register (TSTR)

TSTR is an 8-bit readable/writable register that starts and stops the timer counter (TCNT) in channels 0 to 4.



TSTR is initialized to H'E0 by a reset and in standby mode.

Bits 7 to 5—Reserved: Read-only bits, always read as 1.

Bit 4—Counter Start 4 (STR4): Starts and stops timer counter 4 (TCNT4).

Bit 4 STR4	Description	
0	TCNT4 is halted	(Initial value)
1	TCNT4 is counting	

Bit 3—Counter Start 3 (STR3): Starts and stops timer counter 3 (TCNT3).

Bit 3 STR3	Description	
0	TCNT3 is halted	(Initial value)
1	TCNT3 is counting	

Bit 2—Counter Start 2 (STR2): Starts and stops timer counter 2 (TCNT2).

Bit 2 STR2	Description	
0	TCNT2 is halted	(Initial value)
1	TCNT2 is counting	

Bit 1—Counter Start 1 (STR1): Starts and stops timer counter 1 (TCNT1).

Bit 1 STR1	Description	
0	TCNT1 is halted	(Initial value)
1	TCNT1 is counting	

Bit 0—Counter Start 0 (STR0): Starts and stops timer counter 0 (TCNT0).

Bit 0 STR0	Description	
0	TCNT0 is halted	(Initial value)
1	TCNT0 is counting	

10.2.2 Timer Synchro Register (TSNC)

TSNC is an 8-bit readable/writable register that selects whether channels 0 to 4 operate independently or synchronously. Channels are synchronized by setting the corresponding bits to 1.

Bit	7	6	5	4	3	2	1	0
	—	—	—	SYNC4	SYNC3	SYNC2	SYNC1	SYNC0
Initial value	1	1	1	0	0	0	0	0
Read/Write	—	—	—	R/W	R/W	R/W	R/W	R/W

Reserved bits

Timer sync 4 to 0
These bits synchronize channels 4 to 0

TSNC is initialized to H'E0 by a reset and in standby mode.

Bits 7 to 5—Reserved: Read-only bits, always read as 1.

Bit 4—Timer Sync 4 (SYNC4): Selects whether channel 4 operates independently or synchronously.

Bit 4 SYNC4	Description	
0	Channel 4's timer counter (TCNT4) operates independently TCNT4 is preset and cleared independently of other channels	(Initial value)
1	Channel 4 operates synchronously TCNT4 can be synchronously preset and cleared	

Bit 3—Timer Sync 3 (SYNC3): Selects whether channel 3 operates independently or synchronously.

Bit 3 SYNC3	Description	
0	Channel 3's timer counter (TCNT3) operates independently TCNT3 is preset and cleared independently of other channels	(Initial value)
1	Channel 3 operates synchronously TCNT3 can be synchronously preset and cleared	

Bit 2—Timer Sync 2 (SYNC2): Selects whether channel 2 operates independently or synchronously.

Bit 2 SYNC2	Description	
0	Channel 2's timer counter (TCNT2) operates independently TCNT2 is preset and cleared independently of other channels	(Initial value)
1	Channel 2 operates synchronously TCNT2 can be synchronously preset and cleared	

Bit 1—Timer Sync 1 (SYNC1): Selects whether channel 1 operates independently or synchronously.

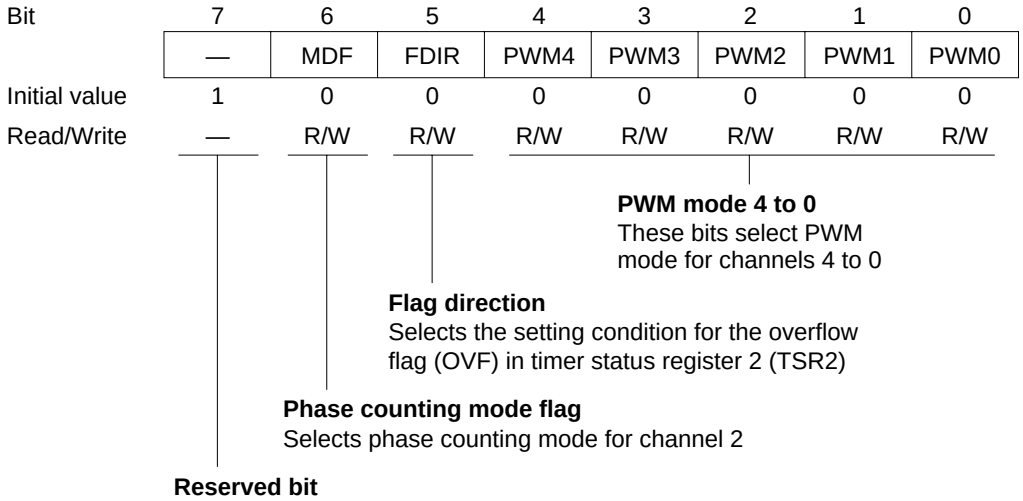
Bit 1 SYNC1	Description	
0	Channel 1's timer counter (TCNT1) operates independently TCNT1 is preset and cleared independently of other channels	(Initial value)
1	Channel 1 operates synchronously TCNT1 can be synchronously preset and cleared	

Bit 0—Timer Sync 0 (SYNC0): Selects whether channel 0 operates independently or synchronously.

Bit 0 SYNC0	Description	
0	Channel 0's timer counter (TCNT0) operates independently TCNT0 is preset and cleared independently of other channels	(Initial value)
1	Channel 0 operates synchronously TCNT0 can be synchronously preset and cleared	

10.2.3 Timer Mode Register (TMDR)

TMDR is an 8-bit readable/writable register that selects PWM mode for channels 0 to 4. It also selects phase counting mode and the overflow flag (OVF) setting conditions for channel 2.



TMDR is initialized to H'80 by a reset and in standby mode.

Bit 7—Reserved: Read-only bit, always read as 1.

Bit 6—Phase Counting Mode Flag (MDF): Selects whether channel 2 operates normally or in phase counting mode.

Bit 6 MDF	Description	
0	Channel 2 operates normally	(Initial value)
1	Channel 2 operates in phase counting mode	

When MDF is set to 1 to select phase counting mode, timer counter 2 (TCNT2) operates as an up/down-counter and pins TCLKA and TCLKB become counter clock input pins. TCNT2 counts both rising and falling edges of TCLKA and TCLKB, and counts up or down as follows.

Counting Direction	Down-Counting				Up-Counting			
TCLKA pin	↑	High	↓	Low	↑	Low	↓	High
TCLKB pin	Low	↑	High	↓	High	↑	Low	↓

In phase counting mode channel 2 operates as above regardless of the external clock edges selected by bits CKEG1 and CKEG0 and the clock source selected by bits TPSC2 to TPSC0 in timer control register 2 (TCR2). Phase counting mode takes precedence over these settings.

The counter clearing condition selected by the CCLR1 and CCLR0 bits in TCR2 and the compare match/input capture settings and interrupt functions of timer I/O control register 2 (TIOR2), timer interrupt enable register 2 (TIER2), and timer status register 2 (TSR2) remain effective in phase counting mode.

Bit 5—Flag Direction (FDIR): Designates the setting condition for the overflow flag (OVF) in timer status register 2 (TSR2). The FDIR designation is valid in all modes in channel 2.

Bit 5 FDIR	Description	
0	OVF is set to 1 in TSR2 when TCNT2 overflows or underflows	(Initial value)
1	OVF is set to 1 in TSR2 when TCNT2 overflows	

Bit 4—PWM Mode 4 (PWM4): Selects whether channel 4 operates normally or in PWM mode.

Bit 4 PWM4	Description	
0	Channel 4 operates normally	(Initial value)
1	Channel 4 operates in PWM mode	

When bit PWM4 is set to 1 to select PWM mode, pin TIOCA4 becomes a PWM output pin. The output goes to 1 at compare match with general register A4 (GRA4), and to 0 at compare match with general register B4 (GRB4).

If complementary PWM mode or reset-synchronized PWM mode is selected by bits CMD1 and CMD0 in the timer function control register (TFCR), the CMD1 and CMD0 setting takes precedence and the PWM4 setting is ignored.

Bit 3—PWM Mode 3 (PWM3): Selects whether channel 3 operates normally or in PWM mode.

Bit 3 PWM3	Description	
0	Channel 3 operates normally	(Initial value)
1	Channel 3 operates in PWM mode	

When bit PWM3 is set to 1 to select PWM mode, pin TIOCA3 becomes a PWM output pin. The output goes to 1 at compare match with general register A3 (GRA3), and to 0 at compare match with general register B3 (GRB3).

If complementary PWM mode or reset-synchronized PWM mode is selected by bits CMD1 and CMD0 in the timer function control register (TFCR), the CMD1 and CMD0 setting takes precedence and the PWM3 setting is ignored.

Bit 2—PWM Mode 2 (PWM2): Selects whether channel 2 operates normally or in PWM mode.

Bit 2 PWM2	Description	
0	Channel 2 operates normally	(Initial value)
1	Channel 2 operates in PWM mode	

When bit PWM2 is set to 1 to select PWM mode, pin TIOCA2 becomes a PWM output pin. The output goes to 1 at compare match with general register A2 (GRA2), and to 0 at compare match with general register B2 (GRB2).

Bit 1—PWM Mode 1 (PWM1): Selects whether channel 1 operates normally or in PWM mode.

Bit 1 PWM1	Description	
0	Channel 1 operates normally	(Initial value)
1	Channel 1 operates in PWM mode	

When bit PWM1 is set to 1 to select PWM mode, pin TIOCA1 becomes a PWM output pin. The output goes to 1 at compare match with general register A1 (GRA1), and to 0 at compare match with general register B1 (GRB1).

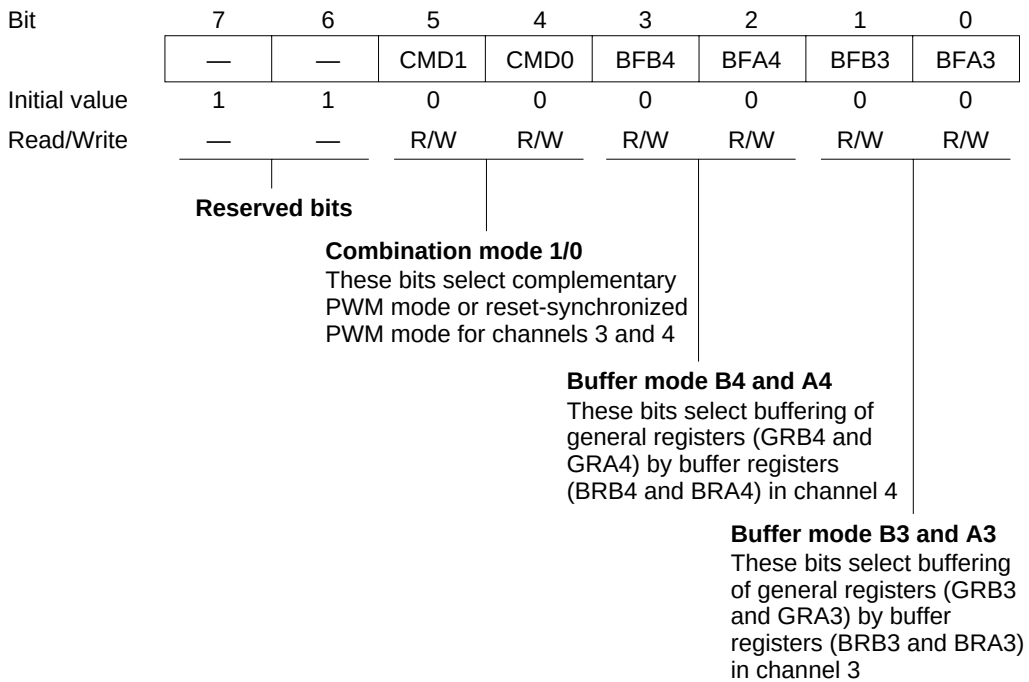
Bit 0—PWM Mode 0 (PWM0): Selects whether channel 0 operates normally or in PWM mode.

Bit 0 PWM0	Description	
0	Channel 0 operates normally	(Initial value)
1	Channel 0 operates in PWM mode	

When bit PWM0 is set to 1 to select PWM mode, pin TIOCA0 becomes a PWM output pin. The output goes to 1 at compare match with general register A0 (GRA0), and to 0 at compare match with general register B0 (GRB0).

10.2.4 Timer Function Control Register (TFCR)

TFCR is an 8-bit readable/writable register that selects complementary PWM mode, reset-synchronized PWM mode, and buffering for channels 3 and 4.



TFCR is initialized to H'C0 by a reset and in standby mode.

Bits 7 and 6—Reserved: Read-only bits, always read as 1.

Bits 5 and 4—Combination Mode 1 and 0 (CMD1, CMD0): These bits select whether channels 3 and 4 operate in normal mode, complementary PWM mode, or reset-synchronized PWM mode.

Bit 5 CMD1	Bit 4 CMD0	Description	
0	0	Channels 3 and 4 operate normally	(Initial value)
	1		
1	0	Channels 3 and 4 operate together in complementary PWM mode	
	1	Channels 3 and 4 operate together in reset-synchronized PWM mode	

Before selecting reset-synchronized PWM mode or complementary PWM mode, halt the timer counter or counters that will be used in these modes.

When these bits select complementary PWM mode or reset-synchronized PWM mode, they take precedence over the setting of the PWM mode bits (PWM4 and PWM3) in TMDR. Settings of timer sync bits SYNC4 and SYNC3 in the timer synchro register (TSNC) are valid in complementary PWM mode and reset-synchronized PWM mode, however. When complementary PWM mode is selected, channels 3 and 4 must not be synchronized (do not set bits SYNC3 and SYNC4 both to 1 in TSNC).

Bit 3—Buffer Mode B4 (BFB4): Selects whether GRB4 operates normally in channel 4, or whether GRB4 is buffered by BRB4.

Bit 3 BFB4	Description	
0	GRB4 operates normally	(Initial value)
1	GRB4 is buffered by BRB4	

Bit 2—Buffer Mode A4 (BFA4): Selects whether GRA4 operates normally in channel 4, or whether GRA4 is buffered by BRA4.

Bit 2 BFA4	Description	
0	GRA4 operates normally	(Initial value)
1	GRA4 is buffered by BRA4	

Bit 1—Buffer Mode B3 (BFB3): Selects whether GRB3 operates normally in channel 3, or whether GRB3 is buffered by BRB3.

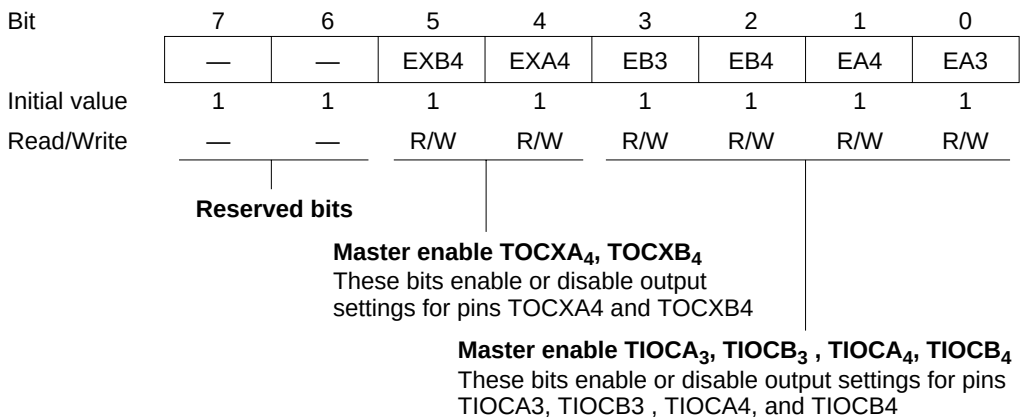
Bit 1 BFB3	Description	
0	GRB3 operates normally	(Initial value)
1	GRB3 is buffered by BRB3	

Bit 0—Buffer Mode A3 (BFA3): Selects whether GRA3 operates normally in channel 3, or whether GRA3 is buffered by BRA3.

Bit 0 BFA3	Description	
0	GRA3 operates normally	(Initial value)
1	GRA3 is buffered by BRA3	

10.2.5 Timer Output Master Enable Register (TOER)

TOER is an 8-bit readable/writable register that enables or disables output settings for channels 3 and 4.



TOER is initialized to H'FF by a reset and in standby mode.

Bits 7 and 6—Reserved: Read-only bits, always read as 1.

Bit 5—Master Enable $TOCXB_4$ (EXB4): Enables or disables ITU output at pin $TOCXB_4$.

Bit 5 EXB4	Description
0	$TOCXB_4$ output is disabled regardless of TFCR settings ($TOCXB_4$ operates as a generic input/output pin). If XTGD = 0, EXB4 is cleared to 0 when input capture A occurs in channel 1.
1	$TOCXB_4$ is enabled for output according to TFCR settings (Initial value)

Bit 4—Master Enable $TOCXA_4$ (EXA4): Enables or disables ITU output at pin TOCXA4.

Bit 4 EXA4	Description
0	$TOCXA_4$ output is disabled regardless of TFCR settings ($TOCXA_4$ operates as a generic input/output pin). If XTGD = 0, EXA4 is cleared to 0 when input capture A occurs in channel 1.
1	$TOCXA_4$ is enabled for output according to TFCR settings (Initial value)

Bit 3—Master Enable $TIOCB_3$ (EB3): Enables or disables ITU output at pin TIOCB3.

Bit 3 EB3	Description
0	$TIOCB_3$ output is disabled regardless of TIOR3 and TFCR settings ($TIOCB_3$ operates as a generic input/output pin). If XTGD = 0, EB3 is cleared to 0 when input capture A occurs in channel 1.
1	$TIOCB_3$ is enabled for output according to TIOR3 and TFCR settings (Initial value)

Bit 2—Master Enable $TIOCB_4$ (EB4): Enables or disables ITU output at pin TIOCB4.

Bit 2 EB4	Description
0	$TIOCB_4$ output is disabled regardless of TIOR4 and TFCR settings ($TIOCB_4$ operates as a generic input/output pin). If XTGD = 0, EB4 is cleared to 0 when input capture A occurs in channel 1.
1	$TIOCB_4$ is enabled for output according to TIOR4 and TFCR settings (Initial value)

Bit 1—Master Enable $TIOCA_4$ (EA4): Enables or disables ITU output at pin TIOCA4.

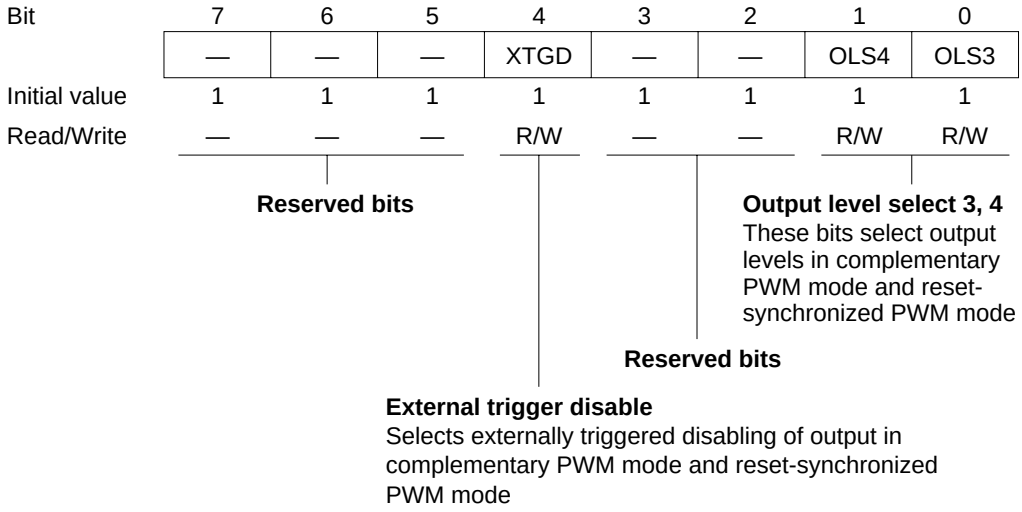
Bit 1 EA4	Description
0	$TIOCA_4$ output is disabled regardless of TIOR4, TMDR, and TFCR settings ($TIOCA_4$ operates as a generic input/output pin). If XTGD = 0, EA4 is cleared to 0 when input capture A occurs in channel 1.
1	$TIOCA_4$ is enabled for output according to TIOR4, TMDR, and TFCR settings (Initial value)

Bit 0—Master Enable $TIOCA_3$ (EA3): Enables or disables ITU output at pin TIOCA3.

Bit 0 EA3	Description
0	$TIOCA_3$ output is disabled regardless of TIOR3, TMDR, and TFCR settings ($TIOCA_3$ operates as a generic input/output pin). If XTGD = 0, EA3 is cleared to 0 when input capture A occurs in channel 1.
1	$TIOCA_3$ is enabled for output according to TIOR3, TMDR, and TFCR settings (Initial value)

10.2.6 Timer Output Control Register (TOCR)

TOCR is an 8-bit readable/writable register that selects externally triggered disabling of output in complementary PWM mode and reset-synchronized PWM mode, and inverts the output levels.



The settings of the XTGD, OLS4, and OLS3 bits are valid only in complementary PWM mode and reset-synchronized PWM mode. These settings do not affect other modes.

TOCR is initialized to H'FF by a reset and in standby mode.

Bits 7 to 5—Reserved: Read-only bits, always read as 1.

Bit 4—External Trigger Disable (XTGD): Selects externally triggered disabling of ITU output in complementary PWM mode and reset-synchronized PWM mode.

Bit 4 XTGD	Description	
0	Input capture A in channel 1 is used as an external trigger signal in complementary PWM mode and reset-synchronized PWM mode. When an external trigger occurs, bits 5 to 0 in the timer output master enable register (TOER) are cleared to 0, disabling ITU output.	
1	External triggering is disabled	(Initial value)

Bits 3 and 2—Reserved: Read-only bits, always read as 1.

Bit 1—Output Level Select 4 (OLS4): Selects output levels in complementary PWM mode and reset-synchronized PWM mode.

Bit 1 OLS4	Description	
0	TIOCA3, TIOCA4, and TIOCB4 outputs are inverted	
1	TIOCA3, TIOCA4, and TIOCB4 outputs are not inverted	(Initial value)

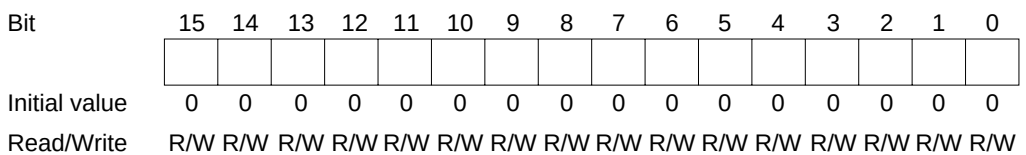
Bit 0—Output Level Select 3 (OLS3): Selects output levels in complementary PWM mode and reset-synchronized PWM mode.

Bit 0 OLS3	Description	
0	TIOCB3, TOCXA4, and TOCXB4 outputs are inverted	
1	TIOCB3, TOCXA4, and TOCXB4 outputs are not inverted	(Initial value)

10.2.7 Timer Counters (TCNT)

TCNT is a 16-bit counter. The ITU has five TCNTs, one for each channel.

Channel	Abbreviation	Function
0	TCNT0	Up-counter
1	TCNT1	
2	TCNT2	Phase counting mode: up/down-counter Other modes: up-counter
3	TCNT3	Complementary PWM mode: up/down-counter Other modes: up-counter
4	TCNT4	



Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Each TCNT is a 16-bit readable/writable register that counts pulse inputs from a clock source. The clock source is selected by bits TPSC2 to TPSC0 in the timer control register (TCR).

TCNT0 and TCNT1 are up-counters. TCNT2 is an up/down-counter in phase counting mode and an up-counter in other modes. TCNT3 and TCNT4 are up/down-counters in complementary PWM mode and up-counters in other modes.

TCNT can be cleared to H'0000 by compare match with general register A or B (GRA or GRB) or by input capture to GRA or GRB (counter clearing function) in the same channel.

When TCNT overflows (changes from H'FFFF to H'0000), the overflow flag (OVF) is set to 1 in the timer status register (TSR) of the corresponding channel.

When TCNT underflows (changes from H'0000 to H'FFFF), the overflow flag (OVF) is set to 1 in TSR of the corresponding channel.

The TCNTs are linked to the CPU by an internal 16-bit bus and can be written or read by either word access or byte access.

Each TCNT is initialized to H'0000 by a reset and in standby mode.

10.2.8 General Registers (GRA, GRB)

The general registers are 16-bit registers. The ITU has 10 general registers, two in each channel.

Channel	Abbreviation	Function
0	GRA0, GRB0	Output compare/input capture register
1	GRA1, GRB1	
2	GRA2, GRB2	
3	GRA3, GRB3	Output compare/input capture register; can be buffered by buffer registers BRA and BRB
4	GRA4, GRB4	

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

A general register is a 16-bit readable/writable register that can function as either an output compare register or an input capture register. The function is selected by settings in the timer I/O control register (TIOR).

When a general register is used as an output compare register, its value is constantly compared with the TCNT value. When the two values match (compare match), the IMFA or IMFB flag is set to 1 in the timer status register (TSR). Compare match output can be selected in TIOR.

When a general register is used as an input capture register, rising edges, falling edges, or both edges of an external input capture signal are detected and the current TCNT value is stored in the general register. The corresponding IMFA or IMFB flag in TSR is set to 1 at the same time. The valid edge or edges of the input capture signal are selected in TIOR.

TIOR settings are ignored in PWM mode, complementary PWM mode, and reset-synchronized PWM mode.

General registers are linked to the CPU by an internal 16-bit bus and can be written or read by either word access or byte access.

General registers are initialized to the output compare function (with no output signal) by a reset and in standby mode. The initial value is H'FFFF.

10.2.9 Buffer Registers (BRA, BRB)

The buffer registers are 16-bit registers. The ITU has four buffer registers, two each in channels 3 and 4.

Channel	Abbreviation	Function
3	BRA3, BRB3	Used for buffering
4	BRA4, BRB4	• When the corresponding GRA or GRB functions as an output compare register, BRA or BRB can function as an output compare buffer register: the BRA or BRB value is automatically transferred to GRA or GRB at compare match • When the corresponding GRA or GRB functions as an input capture register, BRA or BRB can function as an input capture buffer register: the GRA or GRB value is automatically transferred to BRA or BRB at input capture

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

A buffer register is a 16-bit readable/writable register that is used when buffering is selected. Buffering can be selected independently by bits BFB4, BFA4, BFB3, and BFA3 in TFCR.

The buffer register and general register operate as a pair. When the general register functions as an output compare register, the buffer register functions as an output compare buffer register. When the general register functions as an input capture register, the buffer register functions as an input capture buffer register.

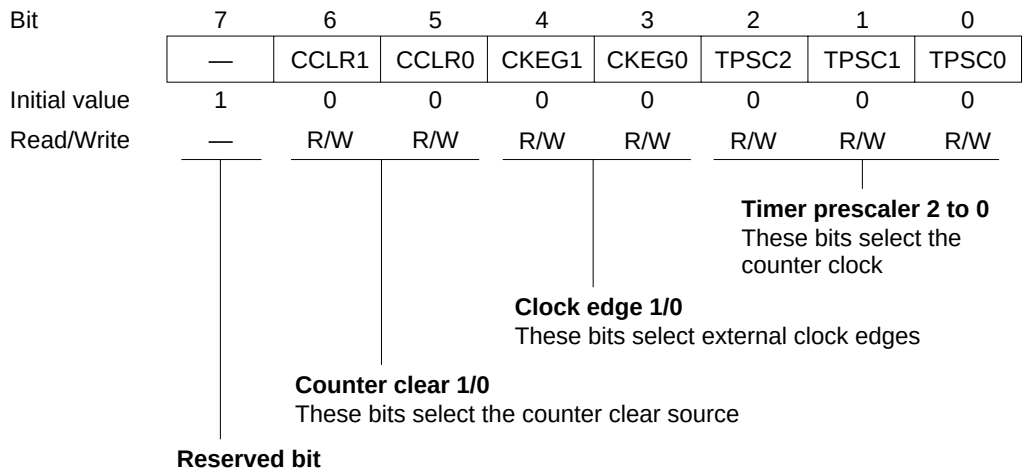
The buffer registers are linked to the CPU by an internal 16-bit bus and can be written or read by either word or byte access.

Buffer registers are initialized to H'FFFF by a reset and in standby mode.

10.2.10 Timer Control Registers (TCR)

TCR is an 8-bit register. The ITU has five TCRs, one in each channel.

Channel	Abbreviation	Function
0	TCR0	TCR controls the timer counter. The TCRs in all channels are functionally identical. When phase counting mode is selected in channel 2, the settings of bits CKEG1 and CKEG0 and TPSC2 to TPSC0 in TCR2 are ignored.
1	TCR1	
2	TCR2	
3	TCR3	
4	TCR4	



Each TCR is an 8-bit readable/writable register that selects the timer counter clock source, selects the edge or edges of external clock sources, and selects how the counter is cleared.

TCR is initialized to H'80 by a reset and in standby mode.

Bit 7—Reserved: Read-only bit, always read as 1.

Bits 6 and 5—Counter Clear 1/0 (CCLR1, CCLR0): These bits select how TCNT is cleared.

Bit 6 CCLR1	Bit 5 CCLR0	Description	
0	0	TCNT is not cleared	(Initial value)
	1	TCNT is cleared by GRA compare match or input capture*1	
1	0	TCNT is cleared by GRB compare match or input capture*1	
	1	Synchronous clear: TCNT is cleared in synchronization with other synchronized timers*2	

Notes: 1. TCNT is cleared by compare match when the general register functions as a compare match register, and by input capture when the general register functions as an input capture register.
2. Selected in the timer synchro register (TSNC).

Bits 4 and 3—Clock Edge 1/0 (CKEG1, CKEG0): These bits select external clock input edges when an external clock source is used.

Bit 4 CKEG1	Bit 3 CKEG0	Description	
0	0	Count rising edges	(Initial value)
	1	Count falling edges	
1	—	Count both edges	

When channel 2 is set to phase counting mode, bits CKEG1 and CKEG0 in TCR2 are ignored. Phase counting takes precedence.

Bits 2 to 0—Timer Prescaler 2 to 0 (TPSC2 to TPSC0): These bits select the counter clock source.

Bit 2 TPSC2	Bit 1 TPSC1	Bit 0 TPSC0	Function	
0	0	0	Internal clock: ø	(Initial value)
		1	Internal clock: ø/2	
	1	0	Internal clock: ø/4	
		1	Internal clock: ø/8	
1	0	0	External clock A: TCLKA input	
		1	External clock B: TCLKB input	
	1	0	External clock C: TCLKC input	
		1	External clock D: TCLKD input	

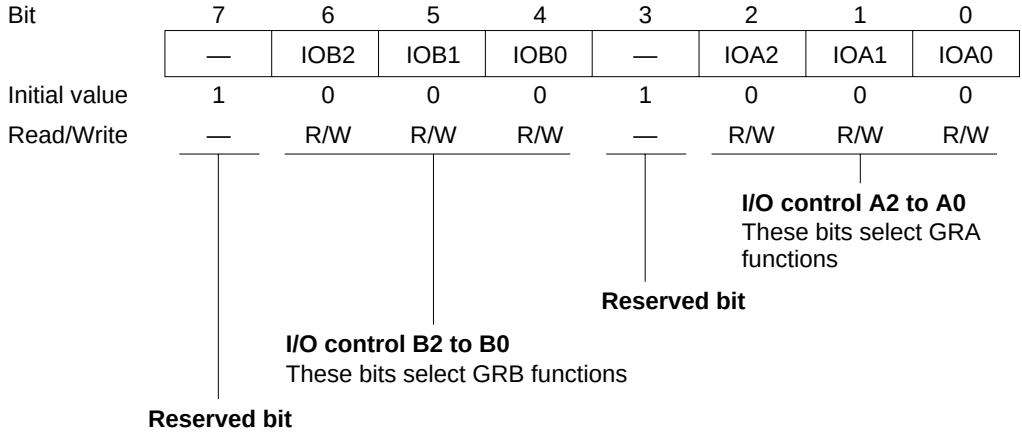
When bit TPSC2 is cleared to 0 an internal clock source is selected, and the timer counts only falling edges. When bit TPSC2 is set to 1 an external clock source is selected, and the timer counts the edge or edges selected by bits CKEG1 and CKEG0.

When channel 2 is set to phase counting mode (MDF = 1 in TMDR), the settings of bits TPSC2 to TPSC0 in TCR2 are ignored. Phase counting takes precedence.

10.2.11 Timer I/O Control Register (TIOR)

TIOR is an 8-bit register. The ITU has five TIORs, one in each channel.

Channel	Abbreviation	Function
0	TIOR0	TIOR controls the general registers. Some functions differ in PWM mode. TIOR3 and TIOR4 settings are ignored when complementary PWM mode or reset-synchronized PWM mode is selected in channels 3 and 4.
1	TIOR1	
2	TIOR2	
3	TIOR3	
4	TIOR4	



Each TIOR is an 8-bit readable/writable register that selects the output compare or input capture function for GRA and GRB, and specifies the functions of the TIOCA and TIOCB pins. If the output compare function is selected, TIOR also selects the type of output. If input capture is selected, TIOR also selects the edge or edges of the input capture signal.

TIOR is initialized to H'88 by a reset and in standby mode.

Bit 7—Reserved: Read-only bit, always read as 1.

Bits 6 to 4—I/O Control B2 to B0 (IOB2 to IOB0): These bits select the GRB function.

Bit 6 IOB2	Bit 5 IOB1	Bit 4 IOB0	Function		
0	0	0	GRB is an output compare register	No output at compare match	(Initial value)
		1		0 output at GRB compare match*1	
	1	0		1 output at GRB compare match*1	
		1		Output toggles at GRB compare match (1 output in channel 2)*1, *2	
1	0	0	GRB is an input capture register	GRB captures rising edge of input	
		1		GRB captures falling edge of input	
	1	0		GRB captures both edges of input	
		1			

Notes: 1. After a reset, the output is 0 until the first compare match.
2. Channel 2 output cannot be toggled by compare match. This setting selects 1 output instead.

Bit 3—Reserved: Read-only bit, always read as 1.

Bits 2 to 0—I/O Control A2 to A0 (IOA2 to IOA0): These bits select the GRA function.

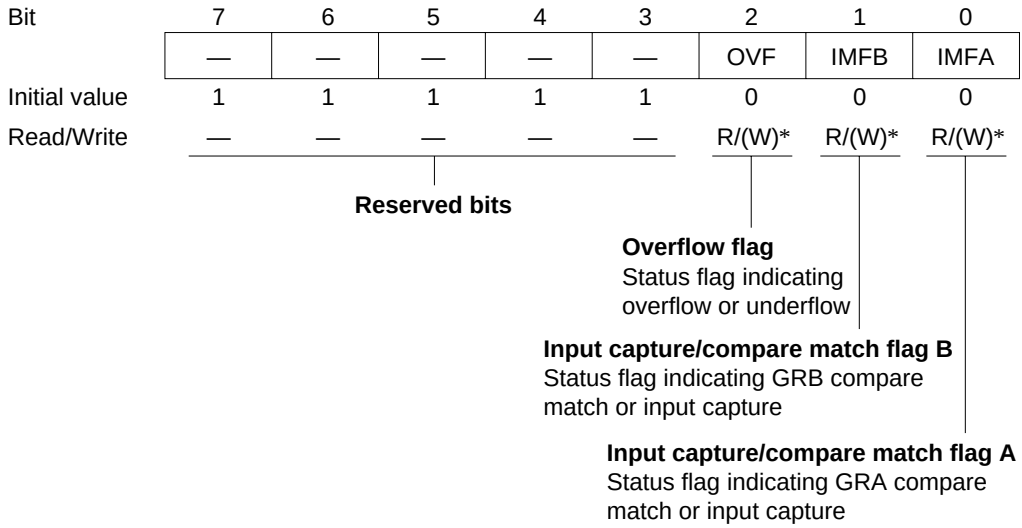
Bit 2 IOA2	Bit 1 IOA1	Bit 0 IOA0	Function	
0	0	0	GRA is an output compare register	No output at compare match (Initial value)
		1		0 output at GRA compare match*1
	1	0		1 output at GRA compare match*1
		1		Output toggles at GRA compare match (1 output in channel 2)*1, *2
1	0	0	GRA is an input capture register	GRA captures rising edge of input
		1		GRA captures falling edge of input
	1	0		GRA captures both edges of input
		1		

Notes: 1. After a reset, the output is 0 until the first compare match.
2. Channel 2 output cannot be toggled by compare match. This setting selects 1 output instead.

10.2.12 Timer Status Register (TSR)

TSR is an 8-bit register. The ITU has five TSRs, one in each channel.

Channel	Abbreviation	Function
0	TSR0	Indicates input capture, compare match, and overflow status
1	TSR1	
2	TSR2	
3	TSR3	
4	TSR4	



Note: * Only 0 can be written, to clear the flag.

Each TSR is an 8-bit readable/writable register containing flags that indicate TCNT overflow or underflow and GRA or GRB compare match or input capture. These flags are interrupt sources and generate CPU interrupts if enabled by corresponding bits in the timer interrupt enable register (TIER).

TSR is initialized to H'F8 by a reset and in standby mode.

Bits 7 to 3—Reserved: Read-only bits, always read as 1.

Bit 2—Overflow Flag (OVF): This status flag indicates TCNT overflow or underflow.

Bit 2 OVF	Description	
0	[Clearing condition] Read OVF when OVF = 1, then write 0 in OVF	(Initial value)
1	[Setting condition] TCNT overflowed from H'FFFF to H'0000, or underflowed from H'0000 to H'FFFF*	

Notes: * TCNT underflow occurs when TCNT operates as an up/down-counter. Underflow occurs only under the following conditions:

1. Channel 2 operates in phase counting mode (MDF = 1 in TMDR)
2. Channels 3 and 4 operate in complementary PWM mode (CMD1 = 1 and CMD0 = 0 in TFCR)

Bit 1—Input Capture/Compare Match Flag B (IMFB): This status flag indicates GRB compare match or input capture events.

Bit 1 IMFB	Description	
0	[Clearing condition] Read IMFB when IMFB = 1, then write 0 in IMFB	(Initial value)
1	[Setting conditions] TCNT = GRB when GRB functions as a compare match register. TCNT value is transferred to GRB by an input capture signal, when GRB functions as an input capture register.	

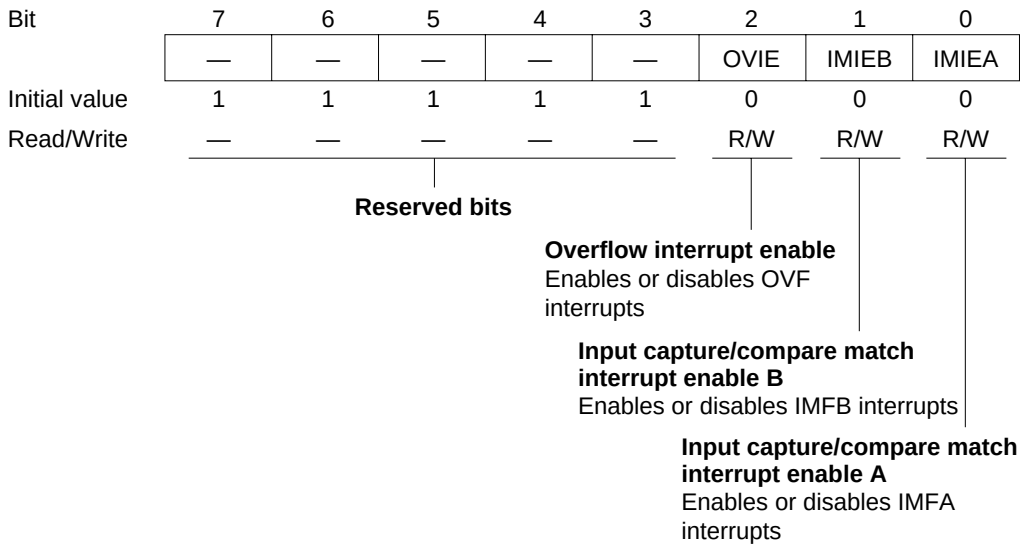
Bit 0—Input Capture/Compare Match Flag A (IMFA): This status flag indicates GRA compare match or input capture events.

Bit 0 IMFA	Description	
0	[Clearing condition] Read IMFA when IMFA = 1, then write 0 in IMFA. DMAC activated by IMIA interrupt (channels 0 to 3 only).	(Initial value)
1	[Setting conditions] TCNT = GRA when GRA functions as a compare match register. TCNT value is transferred to GRA by an input capture signal, when GRA functions as an input capture register.	

10.2.13 Timer Interrupt Enable Register (TIER)

TIER is an 8-bit register. The ITU has five TIERs, one in each channel.

Channel	Abbreviation	Function
0	TIER0	Enables or disables interrupt requests.
1	TIER1	
2	TIER2	
3	TIER3	
4	TIER4	



Each TIER is an 8-bit readable/writable register that enables and disables overflow interrupt requests and general register compare match and input capture interrupt requests.

TIER is initialized to H'F8 by a reset and in standby mode.

Bits 7 to 3—Reserved: Read-only bits, always read as 1.

Bit 2—Overflow Interrupt Enable (OVIE): Enables or disables the interrupt requested by the overflow flag (OVF) in TSR when OVF is set to 1.

Bit 2 OVIE	Description	
0	OVI interrupt requested by OVF is disabled	(Initial value)
1	OVI interrupt requested by OVF is enabled	

Bit 1—Input Capture/Compare Match Interrupt Enable B (IMIEB): Enables or disables the interrupt requested by the IMFB flag in TSR when IMFB is set to 1.

Bit 1 IMIEB	Description	
0	IMIB interrupt requested by IMFB is disabled	(Initial value)
1	IMIB interrupt requested by IMFB is enabled	

Bit 0—Input Capture/Compare Match Interrupt Enable A (IMIEA): Enables or disables the interrupt requested by the IMFA flag in TSR when IMFA is set to 1.

Bit 0 IMIEA	Description	
0	IMIA interrupt requested by IMFA is disabled	(Initial value)
1	IMIA interrupt requested by IMFA is enabled	

10.3 CPU Interface

10.3.1 16-Bit Accessible Registers

The timer counters (TCNTs), general registers A and B (GRAs and GRBs), and buffer registers A and B (BRAs and BRBs) are 16-bit registers, and are linked to the CPU by an internal 16-bit data bus. These registers can be written or read a word at a time, or a byte at a time.

Figures 10-6 and 10-7 show examples of word access to a timer counter (TCNT). Figures 10-8, 10-9, 10-10, and 10-11 show examples of byte access to TCNTH and TCNTL.

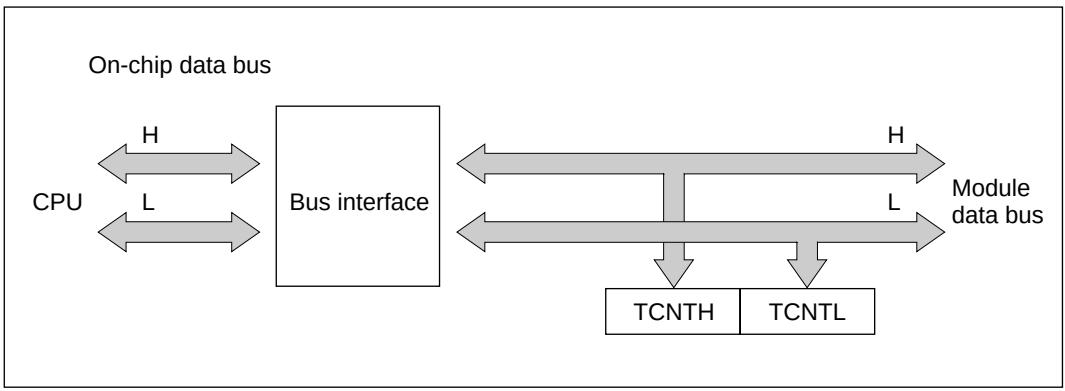


Figure 10-6 Access to Timer Counter (CPU Writes to TCNT, Word)

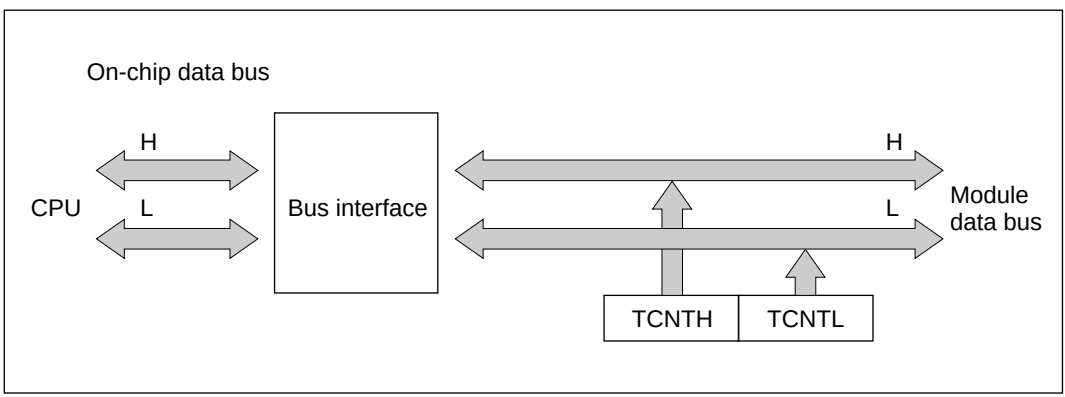


Figure 10-7 Access to Timer Counter (CPU Reads TCNT, Word)

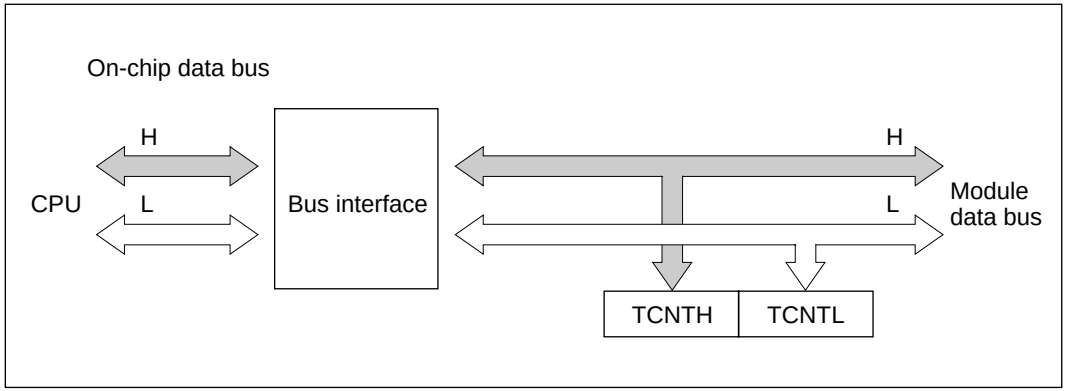


Figure 10-8 Access to Timer Counter (CPU Writes to TCNT, Upper Byte)

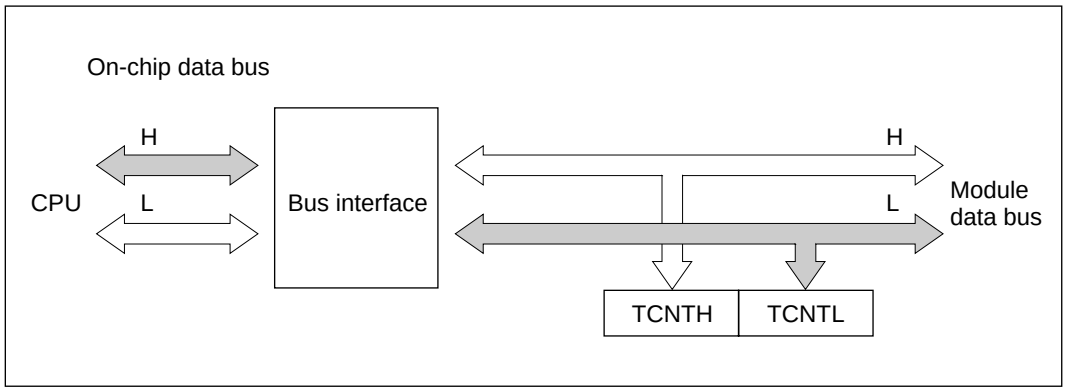


Figure 10-9 Access to Timer Counter (CPU Writes to TCNT, Lower Byte)

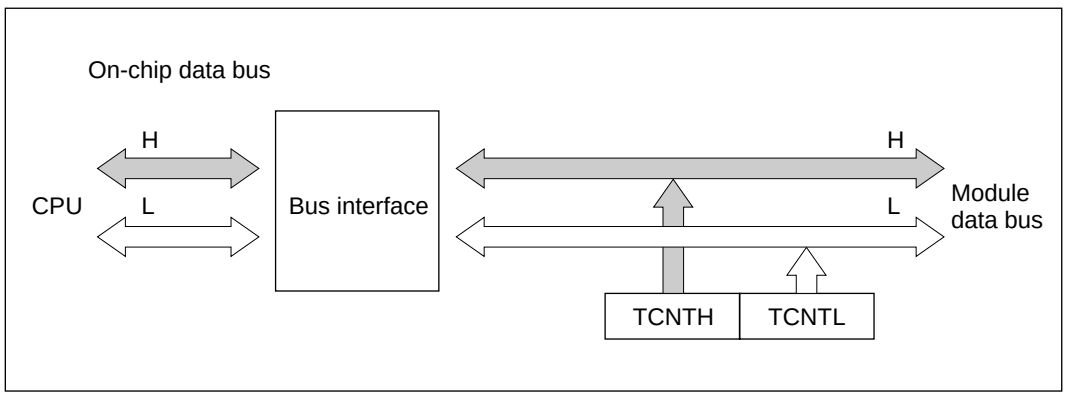


Figure 10-10 Access to Timer Counter (CPU Reads TCNT, Upper Byte)

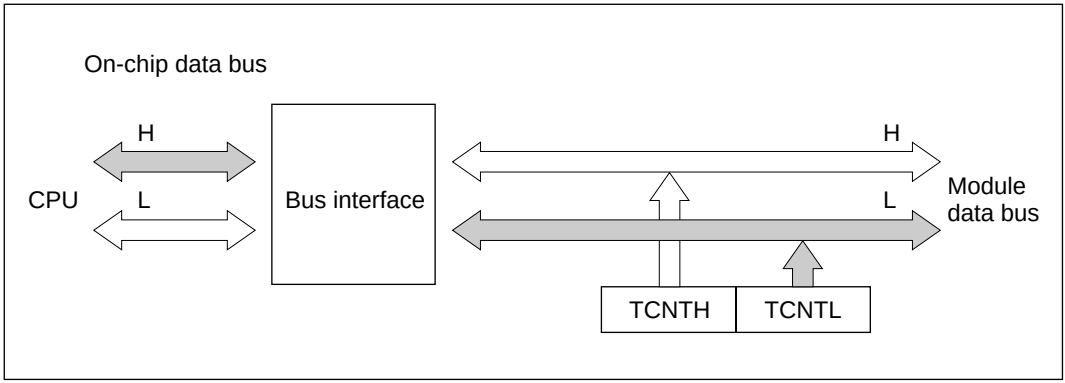


Figure 10-11 Access to Timer Counter (CPU Reads TCNT, Lower Byte)

10.3.2 8-Bit Accessible Registers

The registers other than the timer counters, general registers, and buffer registers are 8-bit registers. These registers are linked to the CPU by an internal 8-bit data bus.

Figures 10-12 and 10-13 show examples of byte read and write access to a TCR.

If a word-size data transfer instruction is executed, two byte transfers are performed.

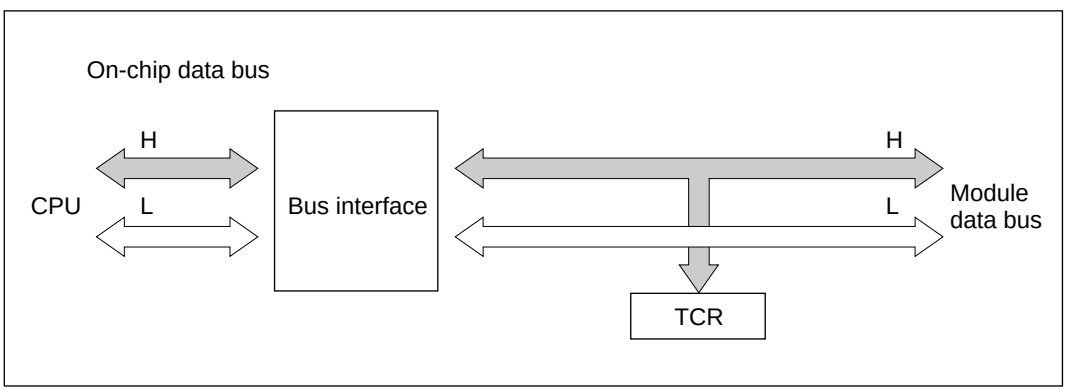


Figure 10-12 TCR Access (CPU Writes to TCR)

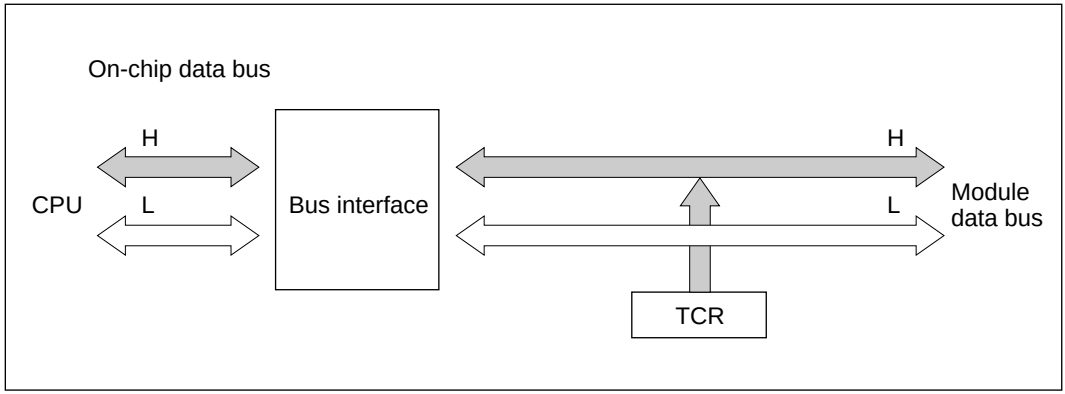


Figure 10-13 TCR Access (CPU Reads TCR)

10.4 Operation

10.4.1 Overview

A summary of operations in the various modes is given below.

Normal Operation: Each channel has a timer counter and general registers. The timer counter counts up, and can operate as a free-running counter, periodic counter, or external event counter. General registers A and B can be used for input capture or output compare.

Synchronous Operation: The timer counters in designated channels are preset synchronously. Data written to the timer counter in any one of these channels is simultaneously written to the timer counters in the other channels as well. The timer counters can also be cleared synchronously if so designated by the CCLR1 and CCLR0 bits in the TCRs.

PWM Mode: A PWM waveform is output from the TIOCA pin. The output goes to 1 at compare match A and to 0 at compare match B. The duty cycle can be varied from 0% to 100% depending on the settings of GRA and GRB. When a channel is set to PWM mode, its GRA and GRB automatically become output compare registers.

Reset-Synchronized PWM Mode: Channels 3 and 4 are paired for three-phase PWM output with complementary waveforms. (The three phases are related by having a common transition point.) When reset-synchronized PWM mode is selected GRA3, GRB3, GRA4, and GRB4 automatically function as output compare registers, TIOCA3, TIOCB3, TIOCA4, TOCXA4, TIOCB4, and TOCXB4 function as PWM output pins, and TCNT3 operates as an up-counter. TCNT4 operates independently, and is not compared with GRA4 or GRB4.

Complementary PWM Mode: Channels 3 and 4 are paired for three-phase PWM output with non-overlapping complementary waveforms. When complementary PWM mode is selected GRA3, GRB3, GRA4, and GRB4 automatically function as output compare registers, and TIOCA3, TIOCB3, TIOCA4, TOCXA4, TIOCB4, and TOCXB4 function as PWM output pins. TCNT3 and TCNT4 operate as up/down-counters.

Phase Counting Mode: The phase relationship between two clock signals input at TCLKA and TCLKB is detected and TCNT2 counts up or down accordingly. When phase counting mode is selected TCLKA and TCLKB become clock input pins and TCNT2 operates as an up/down-counter.

Buffering

- If the general register is an output compare register

  When compare match occurs the buffer register value is transferred to the general register.

- If the general register is an input capture register

  When input capture occurs the TCNT value is transferred to the general register, and the previous general register value is transferred to the buffer register.

- Complementary PWM mode

  The buffer register value is transferred to the general register when TCNT3 and TCNT4 change counting direction.

- Reset-synchronized PWM mode

  The buffer register value is transferred to the general register at GRA3 compare match.

10.4.2 Basic Functions

Counter Operation: When one of bits STR0 to STR4 is set to 1 in the timer start register (TSTR), the timer counter (TCNT) in the corresponding channel starts counting. The counting can be free-running or periodic.

- Sample setup procedure for counter

  Figure 10-14 shows a sample procedure for setting up a counter.

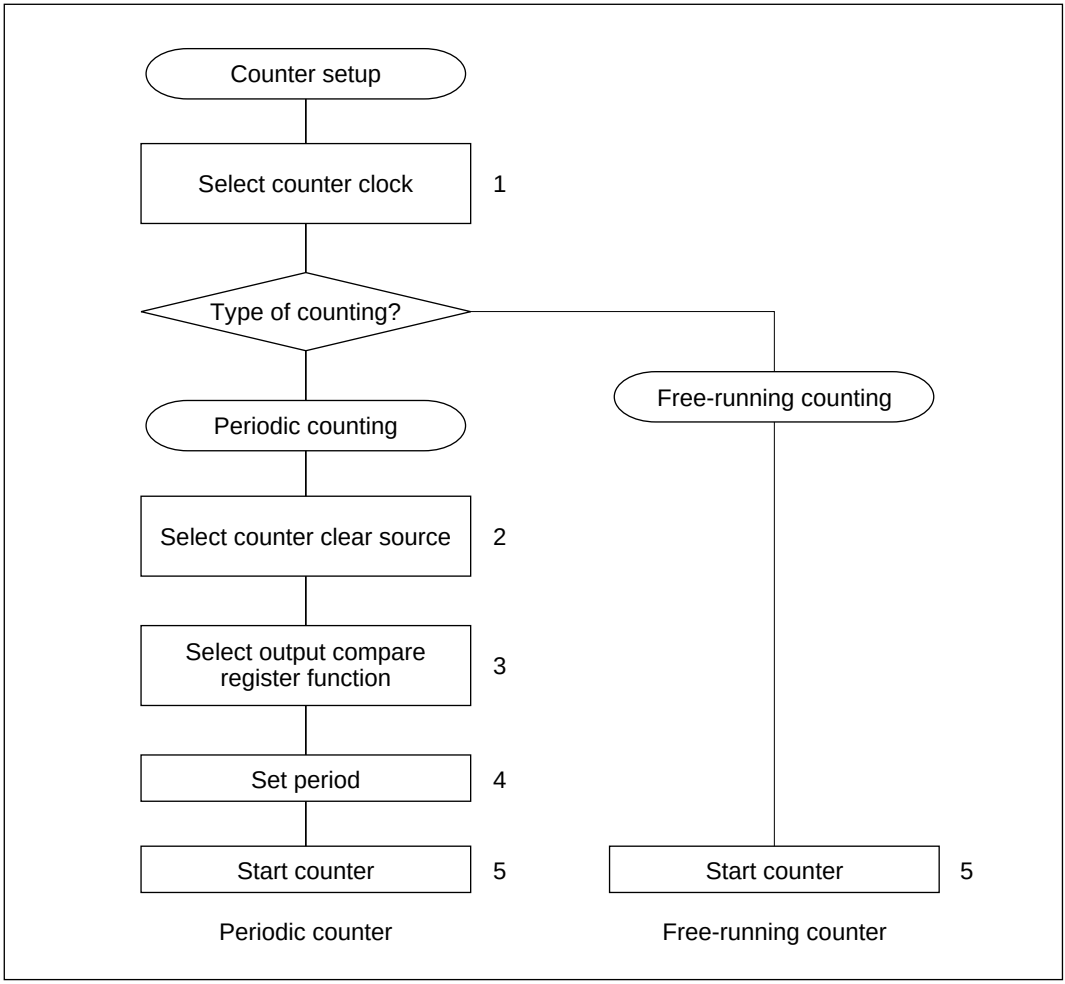


Figure 10-14 Counter Setup Procedure (Example)

1. Set bits TPSC2 to TPSC0 in TCR to select the counter clock source. If an external clock source is selected, set bits CKEG1 and CKEG0 in TCR to select the desired edge(s) of the external clock signal.
2. For periodic counting, set CCLR1 and CCLR0 in TCR to have TCNT cleared at GRA compare match or GRB compare match.
3. Set TIOR to select the output compare function of GRA or GRB, whichever was selected in step 2.
4. Write the count period in GRA or GRB, whichever was selected in step 2.
5. Set the STR bit to 1 in TSTR to start the timer counter.

- Free-running and periodic counter operation

  A reset leaves the counters (TCNTs) in ITU channels 0 to 4 all set as free-running counters. A free-running counter starts counting up when the corresponding bit in TSTR is set to 1. When the count overflows from H'FFFF to H'0000, the overflow flag (OVF) is set to 1 in the timer status register (TSR). If the corresponding OVIE bit is set to 1 in the timer interrupt enable register, a CPU interrupt is requested. After the overflow, the counter continues counting up from H'0000. Figure 10-15 illustrates free-running counting.

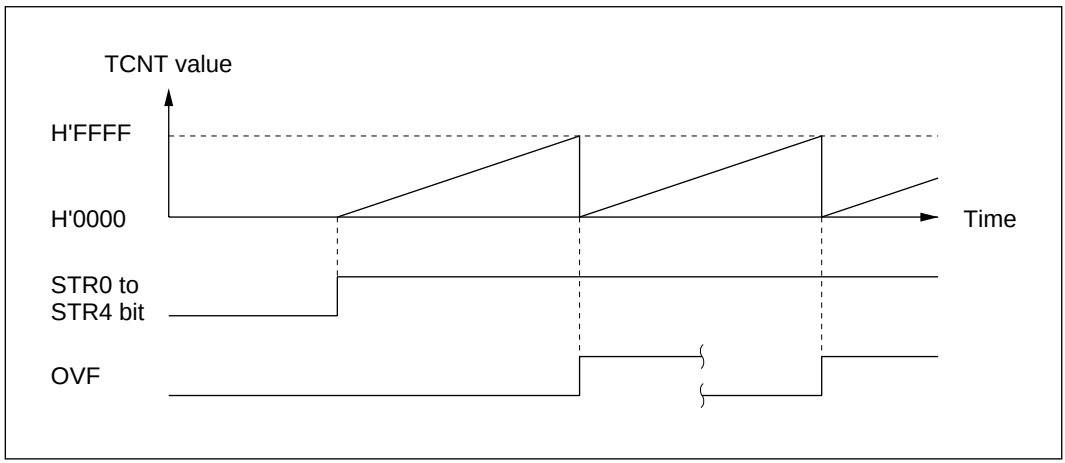


Figure 10-15 Free-Running Counter Operation

When a channel is set to have its counter cleared by compare match, in that channel TCNT operates as a periodic counter. Select the output compare function of GRA or GRB, set bit CCLR1 or CCLR0 in the timer control register (TCR) to have the counter cleared by compare match, and set the count period in GRA or GRB. After these settings, the counter starts counting up as a periodic counter when the corresponding bit is set to 1 in TSTR. When the count matches GRA or GRB, the IMFA or IMFB flag is set to 1 in TSR and the counter is cleared to H'0000. If the corresponding IMIEA or IMIEB bit is set to 1 in TIER, a CPU interrupt is requested at this time. After the compare match, TCNT continues counting up from H'0000. Figure 10-16 illustrates periodic counting.

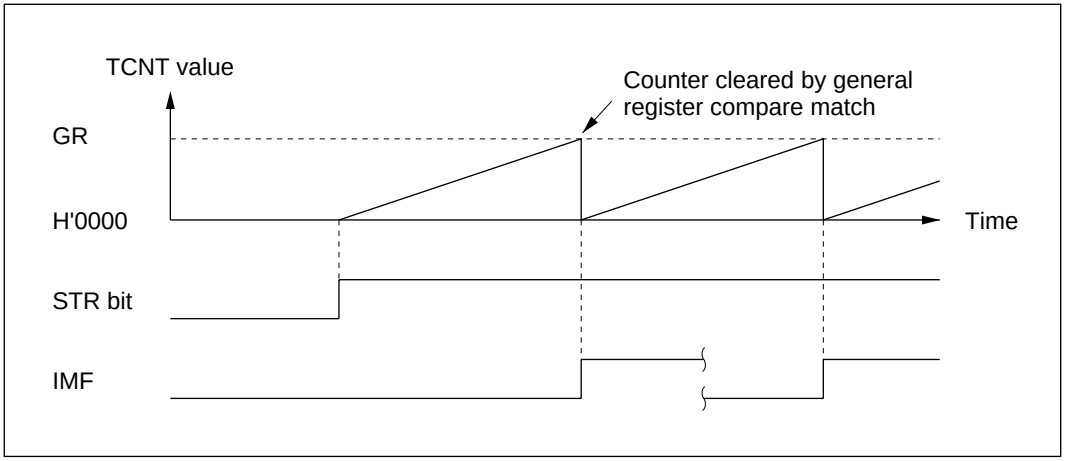


Figure 10-16 Periodic Counter Operation

- Count timing

  — Internal clock source

  Bits TPSC2 to TPSC0 in TCR select the system clock (ø) or one of three internal clock sources obtained by prescaling the system clock (ø/2, ø/4, ø/8).
  Figure 10-17 shows the timing.

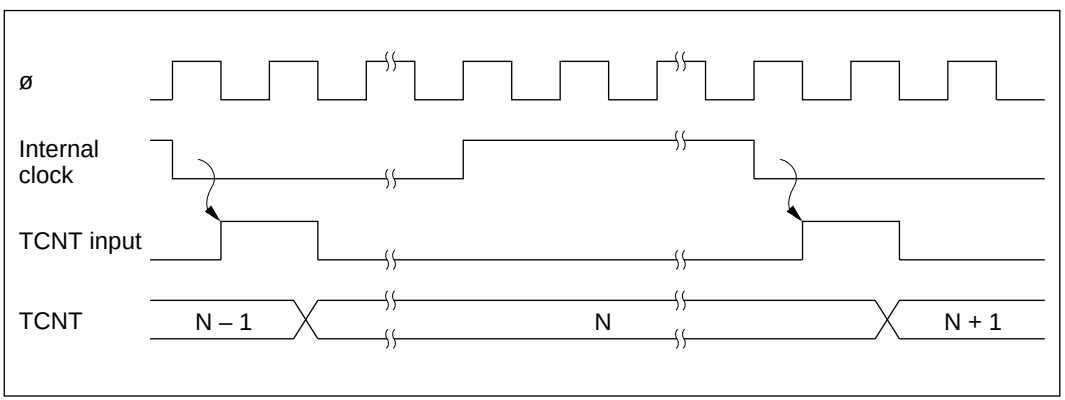


Figure 10-17 Count Timing for Internal Clock Sources

— External clock source

Bits TPSC2 to TPSC0 in TCR select an external clock input pin (TCLKA to TCLKD), and its valid edge or edges are selected by bits CKEG1 and CKEG0. The rising edge, falling edge, or both edges can be selected.

The pulse width of the external clock signal must be at least 1.5 system clocks when a single edge is selected, and at least 2.5 system clocks when both edges are selected. Shorter pulses will not be counted correctly.

Figure 10-18 shows the timing when both edges are detected.

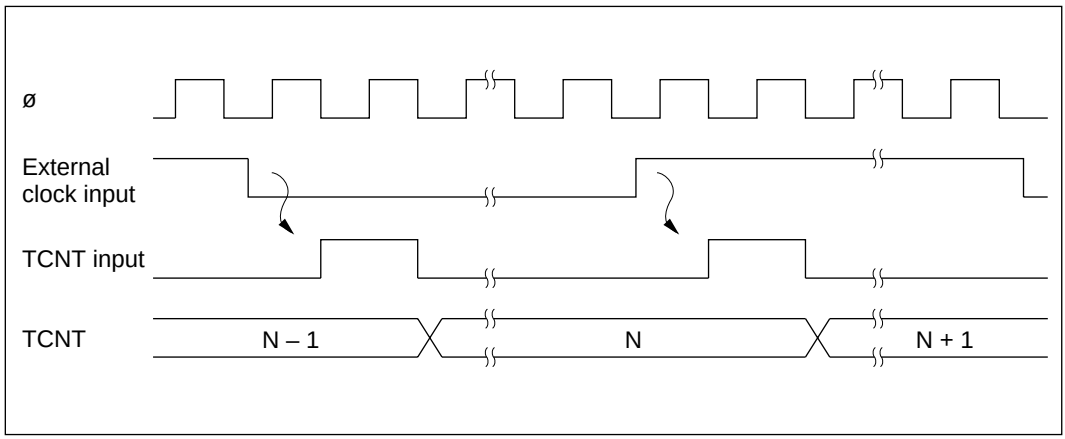


Figure 10-18 Count Timing for External Clock Sources (when Both Edges are Detected)

Waveform Output by Compare Match: In ITU channels 0, 1, 3, and 4, compare match A or B can cause the output at the TIOCA or TIOCB pin to go to 0, go to 1, or toggle. In channel 2 the output can only go to 0 or go to 1.

- Sample setup procedure for waveform output by compare match

  Figure 10-19 shows a sample procedure for setting up waveform output by compare match.

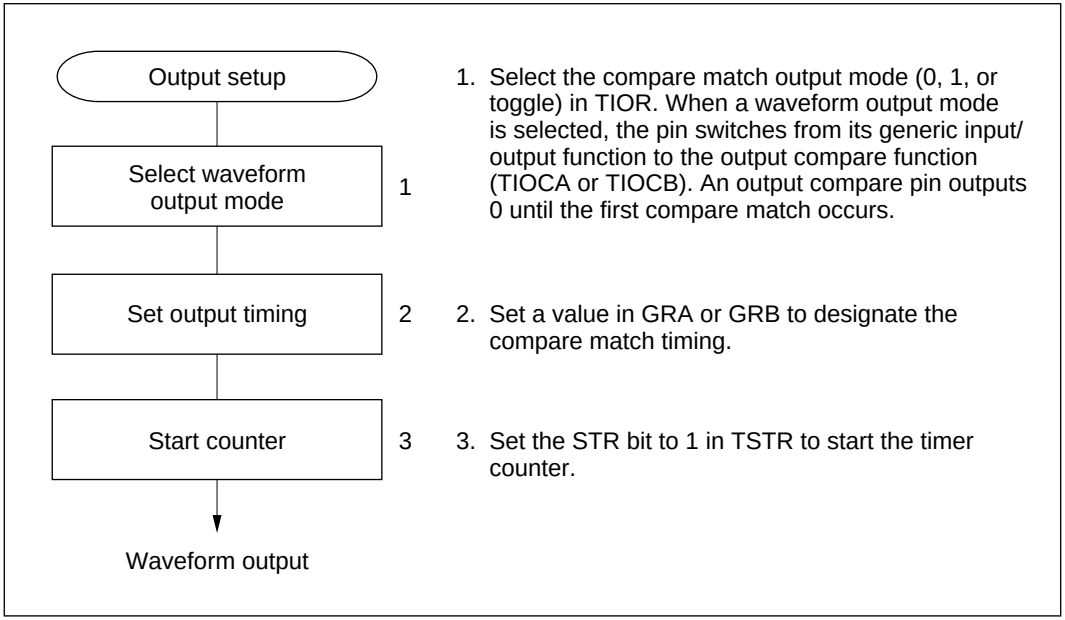


Figure 10-19 Setup Procedure for Waveform Output by Compare Match (Example)

- Examples of waveform output

  Figure 10-20 shows examples of 0 and 1 output. TCNT operates as a free-running counter, 0 output is selected for compare match A, and 1 output is selected for compare match B. When the pin is already at the selected output level, the pin level does not change.

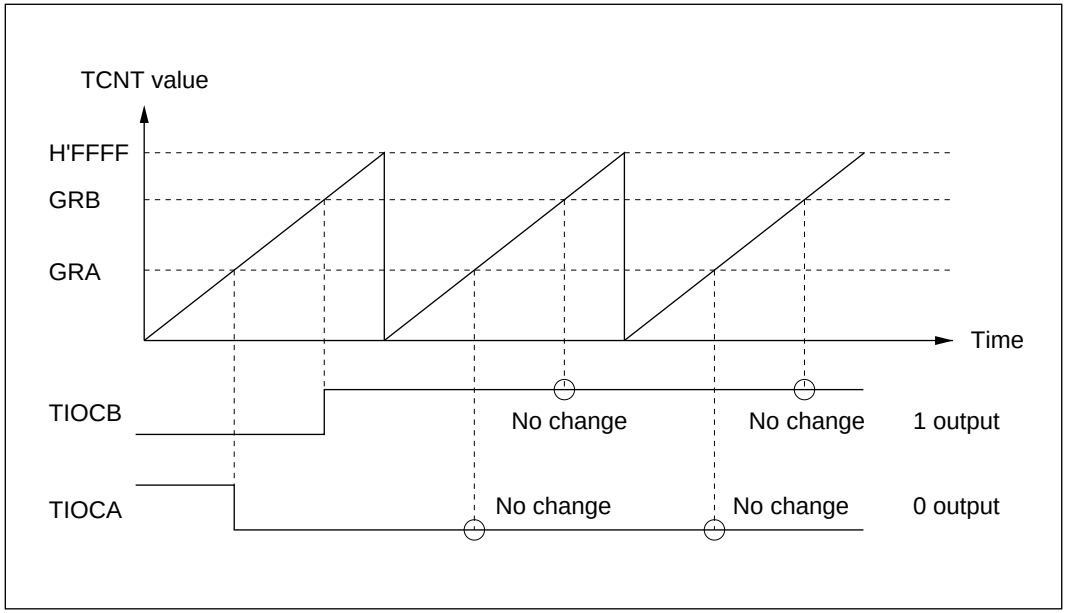


Figure 10-20 0 and 1 Output (Examples)

Figure 10-21 shows examples of toggle output. TCNT operates as a periodic counter, cleared by compare match B. Toggle output is selected for both compare match A and B.

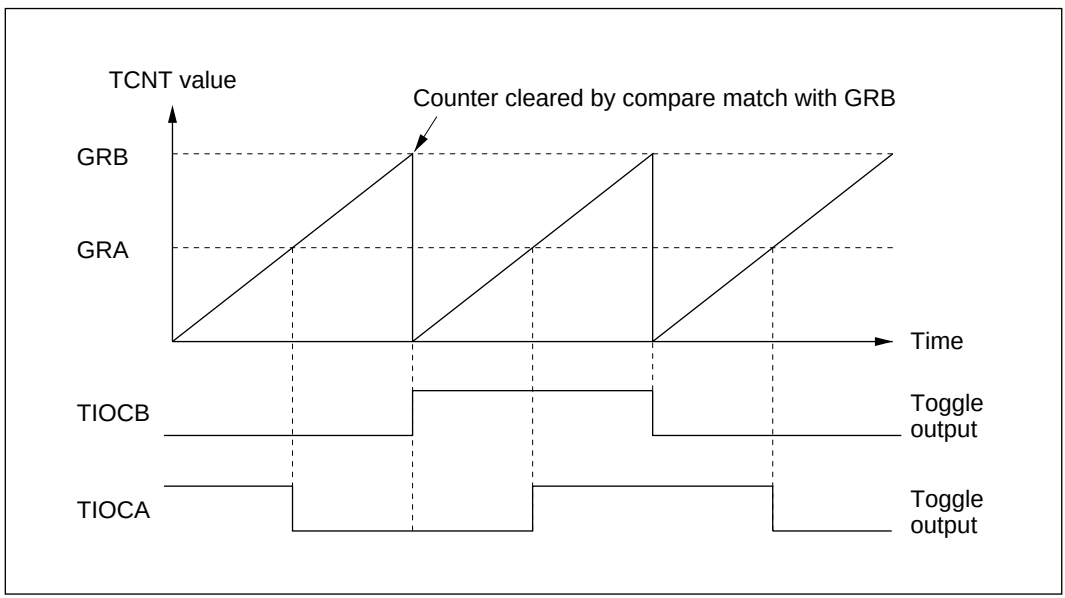


Figure 10-21 Toggle Output (Example)

- Output compare timing

  The compare match signal is generated in the last state in which TCNT and the general register match (when TCNT changes from the matching value to the next value). When the compare match signal is generated, the output value selected in TIOR is output at the output compare pin (TIOCA or TIOCB). When TCNT matches a general register, the compare match signal is not generated until the next counter clock pulse.
  Figure 10-22 shows the output compare timing.

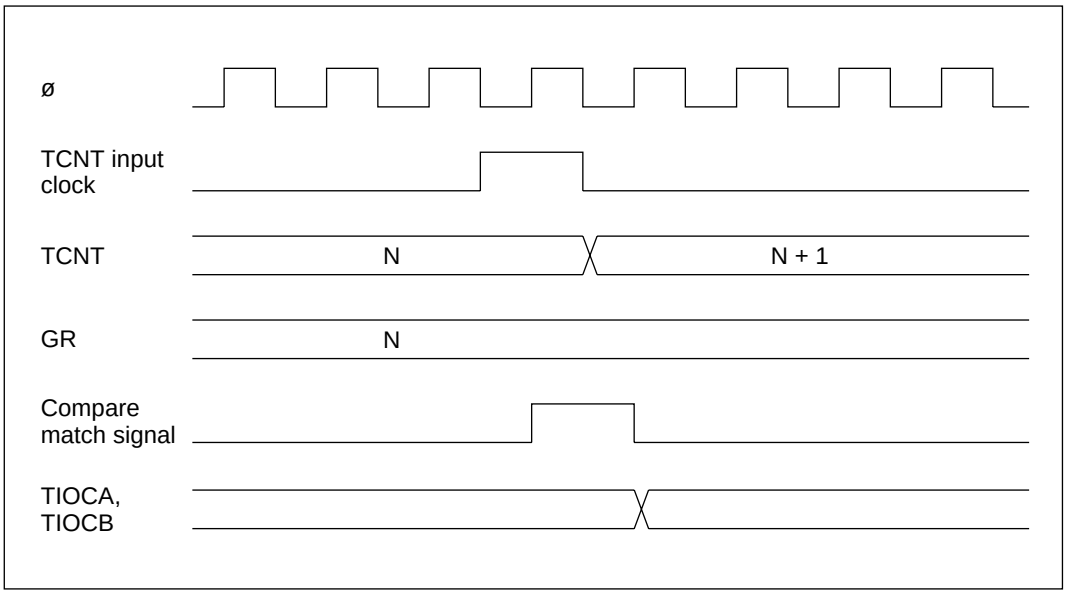


Figure 10-22 Output Compare Timing

Input Capture Function: The TCNT value can be captured into a general register when a transition occurs at an input capture/output compare pin (TIOCA or TIOCB). Capture can take place on the rising edge, falling edge, or both edges. The input capture function can be used to measure pulse width or period.

- Sample setup procedure for input capture

  Figure 10-23 shows a sample procedure for setting up input capture.

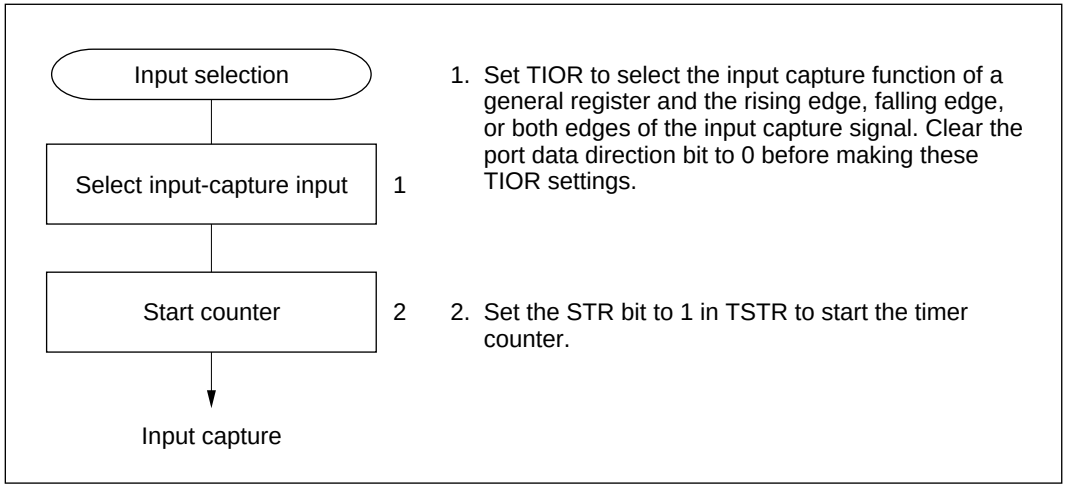


Figure 10-23 Setup Procedure for Input Capture (Example)

- Examples of input capture

  Figure 10-24 illustrates input capture when the falling edge of TIOCB and both edges of TIOCA are selected as capture edges. TCNT is cleared by input capture into GRB.

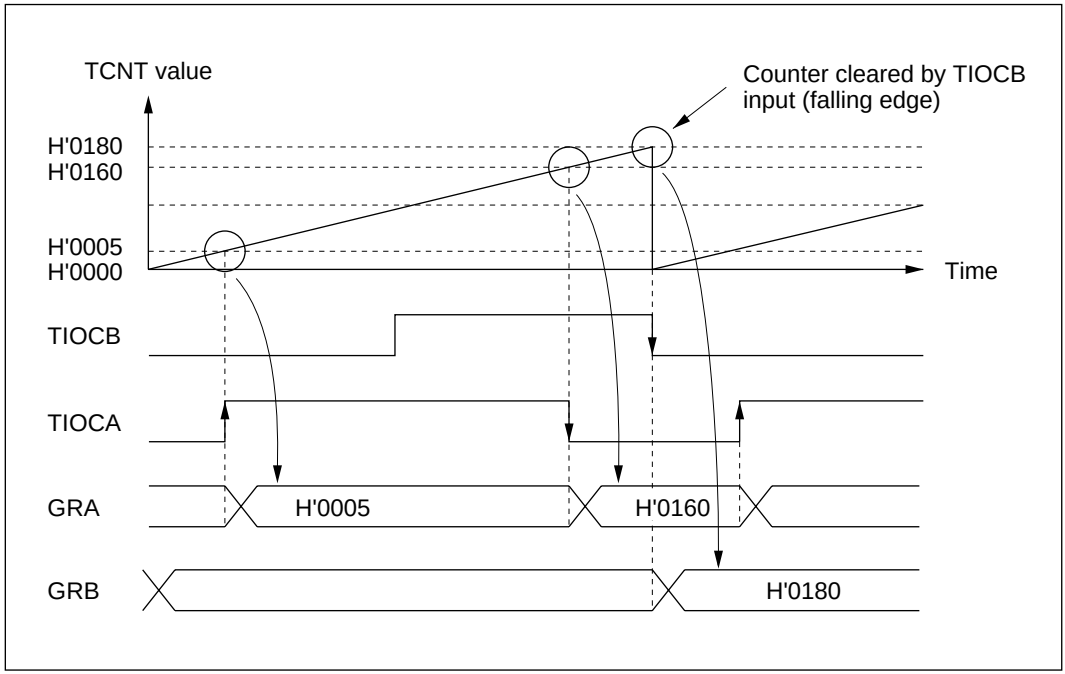


Figure 10-24 Input Capture (Example)

- Input capture signal timing

  Input capture on the rising edge, falling edge, or both edges can be selected by settings in TIOR. Figure 10-25 shows the timing when the rising edge is selected. The pulse width of the input capture signal must be at least 1.5 system clocks for single-edge capture, and 2.5 system clocks for capture of both edges.

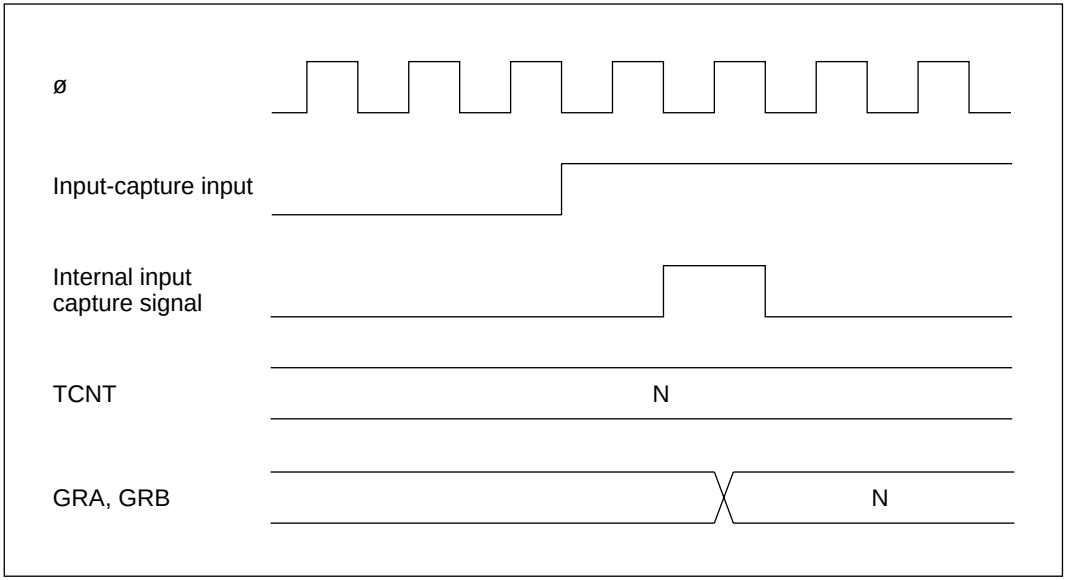
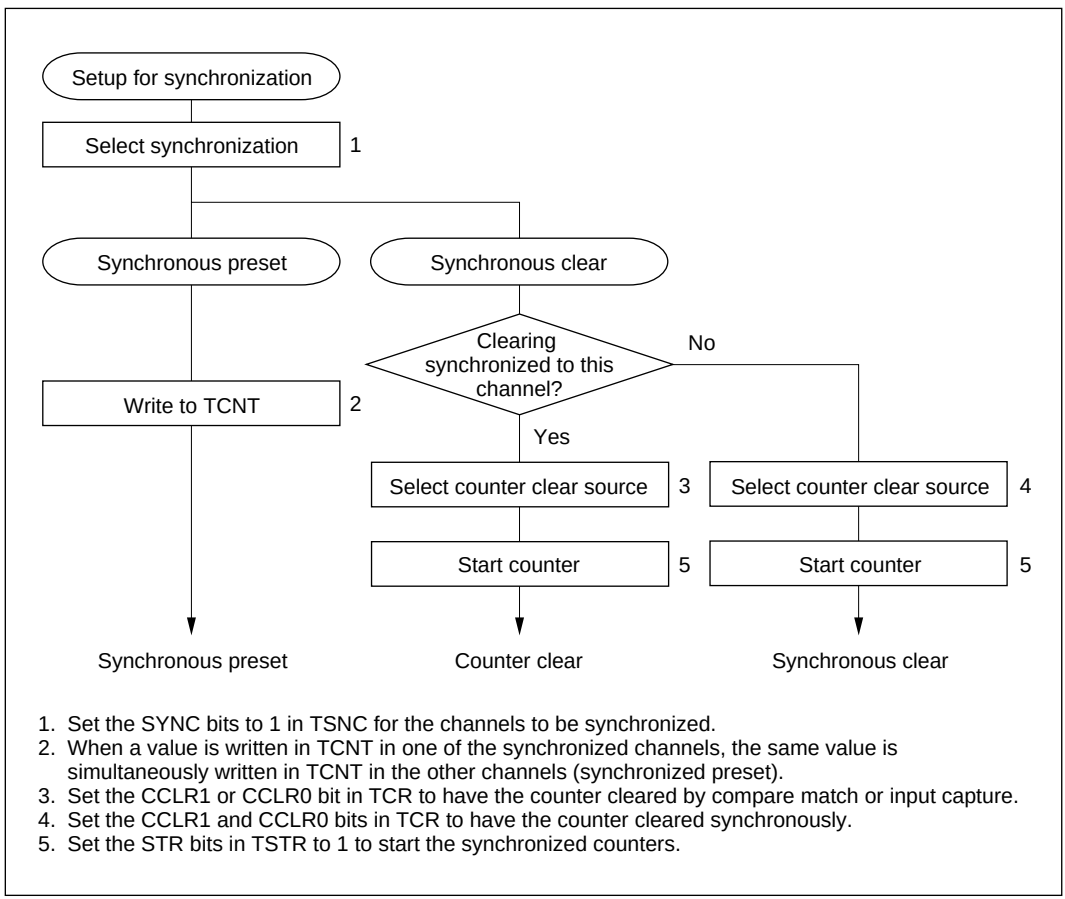


Figure 10-25 Input Capture Signal Timing

10.4.3 Synchronization

The synchronization function enables two or more timer counters to be synchronized by writing the same data to them simultaneously (synchronous preset). With appropriate TCR settings, two or more timer counters can also be cleared simultaneously (synchronous clear). Synchronization enables additional general registers to be associated with a single time base. Synchronization can be selected for all channels (0 to 4).

Sample Setup Procedure for Synchronization: Figure 10-26 shows a sample procedure for setting up synchronization.



1. Set the SYNC bits to 1 in TSNC for the channels to be synchronized.
2. When a value is written in TCNT in one of the synchronized channels, the same value is simultaneously written in TCNT in the other channels (synchronized preset).
3. Set the CCLR1 or CCLR0 bit in TCR to have the counter cleared by compare match or input capture.
4. Set the CCLR1 and CCLR0 bits in TCR to have the counter cleared synchronously.
5. Set the STR bits in TSTR to 1 to start the synchronized counters.

Figure 10-26 Setup Procedure for Synchronization (Example)

Example of Synchronization: Figure 10-27 shows an example of synchronization. Channels 0, 1, and 2 are synchronized, and are set to operate in PWM mode. Channel 0 is set for counter clearing by compare match with GRB0. Channels 1 and 2 are set for synchronous counter clearing. The timer counters in channels 0, 1, and 2 are synchronously preset, and are synchronously cleared by compare match with GRB0. A three-phase PWM waveform is output from pins TIOCA0, TIOCA1, and TIOCA2. For further information on PWM mode, see section 10.4.4, PWM Mode.

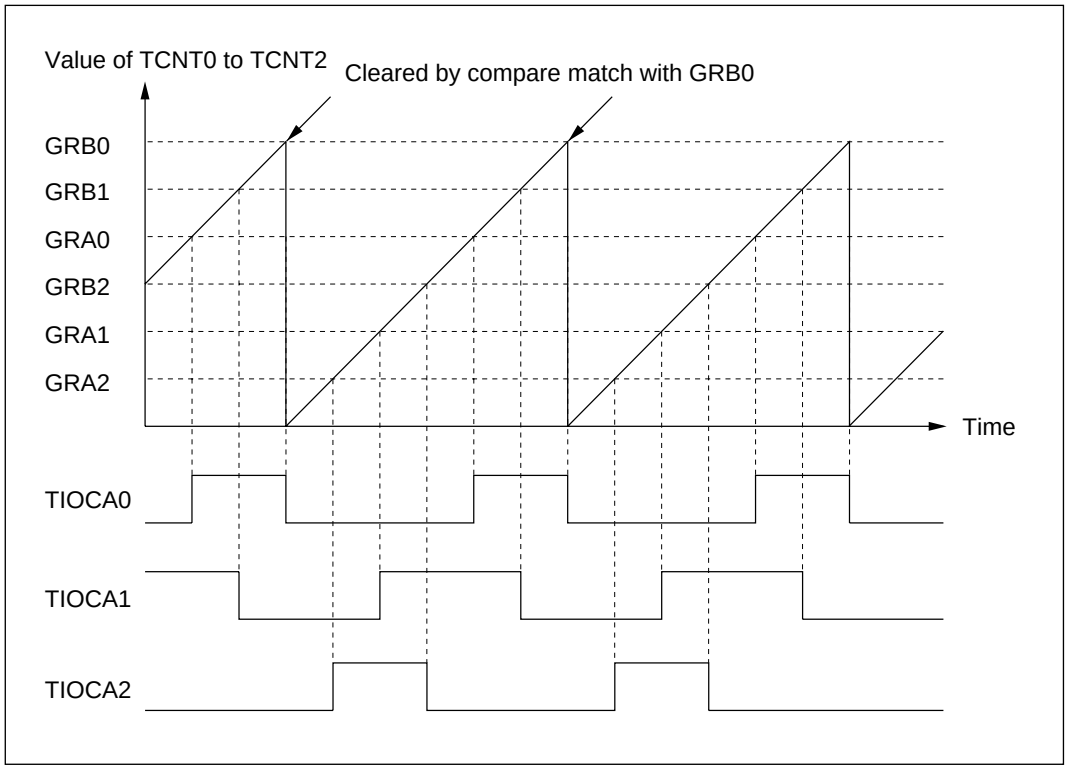


Figure 10-27 Synchronization (Example)

10.4.4 PWM Mode

In PWM mode GRA and GRB are paired and a PWM waveform is output from the TIOCA pin. GRA specifies the time at which the PWM output changes to 1. GRB specifies the time at which the PWM output changes to 0. If either GRA or GRB is selected as the counter clear source, a PWM waveform with a duty cycle from 0% to 100% is output at the TIOCA pin. PWM mode can be selected in all channels (0 to 4).

Table 10-4 summarizes the PWM output pins and corresponding registers. If the same value is set in GRA and GRB, the output does not change when compare match occurs.

Table 10-4 PWM Output Pins and Registers

Channel	Output Pin	1 Output	0 Output
0	TIOCA0	GRA0	GRB0
1	TIOCA1	GRA1	GRB1
2	TIOCA2	GRA2	GRB2
3	TIOCA3	GRA3	GRB3
4	TIOCA4	GRA4	GRB4

Sample Setup Procedure for PWM Mode: Figure 10-28 shows a sample procedure for setting up PWM mode.

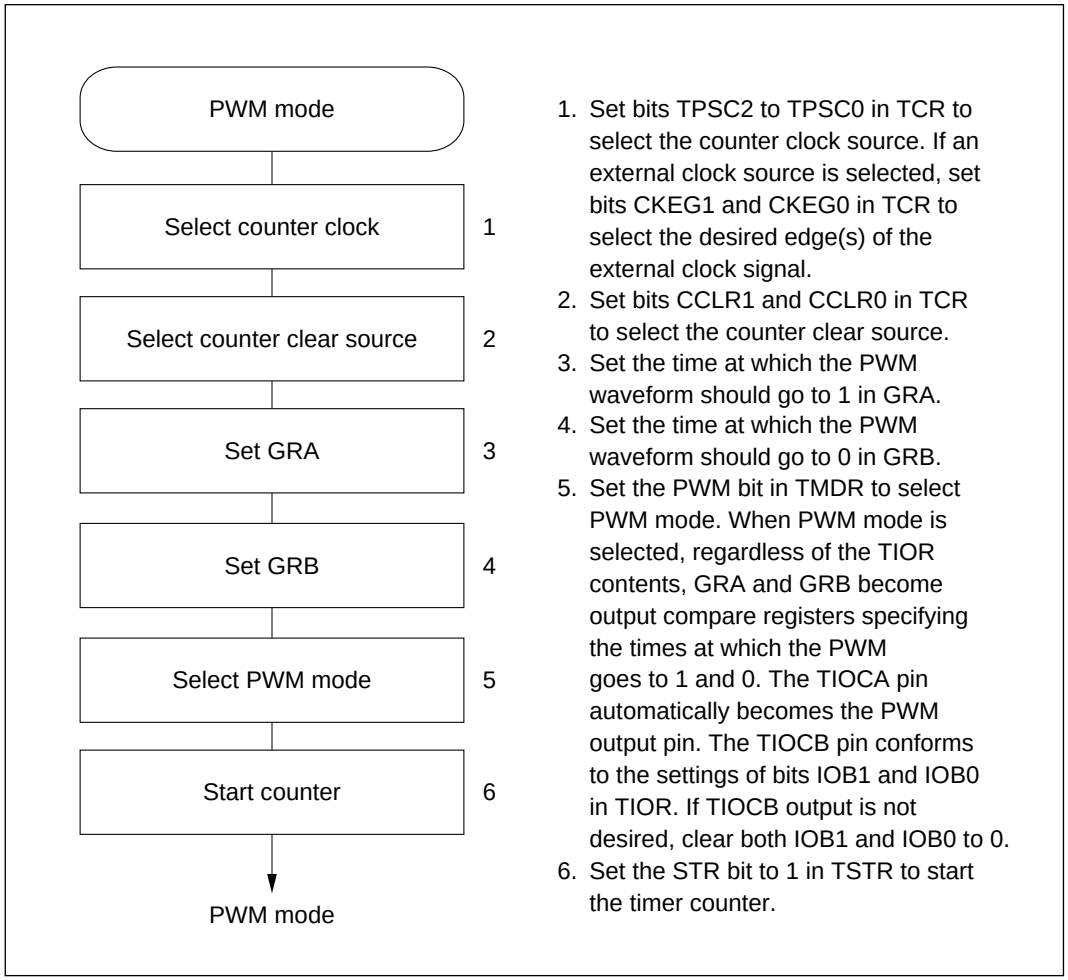


Figure 10-28 Setup Procedure for PWM Mode (Example)

Examples of PWM Mode: Figure 10-29 shows examples of operation in PWM mode. The PWM waveform is output from the TIOCA pin. The output goes to 1 at compare match with GRA, and to 0 at compare match with GRB.

In the examples shown, TCNT is cleared by compare match with GRA or GRB. Synchronized operation and free-running counting are also possible.

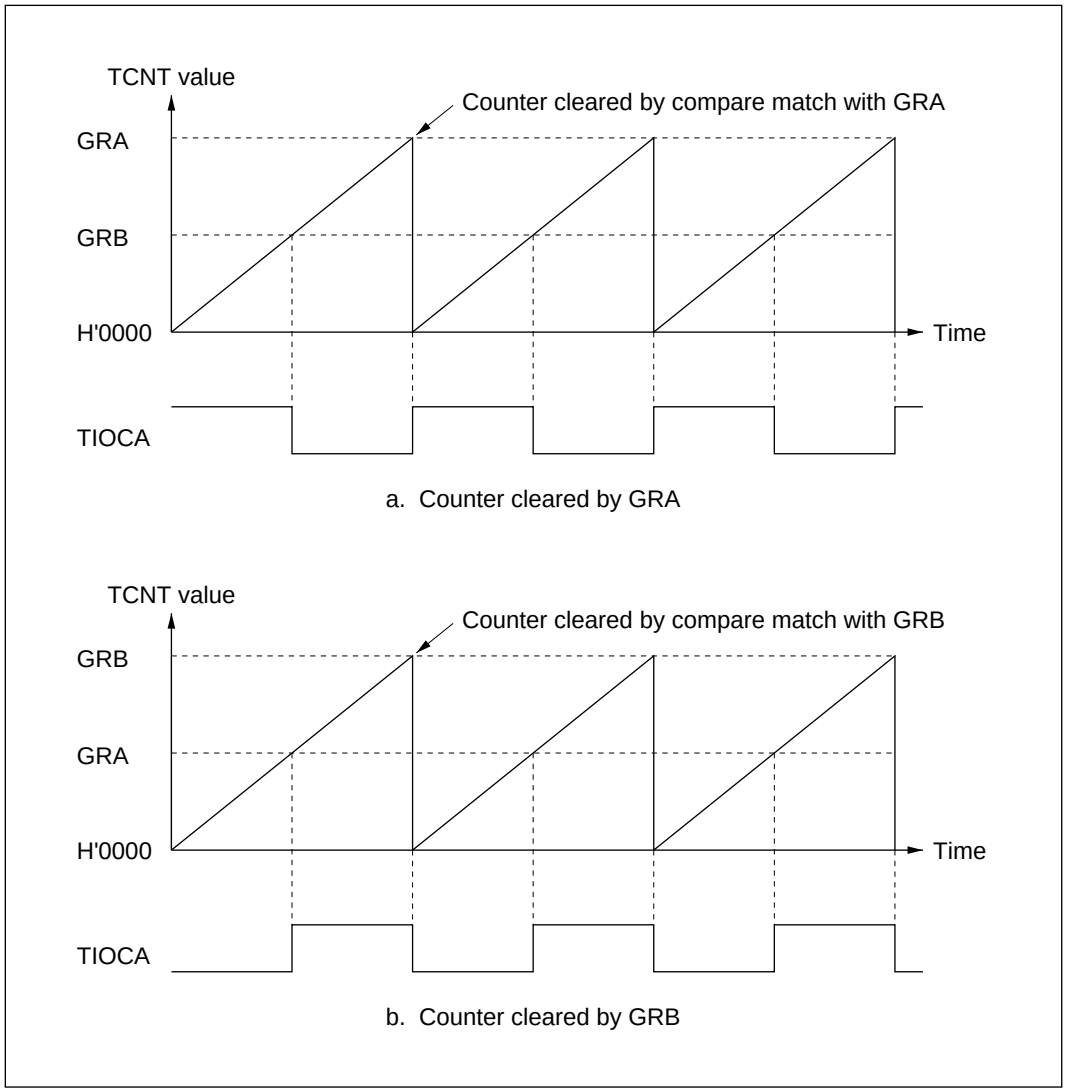


Figure 10-29 PWM Mode (Example 1)

Figure 10-30 shows examples of the output of PWM waveforms with duty cycles of 0% and 100%. If the counter is cleared by compare match with GRB, and GRA is set to a higher value than GRB, the duty cycle is 0%. If the counter is cleared by compare match with GRA, and GRB is set to a higher value than GRA, the duty cycle is 100%.

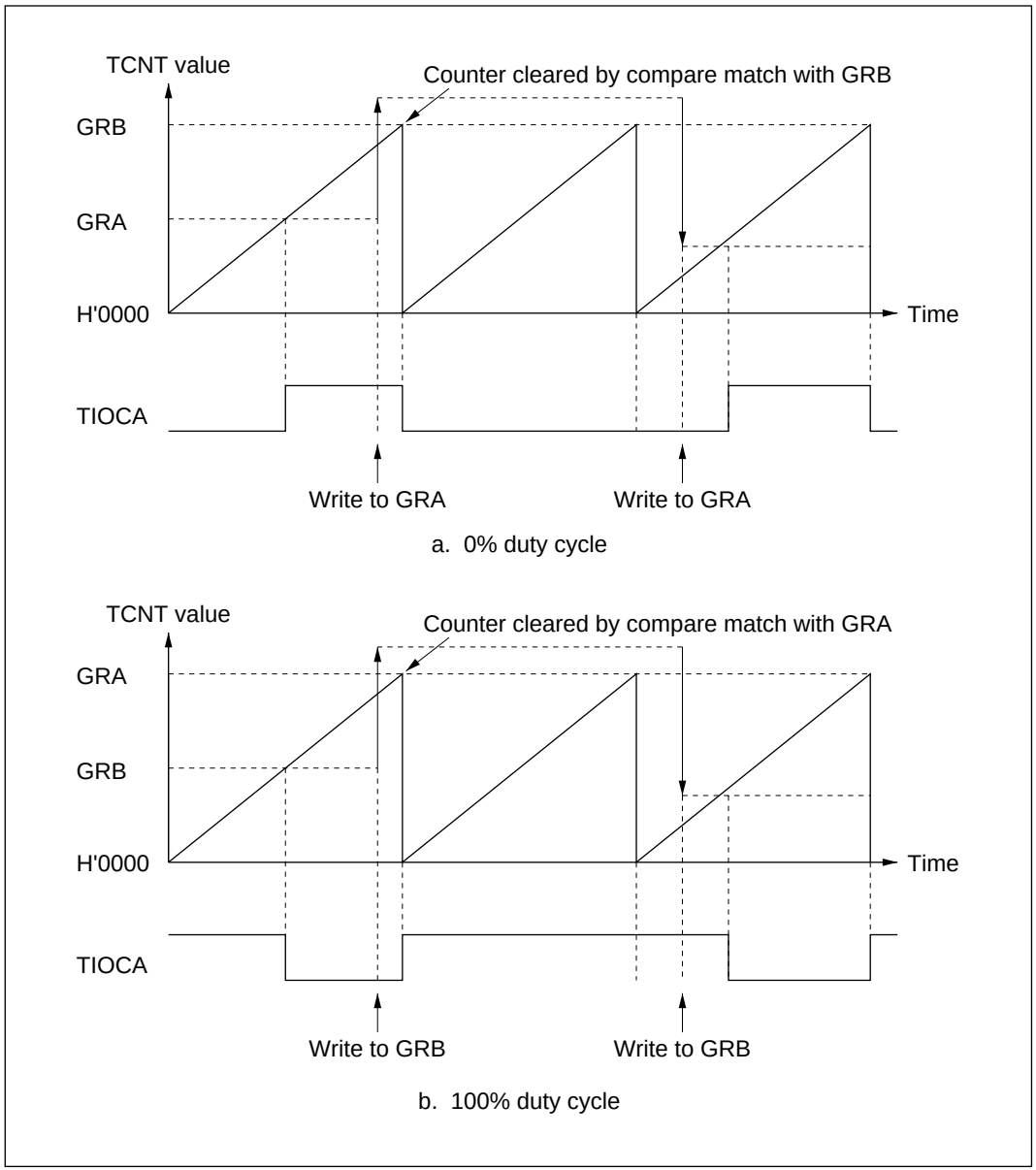


Figure 10-30 PWM Mode (Example 2)

10.4.5 Reset-Synchronized PWM Mode

In reset-synchronized PWM mode channels 3 and 4 are combined to produce three pairs of complementary PWM waveforms, all having one waveform transition point in common.

When reset-synchronized PWM mode is selected TIOCA3, TIOCB3, TIOCA4, TOCXA4, TIOCB4, and TOCXB4 automatically become PWM output pins, and TCNT3 functions as an up-counter.

Table 10-5 lists the PWM output pins. Table 10-6 summarizes the register settings.

Table 10-5 Output Pins in Reset-Synchronized PWM Mode

Channel	Output Pin	Description
3	TIOCA3	PWM output 1
	TIOCB3	PWM output 1′ (complementary waveform to PWM output 1)
4	TIOCA4	PWM output 2
	TOCXA4	PWM output 2′ (complementary waveform to PWM output 2)
	TIOCB4	PWM output 3
	TOCXB4	PWM output 3′ (complementary waveform to PWM output 3)

Table 10-6 Register Settings in Reset-Synchronized PWM Mode

Register	Setting
TCNT3	Initially set to H'0000
TCNT4	Not used (operates independently)
GRA3	Specifies the count period of TCNT3
GRB3	Specifies a transition point of PWM waveforms output from TIOCA3 and TIOCB3
GRA4	Specifies a transition point of PWM waveforms output from TIOCA4 and TOCXA4
GRB4	Specifies a transition point of PWM waveforms output from TIOCB4 and TOCXB4

Sample Setup Procedure for Reset-Synchronized PWM Mode: Figure 10-31 shows a sample procedure for setting up reset-synchronized PWM mode.

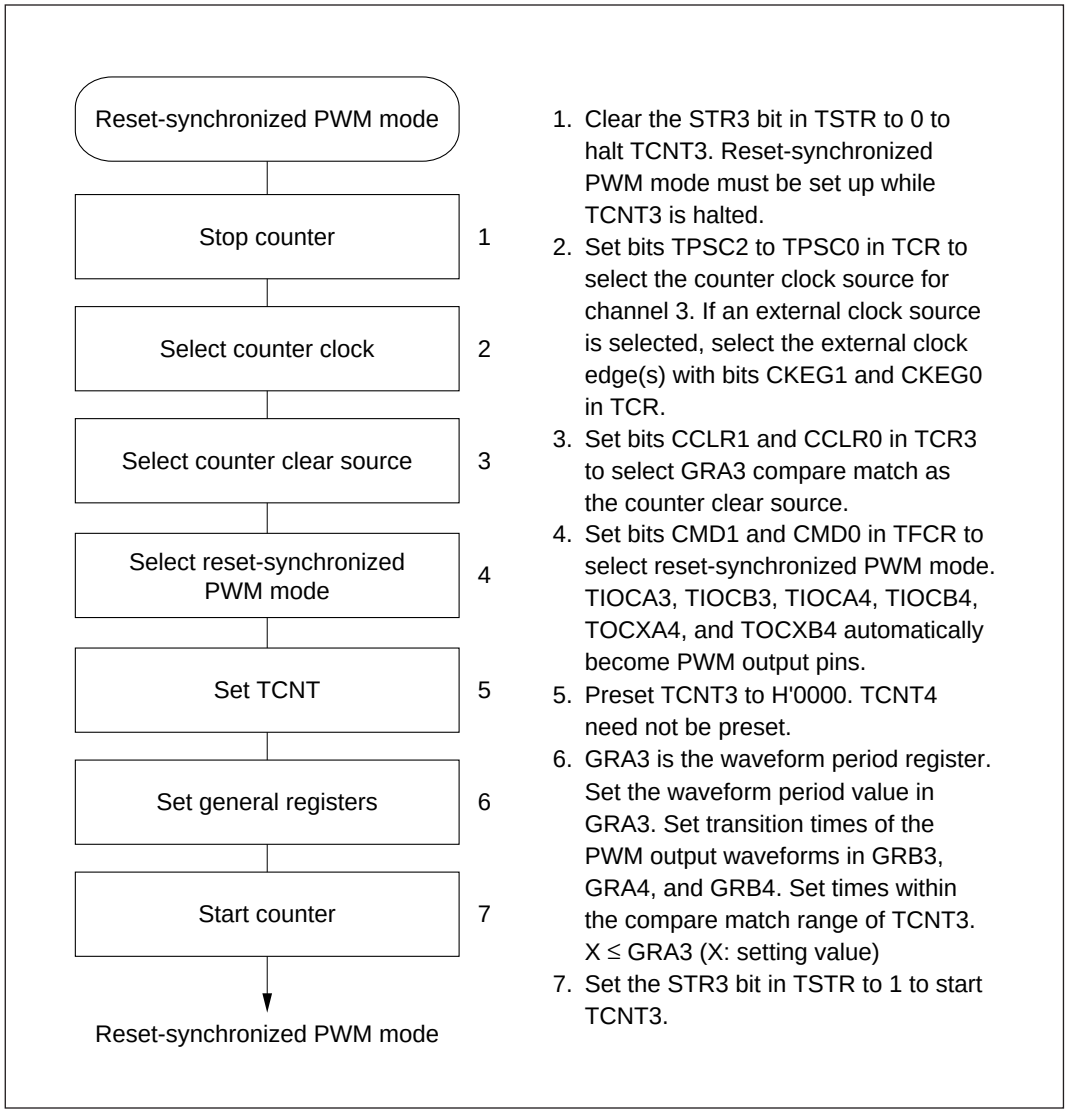


Figure 10-31 Setup Procedure for Reset-Synchronized PWM Mode (Example)

Example of Reset-Synchronized PWM Mode: Figure 10-32 shows an example of operation in reset-synchronized PWM mode. TCNT3 operates as an up-counter in this mode. TCNT4 operates independently, detached from GRA4 and GRB4. When TCNT3 matches GRA3, TCNT3 is cleared and resumes counting from H'0000. The PWM outputs toggle at compare match with GRB3, GRA4, GRB4, and TCNT3 respectively, and all toggle when the counter is cleared.

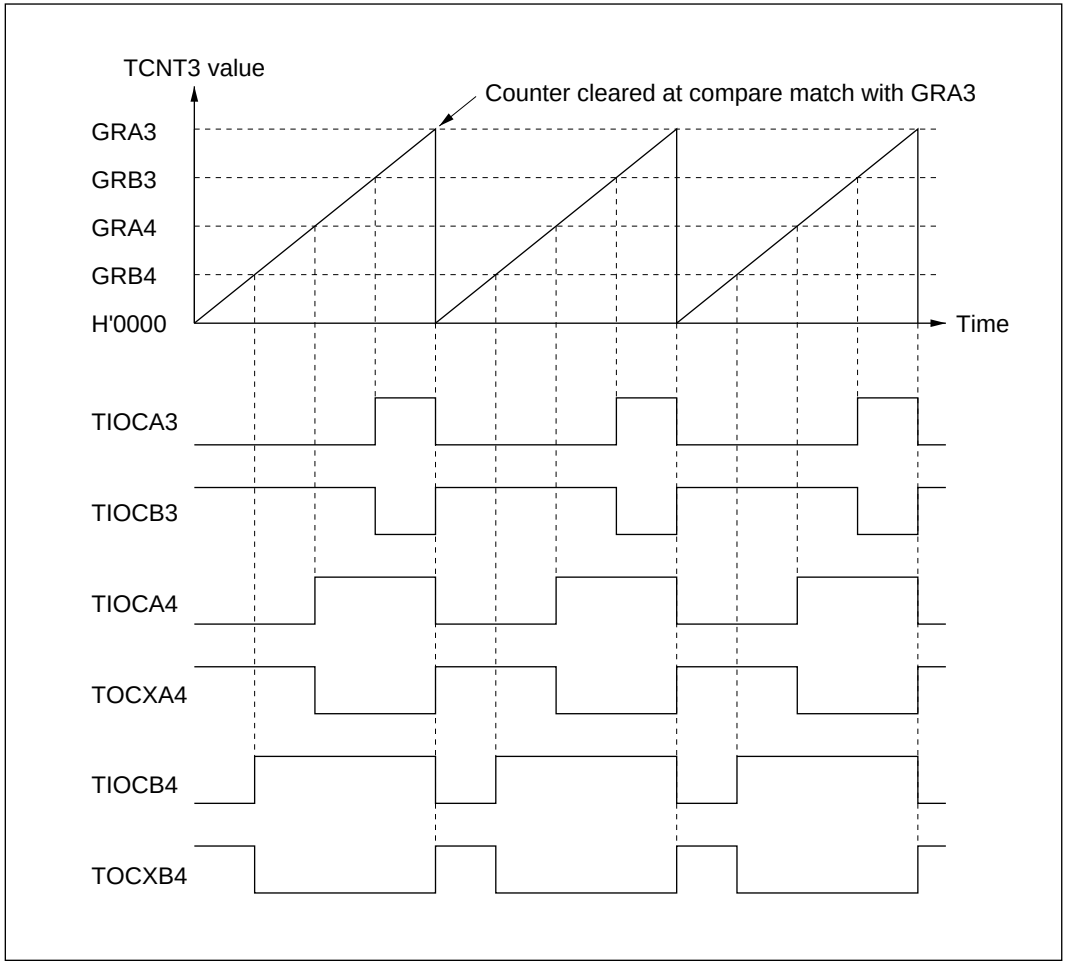


Figure 10-32 Operation in Reset-Synchronized PWM Mode (When OLS3 = OLS4 = 1) (Example)

For the settings and operation when reset-synchronized PWM mode and buffer mode are both selected, see section 10.4.8, Buffering.

10.4.6 Complementary PWM Mode

In complementary PWM mode channels 3 and 4 are combined to output three pairs of complementary, non-overlapping PWM waveforms.

When complementary PWM mode is selected $TIOCA_3$, $TIOCB_3$, $TIOCA_4$, $TOCXA_4$, $TIOCB_4$, and $TOCXB_4$ automatically become PWM output pins, and TCNT3 and TCNT4 function as up/down-counters.

Table 10-7 lists the PWM output pins. Table 10-8 summarizes the register settings.

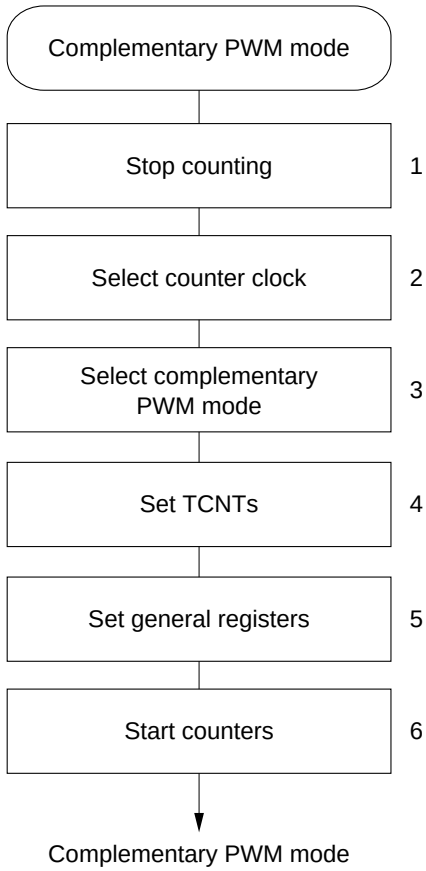
Table 10-7 Output Pins in Complementary PWM Mode

Channel	Output Pin	Description
3	$TIOCA_3$	PWM output 1
	$TIOCB_3$	PWM output 1′ (non-overlapping complementary waveform to PWM output 1)
4	$TIOCA_4$	PWM output 2
	$TOCXA_4$	PWM output 2′ (non-overlapping complementary waveform to PWM output 2)
	$TIOCB_4$	PWM output 3
	$TOCXB_4$	PWM output 3′ (non-overlapping complementary waveform to PWM output 3)

Table 10-8 Register Settings in Complementary PWM Mode

Register	Setting
TCNT3	Initially specifies the non-overlap margin (difference to TCNT4)
TCNT4	Initially set to H'0000
GRA3	Specifies the upper limit value of TCNT3 minus 1
GRB3	Specifies a transition point of PWM waveforms output from $TIOCA_3$ and $TIOCB_3$
GRA4	Specifies a transition point of PWM waveforms output from $TIOCA_4$ and $TOCXA_4$
GRB4	Specifies a transition point of PWM waveforms output from $TIOCB_4$ and $TOCXB_4$

Setup Procedure for Complementary PWM Mode: Figure 10-33 shows a sample procedure for setting up complementary PWM mode.



1. Clear bits STR3 and STR4 to 0 in TSTR to halt the timer counters. Complementary PWM mode must be set up while TCNT3 and TCNT4 are halted.
2. Set bits TPSC2 to TPSC0 in TCR to select the same counter clock source for channels 3 and 4. If an external clock source is selected, select the external clock edge(s) with bits CKEG1 and CKEG0 in TCR. Do not select any counter clear source with bits CCLR1 and CCLR0 in TCR.
3. Set bits CMD1 and CMD0 in TFCR to select complementary PWM mode. TIOCA3, TIOCB3, TIOCA4, TIOCB4, TOCXA4, and TOCXB4 automatically become PWM output pins.
4. Clear TCNT4 to H'0000. Set the non-overlap margin in TCNT3. Do not set TCNT3 and TCNT4 to the same value.
5. GRA3 is the waveform period register. Set the upper limit value of TCNT3 minus 1 in GRA3. Set transition times of the PWM output waveforms in GRB3, GRA4, and GRB4. Set times within the compare match range of TCNT3 and TCNT4. $T \leq X$ (X: initial setting of GRB3, GRA4, or GRB4. T: initial setting of TCNT3)
6. Set bits STR3 and STR4 in TSTR to 1 to start TCNT3 and TCNT4.

Note: After exiting complementary PWM mode, to resume operating in complementary PWM mode, follow the entire setup procedure from step 1 again.

Figure 10-33 Setup Procedure for Complementary PWM Mode (Example)

Clearing Procedure for Complementary PWM Mode: Figure 10-34 shows the steps to clear complementary PWM mode. First, (1) set combination mode (CMD) 1 and 0 bits in the timer function control register (TFCR) from 10 back to 00 or 01, to switch from complementary PWM mode to normal operating mode. Next, (2) wait at least one period of the counter input clock used by channels 3 and 4, then clear counter start (STR) 3 and 4 bits in the timer start register (TSTR) to stop operation of counters TCNT3 and TCNT4 in channels 3 and 4.

If a procedure other than that described above is used to clear complementary PWM mode, the output waveform may not change according to the setting when complementary PWM mode is set again.

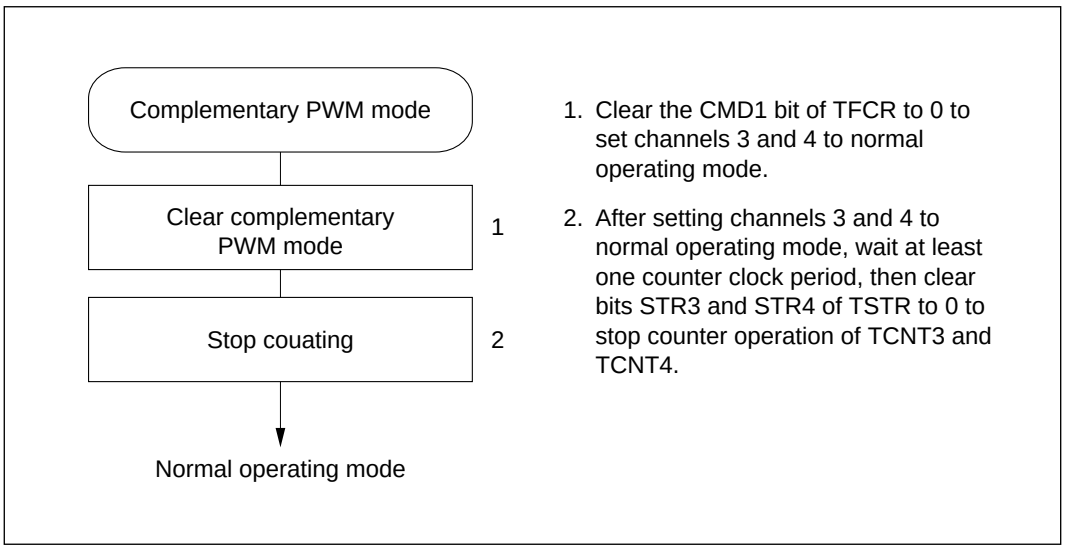


Figure 10-34 Clearing Procedure for Complementary PWM Mode

Examples of Complementary PWM Mode: Figure 10-35 shows an example of operation in complementary PWM mode. TCNT3 and TCNT4 operate as up/down-counters, counting down from compare match between TCNT3 and GRA3 and counting up from the point at which TCNT4 underflows. During each up-and-down counting cycle, PWM waveforms are generated by compare match with general registers GRB3, GRA4, and GRB4. Since TCNT3 is initially set to a higher value than TCNT4, compare match events occur in the sequence TCNT3, TCNT4, TCNT4, TCNT3.

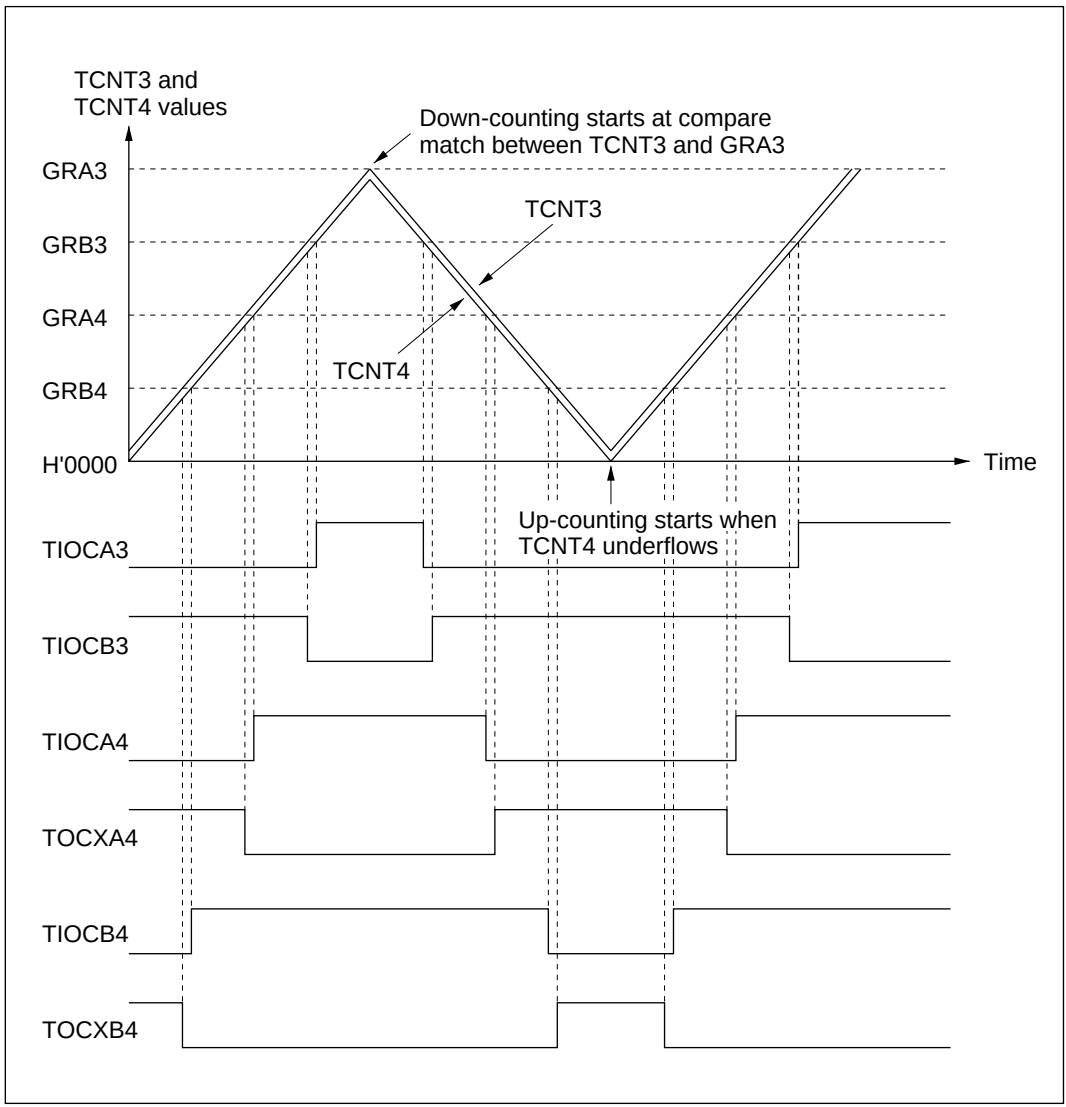


Figure 10-35 Operation in Complementary PWM Mode (When OLS3 = OLS4 = 1) (Example 1)

Figure 10-36 shows examples of waveforms with 0% and 100% duty cycles (in one phase) in complementary PWM mode. In this example the outputs change at compare match with GRB3, so waveforms with duty cycles of 0% or 100% can be output by setting GRB3 to a value larger than GRA3. The duty cycle can be changed easily during operation by use of the buffer registers. For further information see section 10.4.8, Buffering.

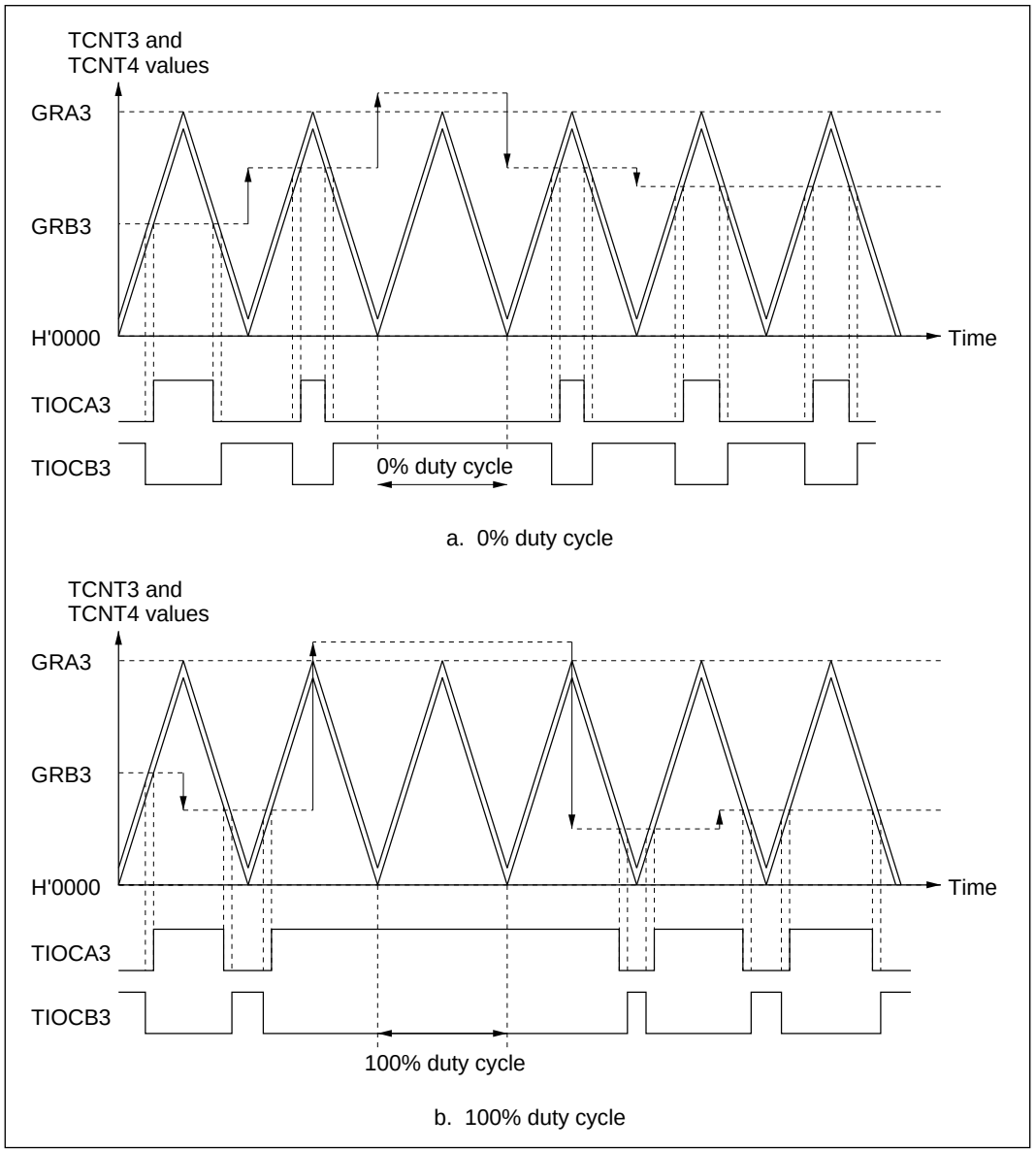


Figure 10-36 Operation in Complementary PWM Mode (When OLS3 = OLS4 = 1) (Example 2)

In complementary PWM mode, TCNT3 and TCNT4 overshoot and undershoot at the transitions between up-counting and down-counting. The setting conditions for the IMFA bit in channel 3 and the OVF bit in channel 4 differ from the usual conditions. In buffered operation the buffer transfer conditions also differ. Timing diagrams are shown in figures 10-37 and 10-38.

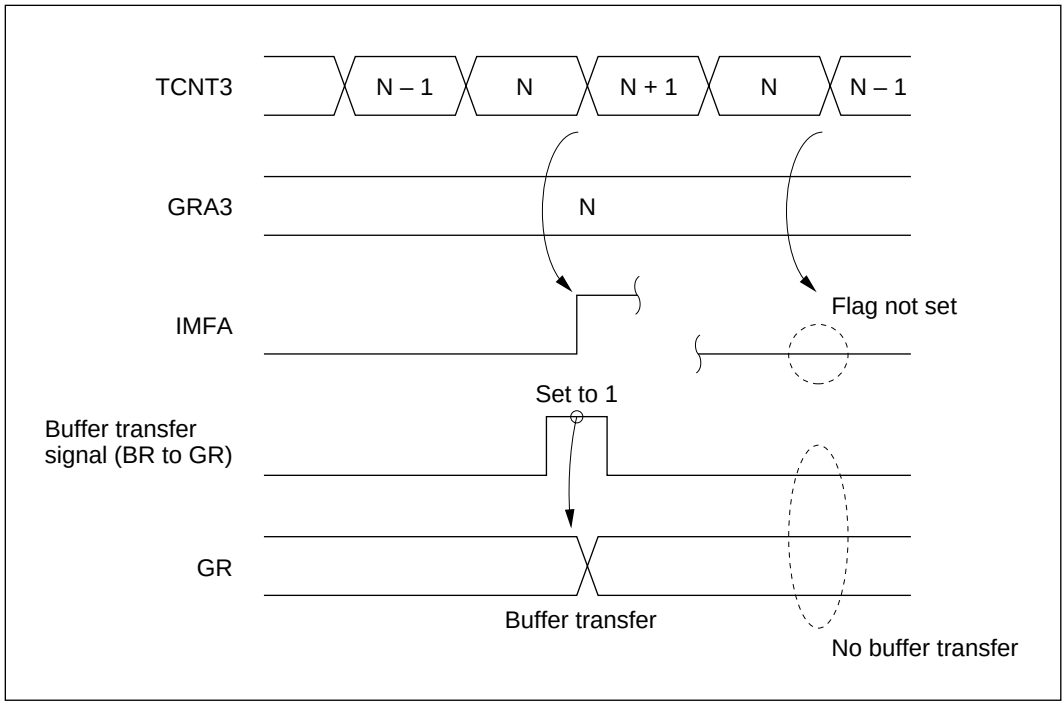


Figure 10-37 Overshoot Timing

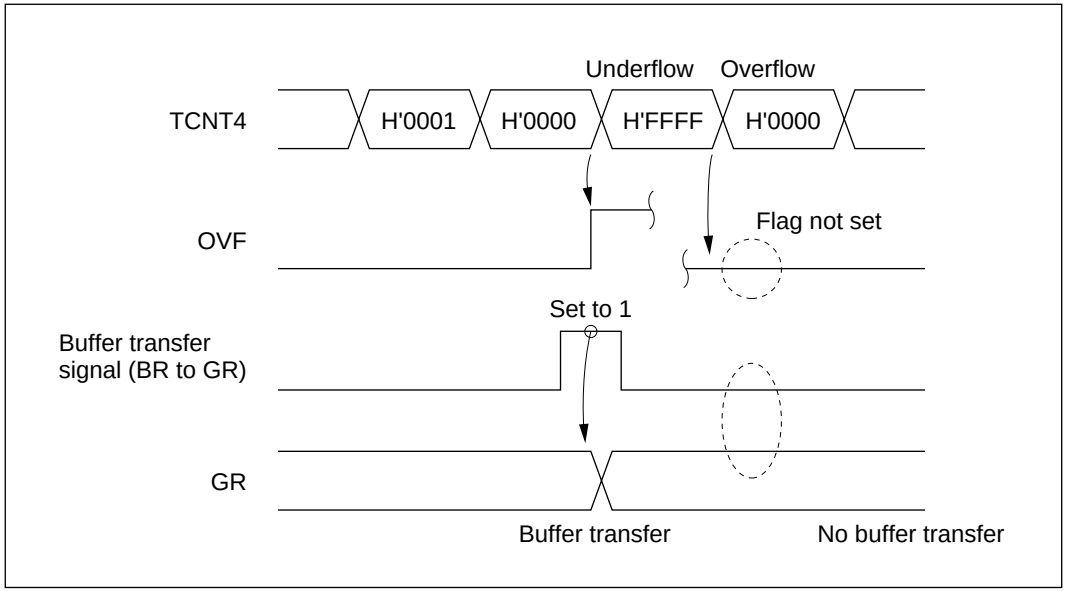


Figure 10-38 Undershoot Timing

In channel 3, IMFA is set to 1 only during up-counting. In channel 4, OVF is set to 1 only when an underflow occurs. When buffering is selected, buffer register contents are transferred to the general register at compare match A3 during up-counting, and when TCNT4 underflows.

General Register Settings in Complementary PWM Mode: When setting up general registers for complementary PWM mode or changing their settings during operation, note the following points.

- Initial settings

  Do not set values from H'0000 to T – 1 (where T is the initial value of TCNT3). After the counters start and the first compare match A3 event has occurred, however, settings in this range also become possible.

- Changing settings

  Use the buffer registers. Correct waveform output may not be obtained if a general register is written to directly.

- Cautions on changes of general register settings

  Figure 10-39 shows six correct examples and one incorrect example.

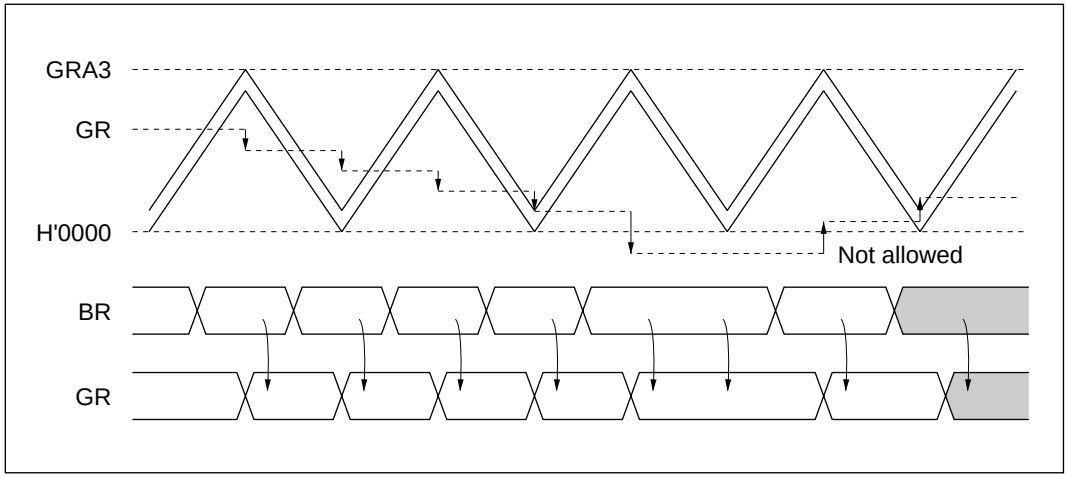


Figure 10-39 Changing a General Register Setting by Buffer Transfer (Example 1)

— Buffer transfer at transition from up-counting to down-counting

If the general register value is in the range from GRA3 – T + 1 to GRA3, do not transfer a buffer register value outside this range. Conversely, if the general register value is outside this range, do not transfer a value within this range. See figure 10-40.

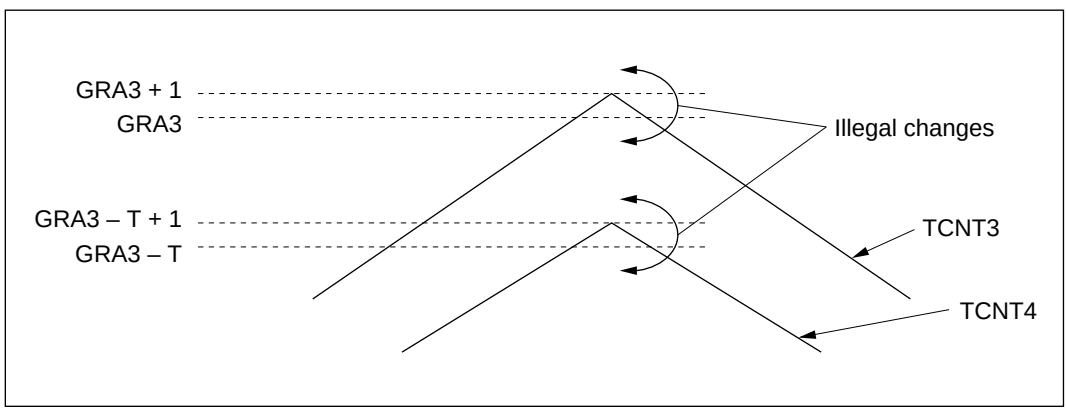


Figure 10-40 Changing a General Register Setting by Buffer Transfer (Caution 1)

— Buffer transfer at transition from down-counting to up-counting

If the general register value is in the range from H'0000 to T – 1, do not transfer a buffer register value outside this range. Conversely, when a general register value is outside this range, do not transfer a value within this range. See figure 10-41.

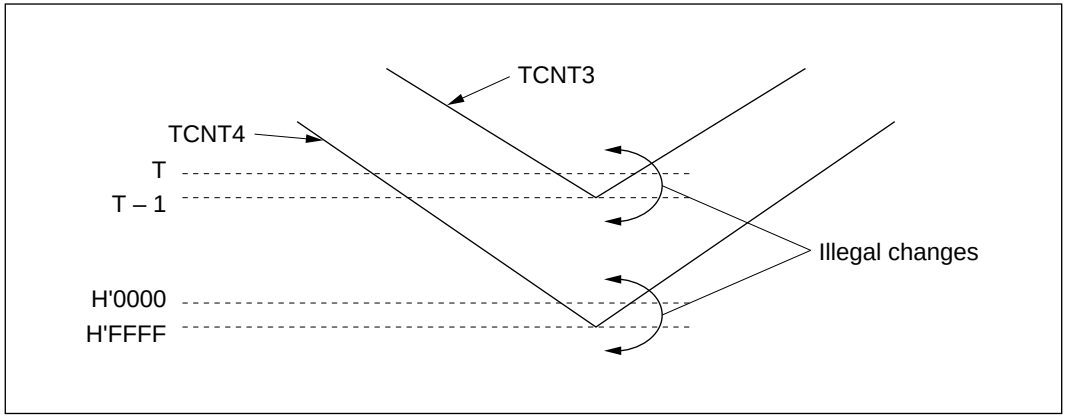


Figure 10-41 Changing a General Register Setting by Buffer Transfer (Caution 2)

— General register settings outside the counting range (H'0000 to GRA3)

Waveforms with a duty cycle of 0% or 100% can be output by setting a general register to a value outside the counting range. When a buffer register is set to a value outside the counting range, then later restored to a value within the counting range, the counting direction (up or down) must be the same both times. See figure 10-42.

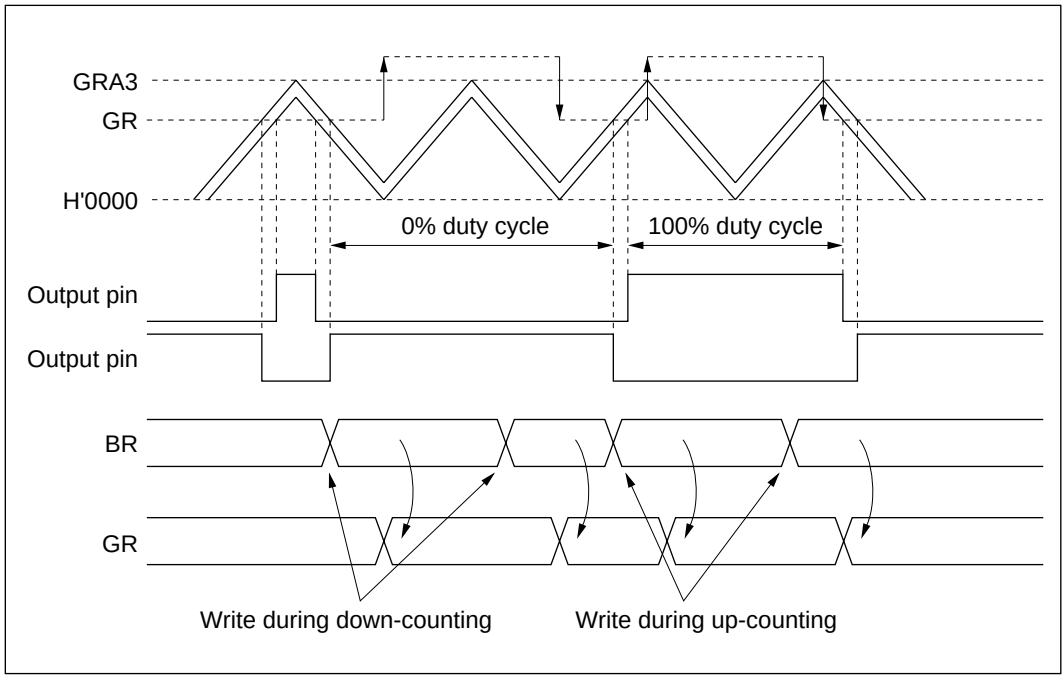


Figure 10-42 Changing a General Register Setting by Buffer Transfer (Example 2)

Settings can be made in this way by detecting GRA3 compare match or TCNT4 underflow before writing to the buffer register. They can also be made by using GRA3 compare match to activate the DMAC.

10.4.7 Phase Counting Mode

In phase counting mode the phase difference between two external clock inputs (at the TCLKA and TCLKB pins) is detected, and TCNT2 counts up or down accordingly.

In phase counting mode, the TCLKA and TCLKB pins automatically function as external clock input pins and TCNT2 becomes an up/down-counter, regardless of the settings of bits TPSC2 to TPSC0, CKEG1, and CKEG0 in TCR2. Settings of bits CCLR1, CCLR0 in TCR2, and settings in TIOR2, TIER2, TSR2, GRA2, and GRB2 are valid. The input capture and output compare functions can be used, and interrupts can be generated.

Phase counting is available only in channel 2.

Sample Setup Procedure for Phase Counting Mode: Figure 10-43 shows a sample procedure for setting up phase counting mode.

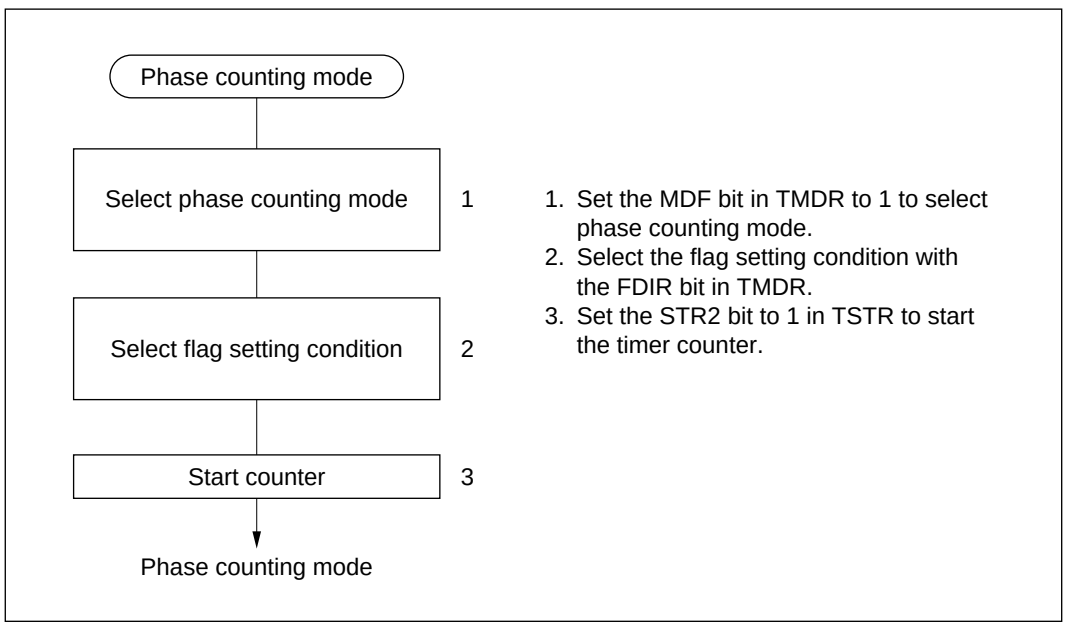


Figure 10-43 Setup Procedure for Phase Counting Mode (Example)

Example of Phase Counting Mode: Figure 10-44 shows an example of operations in phase counting mode. Table 10-9 lists the up-counting and down-counting conditions for TCNT2.

In phase counting mode both the rising and falling edges of TCLKA and TCLKB are counted. The phase difference between TCLKA and TCLKB must be at least 1.5 states, the phase overlap must also be at least 1.5 states, and the pulse width must be at least 2.5 states. See figure 10-45.

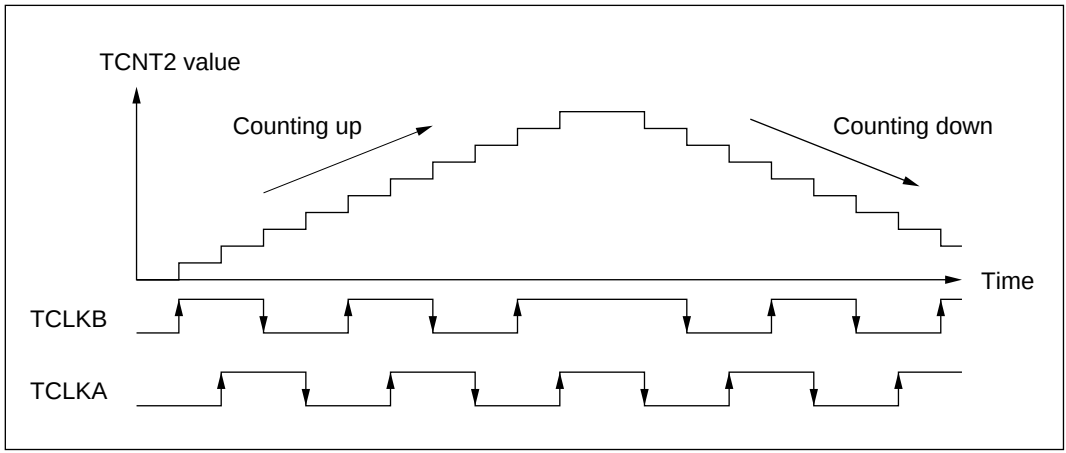


Figure 10-44 Operation in Phase Counting Mode (Example)

Table 10-9 Up/Down Counting Conditions

Counting Direction	Up-Counting				Down-Counting			
TCLKB	↑	High	↓	Low	High	↓	Low	↑
TCLKA	Low	↑	High	↓	↓	Low	↑	High

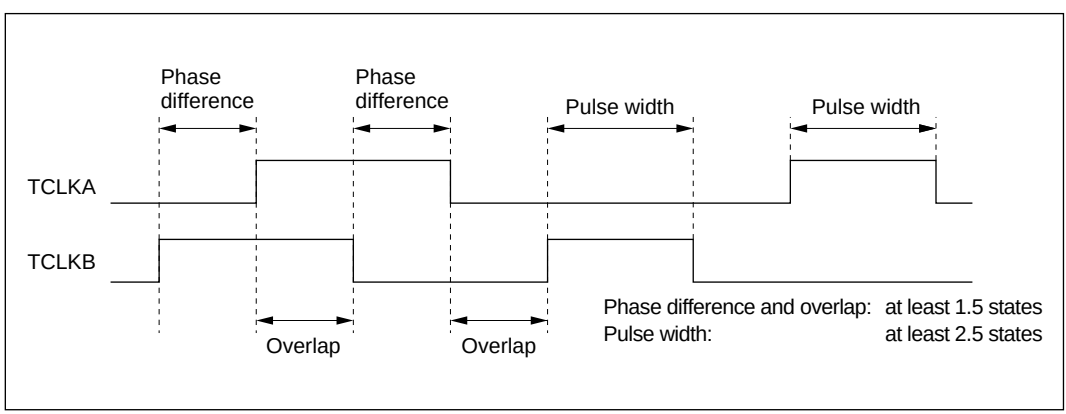


Figure 10-45 Phase Difference, Overlap, and Pulse Width in Phase Counting Mode

10.4.8 Buffering

Buffering operates differently depending on whether a general register is an output compare register or an input capture register, with further differences in reset-synchronized PWM mode and complementary PWM mode. Buffering is available only in channels 3 and 4. Buffering operations under the conditions mentioned above are described next.

- General register used for output compare

  The buffer register value is transferred to the general register at compare match. See figure 10-46.

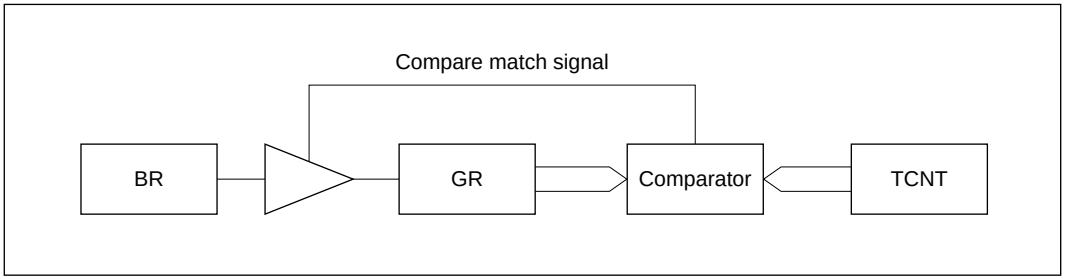


Figure 10-46 Compare Match Buffering

- General register used for input capture

  The TCNT value is transferred to the general register at input capture. The previous general register value is transferred to the buffer register.
  See figure 10-47.

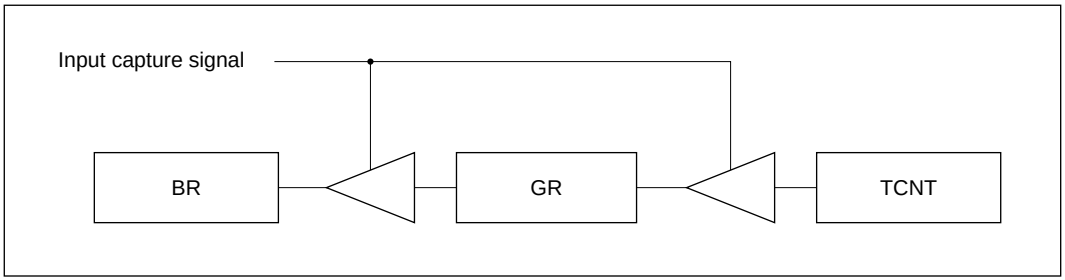


Figure 10-47 Input Capture Buffering

- Complementary PWM mode

  The buffer register value is transferred to the general register when TCNT3 and TCNT4 change counting direction. This occurs at the following two times:

  — When TCNT3 matches GRA3
  — When TCNT4 underflows

- Reset-synchronized PWM mode

  The buffer register value is transferred to the general register at compare match A3.

Sample Buffering Setup Procedure: Figure 10-48 shows a sample buffering setup procedure.

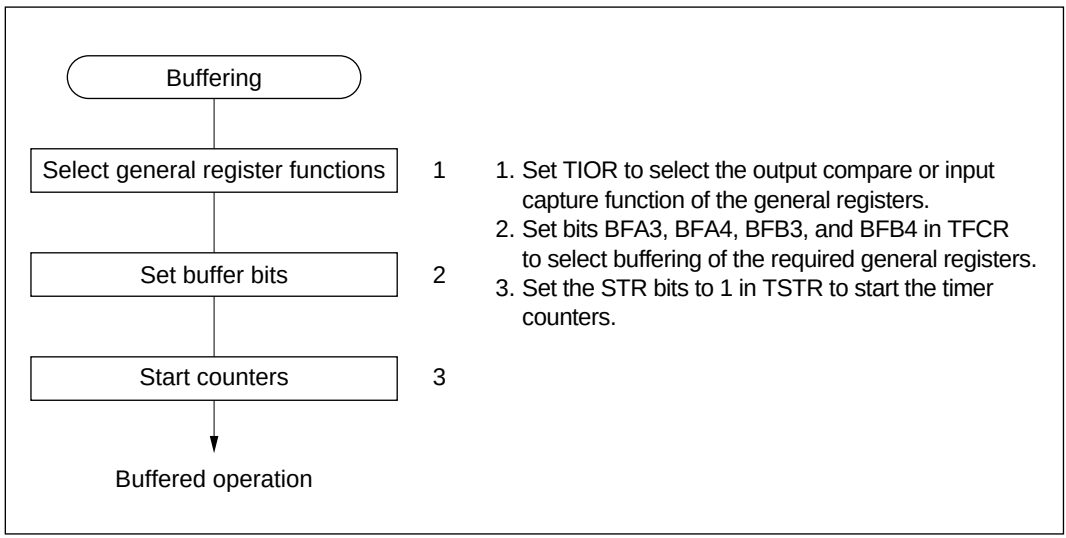


Figure 10-48 Buffering Setup Procedure (Example)

Examples of Buffering: Figure 10-49 shows an example in which GRA is set to function as an output compare register buffered by BRA, TCNT is set to operate as a periodic counter cleared by GRB compare match, and TIOCA and TIOCB are set to toggle at compare match A and B. Because of the buffer setting, when TIOCA toggles at compare match A, the BRA value is simultaneously transferred to GRA. This operation is repeated each time compare match A occurs. Figure 10-50 shows the transfer timing.

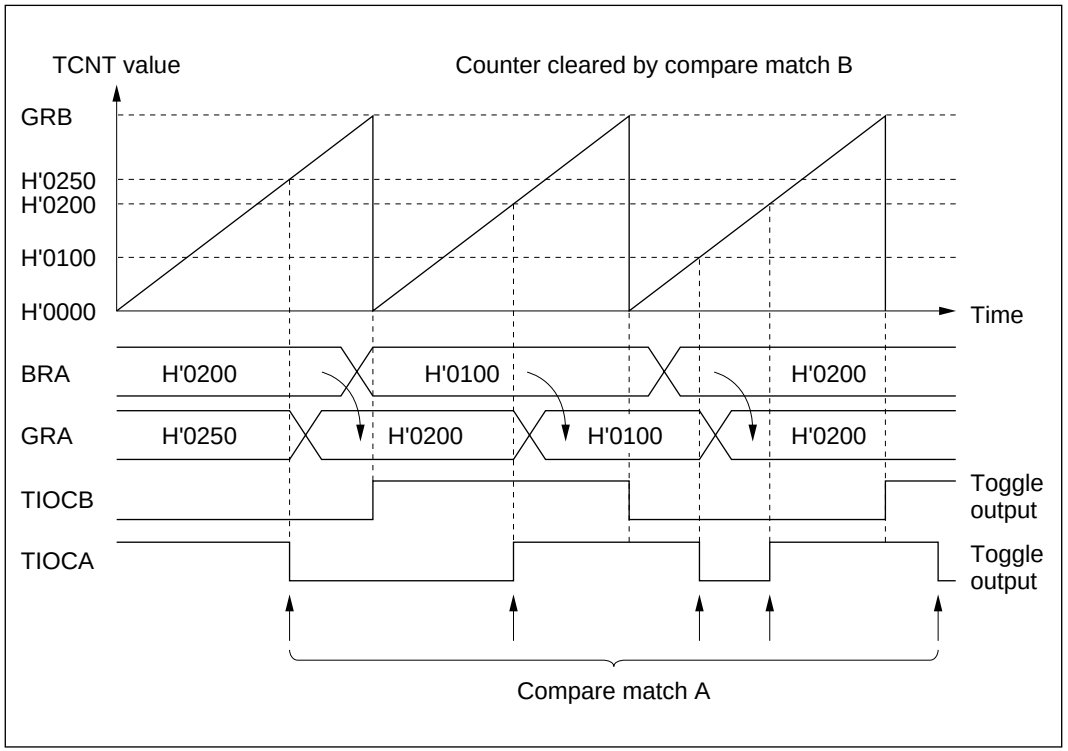


Figure 10-49 Register Buffering (Example 1: Buffering of Output Compare Register)

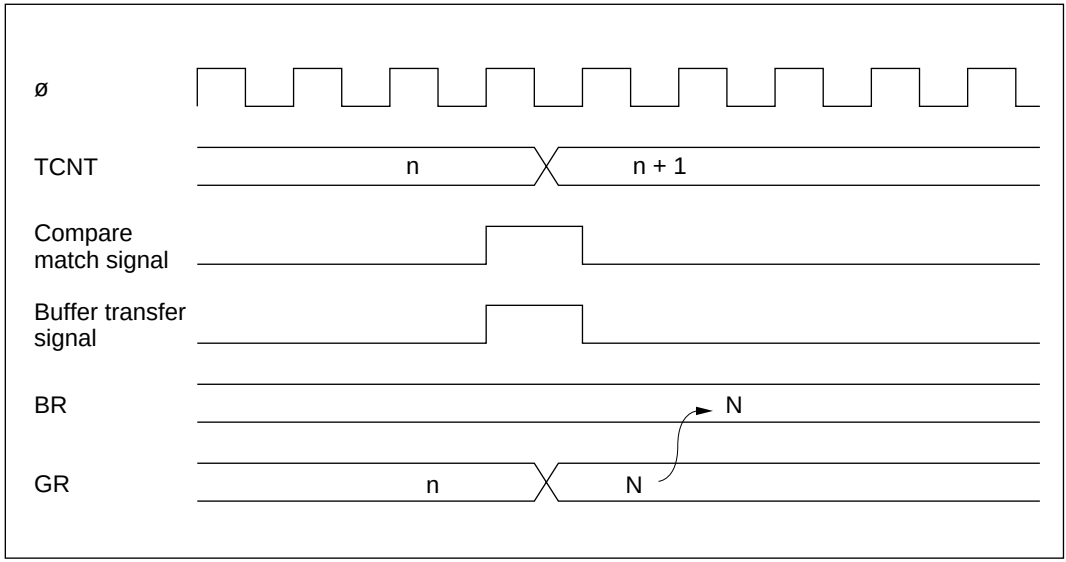


Figure 10-50 Compare Match and Buffer Transfer Timing (Example)

Figure 10-51 shows an example in which GRA is set to function as an input capture register buffered by BRA, and TCNT is cleared by input capture B. The falling edge is selected as the input capture edge at TIOCB. Both edges are selected as input capture edges at TIOCA. Because of the buffer setting, when the TCNT value is captured into GRA at input capture A, the previous GRA value is simultaneously transferred to BRA. Figure 10-52 shows the transfer timing.

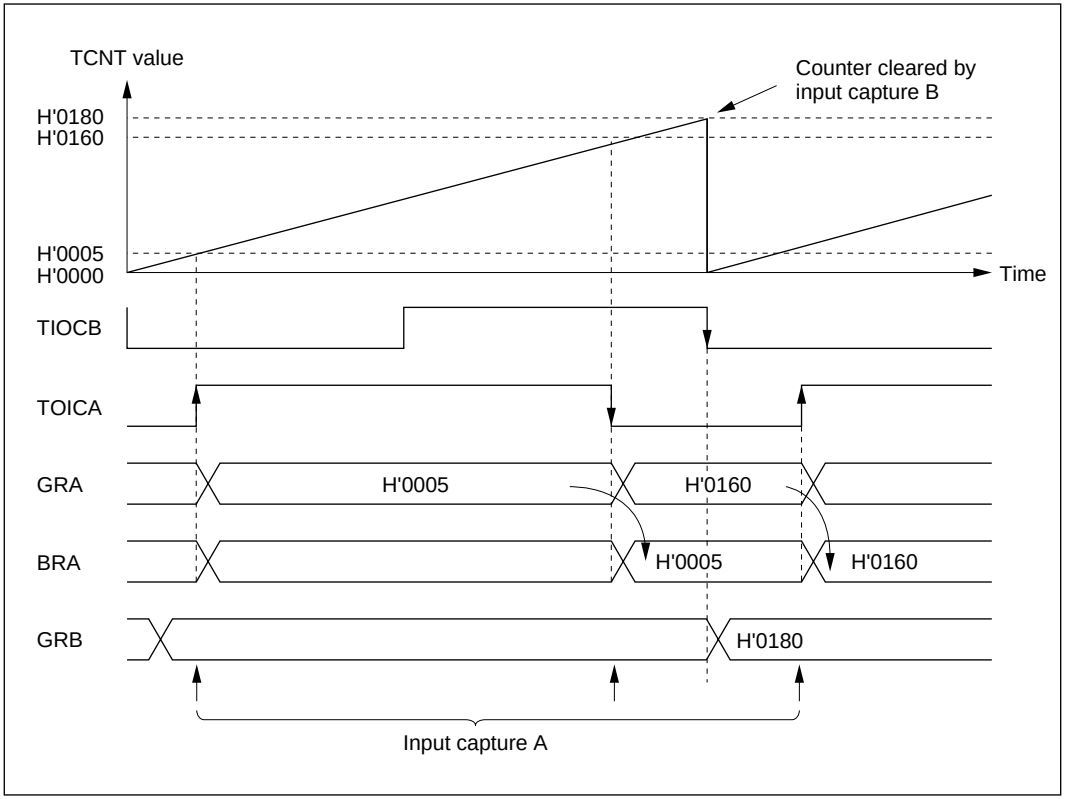


Figure 10-51 Register Buffering (Example 2: Buffering of Input Capture Register)

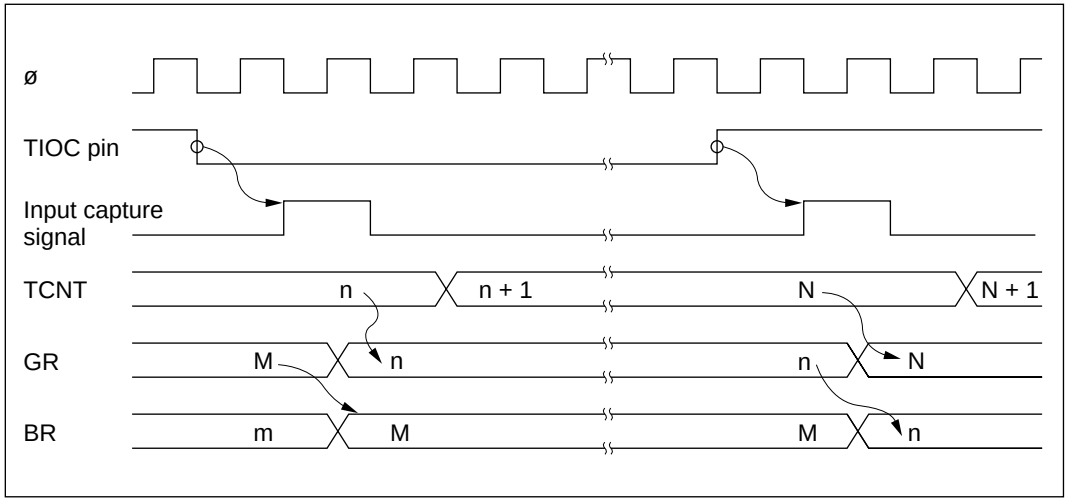


Figure 10-52 Input Capture and Buffer Transfer Timing (Example)

Figure 10-53 shows an example in which GRB3 is buffered by BRB3 in complementary PWM mode. Buffering is used to set GRB3 to a higher value than GRA3, generating a PWM waveform with 0% duty cycle. The BRB3 value is transferred to GRB3 when TCNT3 matches GRA3, and when TCNT4 underflows.

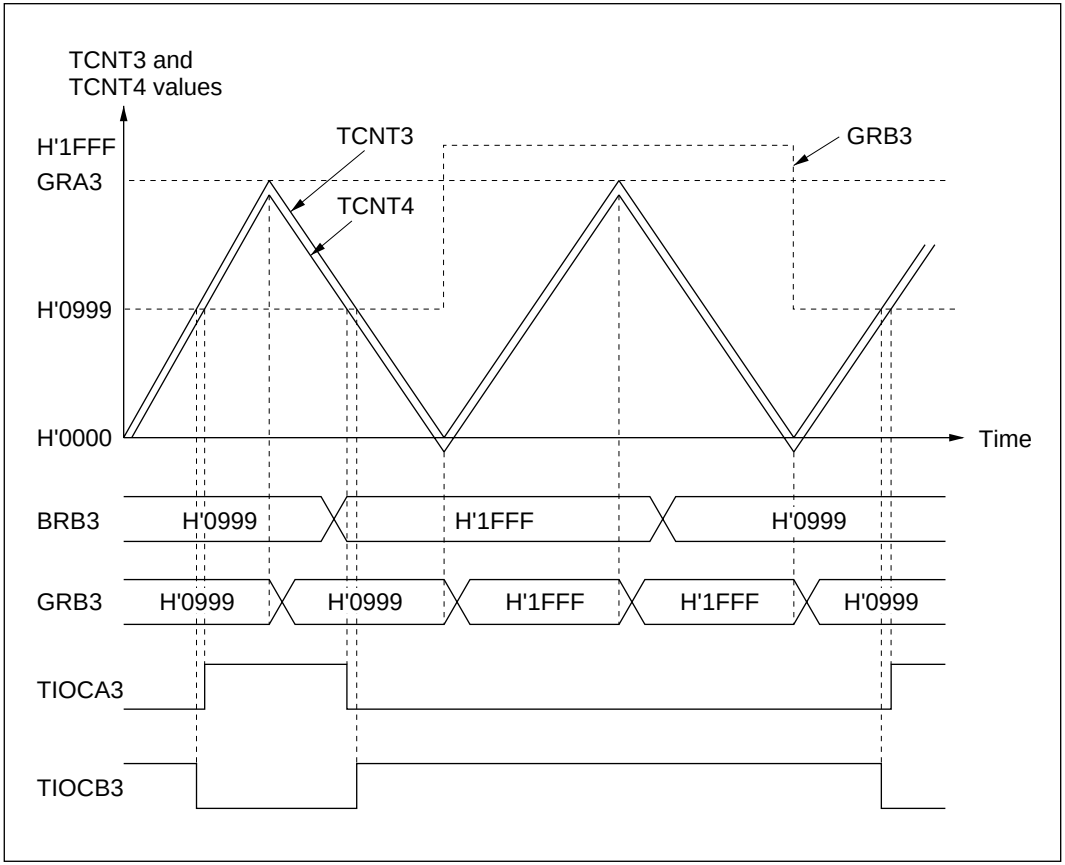


Figure 10-53 Register Buffering (Example 4: Buffering in Complementary PWM Mode)

10.4.9 ITU Output Timing

The ITU outputs from channels 3 and 4 can be disabled by bit settings in TOER or by an external trigger, or inverted by bit settings in TOCR.

Timing of Enabling and Disabling of ITU Output by TOER: In this example an ITU output is disabled by clearing a master enable bit to 0 in TOER. An arbitrary value can be output by appropriate settings of the data register (DR) and data direction register (DDR) of the corresponding input/output port. Figure 10-54 illustrates the timing of the enabling and disabling of ITU output by TOER.

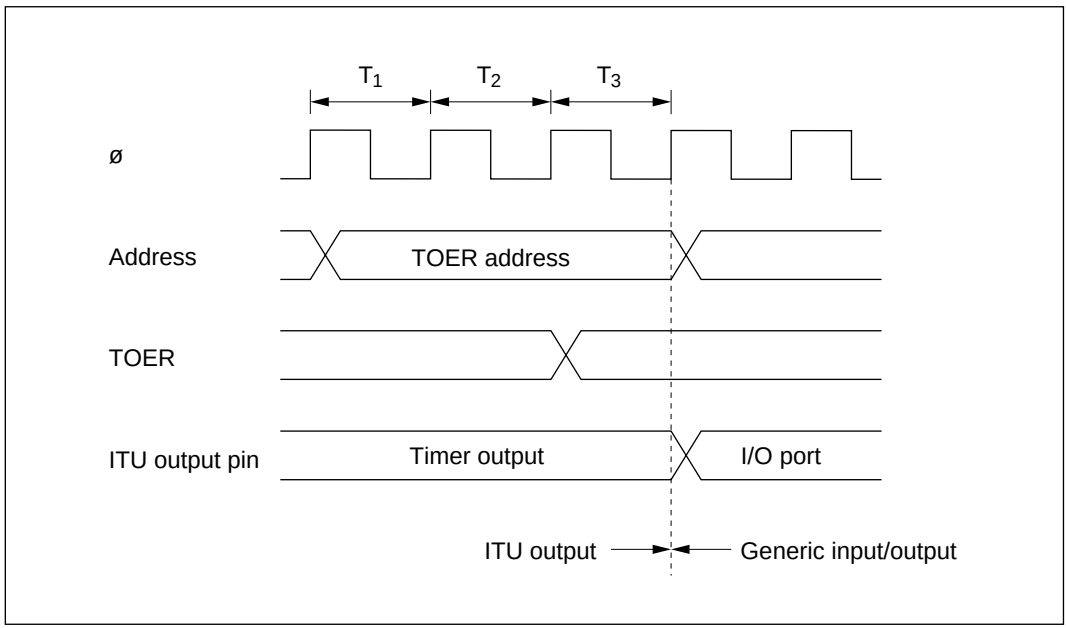


Figure 10-54 Timing of Disabling of ITU Output by Writing to TOER (Example)

Timing of Disabling of ITU Output by External Trigger: If the XTGD bit is cleared to 0 in TOCR in reset-synchronized PWM mode or complementary PWM mode, when an input capture A signal occurs in channel 1, the master enable bits are cleared to 0 in TOER, disabling ITU output. Figure 10-55 shows the timing.

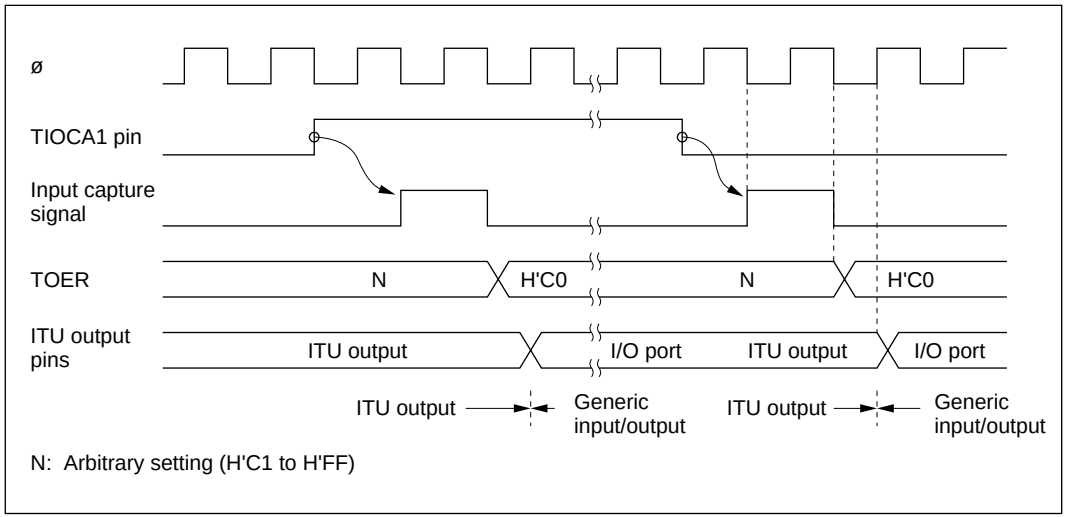


Figure 10-55 Timing of Disabling of ITU Output by External Trigger (Example)

Timing of Output Inversion by TOCR: The output levels in reset-synchronized PWM mode and complementary PWM mode can be inverted by inverting the output level select bits (OLS4 and OLS3) in TOCR. Figure 10-56 shows the timing.

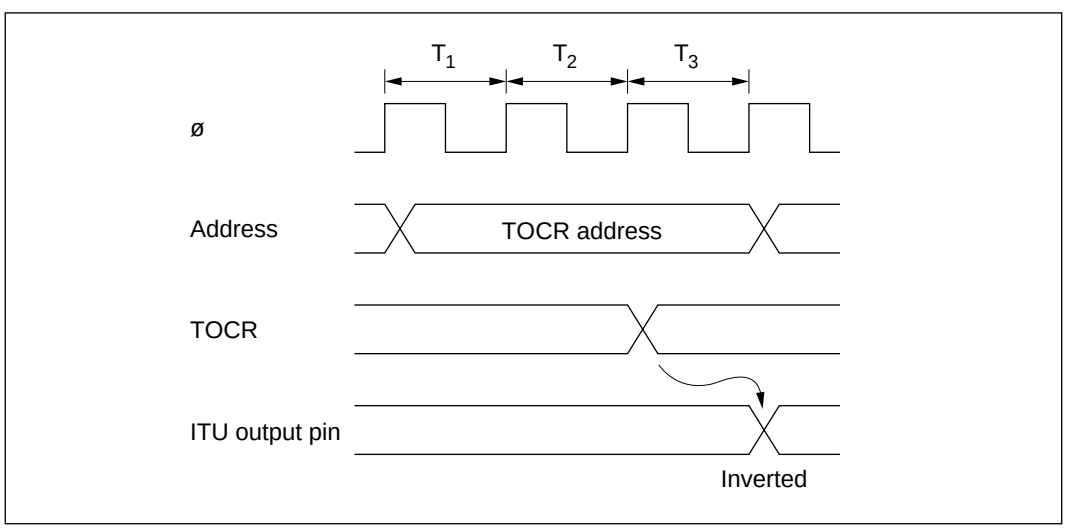


Figure 10-56 Timing of Inverting of ITU Output Level by Writing to TOCR (Example)

10.5 Interrupts

The ITU has two types of interrupts: input capture/compare match interrupts, and overflow interrupts.

10.5.1 Setting of Status Flags

Timing of Setting of IMFA and IMFB at Compare Match: IMFA and IMFB are set to 1 by a compare match signal generated when TCNT matches a general register (GR). The compare match signal is generated in the last state in which the values match (when TCNT is updated from the matching count to the next count). Therefore, when TCNT matches a general register, the compare match signal is not generated until the next timer clock input. Figure 10-57 shows the timing of the setting of IMFA and IMFB.

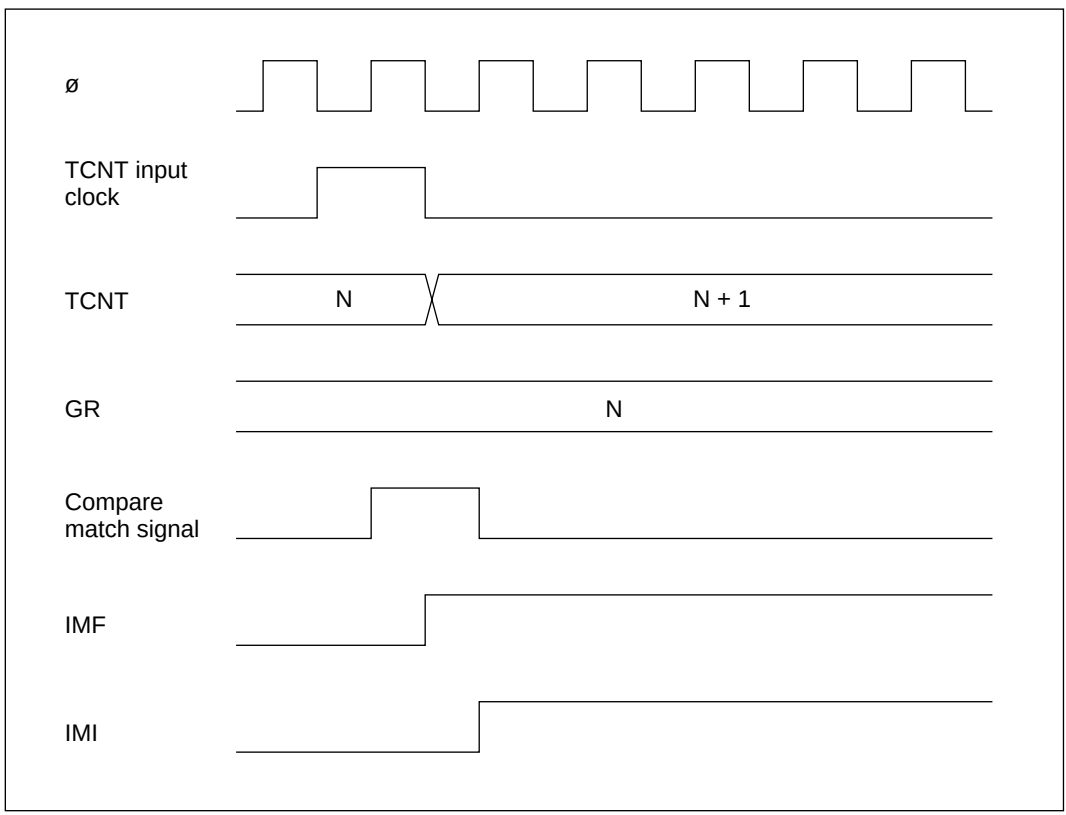


Figure 10-57 Timing of Setting of IMFA and IMFB by Compare Match

Timing of Setting of IMFA and IMFB by Input Capture: IMFA and IMFB are set to 1 by an input capture signal. The TCNT contents are simultaneously transferred to the corresponding general register. Figure 10-58 shows the timing.

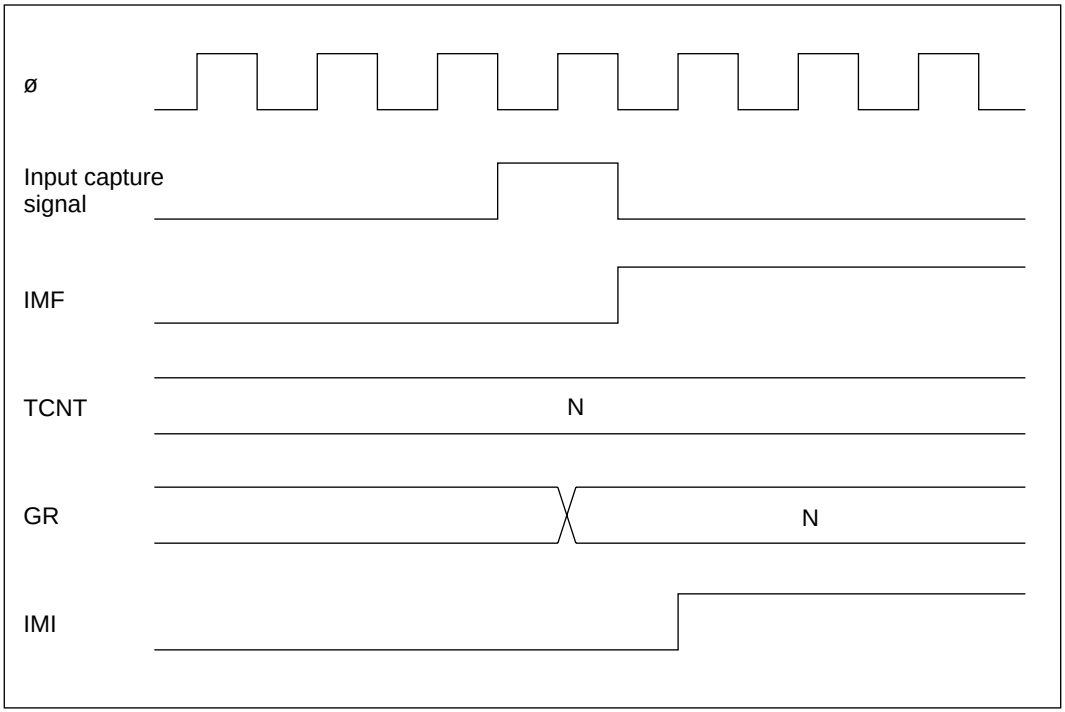


Figure 10-58 Timing of Setting of IMFA and IMFB by Input Capture

Timing of Setting of Overflow Flag (OVF): OVF is set to 1 when TCNT overflows from H'FFFF to H'0000 or underflows from H'0000 to H'FFFF. Figure 10-59 shows the timing.

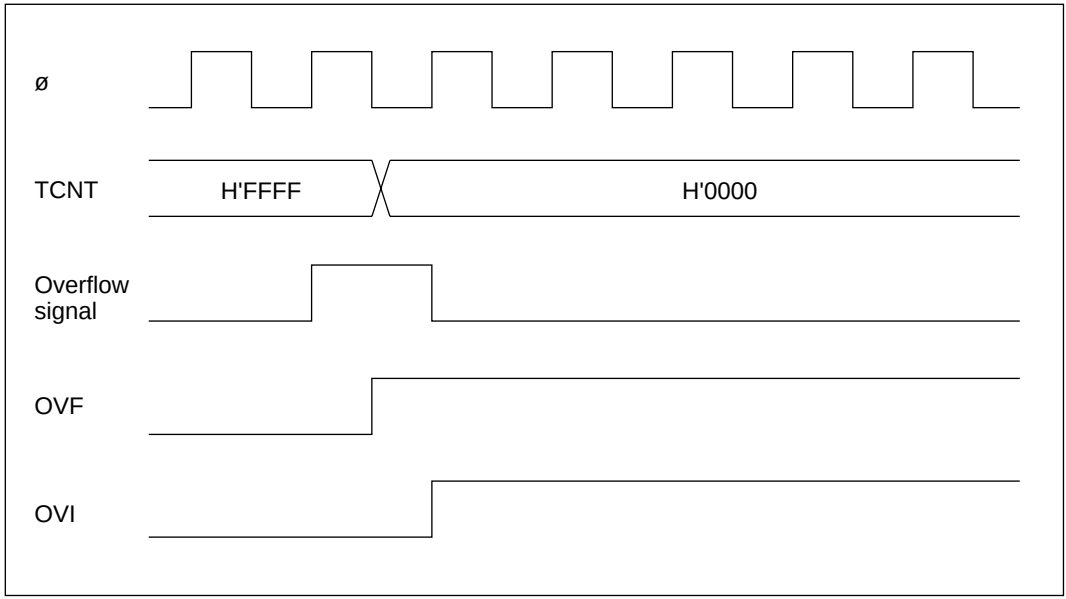


Figure 10-59 Timing of Setting of OVF

10.5.2 Clearing of Status Flags

If the CPU reads a status flag while it is set to 1, then writes 0 in the status flag, the status flag is cleared. Figure 10-60 shows the timing.

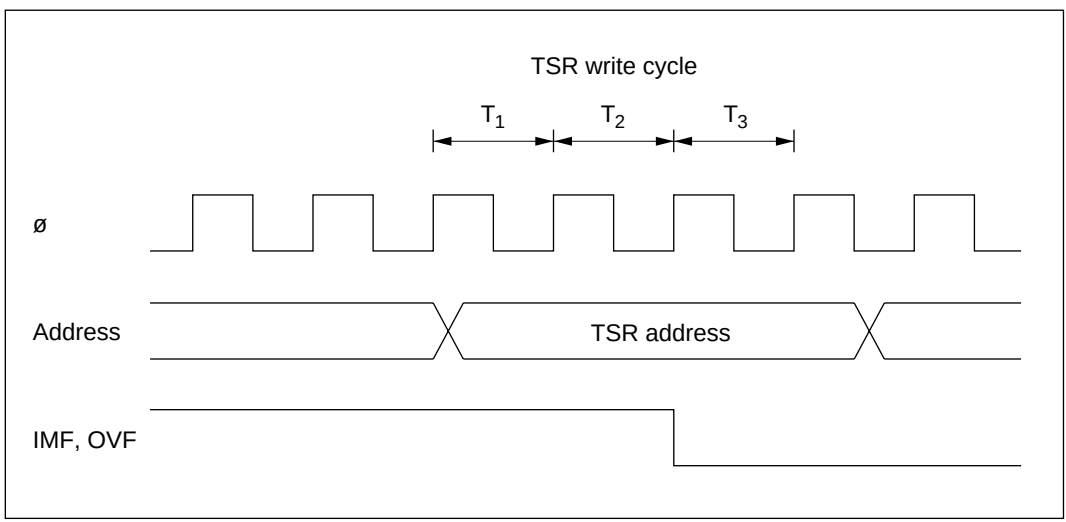


Figure 10-60 Timing of Clearing of Status Flags

10.5.3 Interrupt Sources and DMA Controller Activation

Each ITU channel can generate a compare match/input capture A interrupt, a compare match/input capture B interrupt, and an overflow interrupt. In total there are 15 interrupt sources, all independently vectored. An interrupt is requested when the interrupt request flag and interrupt enable bit are both set to 1.

The priority order of the channels can be modified in interrupt priority registers A and B (IPRA and IPRB). For details see section 5, Interrupt Controller.

Compare match/input capture A interrupts in channels 0 to 3 can activate the DMA controller (DMAC). When the DMAC is activated a CPU interrupt is not requested.

Table 10-10 lists the interrupt sources.

Table 10-10 ITU Interrupt Sources

Channel	Interrupt Source	Description	DMAC Activatable	Priority*
0	IMIA0	Compare match/input capture A0	Yes	High
	IMIB0	Compare match/input capture B0	No	
	OVI0	Overflow 0	No	
1	IMIA1	Compare match/input capture A1	Yes	
	IMIB1	Compare match/input capture B1	No	
	OVI1	Overflow 1	No	
2	IMIA2	Compare match/input capture A2	Yes	
	IMIB2	Compare match/input capture B2	No	
	OVI2	Overflow 2	No	
3	IMIA3	Compare match/input capture A3	Yes	
	IMIB3	Compare match/input capture B3	No	
	OVI3	Overflow 3	No	
4	IMIA4	Compare match/input capture A4	No	
	IMIB4	Compare match/input capture B4	No	
	OVI4	Overflow 4	No	Low

Note: * The priority immediately after a reset is indicated. Inter-channel priorities can be changed by settings in IPRA and IPRB.

10.6 Usage Notes

This section describes contention and other matters requiring special attention during ITU operations.

Contention between TCNT Write and Clear: If a counter clear signal occurs in the T_3 state of a TCNT write cycle, clearing of the counter takes priority and the write is not performed. See figure 10-61.

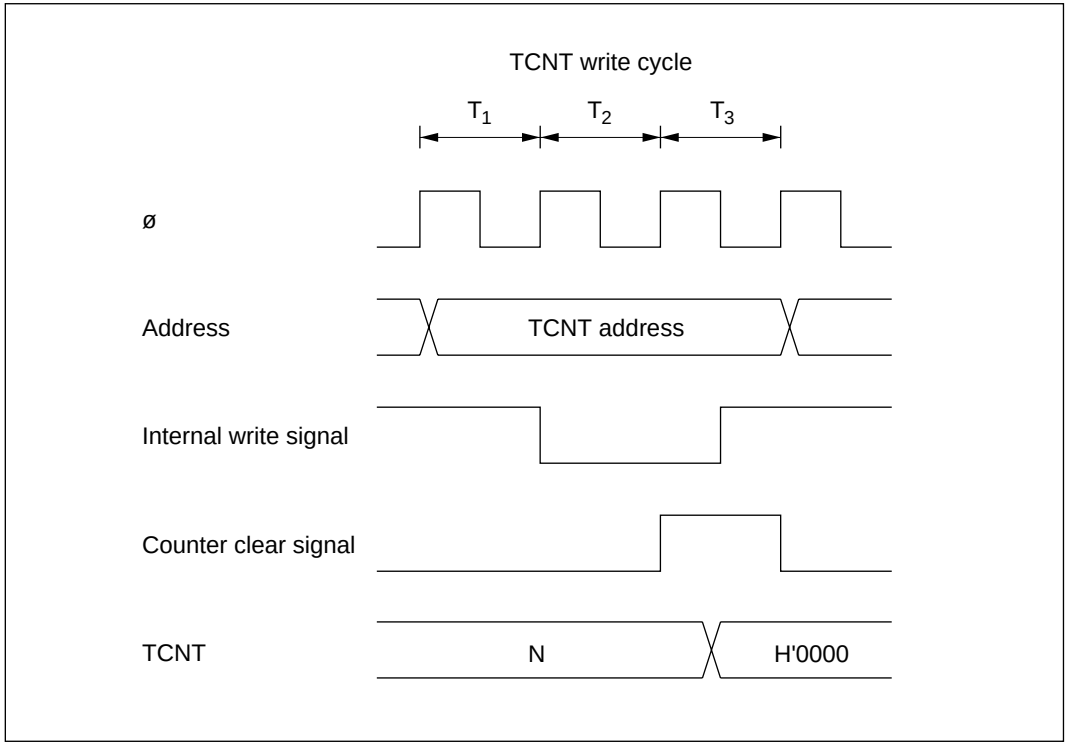


Figure 10-61 Contention between TCNT Write and Clear

Contention between TCNT Word Write and Increment: If an increment pulse occurs in the T_3 state of a TCNT word write cycle, writing takes priority and TCNT is not incremented. See figure 10-62.

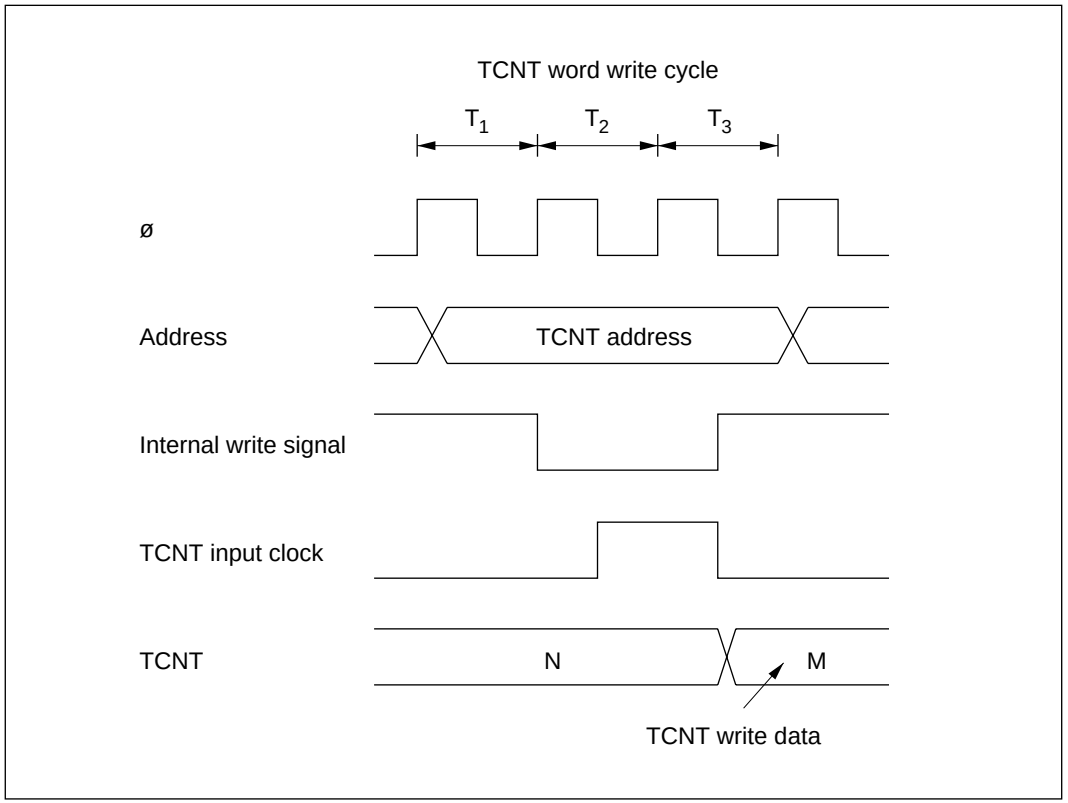


Figure 10-62 Contention between TCNT Word Write and Increment

Contention between TCNT Byte Write and Increment: If an increment pulse occurs in the T_2 or T_3 state of a TCNT byte write cycle, writing takes priority and TCNT is not incremented. The TCNT byte that was not written retains its previous value. See figure 10-63, which shows an increment pulse occurring in the T_2 state of a byte write to TCNTH.

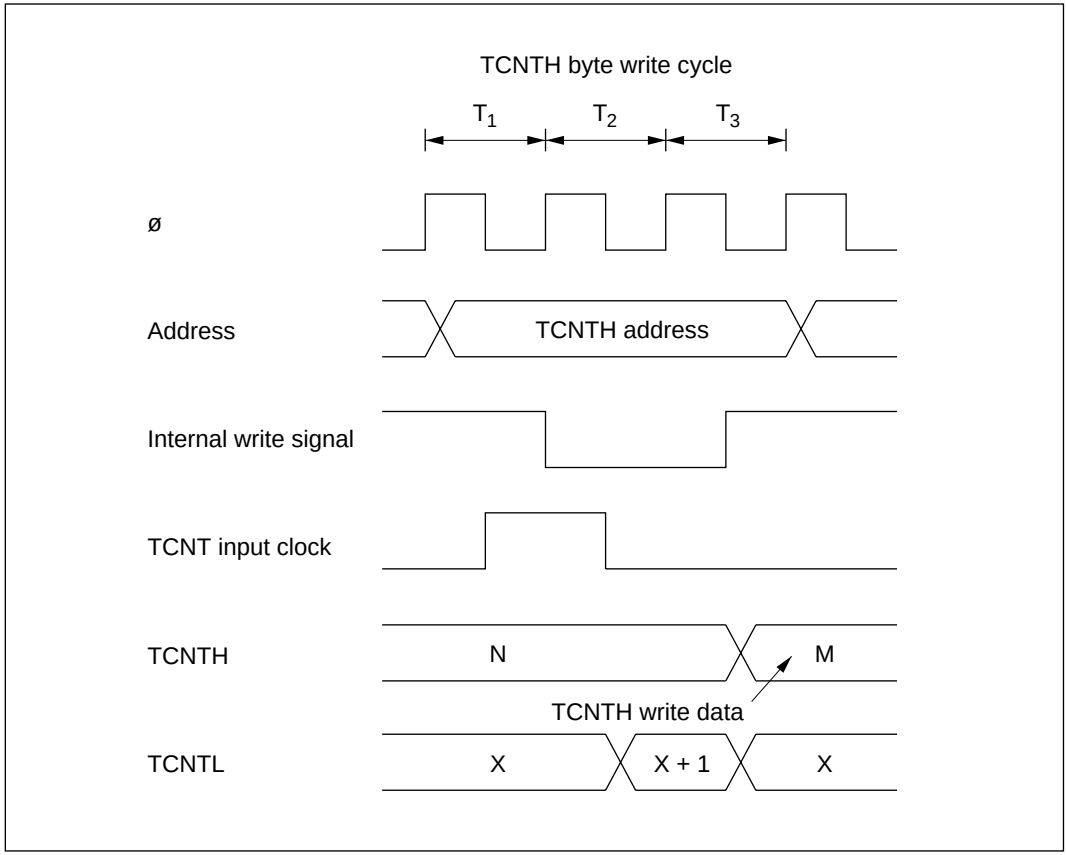


Figure 10-63 Contention between TCNT Byte Write and Increment

Contention between General Register Write and Compare Match: If a compare match occurs in the T_3 state of a general register write cycle, writing takes priority and the compare match signal is inhibited. See figure 10-64.

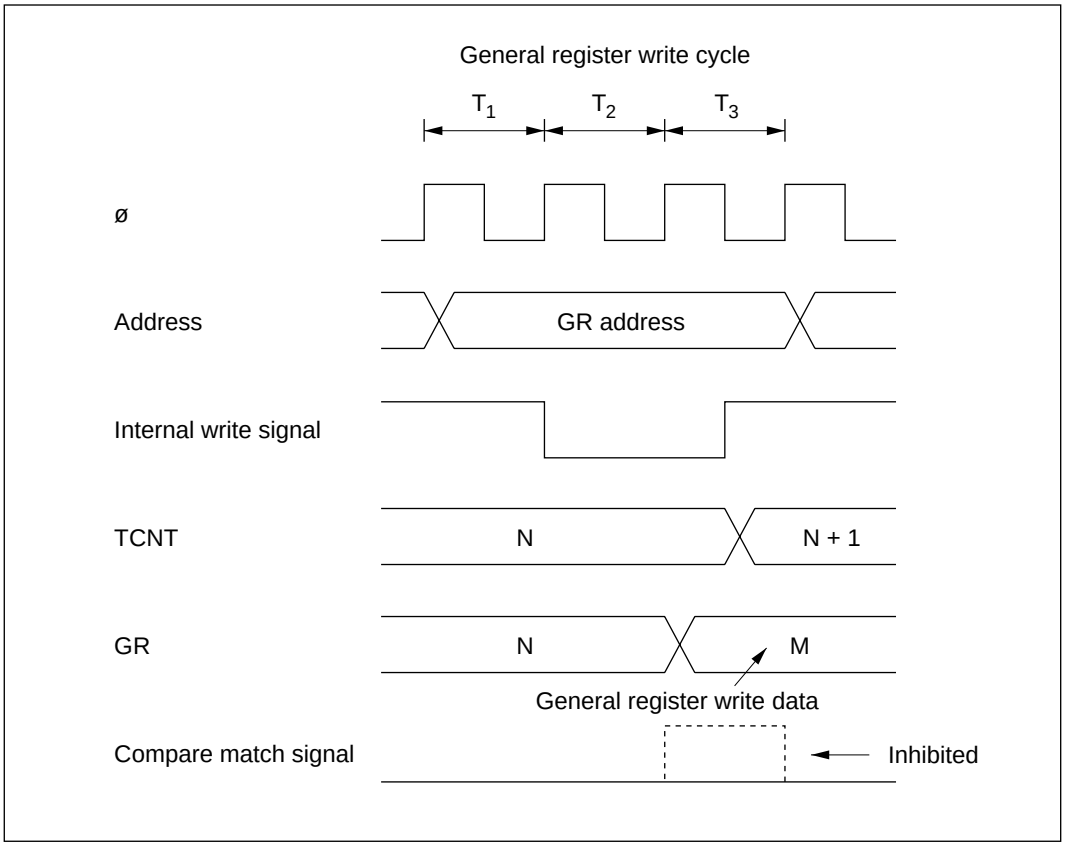


Figure 10-64 Contention between General Register Write and Compare Match

Contention between TCNT Write and Overflow or Underflow: If an overflow occurs in the T_3 state of a TCNT write cycle, writing takes priority and the counter is not incremented. OVF is set to 1.The same holds for underflow. See figure 10-65.

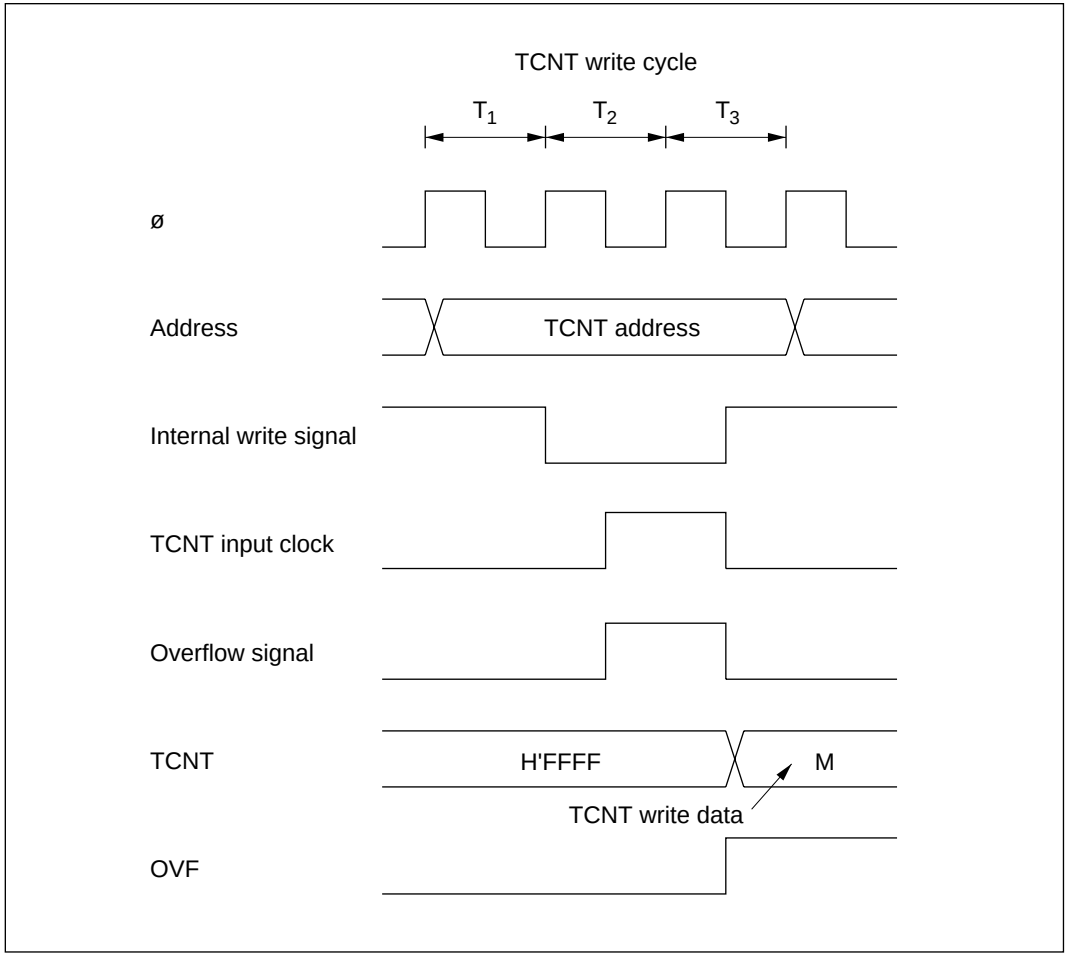


Figure 10-65 Contention between TCNT Write and Overflow

Contention between General Register Read and Input Capture: If an input capture signal occurs during the T_3 state of a general register read cycle, the value before input capture is read. See figure 10-66.

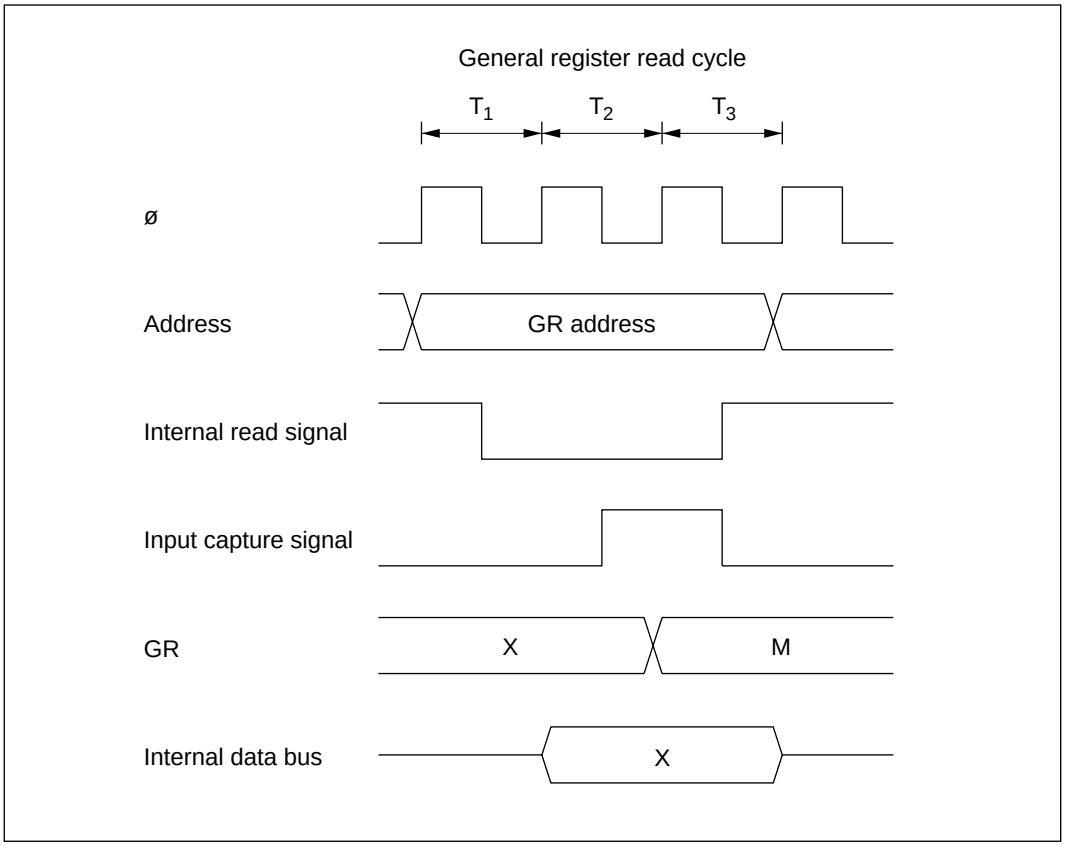


Figure 10-66 Contention between General Register Read and Input Capture

Contention between Counter Clearing by Input Capture and Counter Increment: If an input capture signal and counter increment signal occur simultaneously, the counter is cleared according to the input capture signal. The counter is not incremented by the increment signal. The value before the counter is cleared is transferred to the general register. See figure 10-67.

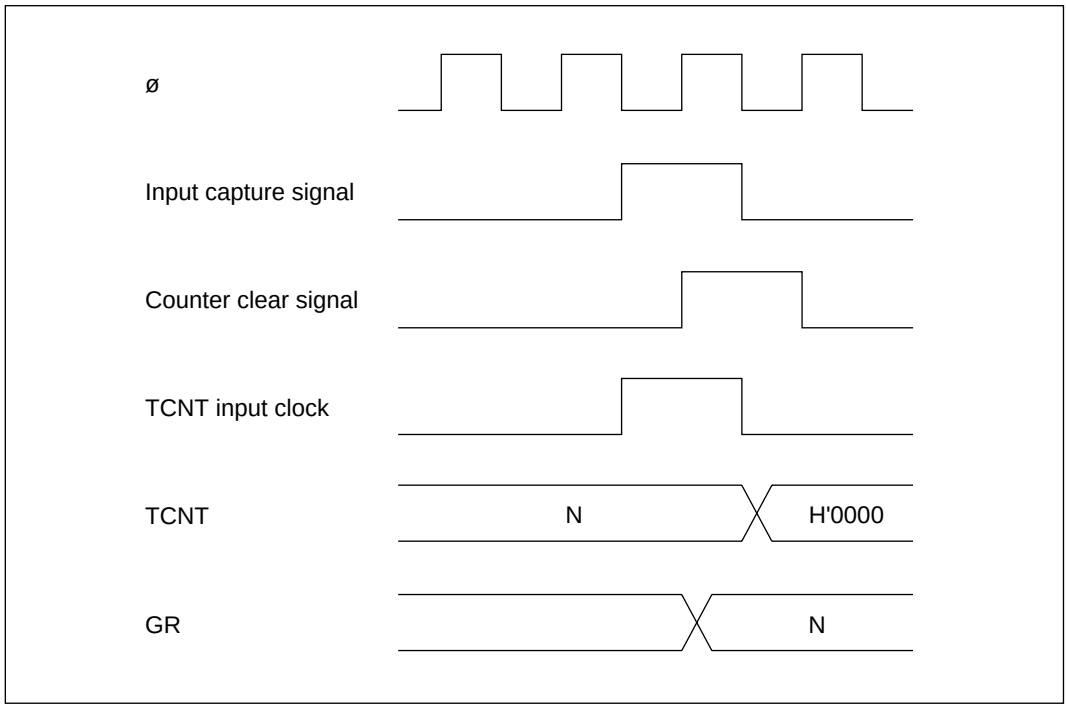


Figure 10-67 Contention between Counter Clearing by Input Capture and Counter Increment

Contention between General Register Write and Input Capture: If an input capture signal occurs in the T_3 state of a general register write cycle, input capture takes priority and the write to the general register is not performed. See figure 10-68.

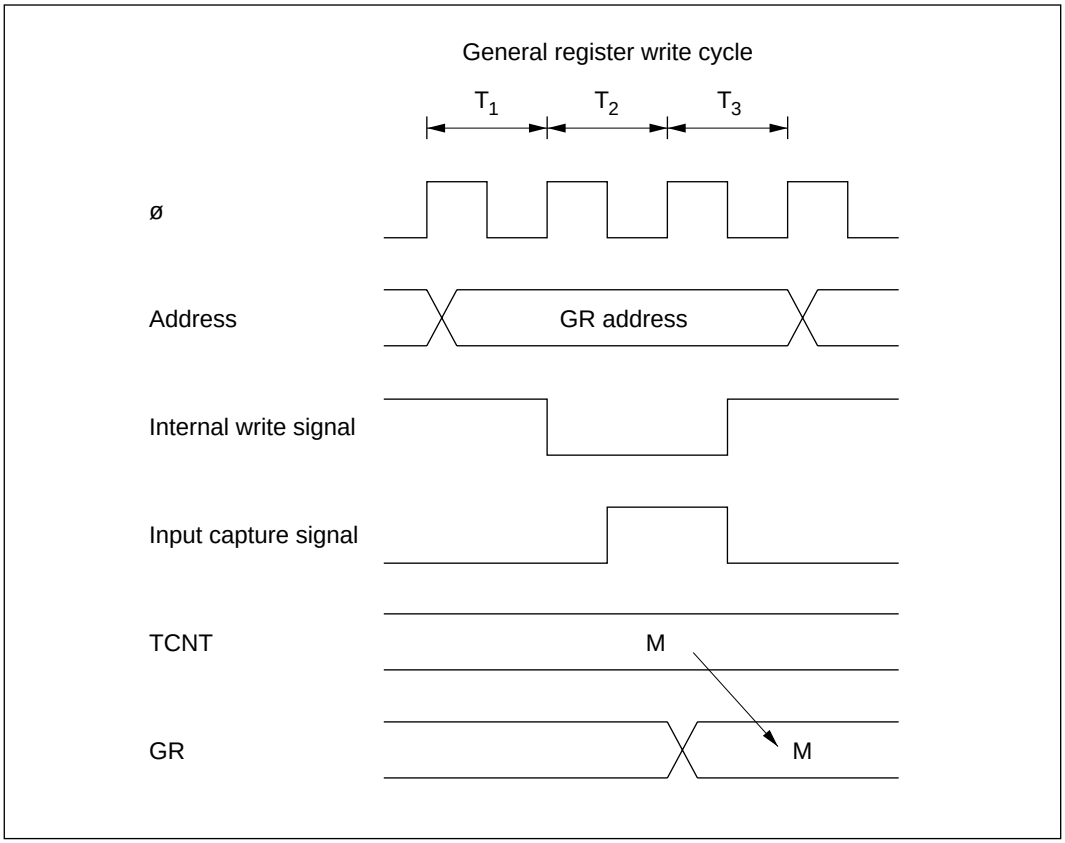


Figure 10-68 Contention between General Register Write and Input Capture

Note on Waveform Period Setting: When a counter is cleared by compare match, the counter is cleared in the last state at which the TCNT value matches the general register value, at the time when this value would normally be updated to the next count. The actual counter frequency is therefore given by the following formula:

$$f = \frac{ø}{(N + 1)}$$

(f: counter frequency. ø: system clock frequency. N: value set in general register.)

Contention between Buffer Register Write and Input Capture: If a buffer register is used for input capture buffering and an input capture signal occurs in the T_3 state of a write cycle, input capture takes priority and the write to the buffer register is not performed.
See figure 10-69.

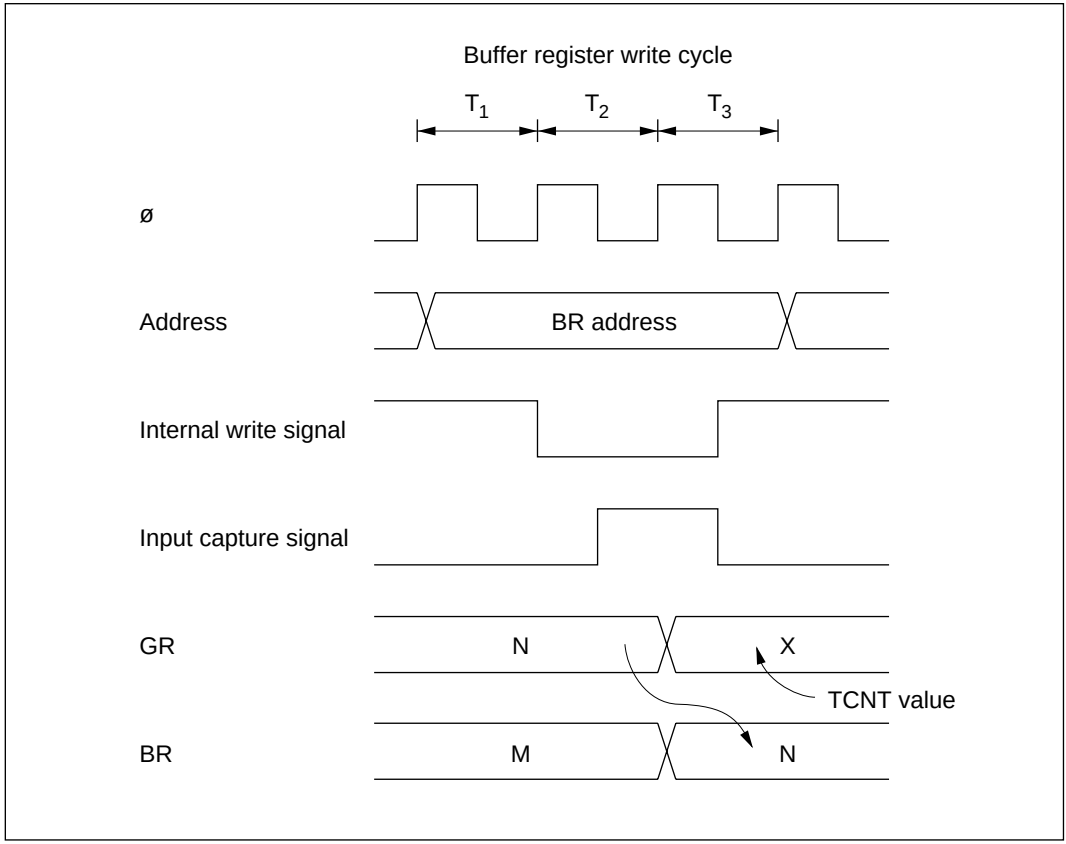
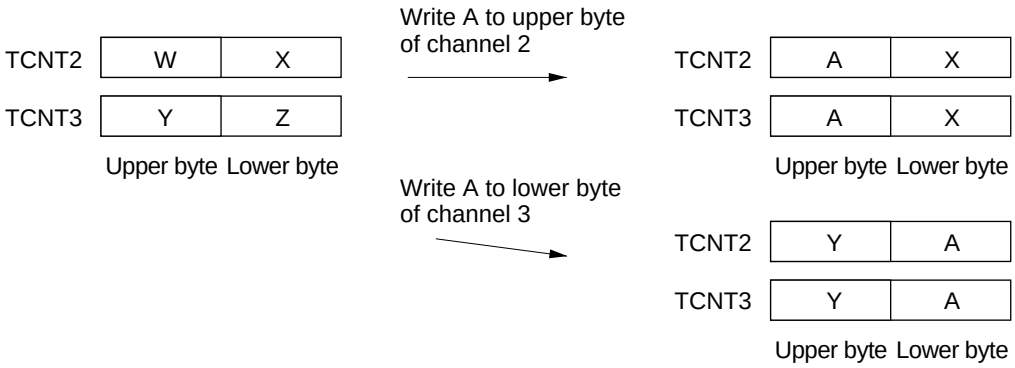


Figure 10-69 Contention between Buffer Register Write and Input Capture

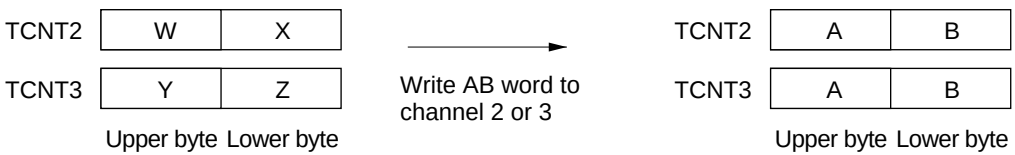
Note on Synchronous Preset: When channels are synchronized, if a TCNT value is modified by byte write access, all 16 bits of all synchronized counters assume the same value as the counter that was addressed.

(Example) When channels 2 and 3 are synchronized

- Byte write to channel 2 or byte write to channel 3



- Word write to channel 2 or word write to channel 3



Note on Setup of Reset-Synchronized PWM Mode and Complementary PWM Mode: When setting bits CMD1 and CMD0 in TFCR, take the following precautions:

- Write to bits CMD1 and CMD0 only when TCNT3 and TCNT4 are stopped.
- Do not switch directly between reset-synchronized PWM mode and complementary PWM mode. First switch to normal mode (by clearing bit CMD1 to 0), then select reset-synchronized PWM mode or complementary PWM mode.

Table 10-11 (a) ITU Operating Modes (Channel 0)

		Register Settings												
		TSNC	TMDR			TFCR			TOCR		TOER	TIOR0		TCR0	
Operating Mode		Synchro-nization	MDF	FDIR	PWM	Comple-mentary PWM	Reset-Synchro-nized PWM	Buffer-ing	XTGD	Output Level Select	Master Enable	IOA	IOB	Clear Select	Clock Select
Synchronous preset		SYNC0 = 1	—	—	○	—	—	—	—	—	—	○	○	○	○
PWM mode		○	—	—	PWM0 = 1	—	—	—	—	—	—	—*	○*	○	○
Output compare A		○	—	—	PWM0 = 0	—	—	—	—	—	—	IOA2 = 0 Other bits unrestricted	○	○	○
Output compare B		○	—	—	○	—	—	—	—	—	—	○	IOB2 = 0 Other bits unrestricted	○	○
Input capture A		○	—	—	PWM0 = 0	—	—	—	—	—	—	IOA2 = 1 Other bits unrestricted	○	○	○
Input capture B		○	—	—	PWM0 = 0	—	—	—	—	—	—	○	IOB2 = 1 Other bits unrestricted	○	○
Counter clearing	By compare match/input capture A	○	—	—	○	—	—	—	—	—	—	○	○	CCLR1 = 0 CCLR0 = 1	○
	By compare match/input capture B	○	—	—	○	—	—	—	—	—	—	○	○	CCLR1 = 1 CCLR0 = 0	○
	Syn-chronous clear	SYNC0 = 1	—	—	○	—	—	—	—	—	—	○	○	CCLR1 = 1 CCLR0 = 1	○

Legend: ○ Setting available (valid). — Setting does not affect this mode.

Note: * The input capture function cannot be used in PWM mode. If compare match A and compare match B occur simultaneously, the compare match signal is inhibited.

Table 10-11 (b) ITU Operating Modes (Channel 1)

		Register Settings												
		TSNC	TMDR			TFCR			TOCR		TOER	TIOR1		TCR1	
Operating Mode		Synchro-nization	MDF	FDIR	PWM	Comple-mentary PWM	Reset-Synchro-nized PWM	Buffer-ing	XTGD	Output Level Select	Master Enable	IOA	IOB	Clear Select	Clock Select
Synchronous preset		SYNC1 = 1	—	—	○	—	—	—	—	—	—	○	○	○	○
PWM mode		○	—	—	PWM1 = 1	—	—	—	—	—	—	—	○*1	○	○
Output compare A		○	—	—	PWM1 = 0	—	—	—	—	—	—	IOA2 = 0 Other bits unrestricted	○	○	○
Output compare B		○	—	—	○	—	—	—	—	—	—	○	IOB2 = 0 Other bits unrestricted	○	○
Input capture A		○	—	—	PWM1 = 0	—	—	—	○*2	—	—	IOA2 = 1 Other bits unrestricted	○	○	○
Input capture B		○	—	—	PWM1 = 0	—	—	—	—	—	—	○	IOB2 = 1 Other bits unrestricted	○	○
Counter clearing	By compare match/input capture A	○	—	—	○	—	—	—	—	—	—	○	○	CCLR1 = 0 CCLR0 = 1	○
	By compare match/input capture B	○	—	—	○	—	—	—	—	—	—	○	○	CCLR1 = 1 CCLR0 = 0	○
	Syn-chronous clear	SYNC1 = 1	—	—	○	—	—	—	—	—	—	○	○	CCLR1 = 1 CCLR0 = 1	○

Legend: ○ Setting available (valid). — Setting does not affect this mode.

Notes: 1. The input capture function cannot be used in PWM mode. If compare match A and compare match B occur simultaneously, the compare match signal is inhibited.
2. Valid only when channels 3 and 4 are operating in complementary PWM mode or reset-synchronized PWM mode.

Table 10-11 (c) ITU Operating Modes (Channel 2)

		Register Settings												
		TSNC	TMDR			TFCR			TOCR		TOER	TIOR2		TCR2	
Operating Mode		Synchro-nization	MDF	FDIR	PWM	Comple-mentary PWM	Reset-Synchro-nized PWM	Buffer-ing	XTGD	Output Level Select	Master Enable	IOA	IOB	Clear Select	Clock Select
Synchronous preset		SYNC2 = 1	○	—	○	—	—	—	—	—	—	○	○	○	○
PWM mode		○	○	—	PWM2 = 1	—	—	—	—	—	—	—	○*	○	○
Output compare A		○	○	—	PWM2 = 0	—	—	—	—	—	—	IOA2 = 0 Other bits unrestricted	○	○	○
Output compare B		○	○	—	○	—	—	—	—	—	—	○	IOB2 = 0 Other bits unrestricted	○	○
Input capture A		○	—	—	PWM2 = 0	—	—	—	—	—	—	IOA2 = 1 Other bits unrestricted	○	○	○
Input capture B		○	—	—	PWM2 = 0	—	—	—	—	—	—	○	IOB2 = 1 Other bits unrestricted	○	○
Counter clearing	By compare match/input capture A	○	○	—	○	—	—	—	—	—	—	○	○	CCLR1 = 0 CCLR0 = 1	○
	By compare match/input capture B	○	○	—	○	—	—	—	—	—	—	○	○	CCLR1 = 1 CCLR0 = 0	○
	Syn-chronous clear	SYNC2 = 1	○	—	○	—	—	—	—	—	—	○	○	CCLR1 = 1 CCLR0 = 1	○
Phase counting mode		○	MDF = 1	○	○	—	—	—	—	—	—	○	○	○	—

Legend: ○ Setting available (valid). — Setting does not affect this mode.
Note: * The input capture function cannot be used in PWM mode. If compare match A and compare match B occur simultaneously, the compare match signal is inhibited.

Table 10-11 (d) ITU Operating Modes (Channel 3)

		Register Settings													
		TSNC	TMDR			TFCR			TOCR		TOER	TIOR3		TCR3	
Operating Mode		Synchro-nization	MDF	FDIR	PWM	Comple-mentary PWM	Reset-Synchro-nized PWM	Buffering	XTGD	Output Level Select	Master Enable	IOA	IOB	Clear Select	Clock Select
Synchronous preset		SYNC3 = 1	—	—	○	○*3	○	○	—	—	○*1	○	○	○	○
PWM mode		○	—	—	PWM3 = 1	CMD1 = 0	CMD1 = 0	○	—	—	○	—	○*2	○	○
Output compare A		○	—	—	PWM3 = 0	CMD1 = 0	CMD1 = 0	○	—	—	○	IOA2 = 0 Other bits unrestricted	○	○	○
Output compare B		○	—	—	○	CMD1 = 0	CMD1 = 0	○	—	—	○	○	IOB2 = 0 Other bits unrestricted	○	○
Input capture A		○	—	—	PWM3 = 0	CMD1 = 0	CMD1 = 0	○	—	—	EA3 ignored Other bits unrestricted	IOA2 = 1 Other bits unrestricted	○	○	○
Input capture B		○	—	—	PWM3 = 0	CMD1 = 0	CMD1 = 0	○	—	—	EA3 ignored Other bits unrestricted	○	IOA2 = 1 Other bits unrestricted	○	○
Counter clearing	By compare match/input capture A	○	—	—	○	Illegal setting: CMD1 = 1 CMD0 = 0	○*4	○	—	—	○*1	○	○	CCLR1 = 0 CCLR0 = 1	○
	By compare match/input capture B	○	—	—	○	CMD1 = 0	CMD1 = 0	○	—	—	○*1	○	○	CCLR1 = 1 CCLR0 = 0	○
	Syn-chronous clear	SYNC3 = 1	—	—	○	Illegal setting: CMD1 = 1 CMD0 = 0	○	○	—	—	○*1	○	○	CCLR1 = 1 CCLR0 = 1	○
Complementary PWM mode		○*3	—	—	—	CMD1 = 1 CMD0 = 0	CMD1 = 1 CMD0 = 0	○	○*6	○	○	—	—	CCLR1 = 0 CCLR0 = 0	○*5
Reset-synchronized PWM mode		○	—	—	—	CMD1 = 1 CMD0 = 1	CMD1 = 1 CMD0 = 1	○	○*6	○	○	—	—	CCLR1 = 0 CCLR0 = 1	○
Buffering (BRA)		○	—	—	○	○	○	BFA3 = 1 Other bits unrestricted	—	—	○*1	○	○	○	○
Buffering (BRB)		○	—	—	○	○	○	BFB3 = 1 Other bits unrestricted	—	—	○*1	○	○	○	○

Legend: ○ Setting available (valid). — Setting does not affect this mode.

Notes:
1. Master enable bit settings are valid only during waveform output.
2. The input capture function cannot be used in PWM mode. If compare match A and compare match B occur simultaneously, the compare match signal is inhibited.
3. Do not set both channels 3 and 4 for synchronous operation when complementary PWM mode is selected.
4. The counter cannot be cleared by input capture A when reset-synchronized PWM mode is selected.
5. In complementary PWM mode, select the same clock source for channels 3 and 4.
6. Use the input capture A function in channel 1.

Table 10-11 (e) ITU Operating Modes (Channel 4)

		Register Settings													
		TSNC	TMDR			TFCR			TOCR		TOER	TIOR4		TCR4	
Operating Mode		Synchro-nization	MDF	FDIR	PWM	Comple-mentary PWM	Reset-Synchro-nized PWM	Buffering	XTGD	Output Level Select	Master Enable	IOA	IOB	Clear Select	Clock Select
Synchronous preset		SYNC4 = 1	—	—	○	○*3	○	○	—	—	○*1	○	○	○	○
PWM mode		○	—	—	PWM4 = 1	CMD1 = 0	CMD1 = 0	○	—	—	○	—	○*2	○	○
Output compare A		○	—	—	PWM4 = 0	CMD1 = 0	CMD1 = 0	○	—	—	○	IOA2 = 0 Other bits unrestricted	○	○	○
Output compare B		○	—	—	○	CMD1 = 0	CMD1 = 0	○	—	—	○	○	IOB2 = 0 Other bits unrestricted	○	○
Input capture A		○	—	—	PWM4 = 0	CMD1 = 0	CMD1 = 0	○	—	—	EA4 ignored Other bits unrestricted	IOA2 = 1 Other bits unrestricted	○	○	○
Input capture B		○	—	—	PWM4 = 0	CMD1 = 0	CMD1 = 0	○	—	—	EB4 ignored Other bits unrestricted	○	IOB2 = 1 Other bits unrestricted	○	○
Counter clearing	By compare match/input capture A	○	—	—	○	Illegal setting: CMD1 = 1 CMD0 = 0	○*4	○	—	—	○*1	○	○	CCLR1 = 0 CCLR0 = 1	○
	By compare match/input capture B	○	—	—	○	Illegal setting: CMD1 = 1 CMD0 = 0	○*4	○	—	—	○*1	○	○	CCLR1 = 1 CCLR0 = 0	○
	Syn-chronous clear	SYNC4 = 1	—	—	○	Illegal setting: CMD1 = 1 CMD0 = 0	○*4	○	—	—	○*1	○	○	CCLR1 = 1 CCLR0 = 1	○
Complementary PWM mode		○*3	—	—	—	CMD1 = 1 CMD0 = 0	CMD1 = 1 CMD0 = 0	○	○	○	○	—	—	CCLR1 = 0 CCLR0 = 0	○*5
Reset-synchronized PWM mode		○	—	—	—	CMD1 = 1 CMD0 = 1	CMD1 = 1 CMD0 = 1	○	○	○	○	—	—	○*6	○*6
Buffering (BRA)		○	—	—	○	○	○	BFA4 = 1 Other bits unrestricted	—	—	○*1	○	○	○	○
Buffering (BRB)		○	—	—	○	○	○	BFB4 = 1 Other bits unrestricted	—	—	○*1	○	○	○	○

Legend: ○ Setting available (valid). — Setting does not affect this mode.

Notes: 1. Master enable bit settings are valid only during waveform output.
2. The input capture function cannot be used in PWM mode. If compare match A and compare match B occur simultaneously, the compare match signal is inhibited.
3. Do not set both channels 3 and 4 for synchronous operation when complementary PWM mode is selected.
4. When reset-synchronized PWM mode is selected, TCNT4 operates independently and the counter clearing function is available. Waveform output is not affected.
5. In complementary PWM mode, select the same clock source for channels 3 and 4.
6. TCR4 settings are valid in reset-synchronized PWM mode, but TCNT4 operates independently, without affecting waveform output.

Section 11 Programmable Timing Pattern Controller

11.1 Overview

The H8/3003 has a built-in programmable timing pattern controller (TPC) that provides pulse outputs by using the 16-bit integrated timer-pulse unit (ITU) as a time base. The TPC pulse outputs are divided into 4-bit groups (group 3 to group 0) that can operate simultaneously and independently.

11.1.1 Features

TPC features are listed below.

- 16-bit output data

  Maximum 16-bit data can be output. TPC output can be enabled on a bit-by-bit basis.

- Four output groups

  Output trigger signals can be selected in 4-bit groups to provide up to four different 4-bit outputs.

- Selectable output trigger signals

  Output trigger signals can be selected for each group from the compare-match signals of four ITU channels.

- Non-overlap mode

  A non-overlap margin can be provided between pulse outputs.

- Can operate together with the DMA controller (DMAC)

  The compare-match signals selected as trigger signals can activate the DMAC for sequential output of data without CPU intervention.

11.1.2 Block Diagram

Figure 11-1 shows a block diagram of the TPC.

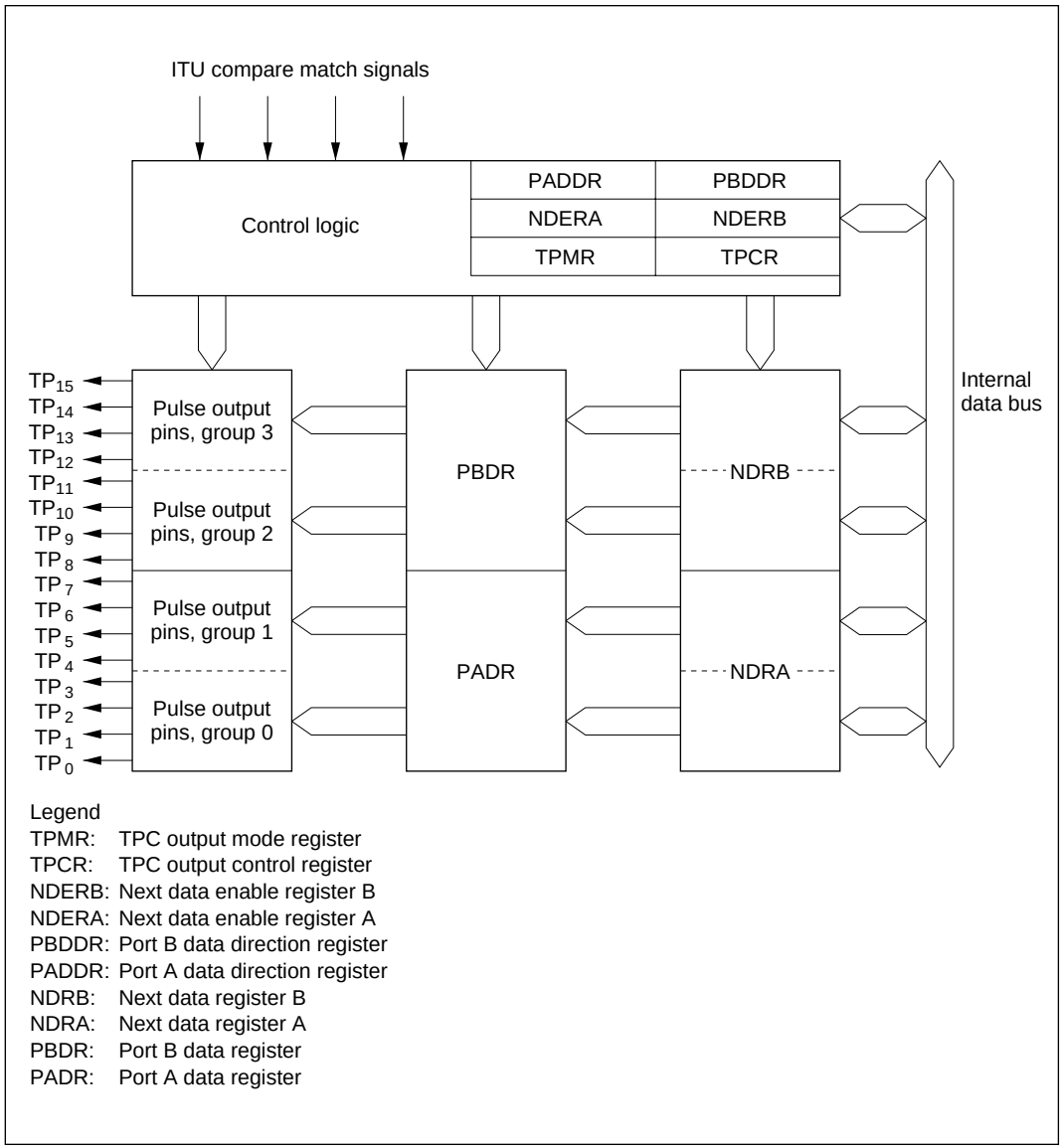


Figure 11-1 TPC Block Diagram

11.1.3 TPC Pins

Table 11-1 summarizes the TPC output pins.

Table 11-1 TPC Pins

Name	Symbol	I/O	Function
TPC output 0	TP_0	Output	Group 0 pulse output
TPC output 1	TP_1	Output	
TPC output 2	TP_2	Output	
TPC output 3	TP_3	Output	
TPC output 4	TP_4	Output	Group 1 pulse output
TPC output 5	TP_5	Output	
TPC output 6	TP_6	Output	
TPC output 7	TP_7	Output	
TPC output 8	TP_8	Output	Group 2 pulse output
TPC output 9	TP_9	Output	
TPC output 10	TP_{10}	Output	
TPC output 11	TP_{11}	Output	
TPC output 12	TP_{12}	Output	Group 3 pulse output
TPC output 13	TP_{13}	Output	
TPC output 14	TP_{14}	Output	
TPC output 15	TP_{15}	Output	

11.1.4 Registers

Table 11-2 summarizes the TPC registers.

Table 11-2 TPC Registers

Address*1	Name	Abbreviation	R/W	Initial Value
H'FFD1	Port A data direction register	PADDR	W	H'00
H'FFD3	Port A data register	PADR	R/(W)*2	H'00
H'FFD4	Port B data direction register	PBDDR	W	H'00
H'FFD6	Port B data register	PBDR	R/(W)*2	H'00
H'FFA0	TPC output mode register	TPMR	R/W	H'F0
H'FFA1	TPC output control register	TPCR	R/W	H'FF
H'FFA2	Next data enable register B	NDERB	R/W	H'00
H'FFA3	Next data enable register A	NDERA	R/W	H'00
H'FFA5/ H'FFA7*3	Next data register A	NDRA	R/W	H'00
H'FFA4 H'FFA6*3	Next data register B	NDRB	R/W	H'00

Notes: 1. Lower 16 bits of the address.
2. Bits used for TPC output cannot be written.
3. The NDRA address is H'FFA5 when the same output trigger is selected for TPC output groups 0 and 1 by settings in TPCR. When the output triggers are different, the NDRA address is H'FFA7 for group 0 and H'FFA5 for group 1. Similarly, the address of NDRB is H'FFA4 when the same output trigger is selected for TPC output groups 2 and 3 by settings in TPCR. When the output triggers are different, the NDRB address is H'FFA6 for group 2 and H'FFA4 for group 3.

11.2 Register Descriptions

11.2.1 Port A Data Direction Register (PADDR)

PADDR is an 8-bit write-only register that selects input or output for each pin in port A.

Bit	7	6	5	4	3	2	1	0
	PA_7DDR	PA_6DDR	PA_5DDR	PA_4DDR	PA_3DDR	PA_2DDR	PA_1DDR	PA_0DDR
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port A data direction 7 to 0
These bits select input or output for port A pins

Port A is multiplexed with pins TP_7 to TP_0. Bits corresponding to pins used for TPC output must be set to 1. For further information about PADDR, see section 9.8, Port A.

11.2.2 Port A Data Register (PADR)

PADR is an 8-bit readable/writable register that stores TPC output data for groups 0 and 1, when these TPC output groups are used.

Bit	7	6	5	4	3	2	1	0
	PA_7	PA_6	PA_5	PA_4	PA_3	PA_2	PA_1	PA_0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*

Port A data 7 to 0
These bits store output data for TPC output groups 0 and 1

Note: * Bits selected for TPC output by NDERA settings become read-only bits.

For further information about PADR, see section 9.8, Port A.

11.2.3 Port B Data Direction Register (PBDDR)

PBDDR is an 8-bit write-only register that selects input or output for each pin in port B.

Bit	7	6	5	4	3	2	1	0
	PB_7DDR	PB_6DDR	PB_5DDR	PB_4DDR	PB_3DDR	PB_2DDR	PB_1DDR	PB_0DDR
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port B data direction 7 to 0
These bits select input or output for port B pins

Port B is multiplexed with pins TP_{15} to TP_8. Bits corresponding to pins used for TPC output must be set to 1. For further information about PBDDR, see section 9.9, Port B.

11.2.4 Port B Data Register (PBDR)

PBDR is an 8-bit readable/writable register that stores TPC output data for groups 2 and 3, when these TPC output groups are used.

Bit	7	6	5	4	3	2	1	0
	PB_7	PB_6	PB_5	PB_4	PB_3	PB_2	PB_1	PB_0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*

Port B data 7 to 0
These bits store output data for TPC output groups 2 and 3

Note: * Bits selected for TPC output by NDERB settings become read-only bits.

For further information about PBDR, see section 9.9, Port B.

11.2.5 Next Data Register A (NDRA)

NDRA is an 8-bit readable/writable register that stores the next output data for TPC output groups 1 and 0 (pins TP_7 to TP_0). During TPC output, when an ITU compare match event specified in TPCR occurs, NDRA contents are transferred to the corresponding bits in PADR. The address of NDRA differs depending on whether TPC output groups 0 and 1 have the same output trigger or different output triggers.

NDRA is initialized to H'00 by a reset and in hardware standby mode. It is not initialized in software standby mode.

Same Trigger for TPC Output Groups 0 and 1: If TPC output groups 0 and 1 are triggered by the same compare match event, the NDRA address is H'FFA5. The upper 4 bits belong to group 1 and the lower 4 bits to group 0. Address H'FFA7 consists entirely of reserved bits that cannot be modified and always read 1.

Address H'FFA5

Bit	7	6	5	4	3	2	1	0
	NDR7	NDR6	NDR5	NDR4	NDR3	NDR2	NDR1	NDR0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Next data 7 to 4
These bits store the next output data for TPC output group 1

Next data 3 to 0
These bits store the next output data for TPC output group 0

Address H'FFA7

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	—	—	—
Initial value	1	1	1	1	1	1	1	1
Read/Write	—	—	—	—	—	—	—	—

Reserved bits

Different Triggers for TPC Output Groups 0 and 1: If TPC output groups 0 and 1 are triggered by different compare match events, the address of the upper 4 bits of NDRA (group 1) is H'FFA5 and the address of the lower 4 bits (group 0) is H'FFA7. Bits 3 to 0 of address H'FFA5 and bits 7 to 4 of address H'FFA7 are reserved bits that cannot be modified and always read 1.

Address H'FFA5

Bit	7	6	5	4	3	2	1	0
	NDR7	NDR6	NDR5	NDR4	—	—	—	—
Initial value	0	0	0	0	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	—	—	—	—

Next data 7 to 4
These bits store the next output data for TPC output group 1

Reserved bits

Address H'FFA7

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	NDR3	NDR2	NDR1	NDR0
Initial value	1	1	1	1	0	0	0	0
Read/Write	—	—	—	—	R/W	R/W	R/W	R/W

Reserved bits

Next data 3 to 0
These bits store the next output data for TPC output group 0

11.2.6 Next Data Register B (NDRB)

NDRB is an 8-bit readable/writable register that stores the next output data for TPC output groups 3 and 2 (pins TP_{15} to TP_8). During TPC output, when an ITU compare match event specified in TPCR occurs, NDRB contents are transferred to the corresponding bits in PBDR. The address of NDRB differs depending on whether TPC output groups 2 and 3 have the same output trigger or different output triggers.

NDRB is initialized to H'00 by a reset and in hardware standby mode. It is not initialized in software standby mode.

Same Trigger for TPC Output Groups 2 and 3: If TPC output groups 2 and 3 are triggered by the same compare match event, the NDRB address is H'FFA4. The upper 4 bits belong to group 3 and the lower 4 bits to group 2. Address H'FFA6 consists entirely of reserved bits that cannot be modified and always read 1.

Address H'FFA4

Bit	7	6	5	4	3	2	1	0
	NDR15	NDR14	NDR13	NDR12	NDR11	NDR10	NDR9	NDR8
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Next data 15 to 12
These bits store the next output data for TPC output group 3

Next data 11 to 8
These bits store the next output data for TPC output group 2

Address H'FFA6

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	—	—	—
Initial value	1	1	1	1	1	1	1	1
Read/Write	—	—	—	—	—	—	—	—

Reserved bits

Different Triggers for TPC Output Groups 2 and 3: If TPC output groups 2 and 3 are triggered by different compare match events, the address of the upper 4 bits of NDRB (group 3) is H'FFA4 and the address of the lower 4 bits (group 2) is H'FFA6. Bits 3 to 0 of address H'FFA4 and bits 7 to 4 of address H'FFA6 are reserved bits that cannot be modified and always read 1.

Address H'FFA4

Bit	7	6	5	4	3	2	1	0
	NDR15	NDR14	NDR13	NDR12	—	—	—	—
Initial value	0	0	0	0	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	—	—	—	—

Next data 15 to 12
These bits store the next output data for TPC output group 3

Reserved bits

Address H'FFA6

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	NDR11	NDR10	NDR9	NDR8
Initial value	1	1	1	1	0	0	0	0
Read/Write	—	—	—	—	R/W	R/W	R/W	R/W

Reserved bits

Next data 11 to 8
These bits store the next output data for TPC output group 2

11.2.7 Next Data Enable Register A (NDERA)

NDERA is an 8-bit readable/writable register that enables or disables TPC output groups 1 and 0 (TP_7 to TP_0) on a bit-by-bit basis.

Bit	7	6	5	4	3	2	1	0
	NDER7	NDER6	NDER5	NDER4	NDER3	NDER2	NDER1	NDER0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Next data enable 7 to 0
These bits enable or disable TPC output groups 1 and 0

If a bit is enabled for TPC output by NDERA, then when the ITU compare match event selected in the TPC output control register (TPCR) occurs, the NDRA value is automatically transferred to the corresponding PADR bit, updating the output value. If TPC output is disabled, the bit value is not transferred from NDRA to PADR and the output value does not change.

NDERA is initialized to H'00 by a reset and in hardware standby mode. It is not initialized in software standby mode.

Bits 7 to 0—Next Data Enable 7 to 0 (NDER7 to NDER0): These bits enable or disable TPC output groups 1 and 0 (TP_7 to TP_0) on a bit-by-bit basis.

Bits 7 to 0 NDER7 to NDER0	Description	
0	TPC outputs TP_7 to TP_0 are disabled (NDR7 to NDR0 are not transferred to PA_7 to PA_0)	(Initial value)
1	TPC outputs TP_7 to TP_0 are enabled (NDR7 to NDR0 are transferred to PA_7 to PA_0)	

11.2.8 Next Data Enable Register B (NDERB)

NDERB is an 8-bit readable/writable register that enables or disables TPC output groups 3 and 2 (TP_{15} to TP_8) on a bit-by-bit basis.

Bit	7	6	5	4	3	2	1	0
	NDER15	NDER14	NDER13	NDER12	NDER11	NDER10	NDER9	NDER8
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Next data enable 15 to 8
These bits enable or disable TPC output groups 3 and 2

If a bit is enabled for TPC output by NDERB, then when the ITU compare match event selected in the TPC output control register (TPCR) occurs, the NDRB value is automatically transferred to the corresponding PBDR bit, updating the output value. If TPC output is disabled, the bit value is not transferred from NDRB to PBDR and the output value does not change.

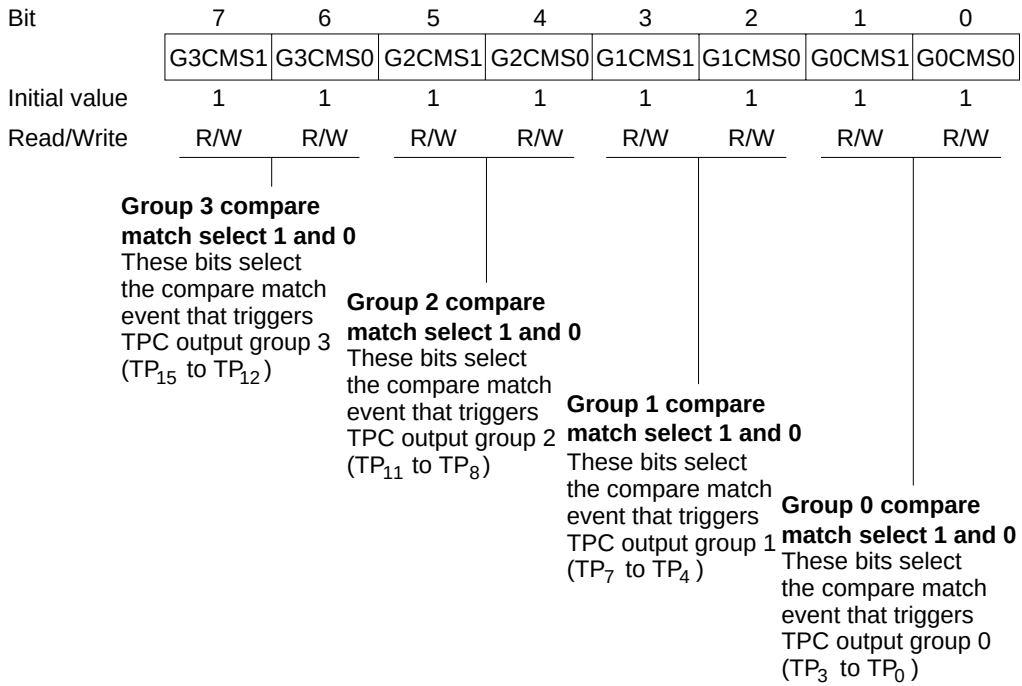
NDERB is initialized to H'00 by a reset and in hardware standby mode. It is not initialized in software standby mode.

Bits 7 to 0—Next Data Enable 15 to 8 (NDER15 to NDER8): These bits enable or disable TPC output groups 3 and 2 (TP_{15} to TP_8) on a bit-by-bit basis.

Bits 7 to 0 NDER15 to NDER8	Description	
0	TPC outputs TP_{15} to TP_8 are disabled (NDR15 to NDR8 are not transferred to PB_7 to PB_0)	(Initial value)
1	TPC outputs TP_{15} to TP_8 are enabled (NDR15 to NDR8 are transferred to PB_7 to PB_0)	

11.2.9 TPC Output Control Register (TPCR)

TPCR is an 8-bit readable/writable register that selects output trigger signals for TPC outputs on a group-by-group basis.



TPCR is initialized to H'FF by a reset and in hardware standby mode. It is not initialized in software standby mode.

Bits 7 and 6—Group 3 Compare Match Select 1 and 0 (G3CMS1, G3CMS0): These bits select the compare match event that triggers TPC output group 3 (TP_{15} to TP_{12}).

Bit 7 G3CMS1	Bit 6 G3CMS0	Description
0	0	TPC output group 3 (TP_{15} to TP_{12}) is triggered by compare match in ITU channel 0
	1	TPC output group 3 (TP_{15} to TP_{12}) is triggered by compare match in ITU channel 1
1	0	TPC output group 3 (TP_{15} to TP_{12}) is triggered by compare match in ITU channel 2
	1	TPC output group 3 (TP_{15} to TP_{12}) is triggered by compare match in ITU channel 3 (Initial value)

Bits 5 and 4—Group 2 Compare Match Select 1 and 0 (G2CMS1, G2CMS0): These bits select the compare match event that triggers TPC output group 2 (TP_{11} to TP_{8}).

Bit 5 G2CMS1	Bit 4 G2CMS0	Description
0	0	TPC output group 2 (TP_{11} to TP_{8}) is triggered by compare match in ITU channel 0
	1	TPC output group 2 (TP_{11} to TP_{8}) is triggered by compare match in ITU channel 1
1	0	TPC output group 2 (TP_{11} to TP_{8}) is triggered by compare match in ITU channel 2
	1	TPC output group 2 (TP_{11} to TP_{8}) is triggered by compare match in ITU channel 3 (Initial value)

Bits 3 and 2—Group 1 Compare Match Select 1 and 0 (G1CMS1, G1CMS0): These bits select the compare match event that triggers TPC output group 1 (TP_7 to TP_4).

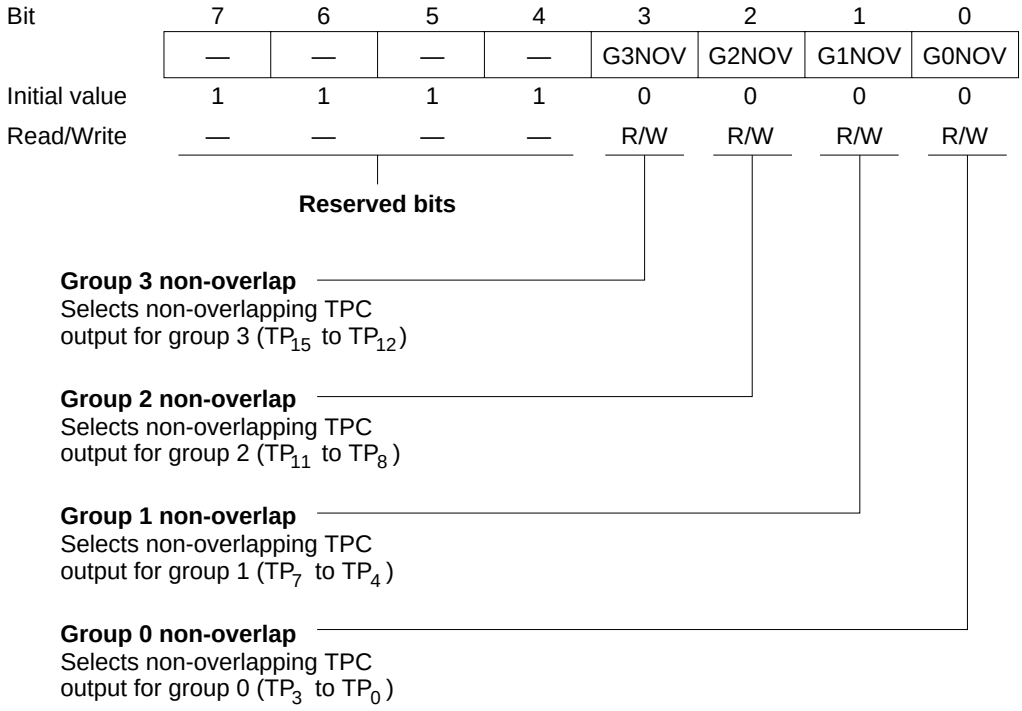
Bit 3 G1CMS1	Bit 2 G1CMS0	Description
0	0	TPC output group 1 (TP_7 to TP_4) is triggered by compare match in ITU channel 0
	1	TPC output group 1 (TP_7 to TP_4) is triggered by compare match in ITU channel 1
1	0	TPC output group 1 (TP_7 to TP_4) is triggered by compare match in ITU channel 2
	1	TPC output group 1 (TP_7 to TP_4) is triggered by compare match in ITU channel 3 (Initial value)

Bits 1 and 0—Group 0 Compare Match Select 1 and 0 (G0CMS1, G0CMS0): These bits select the compare match event that triggers TPC output group 0 (TP_3 to TP_0).

Bit 1 G0CMS1	Bit 0 G0CMS0	Description
0	0	TPC output group 0 (TP_3 to TP_0) is triggered by compare match in ITU channel 0
	1	TPC output group 0 (TP_3 to TP_0) is triggered by compare match in ITU channel 1
1	0	TPC output group 0 (TP_3 to TP_0) is triggered by compare match in ITU channel 2
	1	TPC output group 0 (TP_3 to TP_0) is triggered by compare match in ITU channel 3 (Initial value)

11.2.10 TPC Output Mode Register (TPMR)

TPMR is an 8-bit readable/writable register that selects normal or non-overlapping TPC output for each group.



The output trigger period of a non-overlapping TPC output waveform is set in general register B (GRB) in the ITU channel selected for output triggering. The non-overlap margin is set in general register A (GRA). The output values change at compare match A and B. For details see section 11.3.4, Non-Overlapping TPC Output.

TPMR is initialized to H'F0 by a reset and in hardware standby mode. It is not initialized in software standby mode.

Bits 7 to 4—Reserved: Read-only bits, always read as 1.

Bit 3—Group 3 Non-Overlap (G3NOV): Selects normal or non-overlapping TPC output for group 3 (TP_{15} to TP_{12}).

Bit 3 G3NOV	Description	
0	Normal TPC output in group 3 (output values change at compare match A in the selected ITU channel)	(Initial value)
1	Non-overlapping TPC output in group 3 (independent 1 and 0 output at compare match A and B in the selected ITU channel)	

Bit 2—Group 2 Non-Overlap (G2NOV): Selects normal or non-overlapping TPC output for group 2 (TP_{11} to TP_8).

Bit 2 G2NOV	Description	
0	Normal TPC output in group 2 (output values change at compare match A in the selected ITU channel)	(Initial value)
1	Non-overlapping TPC output in group 2 (independent 1 and 0 output at compare match A and B in the selected ITU channel)	

Bit 1—Group 1 Non-Overlap (G1NOV): Selects normal or non-overlapping TPC output for group 1 (TP_7 to TP_4).

Bit 1 G1NOV	Description	
0	Normal TPC output in group 1 (output values change at compare match A in the selected ITU channel)	(Initial value)
1	Non-overlapping TPC output in group 1 (independent 1 and 0 output at compare match A and B in the selected ITU channel)	

Bit 0—Group 0 Non-Overlap (G0NOV): Selects normal or non-overlapping TPC output for group 0 (TP_3 to TP_0).

Bit 0 G0NOV	Description	
0	Normal TPC output in group 0 (output values change at compare match A in the selected ITU channel)	(Initial value)
1	Non-overlapping TPC output in group 0 (independent 1 and 0 output at compare match A and B in the selected ITU channel)	

11.3 Operation

11.3.1 Overview

When corresponding bits in PADDR or PBDDR and NDERA or NDERB are set to 1, TPC output is enabled. The TPC output initially consists of the corresponding PADR or PBDR contents. When a compare-match event selected in TPCR occurs, the corresponding NDRA or NDRB bit contents are transferred to PADR or PBDR to update the output values.

Figure 11-2 illustrates the TPC output operation. Table 11-3 summarizes the TPC operating conditions.

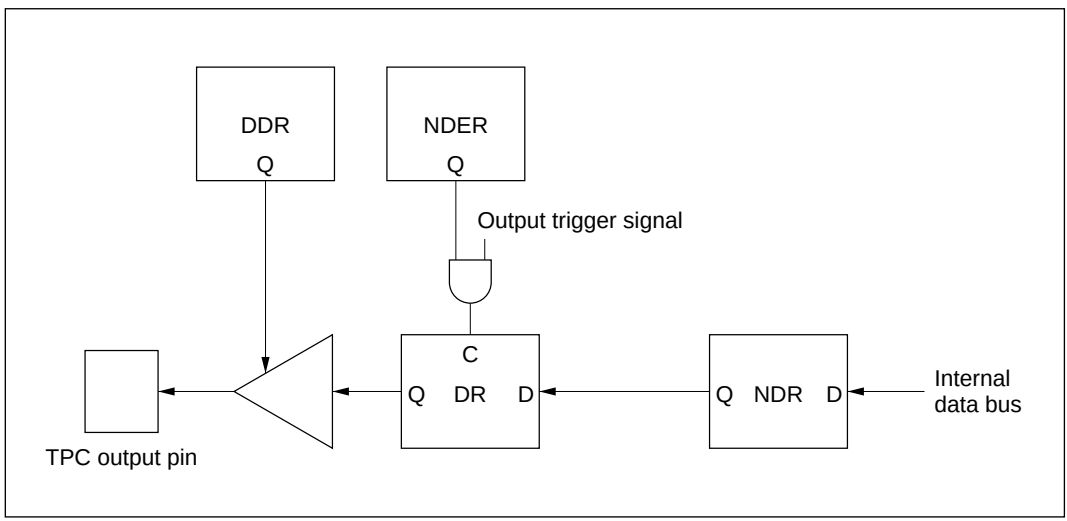


Figure 11-2 TPC Output Operation

Table 11-3 TPC Operating Conditions

NDER	DDR	Pin Function
0	0	Generic input port
	1	Generic output port
1	0	Generic input port (but the DR bit is a read-only bit, and when compare match occurs, the NDR bit value is transferred to the DR bit)
	1	TPC pulse output

Sequential output of up to 16-bit patterns is possible by writing new output data to NDRA and NDRB before the next compare match. For information on non-overlapping operation, see section 11.3.4, Non-Overlapping TPC Output.

11.3.2 Output Timing

If TPC output is enabled, NDRA/NDRB contents are transferred to PADR/PBDR and output when the selected compare match event occurs. Figure 11-3 shows the timing of these operations for the case of normal output in groups 2 and 3, triggered by compare match A.

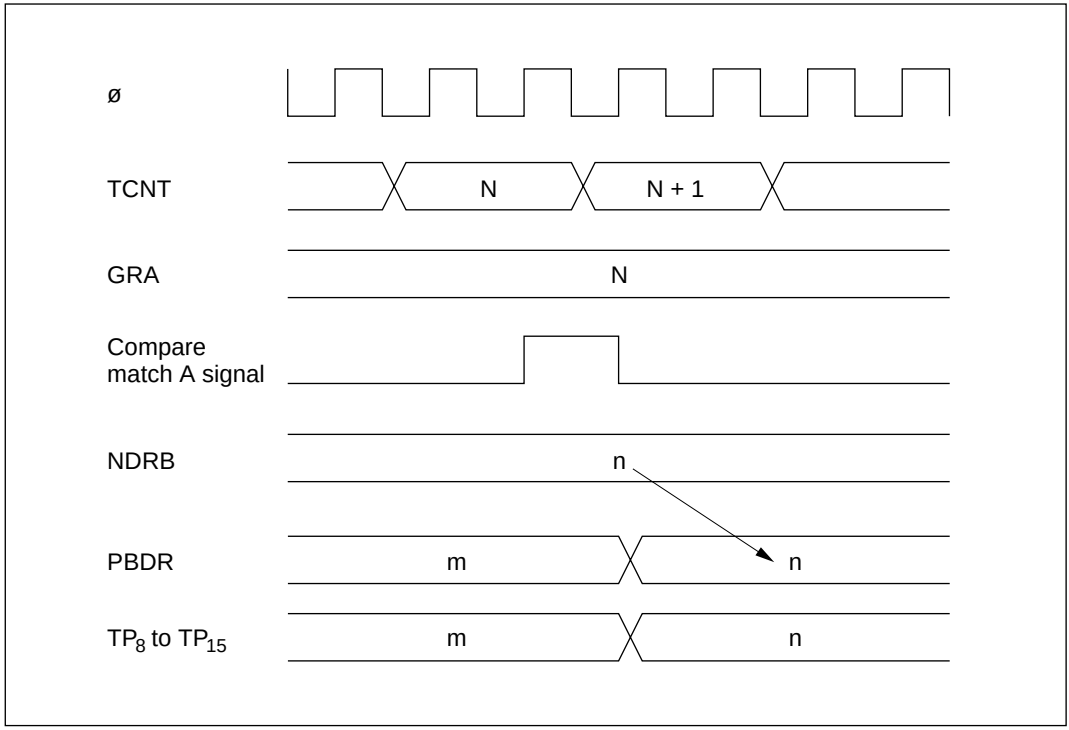


Figure 11-3 Timing of Transfer of Next Data Register Contents and Output (Example)

11.3.3 Normal TPC Output

Sample Setup Procedure for Normal TPC Output: Figure 11-4 shows a sample procedure for setting up normal TPC output.

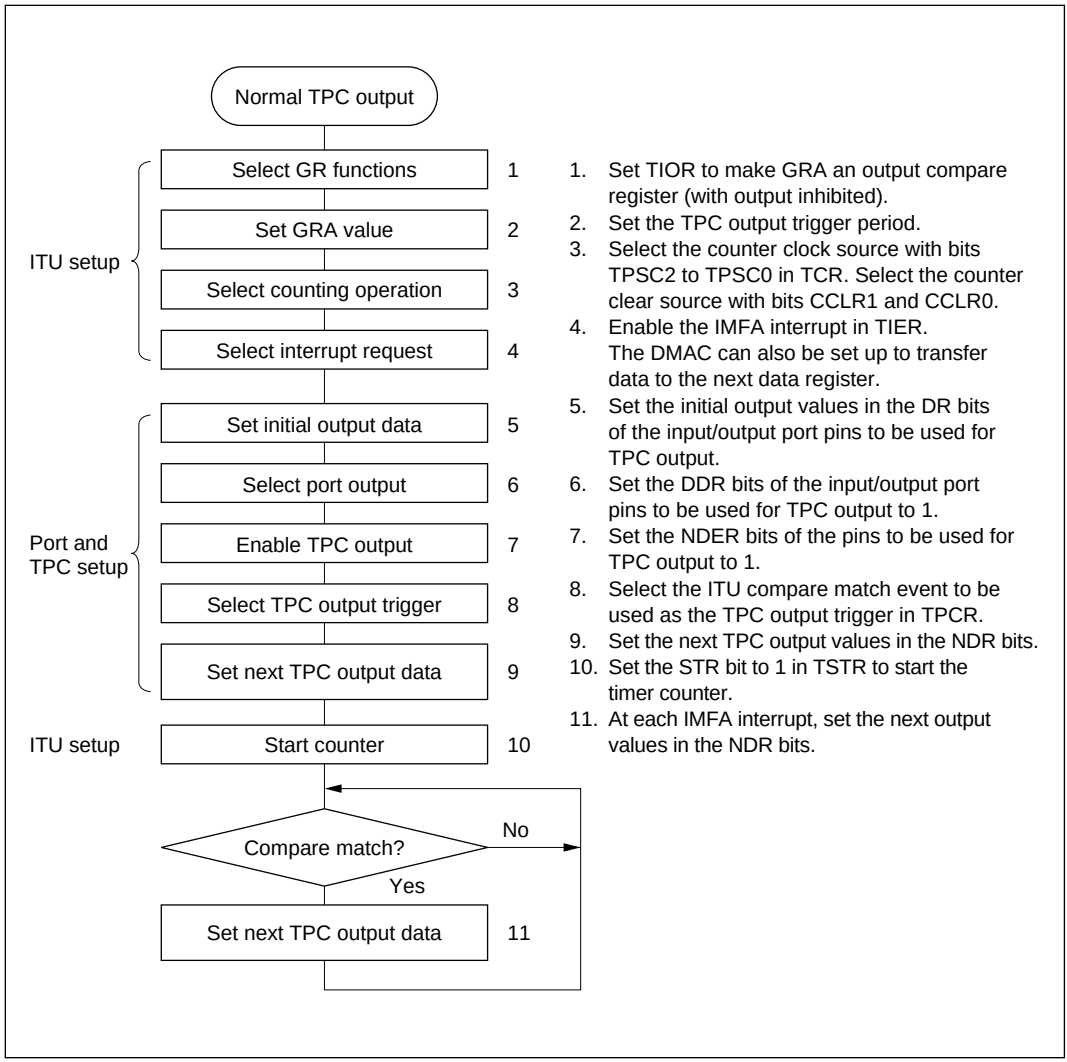
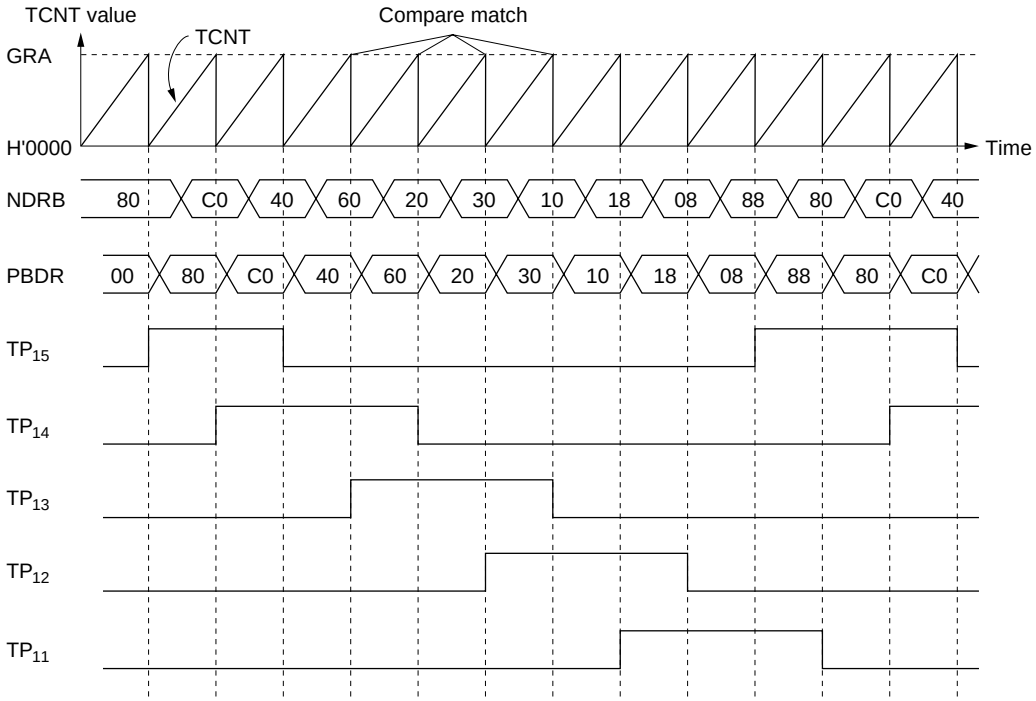


Figure 11-4 Setup Procedure for Normal TPC Output (Example)

Example of Normal TPC Output (Example of Five-Phase Pulse Output): Figure 11-5 shows an example in which the TPC is used for cyclic five-phase pulse output.



- The ITU channel to be used as the output trigger channel is set up so that GRA is an output compare register and the counter will be cleared by compare match A. The trigger period is set in GRA. The IMIEA bit is set to 1 in TIER to enable the compare match A interrupt.
- H'F8 is written in PBDDR and NDERB, and bits G3CMS1, G3CMS0, G2CMS1, and G2CMS0 are set in TPCR to select compare match in the ITU channel set up in step 1 as the output trigger. Output data H'80 is written in NDRB.
- The timer counter in this ITU channel is started. When compare match A occurs, the NDRB contents are transferred to PBDR and output. The compare match/input capture A (IMFA) interrupt service routine writes the next output data (H'C0) in NDRB.
- Five-phase overlapping pulse output (one or two phases active at a time) can be obtained by writing H'40, H'60, H'20, H'30, H'10, H'18, H'08, H'88… at successive IMFA interrupts. If the DMAC is set for activation by this interrupt, pulse output can be obtained without loading the CPU.

Figure 11-5 Normal TPC Output Example (Five-Phase Pulse Output)

11.3.4 Non-Overlapping TPC Output

Sample Setup Procedure for Non-Overlapping TPC Output: Figure 11-6 shows a sample procedure for setting up non-overlapping TPC output.

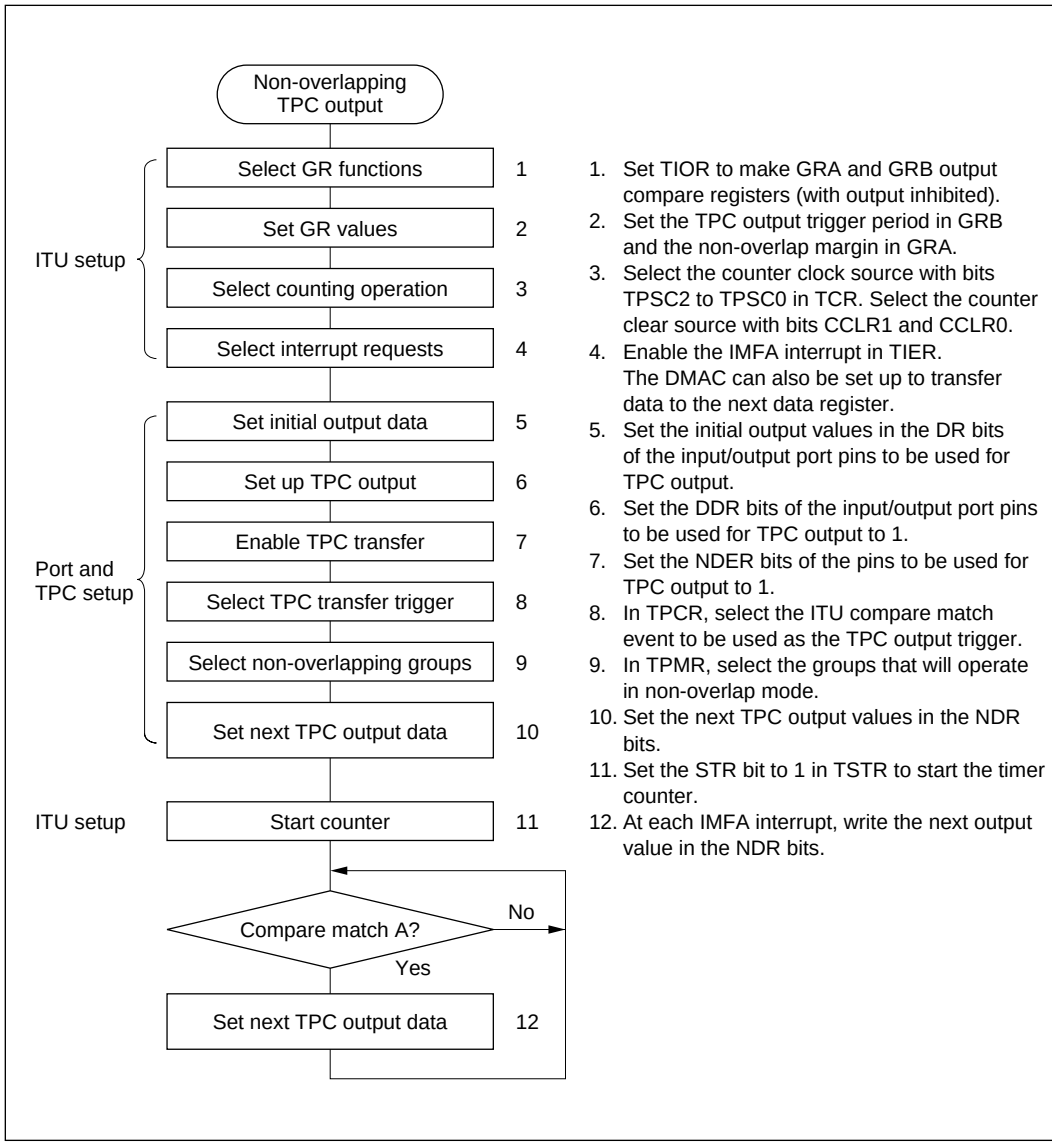
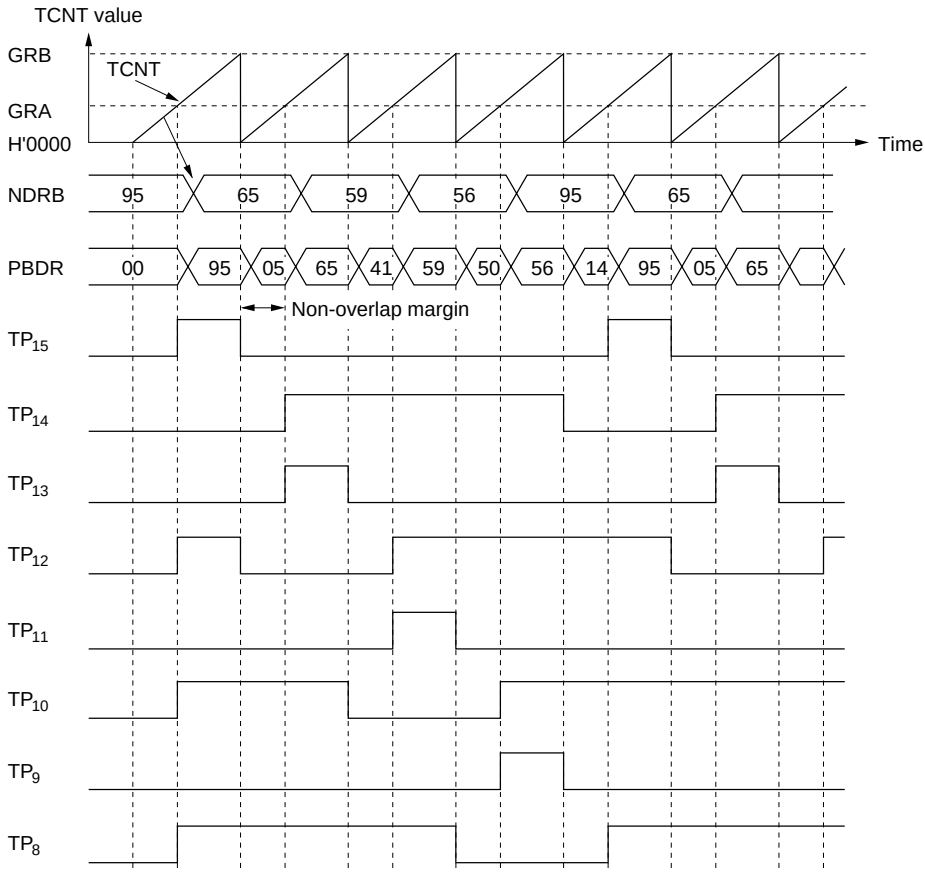


Figure 11-6 Setup Procedure for Non-Overlapping TPC Output (Example)

Example of Non-Overlapping TPC Output (Example of Four-Phase Complementary Non-Overlapping Output): Figure 11-7 shows an example of the use of TPC output for four-phase complementary non-overlapping pulse output.



- The ITU channel to be used as the output trigger channel is set up so that GRA and GRB are output compare registers and the counter will be cleared by compare match B. The TPC output trigger period is set in GRB. The non-overlap margin is set in GRA. The IMIEA bit is set to 1 in TIER to enable IMFA interrupts.
- H'FF is written in PBDDR and NDERB, and bits G3CMS1, G3CMS0, G2CMS1, and G2CMS0 are set Bits G3NOV and G2NOV are set to 1 in TPMR to select non-overlapping output. Output data H'95 is written in NDRB.
- The timer counter in this ITU channel is started. When compare match B occurs, outputs change from 1 to 0. When compare match A occurs, outputs change from 0 to 1 (the change from 0 to 1 is delayed by the value of GRA). The IMFA interrupt service routine writes the next output data (H'65) in NDRB.
- Four-phase complementary non-overlapping pulse output can be obtained by writing H'59, H'56, H'95… at successive IMFA interrupts. If the DMAC is set for activation by this interrupt, pulse output can be obtained without loading the CPU.

Figure 11-7 Non-Overlapping TPC Output Example (Four-Phase Complementary Non-Overlapping Pulse Output)

11.3.5 TPC Output Triggering by Input Capture

TPC output can be triggered by ITU input capture as well as by compare match. If GRA functions as an input capture register in the ITU channel selected in TPCR, TPC output will be triggered by the input capture signal. Figure 11-8 shows the timing.

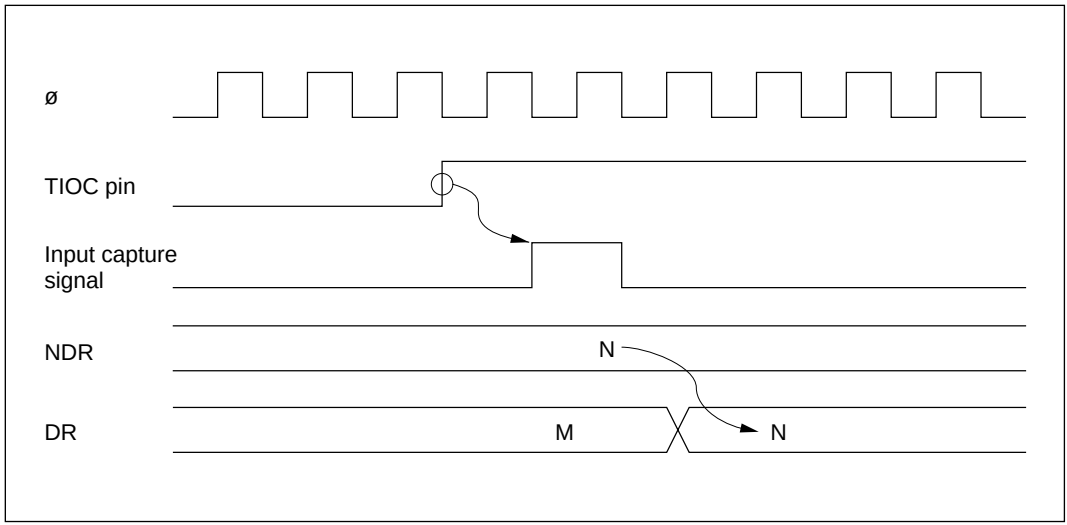


Figure 11-8 TPC Output Triggering by Input Capture (Example)

11.4 Usage Notes

11.4.1 Operation of TPC Output Pins

TP_0 to TP_{15} are multiplexed with ITU, DMAC, and other pin functions. When ITU or DMAC output is enabled, the corresponding pins cannot be used for TPC output. The data transfer from NDR bits to DR bits takes place, however, regardless of the usage of the pin.

Pin functions should be changed only under conditions in which the output trigger event will not occur.

11.4.2 Note on Non-Overlapping Output

During non-overlapping operation, the transfer of NDR bit values to DR bits takes place as follows.

1. NDR bits are always transferred to DR bits at compare match A.

2. At compare match B, NDR bits are transferred only if their value is 0. Bits are not transferred if their value is 1.

Figure 11-9 illustrates the non-overlapping TPC output operation.

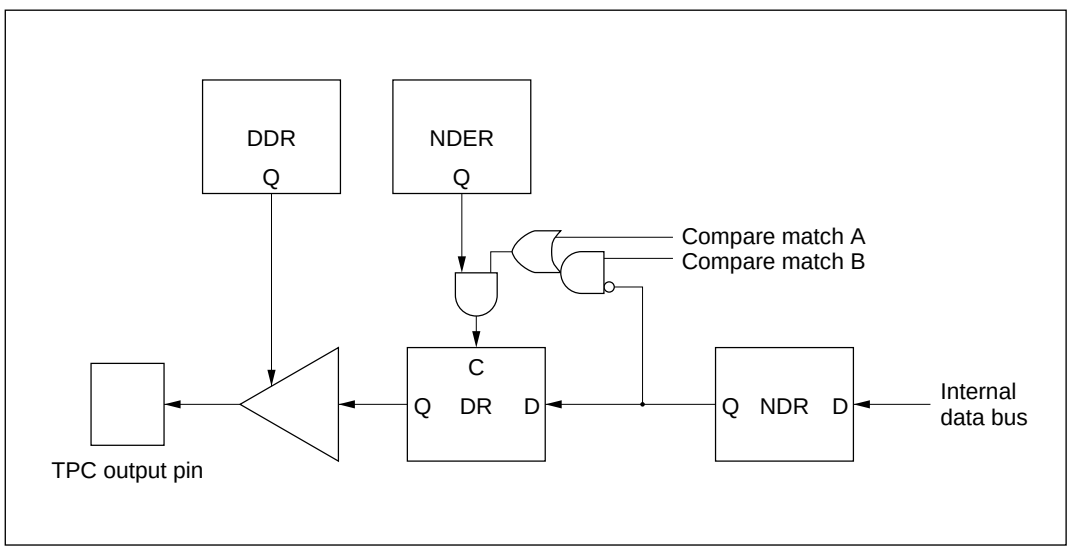


Figure 11-9 Non-Overlapping TPC Output

Therefore, 0 data can be transferred ahead of 1 data by making compare match B occur before compare match A. NDR contents should not be altered during the interval from compare match B to compare match A (the non-overlap margin).

This can be accomplished by having the IMFA interrupt service routine write the next data in NDR, or by having the IMFA interrupt activate the DMAC. The next data must be written before the next compare match B occurs.

Figure 11-10 shows the timing relationships.

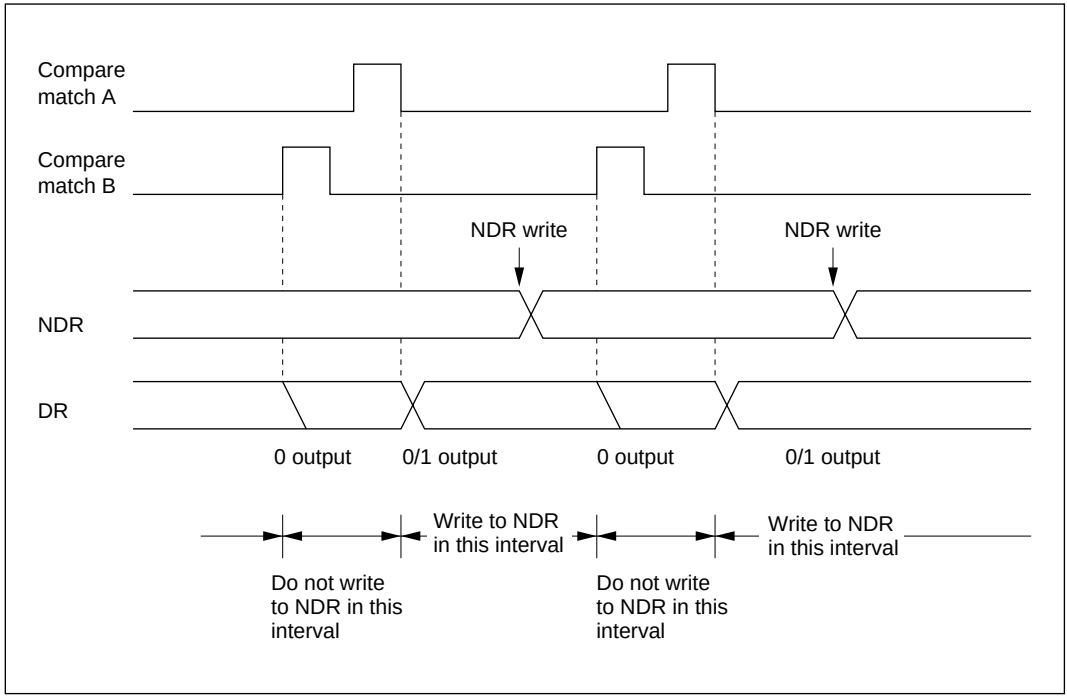


Figure 11-10 Non-Overlapping Operation and NDR Write Timing

Section 12 Watchdog Timer

12.1 Overview

The H8/3003 has an on-chip watchdog timer (WDT). The WDT has two selectable functions: it can operate as a watchdog timer to supervise system operation, or it can operate as an interval timer. As a watchdog timer, it generates a reset signal for the H8/3003 chip if a system crash allows the timer counter (TCNT) to overflow before being rewritten. In interval timer operation, an interval timer interrupt is requested at each TCNT overflow.

12.1.1 Features

WDT features are listed below.

- Selection of eight counter clock sources

  ø/2, ø/32, ø/64, ø/128, ø/256, ø/512, ø/2048, or ø/4096

- Interval timer option

- Timer counter overflow generates a reset signal or interrupt.

  The reset signal is generated in watchdog timer operation. An interval timer interrupt is generated in interval timer operation.

- Watchdog timer reset signal resets the entire H8/3003 internally, and can also be output externally.

  The reset signal generated by timer counter overflow during watchdog timer operation resets the entire H8/3003 internally. An external reset signal can be output from the $\overline{\text{RESO}}$ pin to reset other system devices simultaneously.

12.1.2 Block Diagram

Figure 12-1 shows a block diagram of the WDT.

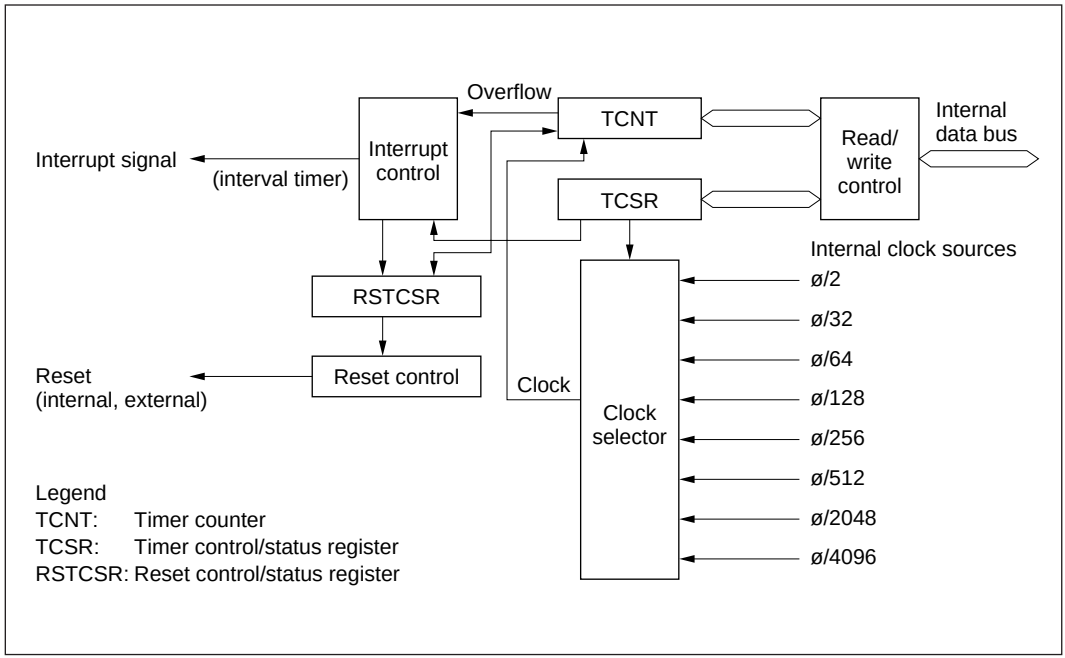


Figure 12-1 WDT Block Diagram

12.1.3 Pin Configuration

Table 12-1 describes the WDT output pin.

Table 12-1 WDT Pin

Name	Abbreviation	I/O	Function
Reset output	$\overline{\text{RESO}}$	Output	External output of the watchdog timer reset signal

12.1.4 Register Configuration

Table 12-2 summarizes the WDT registers.

Table 12-2 WDT Registers

Address[*1]					
Write[*2]	**Read**	**Name**	**Abbreviation**	**R/W**	**Initial Value**
H'FFA8	H'FFA8	Timer control/status register	TCSR	R/(W)[*3]	H'18
	H'FFA9	Timer counter	TCNT	R/W	H'00
H'FFAA	H'FFAB	Reset control/status register	RSTCSR	R/(W)[*3]	H'3F

Notes: 1. Lower 16 bits of the address.
2. Write word data starting at this address.
3. Only 0 can be written in bit 7, to clear the flag.

12.2 Register Descriptions

12.2.1 Timer Counter (TCNT)

TCNT is an 8-bit readable and writable* up-counter.

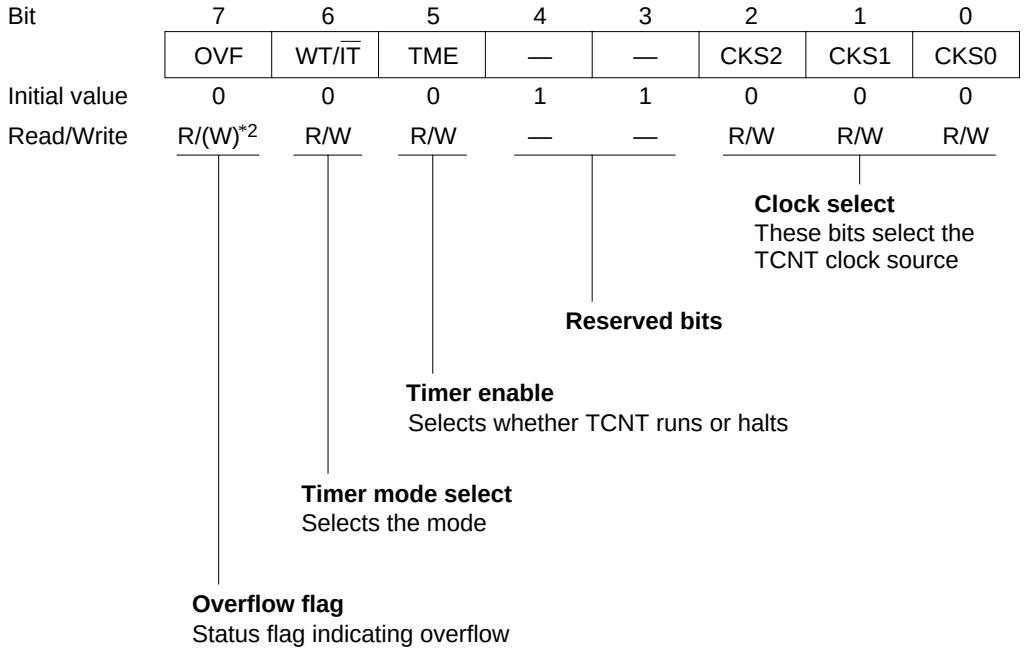
Bit	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

When the TME bit is set to 1 in TCSR, TCNT starts counting pulses generated from an internal clock source selected by bits CKS2 to CKS0 in TCSR. When the count overflows (changes from H'FF to H'00), the OVF bit is set to 1 in TCSR. TCNT is initialized to H'00 by a reset and when the TME bit is cleared to 0.

Note: * TCNT is write-protected by a password. For details see section 12.2.4, Notes on Register Access.

12.2.2 Timer Control/Status Register (TCSR)

TCSR is an 8-bit readable and writable[*1] register. Its functions include selecting the timer mode and clock source.



Bits 7 to 5 are initialized to 0 by a reset and in standby mode. Bits 2 to 0 are initialized to 0 by a reset. In software standby mode bits 2 to 0 are not initialized, but retain their previous values.

Notes: 1. TCSR is write-protected by a password. For details see section 12.2.4, Notes on Register Access.
2. Only 0 can be written, to clear the flag.

Bit 7—Overflow Flag (OVF): This status flag indicates that the timer counter has overflowed from H'FF to H'00.

Bit 7 OVF	Description	
0	[Clearing condition] Cleared by reading OVF when OVF = 1, then writing 0 in OVF	(Initial value)
1	[Setting condition] Set when TCNT changes from H'FF to H'00	

Bit 6—Timer Mode Select (WT/$\overline{IT}$): Selects whether to use the WDT as a watchdog timer or interval timer. If used as an interval timer, the WDT generates an interval timer interrupt request when TCNT overflows. If used as a watchdog timer, the WDT generates a reset signal when TCNT overflows.

Bit 6 WT/$\overline{IT}$	Description	
0	Interval timer: requests interval timer interrupts	(Initial value)
1	Watchdog timer: generates a reset signal	

Bit 5—Timer Enable (TME): Selects whether TCNT runs or is halted.

Bit 5 TME	Description	
0	TCNT is initialized to H'00 and halted	(Initial value)
1	TCNT is counting	

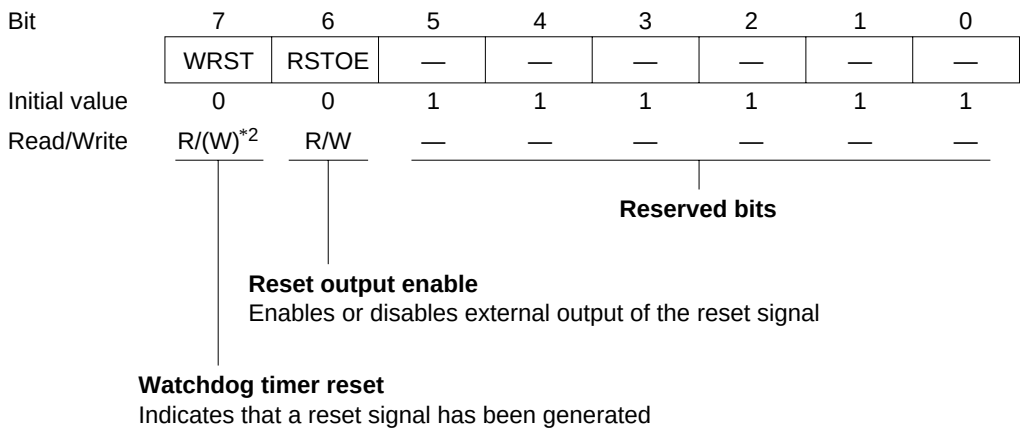
Bits 4 and 3—Reserved: Read-only bits, always read as 1.

Bits 2 to 0—Clock Select 2 to 0 (CKS2/1/0): These bits select one of eight internal clock sources, obtained by prescaling the system clock (ø), for input to TCNT.

Bit 2 CKS2	Bit 1 CKS1	Bit 0 CKS0	Description	
0	0	0	ø/2	(Initial value)
		1	ø/32	
	1	0	ø/64	
		1	ø/128	
1	0	0	ø/256	
		1	ø/512	
	1	0	ø/2048	
		1	ø/4096	

12.2.3 Reset Control/Status Register (RSTCSR)

RSTCSR is an 8-bit readable and writable[*1] register that indicates when a reset signal has been generated by watchdog timer overflow, and controls external output of the reset signal.



Bits 7 and 6 are initialized by input of a reset signal at the $\overline{\text{RES}}$ pin. They are not initialized by reset signals generated by watchdog timer overflow.

Notes: 1. RSTCSR is write-protected by a password. For details see section 12.2.4, Notes on Register Access.
2. Only 0 can be written in bit 7, to clear the flag.

Bit 7—Watchdog Timer Reset (WRST): During watchdog timer operation, this bit indicates that TCNT has overflowed and generated a reset signal. This reset signal resets the entire H8/3003 chip internally. If bit RSTOE is set to 1, this reset signal is also output (low) at the $\overline{\text{RESO}}$ pin to initialize external system devices.

Bit 7 WRST	Description	
0	[Clearing condition] Cleared to 0 by reset signal input at $\overline{\text{RES}}$ pin, or by writing 0	(Initial value)
1	[Setting condition] Set when TCNT overflow generates a reset signal during watchdog timer operation	

Bit 6—Reset Output Enable (RSTOE): Enables or disables external output at the $\overline{\text{RESO}}$ pin of the reset signal generated if TCNT overflows during watchdog timer operation.

Bit 6 RSTOE	Description	
0	Reset signal is not output externally	(Initial value)
1	Reset signal is output externally	

Bits 5 to 0—Reserved: Read-only bits, always read as 1.

12.2.4 Notes on Register Access

The watchdog timer's TCNT, TCSR, and RSTCSR registers differ from other registers in being more difficult to write. The procedures for writing and reading these registers are given below.

Writing to TCNT and TCSR: These registers must be written by a word transfer instruction. They cannot be written by byte instructions. Figure 12-2 shows the format of data written to TCNT and TCSR. TCNT and TCSR both have the same write address. The write data must be contained in the lower byte of the written word. The upper byte must contain H'5A (password for TCNT) or H'A5 (password for TCSR). This transfers the write data from the lower byte to TCNT or TCSR.

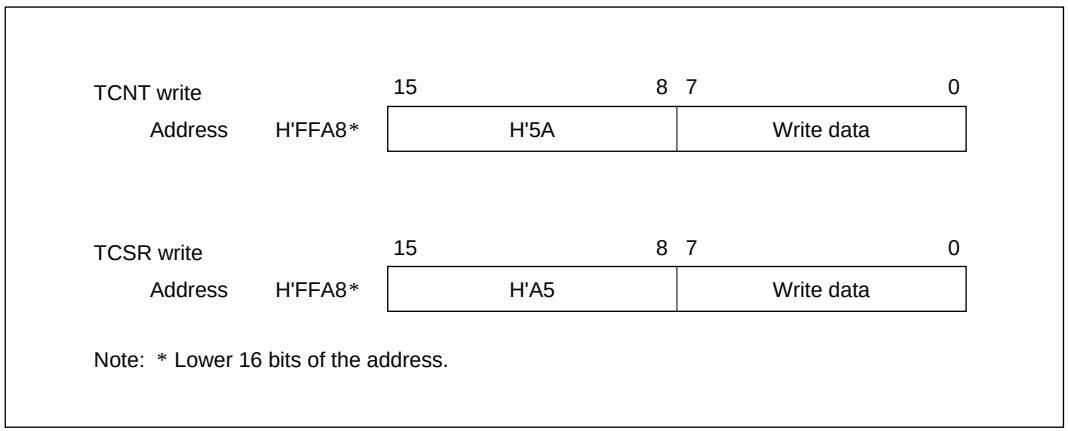


Figure 12-2 Format of Data Written to TCNT and TCSR

Writing to RSTCSR: RSTCSR must be written by a word transfer instruction. It cannot be written by byte transfer instructions. Figure 12-3 shows the format of data written to RSTCSR. To write 0 in the WRST bit, the write data must have H'A5 in the upper byte and H'00 in the lower byte. The H'00 in the lower byte clears the WRST bit in RSTCSR to 0. To write to the RSTOE bit, the upper byte must contain H'5A and the lower byte must contain the write data. Writing this word transfers a write data value into the RSTOE bit.

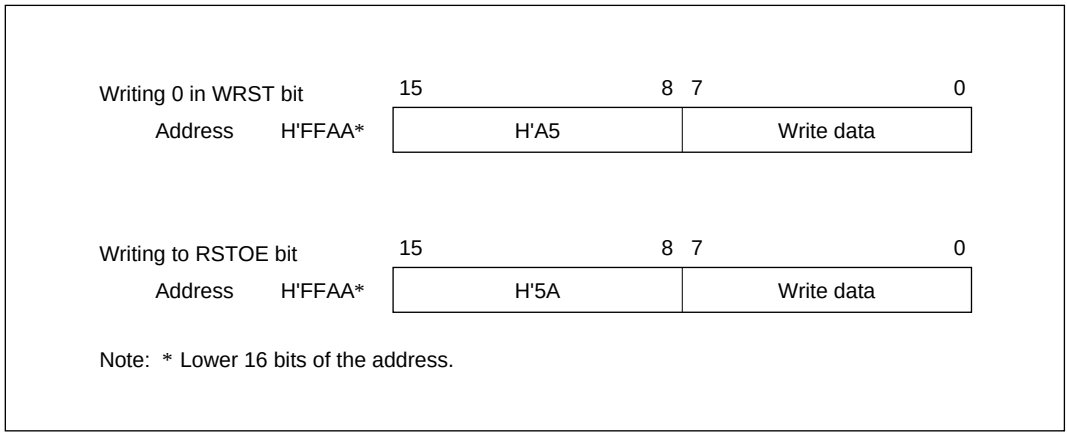


Figure 12-3 Format of Data Written to RSTCSR

Reading TCNT, TCSR, and RSTCSR: These registers are read like other registers. Byte access instructions can be used. The read addresses are H'FFA8 for TCSR, H'FFA9 for TCNT, and H'FFAB for RSTCSR, as listed in table 12-3.

Table 12-3 Read Addresses of TCNT, TCSR, and RSTCSR

Address*	Register
H'FFA8	TCSR
H'FFA9	TCNT
H'FFAB	RSTCSR

Note: * Lower 16 bits of the address.

12.3 Operation

Operations when the WDT is used as a watchdog timer and as an interval timer are described below.

12.3.1 Watchdog Timer Operation

Figure 12-4 illustrates watchdog timer operation. To use the WDT as a watchdog timer, set the WT/$\overline{\text{IT}}$ and TME bits to 1 in TCSR. Software must prevent TCNT overflow by rewriting the TCNT value (normally by writing H'00) before overflow occurs. If TCNT fails to be rewritten and overflows due to a system crash etc., the H8/3003 is internally reset for a duration of 518 states.

The watchdog reset signal can be externally output from the $\overline{\text{RESO}}$ pin to reset external system devices. The reset signal is output externally for 132 states. External output can be enabled or disabled by the RSTOE bit in RSTCSR.

A watchdog reset has the same vector as a reset generated by input at the $\overline{\text{RES}}$ pin. Software can distinguish a $\overline{\text{RES}}$ reset from a watchdog reset by checking the WRST bit in RSTCSR.

If a $\overline{\text{RES}}$ reset and a watchdog reset occur simultaneously, the $\overline{\text{RES}}$ reset takes priority.

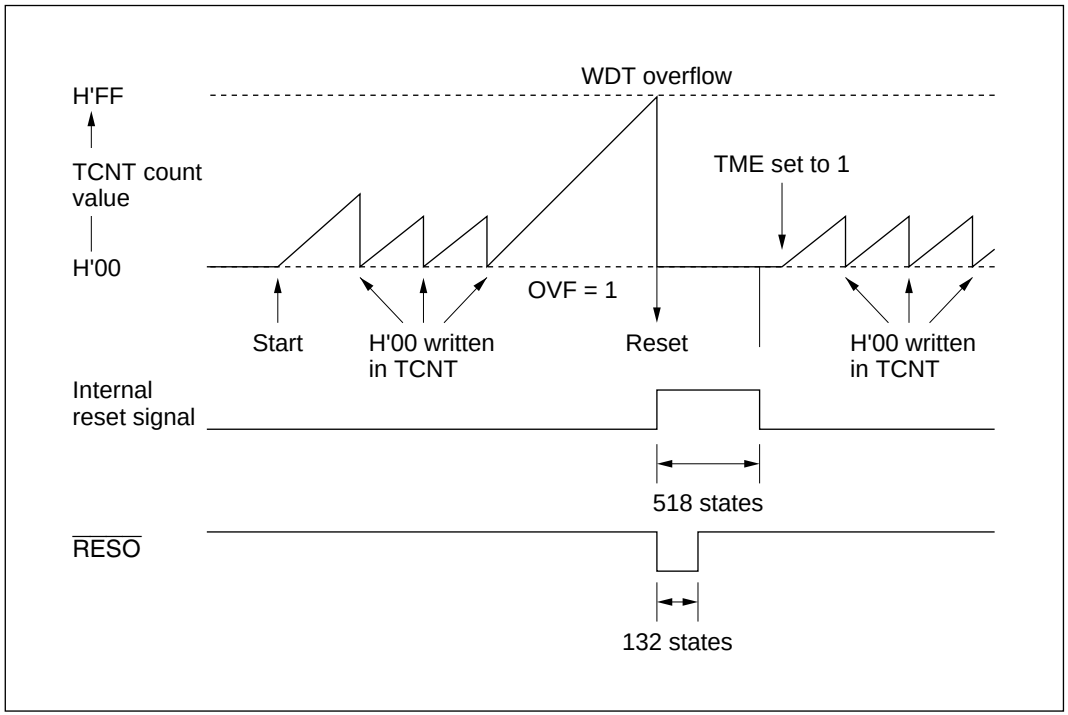


Figure 12-4 Watchdog Timer Operation

12.3.2 Interval Timer Operation

Figure 12-5 illustrates interval timer operation. To use the WDT as an interval timer, clear bit WT/$\overline{IT}$ to 0 and set bit TME to 1 in TCSR. An interval timer interrupt request is generated at each TCNT overflow. This function can be used to generate interval timer interrupts at regular intervals.

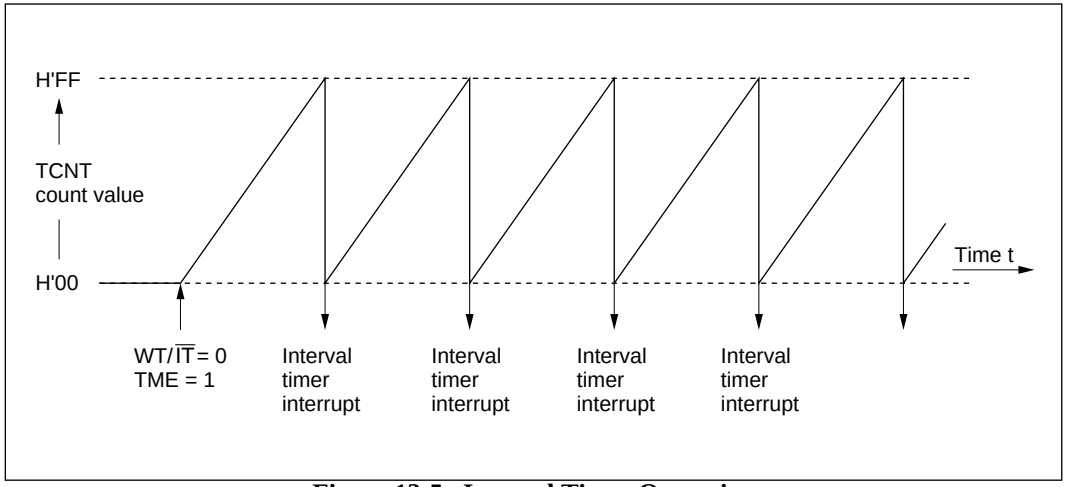


Figure 12-5 Interval Timer Operation

12.3.3 Timing of Setting of Overflow Flag (OVF)

Figure 12-6 shows the timing of setting of the OVF flag in TCSR. The OVF flag is set to 1 when TCNT overflows. At the same time, a reset signal is generated in watchdog timer operation, or an interval timer interrupt is generated in interval timer operation.

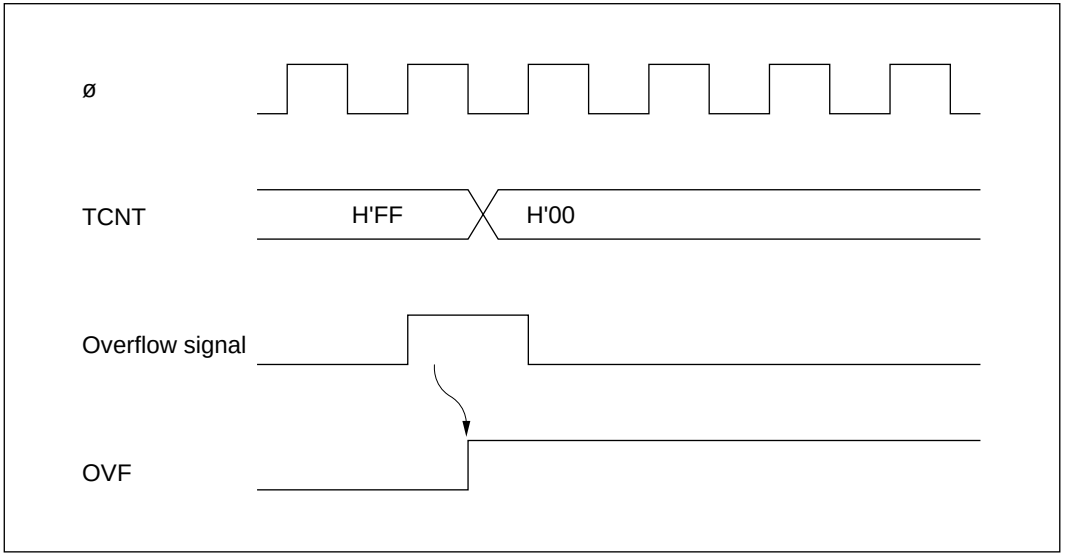


Figure 12-6 Timing of Setting of OVF

12.3.4 Timing of Setting of Watchdog Timer Reset Bit (WRST)

The WRST bit in RSTCSR is valid when bits WT/$\overline{IT}$ and TME are both set to 1 in TCSR. Figure 12-7 shows the timing of setting of WRST and the internal reset timing. The WRST bit is set to 1 when TCNT overflows and OVF is set to 1. At the same time an internal reset signal is generated for the entire H8/3003 chip. This internal reset signal clears OVF to 0, but the WRST bit remains set to 1. The reset routine must therefore clear the WRST bit.

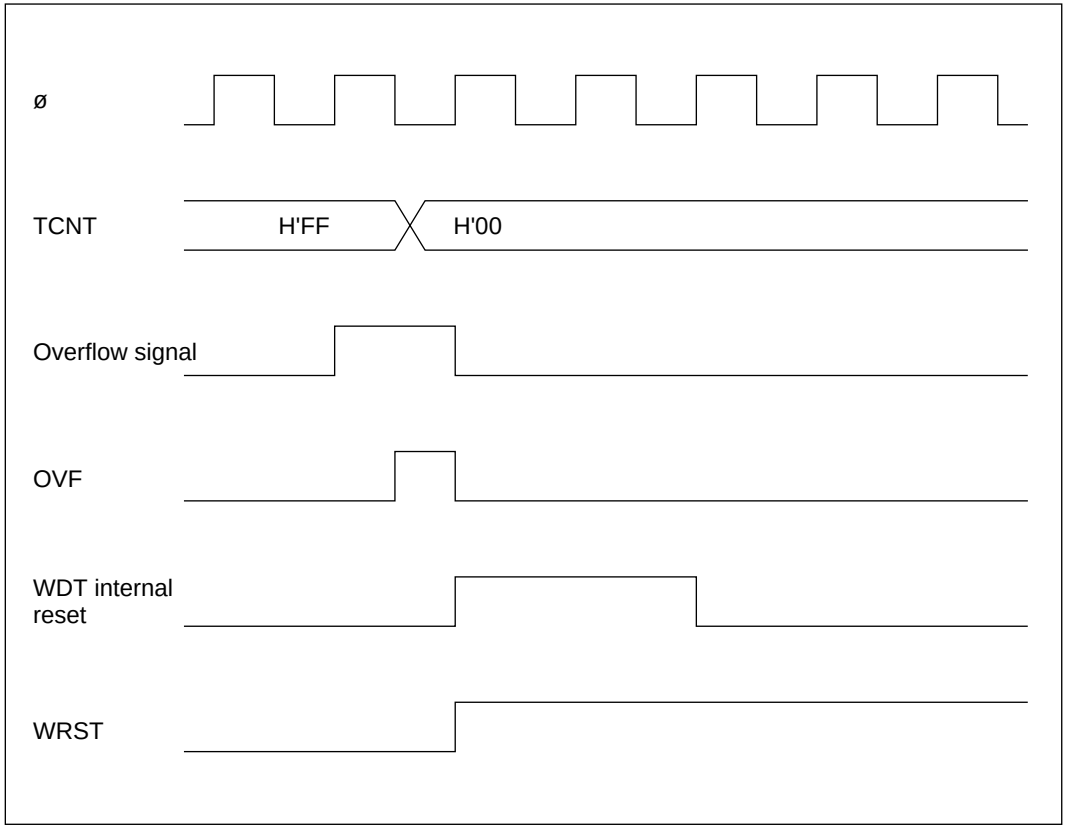


Figure 12-7 Timing of Setting of WRST Bit and Internal Reset

12.4 Interrupts

During interval timer operation, an overflow generates an interval timer interrupt (WOVI). The interval timer interrupt is requested whenever the OVF bit is set to 1 in TCSR.

12.5 Usage Notes

Contention between TCNT Write and Increment: If a timer counter clock pulse is generated during the T_3 state of a write cycle to TCNT, the write takes priority and the timer count is not incremented. See figure 12-8.

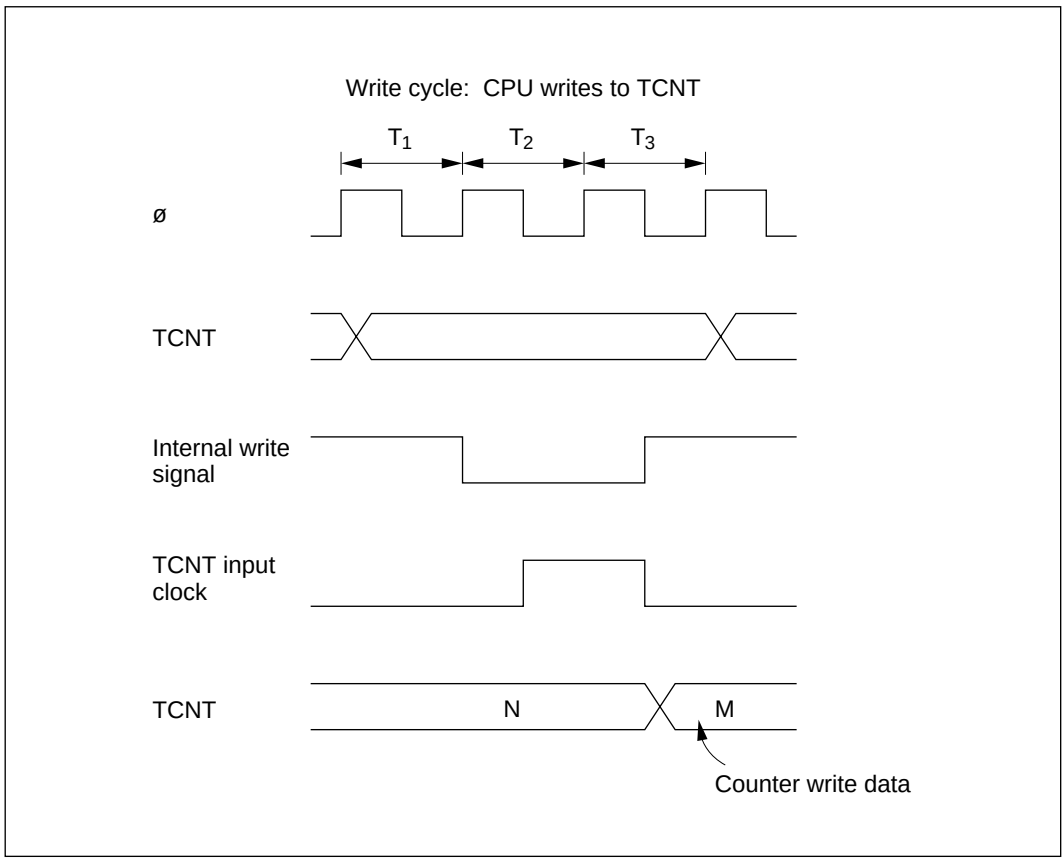


Figure 12-8 Contention between TCNT Write and Increment

Changing CKS2 to CKS0 Values: Halt TCNT by clearing the TME bit to 0 in TCSR before changing the values of bits CKS2 to CKS0.

Section 13 Serial Communication Interface

13.1 Overview

The H8/3003 has a serial communication interface (SCI) with two independent channels. Both channels are functionally identical. The SCI can communicate in asynchronous mode or synchronous mode, and has a multiprocessor communication function for serial communication among two or more processors.

13.1.1 Features

SCI features are listed below.

- Selection of asynchronous or synchronous mode for serial communication

a. Asynchronous mode

Serial data communication is synchronized one character at a time. The SCI can communicate with a universal asynchronous receiver/transmitter (UART), asynchronous communication interface adapter (ACIA), or other chip that employs standard asynchronous serial communication. It can also communicate with two or more other processors using the multiprocessor communication function. There are twelve selectable serial data communication formats.

— Data length: 7 or 8 bits
— Stop bit length: 1 or 2 bits
— Parity bit: even, odd, or none
— Multiprocessor bit: 1 or 0
— Receive error detection: parity, overrun, and framing errors
— Break detection: by reading the RxD level directly when a framing error occurs

b. Synchronous mode

Serial data communication is synchronized with a clock signal. The SCI can communicate with other chips having a synchronous communication function. There is one serial data communication format.

— Data length: 8 bits
— Receive error detection: overrun errors

- Full duplex communication

  The transmitting and receiving sections are independent, so the SCI can transmit and receive simultaneously. The transmitting and receiving sections are both double-buffered, so serial data can be transmitted and received continuously.

- Built-in baud rate generator with selectable bit rates

- Selectable transmit/receive clock sources: internal clock from baud rate generator, or external clock from the SCK pin.

- Four types of interrupts

  Transmit-data-empty, transmit-end, receive-data-full, and receive-error interrupts are requested independently. The transmit-data-empty and receive-data-full interrupts can activate the DMA controller (DMAC) to transfer data.

13.1.2 Block Diagram

Figure 13-1 shows a block diagram of the SCI.

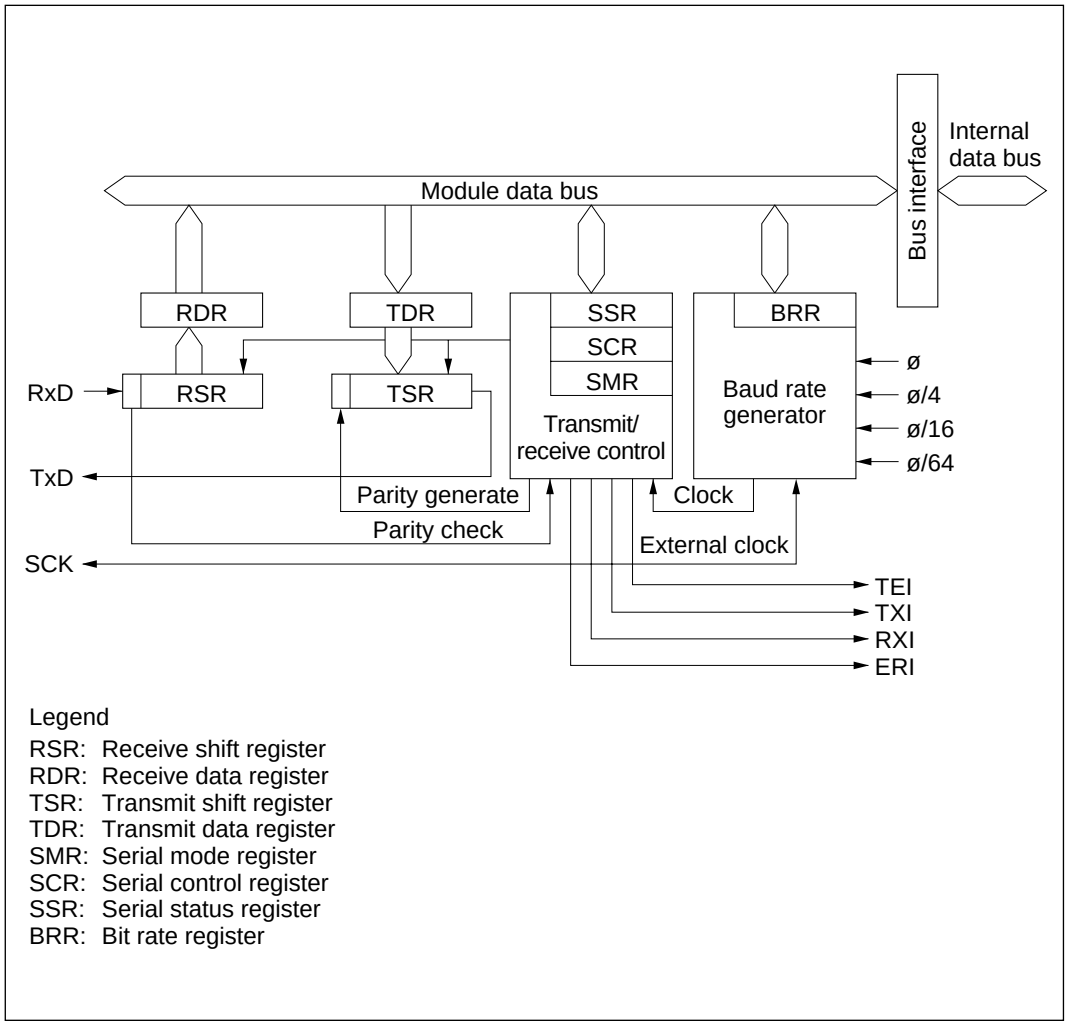


Figure 13-1 SCI Block Diagram

13.1.3 Input/Output Pins

The SCI has serial pins for each channel as listed in table 13-1.

Table 13-1 SCI Pins

Channel	Name	Abbreviation	I/O	Function
0	Serial clock pin	SCK_0	Input/output	SCI_0 clock input/output
	Receive data pin	RxD_0	Input	SCI_0 receive data input
	Transmit data pin	TxD_0	Output	SCI_0 transmit data output
1	Serial clock pin	SCK_1	Input/output	SCI_1 clock input/output
	Receive data pin	RxD_1	Input	SCI_1 receive data input
	Transmit data pin	TxD_1	Output	SCI_1 transmit data output

13.1.4 Register Configuration

The SCI has internal registers as listed in table 13-2. These registers select asynchronous or synchronous mode, specify the data format and bit rate, and control the transmitter and receiver sections.

Table 13-2 Registers

Channel	Address*1	Name	Abbreviation	R/W	Initial Value
0	H'FFB0	Serial mode register	SMR	R/W	H'00
	H'FFB1	Bit rate register	BRR	R/W	H'FF
	H'FFB2	Serial control register	SCR	R/W	H'00
	H'FFB3	Transmit data register	TDR	R/W	H'FF
	H'FFB4	Serial status register	SSR	R/(W)*2	H'84
	H'FFB5	Receive data register	RDR	R	H'00
1	H'FFB8	Serial mode register	SMR	R/W	H'00
	H'FFB9	Bit rate register	BRR	R/W	H'FF
	H'FFBA	Serial control register	SCR	R/W	H'00
	H'FFBB	Transmit data register	TDR	R/W	H'FF
	H'FFBC	Serial status register	SSR	R/(W)*2	H'84
	H'FFBD	Receive data register	RDR	R	H'00

Notes: 1. Lower 16 bits of the address.
2. Only 0 can be written, to clear flags.

13.2 Register Descriptions

13.2.1 Receive Shift Register (RSR)

RSR is the register that receives serial data.

Bit	7	6	5	4	3	2	1	0
Initial value								
Read/Write	—	—	—	—	—	—	—	—

The SCI loads serial data input at the RxD pin into RSR in the order received, LSB (bit 0) first, thereby converting the data to parallel data. When 1 byte has been received, it is automatically transferred to RDR. The CPU cannot read or write RSR directly.

13.2.2 Receive Data Register (RDR)

RDR is the register that stores received serial data.

Bit	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R	R	R	R	R	R	R	R

When the SCI finishes receiving 1 byte of serial data, it transfers the received data from RSR into RDR for storage. RSR is then ready to receive the next data. This double buffering allows data to be received continuously.

RDR is a read-only register. Its contents cannot be modified by the CPU. RDR is initialized to H'00 by a reset and in standby mode.

13.2.3 Transmit Shift Register (TSR)

TSR is the register that transmits serial data.

Bit	7	6	5	4	3	2	1	0
Initial value								
Read/Write	—	—	—	—	—	—	—	—

The SCI loads transmit data from TDR into TSR, then transmits the data serially from the TxD pin, LSB (bit 0) first. After transmitting one data byte, the SCI automatically loads the next transmit data from TDR into TSR and starts transmitting it. If the TDRE flag is set to 1 in SSR, however, the SCI does not load the TDR contents into TSR. The CPU cannot read or write TSR directly.

13.2.4 Transmit Data Register (TDR)

TDR is an 8-bit register that stores data for serial transmission.

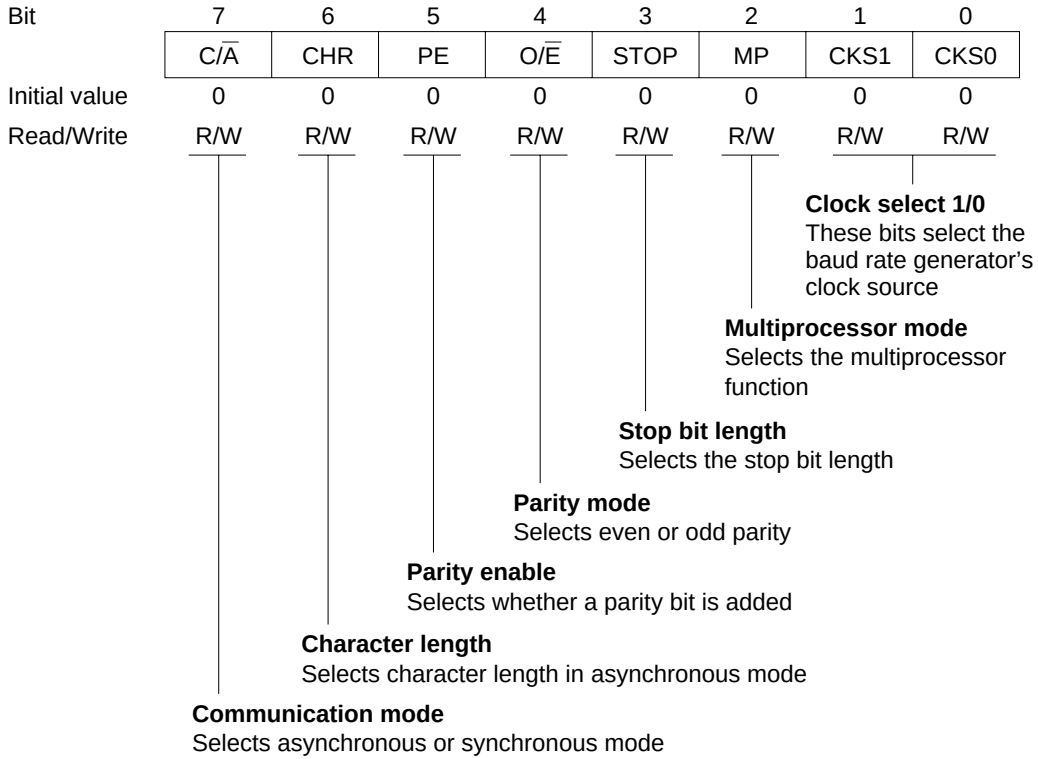
Bit	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

When the SCI detects that TSR is empty, it moves transmit data written in TDR from TDR into TSR and starts serial transmission. Continuous serial transmission is possible by writing the next transmit data in TDR during serial transmission from TSR.

The CPU can always read and write TDR. TDR is initialized to H'FF by a reset and in standby mode.

13.2.5 Serial Mode Register (SMR)

SMR is an 8-bit register that specifies the SCI serial communication format and selects the clock source for the baud rate generator.



The CPU can always read and write SMR. SMR is initialized to H'00 by a reset and in standby mode.

Bit 7—Communication Mode (C/$\overline{A}$): Selects whether the SCI operates in asynchronous or synchronous mode.

Bit 7 C/$\overline{A}$	Description	
0	Asynchronous mode	(Initial value)
1	Synchronous mode	

Bit 6—Character Length (CHR): Selects 7-bit or 8-bit data length in asynchronous mode. In synchronous mode the data length is 8 bits regardless of the CHR setting.

Bit 6 CHR	Description	
0	8-bit data	(Initial value)
1	7-bit data*	

Note: * When 7-bit data is selected, the MSB (bit 7) in TDR is not transmitted.

Bit 5—Parity Enable (PE): In asynchronous mode, this bit enables or disables the addition of a parity bit to transmit data, and the checking of the parity bit in receive data. In synchronous mode the parity bit is neither added nor checked, regardless of the PE setting.

Bit 5 PE	Description	
0	Parity bit not added or checked	(Initial value)
1	Parity bit added and checked*	

Note: * When PE is set to 1, an even or odd parity bit is added to transmit data according to the even or odd parity mode selected by the O/$\overline{E}$ bit, and the parity bit in receive data is checked to see that it matches the even or odd mode selected by the O/$\overline{E}$ bit.

Bit 4—Parity Mode (O/$\overline{E}$): Selects even or odd parity. The O/$\overline{E}$ bit setting is valid in asynchronous mode when the PE bit is set to 1 to enable the adding and checking of a parity bit. The O/$\overline{E}$ setting is ignored in synchronous mode, or when parity adding and checking is disabled in asynchronous mode.

Bit 4 O/$\overline{E}$	Description	
0	Even parity*1	(Initial value)
1	Odd parity*2	

Notes: 1. When even parity is selected, the parity bit added to transmit data makes an even number of 1s in the transmitted character and parity bit combined. Receive data must have an even number of 1s in the received character and parity bit combined.
2. When odd parity is selected, the parity bit added to transmit data makes an odd number of 1s in the transmitted character and parity bit combined. Receive data must have an odd number of 1s in the received character and parity bit combined.

Bit 3—Stop Bit Length (STOP): Selects one or two stop bits in asynchronous mode. This setting is used only in asynchronous mode. In synchronous mode no stop bit is added, so the STOP bit setting is ignored.

Bit 3 STOP	Description	
0	One stop bit*1	(Initial value)
1	Two stop bits*2	

Notes: 1. One stop bit (with value 1) is added at the end of each transmitted character.
2. Two stop bits (with value 1) are added at the end of each transmitted character.

In receiving, 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 the second stop bit is 0 it is treated as the start bit of the next incoming character.

Bit 2—Multiprocessor Mode (MP): Selects a multiprocessor format. When a multiprocessor format is selected, parity settings made by the PE and O/$\overline{E}$ bits are ignored. The MP bit setting is valid only in asynchronous mode. It is ignored in synchronous mode.

For further information on the multiprocessor communication function, see section 13.3.3, Multiprocessor Communication Function.

Bit 2 MP	Description	
0	Multiprocessor function disabled	(Initial value)
1	Multiprocessor format selected	

Bits 1 and 0—Clock Select 1 and 0 (CKS1/0): These bits select the clock source of the on-chip baud rate generator. Four clock sources are available: ø, ø/4, ø/16, and ø/64.

For the relationship between the clock source, bit rate register setting, and baud rate, see section 13.2.8, Bit Rate Register.

Bit 1 CKS1	Bit 0 CKS0	Description	
0	0	ø	(Initial value)
0	1	ø/4	
1	0	ø/16	
1	1	ø/64	

13.2.6 Serial Control Register (SCR)

SCR enables the SCI transmitter and receiver, enables or disables serial clock output in asynchronous mode, enables or disables interrupts, and selects the transmit/receive clock source.

Bit	7	6	5	4	3	2	1	0
	TIE	RIE	TE	RE	MPIE	TEIE	CKE1	CKE0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Clock enable 1/0
These bits select the SCI clock source

Transmit end interrupt enable
Enables or disables transmit-end interrupts (TEI)

Multiprocessor interrupt enable
Enables or disables multiprocessor interrupts

Receive enable
Enables or disables the receiver

Transmit enable
Enables or disables the transmitter

Receive interrupt enable
Enables or disables receive-data-full interrupts (RXI) and receive-error interrupts (ERI)

Transmit interrupt enable
Enables or disables transmit-data-empty interrupts (TXI)

The CPU can always read and write SCR. SCR is initialized to H'00 by a reset and in standby mode.

Bit 7—Transmit Interrupt Enable (TIE): Enables or disables the transmit-data-empty interrupt (TXI) requested when the TDRE flag in SSR is set to 1 due to transfer of serial transmit data from TDR to TSR.

Bit 7 TIE	Description	
0	Transmit-data-empty interrupt request (TXI) is disabled*	(Initial value)
1	Transmit-data-empty interrupt request (TXI) is enabled	

Note: * TXI interrupt requests can be cleared by reading the value 1 from the TDRE flag, then clearing it to 0; or by clearing the TIE bit to 0.

Bit 6—Receive Interrupt Enable (RIE): Enables or disables the receive-data-full interrupt (RXI) requested when the RDRF flag is set to 1 in SSR due to transfer of serial receive data from RSR to RDR; also enables or disables the receive-error interrupt (ERI).

Bit 6 RIE	Description	
0	Receive-end (RXI) and receive-error (ERI) interrupt requests are disabled	(Initial value)
1	Receive-end (RXI) and receive-error (ERI) interrupt requests are enabled	

Note: * RXI and ERI interrupt requests can be cleared by reading the value 1 from the RDRF, FER, PER, or ORER flag, then clearing it to 0; or by clearing the RIE bit to 0.

Bit 5—Transmit Enable (TE): Enables or disables the start of SCI serial transmitting operations.

Bit 5 TE	Description	
0	Transmitting disabled*1	(Initial value)
1	Transmitting enabled*2	

Notes: 1. The TDRE bit is locked at 1 in SSR.
2. In the enabled state, serial transmitting starts when the TDRE bit in SSR is cleared to 0 after writing of transmit data into TDR. Select the transmit format in SMR before setting the TE bit to 1.

Bit 4—Receive Enable (RE): Enables or disables the start of SCI serial receiving operations.

Bit 4 RE	Description	
0	Receiving disabled*1	(Initial value)
1	Receiving enabled*2	

Notes: 1. Clearing the RE bit to 0 does not affect the RDRF, FER, PER, and ORER flags. These flags retain their previous values.
2. In the enabled state, serial receiving starts when a start bit is detected in asynchronous mode, or serial clock input is detected in synchronous mode. Select the receive format in SMR before setting the RE bit to 1.

Bit 3—Multiprocessor Interrupt Enable (MPIE): Enables or disables multiprocessor interrupts. The MPIE setting is valid only in asynchronous mode, and only if the MP bit is set to 1 in SMR. The MPIE setting is ignored in synchronous mode or when the MP bit is cleared to 0.

Bit 3 MPIE	Description	
0	Multiprocessor interrupts are disabled (normal receive operation) [Clearing conditions] The MPIE bit is cleared to 0. MPB = 1 in received data.	(Initial value)
1	Multiprocessor interrupts are enabled* Receive-data-full interrupts (RXI), receive-error interrupts (ERI), and setting of the RDRF, FER, and ORER status flags in SSR are disabled until data with the multiprocessor bit set to 1 is received.	

Note: * The SCI does not transfer receive data from RSR to RDR, does not detect receive errors, and does not set the RDRF, FER, and ORER flags in SSR. When it receives data in which MPB = 1, the SCI sets the MPB bit to 1 in SSR, automatically clears the MPIE bit to 0, enables RXI and ERI interrupts (if the RIE bit is set to 1 in SCR), and allows the FER and ORER flags to be set.

Bit 2—Transmit-End Interrupt Enable (TEIE): Enables or disables the transmit-end interrupt (TEI) requested if TDR does not contain new transmit data when the MSB is transmitted.

Bit 2 TEIE	Description	
0	Transmit-end interrupt requests (TEI) are disabled*	(Initial value)
1	Transmit-end interrupt requests (TEI) are enabled*	

Note: * TEI interrupt requests can be cleared by reading the value 1 from the TDRE flag in SSR, then clearing the TDRE flag to 0, thereby also clearing the TEND flag to 0; or by clearing the TEIE bit to 0.

Bits 1 and 0—Clock Enable 1 and 0 (CKE1/0): These bits select the SCI clock source and enable or disable clock output from the SCK pin. Depending on the settings of CKE1 and CKE0, the SCK pin can be used for generic input/output, serial clock output, or serial clock input.

The CKE0 setting is valid only in asynchronous mode, and only when the SCI is internally clocked (CKE1 = 0). The CKE0 setting is ignored in synchronous mode, or when an external clock source is selected (CKE1 = 1). Set the CKE1 and CKE0 bits after selecting the SCI operating mode in SMR. For further details on selection of the SCI clock source, see table 13-9 in section 13.3, Operation.

Bit 1 CKE1	Bit 0 CKE0	Description	
0	0	Asynchronous mode	Internal clock, SCK pin available for generic input/output *1
		Synchronous mode	Internal clock, SCK pin used for serial clock output *1
0	1	Asynchronous mode	Internal clock, SCK pin used for clock output *2
		Synchronous mode	Internal clock, SCK pin used for serial clock output
1	0	Asynchronous mode	External clock, SCK pin used for clock input *3
		Synchronous mode	External clock, SCK pin used for serial clock input
1	1	Asynchronous mode	External clock, SCK pin used for clock input *3
		Synchronous mode	External clock, SCK pin used for serial clock input

Notes: 1. Initial value
2. The output clock frequency is the same as the bit rate.
3. The input clock frequency is 16 times the bit rate.

13.2.7 Serial Status Register (SSR)

SSR is an 8-bit register containing multiprocessor bit values, and status flags that indicate SCI operating status.

Bit	7	6	5	4	3	2	1	0
	TDRE	RDRF	ORER	FER	PER	TEND	MPB	MPBT
Initial value	1	0	0	0	0	1	0	0
Read/Write	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R	R	R/W

Multiprocessor bit transfer
Value of multi-processor bit to be transmitted

Multiprocessor bit
Stores the received multiprocessor bit value

Transmit end
Status flag indicating end of transmission

Parity error
Status flag indicating detection of a receive parity error

Framing error
Status flag indicating detection of a receive framing error

Overrun error
Status flag indicating detection of a receive overrun error

Receive data register full
Status flag indicating that data has been received and stored in RDR

Transmit data register empty
Status flag indicating that transmit data has been transferred from TDR into TSR and new data can be written in TDR

Note: * Only 0 can be written, to clear the flag.

The CPU can always read and write SSR, but cannot write 1 in the TDRE, RDRF, ORER, PER, and FER flags. These flags can be cleared to 0 only if they have first been read while set to 1. The TEND and MPB flags are read-only bits that cannot be written.

SSR is initialized to H'84 by a reset and in standby mode.

Bit 7—Transmit Data Register Empty (TDRE): Indicates that the SCI has loaded transmit data from TDR into TSR and the next serial transmit data can be written in TDR.

Bit 7 TDRE	Description	
0	TDR contains valid transmit data [Clearing conditions] Software reads TDRE while it is set to 1, then writes 0. The DMAC writes data in TDR.	
1	TDR does not contain valid transmit data [Setting conditions] The chip is reset or enters standby mode. The TE bit in SCR is cleared to 0. TDR contents are loaded into TSR, so new data can be written in TDR.	(Initial value)

Bit 6—Receive Data Register Full (RDRF): Indicates that RDR contains new receive data.

Bit 6 RDRF	Description	
0	RDR does not contain new receive data [Clearing conditions] The chip is reset or enters standby mode. Software reads RDRF while it is set to 1, then writes 0. The DMAC reads data from RDR.	(Initial value)
1	RDR contains new receive data [Setting condition] When serial data is received normally and transferred from RSR to RDR.	

Note: The RDR contents and RDRF flag are not affected by detection of receive errors or by clearing of the RE bit to 0 in SCR. They retain their previous values. If the RDRF flag is still set to 1 when reception of the next data ends, an overrun error occurs and receive data is lost.

Bit 5—Overrun Error (ORER): Indicates that data reception ended abnormally due to an overrun error.

Bit 5 ORER	Description	
0	Receiving is in progress or has ended normally [Clearing conditions] The chip is reset or enters standby mode. Software reads ORER while it is set to 1, then writes 0.	(Initial value)*1
1	A receive overrun error occurred*2 [Setting condition] Reception of the next serial data ends when RDRF = 1.	

Notes:
1. Clearing the RE bit to 0 in SCR does not affect the ORER flag, which retains its previous value.
2. RDR continues to hold the receive data before the overrun error, so subsequent receive data is lost. Serial receiving cannot continue while the ORER flag is set to 1. In synchronous mode, serial transmitting is also disabled.

Bit 4—Framing Error (FER): Indicates that data reception ended abnormally due to a framing error in asynchronous mode.

Bit 4 FER	Description	
0	Receiving is in progress or has ended normally [Clearing conditions] The chip is reset or enters standby mode. Software reads FER while it is set to 1, then writes 0.	(Initial value)*1
1	A receive framing error occurred*2 [Setting condition] The stop bit at the end of receive data is checked and found to be 0.	

Notes:
1. Clearing the RE bit to 0 in SCR does not affect the FER flag, which retains its previous value.
2. When the stop bit length is 2 bits, only the first bit is checked. The second stop bit is not checked. When a framing error occurs the SCI transfers the receive data into RDR but does not set the RDRF flag. Serial receiving cannot continue while the FER flag is set to 1. In synchronous mode, serial transmitting is also disabled.

Bit 3—Parity Error (PER): Indicates that data reception ended abnormally due to a parity error in asynchronous mode.

Bit 3 PER	Description	
0	Receiving is in progress or has ended normally*1 [Clearing conditions] The chip is reset or enters standby mode. Software reads PER while it is set to 1, then writes 0.	(Initial value)
1	A receive parity error occurred*2 [Setting condition] The number of 1s in receive data, including the parity bit, does not match the even or odd parity setting of O/$\overline{E}$ in SMR.	

Notes: 1. Clearing the RE bit to 0 in SCR does not affect the PER flag, which retains its previous value.
2. When a parity error occurs the SCI transfers the receive data into RDR but does not set the RDRF flag. Serial receiving cannot continue while the PER flag is set to 1. In synchronous mode, serial transmitting is also disabled.

Bit 2—Transmit End (TEND): Indicates that when the last bit of a serial character was transmitted TDR did not contain new transmit data, so transmission has ended. The TEND flag is a read-only bit and cannot be written.

Bit 2 TEND	Description	
0	Transmission is in progress [Clearing conditions] Software reads TDRE while it is set to 1, then writes 0 in the TDRE flag. The DMAC writes data in TDR.	
1	End of transmission [Setting conditions] The chip is reset or enters standby mode. The TE bit is cleared to 0 in SCR. TDRE is 1 when the last bit of a serial character is transmitted.	(Initial value)

Bit 1—Multiprocessor Bit (MPB): Stores the value of the multiprocessor bit in receive data when a multiprocessor format is used in asynchronous mode. MPB is a read-only bit and cannot be written.

Bit 1 MPB	Description	
0	Multiprocessor bit value in receive data is 0*	(Initial value)
1	Multiprocessor bit value in receive data is 1	

Note: * If the RE bit is cleared to 0 when a multiprocessor format is selected, MPB retains its previous value.

Bit 0—Multiprocessor Bit Transfer (MPBT): Stores the value of the multiprocessor bit added to transmit data when a multiprocessor format is selected for transmitting in asynchronous mode. The MPBT setting is ignored in synchronous mode, when a multiprocessor format is not selected, or when the SCI is not transmitting.

Bit 0 MPBT	Description	
0	Multiprocessor bit value in transmit data is 0	(Initial value)
1	Multiprocessor bit value in transmit data is 1	

13.2.8 Bit Rate Register (BRR)

BRR is an 8-bit register that, together with the CKS1 and CKS0 bits in SMR that select the baud rate generator clock source, determines the serial communication bit rate.

Bit	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

The CPU can always read and write BRR. BRR is initialized to H'FF by a reset and in standby mode. The two SCI channels have independent baud rate generator control, so different values can be set in the two channels.

Table 13-3 shows examples of BRR settings in asynchronous mode. Table 13-4 shows examples of BRR settings in synchronous mode.

Table 13-3 Examples of Bit Rates and BRR Settings in Asynchronous Mode

	ø (MHz)											
	2			2.097152			2.4576			3		
Bit Rate (bits/s)	n	N	Error (%)	n	N	Error (%)	n	N	Error (%)	n	N	Error (%)
110	1	141	0.03	1	148	–0.04	1	174	–0.26	1	212	0.03
150	1	103	0.16	1	108	0.21	1	127	0	1	155	0.16
300	0	207	0.16	0	217	0.21	0	255	0	1	77	0.16
600	0	103	0.16	0	108	0.21	0	127	0	0	155	0.16
1200	0	51	0.16	0	54	–0.70	0	63	0	0	77	0.16
2400	0	25	0.16	0	26	1.14	0	31	0	0	38	0.16
4800	0	12	0.16	0	13	–2.48	0	15	0	0	19	–2.34
9600	0	6	–6.99	0	6	–2.48	0	7	0	0	9	–2.34
19200	0	2	8.51	0	2	13.78	0	3	0	0	4	–2.34
31250	0	1	0	0	1	4.86	0	1	22.88	0	2	0
38400	0	1	–18.62	0	1	–14.67	0	1	0	—	—	—

	ø (MHz)											
	3.6864			4			4.9152			5		
Bit Rate (bits/s)	n	N	Error (%)	n	N	Error (%)	n	N	Error (%)	n	N	Error (%)
110	2	64	0.70	2	70	0.03	2	86	0.31	2	88	–0.25
150	1	191	0	1	207	0.16	1	255	0	2	64	0.16
300	1	95	0	1	103	0.16	1	127	0	1	129	0.16
600	0	191	0	0	207	0.16	0	255	0	1	64	0.16
1200	0	95	0	0	103	0.16	0	127	0	0	129	0.16
2400	0	47	0	0	51	0.16	0	63	0	0	64	0.16
4800	0	23	0	0	25	0.16	0	31	0	0	32	–1.36
9600	0	11	0	0	12	0.16	0	15	0	0	15	1.73
19200	0	5	0	0	6	–6.99	0	7	0	0	7	1.73
31250	—	—	—	0	3	0	0	4	–1.70	0	4	0
38400	0	2	0	0	2	8.51	0	3	0	0	3	1.73

Table 13-3 Examples of Bit Rates and BRR Settings in Asynchronous Mode (cont)

	ø (MHz)											
	6			6.144			7.3728			8		
Bit Rate (bits/s)	n	N	Error (%)	n	N	Error (%)	n	N	Error (%)	n	N	Error (%)
110	2	106	–0.44	2	108	0.08	2	130	–0.07	2	141	0.03
150	2	77	0.16	2	79	0	2	95	0	2	103	0.16
300	1	155	0.16	1	159	0	1	191	0	1	207	0.16
600	1	77	0.16	1	79	0	1	95	0	1	103	0.16
1200	0	155	0.16	0	159	0	0	191	0	0	207	0.16
2400	0	77	0.16	0	79	0	0	95	0	0	103	0.16
4800	0	38	0.16	0	39	0	0	47	0	0	51	0.16
9600	0	19	–2.34	0	19	0	0	23	0	0	25	0.16
19200	0	9	–2.34	0	9	0	0	11	0	0	12	0.16
31250	0	5	0	0	5	2.40	0	6	5.33	0	7	0
38400	0	4	–2.34	0	4	0	0	5	0	0	6	–6.99

	ø (MHz)											
	9.8304			10			12			12.288		
Bit Rate (bits/s)	n	N	Error (%)	n	N	Error (%)	n	N	Error (%)	n	N	Error (%)
110	2	174	–0.26	2	177	–0.25	2	212	0.03	2	217	0.08
150	2	127	0	2	129	0.16	2	155	0.16	2	159	0
300	1	255	0	2	64	0.16	2	77	0.16	2	79	0
600	1	127	0	1	129	0.16	1	155	0.16	1	159	0
1200	0	255	0	1	64	0.16	1	77	0.16	1	79	0
2400	0	127	0	0	129	0.16	0	155	0.16	0	159	0
4800	0	63	0	0	64	0.16	0	77	0.16	0	79	0
9600	0	31	0	0	32	–1.36	0	38	0.16	0	39	0
19200	0	15	0	0	15	1.73	0	19	–2.34	0	19	0
31250	0	9	–1.70	0	9	0	0	11	0	0	11	2.40
38400	0	7	0	0	7	1.73	0	9	–2.34	0	9	0

Table 13-3 Examples of Bit Rates and BRR Settings in Asynchronous Mode (cont)

	ø (MHz)								
	14			14.7456			16		
Bit Rate (bits/s)	n	N	Error (%)	n	N	Error (%)	n	N	Error (%)
110	2	248	–0.17	3	64	0.70	3	70	0.03
150	2	181	0.16	2	191	0	2	207	0.16
300	2	90	0.16	2	95	0	2	103	0.16
600	1	181	0.16	1	191	0	1	207	0.16
1200	1	90	0.16	1	95	0	1	103	0.16
2400	0	181	0.16	0	191	0	0	207	0.16
4800	0	90	0.16	0	95	0	0	103	0.16
9600	0	45	–0.93	0	47	0	0	51	0.16
19200	0	22	–0.93	0	23	0	0	25	0.16
31250	0	13	0	0	14	–1.70	0	15	0
38400	0	10	3.57	0	11	0	0	12	0.16

Table 13-4 Examples of Bit Rates and BRR Settings in Synchronous Mode

Bit Rate (bits/s)	ø (MHz) 2		4		8		10		16	
	n	N	n	N	n	N	n	N	n	N
110	3	70	—	—	—	—	—	—	—	—
250	2	124	2	249	3	124	—	—	3	249
500	1	249	2	124	2	249	—	—	3	124
1 k	1	124	1	249	2	124	—	—	2	249
2.5 k	0	199	1	99	1	199	1	249	2	99
5 k	0	99	0	199	1	99	1	124	1	199
10 k	0	49	0	99	0	199	0	249	1	99
25 k	0	19	0	39	0	79	0	99	0	159
50 k	0	9	0	19	0	39	0	49	0	79
100 k	0	4	0	9	0	19	0	24	0	39
250 k	0	1	0	3	0	7	0	9	0	15
500 k	0	0*	0	1	0	3	0	4	0	7
1 M			0	0*	0	1	—	—	0	3
2 M					0	0*	—	—	0	1
2.5 M					—	—	0	0*	—	—
4 M									0	0*

Note: Settings with an error of 1% or less are recommended.
Legend
Blank: No setting available
—: Setting possible, but error occurs
*: Continuous transmit/receive not possible

The BRR setting is calculated as follows:

Asynchronous mode:

$$N = \frac{ø}{64 \times 2^{2n-1} \times B} \times 10^6 - 1$$

Synchronous mode:

$$N = \frac{ø}{8 \times 2^{2n-1} \times B} \times 10^6 - 1$$

B: Bit rate (bits/s)
N: BRR setting for baud rate generator ($0 \leq N \leq 255$)
ø: System clock frequency (MHz)
n: Baud rate generator clock source (n = 0, 1, 2, 3)
(For the clock sources and values of n, see the table below.)

		SMR Settings	
n	**Clock Source**	**CKS1**	**CKS0**
0	ø	0	0
1	ø/4	0	1
2	ø/16	1	0
3	ø/64	1	1

The bit rate error in asynchronous mode is calculated as follows.

$$\text{Error (\%)} = \left\{ \frac{\text{ø} \times 10^6}{(N + 1) \times B \times 64 \times 2^{2n-1}} - 1 \right\} \times 100$$

Table 13-5 indicates the maximum bit rates in asynchronous mode for various system clock frequencies. Tables 13-6 and 13-7 indicate the maximum bit rates with external clock input.

Table 13-5 Maximum Bit Rates for Various Frequencies (Asynchronous Mode)

		Settings	
ø (MHz)	**Maximum Bit Rate (bits/s)**	**n**	**N**
2	62500	0	0
2.097152	65536	0	0
2.4576	76800	0	0
3	93750	0	0
3.6864	115200	0	0
4	125000	0	0
4.9152	153600	0	0
5	156250	0	0
6	187500	0	0
6.144	192000	0	0
7.3728	230400	0	0
8	250000	0	0
9.8304	307200	0	0
10	312500	0	0
12	375000	0	0
12.288	384000	0	0
14	437500	0	0
14.7456	460800	0	0
16	500000	0	0

Table 13-6 Maximum Bit Rates with External Clock Input (Asynchronous Mode)

ø (MHz)	External Input Clock (MHz)	Maximum Bit Rate (bits/s)
2	0.5000	31250
2.097152	0.5243	32768
2.4576	0.6144	38400
3	0.7500	46875
3.6864	0.9216	57600
4	1.0000	62500
4.9152	1.2288	76800
5	1.2500	78125
6	1.5000	93750
6.144	1.5360	96000
7.3728	1.8432	115200
8	2.0000	125000
9.8304	2.4576	153600
10	2.5000	156250
12	3.0000	187500
12.288	3.0720	192000
14	3.5000	218750
14.7456	3.6864	230400
16	4.0000	250000

Table 13-7 Maximum Bit Rates with External Clock Input (Synchronous Mode)

ø (MHz)	External Input Clock (MHz)	Maximum Bit Rate (bits/s)
2	0.3333	333333.3
4	0.6667	666666.7
6	1.0000	1000000.0
8	1.3333	1333333.3
10	1.6667	1666666.7
12	2.0000	2000000.0
14	2.3333	2333333.3
16	2.6667	2666666.7

13.3 Operation

13.3.1 Overview

The SCI has an asynchronous mode in which characters are synchronized individually, and a synchronous mode in which communication is synchronized with clock pulses. Serial communication is possible in either mode. Asynchronous or synchronous mode and the communication format are selected in SMR, as shown in table 13-8. The SCI clock source is selected by the C/$\overline{A}$ bit in SMR and the CKE1 and CKE0 bits in SCR, as shown in table 13-9.

Asynchronous Mode

- Data length is selectable: 7 or 8 bits.
- Parity and multiprocessor bits are selectable. So is the stop bit length (1 or 2 bits). These selections determine the communication format and character length.
- In receiving, it is possible to detect framing errors, parity errors, overrun errors, and the break state.
- An internal or external clock can be selected as the SCI clock source.
  - — When an internal clock is selected, the SCI operates using the on-chip baud rate generator, and can output a serial clock signal with a frequency matching the bit rate.
  - — When an external clock is selected, the external clock input must have a frequency 16 times the bit rate. (The on-chip baud rate generator is not used.)

Synchronous Mode

- The communication format has a fixed 8-bit data length.
- In receiving, it is possible to detect overrun errors.
- An internal or external clock can be selected as the SCI clock source.
  - — When an internal clock is selected, the SCI operates using the on-chip baud rate generator, and outputs a serial clock signal to external devices.
  - — When an external clock is selected, the SCI operates on the input serial clock. The on-chip baud rate generator is not used.

Table 13-8 SMR Settings and Serial Communication Formats

SMR Settings						SCI Communication Format			
Bit 7 C/$\overline{A}$	Bit 6 CHR	Bit 2 MP	Bit 5 PE	Bit 3 STOP	Mode	Data Length	Multi-processor Bit	Parity Bit	Stop Bit Length
0	0	0	0	0	Asynchronous mode	8-bit data	Absent	Absent	1 bit
0	0	0	0	1					2 bits
0	0	0	1	0				Present	1 bit
0	0	0	1	1					2 bits
0	1	0	0	0		7-bit data		Absent	1 bit
0	1	0	0	1					2 bits
0	1	0	1	0				Present	1 bit
0	1	0	1	1					2 bits
0	0	1	—	0	Asynchronous mode (multi-processor format)	8-bit data	Present	Absent	1 bit
0	0	1	—	1					2 bits
0	1	1	—	0		7-bit data			1 bit
0	1	1	—	1					2 bits
1	—	—	—	—	Synchronous mode	8-bit data	Absent		None

Table 13-9 SMR and SCR Settings and SCI Clock Source Selection

SMR	SCR Settings			SCI Transmit/Receive Clock	
Bit 7 C/$\overline{A}$	Bit 1 CKE1	Bit 0 CKE0	Mode	Clock Source	SCK Pin Function
0	0	0	Asynchronous mode	Internal	SCI does not use the SCK pin
0	0	1			Outputs a clock with frequency matching the bit rate
0	1	0		External	Inputs a clock with frequency 16 times the bit rate
0	1	1			
1	0	0	Synchronous mode	Internal	Outputs the serial clock
1	0	1			
1	1	0		External	Inputs the serial clock
1	1	1			

13.3.2 Operation in Asynchronous Mode

In asynchronous mode each transmitted or received character begins with a start bit and ends with a stop bit. Serial communication is synchronized one character at a time.

The transmitting and receiving sections of the SCI are independent, so full duplex communication is possible. The transmitter and receiver are both double buffered, so data can be written and read while transmitting and receiving are in progress, enabling continuous transmitting and receiving.

Figure 13-2 shows the general format of asynchronous serial communication. In asynchronous serial communication the communication line is normally held in the mark (high) state. The SCI monitors the line and starts serial communication when the line goes to the space (low) state, indicating a start bit. One serial character consists of a start bit (low), data (LSB first), parity bit (high or low), and stop bit (high), in that order.

When receiving in asynchronous mode, the SCI synchronizes at the falling edge of the start bit. The SCI samples each data bit on the eighth pulse of a clock with a frequency 16 times the bit rate. Receive data is latched at the center of each bit.

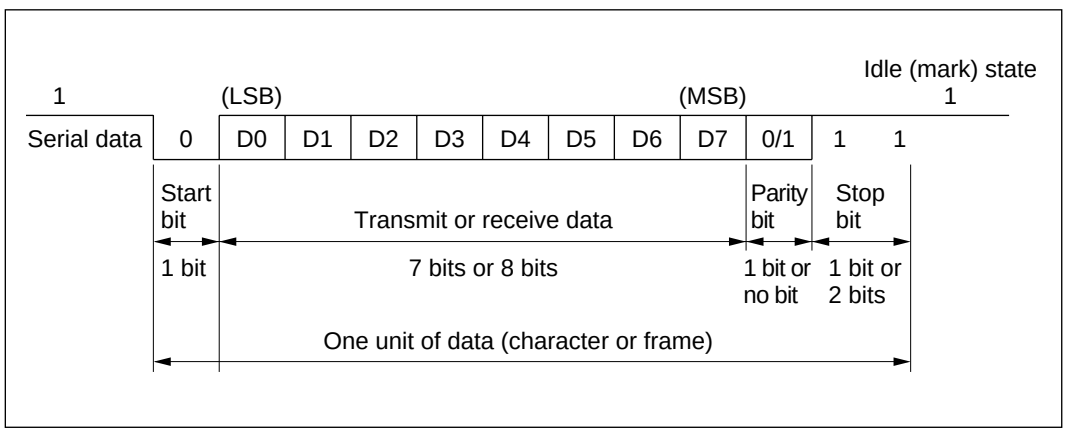


Figure 13-2 Data Format in Asynchronous Communication (Example: 8-Bit Data with Parity and 2 Stop Bits)

Communication Formats: Table 13-10 shows the 12 communication formats that can be selected in asynchronous mode. The format is selected by settings in SMR.

Table 13-10 Serial Communication Formats (Asynchronous Mode)

SMR Settings				Serial Communication Format and Frame Length
CHR	PE	MP	STOP	1 2 3 4 5 6 7 8 9 10 11 12
0	0	0	0	S 8-bit data STOP
0	0	0	1	S 8-bit data STOP STOP
0	1	0	0	S 8-bit data P STOP
0	1	0	1	S 8-bit data P STOP STOP
1	0	0	0	S 7-bit data STOP
1	0	0	1	S 7-bit data STOP STOP
1	1	0	0	S 7-bit data P STOP
1	1	0	1	S 7-bit data P STOP STOP
0	—	1	0	S 8 bit data MPB STOP
0	—	1	1	S 8 bit data MPB STOP STOP
1	—	1	0	S 7-bit data MPB STOP
1	—	1	1	S 7-bit data MPB STOP STOP

Legend
S: Start bit
STOP: Stop bit
P: Parity bit
MPB: Multiprocessor bit

Clock: An internal clock generated by the on-chip baud rate generator or an external clock input from the SCK pin can be selected as the SCI transmit/receive clock. The clock source is selected by the C/$\overline{A}$ bit in SMR and bits CKE1 and CKE0 in SCR. See table 13-9.

When an external clock is input at the SCK pin, it must have a frequency equal to 16 times the desired bit rate.

When the SCI operates on an internal clock, it can output a clock signal at the SCK pin. The frequency of this output clock is equal to the bit rate. The phase is aligned as in figure 13-3 so that the rising edge of the clock occurs at the center of each transmit data bit.

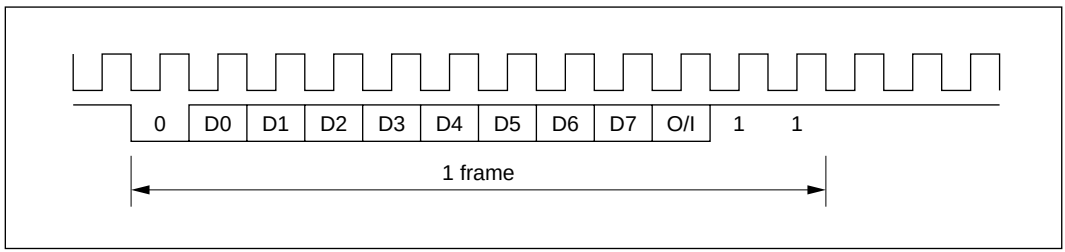


Figure 13-3 Phase Relationship between Output Clock and Serial Data (Asynchronous Mode)

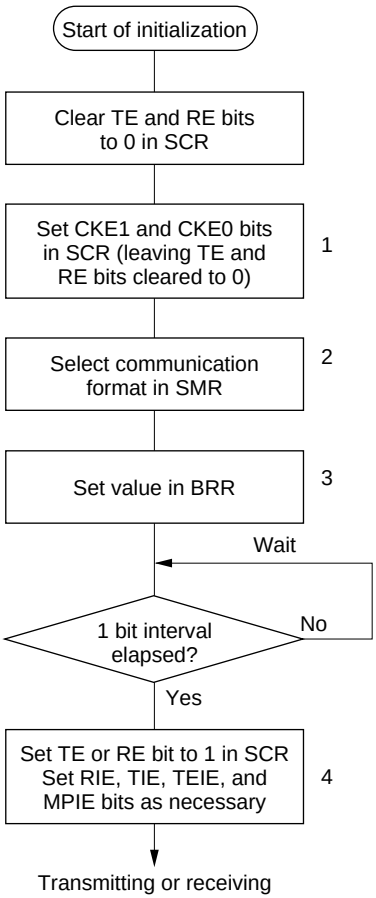
Transmitting and Receiving Data

SCI Initialization (Asynchronous Mode): Before transmitting or receiving, clear the TE and RE bits to 0 in SCR, then initialize the SCI as follows.

When changing the communication mode or format, always clear the TE and RE bits to 0 before following the procedure given below. Clearing TE to 0 sets the TDRE flag to 1 and initializes TSR. Clearing RE to 0, however, does not initialize the RDRF, PER, FER, and ORER flags and RDR, which retain their previous contents.

When an external clock is used, the clock should not be stopped during initialization or subsequent operation. SCI operation becomes unreliable if the clock is stopped.

Figure 13-4 is a sample flowchart for initializing the SCI.



1. Select the clock source in SCR. Clear the RIE, TIE, TEIE, MPIE, TE, and RE bits to 0. If clock output is selected in asynchronous mode, clock output starts immediately after the setting is made in SCR.
2. Select the communication format in SMR.
3. Write the value corresponding to the bit rate in BRR. This step is not necessary when an external clock is used.
4. Wait for at least the interval required to transmit or receive 1 bit, then set the TE or RE bit to 1 in SCR. Set the RIE, TIE, TEIE, and MPIE bits as necessary. Setting the TE or RE bit enables the SCI to use the TxD or RxD pin.

Figure 13-4 Sample Flowchart for SCI Initialization

Transmitting Serial Data (Asynchronous Mode): Figure 13-5 shows a sample flowchart for transmitting serial data and indicates the procedure to follow.

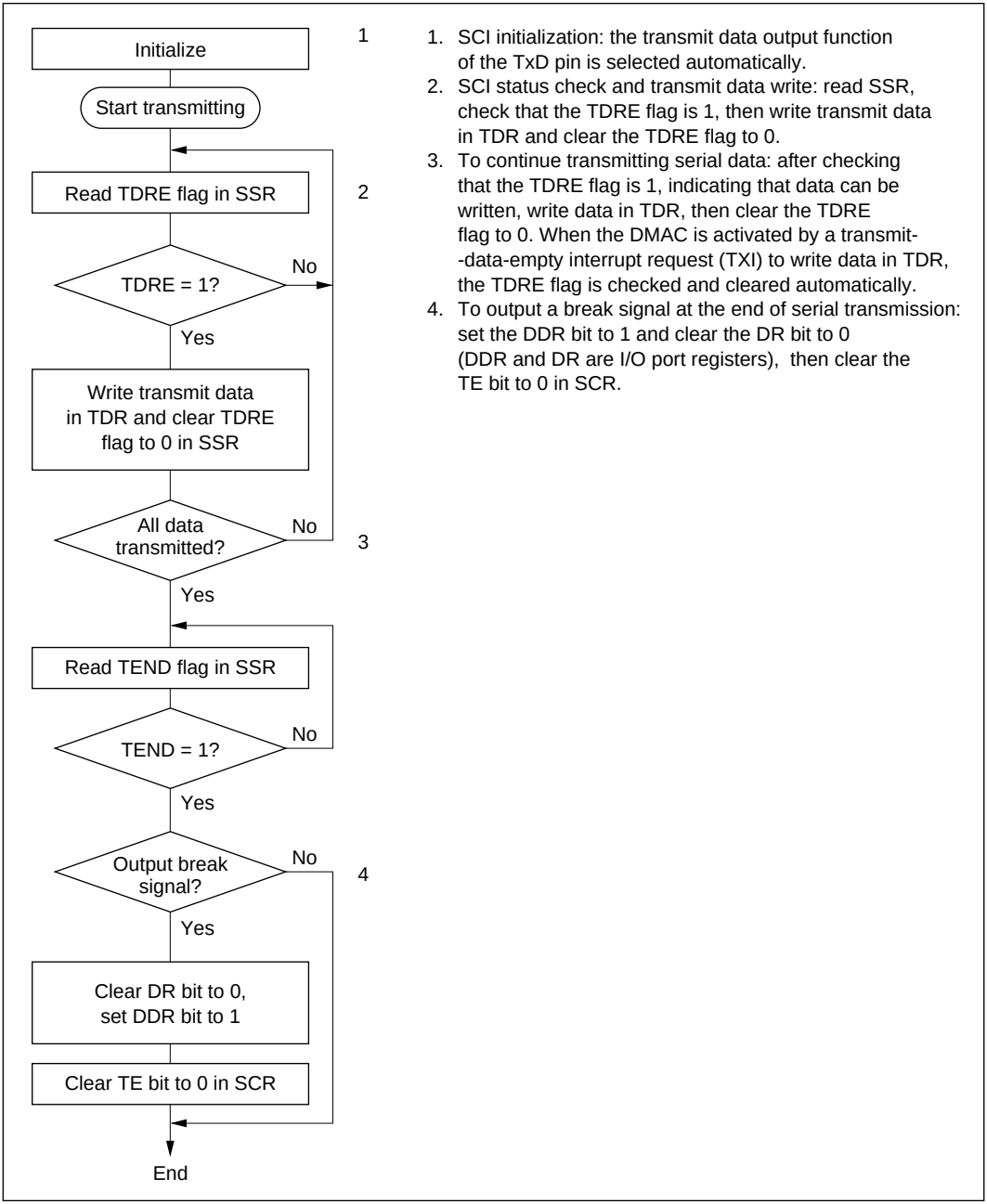


Figure 13-5 Sample Flowchart for Transmitting Serial Data

In transmitting serial data, the SCI operates as follows.

- The SCI monitors the TDRE flag in SSR. When the TDRE flag is cleared to 0 the SCI recognizes that TDR contains new data, and loads this data from TDR into TSR.

- After loading the data from TDR into TSR, the SCI sets the TDRE flag to 1 and starts transmitting. If the TIE bit is set to 1 in SCR, the SCI requests a transmit-data-empty interrupt (TXI) at this time.

  Serial transmit data is transmitted in the following order from the TxD pin:

  — Start bit: One 0 bit is output.
  — Transmit data: 7 or 8 bits are output, LSB first.
  — Parity bit or multiprocessor bit: One parity bit (even or odd parity) or one multiprocessor bit is output. Formats in which neither a parity bit nor a multiprocessor bit is output can also be selected.
  — Stop bit: One or two 1 bits (stop bits) are output.
  — Mark state: Output of 1 bits continues until the start bit of the next transmit data.

- The SCI checks the TDRE flag when it outputs the stop bit. If the TDRE flag is 0, the SCI loads new data from TDR into TSR, outputs the stop bit, then begins serial transmission of the next frame. If the TDRE flag is 1, the SCI sets the TEND flag to 1 in SSR, outputs the stop bit, then continues output of 1 bits in the mark state. If the TEIE bit is set to 1 in SCR, a transmit-end interrupt (TEI) is requested at this time.

Figure 13-6 shows an example of SCI transmit operation in asynchronous mode.

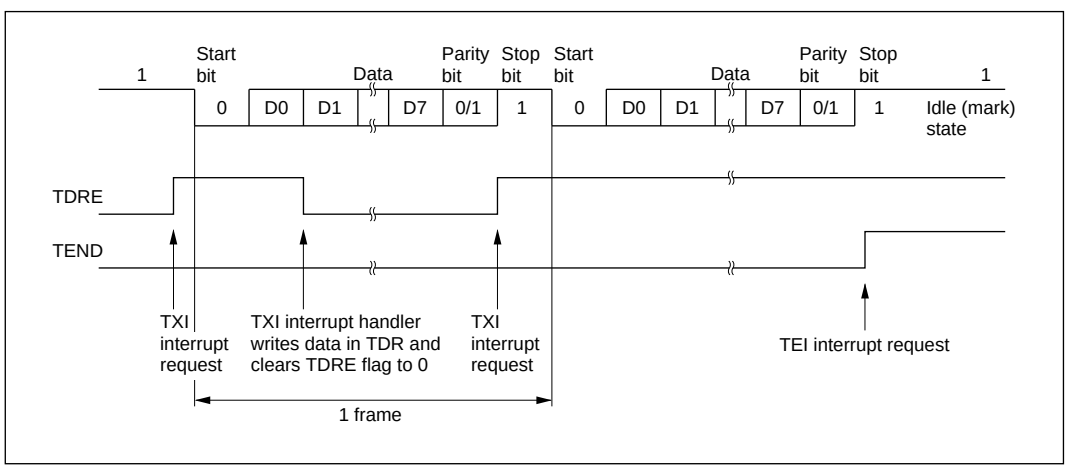


Figure 13-6 Example of SCI Transmit Operation in Asynchronous Mode (8-Bit Data with Parity and 1 Stop Bit)

Receiving Serial Data (Asynchronous Mode): Figure 13-7 shows a sample flowchart for receiving serial data and indicates the procedure to follow.

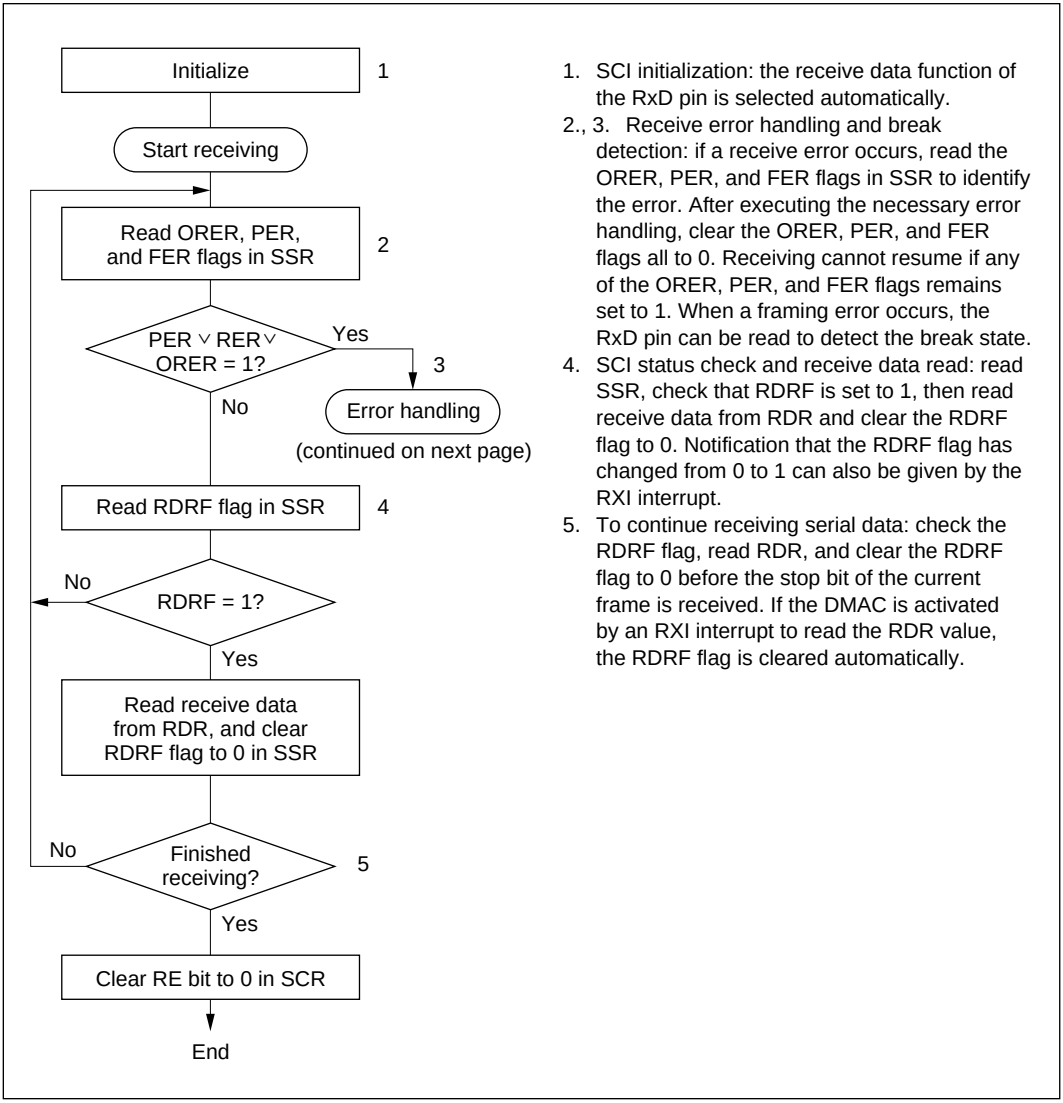


Figure 13-7 Sample Flowchart for Receiving Serial Data (1)

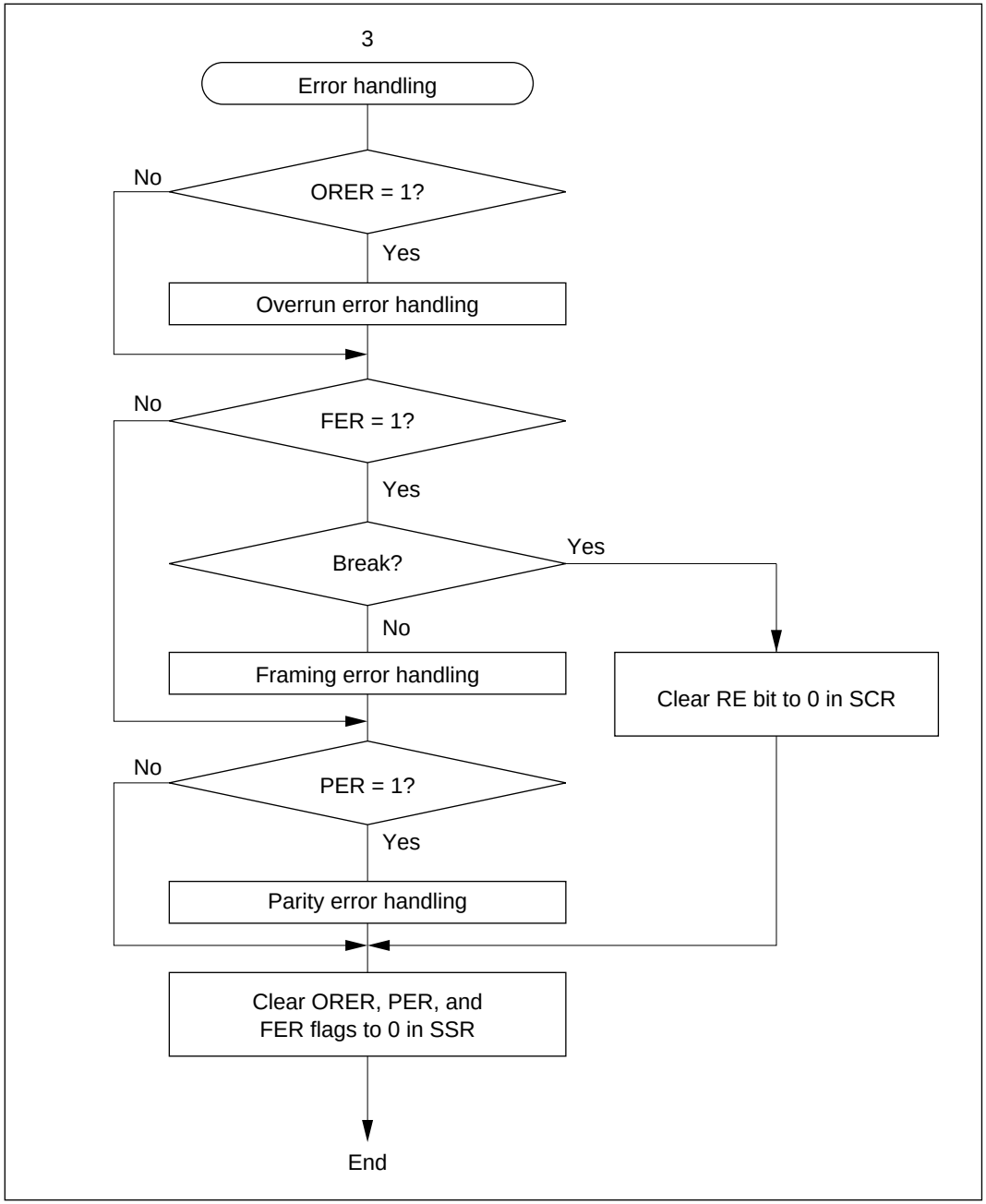


Figure 13-7 Sample Flowchart for Receiving Serial Data (2)

In receiving, the SCI operates as follows.

- The SCI monitors the receive data line. When it detects a start bit, the SCI synchronizes internally and starts receiving.
- Receive data is stored in RSR in order from LSB to MSB.
- The parity bit and stop bit are received.

After receiving, the SCI makes the following checks:

— Parity check: The number of 1s in the receive data must match the even or odd parity setting of the O/$\overline{E}$ bit in SMR.
— Stop bit check: The stop bit value must be 1. If there are two stop bits, only the first stop bit is checked.
— Status check: The RDRF flag must be 0 so that receive data can be transferred from RSR into RDR.

If these checks all pass, the RDRF flag is set to 1 and the received data is stored in RDR. If one of the checks fails (receive error), the SCI operates as indicated in table 13-11.

Note: When a receive error occurs, further receiving is disabled. In receiving, the RDRF flag is not set to 1. Be sure to clear the error flags.

- When the RDRF flag is set to 1, if the RIE bit is set to 1 in SCR, a receive-data-full interrupt (RXI) is requested. If the ORER, PER, or FER flag is set to 1 and the RIE bit in SCR is also set to 1, a receive-error interrupt (ERI) is requested.

Table 13-11 Receive Error Conditions

Receive Error	Abbreviation	Condition	Data Transfer
Overrun error	ORER	Receiving of next data ends while RDRF flag is still set to 1 in SSR	Receive data not transferred from RSR to RDR
Framing error	FER	Stop bit is 0	Receive data transferred from RSR to RDR
Parity error	PER	Parity of receive data differs from even/odd parity setting in SMR	Receive data transferred from RSR to RDR

Figure 13-8 shows an example of SCI receive operation in asynchronous mode.

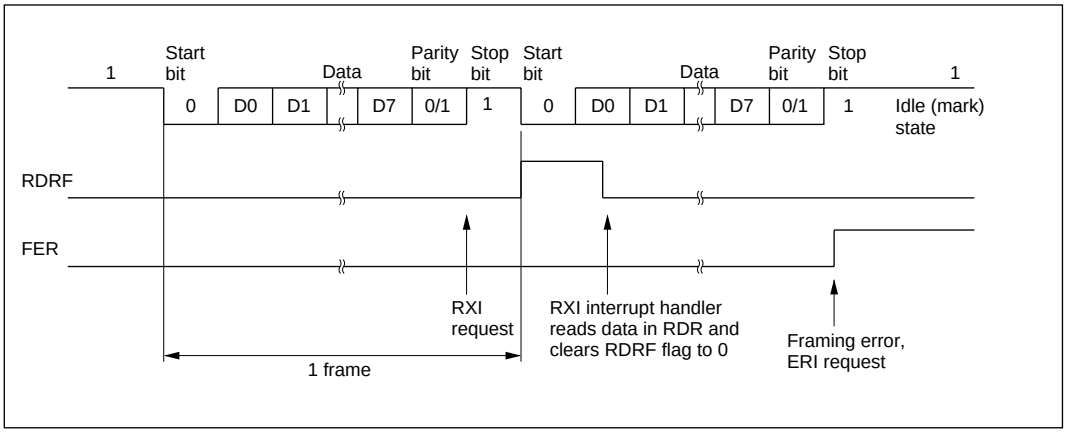


Figure 13-8 Example of SCI Receive Operation (8-Bit Data with Parity and One Stop Bit)

13.3.3 Multiprocessor Communication

The multiprocessor communication function enables several processors to share a single serial communication line. The processors communicate in asynchronous mode using a format with an additional multiprocessor bit (multiprocessor format).

In multiprocessor communication, each receiving processor is addressed by an ID. A serial communication cycle consists of an ID-sending cycle that identifies the receiving processor, and a data-sending cycle. The multiprocessor bit distinguishes ID-sending cycles from data-sending cycles.

The transmitting processor starts by sending the ID of the receiving processor with which it wants to communicate as data with the multiprocessor bit set to 1. Next the transmitting processor sends transmit data with the multiprocessor bit cleared to 0.

Receiving processors skip incoming data until they receive data with the multiprocessor bit set to 1. When they receive data with the multiprocessor bit set to 1, receiving processors compare the data with their IDs. The receiving processor with a matching ID continues to receive further incoming data. Processors with IDs not matching the received data skip further incoming data until they again receive data with the multiprocessor bit set to 1. Multiple processors can send and receive data in this way.

Figure 13-9 shows an example of communication among different processors using a multiprocessor format.

Communication Formats: Four formats are available. Parity-bit settings are ignored when a multiprocessor format is selected. For details see table 13-8.

Clock: See the description of asynchronous mode.

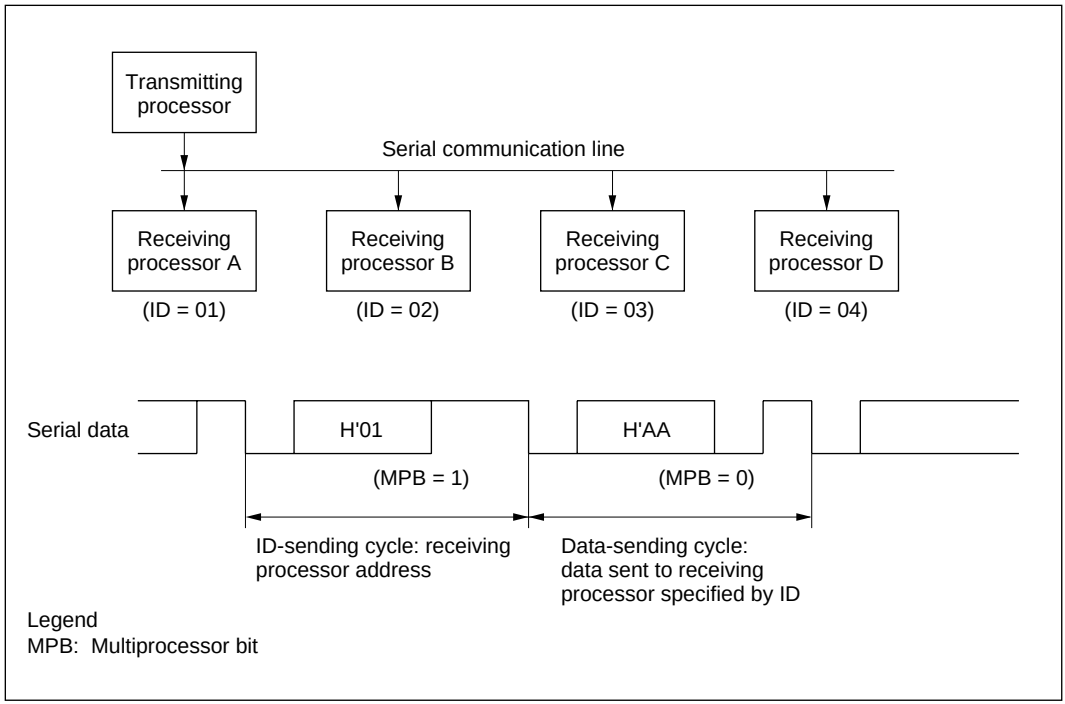


Figure 13-9 Example of Communication among Processors using Multiprocessor Format (Sending Data H'AA to Receiving Processor A)

Transmitting Multiprocessor Serial Data: Figure 13-10 shows a sample flowchart for transmitting multiprocessor serial data and indicates the procedure to follow.

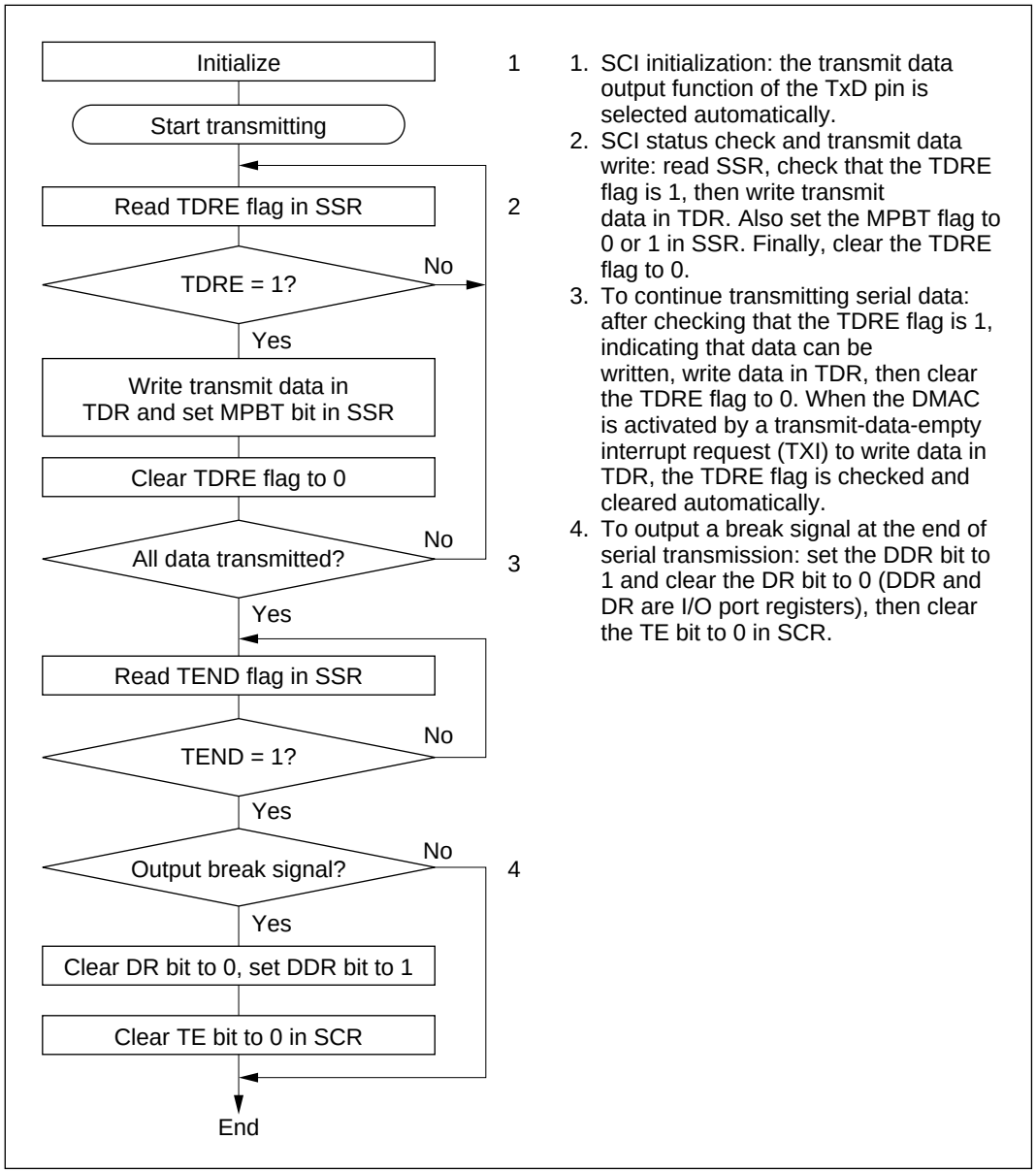


Figure 13-10 Sample Flowchart for Transmitting Multiprocessor Serial Data

In transmitting serial data, the SCI operates as follows.

- The SCI monitors the TDRE flag in SSR. When the TDRE flag is cleared to 0 the SCI recognizes that TDR contains new data, and loads this data from TDR into TSR.
- After loading the data from TDR into TSR, the SCI sets the TDRE flag to 1 and starts transmitting. If the TIE bit in SCR is set to 1, the SCI requests a transmit-data-empty interrupt (TXI) at this time.

Serial transmit data is transmitted in the following order from the TxD pin:

— Start bit: One 0 bit is output.
— Transmit data: 7 or 8 bits are output, LSB first.
— Multiprocessor bit: One multiprocessor bit (MPBT value) is output.
— Stop bit: One or two 1 bits (stop bits) are output.
— Mark state: Output of 1 bits continues until the start bit of the next transmit data.

- The SCI checks the TDRE flag when it outputs the stop bit. If the TDRE flag is 0, the SCI loads data from TDR into TSR, outputs the stop bit, then begins serial transmission of the next frame. If the TDRE flag is 1, the SCI sets the TEND flag in SSR to 1, outputs the stop bit, then continues output of 1 bits in the mark state. If the TEIE bit is set to 1 in SCR, a transmit-end interrupt (TEI) is requested at this time.

Figure 13-11 shows an example of SCI transmit operation using a multiprocessor format.

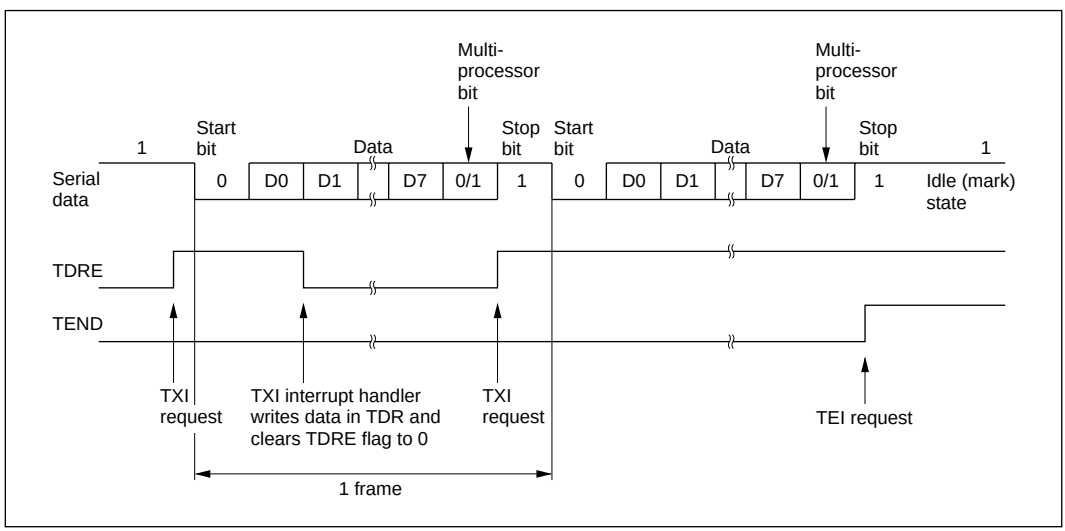


Figure 13-11 Example of SCI Transmit Operation (8-Bit Data with Multiprocessor Bit and One Stop Bit)

Receiving Multiprocessor Serial Data: Figure 13-12 shows a sample flowchart for receiving multiprocessor serial data and indicates the procedure to follow.

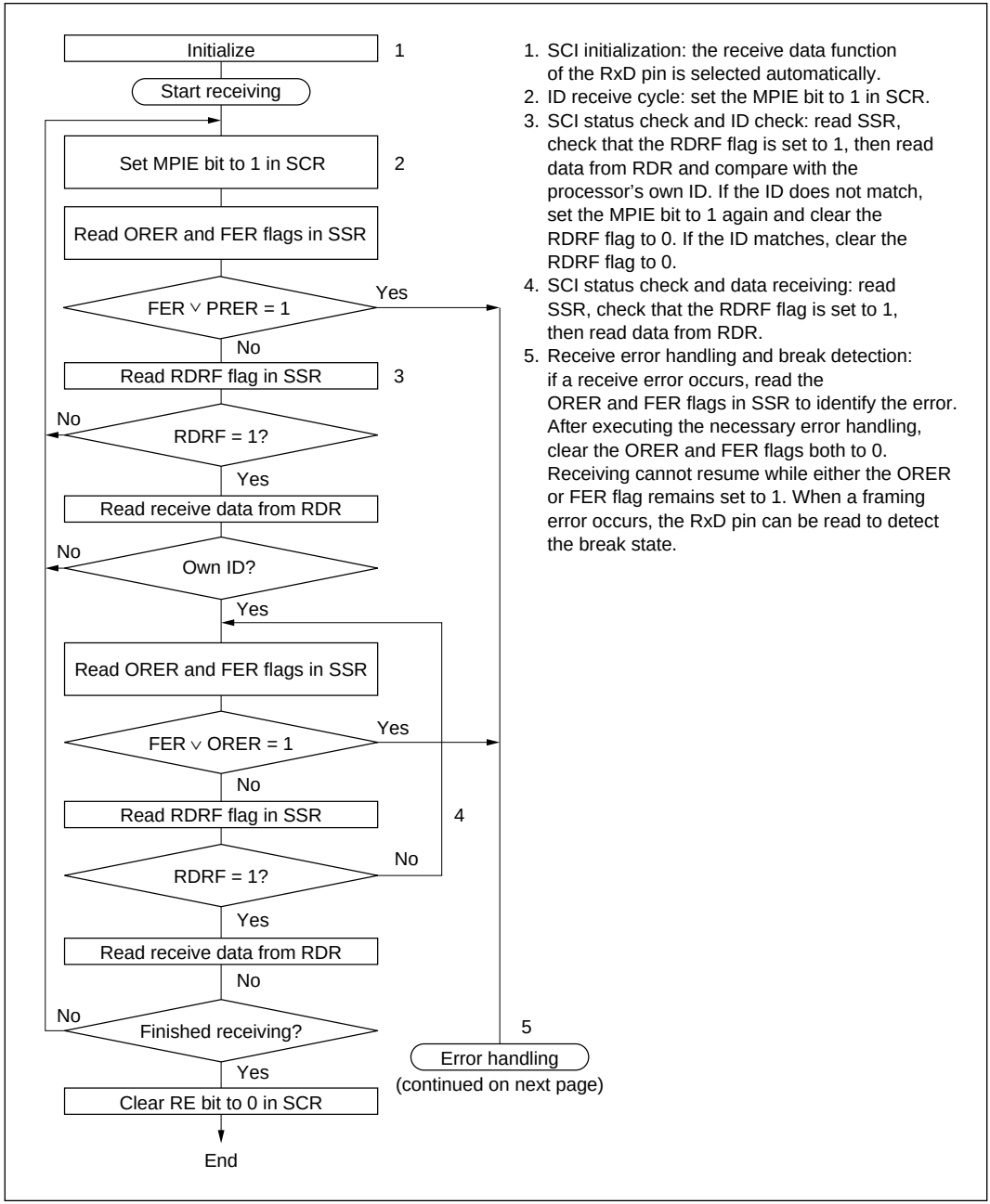


Figure 13-12 Sample Flowchart for Receiving Multiprocessor Serial Data (1)

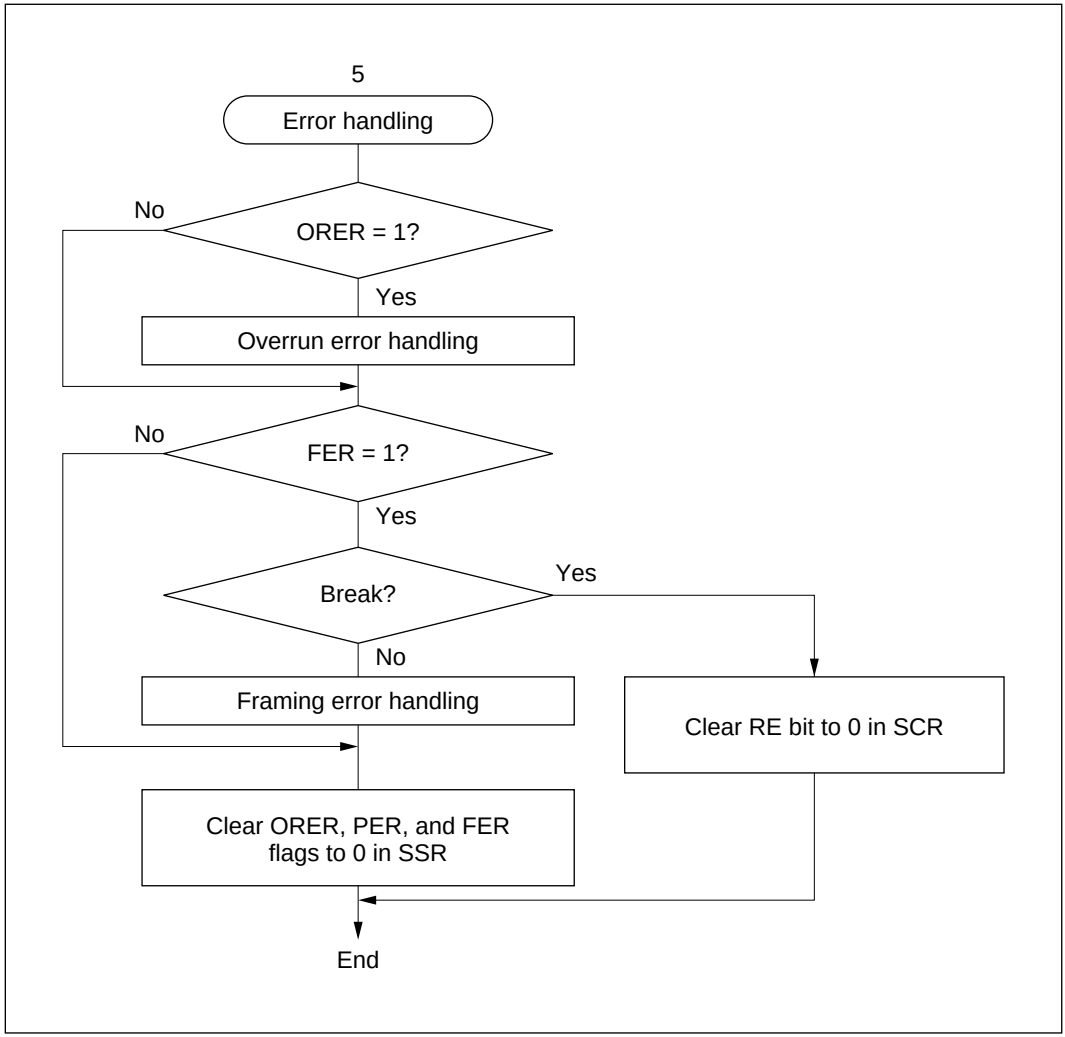


Figure 13-12 Sample Flowchart for Receiving Multiprocessor Serial Data (2)

Figure 13-13 shows an example of SCI receive operation using a multiprocessor format.

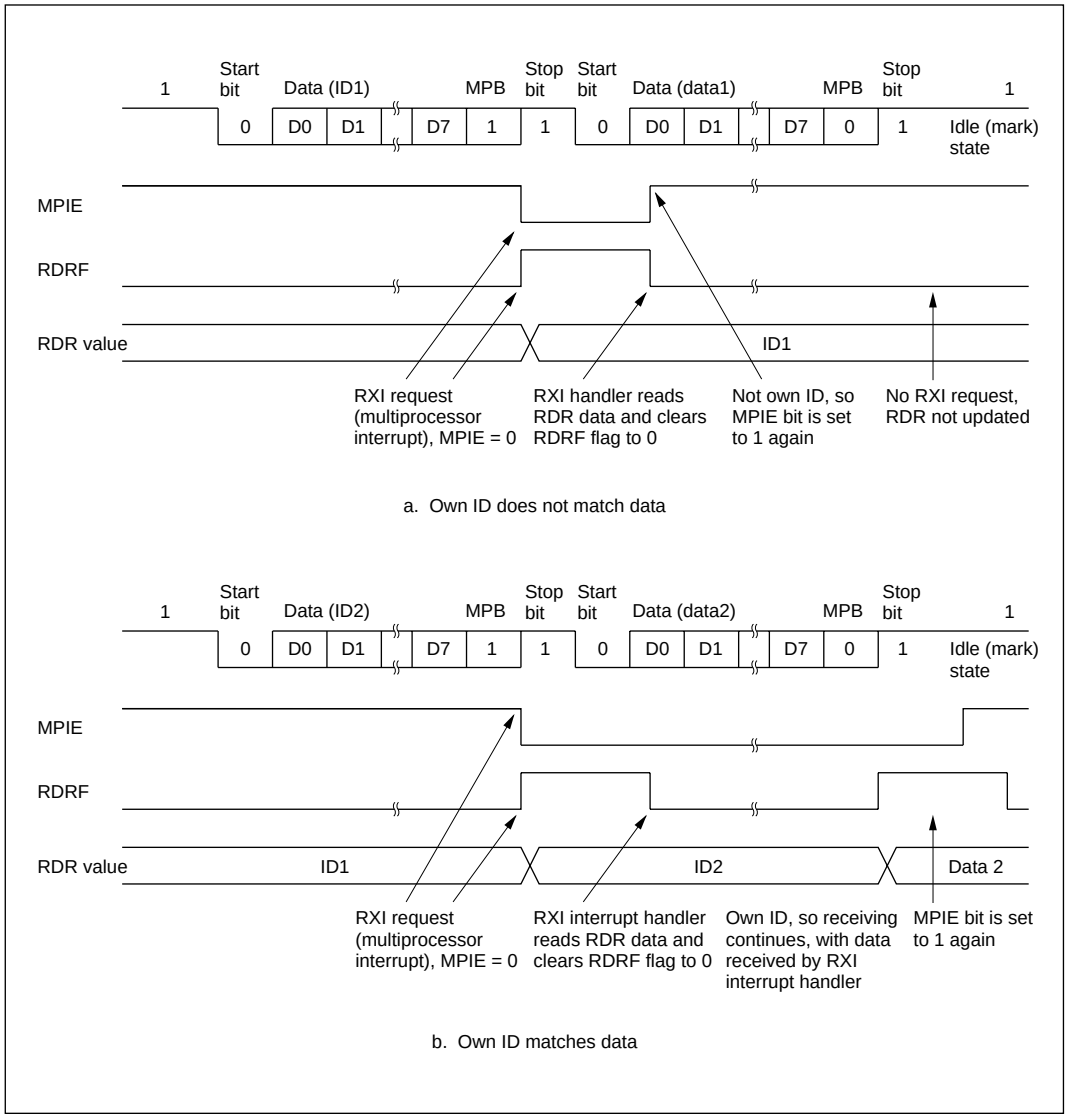


Figure 13-13 Example of SCI Receive Operation (8-Bit Data with Multiprocessor Bit and One Stop Bit)

13.3.4 Synchronous Operation

In synchronous mode, the SCI transmits and receives data in synchronization with clock pulses. This mode is suitable for high-speed serial communication.

The SCI transmitter and receiver share the same clock but are otherwise independent, so full duplex communication is possible. The transmitter and receiver are also double buffered, so continuous transmitting or receiving is possible by reading or writing data while transmitting or receiving is in progress.

Figure 13-14 shows the general format in synchronous serial communication.

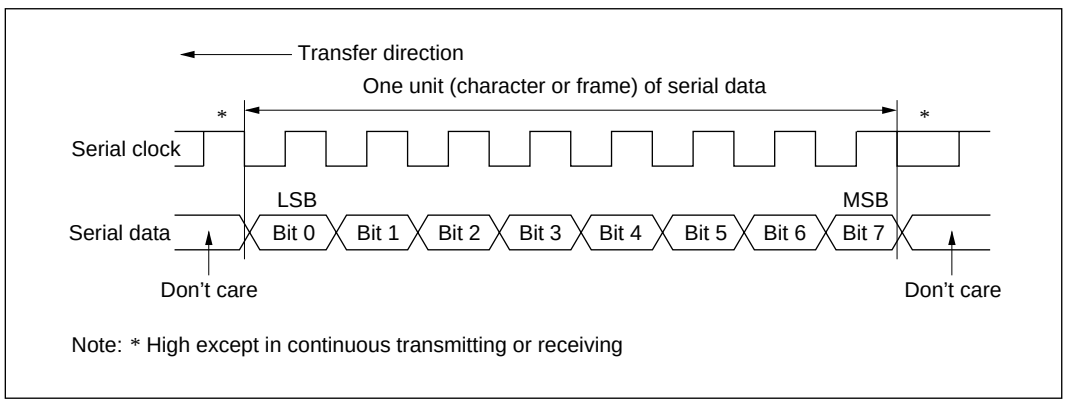


Figure 13-14 Data Format in Synchronous Communication

In synchronous serial communication, each data bit is placed on the communication line from one falling edge of the serial clock to the next. Data is guaranteed valid at the rise of the serial clock. In each character, the serial data bits are transmitted in order from LSB (first) to MSB (last). After output of the MSB, the communication line remains in the state of the MSB. In synchronous mode the SCI receives data by synchronizing with the rise of the serial clock.

Communication Format: The data length is fixed at 8 bits. No parity bit or multiprocessor bit can be added.

Clock: An internal clock generated by the on-chip baud rate generator or an external clock input from the SCK pin can be selected by clearing or setting the CKE1 bit in SCR. See table 13-9. When the SCI operates on an internal clock, it outputs the clock signal at the SCK pin. Eight clock pulses are output per transmitted or received character. When the SCI is not transmitting or receiving, the clock signal remains in the high state. When the SCI is only receiving, it receives in units of two characters, so it outputs 16 clock pulses. To receive in units of one character, an external clock source must be selected.

Transmitting and Receiving Data

SCI Initialization (Synchronous Mode): Before transmitting or receiving, clear the TE and RE bits to 0 in SCR, then initialize the SCI as follows.

When changing the communication mode or format, always clear the TE and RE bits to 0 before following the procedure given below. Clearing the TE bit to 0 sets the TDRE flag to 1 and initializes TSR. Clearing the RE bit to 0, however, does not initialize the RDRF, PER, FER, and ORE flags and RDR, which retain their previous contents.

Figure 13-15 is a sample flowchart for initializing the SCI.

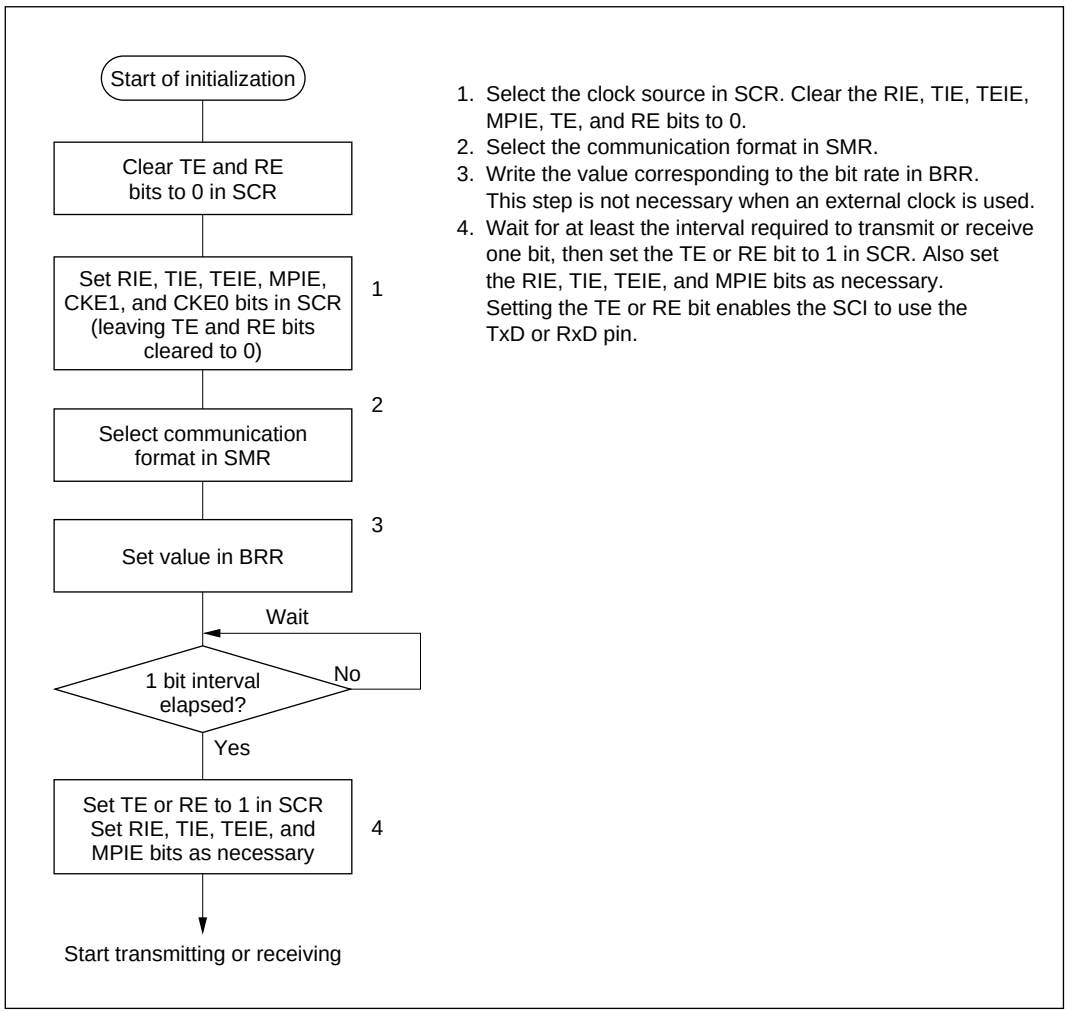
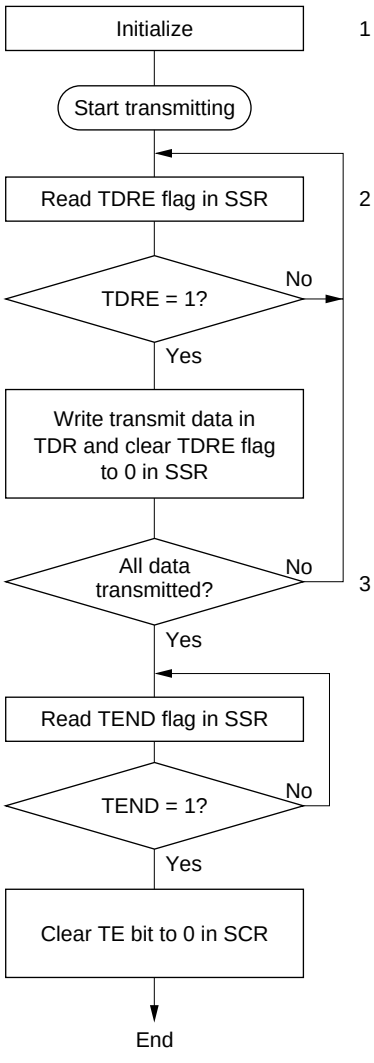


Figure 13-15 Sample Flowchart for SCI Initialization

Transmitting Serial Data (Synchronous Mode): Figure 13-16 shows a sample flowchart for transmitting serial data and indicates the procedure to follow.



1. SCI initialization: the transmit data output function of the TxD pin is selected automatically.
2. SCI status check and transmit data write: read SSR, check that the TDRE flag is 1, then write transmit data in TDR and clear the TDRE flag to 0.
3. To continue transmitting serial data: after checking that the TDRE flag is 1, indicating that data can be written, write data in TDR, then clear the TDRE flag to 0. When the DMAC is activated by a transmit-data-empty interrupt request (TXI) to write data in TDR, the TDRE flag is checked and cleared automatically.

Figure 13-16 Sample Flowchart for Serial Transmitting

In transmitting serial data, the SCI operates as follows.

- The SCI monitors the TDRE flag in SSR. When the TDRE flag is cleared to 0 the SCI recognizes that TDR contains new data, and loads this data from TDR into TSR.
- After loading the data from TDR into TSR, the SCI sets the TDRE flag to 1 and starts transmitting. If the TIE bit is set to 1 in SCR, the SCI requests a transmit-data-empty interrupt (TXI) at this time.

  If clock output is selected, the SCI outputs eight serial clock pulses. If an external clock source is selected, the SCI outputs data in synchronization with the input clock. Data is output from the TxD pin in order from LSB (bit 0) to MSB (bit 7).
- The SCI checks the TDRE flag when it outputs the MSB (bit 7). If the TDRE flag is 0, the SCI loads data from TDR into TSR and begins serial transmission of the next frame. If the TDRE flag is 1, the SCI sets the TEND flag to 1 in SSR, and after transmitting the MSB, holds the TxD pin in the MSB state. If the TEIE bit in SCR is set to 1, a transmit-end interrupt (TEI) is requested at this time.
- After the end of serial transmission, the SCK pin is held in a constant state.

Figure 13-17 shows an example of SCI transmit operation.

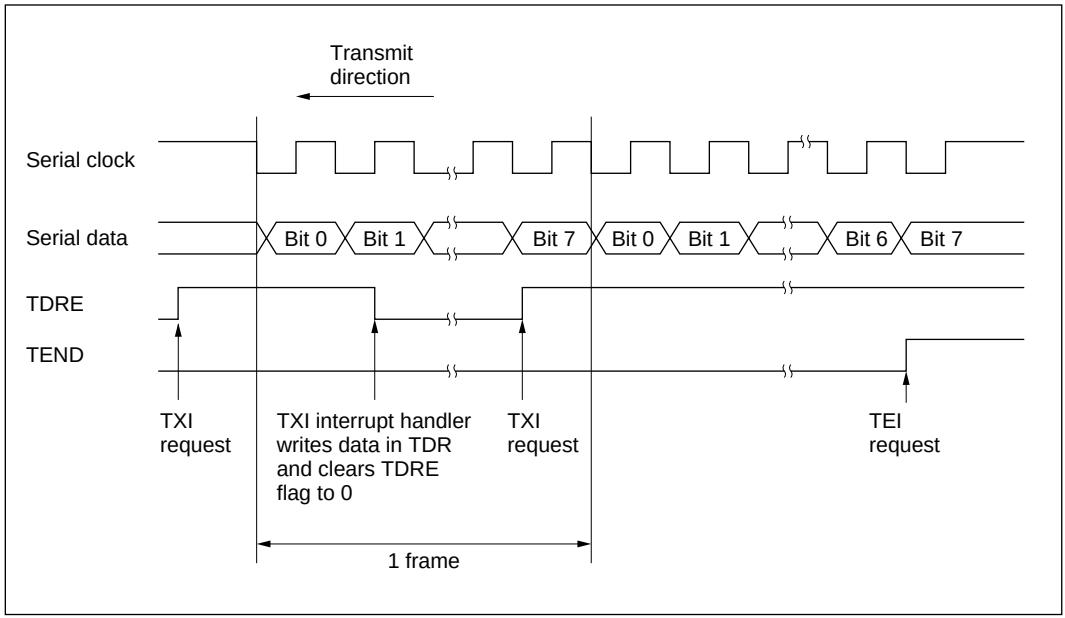
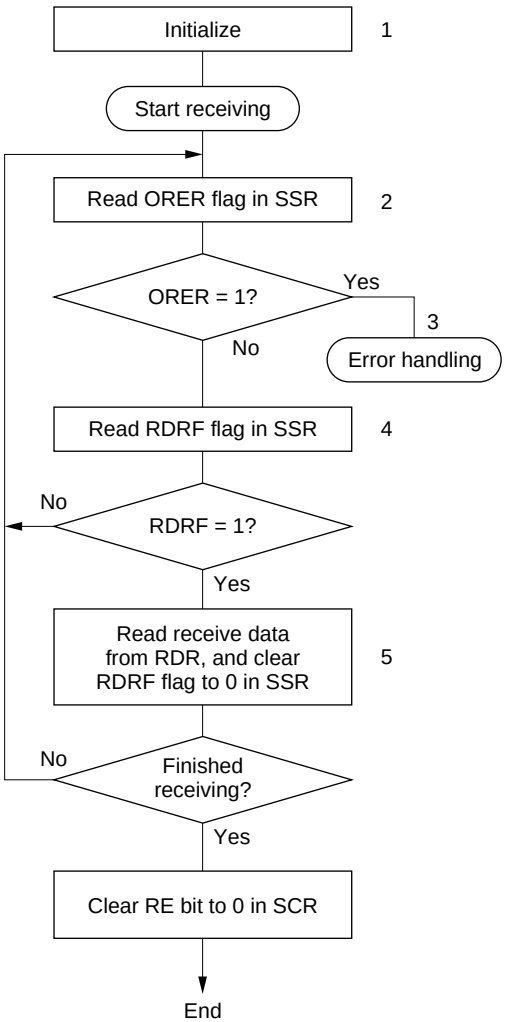


Figure 13-17 Example of SCI Transmit Operation

Receiving Serial Data: Figure 13-18 shows a sample flowchart for receiving serial data and indicates the procedure to follow. When switching from asynchronous mode to synchronous mode, make sure that the ORER, PER, and FER flags are cleared to 0. If the FER or PER flag is set to 1 the RDRF flag will not be set and both transmitting and receiving will be disabled.



1. SCI initialization: the receive data function of the RxD pin is selected automatically.
2., 3. Receive error handling: if a receive error occurs, read the ORER flag in SSR, then after executing the necessary error handling, clear the ORER flag to 0. Neither transmitting nor receiving can resume while the ORER flag remains set to 1.
4. SCI status check and receive data read: read SSR, check that the RDRF flag is set to 1, then read receive data from RDR and clear the RDRF flag to 0. Notification that the RDRF flag has changed from 0 to 1 can also be given by the RXI interrupt.
5. To continue receiving serial data: check the RDRF flag, read RDR, and clear the RDRF flag to 0 before the MSB (bit 7) of the current frame is received. If the DMAC is activated by a receive-data-full interrupt request (RXI) to read RDR, the RDRF flag is cleared automatically.

Figure 13-18 Sample Flowchart for Serial Receiving (1)

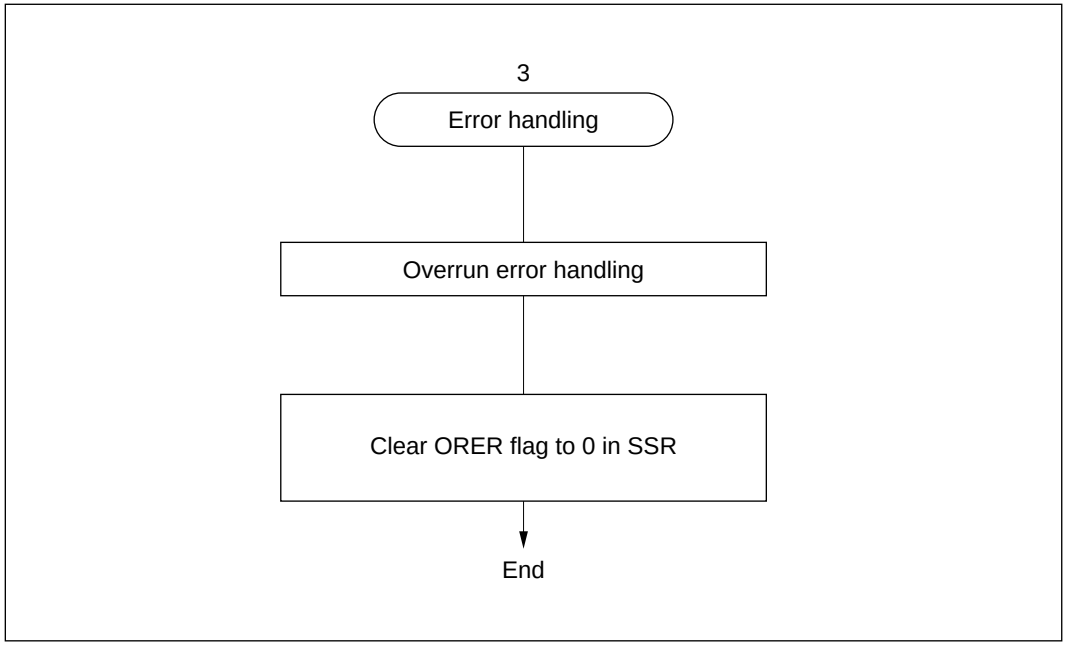


Figure 13-18 Sample Flowchart for Serial Receiving (2)

In receiving, the SCI operates as follows.

- The SCI synchronizes with serial clock input or output and initializes internally.
- Receive data is stored in RSR in order from LSB to MSB.

  After receiving the data, the SCI checks that the RDRF flag is 0 so that receive data can be transferred from RSR to RDR. If this check passes, the RDRF flag is set to 1 and the received data is stored in RDR. If the check does not pass (receive error), the SCI operates as indicated in table 13-11.
- After setting the RDRF flag to 1, if the RIE bit is set to 1 in SCR, the SCI requests a receive-data-full interrupt (RXI). If the ORER flag is set to 1 and the RIE bit in SCR is also set to 1, the SCI requests a receive-error interrupt (ERI).

Figure 13-19 shows an example of SCI receive operation.

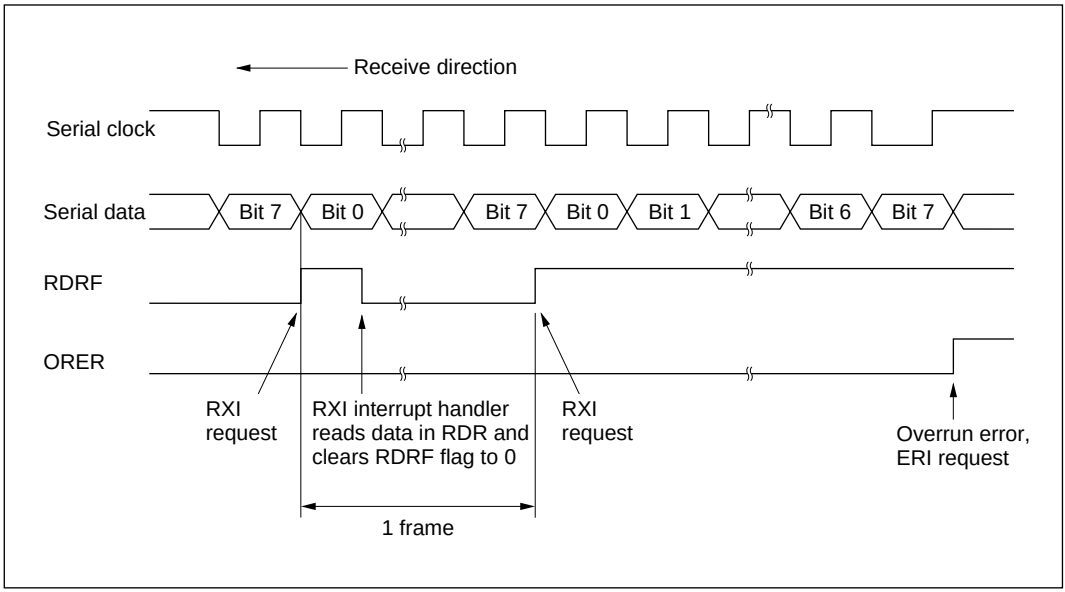
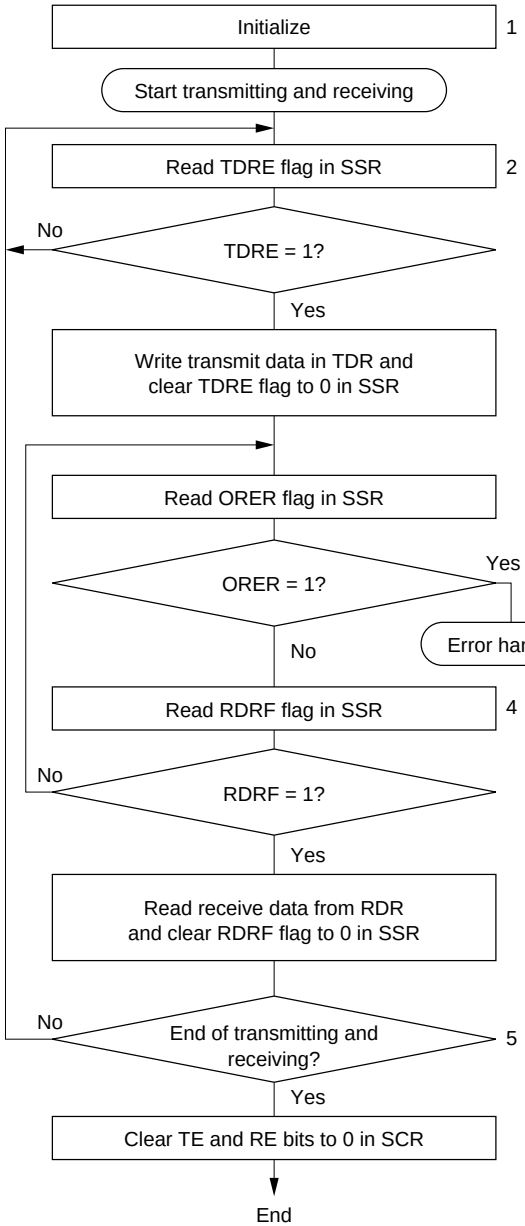


Figure 13-19 Example of SCI Receive Operation

Transmitting and Receiving Serial Data Simultaneously (Synchronous Mode): Figure 13-20 shows a sample flowchart for transmitting and receiving serial data simultaneously and indicates the procedure to follow.



Note: * When switching from transmitting or receiving to simultaneous transmitting and receiving, clear the TE and RE bits both to 0, then set the TE and RE bits both to 1.

1. SCI initialization: the transmit data output function of the TxD pin and receive data input function of the RxD pin are selected, enabling simultaneous transmitting and receiving.
2. SCI status check and transmit data write: read SSR, check that the TDRE flag is 1, then write transmit data in TDR and clear the TDRE flag to 0.
   Notification that the TDRE flag has changed from 0 to 1 can also be given by the TXI interrupt.
3. Receive error handling: if a receive error occurs, read the ORER flag in SSR, then after executing the necessary error handling, clear the ORER flag to 0.
   Neither transmitting nor receiving can resume while the ORER flag remains set to 1.
4. SCI status check and receive data read: read SSR, check that the RDRF flag is 1, then read receive data from RDR and clear the RDRF flag to 0. Notification that the RDRF flag has changed from 0 to 1 can also be given by the RXI interrupt.
5. To continue transmitting and receiving serial data: check the RDRF flag, read RDR, and clear the RDRF flag to 0 before the MSB (bit 7) of the current frame is received. Also check that the TDRE flag is (bit 7) of the current frame is received. Also check that the TDRE flag is set to 1, indicating that data can be written, write data in TDR, then clear the TDRE flag to 0 before the MSB (bit 7) of the current frame is transmitted. When the DMAC is activated by a transmit-data-empty interrupt request (TXI) to write data in TDR, the TDRE flag is checked and cleared automatically. When the DMAC is activated by a receive-data-full interrupt request (RXI) to read RDR, the RDRF flag is cleared automatically.

Figure 13-20 Sample Flowchart for Serial Transmitting

13.4 SCI Interrupts

The SCI has four interrupt request sources: TEI (transmit-end interrupt), ERI (receive-error interrupt), RXI (receive-data-full interrupt), and TXI (transmit-data-empty interrupt). Table 13-12 lists the interrupt sources and indicates their priority. These interrupts can be enabled and disabled by the TIE, TEIE, and RIE bits in SCR. Each interrupt request is sent separately to the interrupt controller.

The TXI interrupt is requested when the TDRE flag is set to 1 in SSR. The TEI interrupt is requested when the TEND flag is set to 1 in SSR. The TXI interrupt request can activate the DMAC to transfer data. Data transfer by the DMAC automatically clears the TDRE flag to 0. The TEI interrupt request cannot activate the DMAC.

The RXI interrupt is requested when the RDRF flag is set to 1 in SSR. The ERI interrupt is requested when the ORER, PER, or FER flag is set to 1 in SSR. The RXI interrupt request can activate the DMAC to transfer data. Data transfer by the DMAC automatically clears the RDRF flag to 0. The ERI interrupt request cannot activate the DMAC.

DMAC channels in group 0 can be activated by interrupts from SCI channel 0. DMAC channels in group 1 can be activated by interrupts from SCI channel 1.

Table 13-12 SCI Interrupt Sources

Interrupt	Description	Priority
ERI	Receive error (ORER, FER, or PER)	High
RXI	Receive data register full (RDRF)	
TXI	Transmit data register empty (TDRE)	
TEI	Transmit end (TEND)	Low

13.5 Usage Notes

Note the following points when using the SCI.

TDR Write and TDRE Flag: The TDRE flag in SSR is a status flag indicating the loading of transmit data from TDR into TSR. The SCI sets the TDRE flag to 1 when it transfers data from TDR to TSR.

Data can be written into TDR regardless of the state of the TDRE flag. If new data is written in TDR when the TDRE flag is 0, the old data stored in TDR will be lost because this data has not yet been transferred to TSR. Before writing transmit data in TDR, be sure to check that the TDRE flag is set to 1.

Simultaneous Multiple Receive Errors: Table 13-13 indicates the state of SSR status flags when multiple receive errors occur simultaneously. When an overrun error occurs the RSR contents are not transferred to RDR, so receive data is lost.

Table 13-13 SSR Status Flags and Transfer of Receive Data

SSR Status Flags				Receive Data Transfer	
RDRF	ORER	FER	PER	RSR → RDR	Receive Errors
1	1	0	0	×	Overrun error
0	0	1	0	○	Framing error
0	0	0	1	○	Parity error
1	1	1	0	×	Overrun error + framing error
1	1	0	1	×	Overrun error + parity error
0	0	1	1	○	Framing error + parity error
1	1	1	1	×	Overrun error + framing error + parity error

Notes: ○: Receive data is transferred from RSR to RDR.
× Receive data is not transferred from RSR to RDR.

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. In the break state the SCI receiver continues to operate, so if the FER flag is cleared to 0 it will be set to 1 again.

Sending a Break Signal: When the TE bit is cleared to 0 the TxD pin becomes an I/O port, the level and direction (input or output) of which are determined by DR and DDR bits. This feature can be used to send a break signal.

After the serial transmitter is initialized, the DR value substitutes for the mark state until the TE bit is set to 1 (the TxD pin function is not selected until the TE bit is set to 1). The DDR and DR bits should therefore both be set to 1 beforehand.

To send a break signal during serial transmission, clear the DR bit to 0, then clear the TE bit to 0. When the TE bit is cleared to 0 the transmitter is initialized, regardless of its current state, so the TxD pin becomes an output port outputting the value 0.

Receive Error Flags and Transmitter Operation (Synchronous Mode Only): When a receive error flag (ORER, PER, or FER) is set to 1 the SCI will not start transmitting, even if the TDRE flag is clear to 0. Be sure to clear the receive error flags to 0 when starting to transmit. Note that clearing the RE bit to 0 does not clear the receive error flags to 0.

Receive Data Sampling Timing in Asynchronous Mode and Receive Margin: In asynchronous mode the SCI operates on a base clock with 16 times the bit rate frequency. In receiving, the SCI 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 eighth base clock pulse. See figure 13-21.

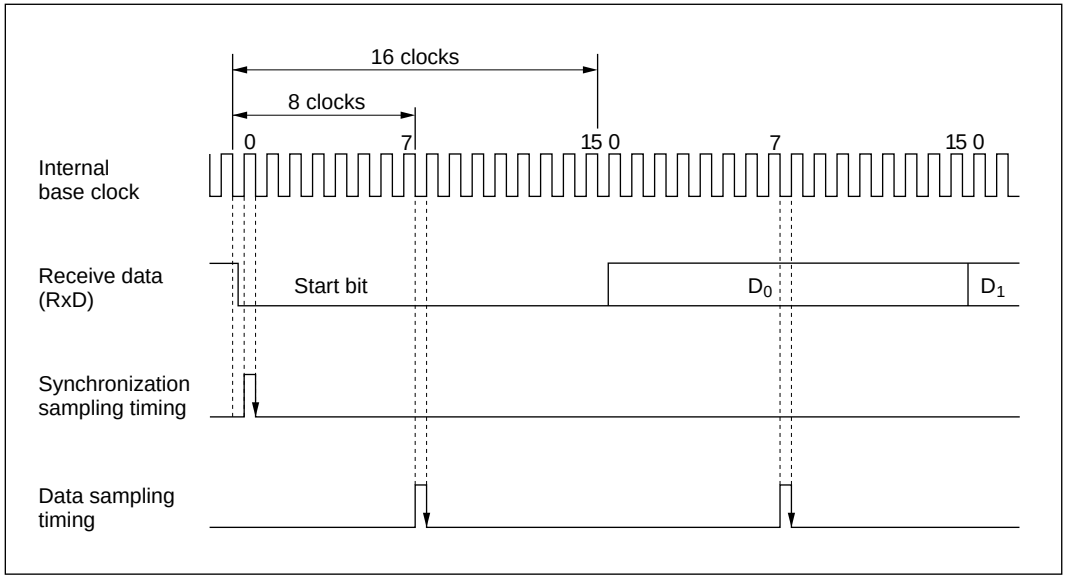


Figure 13-21 Receive Data Sampling Timing in Asynchronous Mode

The receive margin in asynchronous mode can therefore be expressed as in equation (1).

$$M = \left| (0.5 - \frac{1}{2N}) - (L - 0.5)\, F - \frac{|\, D - 0.5\,|}{N} (1 + F) \right| \times 100\% \quad \text{.....(1)}$$

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).

$D = 0.5, F = 0$

$$M = (0.5 - \frac{1}{2 \times 16}) \times 100\%$$

$$= 46.875\% \text{.....(2)}$$

This is a theoretical value. A reasonable margin to allow in system designs is 20% to 30%.

Restrictions on Usage of DMAC

- When an external clock source is used for the serial clock, after the DMAC updates TDR, allow an interval of at least five system clock (ø) cycles before input of the serial clock to start transmitting. If the serial clock is input within four states of the TDR update, a malfunction may occur. (See figure 13-22.)

- To have the DMAC read RDR, be sure to select the SCI receive-data-full interrupt (RXI) as the activation source with bits DTS2 to DTS0 in DTCR.

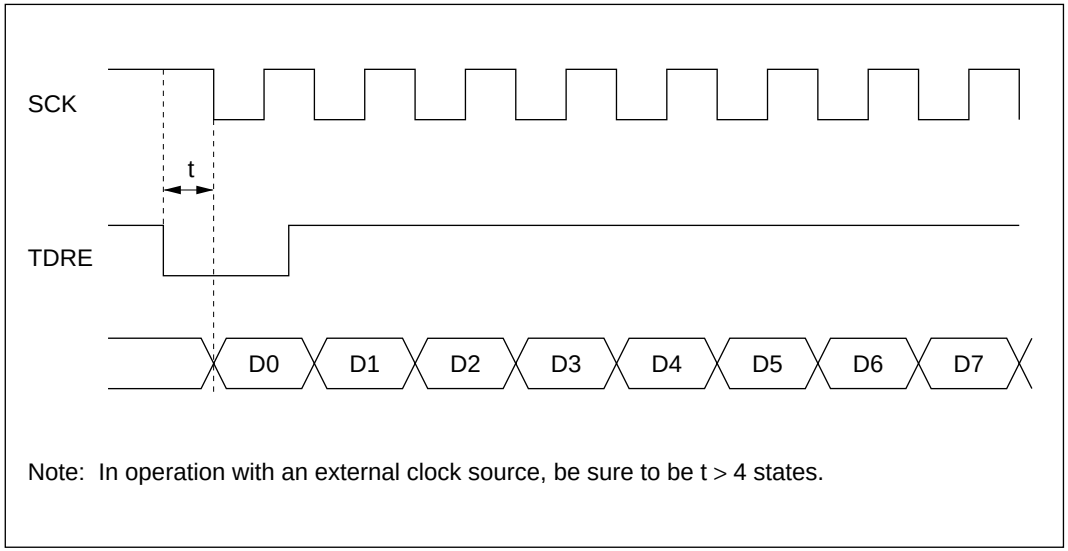


Figure 13-22 Synchronous Transmission Using DMAC (Example)

Section 14 A/D Converter

14.1 Overview

The H8/3003 includes a 10-bit successive-approximations A/D converter with a selection of up to eight analog input channels.

14.1.1 Features

A/D converter features are listed below.

- 10-bit resolution
- Eight input channels
- Selectable analog conversion voltage range

  The analog voltage conversion range can be programmed by input of an analog reference voltage at the V_{REF} pin.
- High-speed conversion

  Conversion time: maximum 8.4 µs per channel (with 16 MHz system clock)
- Two conversion modes

  Single mode: A/D conversion of one channel
  Scan mode: continuous conversion on one to four channels
- Four 16-bit data registers

  A/D conversion results are transferred for storage into data registers corresponding to the channels.
- Sample-and-hold function
- A/D conversion can be externally triggered
- A/D interrupt requested at end of conversion

  At the end of A/D conversion, an A/D end interrupt (ADI) can be requested.

14.1.2 Block Diagram

Figure 14-1 shows a block diagram of the A/D converter.

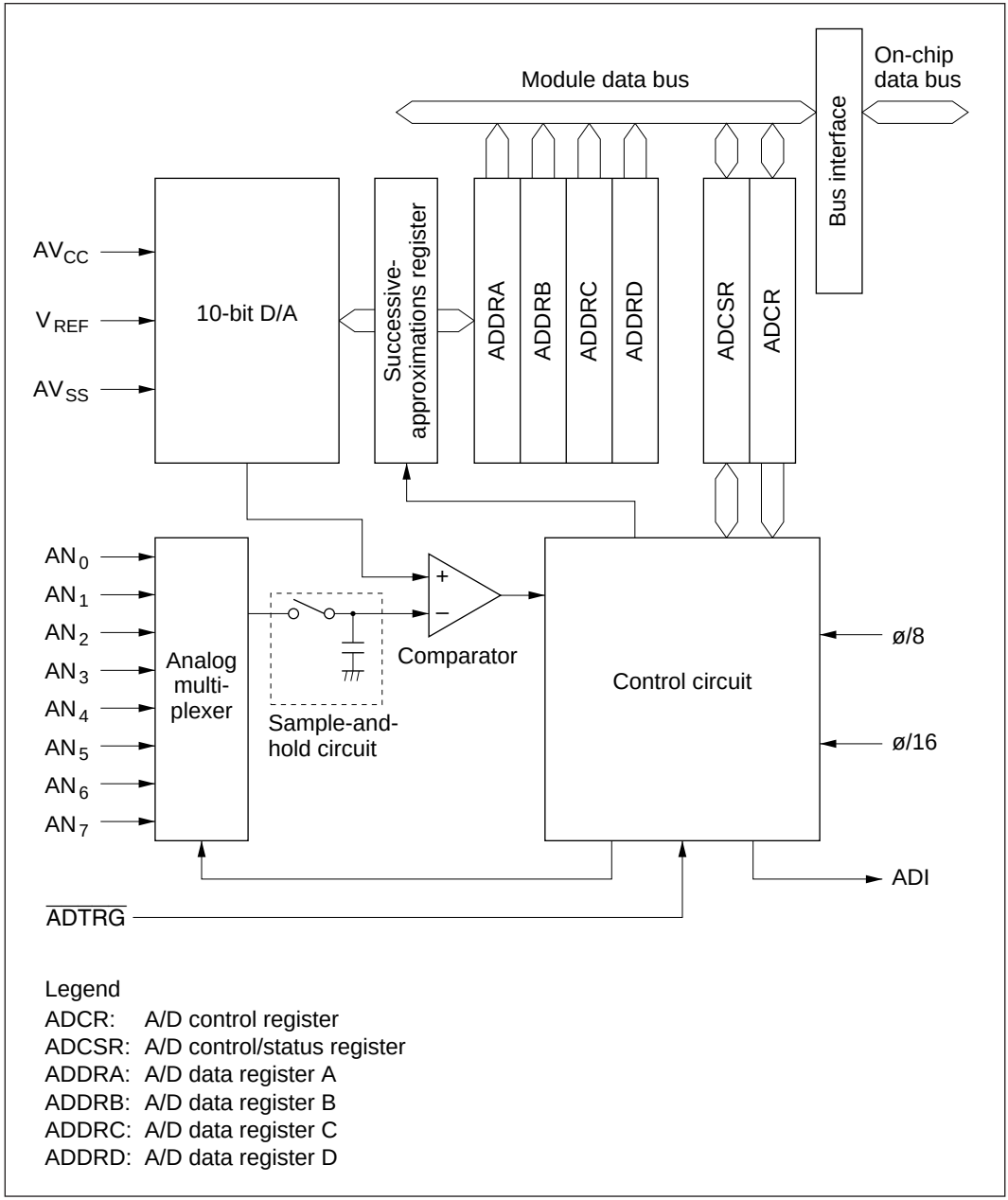


Figure 14-1 A/D Converter Block Diagram

14.1.3 Input Pins

Table 14-1 summarizes the A/D converter's input pins. The eight analog input pins are divided into two groups: group 0 (AN_0 to AN_3), and group 1 (AN_4 to AN_7). AV_{CC} and AV_{SS} are the power supply for the analog circuits in the A/D converter. V_{REF} is the A/D conversion reference voltage.

Table 14-1 A/D Converter Pins

Pin Name	Abbreviation	I/O	Function
Analog power supply pin	AV_{CC}	Input	Analog power supply
Analog ground pin	AV_{SS}	Input	Analog ground and reference voltage
Reference voltage pin	V_{REF}	Input	Analog reference voltage
Analog input pin 0	AN_0	Input	Group 0 analog inputs
Analog input pin 1	AN_1	Input	
Analog input pin 2	AN_2	Input	
Analog input pin 3	AN_3	Input	
Analog input pin 4	AN_4	Input	Group 1 analog inputs
Analog input pin 5	AN_5	Input	
Analog input pin 6	AN_6	Input	
Analog input pin 7	AN_7	Input	
A/D external trigger input pin	$\overline{\text{ADTRG}}$	Input	External trigger input for starting A/D conversion

14.1.4 Register Configuration

Table 14-2 summarizes the A/D converter's registers.

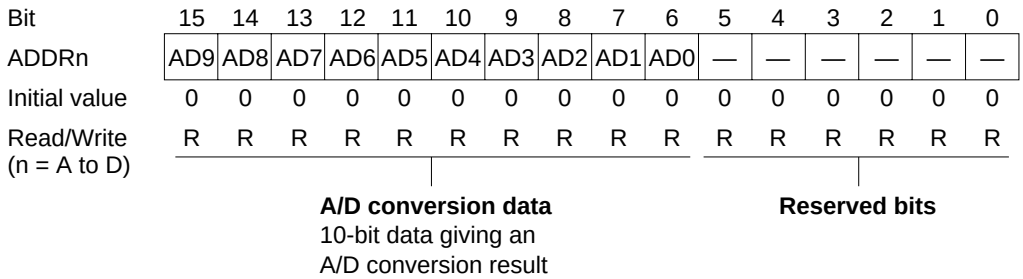
Table 14-2 A/D Converter Registers

Address*1	Name	Abbreviation	R/W	Initial Value
H'FFE0	A/D data register A (high)	ADDRAH	R	H'00
H'FFE1	A/D data register A (low)	ADDRAL	R	H'00
H'FFE2	A/D data register B (high)	ADDRBH	R	H'00
H'FFE3	A/D data register B (low)	ADDRBL	R	H'00
H'FFE4	A/D data register C (high)	ADDRCH	R	H'00
H'FFE5	A/D data register C (low)	ADDRCL	R	H'00
H'FFE6	A/D data register D (high)	ADDRDH	R	H'00
H'FFE7	A/D data register D (low)	ADDRDL	R	H'00
H'FFE8	A/D control/status register	ADCSR	R/(W)*2	H'00
H'FFE9	A/D control register	ADCR	R/W	H'7E

Notes: 1. Lower 16 bits of the address
2. Only 0 can be written in bit 7, to clear the flag.

14.2 Register Descriptions

14.2.1 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.

An A/D conversion produces 10-bit data, which is transferred for storage into the A/D data register corresponding to the selected channel. The upper 8 bits of the result are stored in the upper byte of the A/D data register. The lower 2 bits are stored in the lower byte. Bits 5 to 0 of an A/D data register are reserved bits that always read 0. Table 14-3 indicates the pairings of analog input channels and A/D data registers.

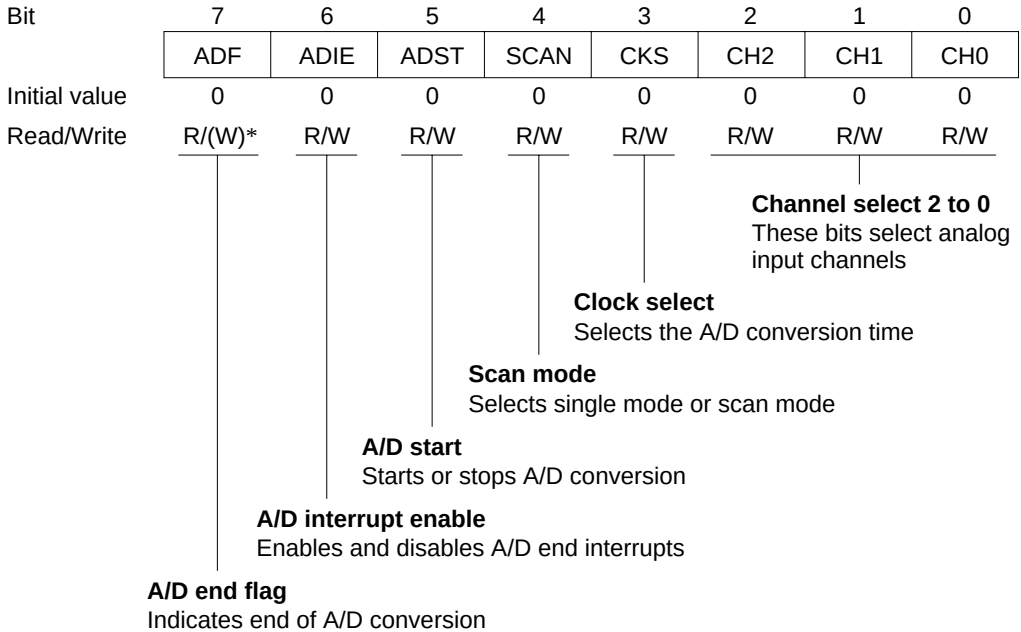
The CPU can always read and write the A/D data registers. The upper byte can be read directly, but the lower byte is read through a temporary register (TEMP). For details see section 14.3, CPU Interface.

The A/D data registers are initialized to H'0000 by a reset and in standby mode.

Table 14-3 Analog Input Channels and A/D Data Registers

Analog Input Channel		
Group 0	**Group 1**	**A/D Data Register**
AN_0	AN_4	ADDRA
AN_1	AN_5	ADDRB
AN_2	AN_6	ADDRC
AN_3	AN_7	ADDRD

14.2.2 A/D Control/Status Register (ADCSR)



Note: * Only 0 can be written, to clear the flag.

ADCSR is an 8-bit readable/writable register that selects the mode and controls the A/D converter. ADCSR is initialized to H'00 by a reset and in standby mode.

Bit 7—A/D End Flag (ADF): Indicates the end of A/D conversion.

Bit 7 ADF	Description	
0	[Clearing condition] Cleared by reading ADF while ADF = 1, then writing 0 in ADF	(Initial value)
1	[Setting conditions] Single mode: A/D conversion ends Scan mode: A/D conversion ends in all selected channels	

Bit 6—A/D Interrupt Enable (ADIE): Enables or disables the interrupt (ADI) requested at the end of A/D conversion.

Bit 6 ADIE	Description	
0	A/D end interrupt request (ADI) is disabled	(Initial value)
1	A/D end interrupt request (ADI) is enabled	

Bit 5—A/D Start (ADST): Starts or stops A/D conversion. The ADST bit remains set to 1 during A/D conversion. It can also be set to 1 by external trigger input at the $\overline{\text{ADTRG}}$ pin.

Bit 5 ADST	Description	
0	A/D conversion is stopped	(Initial value)
1	Single mode: A/D conversion starts; ADST is automatically cleared to 0 when conversion ends. Scan mode: A/D conversion starts and continues, cycling among the selected channels, until ADST is cleared to 0 by software, by a reset, or by a transition to standby mode.	

Bit 4—Scan Mode (SCAN): Selects single mode or scan mode. For further information on operation in these modes, see section 14.4, Operation. Clear the ADST bit to 0 before switching the conversion mode.

Bit 4 SCAN	Description	
0	Single mode	(Initial value)
1	Scan mode	

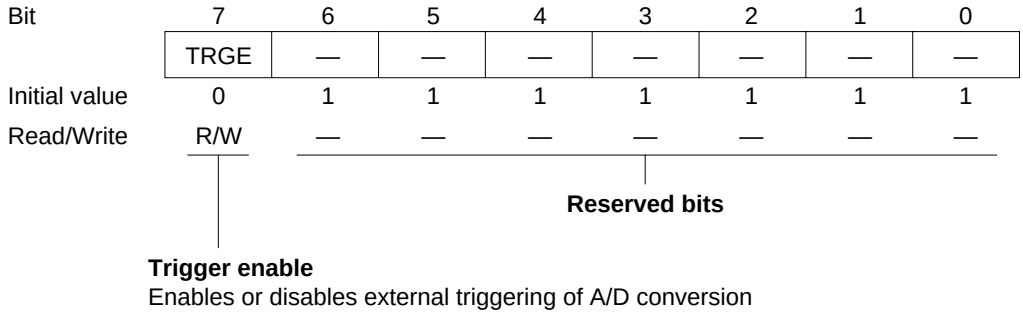
Bit 3—Clock Select (CKS): Selects the A/D conversion time. Clear the ADST bit to 0 before switching the conversion time.

Bit 3 CKS	Description	
0	Conversion time = 266 states (maximum)	(Initial value)
1	Conversion time = 134 states (maximum)	

Bits 2 to 0—Channel Select 2 to 0 (CH2 to CH0): These bits and the SCAN bit select the analog input channels. Clear the ADST bit to 0 before changing the channel selection.

Group Selection	Channel Selection		Description	
CH2	CH1	CH0	Single Mode	Scan Mode
0	0	0	AN_0 (Initial value)	AN_0
		1	AN_1	AN_0, AN_1
	1	0	AN_2	AN_0 to AN_2
		1	AN_3	AN_0 to AN_3
1	0	0	AN_4	AN_4
		1	AN_5	AN_4, AN_5
	1	0	AN_6	AN_4 to AN_6
		1	AN_7	AN_4 to AN_7

14.2.3 A/D Control Register (ADCR)



ADCR is an 8-bit readable/writable register that enables or disables external triggering of A/D conversion. ADCR is initialized to H'7F by a reset and in standby mode.

Bit 7—Trigger Enable (TRGE): Enables or disables external triggering of A/D conversion.

Bit 7 TRGE	Description	
0	A/D conversion cannot be externally triggered	(Initial value)
1	A/D conversion starts at the falling edge of the external trigger signal ($\overline{\text{ADTRG}}$)	

Bits 6 to 0—Reserved: Read-only bits, always read as 1.

14.3 CPU Interface

ADDRA to ADDRD are 16-bit registers, but they are connected to the CPU by an 8-bit data bus. Therefore, although the upper byte can be be accessed directly by the CPU, the lower byte is read through an 8-bit temporary register (TEMP).

An A/D data register is read as follows. When the upper byte is read, the upper-byte value is transferred directly to the CPU and the lower-byte value is transferred into TEMP. Next, when the lower byte is read, the TEMP contents are transferred to the CPU.

When reading an A/D data register, always read the upper byte before the lower byte. It is possible to read only the upper byte, but if only the lower byte is read, incorrect data may be obtained.

Figure 14-2 shows the data flow for access to an A/D data register.

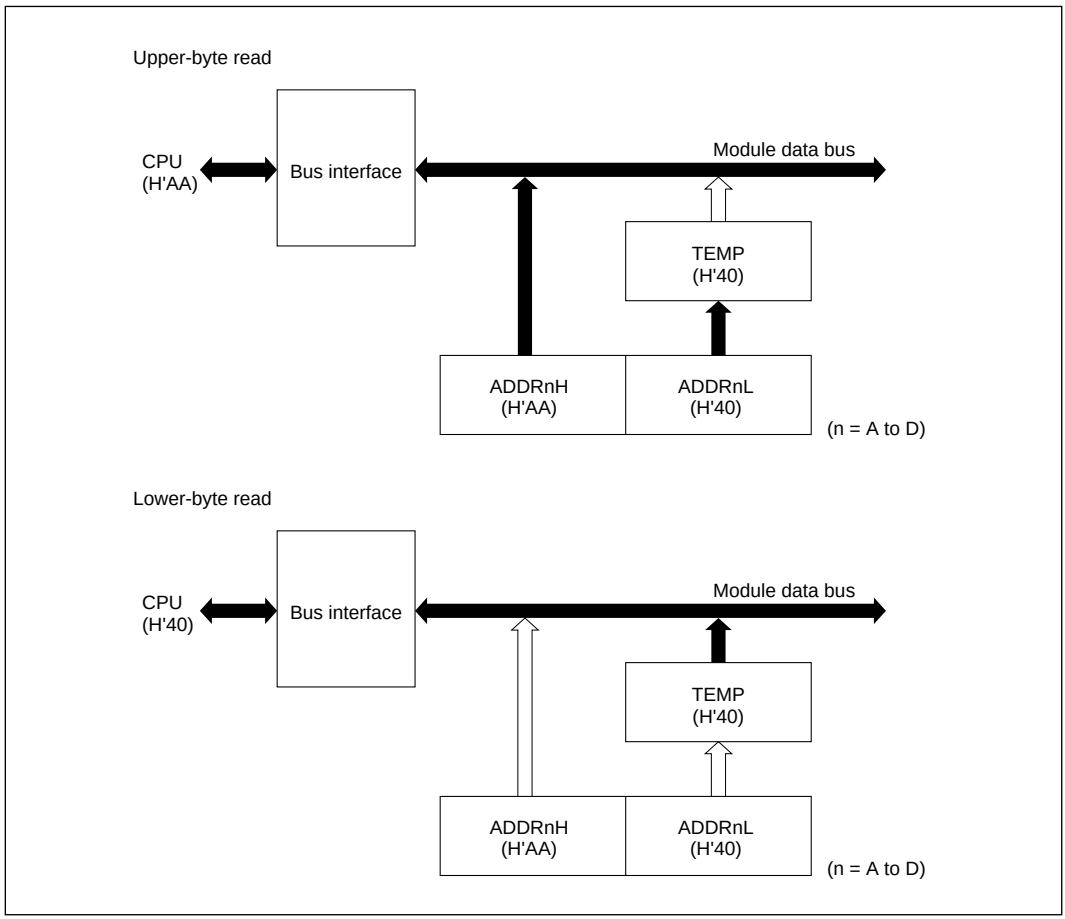


Figure 14-2 A/D Data Register Access Operation (Reading H'AA40)

14.4 Operation

The A/D converter operates by successive approximations with 10-bit resolution. It has two operating modes: single mode and scan mode.

14.4.1 Single Mode (SCAN = 0)

Single mode should be selected when only one A/D conversion on one channel is required. A/D conversion starts when the ADST bit is set to 1 by software, or by external trigger input. The ADST bit remains set to 1 during A/D conversion and is automatically cleared to 0 when conversion ends.

When conversion ends the ADF bit is set to 1. If the ADIE bit is also set to 1, an ADI interrupt is requested at this time. To clear the ADF flag to 0, first read ADCSR, then write 0 in ADF.

When the mode or analog input channel must be switched during analog conversion, to prevent incorrect operation, first clear the ADST bit to 0 in ADCSR to halt A/D conversion. After making the necessary changes, set the ADST bit to 1 to start A/D conversion again. The ADST bit can be set at the same time as the mode or channel is changed.

Typical operations when channel 1 (AN_1) is selected in single mode are described next. Figure 14-3 shows a timing diagram for this example.

1. Single mode is selected (SCAN = 0), input channel AN_1 is selected (CH2 = CH1 = 0, CH0 = 1), the A/D interrupt is enabled (ADIE = 1), and A/D conversion is started (ADST = 1).

2. When A/D conversion is completed, the result is transferred into ADDRB. At the same time the ADF flag is set to 1, the ADST bit is cleared to 0, and the A/D converter becomes idle.

3. Since ADF = 1 and ADIE = 1, an ADI interrupt is requested.

4. The A/D interrupt handling routine starts.

5. The routine reads ADCSR, then writes 0 in the ADF flag.

6. The routine reads and processes the conversion result (ADDRB).

7. Execution of the A/D interrupt handling routine ends. After that, if the ADST bit is set to 1, A/D conversion starts again and steps 2 to 7 are repeated.

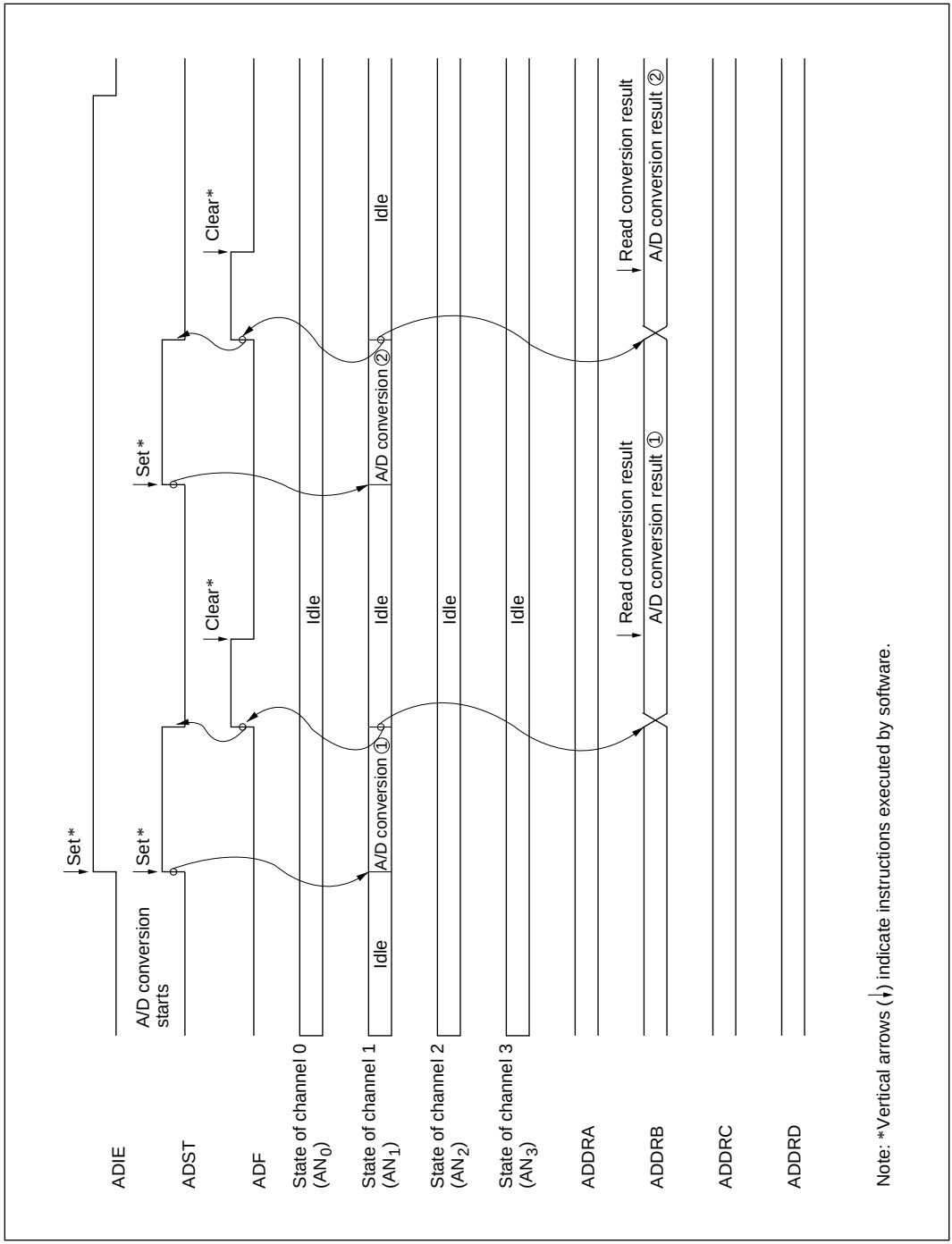


Figure 14-3 Example of A/D Converter Operation (Single Mode, Channel 1 Selected)

14.4.2 Scan Mode (SCAN = 1)

Scan mode is useful for monitoring analog inputs in a group of one or more channels. When the ADST bit is set to 1 by software or external trigger input, A/D conversion starts on the first channel in the group (AN_0 when CH2 = 0, AN_4 when CH2 = 1). When two or more channels are selected, after conversion of the first channel ends, conversion of the second channel (AN_1 or AN_5) starts immediately. A/D conversion continues cyclically on the selected channels until the ADST bit is cleared to 0. The conversion results are transferred for storage into the A/D data registers corresponding to the channels.

When the mode or analog input channel selection must be changed during analog conversion, to prevent incorrect operation, first clear the ADST bit to 0 in ADCSR to halt A/D conversion. After making the necessary changes, set the ADST bit to 1. A/D conversion will start again from the first channel in the group. The ADST bit can be set at the same time as the mode or channel selection is changed.

Typical operations when three channels in group 0 (AN_0 to AN_2) are selected in scan mode are described next. Figure 14-4 shows a timing diagram for this example.

1. Scan mode is selected (SCAN = 1), scan group 0 is selected (CH2 = 0), analog input channels AN_0 to AN_2 are selected (CH1 = 1, CH0 = 0), and A/D conversion is started (ADST = 1).

2. When A/D conversion of the first channel (AN_0) is completed, the result is transferred into ADDRA. Next, conversion of the second channel (AN_1) starts automatically.

3. Conversion proceeds in the same way through the third channel (AN_2).

4. When conversion of all selected channels (AN_0 to AN_2) is completed, the ADF flag is set to 1 and conversion of the first channel (AN_0) starts again. If the ADIE bit is set to 1, an ADI interrupt is requested at this time.

5. Steps 2 to 4 are repeated as long as the ADST bit remains set to 1. When the ADST bit is cleared to 0, A/D conversion stops. After that, if the ADST bit is set to 1, A/D conversion starts again from the first channel (AN_0).

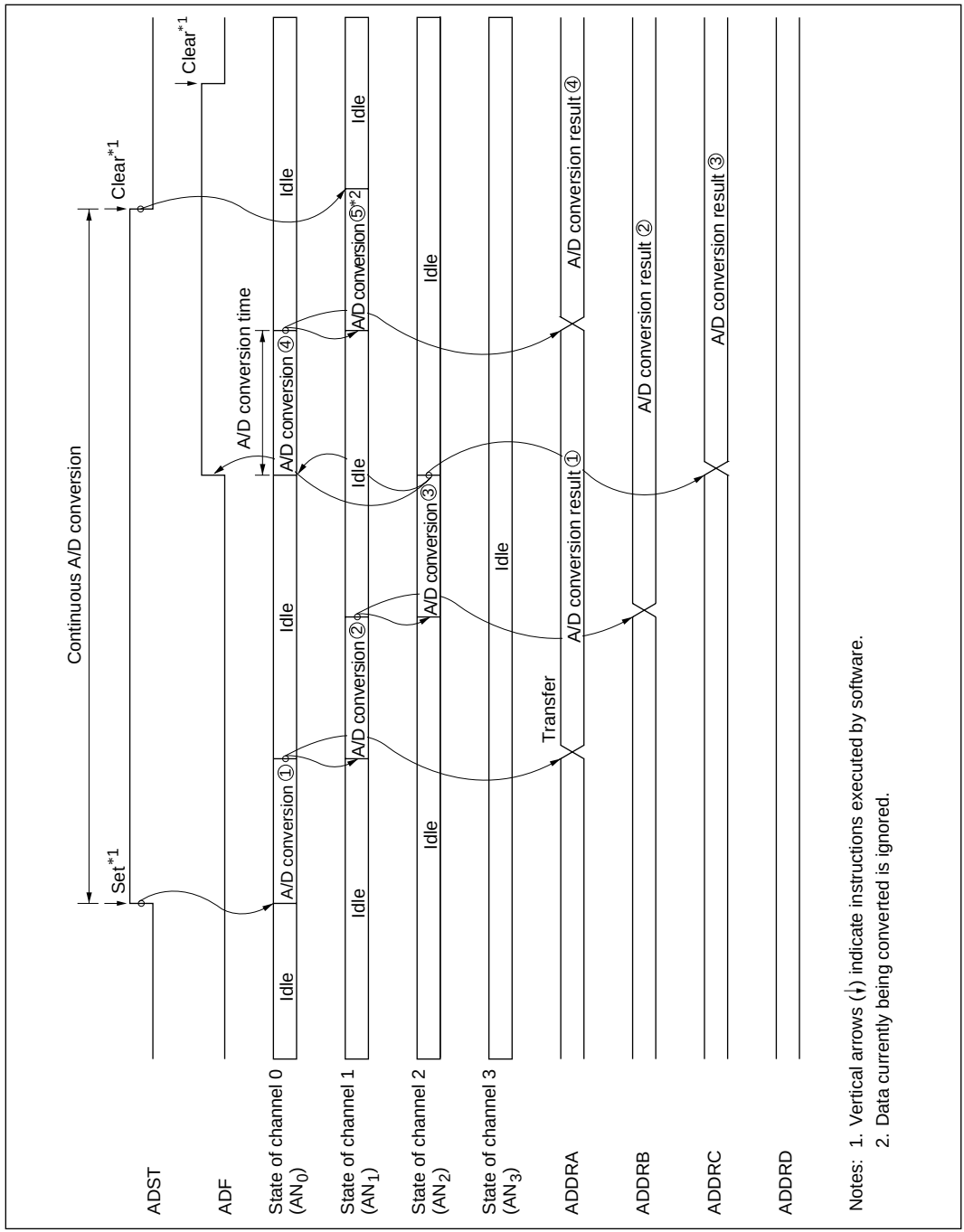


Figure 14-4 Example of A/D Converter Operation (Scan Mode, Channels AN_0 to AN_2 Selected)

14.4.3 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 a time t_D after the ADST bit is set to 1, then starts conversion. Figure 14-5 shows the A/D conversion timing. Table 14-4 indicates the A/D conversion time.

As indicated in figure 14-5, the A/D conversion time includes t_D and the input sampling time. 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 14-4.

In scan mode, the values given in table 14-4 apply to the first conversion. In the second and subsequent conversions the conversion time is fixed at 256 states when CKS = 0 or 128 states when CKS = 1.

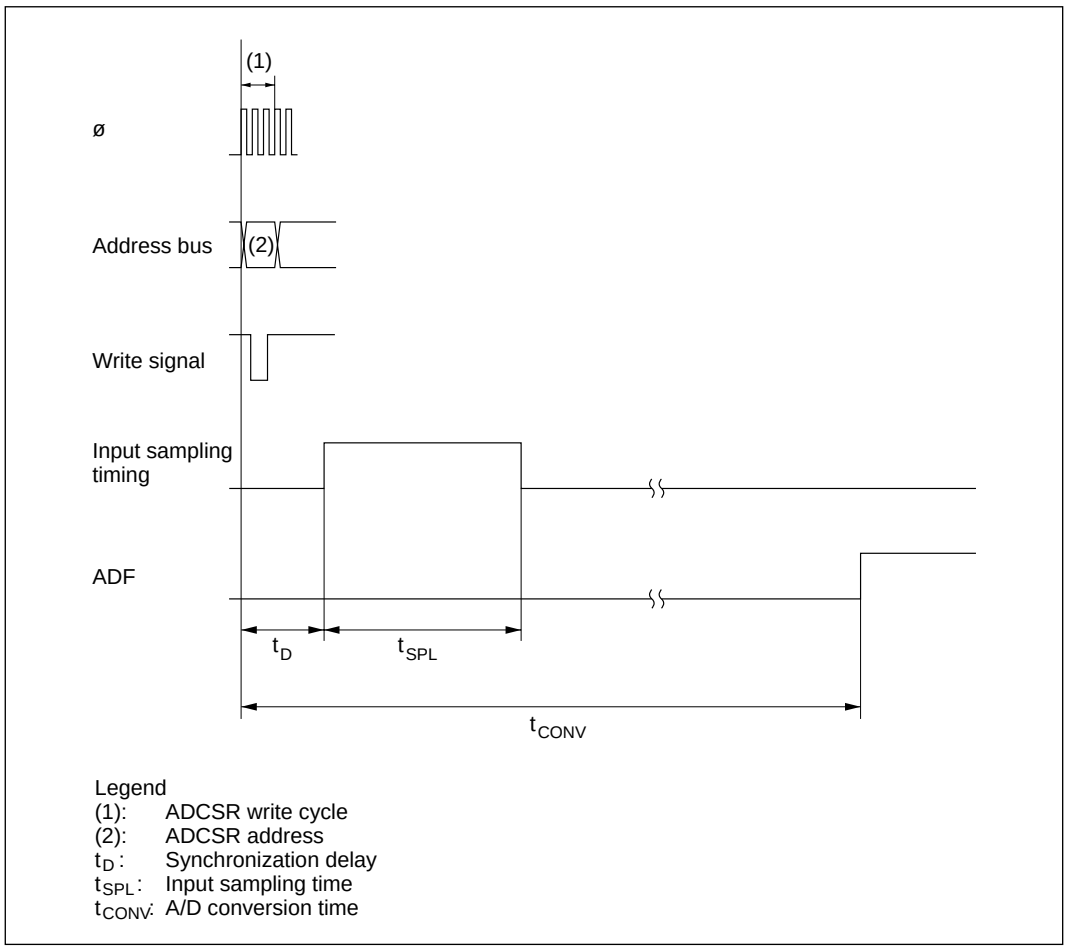


Figure 14-5 A/D Conversion Timing

Table 14-4 A/D Conversion Time (Single Mode)

		CKS = 0			CKS = 1		
	Symbol	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**
Synchronization delay	t_D	10	—	17	6	—	9
Input sampling time	t_{SPL}	—	80	—	—	40	—
A/D conversion time	t_{CONV}	259	—	266	131	—	134

Note: Values in the table are numbers of states.

14.4.4 External Trigger Input Timing

A/D conversion can be externally triggered. When the TRGE bit is set to 1 in ADCR, external trigger input is enabled at the $\overline{\text{ADTRG}}$ pin. A high-to-low transition at the $\overline{\text{ADTRG}}$ pin sets the ADST bit to 1 in ADCSR, starting A/D conversion. Other operations, in both single and scan modes, are the same as if the ADST bit had been set to 1 by software. Figure 14-6 shows the timing.

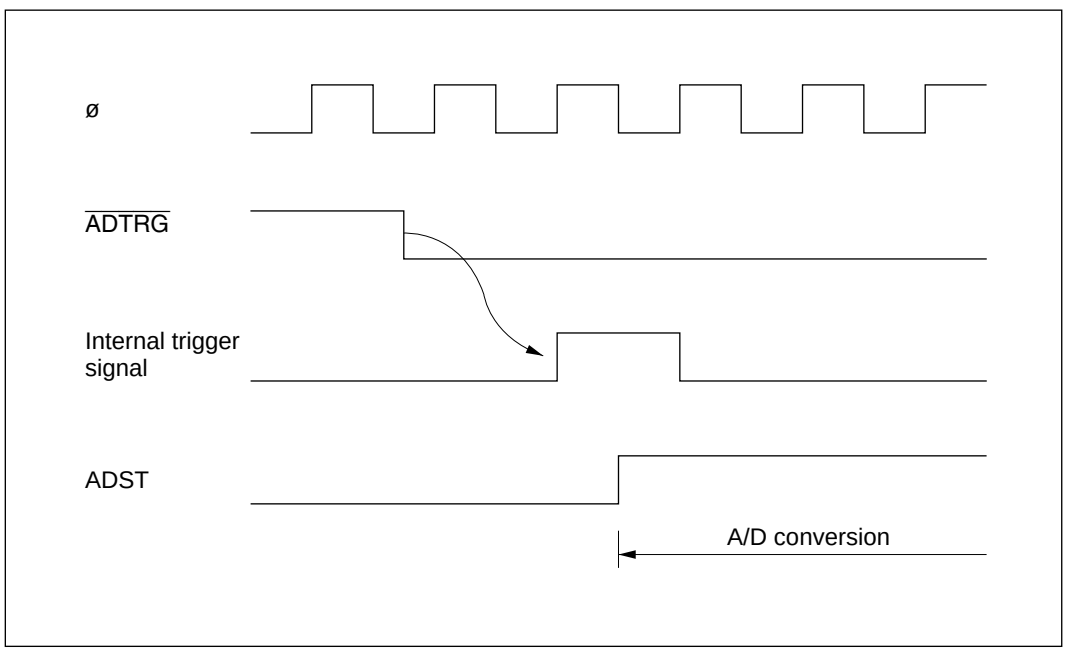


Figure 14-6 External Trigger Input Timing

14.5 Interrupts

The A/D converter generates an interrupt (ADI) at the end of A/D conversion. The ADI interrupt request can be enabled or disabled by the ADIE bit in ADCSR.

14.6 Usage Notes

When using the A/D converter, note the following points:

Analog Input Voltage Range: During A/D conversion, the voltages input to the analog input pins AN_n should be in the range $AV_{SS} \leq AN_n \leq V_{REF}$. (n = 0 to 7)

AV_{CC} and AV_{SS} Input Voltages: AV_{SS} should have the following values: $AV_{SS} = V_{SS}$.
If the A/D converter is not used, the values should be $AV_{CC} = V_{CC}$ and $AV_{SS} = V_{SS}$.

V_{REF} Input Range: The analog reference voltage input at the V_{REF} pin should be in the range $V_{REF} \leq AV_{CC}$. If the A/D converter is not used, the value should be $V_{REF} = V_{CC}$.

Section 15 RAM

15.1 Overview

The H8/3003 has 512 bytes of on-chip static RAM. The RAM is connected to the CPU by a 16-bit data bus. The CPU accesses both byte data and word data in two states, making the RAM suitable for rapid data transfer.

The on-chip RAM is assigned to addresses H'FFD10 to H'FFF0F in modes 1 and 2, and addresses H'FFFD10 to H'FFFF0F in modes 3 and 4. The RAM enable bit (RAME) in the system control register (SYSCR) can enable or disable the on-chip RAM.

15.1.1 Block Diagram

Figure 15-1 shows a block diagram of the on-chip RAM.

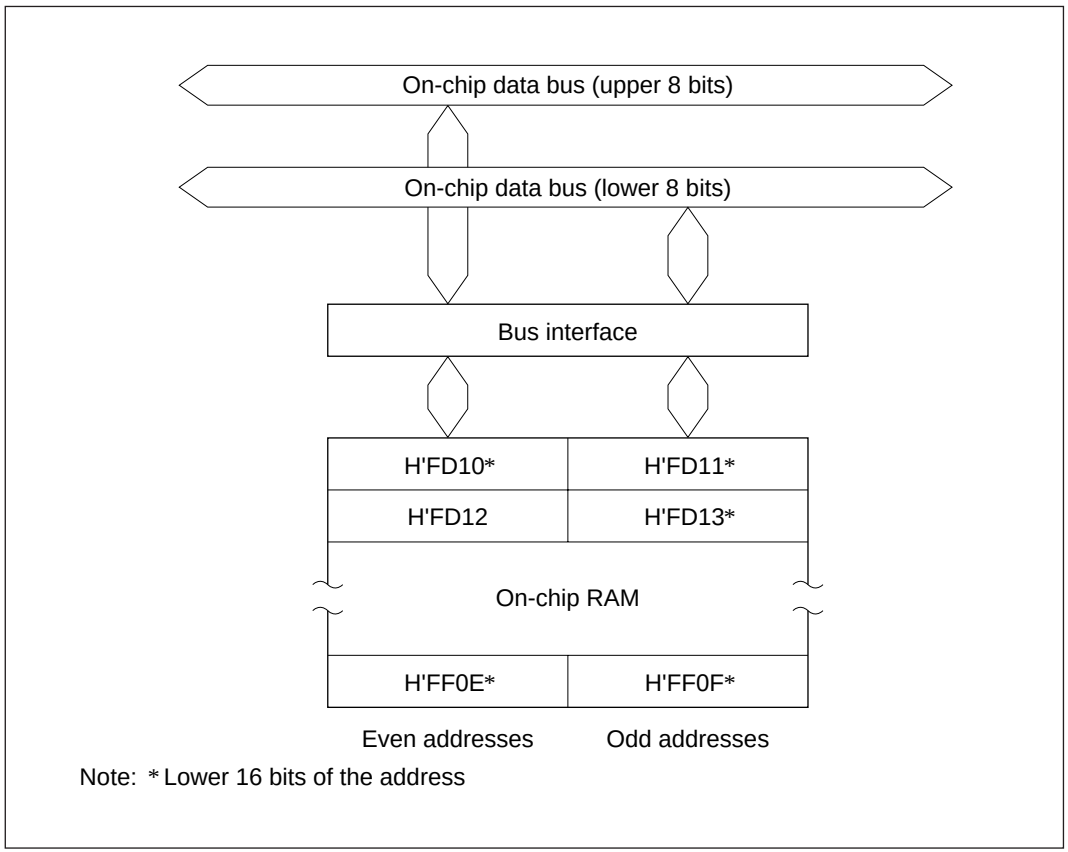


Figure 15-1 RAM Block Diagram

15.1.2 Register Configuration

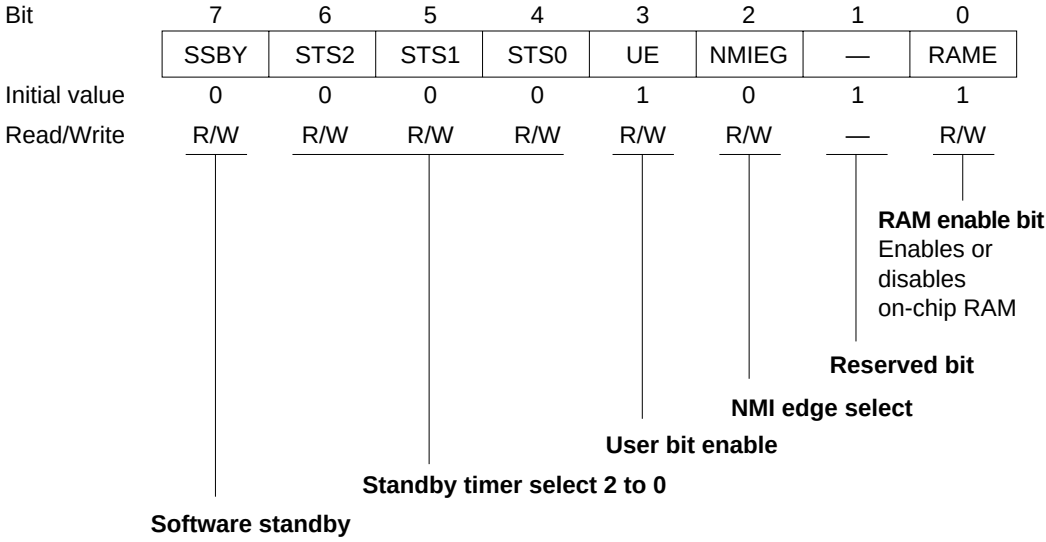
The on-chip RAM is controlled by the system control register (SYSCR). Table 15-1 gives the address and initial value of SYSCR.

Table 15-1 RAM Control Register

Address*	Name	Abbreviation	R/W	Initial Value
H'FFF2	System control register	SYSCR	R/W	H'0B

Note: * Lower 16 bits of the address

15.2 System Control Register (SYSCR)



One function of SYSCR is to enable or disable access to the on-chip RAM. The on-chip RAM is enabled or disabled by the RAME bit in SYSCR. For details about the other bits, see section 3.3, System Control Register.

Bit 0—RAM Enable (RAME): Enables or disables the on-chip RAM. The RAME bit is initialized at the rising edge of the input at the $\overline{\text{RES}}$ pin. It is not initialized in software standby mode.

Bit 0 RAME	Description	
0	On-chip RAM is disabled	
1	On-chip RAM is enabled	(Initial value)

15.3 Operation

When the RAME bit is set to 1, accesses to addresses H'FFD10 to H'FFF0F in modes 1 and 2, and to addresses H'FFFD10 to H'FFFF0F in modes 3 and 4, are directed to the on-chip RAM. When the RAME bit is cleared to 0, the off-chip address space is accessed.

Since the on-chip RAM is connected to the CPU by an internal 16-bit data bus, it can be written and read by word access. It can also be written and read by byte access. Byte data is accessed in two states using the upper 8 bits of the data bus. Word data starting at an even address is accessed in two states using all 16 bits of the data bus.

Section 16 Clock Pulse Generator

16.1 Overview

The H8/3003 has a built-in clock pulse generator (CPG) that generates the system clock (ø) and other internal clock signals (ø/2 to ø/4096).

The H8/3003 is available in a clock-halving version and a 1:1 version, which have different clock pulse generator configurations. The clock pulse generator of the clock-halving version consists of an oscillator circuit, a system clock divider, and prescalers for the on-chip supporting modules. The clock pulse generator of the 1:1 version consists of an oscillator circuit, a duty adjustment circuit, and the prescalers.

16.1.1 Block Diagram

Figure 16-1 shows block diagrams of the clock pulse generator.

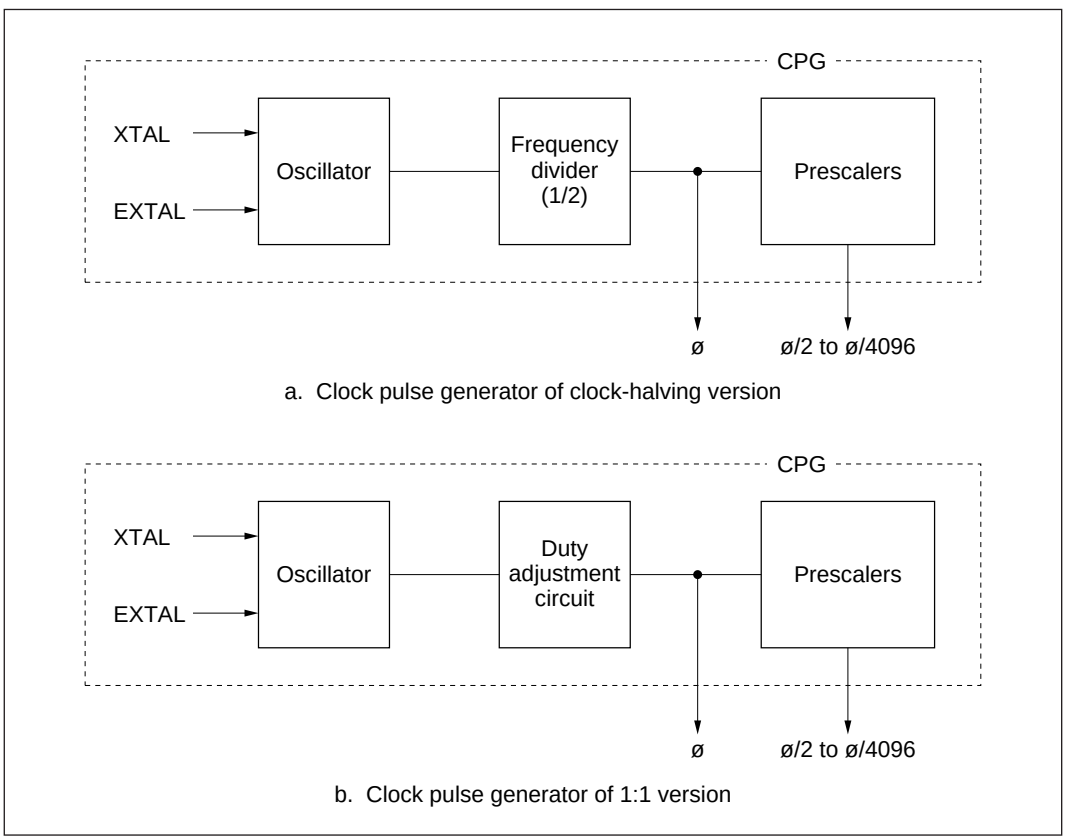


Figure 16-1 Block Diagram of Clock Pulse Generator

16.2 Oscillator Circuit

Clock pulses can be supplied by connecting a crystal resonator, or by input of an external clock signal.

16.2.1 Connecting a Crystal Resonator

Circuit Configuration: A crystal resonator can be connected as in the example in figure 16-2. The damping resistance Rd should be selected according to table 16-1. An AT-cut parallel-resonance crystal should be used.

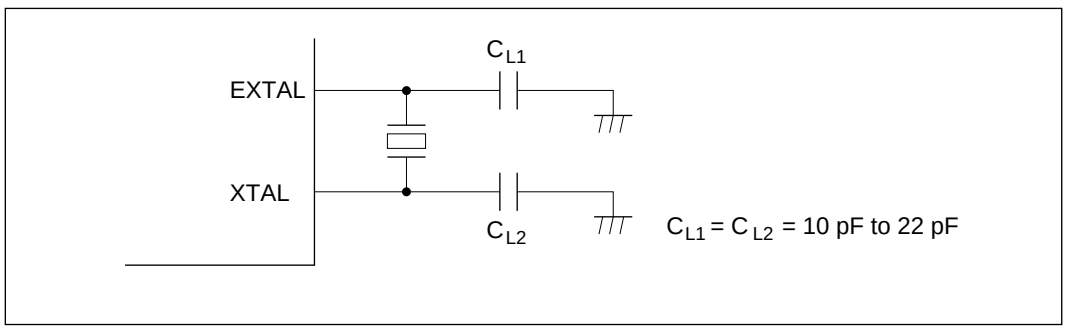


Figure 16-2 Connection of Crystal Resonator (Example)

Table 16-1 Damping Resistance Value

Frequency (MHz)	2	4	8	10	12	16	20	24
Rd (Ω)	1 k	500	200	70	0	0	0	0

Crystal Resonator: Figure 16-3 shows an equivalent circuit of the crystal resonator. The crystal resonator should have the characteristics listed in table 16-2.

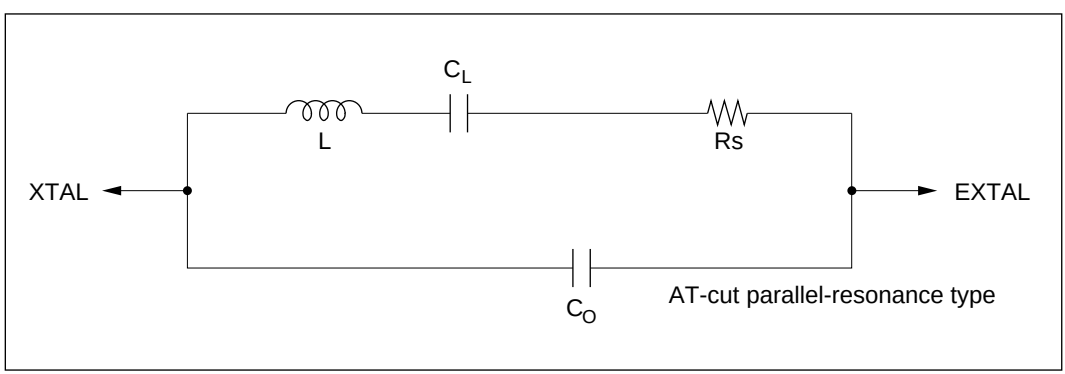


Figure 16-3 Crystal Resonator Equivalent Circuit

Table 16-2 Crystal Resonator Parameters

Frequency (MHz)	2	4	8	10	12	16	20	24
Rs max (Ω)	500	120	80	70	60	50	40	40
Co (pF)	7 pF max							

Clock-Halving Version: Use a crystal resonator with a frequency equal to twice the system clock frequency (ø).

1:1 Version: Use a crystal resonator with a frequency equal to the system clock frequency (ø).

Notes on Board Design: When a crystal resonator is connected, the following points should be noted:

Other signal lines should be routed away from the oscillator circuit to prevent induction from interfering with correct oscillation. See figure 16-4.

When the board is designed, the crystal resonator and its load capacitors should be placed as close as possible to the XTAL and EXTAL pins.

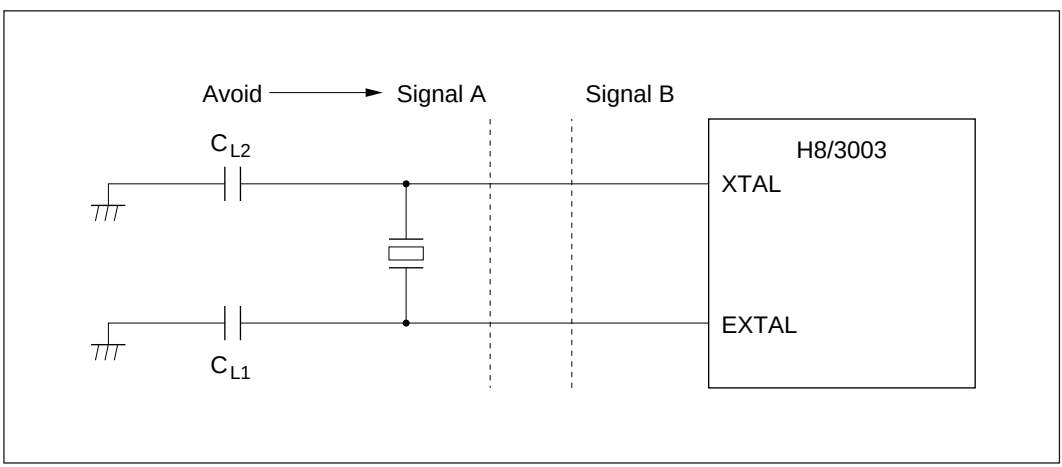


Figure 16-4 Example of Incorrect Board Design

16.2.2 External Clock Input

Circuit Configuration: An external clock signal can be input as shown in the examples in figure 16-5. In example b, the clock should be held high in standby mode.

If the XTAL pin is left open, the stray capacitance should be 10 pF.

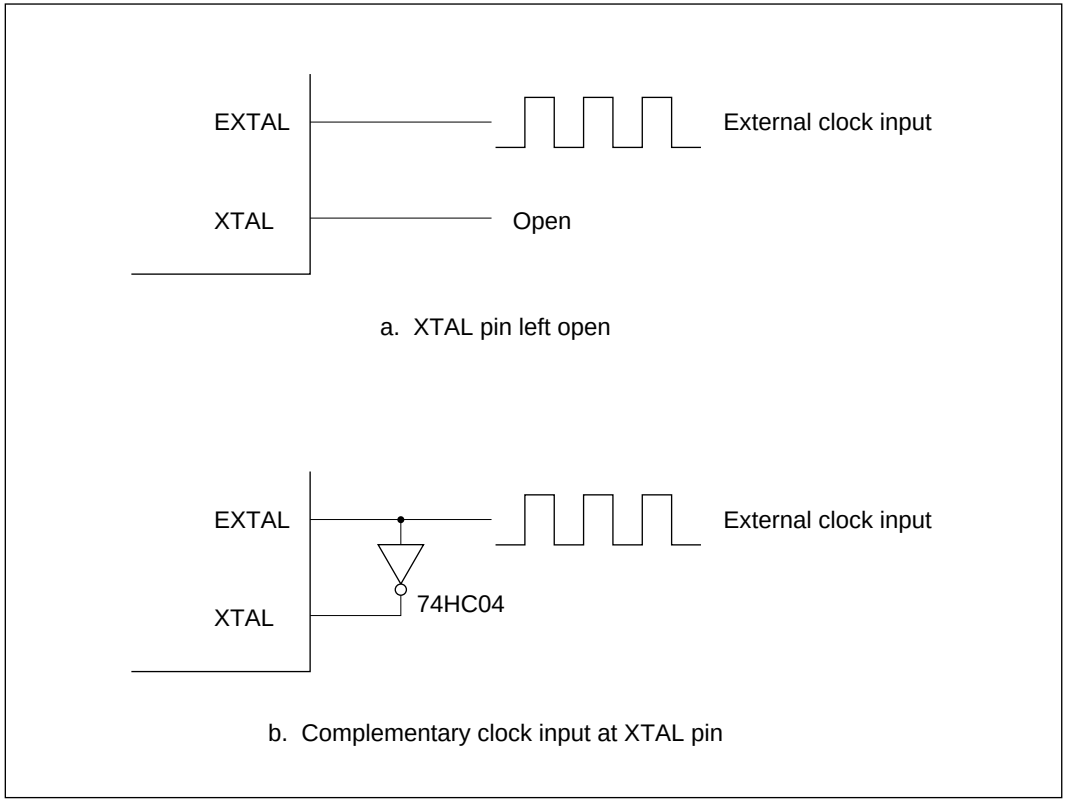


Figure 16-5 External Clock Input (Examples)

External Clock

- Clock-halving version

  The external clock signal should have a frequency equal to twice the system clock frequency (ø) and a duty cycle of 40% to 60%.

- 1:1 version

  The external clock frequency should be equal to the system clock frequency (ø). Table 16-3 and figure 16-6 indicate the clock timing.

Table 16-3 Clock Timing

		V_{CC} = 2.7 to 5.5 V		V_{CC} = 5.0 V ± 10%				
Item	**Symbol**	**Min**	**Max**	**Min**	**Max**	**Unit**	**Test Conditions**	
External clock rise time	t_{EXr}	—	10	—	5	ns		
External clock fall time	t_{EXf}	—	10	—	5	ns		
External clock input duty (a/t_{cyc})	—	30	70	30	70	%	ø ≥ 5 MHz	Figure 16-6
		40	60	40	60	%	ø < 5 MHz	
ø clock width duty (b/t_{cyc})	—	40	60	40	60	%		

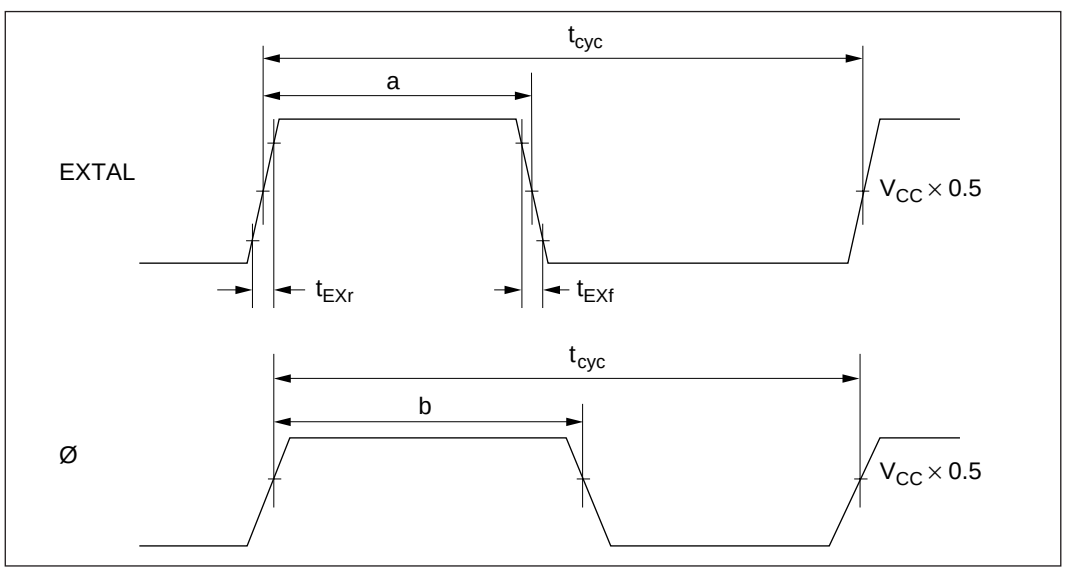


Figure 16-6 External Clock Input Timing

16.3 System Clock Divider (Clock-Halving Version)

The system clock divider divides the oscillator output by 2 to generate the system clock (ø).

16.4 Duty Adjustment Circuit (1:1 Version)

When the oscillator frequency is 5 MHz or higher, the duty adjustment circuit adjusts the duty cycle of the clock signal from the oscillator to generate a system clock (ø).

16.5 Prescalers

The prescalers divide the system clock (ø) to generate internal clocks (ø/2 to ø/4096).

Section 17 Power-Down State

17.1 Overview

The H8/3003 has a power-down state that greatly reduces power consumption by halting CPU functions. The power-down state includes the following three modes:

- Sleep mode
- Software standby mode
- Hardware standby mode

Table 17-1 indicates the methods of entering and exiting these power-down modes and the status of the CPU and on-chip supporting modules in each mode.

Table 17-1 Power-Down State

		State								
Mode	**Entering Conditions**	**Clock**	**CPU**	**CPU Registers**	**DMAC**	**Refresh Controller**	**Supporting Functions**	**RAM**	**I/O Ports**	**Exiting Conditions**
Sleep mode	SLEEP instruction executed while SSBY = 0 in SYSCR	Active	Halted	Held	Active	Active	Active	Held	Held	• Interrupt • $\overline{\text{RES}}$ • $\overline{\text{STBY}}$
Software standby mode	SLEEP instruction executed while SSBY = 1 in SYSCR	Halted	Halted	Held	Halted and reset	Halted and held*1	Halted and reset	Held	Held	• NMI • $\overline{\text{IRQ}_0}$ to $\overline{\text{IRQ}_2}$ • $\overline{\text{RES}}$ • $\overline{\text{STBY}}$
Hardware standby mode	Low input at $\overline{\text{STBY}}$ pin	Halted	Halted	Undetermined	Halted and reset	Halted and reset	Halted and reset	Held*2	High impedance	• $\overline{\text{STBY}}$ • $\overline{\text{RES}}$

Notes: 1. The refresh timer counter (RTCNT) and bits 7 and 6 of the refresh timer control/status register (RTMCSR) are initialized. Other bits and registers hold their previous states.
2. The RAME bit must be cleared to 0 in SYSCR before the transition from the program execution state to hardware standby mode.

Legend
SYSCR: System control register
SSBY: Software standby bit

17.2 Register Configuration

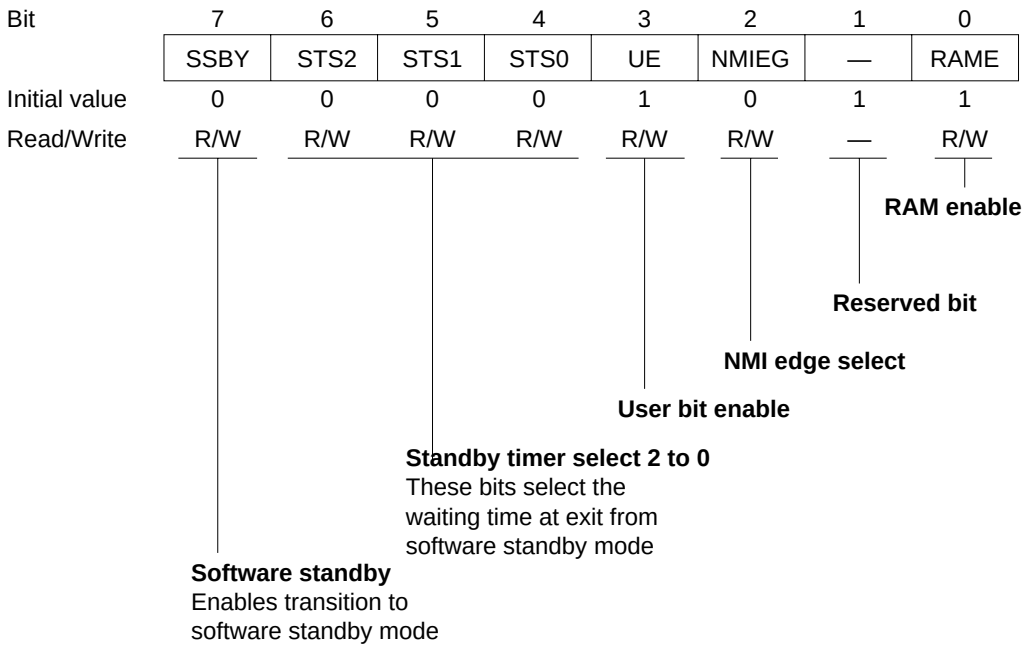
The H8/3003's system control register (SYSCR) controls the power-down state. Table 17-2 summarizes this register.

Table 17-2 Control Register

Address*	Name	Abbreviation	R/W	Initial Value
H'FFF2	System control register	SYSCR	R/W	H'0B

Note: * Lower 16 bits of the address.

17.2.1 System Control Register (SYSCR)



SYSCR is an 8-bit readable/writable register. Bit 7 (SSBY) and bits 6 to 4 (STS2 to STS0) control the power-down state. For information on the other SYSCR bits, see section 3.3, System Control Register.

Bit 7—Software Standby (SSBY): Enables transition to software standby mode. When software standby mode is exited by an external interrupt, this bit remains set to 1 after the return to normal operation. To clear this bit, write 0.

Bit 7 SSBY	Description	
0	SLEEP instruction causes transition to sleep mode	(Initial value)
1	SLEEP instruction causes transition to software standby mode	

Bits 6 to 4—Standby Timer Select (STS2 to STS0): These bits select the length of time the CPU and on-chip supporting modules wait for the clock to settle when software standby mode is exited by an external interrupt. If the clock is generated by a crystal resonator, set these bits according to the clock frequency so that the waiting time will be at least 8 ms. See table 17-3. If an external clock is used, any setting is permitted.

Bit 6 STS2	Bit 5 STS1	Bit 4 STS0	Description	
0	0	0	Waiting time = 8192 states	(Initial value)
		1	Waiting time = 16384 states	
	1	0	Waiting time = 32768 states	
		1	Waiting time = 65536 states	
1	0	—	Waiting time = 131072 states	
	1	—	Waiting time = 4 states*	

Note: * Do not use this setting for the 1:1 clock version.

17.3 Sleep Mode

17.3.1 Transition to Sleep Mode

When the SSBY bit is cleared to 0 in the system control register (SYSCR), execution of the SLEEP instruction causes a transition from the program execution state to sleep mode. Immediately after executing the SLEEP instruction the CPU halts, but the contents of its internal registers are retained. The DMA controller (DMAC), refresh controller, and on-chip supporting modules do not halt in sleep mode.

17.3.2 Exit from Sleep Mode

Sleep mode is exited by an interrupt, or by input at the $\overline{\text{RES}}$ or $\overline{\text{STBY}}$ pin.

Exit by Interrupt: An interrupt terminates sleep mode and causes a transition to the interrupt exception handling state. Sleep mode is not exited by an interrupt source in an on-chip supporting module if the interrupt is disabled in the on-chip supporting module. Sleep mode is not exited by an interrupt other than NMI if the interrupt is masked by IPR and the I and UI bits in CCR.

Exit by $\overline{\text{RES}}$ Input: Low input at the $\overline{\text{RES}}$ pin exits from sleep mode to the reset state.

Exit by $\overline{\text{STBY}}$ Input: Low input at the $\overline{\text{STBY}}$ pin exits from sleep mode to hardware standby mode.

17.4 Software Standby Mode

17.4.1 Transition to Software Standby Mode

To enter software standby mode, execute the SLEEP instruction while the SSBY bit is set to 1 in SYSCR.

In software standby mode, current dissipation is reduced to an extremely low level because the CPU, clock, and on-chip supporting modules all halt. The DMAC and on-chip supporting modules are reset. As long as the specified voltage is supplied, however, CPU register contents and on-chip RAM data are retained. The settings of the I/O ports and refresh controller* are also held.

Note: * The refresh timer counter (RTCNT) and bits 7 and 6 of the refresh timer control/status register (RTMCSR) are initialized. Other bits and registers hold their previous states.

17.4.2 Exit from Software Standby Mode

Software standby mode can be exited by input of an external interrupt at the NMI, $\overline{IRQ_0}$, $\overline{IRQ_1}$, or $\overline{IRQ_2}$ pin, or by input at the $\overline{RES}$ or $\overline{STBY}$ pin.

Exit by Interrupt: When an NMI, IRQ_0, IRQ_1, or IRQ_2 interrupt request signal is received, the clock oscillator begins operating. After the oscillator settling time selected by bits STS2 to STS0 in SYSCR, stable clock signals are supplied to the entire H8/3003 chip, software standby mode ends, and interrupt exception handling begins. Software standby mode is not exited if the interrupt enable bits of interrupts IRQ_0, IRQ_1, and IRQ_2 are cleared to 0, or if these interrupts are masked in the CPU.

Exit by $\overline{\text{RES}}$ Input: When the $\overline{RES}$ input goes low, the clock oscillator starts and clock pulses are supplied immediately to the entire H8/3003 chip. The $\overline{RES}$ signal must be held low long enough for the clock oscillator to stabilize. When $\overline{RES}$ goes high, the CPU starts reset exception handling.

Exit by $\overline{\text{STBY}}$ Input: Low input at the $\overline{STBY}$ pin causes a transition to hardware standby mode.

17.4.3 Selection of Waiting Time for Exit from Software Standby Mode

Bits STS2 to STS0 in SYSCR should be set as follows.

Crystal Resonator: Set STS2 to STS0 so that the waiting time (for the clock to stabilize) is at least 8 ms. Table 17-3 indicates the waiting times that are selected by STS2 to STS0 settings at various system clock frequencies.

External Clock: Any value may be set in the clock-halving version. Normally the minimum value (STS2 = STS1 = STS0 = 1) is recommended. In the 1:1 clock version, any value other than the minimum value may be set.

Table 17-3 Clock Frequency and Waiting Time for Clock to Settle

STS2	STS1	STS0	Waiting Time	16 MHZ	12 MHz	10 MHz	8 MHz	6 MHz	4 MHz	2 MHz	Unit
0	0	0	8192 states	0.51	0.65	0.8	1.0	1.3	2.0	4.1	ms
0	0	1	16384 states	1.0	1.3	1.6	2.0	2.7	4.1	[8.2]	
0	1	0	32768 states	2.0	2.7	3.3	4.1	5.5	[8.2]	16.4	
0	1	1	65536 states	4.1	5.5	6.6	[8.2]	[10.9]	16.4	32.8	
1	0	—	131072 states	[8.2]	[10.9]	[13.1]	16.4	21.8	32.8	65.5	
1	1	—	4 states*	0.25	0.33	0.4	0.5	0.67	1.0	2.0	µs

[ ]: Recommended setting

Note: * This setting cannot be used in the 1:1 clock version.

17.4.4 Sample Application of Software Standby Mode

Figure 17-1 shows an example in which software standby mode is entered at the fall of NMI and exited at the rise of NMI.

With the NMI edge select bit (NMIEG) cleared to 0 in SYSCR (selecting the falling edge), an NMI interrupt occurs. Next the NMIEG bit is set to 1 (selecting the rising edge) and the SSBY bit is set to 1; then the SLEEP instruction is executed to enter software standby mode.

Software standby mode is exited at the next rising edge of the NMI signal .

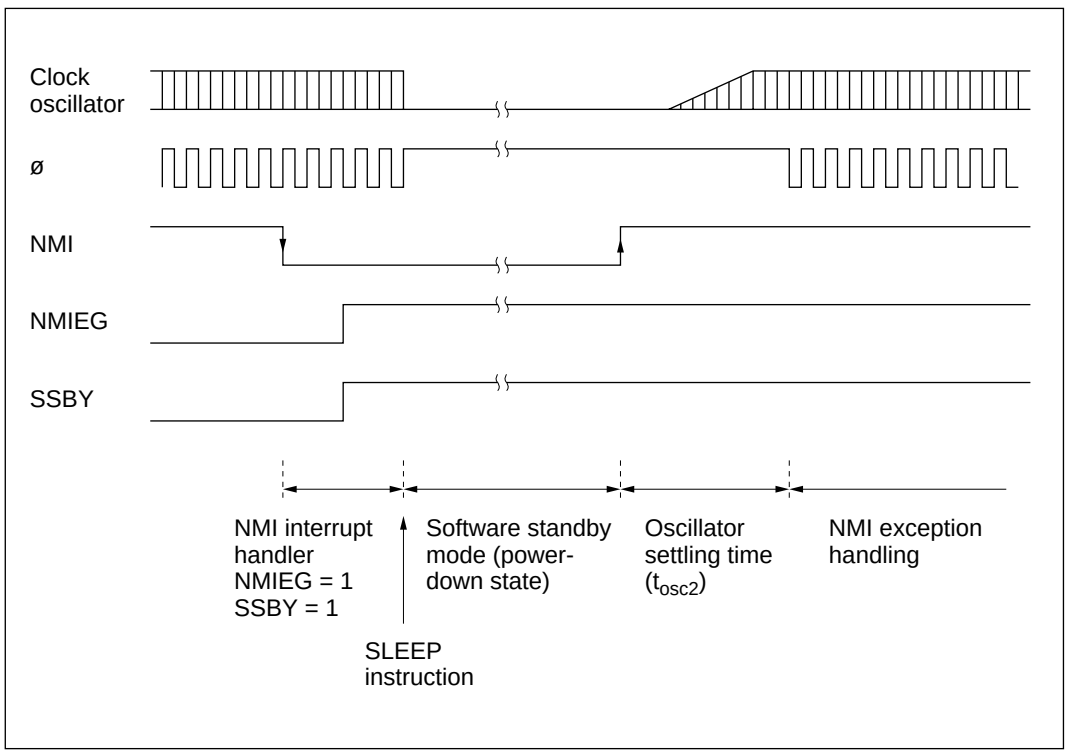


Figure 17-1 NMI Timing for Software Standby Mode (Example)

17.4.5 Note

The I/O ports retain their existing states in software standby mode. If a port is in the high output state, its output current is not reduced.

17.5 Hardware Standby Mode

17.5.1 Transition to Hardware Standby Mode

Regardless of its current state, the chip enters hardware standby mode whenever the $\overline{\text{STBY}}$ pin goes low. Hardware standby mode reduces power consumption drastically by halting all functions of the CPU, DMAC, refresh controller, and on-chip supporting modules. All modules are reset except the on-chip RAM. As long as the specified voltage is supplied, on-chip RAM data is retained*. I/O ports are placed in the high-impedance state.

The inputs at the mode pins (MD2 to MD0) should not be changed during hardware standby mode.

Note: * Clear the RAME bit to 0 in SYSCR before $\overline{\text{STBY}}$ goes low to retain on-chip RAM data.

17.5.2 Exit from Hardware Standby Mode

Hardware standby mode is exited by inputs at the $\overline{\text{STBY}}$ and $\overline{\text{RES}}$ pins. While $\overline{\text{RES}}$ is low, when $\overline{\text{STBY}}$ goes high, the clock oscillator starts running. $\overline{\text{RES}}$ should be held low long enough for the clock oscillator to settle. When $\overline{\text{RES}}$ goes high, reset exception handling begins, followed by a transition to the program execution state.

17.5.3 Timing for Hardware Standby Mode

Figure 17-2 shows the timing relationships for hardware standby mode. To enter hardware standby mode, first drive $\overline{\text{RES}}$ low, then drive $\overline{\text{STBY}}$ low. To exit hardware standby mode, first drive $\overline{\text{STBY}}$ high, wait for the clock to settle, then bring $\overline{\text{RES}}$ from low to high.

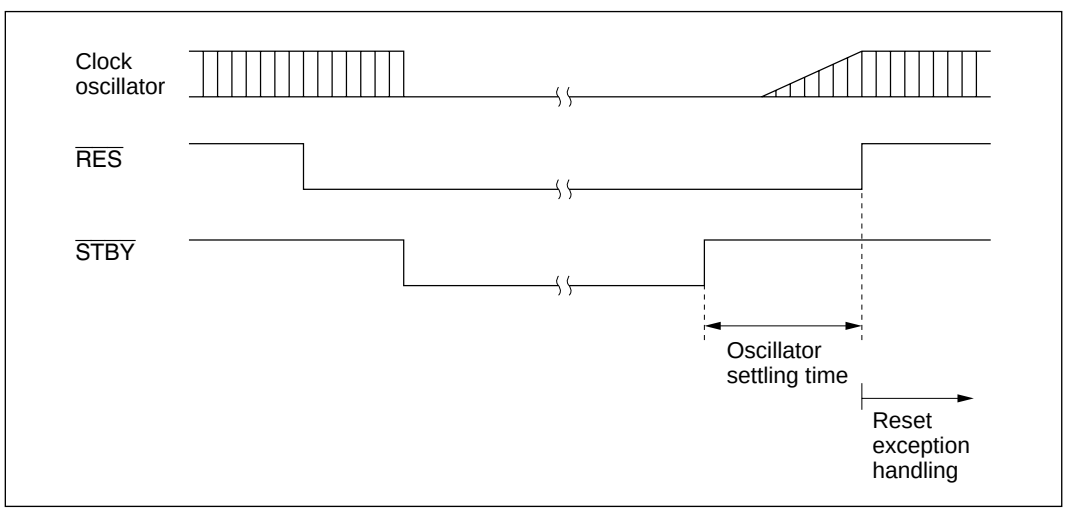


Figure 17-2 Hardware Standby Mode Timing

Section 18 Electrical Characteristics

18.1 Absolute Maximum Ratings

Table 18-1 lists the absolute maximum ratings.

Table 18-1 Absolute Maximum Ratings

Item	Symbol	Value	Unit
Power supply voltage	V_{CC}	–0.3 to +7.0	V
Input voltage (except port 7)	V_{IN}	–0.3 to V_{CC} +0.3	V
Input voltage (port 7)	V_{IN}	–0.3 to AV_{CC} +0.3	V
Reference voltage	V_{REF}	–0.3 to AV_{CC} +0.3	V
Analog power supply voltage	AV_{CC}	–0.3 to +7.0	V
Analog input voltage	V_{AN}	–0.3 to AV_{CC} +0.3	V
Operating temperature	T_{opr}	Regular specifications: –20 to +75	°C
Storage temperature	T_{stg}	Wide-range specifications: –40 to +85	°C
		–55 to +125	°C

Caution: Permanent damage to the chip may result if absolute maximum ratings are exceeded.

18.2 Electrical Characteristics

18.2.1 DC Characteristics

Table 18-2 lists the DC characteristics. Table 18-3 lists the permissible output currents.

Table 18-2 DC Characteristics

Conditions: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC},
V_{SS} = AV_{SS} = 0 V*, T_a = –20°C to +75°C (regular specifications),
T_a = –40°C to +85°C (wide-range specifications)

Item		Symbol	Min	Typ	Max	Unit	Test Conditions
Schmitt trigger input voltages	Port A,	V_T^-	1.0	—	—	V	
	$P8_0$ to $P8_2$,	V_T^+	—	—	$V_{CC} \times 0.7$	V	
	PB_0 to PB_3	$V_T^+ - V_T^-$	0.4	—	—	V	
Input high voltage	$\overline{RES}$, $\overline{STBY}$, NMI, MD_2 to MD_0	V_{IH}	V_{CC} – 0.7	—	V_{CC} + 0.3	V	
	EXTAL		$V_{CC} \times 0.7$	—	V_{CC} + 0.3	V	
	Port 7		2.0	—	AV_{CC} + 0.3	V	
	Ports 4, 5, 6, 9, C, $P8_3$, $P8_4$, PB_4 to PB_7, D_{15} to D_8		2.0	—	V_{CC} + 0.3	V	
Input low voltage	$\overline{RES}$, $\overline{STBY}$, MD_2 to MD_0	V_{IL}	–0.3	—	0.5	V	
	NMI, EXTAL, ports 4, 5, 6, 7, 9, C, $P8_3$, $P8_4$, PB_4 to PB_7, D_{15} to D_8		–0.3	—	0.8	V	
Output high voltage	All output pins	V_{OH}	V_{CC} – 0.5	—	—	V	I_{OH} = –200 µA
			3.5	—	—	V	I_{OH} = –1 mA

Note: * If the A/D converter is not used, do not leave the AV_{CC}, AV_{SS}, and V_{REF} pins open. Connect AV_{CC} and V_{REF} to V_{CC}, and connect AV_{SS} to V_{SS}.

Table 18-2 DC Characteristics (cont)

Conditions: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC} ,
V_{SS} = AV_{SS} = 0 V*1, T_a = –20°C to +75°C (regular specifications),
T_a = –40°C to +85°C (wide-range specifications)

Item		Symbol	Min	Typ	Max	Unit	Test Conditions
Output low voltage	All output pins (except $\overline{RESO}$)	V_{OL}	—	—	0.4	V	I_{OL} = 1.6 mA
	Ports 5 and B, A_{19} to A_0		—	—	1.0	V	I_{OL} = 10 mA
	$\overline{RESO}$		—	—	0.4	V	I_{OL} = 2.6 mA
Input leakage current	$\overline{STBY}$, NMI, $\overline{RES}$, MD_2 to MD_0	$\|I_{IN}\|$	—	—	1.0	µA	V_{IN} = 0.5 to V_{CC} – 0.5 V
	Port 7		—	—	1.0	µA	V_{IN} = 0.5 to AV_{CC} – 0.5 V
Three-state leakage current (off state)	Ports 4, 5, 6, 8 to C, A_{19} to A_0, D_{15} to D_8	$\|I_{TS1}\|$	—	—	1.0	µA	V_{IN} = 0.5 to V_{CC} – 0.5 V
	$\overline{RESO}$		—	—	10.0	µA	V_{IN} = 0.5 to V_{CC} – 0.5 V
Input pull-up current	Ports 4 and 5	$–I_P$	50	—	300	µA	V_{IN} = 0 V
Input capacitance	NMI	C_{IN}	—	—	50	pF	V_{IN} = 0 V f = 1 MHz T_a = 25°C
	All input pins except NMI		—	—	15		
Current dissipation*2	Normal operation	I_{CC}	—	35	55	mA	f = 10 MHz
			—	40	65	mA	f = 12 MHz
			—	50	80	mA	f = 16 MHz
	Sleep mode		—	25	40	mA	f = 10 MHz
			—	30	45	mA	f = 12 MHz
			—	35	60	mA	f = 16 MHz
	Standby mode*3		—	0.01	5.0	µA	$T_a \leq$ 50°C
			—	—	20.0	µA	50°C < T_a

Notes: 1. If the A/D converter is not used, do not leave the AV_{CC}, AV_{SS}, and V_{REF} pins open. Connect AV_{CC} and V_{REF} to V_{CC}, and connect AV_{SS} to V_{SS}.
2. Current dissipation values are for V_{IHmin} = V_{CC} – 0.5 V and V_{ILmax} = 0.5 V with all output pins unloaded and the on-chip pull-up transistors in the off state.
3. The values are for $V_{RAM} \leq V_{CC}$ < 4.5 V, V_{IHmin} = $V_{CC} \times 0.9$, and V_{ILmax} = 0.3 V.

Table 18-2 DC Characteristics (cont)

Conditions: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC},
$V_{SS} = AV_{SS}$ = 0 V*1, T_a = –20°C to +75°C (regular specifications),
T_a = –40°C to +85°C (wide-range specifications)

Item		Symbol	Min	Typ	Max	Unit	Test Conditions
Analog power supply current	During A/D conversion	AI_{CC}	—	1.2	2.0	mA	
	Idle		—	0.01	5.0	µA	
Reference current	During A/D conversion	AI_{CC}	—	0.3	0.6	mA	V_{REF} = 5.0 V
	Idle		—	0.01	5.0	µA	
RAM standby voltage		V_{RAM}	2.0	—	—	V	

Notes: 1. If the A/D converter is not used, do not leave the AV_{CC}, AV_{SS}, and V_{REF} pins open. Connect AV_{CC} and V_{REF} to V_{CC}, and connect AV_{SS} to V_{SS}.
2. Current dissipation values are for $V_{IHmin} = V_{CC} – 0.5$ V and V_{ILmax} = 0.5 V with all output pins unloaded and the on-chip pull-up transistors in the off state.
3. The values are for $V_{RAM} < V_{CC} < 4.5$ V, $V_{IHmin} = V_{CC} \times 0.9$, and V_{ILmax} = 0.3 V.

Conditions: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC},
$V_{SS} = AV_{SS}$ = 0 V*, T_a = –20°C to +75°C (regular specifications),
T_a = –40°C to +85°C (wide-range specifications)

Item		Symbol	Min	Typ	Max	Unit	Test Conditions
Schmitt trigger input voltages	Port A, $P8_0$ to $P8_2$, PB_0 to PB_3	V_T^-	$V_{CC} \times 0.2$	—	—	V	
		V_T^+	—	—	$V_{CC} \times 0.7$	V	
		$V_T^+ – V_T^-$	$V_{CC} \times 0.07$	—	—	V	
Input high voltage	$\overline{RES}$, $\overline{STBY}$, NMI, MD_2 to MD_0	V_{IH}	$V_{CC} \times 0.9$	—	V_{CC} + 0.3	V	
	EXTAL		$V_{CC} \times 0.7$	—	V_{CC} + 0.3	V	
	Port 7		$V_{CC} \times 0.7$	—	AV_{CC} + 0.3	V	
	Ports 4, 5, 6, 9, C, $P8_3$, $P8_4$, PB_4 to PB_7, D_{15} to D_8		$V_{CC} \times 0.7$	—	V_{CC} + 0.3	V	

Note: * If the A/D converter is not used, do not leave the AV_{CC}, AV_{SS}, and V_{REF} pins open. Connect AV_{CC} and V_{REF} to V_{CC}, and connect AV_{SS} to V_{SS}.

Table 18-2 DC Characteristics (cont)

Conditions: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC}, $V_{SS} = AV_{SS}$ = 0 V*, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Item		Symbol	Min	Typ	Max	Unit	Test Conditions
Input low voltage	$\overline{RES}$, $\overline{STBY}$, MD_2 to MD_0	V_{IL}	–0.3	—	$V_{CC} \times 0.1$	V	
	NMI, EXTAL, ports 4, 5, 6, 7, 9, C, $P8_3$, $P8_4$ PB_4 to PB_7, D_{15} to D_8		–0.3	—	$V_{CC} \times 0.2$	V	V_{CC} < 4.0 V
					0.8	V	V_{CC} = 4.0 to 5.5 V
Output high voltage	All output pins	V_{OH}	V_{CC} – 0.5	—	—	V	I_{OH} = –200 µA
			V_{CC} – 1.0	—	—	V	$V_{CC} \le 4.5$ V I_{OH} = –1 mA.
			3.5	—	—	V	4.5 V < $V_{CC} \le$ 5.5 V I_{OH} = –1 mA
Output low voltage	All output pins (except $\overline{RESO}$)	V_{OL}	—	—	0.4	V	I_{OL} = 1.6 mA
	Ports 5 and B, A_{19} to A_0		—	—	1.0	V	$V_{CC} \le 4$ V I_{OL} = 8 mA, 4 V < $V_{CC} \le$ 5.5 V I_{OL} = 10 mA
	$\overline{RESO}$		—	—	0.4	V	I_{OL} = 2.6 mA
Input leakage current	$\overline{STBY}$, NMI, $\overline{RES}$, MD_2 to MD_0	$\|I_{IN}\|$	—	—	1.0	µA	V_{IN} = 0.5 to V_{CC} – 0.5 V
	Port 7		—	—	1.0	µA	V_{IN} = 0.5 to AV_{CC} – 0.5 V
Three-state leakage current (off state)	Ports 4, 5, 6, 8 to C, A_{19} to A_0, D_{15} to D_8	$\|I_{TS1}\|$	—	—	1.0	µA	V_{IN} = 0.5 to V_{CC} – 0.5 V
	$\overline{RESO}$		—	—	10.0	µA	V_{IN} = 0.5 to V_{CC} – 0.5 V
Input pull-up current	Ports 4 and 5	$–I_P$	10	—	300	µA	V_{CC} = 2.7 V to 5.5 V, V_{IN} = 0 V

Note: * If the A/D converter is not used, do not leave the AV_{CC}, AV_{SS}, and V_{REF} pins open. Connect AV_{CC} and V_{REF} to V_{CC}, and connect AV_{SS} to V_{SS}.

Table 18-2 DC Characteristics (cont)

Conditions: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC},
$V_{SS} = AV_{SS}$ = 0 V*1, T_a = –20°C to +75°C (regular specifications),
T_a = –40°C to +85°C (wide-range specifications)

Item		Symbol	Min	Typ	Max	Unit	Test Conditions
Input capacitance	NMI	C_{IN}	—	—	50	pF	V_{IN} = 0 V f = 1 MHz T_a = 25°C
	All input pins except NMI		—	—	15		
Current dissipation*2	Normal operation	I_{CC}*4	—	30 (5.0 V)	36.2 (5.5 V)	mA	f = 8 MHz
	Sleep mode		—	20 (5.0 V)	27.4 (5.5 V)	mA	f = 8 MHz
	Standby mode*3		—	0.01	5.0	µA	$T_a \leq 50°C$
			—	—	20.0	µA	50°C < T_a
Analog power supply current	During A/D conversion	AI_{CC}	—	1.0	2.0	mA	AV_{CC} = 3.0 V
			—	1.2	—	mA	AV_{CC} = 5.0 V
	Idle		—	0.01	5.0	µA	
Reference current	During A/D conversion	AI_{CC}	—	0.2	0.4	mA	V_{REF} = 3.0 V
			—	0.3	—	mA	V_{REF} = 5.0 V
	Idle		—	0.01	5.0	µA	
RAM standby voltage		V_{RAM}	2.0	—	—	V	

Notes:
1. If the A/D converter is not used, do not leave the AV_{CC}, AV_{SS}, and V_{REF} pins open. Connect AV_{CC} and V_{REF} to V_{CC}, and connect AV_{SS} to V_{SS}.
2. Current dissipation values are for $V_{IHmin} = V_{CC} - 0.5$ V and V_{ILmax} = 0.5 V with all output pins unloaded and the on-chip pull-up transistors in the off state.
3. The values are for $V_{RAM} \leq V_{CC} < 2.7$ V, $V_{IHmin} = V_{CC} \times 0.9$, and V_{ILmax} = 0.3 V.
4. I_{CC} depends on V_{CC} and f as follows:
   I_{CCmax} = 1.0 (mA) + 0.8 (mA/MHz · V) × V_{CC} × f [normal mode]
   I_{CCmax} = 1.0 (mA) + 0.6 (mA/MHz · V) × V_{CC} × f [sleep mode]

Table 18-2 DC Characteristics (cont)

Conditions: V_{CC} = 3.0 V to 5.5 V, AV_{CC} = 3.0 V to 5.5 V, V_{REF} = 3.0 V to AV_{CC},
$V_{SS} = AV_{SS}$ = 0 V*1, T_a = –20°C to +75°C (normalspecification product),
T_a = –40°C to +85°C (extended temperature range specification product)

Item		Symbol	Min	Typ	Max	Unit	Test Conditions
Schmitt trigger input voltage	Port A, $P8_0$ to $P8_2$, PB_0 to PB_3	V_T^-	$V_{CC} \times 0.2$	—	—	V	
		V_T^+	—	—	$V_{CC} \times 0.7$	V	
		$V_T^+ - V_T^-$	$V_{CC} \times 0.07$	—	—	V	
Input high voltage	$\overline{RES}$, $\overline{STBY}$, NMI, MD_2 to MD_0	V_{IH}	$V_{CC} \times 0.9$	—	V_{CC} + 0.3	V	
	EXTAL		$V_{CC} \times 0.7$	—	V_{CC} + 0.3	V	
	Port 7		$V_{CC} \times 0.7$	—	AV_{CC} + 0.3	V	
	Ports 4, 5, 6, 9, C, $P8_3$, $P8_4$, PB_4 to PB_7, D_{15} to D_8		$V_{CC} \times 0.7$	—	V_{CC} + 0.3	V	
Input low voltage	$\overline{RES}$, $\overline{STBY}$, MD_2 to MD_0	V_{IL}	–0.3	—	$V_{CC} \times 0.1$	V	V_{CC} < 4.0 V
	NMI, EXTAL, Ports 4, 5, 6, 7, 9, C, $P8_3$, $P8_4$, PB_4 to PB_7, D_{15} to D_8		–0.3	—	$V_{CC} \times 0.2$	V	
					0.8		V_{CC} = 4.0 to 5.5 V
Output high voltage	All output pins	V_{OH}	V_{CC} – 0.5	—	—	V	I_{OH} = –200 µA
			V_{CC} – 1.0	—	—	V	$V_{CC} \le 4.5$ V I_{OH} = –1 mA
			3.5	—	—	V	4.5 V < $V_{CC} \le$ 5.5 V I_{OH} = –1 mA
Output low voltage	All output pins (except $\overline{RESO}$)	V_{OL}	—	—	0.4	V	I_{OL} = 1.6 mA
	Ports 5 and B, A_{19} to A_0		—	—	1.0	V	$V_{CC} \le 4.0$ V, I_{OL} = 8 mA, 4.0 V< $V_{CC} \le$ 5.5 V, I_{OL} = 10 mA
	$\overline{RESO}$		—	—	0.4	V	I_{OL} = 2.6 mA
Input leakage current	$\overline{STBY}$, NMI, $\overline{RES}$, MD_2 to MD_0	$\|I_{IN}\|$	—	—	1.0	µA	V_{IN} = 0.5 to V_{CC} – 0.5 V
	Port 7		—	—	1.0	µA	V_{IN} = 0.5 to AV_{CC} – 0.5 V

Table 18-2 DC Characteristics (cont)

Conditions: V_{CC} = 3.0 V to 5.5 V, AV_{CC} = 3.0 V to 5.5 V, V_{REF} = 3.0 V to AV_{CC}, $V_{SS} = AV_{SS}$ = 0 V*1, T_a = –20°C to +75°C (normalspecification product), T_a = –40°C to +85°C (extended temperature range specification product)

Item		Symbol	Min	Typ	Max	Unit	Test Conditions
Three-state leakage current (off state)	Ports 4, 5, 6, 8 to C, A_{19} to A_0, D_{15} to D_8	$\|I_{TS1}\|$	—	—	1.0	µA	V_{IN} = 0.5 to V_{CC} – 0.5 V
	$\overline{RESO}$		—	—	10.0	µA	
Input pull -up current	Ports 4 and 5	$-I_P$	10	—	300	µA	V_{CC} = 3.0 V to 5.5 V, V_{IN} = 0 V
Input capacitance	NMI	C_{IN}	—	—	50	pF	V_{IN} = 0 V
	All input pins except NMI		—	—	15	pF	f = 1MHz T_a = 25°C
Current dissipation*2	Normal operation	I_{CC}*4	— —	38 (5.0 V)	45 (5.5 V)	mA	f = 10 MHz
	Sleep		— —	27 (5.0 V)	34 (5.5 V)	mA	f = 10 MHz
	Standby*3-[		—	0.01	5.0	µA	$T_a \le 50°C$
			—	—	20.0		50°C < T_a
Analog power supply	During A/D conversion	AI_{CC}	—	1.0	2.0	mA	AV_{CC} = 3.0 V
			—	1.2	—		AV_{CC} = 5.0 V
	A/D conversion standby		—	0.01	5.0	µA	
Reference power supply current	During A/D conversion	AI_{CC}	—	0.2	0.4	mA	V_{REF} = 3.0 V
			—	0.3	—		V_{REF} = 5.0 V
	A/D conversion standby		—	0.01	5.0	µA	
RAM standby voltage		V_{RAM}	2.0	—	—	V	

Notes:
1. When the A/D converter is not used, do not leave the AV_{CC}, V_{REF}, and AV_{SS} pins open. Connect the AV_{CC} and V_{REF} pins to V_{CC}, and the AV_{SS} pin to V_{SS}.
2. The current dissipation value is the value when all output pins are unloaded and the on-chip pull-up MOS is off under the following conditions: V_{IH} min = V_{CC} to 0.5 V, V_{IL} max = 0.5 V.
3. When $V_{RAM} \le V_{CC} < 3.0$ V, the value is for the case where V_{IH}min = $V_{CC} \times 0.9$, and V_{IL}max = 0.3 V.
4. I_{CC} is dependent upon V_{CC} and f in accordance with the following formulas.
   I_{CC}max = 1.0 (mA) + 0.8 (mA/MHz · V) × V_{CC} × f [normal mode]
   I_{CC}max = 1.0 (mA) + 0.6 (mA/MHz · V) × V_{CC} × f [sleep mode]

Table 18-3 Permissible Output Currents

Conditions: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC},
$V_{SS} = AV_{SS}$ = 0 V, T_a = –20°C to +75°C (regular specifications),
T_a = –40°C to +85°C (wide-range specifications)

Item		Symbol	Min	Typ	Max	Unit
Permissible output low current (per pin)	Ports 5 and B, A_{19} to A_0	I_{OL}	—	—	10	mA
	Other output pins		—	—	2.0	mA
Permissible output low current (total)	Total of 32 pins including ports 5 and B and A_{19} to A_0	ΣI_{OL}	—	—	80	mA
	Total of all output pins, including the above		—	—	120	mA
Permissible output high current (per pin)	All output pins	I_{OH}	—	—	2.0	mA
Permissible output high current (total)	Total of all output pins	ΣI_{OH}	—	—	40	mA

Notes: 1. To protect chip reliability, do not exceed the output current values in table 18-3.
2. When driving a darlington pair or LED, always insert a current-limiting resistor in the output line, as shown in figures 18-1 and 18-2.

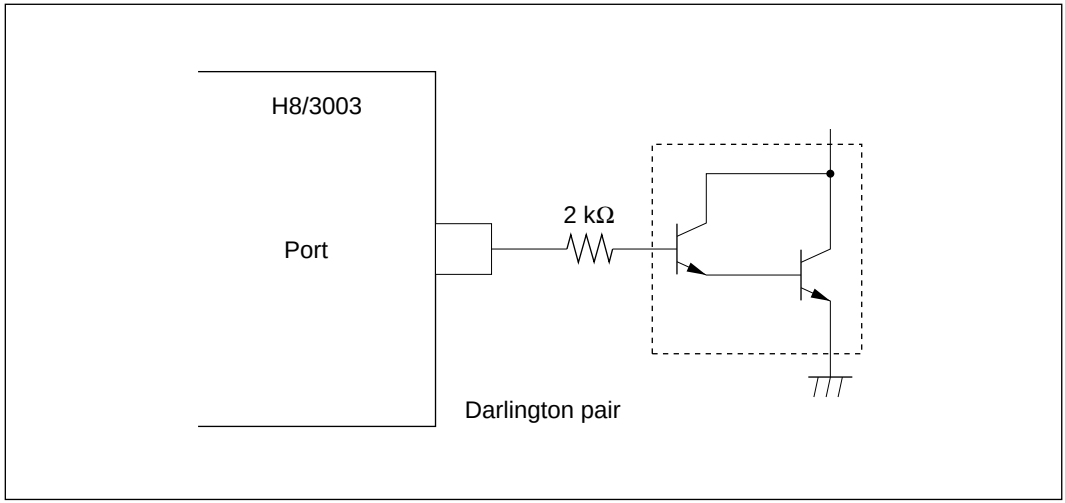


Figure 18-1 Darlington Pair Drive Circuit (Example)

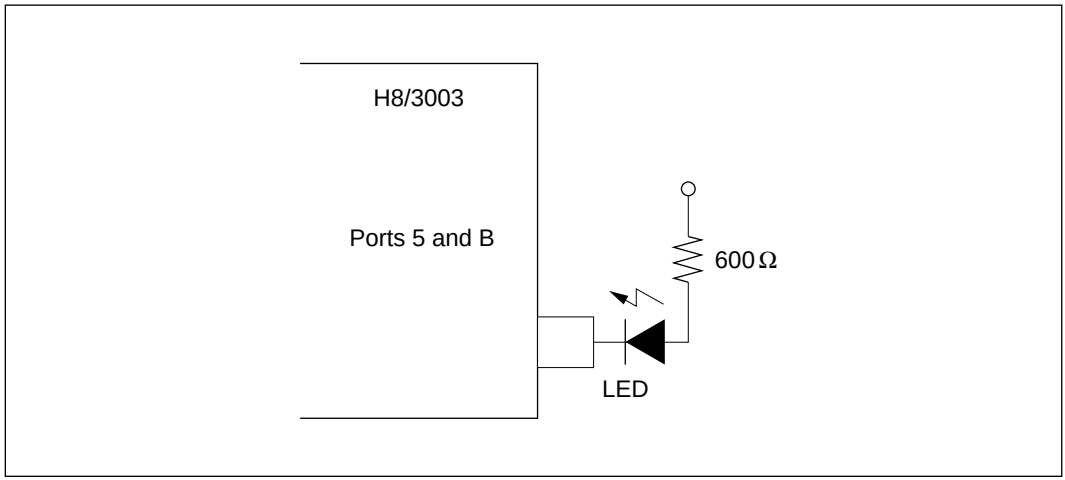


Figure 18-2 LED Drive Circuit (Example)

18.2.2 AC Characteristics

Bus timing parameters are listed in table 18-4. Control signal timing parameters are listed in table 18-5. Refresh controller bus timing parameters are listed in table 18-6. Timing parameters of the on-chip supporting modules are listed in table 18-7.

Table 18-4 Bus Timing

Condition A: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 8 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition B: V_{CC} = 3.0 V to 5.5 V, AV_{CC} = 3.0 V to 5.5 V, V_{REF} = 3.0 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 10 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition C: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 16 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

		Condition A		Condition B		Condition C			
		8 MHz		10 MHz		16 MHz			
Item	Symbol	Min	Max	Min	Max	Min	Max	Unit	Test Conditions
Clock cycle time	t_{CYC}	125	500	100	500	62.5	500	ns	Figure 18-4, Figure 18-5
Clock low pulse width	t_{CL}	40	—	30	—	20	—		
Clock high pulse width	t_{CH}	40	—	30	—	20	—		
Clock rise time	t_{CR}	—	20	—	15	—	10		
Clock fall time	t_{CF}	—	20	—	15	—	10		
Address delay time	t_{AD}	—	60	—	50	—	30		
Address hold time	t_{AH}	25	—	20	—	10	—		
Address strobe delay time	t_{ASD}	—	60	—	40	—	30		
Write strobe delay time	t_{WSD}	—	60	—	50	—	30		
Strobe delay time	t_{SD}	—	60	—	50	—	30		
Write data strobe pulse width 1	t_{WSW1}*	85	—	60	—	35	—		
Write data strobe pulse width 2	t_{WSW2}*	150	—	110	—	65	—		
Address setup time 1	t_{AS1}	20	—	15	—	10	—		
Address setup time 2	t_{AS2}	80	—	65	—	40	—		
Read data setup time	t_{RDS}	50	—	35	—	20	—		
Read data hold time	t_{RDH}	0	—	0	—	0	—		

Table 18-4 Bus Timing (cont)

Condition A: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 8 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition B: V_{CC} = 3.0 V to 5.5 V, AV_{CC} = 3.0 V to 5.5 V, V_{REF} = 3.0 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 10 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition C: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 16 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

		Condition A		Condition B		Condition C			
		8 MHz		10 MHz		16 MHz			
Item	Symbol	Min	Max	Min	Max	Min	Max	Unit	Test Conditions
Write data delay time	t_{WDD}	—	75	—	75	—	60	ns	Figure 18-4, Figure 18-5
Write data setup time 1	t_{WDS1}	60	—	65	—	35	—		
Write data setup time 2	t_{WDS2}	15	—	10	—	5	—		
Write data hold time	t_{WDH}	25	—	20	—	20	—		
Read data access time 1	t_{ACC1}*	—	110	—	100	—	55		
Read data access time 2	t_{ACC2}*	—	230	—	200	—	115		
Read data access time 3	t_{ACC3}*	—	55	—	50	—	25		
Read data access time 4	t_{ACC4}*	—	160	—	150	—	85		
Precharge time	t_{PCH}*	85	—	60	—	40	—		
Wait setup time	t_{WTS}	40	—	40	—	25	—	ns	Figure 18-6
Wait hold time	t_{WTH}	10	—	10	—	5	—		
Bus request setup ime	t_{BRQS}	40	—	40	—	40	—	ns	Figure 18-18
Bus acknowledge delay time 1	t_{BACD1}	—	60	—	50	—	30		
Bus acknowledge delay time 2	t_{BACD2}	—	60	—	50	—	30		
Bus-floating time	t_{BZD}	—	70	—	70	—	40		

Note is on next page.

Note: At 8 MHz, the times below depend as indicated on the clock cycle time.

$t_{ACC1} = 1.5 \times t_{cyc} - 78$ (ns) $t_{WSW1} = 1.0 \times t_{cyc} - 40$ (ns)
$t_{ACC2} = 2.5 \times t_{cyc} - 83$ (ns) $t_{WSW2} = 1.5 \times t_{cyc} - 38$ (ns)
$t_{ACC3} = 1.0 \times t_{cyc} - 70$ (ns) $t_{PCH} = 1.0 \times t_{cyc} - 40$ (ns)
$t_{ACC4} = 2.0 \times t_{cyc} - 90$ (ns)

At 10 MHz, the times below depend as indicated on the clock cycle time.

$t_{ACC1} = 1.5 \times t_{cyc} - 50$ (ns) $t_{WSW1} = 1.0 \times t_{cyc} - 40$ (ns)
$t_{ACC2} = 2.5 \times t_{cyc} - 50$ (ns) $t_{WSW2} = 1.5 \times t_{cyc} - 40$ (ns)
$t_{ACC3} = 1.0 \times t_{cyc} - 50$ (ns) $t_{PCH} = 1.0 \times t_{cyc} - 40$ (ns)
$t_{ACC4} = 2.0 \times t_{cyc} - 50$ (ns)

At 16 MHz, the times below depend as indicated on the clock cycle time.

$t_{ACC1} = 1.5 \times t_{cyc} - 39$ (ns) $t_{WSW1} = 1.0 \times t_{cyc} - 28$ (ns)
$t_{ACC2} = 2.5 \times t_{cyc} - 41$ (ns) $t_{WSW2} = 1.5 \times t_{cyc} - 28$ (ns)
$t_{ACC3} = 1.0 \times t_{cyc} - 38$ (ns) $t_{PCH} = 1.0 \times t_{cyc} - 23$ (ns)
$t_{ACC4} = 2.0 \times t_{cyc} - 40$ (ns)

Table 18-5 Refresh Controller Bus Timing

Condition A: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC}, $V_{SS} = AV_{SS}$ = 0 V, ø = 2 MHz to 8 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition B: V_{CC} = 3.0 V to 5.5 V, AV_{CC} = 3.0 V to 5.5 V, V_{REF} = 3.0 V to AV_{CC}, $V_{SS} = AV_{SS}$ = 0 V, ø = 2 MHz to 10 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition C: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC}, $V_{SS} = AV_{SS}$ = 0 V, ø = 2 MHz to 16 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

		Condition A		Condition B		Condition C			
		8 MHz		10 MHz		16 MHz			Test
Item	Symbol	Min	Max	Min	Max	Min	Max	Unit	Conditions
$\overline{RAS}$ delay time 1	t_{RAD1}	—	60	—	50	—	30	ns	Figure 18-7 to Figure 18-13
$\overline{RAS}$ delay time 2	t_{RAD2}	—	60	—	50	—	30		
$\overline{RAS}$ delay time 3	t_{RAD3}	—	60	—	50	—	30		
Row address hold time*	t_{RAH}	25	—	20	—	15	—		
$\overline{RAS}$ precharge time*	t_{RP}	85	—	70	—	40	—		
$\overline{CAS}$ to $\overline{RAS}$ precharge time*	t_{CRP}	85	—	70	—	40	—		
$\overline{CAS}$ pulse width	t_{CAS}	110	—	85	—	40	—		
$\overline{RAS}$ access time*	t_{RAC}	—	160	—	150	—	85		
Address access time	t_{AA}	—	105	—	75	—	55		
$\overline{CAS}$ access time	t_{CAC}	—	50	—	50	—	25		
Write data setup time 3	t_{WDS3}	75	—	50	—	40	—		
$\overline{CAS}$ setup time*	t_{CSR}	20	—	15	—	15	—		
Read strobe delay time	t_{RSD}	—	60	—	50	—	30		

Note: At 8 MHz, the times below depend as indicated on the clock cycle time.

$t_{RAH} = 0.5 \times t_{cyc} - 38$ (ns) $t_{CAC} = 1.0 \times t_{cyc} - 75$ (ns)

$t_{RAC} = 2.0 \times t_{cyc} - 90$ (ns) $t_{CSR} = 0.5 \times t_{cyc} - 43$ (ns)

$t_{RP} = t_{CRP} = 1.0 \times t_{cyc} - 40$ (ns)

At 10 MHz, the times below depend as indicated on the clock cycle time.

$t_{RAH} = 0.5 \times t_{cyc} - 30$ (ns) $t_{CAC} = 1.0 \times t_{cyc} - 50$ (ns)

$t_{RAC} = 2.0 \times t_{cyc} - 50$ (ns) $t_{CSR} = 0.5 \times t_{cyc} - 35$ (ns)

$t_{RP} = t_{CRP} = 1.0 \times t_{cyc} - 30$ (ns)

At 16 MHz, the times below depend as indicated on the clock cycle time.

$t_{RAH} = 0.5 \times t_{cyc} - 16$ (ns) $t_{CAC} = 1.0 \times t_{cyc} - 38$ (ns)

$t_{RAC} = 2.0 \times t_{cyc} - 40$ (ns) $t_{CSR} = 0.5 \times t_{cyc} - 16$ (ns)

$t_{RP} = t_{CRP} = 1.0 \times t_{cyc} - 23$ (ns)

Table 18-6 Control Signal Timing

Condition A: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 8 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition B: V_{CC} = 3.0 V to 5.5 V, AV_{CC} = 3.0 V to 5.5 V, V_{REF} = 3.0 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 10 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition C: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 16 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

		Condition A		Condition B		Condition C			
		8 MHz		10 MHz		16 MHz			Test
Item	Symbol	Min	Max	Min	Max	Min	Max	Unit	Conditions
$\overline{RES}$ setup time	t_{RESS}	200	—	200	—	200	—	ns	Figure 18-15
$\overline{RES}$ pulse width	t_{RESW}	10	—	10	—	10	—	t_{CYC}	
$\overline{RESO}$ output delay time	t_{RESD}	—	100	—	100	—	100	ns	Figure 18-16
$\overline{RESO}$ output pulse width	t_{RESOW}	132	—	132	—	132	—	t_{CYC}	
NMI setup time (NMI, $\overline{IRQ_7}$ to $\overline{IRQ_0}$)	t_{NMIS}	150	—	150	—	150	—	ns	Figure 18-17
NMI hold time (NMI, $\overline{IRQ_7}$ to $\overline{IRQ_0}$)	t_{NMIH}	10	—	10	—	10	—		
Interrupt pulse width (NMI, $\overline{IRQ_2}$ to $\overline{IRQ_0}$ when exiting software standby mode)	t_{NMIW}	200	—	200	—	200	—		
Clock oscillator settling time at reset (crystal)	t_{OSC1}	20	—	20	—	20	—	ms	Figure 18-19
Clock oscillator settling time in software standby (crystal)	t_{OSC2}	8	—	8	—	8	—		Figure 17-1

Table 18-7 Timing of On-Chip Supporting Modules

Condition A: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 8 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition B: V_{CC} = 3.0 V to 5.5 V, AV_{CC} = 3.0 V to 5.5 V, V_{REF} = 3.0 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 10 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition C: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 16 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

				Condition A 8 MHz		Condition B 10 MHz		Condition C 16 MHz			
Item			**Symbol**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Unit**	**Test Conditions**
DMAC	$\overline{\text{DREQ}}$ setup time		t_{DRQS}	40	—	30	—	30	—	ns	Figure 18-27
	$\overline{\text{DREQ}}$ hold time		t_{DRQH}	10	—	10	—	10	—		
	$\overline{\text{TEND}}$ delay time 1		t_{TED1}	—	100	—	50	—	50		Figure 18-25, Figure 18-26
	$\overline{\text{TEND}}$ delay time 2		t_{TED2}	—	100	—	50	—	50		
ITU	Timer output delay time		t_{TOCD}	—	100	—	100	—	100	ns	Figure 18-21
	Timer input setup time		t_{TICS}	50	—	50	—	50	—		
	Timer clock input setup time		t_{TCKS}	50	—	50	—	50	—		Figure 18-22
	Timer clock pulse width	Single edge	t_{TCKWH}	1.5	—	1.5	—	1.5	—	t_{CYC}	
		Both edges	t_{TCKWL}	2.5	—	2.5	—	2.5	—		
SCI	Input clock cycle	Asyn-chronous	t_{SCYC}	4	—	4	—	4	—		Figure 18-23
		Syn-chronous	t_{SCYC}	6	—	6	—	6	—		
	Input clock rise time		t_{SCKR}	—	1.5	—	1.5	—	1.5		
	Input clock fall time		t_{SCKR}	—	1.5	—	1.5	—	1.5		
	Input clock pulse width		t_{SCKW}	0.4	0.6	0.4	0.6	0.4	0.6	t_{SCYC}	

Table 18-7 Timing of On-Chip Supporting Modules (cont)

Condition A: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 8 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition B: V_{CC} = 3.0 V to 5.5 V, AV_{CC} = 3.0 V to 5.5 V, V_{REF} = 3.0 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 10 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition C: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 16 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

			Condition A 8 MHz		Condition B 10 MHz		Condition C 16 MHz			
Item		**Symbol**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Unit**	**Test Conditions**
SCI	Transmit data delay time	t_{TXD}	—	100	—	100	—	100	ns	Figure 18-24
	Receive data setup time (synchronous)	t_{RXS}	100	—	100	—	100	—		
	Receive data hold time (synchronous)	t_{RXH}	100	—	100	—	100	—		
Ports and TPC	Output data delay time	t_{PWD}	—	100	—	100	—	100	ns	Figure 18-20
	Input data setup time (synchronous)	t_{PRS}	50	—	50	—	50	—		
	Input data hold time (synchronous)	t_{PRH}	50	—	50	—	50	—		

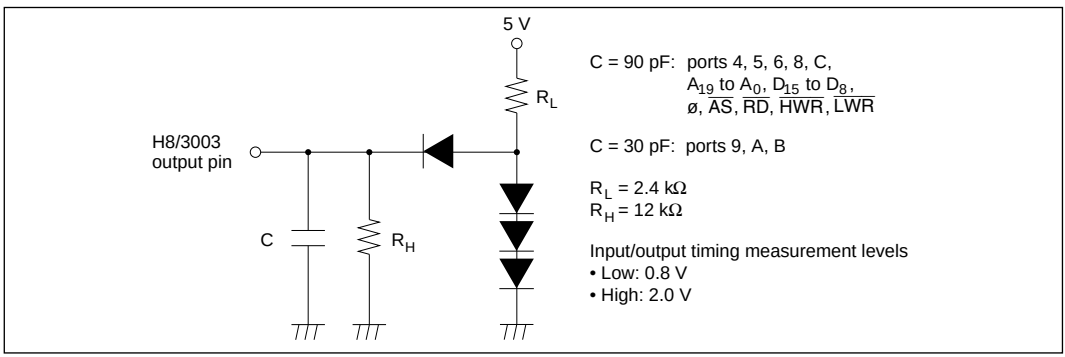


Figure 18-3 Output Load Circuit

18.2.3 A/D Conversion Characteristics

Table 18-8 lists the A/D conversion characteristics.

Table 18-8 A/D Converter Characteristics

Condition A: V_{CC} = 2.7 V to 5.5 V, AV_{CC} = 2.7 V to 5.5 V, V_{REF} = 2.7 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 8 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition B: V_{CC} = 3.0 V to 5.5 V, AV_{CC} = 3.0 V to 5.5 V, V_{REF} = 3.0 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 10 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

Condition C: V_{CC} = 5.0 V ± 10%, AV_{CC} = 5.0 V ± 10%, V_{REF} = 4.5 V to AV_{CC}, V_{SS} = AV_{SS} = 0 V, ø = 2 MHz to 16 MHz, T_a = –20°C to +75°C (regular specifications), T_a = –40°C to +85°C (wide-range specifications)

	Condition A			Condition B			Condition C			
	8 MHz			10 MHz			16 MHz			
Item	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Min**	**Typ**	**Max**	**Unit**
Resolution	10	10	10	10	10	10	10	10	10	bits
Conversion time	—	—	16.8	—	—	13.4	—	—	8.4	µs
Analog input capacitance	—	—	20	—	—	20	—	—	20	pF
Permissible signal-source impedance	—	—	10*1	—	—	10*1	—	—	10*3	kΩ
	—	—	5*2	—	—	5*5	—	—	5*4	
Nonlinearity error	—	—	±6.0	—	—	±6.0	—	—	±3.0	LSB
Offset error	—	—	±4.0	—	—	±4.0	—	—	±2.0	LSB
Full-scale error	—	—	±4.0	—	—	±4.0	—	—	±2.0	LSB
Quantization error	—	—	±0.5	—	—	±0.5	—	—	±0.5	LSB
Absolute accuracy	—	—	±8.0	—	—	±8.0	—	—	±4.0	LSB

Notes: 1. The value is for 4.0 ≤ AV_{CC} ≤ 5.5.
2. The value is for 2.7 ≤ AV_{CC} < 4.0.
3. The value is for ø ≤ 12 MHz.
4. The value is for ø > 12 MHz.
5. The value is for 3.0 ≤ AV_{CC} < 4.0.

18.3 Operational Timing

This section shows timing diagrams.

18.3.1 Bus Timing

Bus timing is shown as follows:

- Basic bus cycle: two-state access

  Figure 18-4 shows the timing of the external two-state access cycle.

- Basic bus cycle: three-state access

  Figure 18-5 shows the timing of the external three-state access cycle.

- Basic bus cycle: three-state access with one wait state

  Figure 18-6 shows the timing of the external three-state access cycle with one wait state inserted.

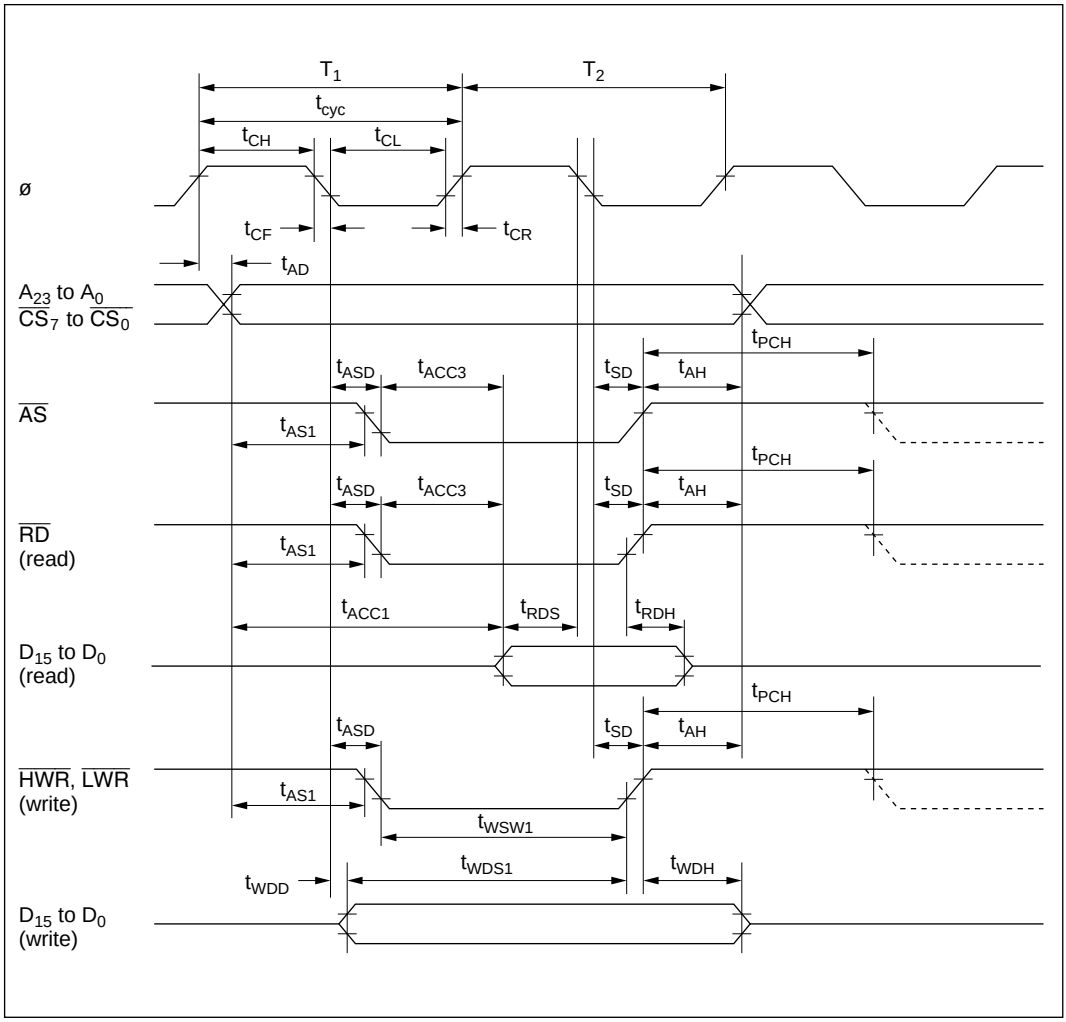


Figure 18-4 Basic Bus Cycle: Two-State Access

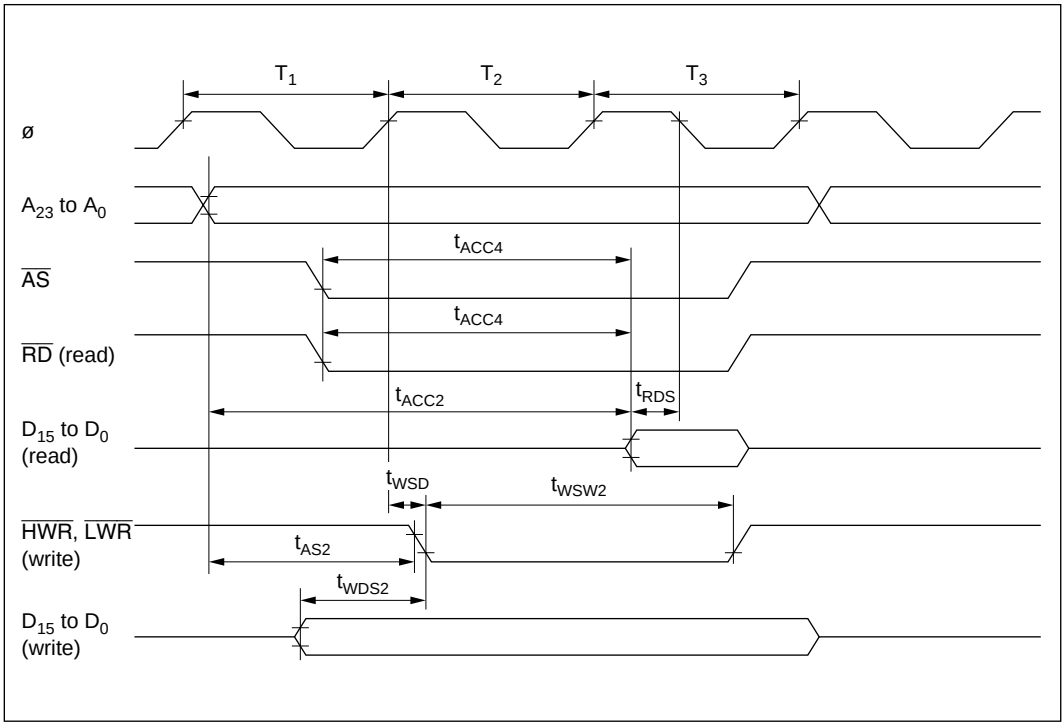


Figure 18-5 Basic Bus Cycle: Three-State Access

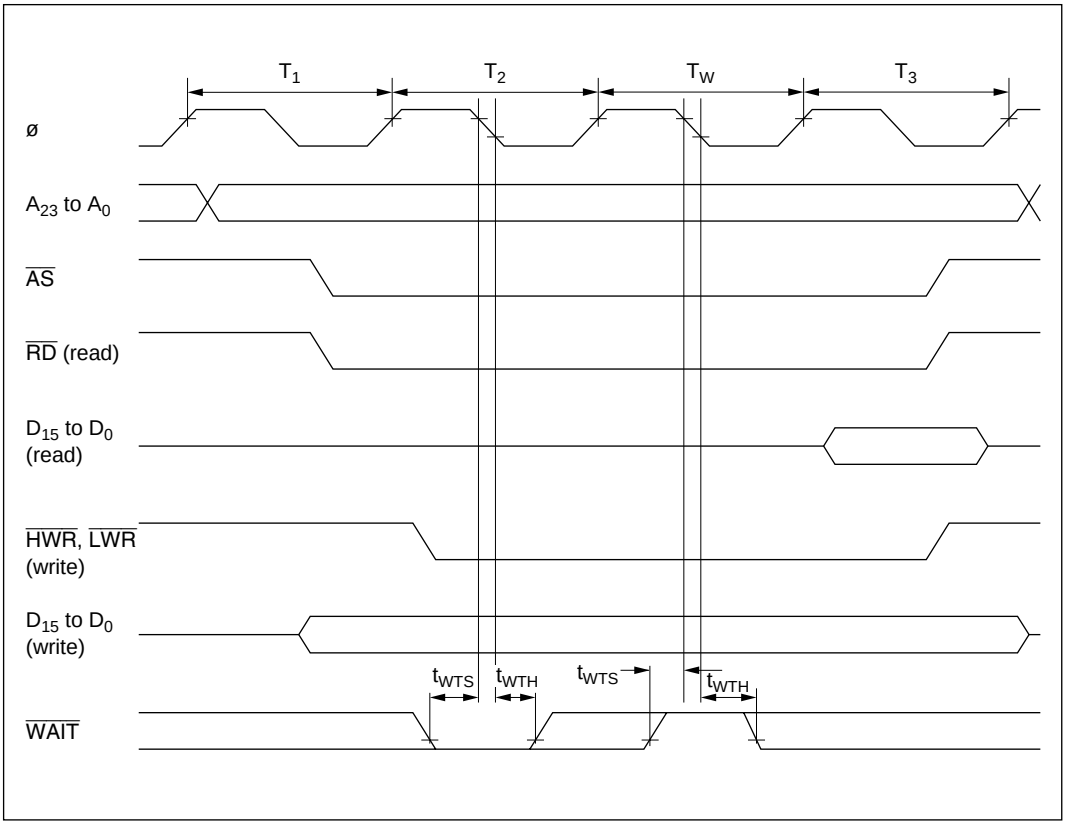


Figure 18-6 Basic Bus Cycle: Three-State Access with One Wait State

18.3.2 Refresh Controller Bus Timing

Refresh controller bus timing is shown as follows:

- DRAM bus timing

  Figures 18-7 to 18-12 show the DRAM bus timing in each operating mode.

- PSRAM bus timing

  Figures 18-13 and 18-14 show the pseudo-static RAM bus timing in each operating mode.

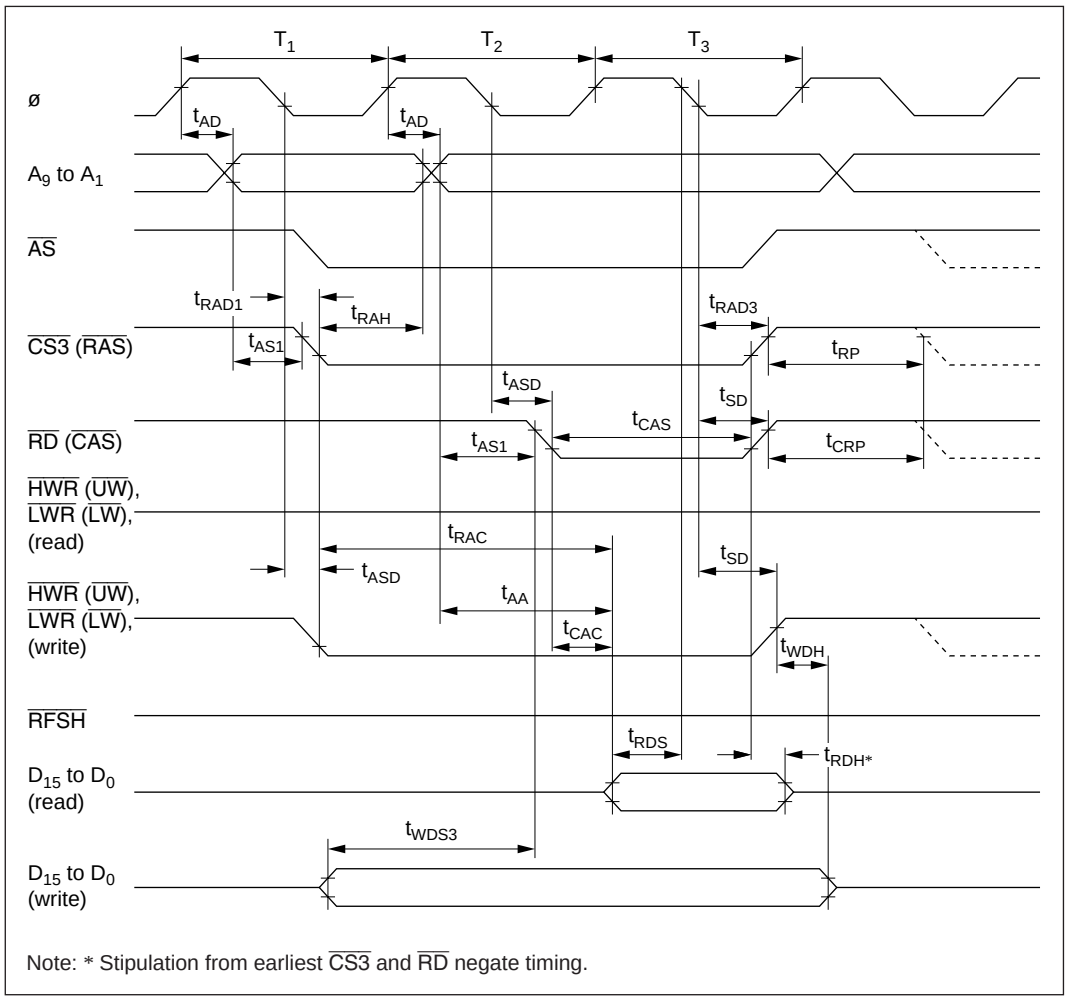


Figure 18-7 DRAM Bus Timing (Read/Write): Three-State Access — 2WE Mode —

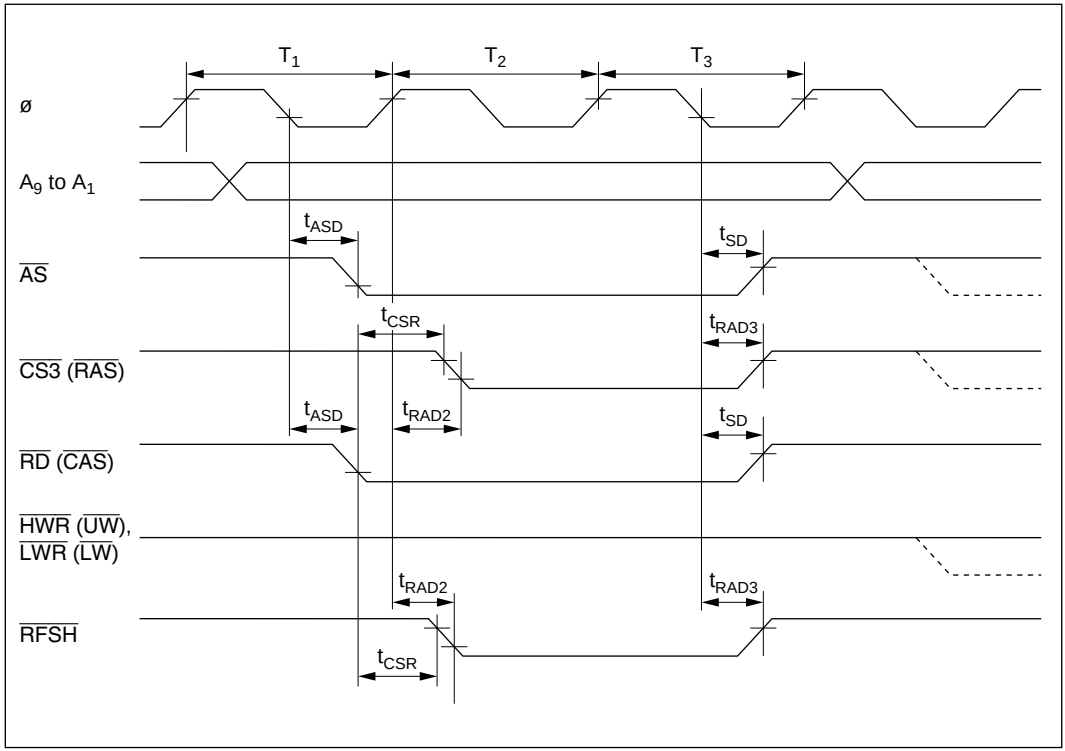


Figure 18-8 DRAM Bus Timing (Refresh Cycle): Three-State Access — 2$\overline{WE}$ Mode —

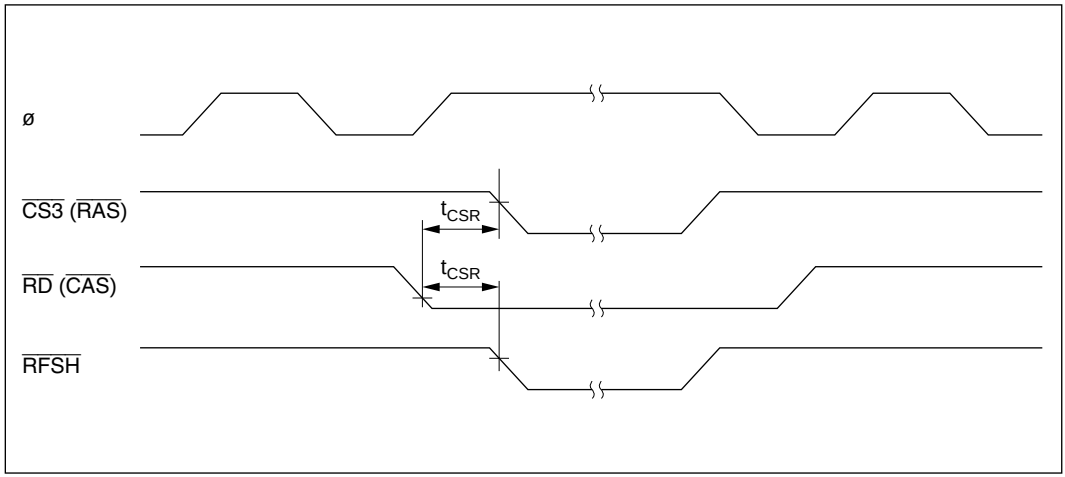
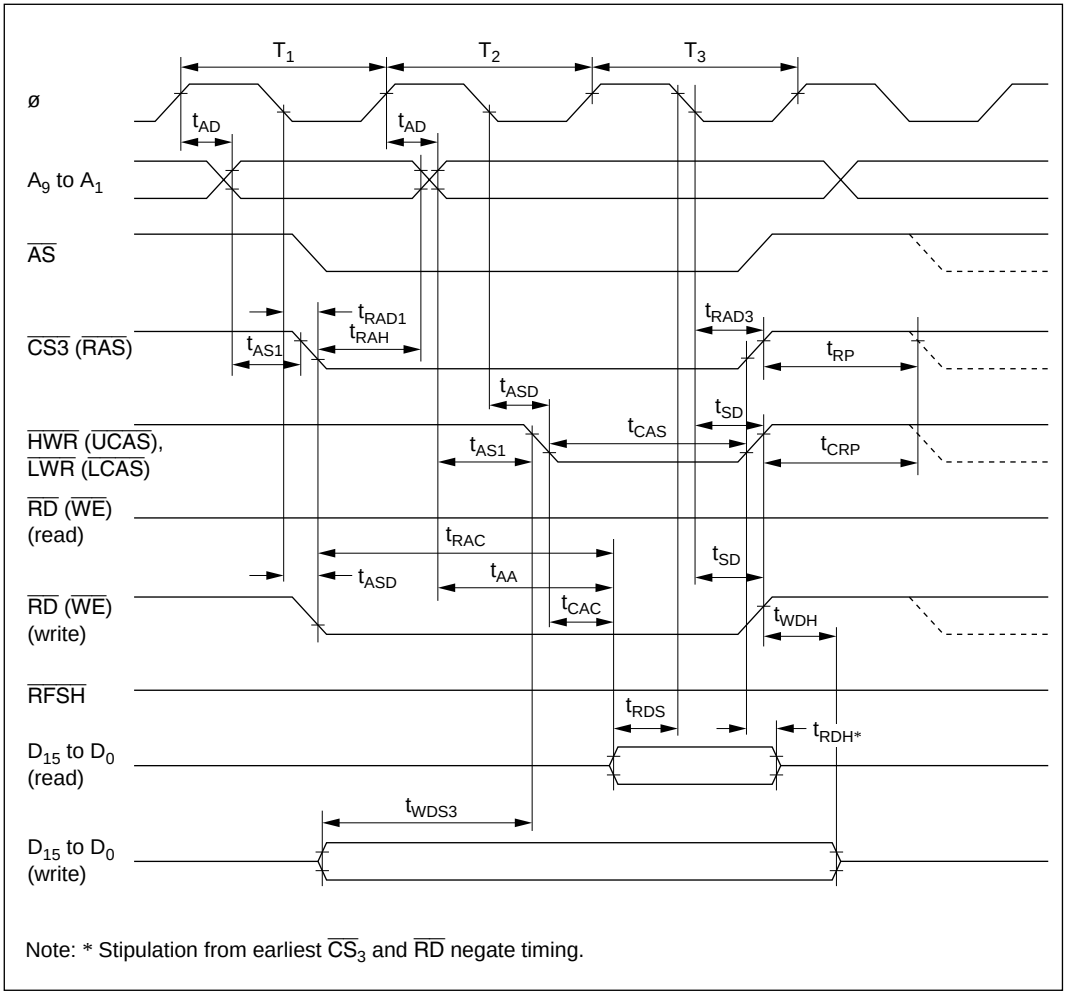


Figure 18-9 DRAM Bus Timing (Self-Refresh Mode) — 2$\overline{WE}$ Mode —



Note: * Stipulation from earliest $\overline{CS}_3$ and $\overline{RD}$ negate timing.

Figure 18-10 DRAM Bus Timing (Read/Write): Three-State Access — 2$\overline{CAS}$ Mode —

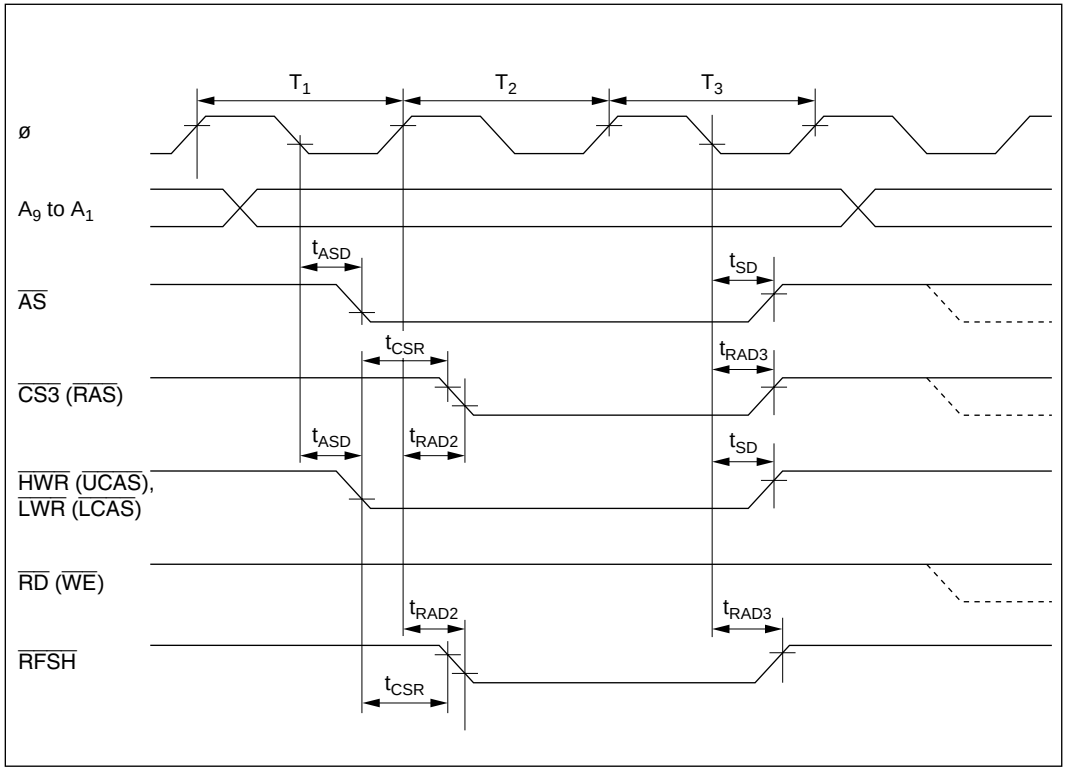


Figure 18-11 DRAM Bus Timing (Refresh Cycle): Three-State Access — 2CAS Mode —

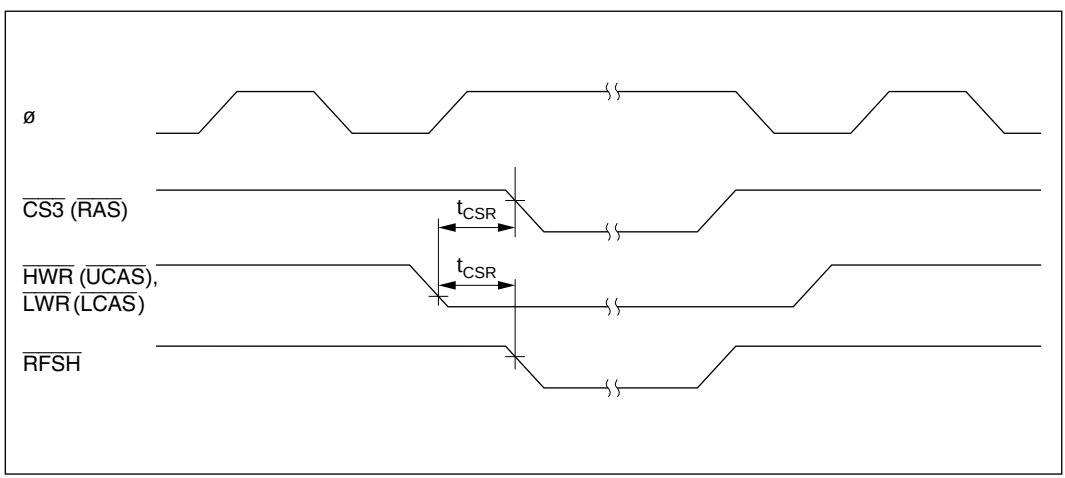


Figure 18-12 DRAM Bus Timing (Self-Refresh Mode) — 2CAS Mode —

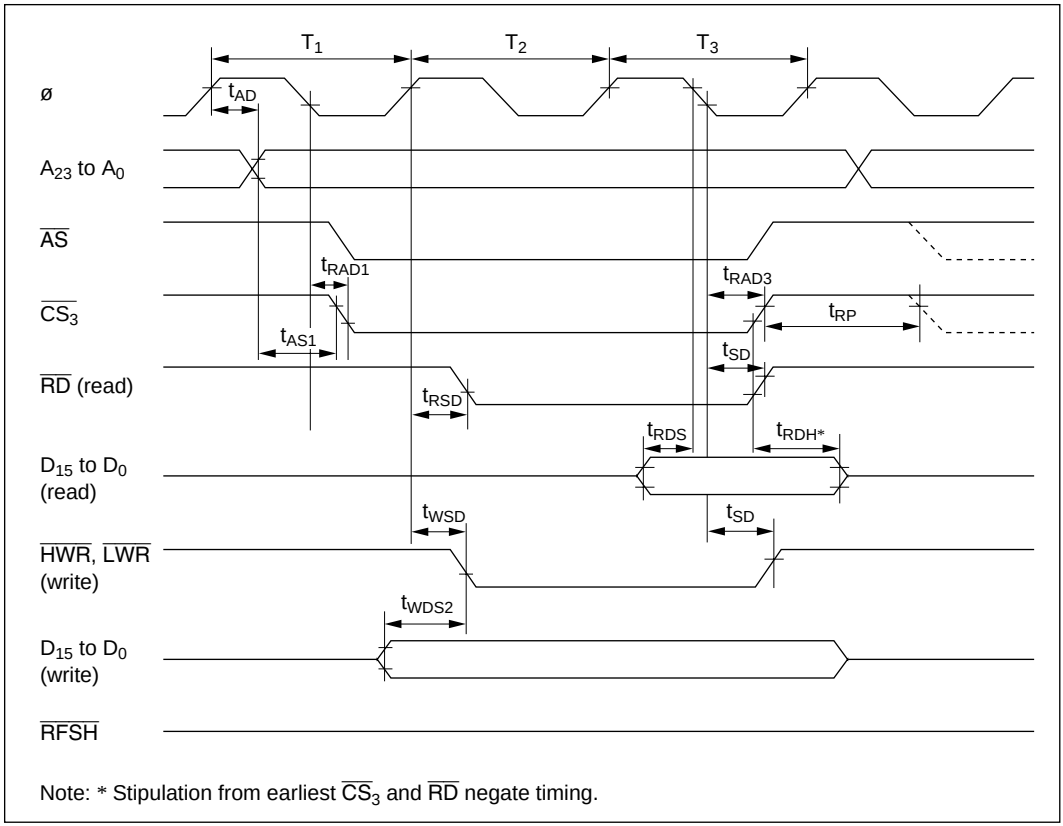


Figure 18-13 PSRAM Bus Timing (Read/Write): Three-State Access

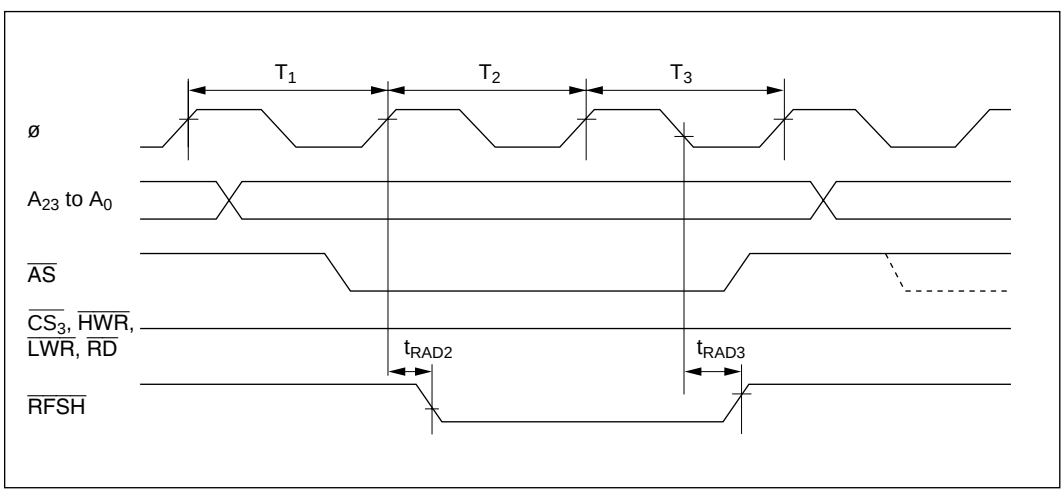


Figure 18-14 PSRAM Bus Timing (Refresh Cycle): Three-State Access

18.3.3 Control Signal Timing

Control signal timing is shown as follows:

- Reset input timing

  Figure 18-15 shows the reset input timing.

- Reset output timing

  Figure 18-16 shows the reset output timing.

- Interrupt input timing

  Figure 18-17 shows the input timing for NMI and $\overline{IRQ}_7$ to $\overline{IRQ}_0$.

- Bus-release mode timing

  Figure 18-18 shows the bus-release mode timing.

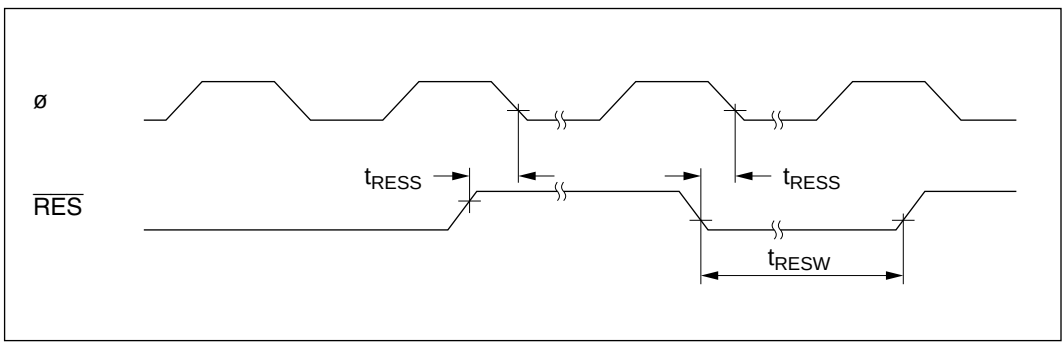


Figure 18-15 Reset Input Timing

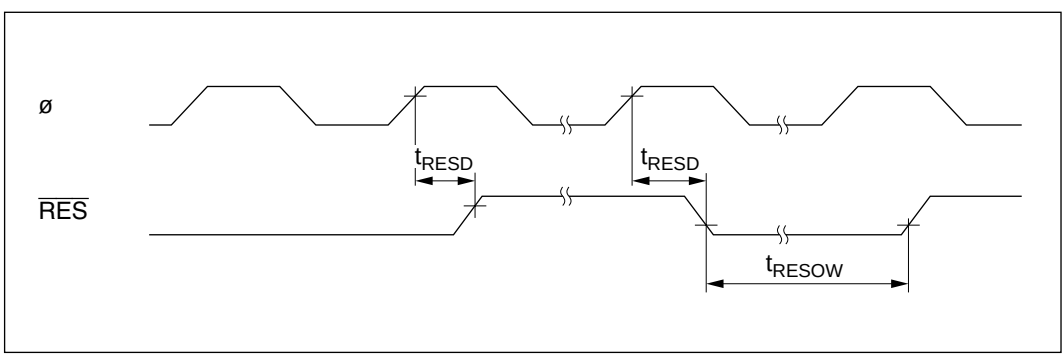


Figure 18-16 Reset Output Timing

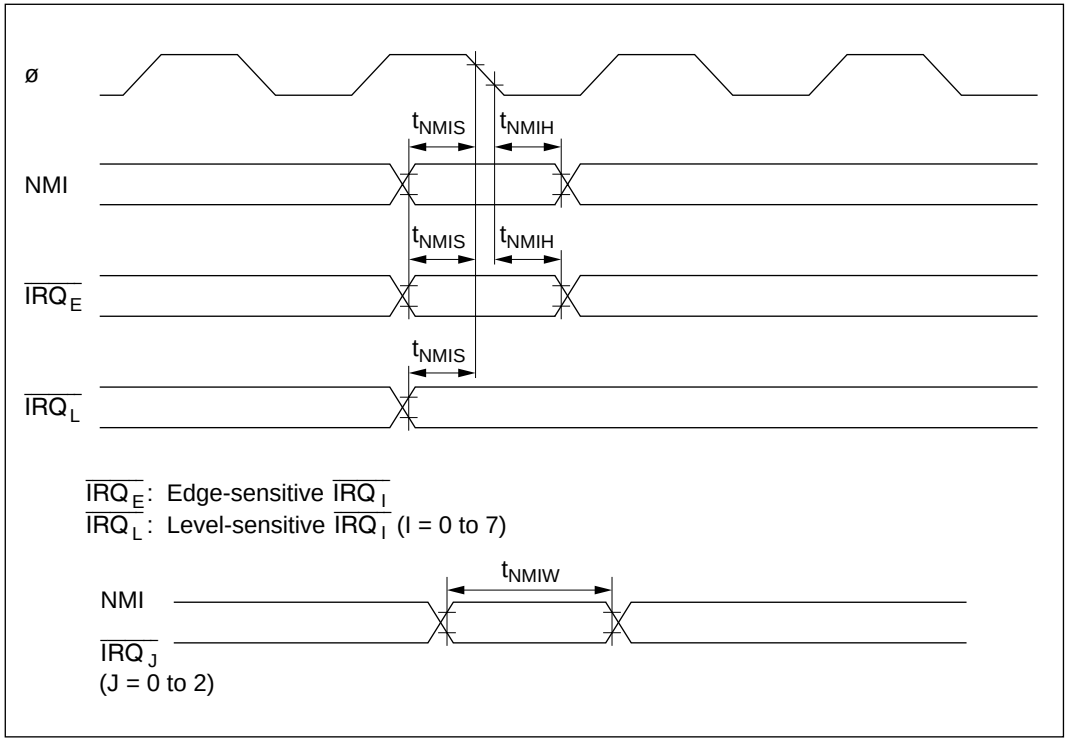


Figure 18-17 Interrupt Input Timing

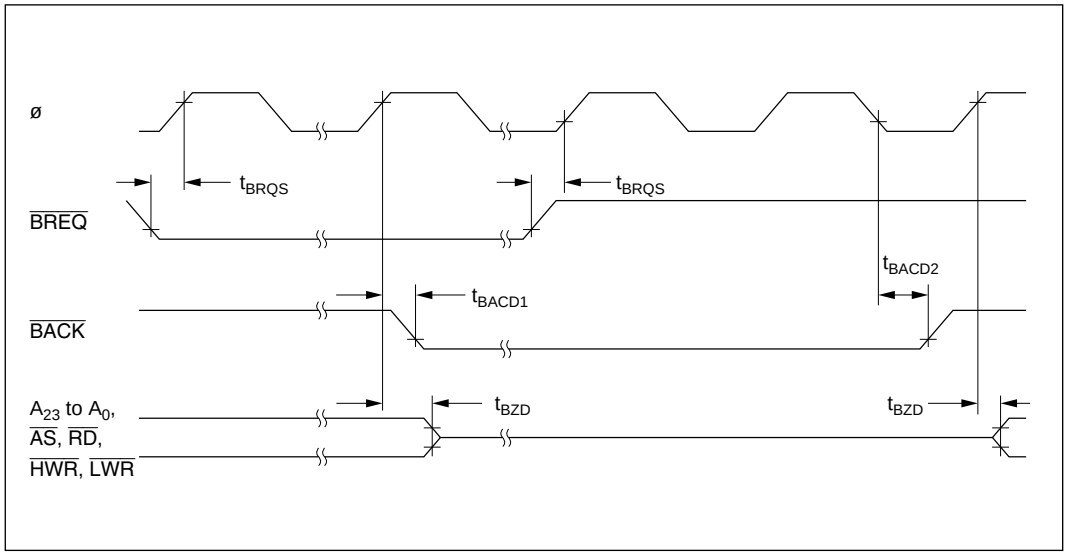


Figure 18-18 Bus-Release Mode Timing

18.3.4 Clock Timing

Clock timing is shown as follows:

- Oscillator settling timing

  Figure 18-19 shows the oscillator settling timing.

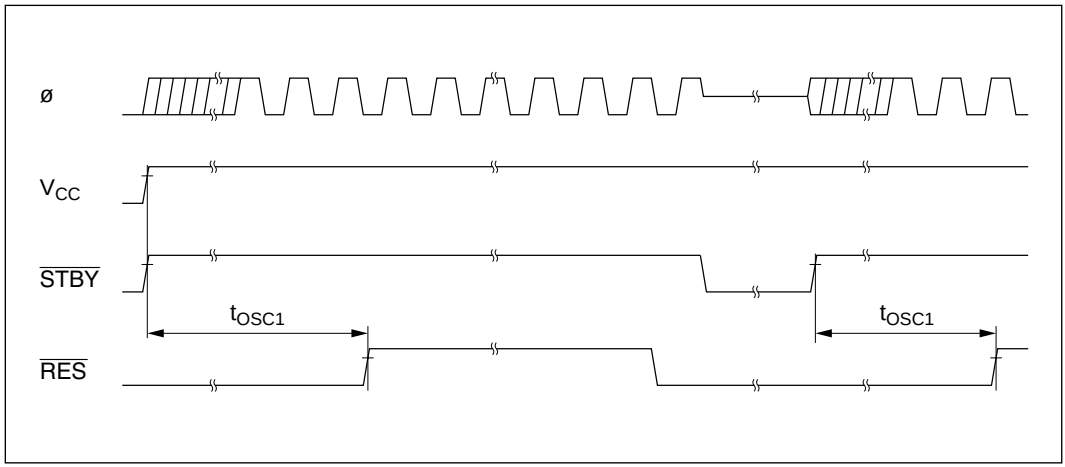


Figure 18-19 Oscillator Settling Timing

18.3.5 TPC and I/O Port Timing

TPC and I/O port timing is shown as follows.

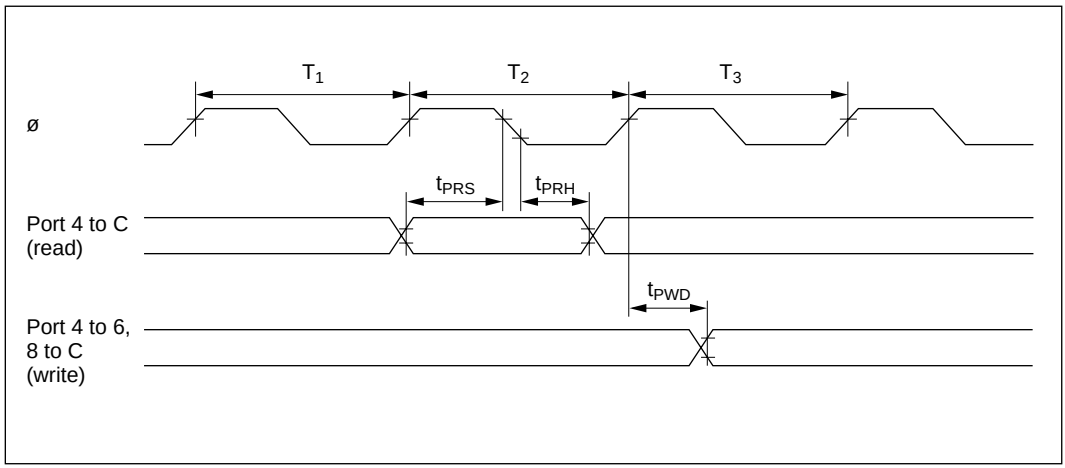


Figure 18-20 TPC and I/O Port Input/Output Timing

18.3.6 ITU Timing

ITU timing is shown as follows:

- ITU input/output timing

  Figure 18-21 shows the ITU input/output timing.

- ITU external clock input timing

  Figure 18-22 shows the ITU external clock input timing.

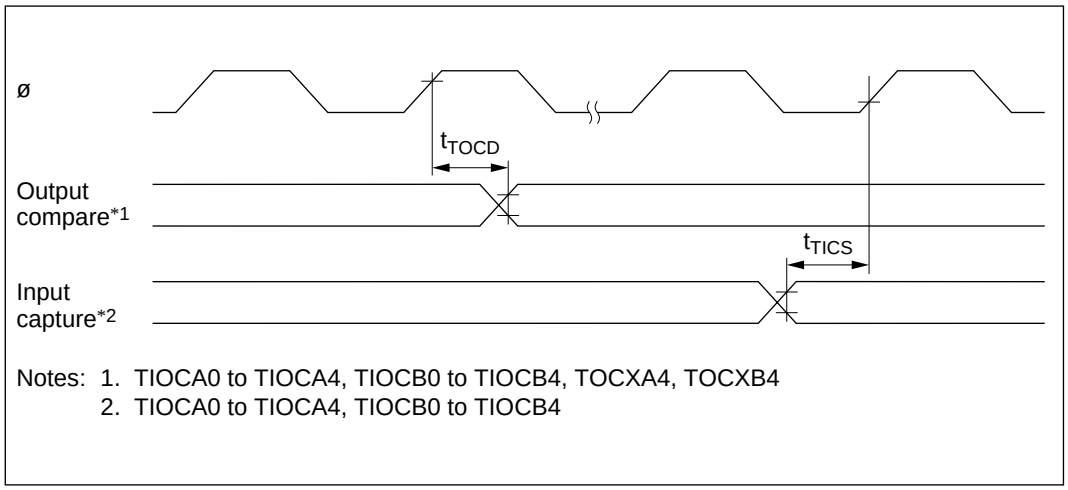


Figure 18-21 ITU Input/Output Timing

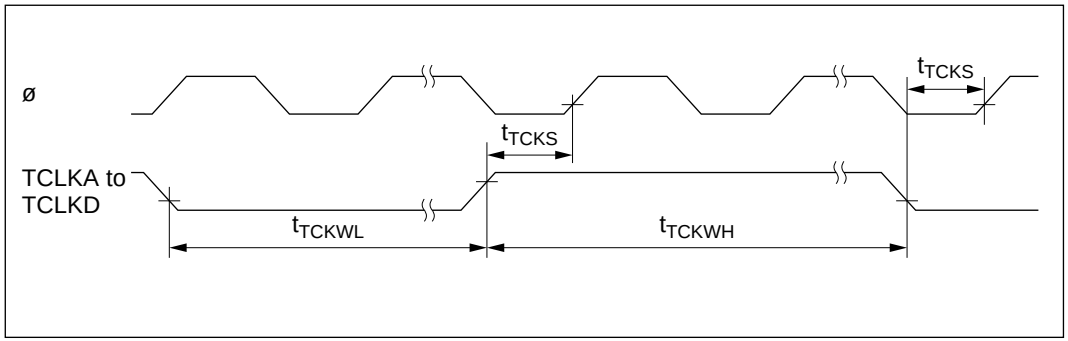


Figure 18-22 ITU Clock Input Timing

18.3.7 SCI Input/Output Timing

SCI timing is shown as follows:

- SCI input clock timing

  Figure 18-23 shows the SCI input clock timing.

- SCI input/output timing (synchronous mode)

  Figure 18-24 shows the SCI input/output timing in synchronous mode.

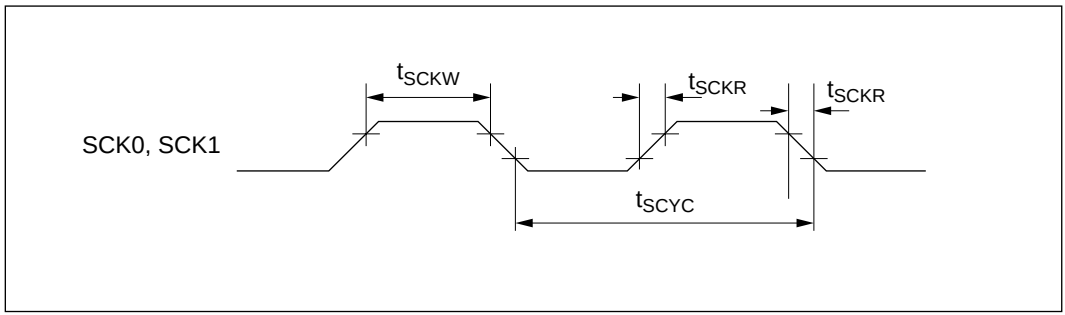


Figure 18-23 SCK Input Clock Timing

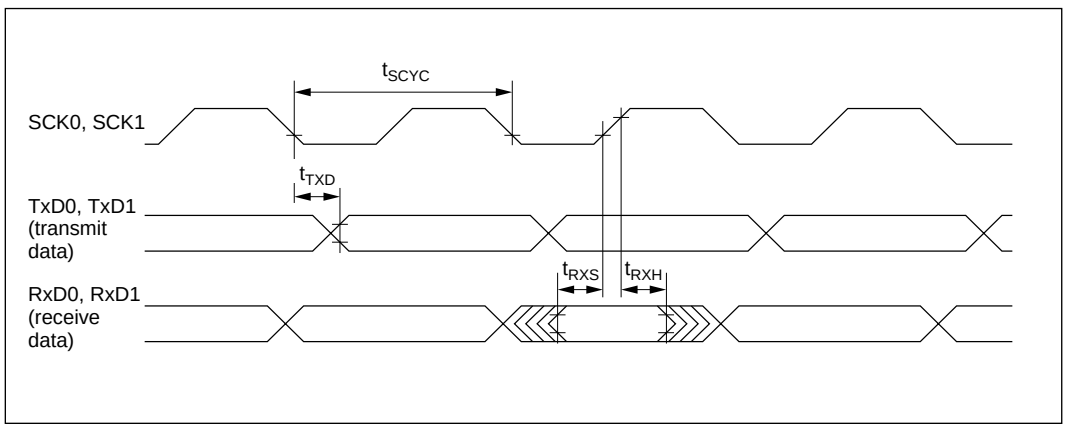


Figure 18-24 SCI Input/Output Timing in Synchronous Mode

18.3.8 DMAC Timing

DMAC timing is shown as follows.

- DMAC $\overline{\text{TEND}}$ output timing/2 state access

  Figure 18-25 shows the DMAC $\overline{\text{TEND}}$ output timing/2 state access

- DMAC $\overline{\text{TEND}}$ output timing/3 state access

  Figure 18-26 shows the DMAC $\overline{\text{TEND}}$ output timing/3 state access.

- DMAC $\overline{\text{DREQ}}$ input timing

  Figure 18-27 shows DMAC $\overline{\text{DREQ}}$ input timing.

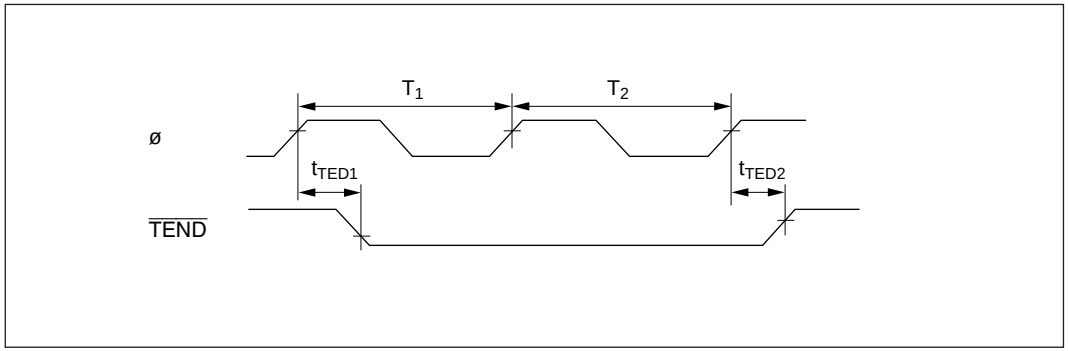


Figure 18-25 DMAC $\overline{\text{TEND}}$ Output Timing/2 State Access

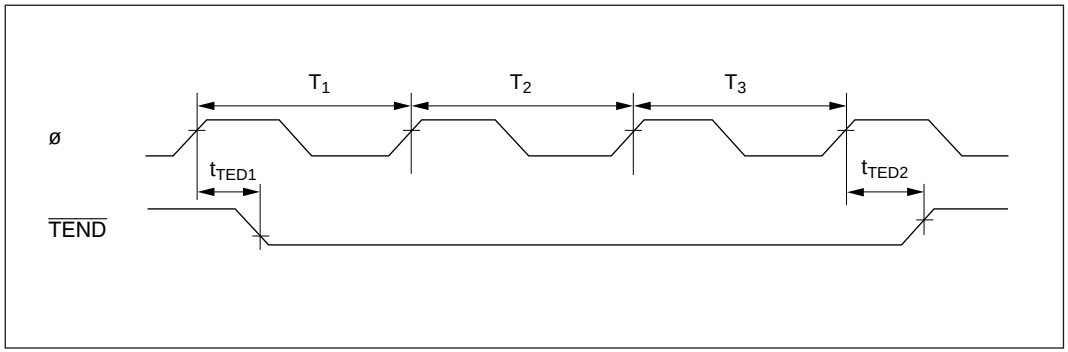


Figure 18-26 DMAC $\overline{\text{TEND}}$ Output Timing/3 State Access

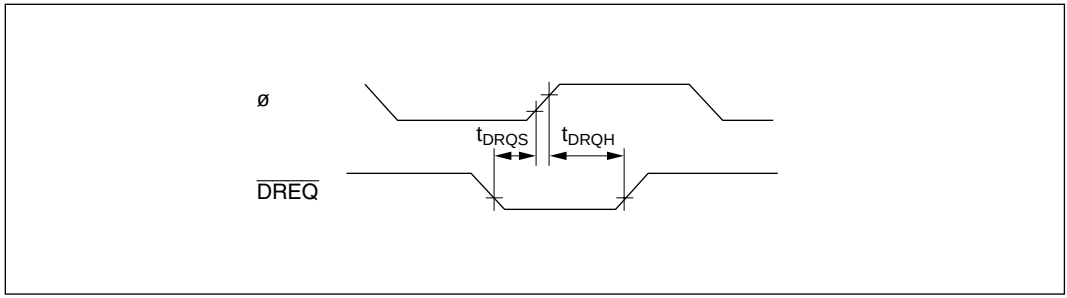


Figure 18-27 DMAC $\overline{DREQ}$ Input Timing

Appendix A Instruction Set

A.1 Instruction List

Operand Notation

Symbol	Description
Rd	General destination register
Rs	General source register
Rn	General register
ERd	General destination register (address register or 32-bit register)
ERs	General source register (address register or 32-bit register)
ERn	General register (32-bit register)
(EAd)	Destination operand
(EAs)	Source operand
PC	Program counter
SP	Stack pointer
CCR	Condition code register
N	N (negative) flag in CCR
Z	Z (zero) flag in CCR
V	V (overflow) flag in CCR
C	C (carry) flag in CCR
disp	Displacement
→	Transfer from the operand on the left to the operand on the right, or transition from the state on the left to the state on the right
+	Addition of the operands on both sides
–	Subtraction of the operand on the right from the operand on the left
×	Multiplication of the operands on both sides
÷	Division of the operand on the left by the operand on the right
∧	Logical AND of the operands on both sides
∨	Logical OR of the operands on both sides
⊕	Exclusive logical OR of the operands on both sides
¬	NOT (logical complement)
( ), < >	Contents of operand

Note: General registers include 8-bit registers (R0H to R7H and R0L to R7L) and 16-bit registers (R0 to R7 and E0 to E7).

Condition Code Notation

Symbol	Description
↕	Changed according to execution result
*	Undetermined (no guaranteed value)
0	Cleared to 0
1	Set to 1
—	Not affected by execution of the instruction
Δ	Varies depending on conditions, described in notes

Table A-1 Instruction Set

1. Data transfer instructions

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
MOV.B #xx:8, Rd	B	#xx:8 → Rd8	2									—	—	↕	↕	0	—	2	
MOV.B Rs, Rd	B	Rs8 → Rd8		2								—	—	↕	↕	0	—	2	
MOV.B @ERs, Rd	B	@ERs → Rd8			2							—	—	↕	↕	0	—	4	
MOV.B @(d:16, ERs), Rd	B	@(d:16, ERs) → Rd8				4						—	—	↕	↕	0	—	6	
MOV.B @(d:24, ERs), Rd	B	@(d:24, ERs) → Rd8				8						—	—	↕	↕	0	—	10	
MOV.B @ERs+, Rd	B	@ERs → RD8 ERs32+1 → ERs32					2					—	—	↕	↕	0	—	6	
MOV.B @aa:8, Rd	B	@aa:8 → Rd8						2				—	—	↕	↕	0	—	4	
MOV.B @aa:16, Rd	B	@aa:16 → Rd8						4				—	—	↕	↕	0	—	6	
MOV.B @aa:24, Rd	B	@aa:24 → Rd8						6				—	—	↕	↕	0	—	8	
MOV.B Rs, @ERd	B	Rs8 → @ERd			2							—	—	↕	↕	0	—	4	
MOV.B Rs, @(d:16, ERd)	B	Rs8 → @(d:16, ERd)				4						—	—	↕	↕	0	—	6	
MOV.B Rs, @(d:24, ERd)	B	Rs8 → @(d:24, ERd)				8						—	—	↕	↕	0	—	10	
MOV.B Rs, @ERd	B	ERd32–1 → ERd32 Rs8 → @ERd					2					—	—	↕	↕	0	—	6	
MOV.B Rs, @aa:8	B	Rs8 → @aa:8						2				—	—	↕	↕	0	—	4	
MOV.B Rs, @aa:16	B	Rs8 → @aa:16						4				—	—	↕	↕	0	—	6	
MOV.B Rs, @aa:24	B	Rs8 → @aa:24						6				—	—	↕	↕	0	—	8	
MOV.W #xx:16, Rd	W	#xx:16 → Rd16	4									—	—	↕	↕	0	—	4	
MOV.W Rs, Rd	W	Rs16 → Rd16		2								—	—	↕	↕	0	—	2	
MOV.W @ERs, Rd	W	@ERs → Rd16			2							—	—	↕	↕	0	—	4	
MOV.W @(d:16, ERs), Rd	W	@(d:16, ERs) → Rd16				4						—	—	↕	↕	0	—	6	
MOV.W @(d:24, ERs), Rd	W	@(d:24, ERs) → Rd16				8						—	—	↕	↕	0	—	10	
MOV.W @ERs+, Rd	W	@ERs → Rd16 ERs32+2 → @ERd32					2					—	—	↕	↕	0	—	6	
MOV.W @aa:16, Rd	W	@aa:16 → Rd16						4				—	—	↕	↕	0	—	6	

Table A-1 Instruction Set (cont)

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
MOV.W @aa:24, Rd	W	@aa:24 → Rd16						6				—	—	↕	↕	0	—	8	
MOV.W Rs, @ERd	W	Rs16 → @ERd			2							—	—	↕	↕	0	—	4	
MOV.W Rs, @(d:16, ERd)	W	Rs16 → @(d:16, ERd)				4						—	—	↕	↕	0	—	6	
MOV.W Rs, @(d:24, ERd)	W	Rs 16 → @(d:24, ERd)				8						—	—	↕	↕	0	—	10	
MOV.W Rs, @–ERd	W	ERd32–2 → ERd32 Rs16 → @ERd					2					—	—	↕	↕	0	—	6	
MOV.W Rs, @aa:16	W	Rs16 → @aa:16						4				—	—	↕	↕	0	—	6	
MOV.W Rs, @aa:24	W	Rs16 → @aa:24						6				—	—	↕	↕	0	—	8	
MOV.L #xx:32, Rd	L	#xx:32 → Rd32	6									—	—	↕	↕	0	—	6	
MOV.L ERs, ERd	L	ERs32 → ERd32		2								—	—	↕	↕	0	—	2	
MOV.L @ERs, ERd	L	@ERs → ERd32			4							—	—	↕	↕	0	—	8	
MOV.L @(d:16, ERs), ERd	L	@(d:16, ERs) → ERd32				6						—	—	↕	↕	0	—	10	
MOV.L @(d:24, ERs), ERd	L	@(d:24, ERs) → ERd32				10						—	—	↕	↕	0	—	14	
MOV.L @ERs+, ERd	L	@ERs → ERd32 ERs32+4 → ERs32					4					—	—	↕	↕	0	—	10	
MOV.L @aa:16, ERd	L	@aa:16 → ERd32						6				—	—	↕	↕	0	—	10	
MOV.L @aa:24, ERd	L	@aa:24 → ERd32						8				—	—	↕	↕	0	—	12	
MOV.L ERs, @ERd	L	ERs32 → @ERd			4							—	—	↕	↕	0	—	8	
MOV.L ERs, @(d:16, ERd)	L	ERs32 → @(d:16, ERd)				6						—	—	↕	↕	0	—	10	
MOV.L ERs, @(d:24, ERd)	L	ERs32 → @(d:24, ERd)				10						—	—	↕	↕	0	—	14	
MOV.L ERs, @–ERd	L	ERd32–4 → ERd32 ERs32 → @ERd					4					—	—	↕	↕	0	—	10	
MOV.L ERs, @aa:16	L	ERs32 → @aa:16						6				—	—	↕	↕	0	—	10	
MOV.L ERs, @aa:24	L	ERs32 → @aa:24						8				—	—	↕	↕	0	—	12	
POP.W Rn	W	@SP → Rn16 SP+2 → SP									2	—	—	↕	↕	0	—	6	
POP.L ERn	L	@SP → ERn32 SP+4 → SP									4	—	—	↕	↕	0	—	10	

Table A-1 Instruction Set (cont)

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
PUSH.W Rn	W	SP–2 → SP Rn16 → @SP									2	—	—	↕	↕	0	—	6	
PUSH.L ERn	L	SP–4 → SP ERn32 → @SP									4	—	—	↕	↕	0	—	10	
MOVFPE @aa:16, Rd	B	Cannot be used in the H8/3003						4				Cannot be used in the H8/3003							
MOVTPE Rs, @aa:16	B	Cannot be used in the H8/3003						4				Cannot be used in the H8/3003							

2. Arithmetic instructions

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
ADD.B #xx:8, Rd	B	Rd8+#xx:8 → Rd8	2									—	↕	↕	↕	↕	↕	2	
ADD.B Rs, Rd	B	Rd8+Rs8 → Rd8		2								—	↕	↕	↕	↕	↕	2	
ADD.W #xx:16, Rd	W	Rd16+#xx:16 → Rd16	4									—	1	↕	↕	↕	↕	4	
ADD.W Rs, Rd	W	Rd16+Rs16 → Rd16		2								—	1	↕	↕	↕	↕	2	
ADD.L #xx:32, ERd	L	ERd32+#xx:32 → ERd32	6									—	2	↕	↕	↕	↕	6	
ADD.L ERs, ERd	L	ERd32+ERs32 → ERd32		2								—	2	↕	↕	↕	↕	2	
ADDX.B #xx:8, Rd	B	Rd8+#xx:8 +C → Rd8	2									—	↕	↕	3	↕	↕	2	
ADDX.B Rs, Rd	B	Rd8+Rs8 +C → Rd8		2								—	↕	↕	3	↕	↕	2	
ADDS.L #1, ERd	L	ERd32+1 → ERd32		2								—	—	—	—	—	—	2	
ADDS.L #2, ERd	L	ERd32+2 → ERd32		2								—	—	—	—	—	—	2	
ADDS.L #4, ERd	L	ERd32+4 → ERd32		2								—	—	—	—	—	—	2	
INC.B Rd	B	Rd8+1 → Rd8		2								—	—	↕	↕	↕	—	2	
INC.W #1, Rd	W	Rd16+1 → Rd16		2								—	—	↕	↕	↕	—	2	
INC.W #2, Rd	W	Rd16+2 → Rd16		2								—	—	↕	↕	↕	—	2	

Table A-1 Instruction Set (cont)

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
INC.L #1, ERd	L	ERd32+1 → ERd32		2								—	—	↕	↕	↕	—	2	
INC.L #2, ERd	L	ERd32+2 → ERd32		2								—	—	↕	↕	↕	—	2	
DAA Rd	B	Rd8 decimal adjust → Rd8		2								—	*	↕	↕	*	—	2	
SUB.B Rs, Rd	B	Rd8–Rs8 → Rd8		2								—	↕	↕	↕	↕	↕	2	
SUB.W #xx:16, Rd	W	Rd16–#xx:16 → Rd16	4									—	1	↕	↕	↕	↕	4	
SUB.W Rs, Rd	W	Rd16–Rs16 → Rd16		2								—	1	↕	↕	↕	↕	2	
SUB.L #xx:32, ERd	L	ERd32–#xx:32 → ERd32	6									—	2	↕	↕	↕	↕	6	
SUB.L ERs, ERd	L	ERd32–ERs32 → ERd32		2								—	2	↕	↕	↕	↕	2	
SUBX.B #xx:8, Rd	B	Rd8–#xx:8–C → Rd8	2									—	↕	↕	3	↕	↕	2	
SUBX.B Rs, Rd	B	Rd8–Rs8–C → Rd8		2								—	↕	↕	3	↕	↕	2	
SUBS.L #1, ERd	L	ERd32–1 → ERd32		2								—	—	—	—	—	—	2	
SUBS.L #2, ERd	L	ERd32–2 → ERd32		2								—	—	—	—	—	—	2	
SUBS.L #4, ERd	L	ERd32–4 → ERd32		2								—	—	—	—	—	—	2	
DEC.B Rd	B	Rd8–1 → Rd8		2								—	—	↕	↕	↕	—	2	
DEC.W #1, Rd	W	Rd16–1 → Rd16		2								—	—	↕	↕	↕	—	2	
DEC.W #2, Rd	W	Rd16–2 → Rd16		2								—	—	↕	↕	↕	—	2	
DEC.L #1, ERd	L	ERd32–1 → ERd32		2								—	—	↕	↕	↕	—	2	
DEC.L #2, ERd	L	ERd32–2 → ERd32		2								—	—	↕	↕	↕	—	2	
DAS.Rd	B	Rd8 decimal adjust → Rd8		2								—	*	↕	↕	*	—	2	
MULXU. B Rs, Rd	B	Rd8 × Rs8 → Rd16 (unsigned multiplication)		2								—	—	—	—	—	—	14	
MULXU. W Rs, ERd	W	Rd16 × Rs16 → ERd32 (unsigned multiplication)		2								—	—	—	—	—	—	22	
MULXS. B Rs, Rd	B	Rd8 × Rs8 → Rd16 (signed multiplication)		4								—	—	↕	↕	—	—	16	
MULXS. W Rs, ERd	W	Rd16 × Rs16 → ERd32 (signed multiplication)		4								—	—	↕	↕	—	—	24	
DIVXU. B Rs, Rd	B	Rd16 ÷ Rs8 → Rd16 (RdH: remainder, RdL: quotient) (unsigned division)		2								—	—	6	7	—	—	14	

Table A-1 Instruction Set (cont)

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
DIVXU. W Rs, ERd	W	ERd32 ÷ Rs16 →ERd32 (Ed: remainder, Rd: quotient) (unsigned division)		2								—	—	6	7	—	—	22	
DIVXS. B Rs, Rd	B	Rd16 ÷ Rs8 → Rd16 (RdH: remainder, RdL: quotient) (signed division)		4								—	—	8	7	—	—	16	
DIVXS. W Rs, ERd	W	ERd32 ÷ Rs16 → ERd32 (Ed: remainder, Rd: quotient) (signed division)		4								—	—	8	7	—	—	24	
CMP.B #xx:8, Rd	B	Rd8–#xx:8	2									—	↕	↕	↕	↕	↕	2	
CMP.B Rs, Rd	B	Rd8–Rs8		2								—	↕	↕	↕	↕	↕	2	
CMP.W #xx:16, Rd	W	Rd16–#xx:16	4									—	1	↕	↕	↕	↕	4	
CMP.W Rs, Rd	W	Rd16–Rs16		2								—	1	↕	↕	↕	↕	2	
CMP.L #xx:32, ERd	L	ERd32–#xx:32	6									—	2	↕	↕	↕	↕	4	
CMP.L ERs, ERd	L	ERd32–ERs32		2								—	2	↕	↕	↕	↕	2	
NEG.B Rd	B	0–Rd8 → Rd8		2								—	↕	↕	↕	↕	↕	2	
NEG.W Rd	W	0–Rd16 → Rd16		2								—	↕	↕	↕	↕	↕	2	
NEG.L ERd	L	0–ERd32 → ERd32		2								—	↕	↕	↕	↕	↕	2	
EXTU.W Rd	W	0 → (<bits 15 to 8> of Rd16)		2								—	—	0	↕	0	—	2	
EXTU.L ERd	L	0 → (<bits 31 to 16> of Rd32)		2								—	—	0	↕	0	—	2	
EXTS.W Rd	W	(<bit 7> of Rd16) → (<bits 15 to 8> of Rd16)		2								—	—	↕	↕	0	—	2	
EXTS.L ERd	L	(<bit 15> of Rd32) → (<bits 31 to 16> of ERd32)		2								—	—	↕	↕	0	—	2	

Table A-1 Instruction Set (cont)

3. Logic instructions

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
AND.B #xx:8, Rd	B	Rd8∧#xx:8 → Rd8	2									—	—	↕	↕	0	—	2	
AND.B Rs, Rd	B	Rd8∧Rs8 → Rd8		2								—	—	↕	↕	0	—	2	
AND.W #xx:16, Rd	W	Rd16∧#xx:16 → Rd16	4									—	—	↕	↕	0	—	4	
AND.W Rs, Rd	W	Rd16∧Rs16 → Rd16		2								—	—	↕	↕	0	—	2	
AND.L #xx:32, ERd	L	ERd32∧#xx:32 → ERd32	6									—	—	↕	↕	0	—	6	
AND.L ERs, ERd	L	ERd32∧ERs32 → ERd32		4								—	—	↕	↕	0	—	4	
OR.B #xx:8, Rd	B	Rd8∨#xx:8 → Rd8	2									—	—	↕	↕	0	—	2	
OR.B Rs, Rd	B	Rd8∨Rs8 → Rd8		2								—	—	↕	↕	0	—	2	
OR.W #xx:16, Rd	W	Rd16∨#xx:16 → Rd16	4									—	—	↕	↕	0	—	4	
OR.W Rs, Rd	W	Rd16∨Rs16 → Rd16		2								—	—	↕	↕	0	—	2	
OR.L #xx:32, ERd	L	ERd32∨#xx:32 → ERd32	6									—	—	↕	↕	0	—	6	
OR.L ERs, ERd	L	ERd32∨ERs32 → ERd32		4								—	—	↕	↕	0	—	4	
XOR.B #xx:8, Rd	B	Rd8⊕#xx:8 → Rd8	2									—	—	↕	↕	0	—	2	
XOR.B Rs, Rd	B	Rd8⊕Rs8 → Rd8		2								—	—	↕	↕	0	—	2	
XOR.W #xx:16, Rd	W	Rd16⊕#xx:16 → Rd16	4									—	—	↕	↕	0	—	4	
XOR.W Rs, Rd	W	Rd16⊕Rs16 → Rd16		2								—	—	↕	↕	0	—	2	
XOR.L #xx:32, ERd	L	ERd32⊕#xx:32 → ERd32	6									—	—	↕	↕	0	—	6	
XOR.L ERs, ERd	L	ERd32⊕ERs32 → ERd32		4								—	—	↕	↕	0	—	4	
NOT.B Rd	B	¬ Rd8 → Rd8		2								—	—	↕	↕	0	—	2	
NOT.W Rd	W	¬ Rd16 → Rd16		2								—	—	↕	↕	0	—	2	
NOT.L ERd	L	¬ Rd32 → Rd32		2								—	—	↕	↕	0	—	2	

Table A-1 Instruction Set (cont)

4. Shift instructions

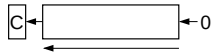
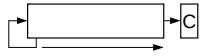
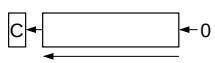
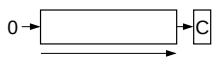
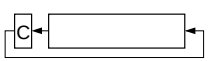
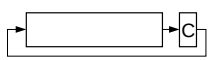
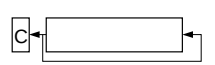
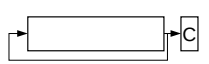
Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
SHAL.B Rd	B			2								—	—	↕	↕	↕	↕	2	
SHAL.W Rd	W			2								—	—	↕	↕	↕	↕	2	
SHAL.L ERd	L			2								—	—	↕	↕	↕	↕	2	
SHAR.B Rd	B			2								—	—	↕	↕	0	↕	2	
SHAR.W Rd	W			2								—	—	↕	↕	0	↕	2	
SHAR.L ERd	L			2								—	—	↕	↕	0	↕	2	
SHLL.B Rd	B			2								—	—	↕	↕	0	↕	2	
SHLL.W Rd	W			2								—	—	↕	↕	0	↕	2	
SHLL.L ERd	L			2								—	—	↕	↕	0	↕	2	
SHLR.B Rd	B			2								—	—	↕	↕	0	↕	2	
SHLR.W Rd	W			2								—	—	↕	↕	0	↕	2	
SHLR.L ERd	L			2								—	—	↕	↕	0	↕	2	
ROTXL.B Rd	B			2								—	—	↕	↕	0	↕	2	
ROTXL.W Rd	W			2								—	—	↕	↕	0	↕	2	
ROTXL.L ERd	L			2								—	—	↕	↕	0	↕	2	
ROTXR.B Rd	B			2								—	—	↕	↕	0	↕	2	
ROTXR.W Rd	W			2								—	—	↕	↕	0	↕	2	
ROTXR.L ERd	L			2								—	—	↕	↕	0	↕	2	
ROTL.B Rd	B			2								—	—	↕	↕	0	↕	2	
ROTL.W Rd	W			2								—	—	↕	↕	0	↕	2	
ROTL.L ERd	L			2								—	—	↕	↕	0	↕	2	
ROTR.B Rd	B			2								—	—	↕	↕	0	↕	2	
ROTR.W Rd	W			2								—	—	↕	↕	0	↕	2	
ROTR.L ERd	L			2								—	—	↕	↕	0	↕	2	

Table A-1 Instruction Set (cont)

5. Bit manipulation instructions

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
BSET #xx:3, Rd	B	(#xx:3 of Rd8) ← 1		2								—	—	—	—	—	—	2	
BSET #xx:3, @ERd	B	(#xx:3 of @ERd) ← 1			4							—	—	—	—	—	—	8	
BSET #xx:3, @aa:8	B	(#xx:3 of @aa:8) ← 1						4				—	—	—	—	—	—	8	
BSET Rn, Rd	B	(Rn8 of Rd8) ← 1		2								—	—	—	—	—	—	2	
BSET Rn, @ERd	B	(Rn8 of @ERd) ← 1			4							—	—	—	—	—	—	8	
BSET Rn, @aa:8	B	(Rn8 of @aa:8) ← 1						4				—	—	—	—	—	—	8	
BCLR #xx:3, Rd	B	(#xx:3 of Rd8) ← 0		2								—	—	—	—	—	—	2	
BCLR #xx:3, @ERd	B	(#xx:3 of @ERd) ← 0			4							—	—	—	—	—	—	8	
BCLR #xx:3, @aa:8	B	(#xx:3 of @aa:8) ← 0						4				—	—	—	—	—	—	8	
BCLR Rn, Rd	B	(Rn8 of Rd8) ← 0		2								—	—	—	—	—	—	2	
BCLR Rn, @ERd	B	(Rn8 of @ERd) ← 0			4							—	—	—	—	—	—	8	
BCLR Rn, @aa:8	B	(Rn8 of @aa:8) ← 0						4				—	—	—	—	—	—	8	
BNOT #xx:3, Rd	B	(#xx:3 of Rd8) ← ¬ (#xx:3 of Rd8)		2								—	—	—	—	—	—	2	
BNOT #xx:3, @ERd	B	(#xx:3 of @ERd) ← ¬ (#xx:3 of @ERd)			4							—	—	—	—	—	—	8	
BNOT #xx:3, @aa:8	B	(#xx:3 of @aa:8) ← ¬ (#xx:3 of @aa:8)						4				—	—	—	—	—	—	8	
BNOT Rn, Rd	B	(Rn8 of Rd8) ← ¬ (Rn8 of Rd8)		2								—	—	—	—	—	—	2	
BNOT Rn, @ERd	B	(Rn8 of @ERd) ← ¬ (Rn8 of @ERd)			4							—	—	—	—	—	—	8	
BNOT Rn, @aa:8	B	(Rn8 of @aa:8) ← ¬ (Rn8 of @aa:8)						4				—	—	—	—	—	—	8	
BTST #xx:3, Rd	B	(#xx:3 of Rd8) → Z		2								—	—	—	↕	—	—	2	
BTST #xx:3, @ERd	B	(#xx:3 of @ERd) → Z			4							—	—	—	↕	—	—	6	
BTST #xx:3, @aa:8	B	(#xx:3 of @aa:8) → Z						4				—	—	—	↕	—	—	6	
BTST Rn, Rd	B	(Rn8 of @Rd8) → Z		2								—	—	—	↕	—	—	2	
BTST Rn, @ERd	B	(Rn8 of @ERd) → Z			4							—	—	—	↕	—	—	6	
BTST Rn, @aa:8	B	(Rn8 of @aa:8) → Z						4				—	—	—	↕	—	—	6	
BLD #xx:3, Rd	B	(#xx:3 of Rd8) → C		2								—	—	—	—	—	↕	2	

Table A-1 Instruction Set (cont)

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
BLD #xx:3, @ERd	B	(#xx:3 of @ERd) → C			4							—	—	—	—	—	↕	6	
BLD #xx:3, @aa:8	B	(#xx:3 of @aa:8) → C						4				—	—	—	—	—	↕	6	
BILD #xx:3, Rd	B	¬ (#xx:3 of Rd8) → C		2								—	—	—	—	—	↕	2	
BILD #xx:3, @ERd	B	¬ (#xx:3 of @ERd) → C			4							—	—	—	—	—	↕	6	
BILD #xx:3, @aa:8	B	¬ (#xx:3 of @aa:8) → C						4				—	—	—	—	—	↕	6	
BST #xx:3, Rd	B	C → (#xx:3 of Rd8)		2								—	—	—	—	—	—	2	
BST #xx:3, @REd	B	C → (#xx:3 of @ERd)			4							—	—	—	—	—	—	8	
BST #xx:3, @aa:8	B	C → (#xx:3 of @aa:8)						4				—	—	—	—	—	—	8	
BIST #xx:3, Rd	B	C → (#xx:3 of Rd8)		2								—	—	—	—	—	—	2	
BIST #xx:3, @ERd	B	C → (#xx:3 of @ERd24)			4							—	—	—	—	—	—	8	
BIST #xx:3, @aa:8	B	C → (#xx:3 of @aa:8)						4				—	—	—	—	—	—	8	
BAND #xx:3, Rd	B	C∧(#xx:3 of Rd8) → C		2								—	—	—	—	—	↕	2	
BAND #xx:3, @ERd	B	C∧(#xx:3 of @ERd24) → C			4							—	—	—	—	—	↕	6	
BAND #xx:3, @aa:8	B	C∧(#xx:3 of @aa:8) → C						4				—	—	—	—	—	↕	6	
BLAND #xx:3, Rd	B	C∧(#xx:3 of Rd8) → C		2								—	—	—	—	—	↕	2	
BLAND #xx:3, @ERd	B	C∧(#xx:3 of @ERd24) → C			4							—	—	—	—	—	↕	6	
BLAND #xx:3, @aa:8	B	C∧(#xx:3 of @aa:8) → C						4				—	—	—	—	—	↕	6	
BOR #xx:3, Rd	B	C∨(#xx:3 of Rd8) → C		2								—	—	—	—	—	↕	2	
BOR #xx:3, @ERd	B	C∨(#xx:3 of @ERd24) → C			4							—	—	—	—	—	↕	6	
BOR #xx:3, @aa:8	B	C∨(#xx:3 of @aa:8) → C						4				—	—	—	—	—	↕	6	
BIOR #xx:3, Rd	B	C∨(#xx:3 of Rd8) → C		2								—	—	—	—	—	↕	2	
BIOR #xx:3, @ERd	B	C∨(#xx:3 of @ERd24) → C			4							—	—	—	—	—	↕	6	
BIOR #xx:3, @aa:8	B	C∨(#xx:3 of @aa:8) → C						4				—	—	—	—	—	↕	6	
BXOR #xx:3, Rd	B	C⊕(#xx:3 of Rd8) → C		2								—	—	—	—	—	↕	2	
BXOR #xx:3, @ERd	B	C⊕(#xx:3 of @ERd24) → C			4							—	—	—	—	—	↕	6	
BXOR #xx:3, @aa:8	B	C⊕(#xx:3 of @aa:8) → C						4				—	—	—	—	—	↕	6	
BIXOR #xx:3, Rd	B	C⊕(#xx:3 of Rd8) → C		2								—	—	—	—	—	↕	2	
BIXOR #xx:3, @ERd	B	C⊕(#xx:3 of @ERd24) → C			4							—	—	—	—	—	↕	6	
BIXOR #xx:3, @aa:8	B	C⊕(#xx:3 of @aa:8) → C						4				—	—	—	—	—	↕	6	

Table A-1 Instruction Set (cont)

6. Branching instructions

Mnemonic	Operand Size	Operation		Addressing Mode and Instruction Length (bytes)										Condition Code						No. of States *1	
				#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
BRA d:8 (BT d:8)	—	If condition is true then PC ← PC+d else next;	Always							2			—	—	—	—	—	—	4	
BRA d:16 (BT d:16)	—									4			—	—	—	—	—	—	6	
BRN d:8 (BF d:8)	—		Never							2			—	—	—	—	—	—	4	
BRN d:16 (BF d:16)	—									4			—	—	—	—	—	—	6	
BHI d:8	—		C ∨ Z = 0							2			—	—	—	—	—	—	4	
BHI d:16	—									4			—	—	—	—	—	—	6	
BLS d:8	—		C ∨ Z = 1							2			—	—	—	—	—	—	4	
BLS d:16	—									4			—	—	—	—	—	—	6	
BCC d:8 (BHS d:8)	—		C = 0							2			—	—	—	—	—	—	4	
BCC d:16 (BHS d:16)	—									4			—	—	—	—	—	—	6	
BCS d:8 (BLO d:8)	—		C = 1							2			—	—	—	—	—	—	4	
BCS d:16 (BLO d:16)	—									4			—	—	—	—	—	—	6	
BNE d:8	—		Z = 0							2			—	—	—	—	—	—	4	
BNE d:16	—									4			—	—	—	—	—	—	6	
BEQ d:8	—		Z = 1							2			—	—	—	—	—	—	4	
BEQ d:16	—									4			—	—	—	—	—	—	6	
BVC d:8	—		V = 0							2			—	—	—	—	—	—	4	
BVC d:16	—									4			—	—	—	—	—	—	6	
BVS d:8	—		V = 1							2			—	—	—	—	—	—	4	
BVS d:16	—									4			—	—	—	—	—	—	6	
BPL d:8	—		N = 0							2			—	—	—	—	—	—	4	
BPL d:16	—									4			—	—	—	—	—	—	6	
BMI d:8	—		N = 1							2			—	—	—	—	—	—	4	
BMI d:16	—									4			—	—	—	—	—	—	6	
BGE d:8	—		N⊕V = 0							2			—	—	—	—	—	—	4	
BGE d:16	—									4			—	—	—	—	—	—	6	
BLT d:8	—		N⊕V = 1							2			—	—	—	—	—	—	4	
BLT d:16	—									4			—	—	—	—	—	—	6	
BGT d:8	—		Z ∨ (N⊕V) = 0							2			—	—	—	—	—	—	4	
BGT d:16	—									4			—	—	—	—	—	—	6	

Table A-1 Instruction Set (cont)

Mnemonic	Operand Size	Operation		Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
				#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
BLE d:8	—	If condition is true then PC ← PC+d else next;	Z ∨ (N⊕V) = 1							2			—	—	—	—	—	—	4	
BLE d:16	—									4			—	—	—	—	—	—	6	
JMP @ERn	—	PC ← ERn				2							—	—	—	—	—	—	4	
JMP @aa:24	—	PC ← aa:24							4				—	—	—	—	—	—	6	
JMP @@aa:8	—	PC ← @aa:8									2		—	—	—	—	—	—	8	10
BSR d:8	—	PC → @–SP PC ← PC+d:8								2			—	—	—	—	—	—	6	8
BSR d:16	—	PC → @–SP PC ← PC+d:16								4			—	—	—	—	—	—	8	10
JSR @ERn	—	PC → @–SP PC ← @ERn				2							—	—	—	—	—	—	6	8
JSR @aa:24	—	PC → @–SP PC ← @aa:24							4				—	—	—	—	—	—	8	10
JSR @@aa:8	—	PC → @–SP PC ← @aa:8									2		—	—	—	—	—	—	8	12
RTS	—	PC ← @SP+										2	—	—	—	—	—	—	8	10

Table A-1 Instruction Set (cont)

7. System control instructions

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
TRAPA #x:2	—	PC → @–SP CCR → @–SP <vector> → PC									2	—	—	—	—	—	—	14	16
RTE	—	CCR ← @SP+ PC ← @SP+										↕	↕	↕	↕	↕	↕	10	
SLEEP	—	Transition to power-down state										—	—	—	—	—	—	2	
LDC #xx:8, CCR	B	#xx:8 → CCR	2									↕	↕	↕	↕	↕	↕	2	
LDC Rs, CCR	B	Rs8 → CCR		2								↕	↕	↕	↕	↕	↕	2	
LDC @ERs, CCR	W	@ERs → CCR			4							↕	↕	↕	↕	↕	↕	6	
LDC @(d:16, ERs), CCR	W	@(d:16, ERs) → CCR				6						↕	↕	↕	↕	↕	↕	8	
LDC @(d:24, ERs), CCR	W	@(d:24, ERs) → CCR				10						↕	↕	↕	↕	↕	↕	12	
LDC @ERs+, CCR	W	@ERs → CCR ERs32+2 → ERs32					4					↕	↕	↕	↕	↕	↕	8	
LDC @aa:16, CCR	W	@aa:16 → CCR						6				↕	↕	↕	↕	↕	↕	8	
LDC @aa:24, CCR	W	@aa:24 → CCR						8				↕	↕	↕	↕	↕	↕	10	
STC CCR, Rd	B	CCR → Rd8		2								—	—	—	—	—	—	2	
STC CCR, @ERd	W	CCR → @ERd			4							—	—	—	—	—	—	6	
STC CCR, @(d:16, ERd)	W	CCR → @(d:16, ERd)				6						—	—	—	—	—	—	8	
STC CCR, @(d:24, ERd)	W	CCR → @(d:24, ERd)				10						—	—	—	—	—	—	12	
STC CCR, @–ERd	W	ERd32–2 → ERd32 CCR → @ERd					4					—	—	—	—	—	—	8	
STC CCR, @aa:16	W	CCR → @aa:16						6				—	—	—	—	—	—	8	
STC CCR, @aa:24	W	CCR → @aa:24						8				—	—	—	—	—	—	10	
ANDC #xx:8, CCR	B	CCR∧#xx:8 → CCR	2									↕	↕	↕	↕	↕	↕	2	
ORC #xx:8, CCR	B	CCR∨#xx:8 → CCR	2									↕	↕	↕	↕	↕	↕	2	
XORC #xx:8, CCR	B	CCR⊕#xx:8 → CCR	2									↕	↕	↕	↕	↕	↕	2	
NOP	—	PC ← PC+2									2	—	—	—	—	—	—	2	

Table A-1 Instruction Set (cont)

8. Block transfer instructions

Mnemonic	Operand Size	Operation	Addressing Mode and Instruction Length (bytes)									Condition Code						No. of States *1	
			#xx	Rn	@ERn	@(d, ERn)	@–ERn/@ERn+	@aa	@(d, PC)	@@aa	Implied	I	H	N	Z	V	C	Normal	Advanced
EEPMOV. B	—	if R4L ≠ 0 then repeat @R5 → @R6 R5+1 → R5 R6+1 → R6 R4L–1 → R4L until R4L=0 else next									4	—	—	—	—	—	—	8+ 4n*2	
EEPMOV. W	—	if R4 ≠ 0 then repeat @R5 → @R6 R5+1 → R5 R6+1 → R6 R4L–1 → R4 until R4=0 else next									4	—	—	—	—	—	—	8+ 4n*2	

Notes: 1. The number of states is the number of states required for execution when the instruction and its operands are located in on-chip memory. For other cases see section A.3, Number of States Required for Execution.

2. n is the value set in register R4L or R4.

1 Set to 1 when a carry or borrow occurs at bit 11; otherwise cleared to 0.
2 Set to 1 when a carry or borrow occurs at bit 27; otherwise cleared to 0.
3 Retains its previous value when the result is zero; otherwise cleared to 0.
4 Set to 1 when the adjustment produces a carry; otherwise retains its previous value.
5 The number of states required for execution of an instruction that transfers data in synchronization with the E clock is variable.
6 Set to 1 when the divisor is negative; otherwise cleared to 0.
7 Set to 1 when the divisor is zero; otherwise cleared to 0.
8 Set to 1 when the quotient is negative; otherwise cleared to 0.

A.2 Operation Code Map (1)

Instruction code:

1st byte		2nd byte	
AH	AL	BH	BL

AH \ AL	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	NOP	Table A.2 (2)	STC	LDC	ORG	XORC	ANDC	LDC	ADD		Table A.2 (2)	Table A.2 (2)	MOV		ADDX	Table A.2 (2)
1	Table A.2 (2)	Table A.2 (2)	Table A.2 (2)	Table A.2 (2)	OR.B	XOR.B	AND.B	Table A.2 (2)	SUB		Table A.2 (2)	Table A.2 (2)	CMP		SUBX	Table A.2 (2)
2																
3																
4	BRA	BRN	BHI	BLS	BCC	BCS	BNE	BEQ	BVC	BVS	BPL	BMI	BGE	BLT	BGT	BLE
5	MULXU.B	DIVXU.B	MULXU.W	DIVXU.W	RTS	BSR	RTE	TRAPA	Table A.2 (2)	JMP			BSR	JSR		
6	BSET	BNOT	BCLR	BTST	OR.W	XOR.W	AND.W	BST / BIST	MOV.B	MOV						
7					BOR / BIOR	BXOR / BIXOR	BAND / BIAND	BLD / BILD	MOV.B/W	Table A.2 (2)	Table A.2 (2)	EEPMOV	Table A.2 (3)			
8	ADD															
9	ADDX															
A	CMP															
B	SUBX															
C	OR															
D	XOR															
E	AND															
F	MOV															

Operation Code Map (2)

Instruction code:

1st byte		2nd byte	
AH	AL	BH	BL

AH AL \ BH	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
01	MOV				LDC/STC				SLEEP				Table A.2 (3)	Table A.2 (3)		Table A.2 (3)
0A	INC								ADD							
0B	ADDS					INC		INC	ADDS					INC		INC
0F	DAA								MOV							
10	SHLL			SHLL					SHAL			SHAL				
11	SHLR			SHLR					SHAR			SHAR				
12	ROTXL			ROTXL					ROTL			ROTL				
13	ROTXR			ROTXR					ROTR			ROTR				
17	NOT			NOT		EXTU		EXTU	NEG			NEG		EXTS		EXTS
1A	DEC								SUB							
1B	SUBS					DEC		DEC	SUB					DEC		DEC
1F	DAS								CMP.L							
58	BRA	BRN	BHI	BLS	BCC	BCS	BNE	BEQ	BVC	BVS	BPL	BMI	BGE	BLT	BGT	BLE
79	MOV	ADD	CMP	SUB	OR	XOR	AND									
7A	MOV	ADD	CMP	SUB	OR	XOR	AND									

Operation Code Map (3)

Instruction code:

1st byte		2nd byte		3rd byte		4th byte	
AH	AL	BH	BL	CH	CL	DH	DL

Instruction when most significant bit of DH is 0.

Instruction when most significant bit of DH is 1.

C / AH / ALBH / BLCH	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
01406										LDC / STC		LBC / STC		LDC / STC		LDC / STC
01C05	MULXS		MULXS													
01D05		DIVXS		DIVXS												
01F06					OR	XOR	AND									
7Cr06 *1				BTST												
7Cr07 *1				BTST	BOR / BIOR	BXOR / BIXOR	BAND / BIAND	BLD / BILD								
7Dr06 *1	BSET	BNOT	BCLR					BST / BIST								
7Dr07 *1	BSET	BNOT	BCLR													
7Eaa6 *2				BTST												
7Eaa7 *2				BTST	BOR / BIOR	BXOR / BIXOR	BAND / BIAND	BLD / BILD								
7Faa6 *2	BSET	BNOT	BCLR					BST / BIST								
7Faa7 *2	BSET	BNOT	BCLR													

Notes: 1. r is the register designation field.
2. aa is the absolute address field.

A.3 Number of States Required for Execution

The tables in this section can be used to calculate the number of states required for instruction execution by the H8/300H CPU. Table A-3 indicates the number of instruction fetch, data read/write, and other cycles occurring in each instruction. Table A-2 indicates the number of states required per cycle according to the bus size. The number of states required for execution of an instruction can be calculated from these two tables as follows:

Number of states = $I \times S_I + J \times S_J + K \times S_K + L \times S_L + M \times S_M + N \times S_N$

Examples of Calculation of Number of States Required for Execution

Examples: Advanced mode, stack located in external address space, on-chip supporting modules accessed with 8-bit bus width, external devices accessed in three states with one wait state and 16-bit bus width.

BSET #0, @FFFFC7:8

From table A-3, I = L = 2 and J = K = M = N = 0
From table A-2, $S_I = 4$ and $S_L = 3$
Number of states = $2 \times 4 + 2 \times 3 = 14$

JSR @@30

From table A-3, I = J = K = 2 and L = M = N = 0
From table A-2, $S_I = S_J = S_K = 4$
Number of states = $2 \times 4 + 2 \times 4 + 2 \times 4 = 24$

Table A-2 Number of States per Cycle

		Access Conditions						
			On-Chip Supporting Module		External Device			
					8-Bit Bus		16-Bit Bus	
Cycle		**On-Chip Memory**	**8-Bit Bus**	**16-Bit Bus**	**2-State Access**	**3-State Access**	**2-State Access**	**3-State Access**
Instruction fetch	S_I	2	6	3	4	6 + 2m	2	3 + m
Branch address read	S_J							
Stack operation	S_K							
Byte data access	S_L		3		2	3 + m		
Word data access	S_M		6		4	6 + 2m		
Internal operation	S_N	1						

Legend
m: Number of wait states inserted into external device access

Table A-3 Number of Cycles per Instruction

Instruction	Mnemonic	Instruction Fetch I	Branch Addr. Read J	Stack Operation K	Byte Data Access L	Word Data Access M	Internal Operation N
ADD	ADD.B #xx:8, Rd	1					
	ADD.B Rs, Rd	1					
	ADD.W #xx:16, Rd	2					
	ADD.W Rs, Rd	1					
	ADD.L #xx:32, ERd	3					
	ADD.L ERs, ERd	1					
ADDS	ADDS #1/2/4, ERd	1					
ADDX	ADDX #xx:8, Rd	1					
	ADDX Rs, Rd	1					
AND	AND.B #xx:8, Rd	1					
	AND.B Rs, Rd	1					
	AND.W #xx:16, Rd	2					
	AND.W Rs, Rd	1					
	AND.L #xx:32, ERd	3					
	AND.L ERs, ERd	2					
ANDC	ANDC #xx:8, CCR	1					
BAND	BAND #xx:3, Rd	1					
	BAND #xx:3, @ERd	2			1		
	BAND #xx:3, @aa:8	2			1		
Bcc	BRA d:8 (BT d:8)	2					
	BRN d:8 (BF d:8)	2					
	BHI d:8	2					
	BLS d:8	2					
	BCC d:8 (BHS d:8)	2					
	BCS d:8 (BLO d:8)	2					
	BNE d:8	2					
	BEQ d:8	2					
	BVC d:8	2					
	BVS d:8	2					
	BPL d:8	2					
	BMI d:8	2					
	BGE d:8	2					
	BLT d:8	2					
	BGT d:8	2					
	BLE d:8	2					

Table A-3 Number of Cycles per Instruction (cont)

Instruction	Mnemonic	Instruction Fetch I	Branch Addr. Read J	Stack Operation K	Byte Data Access L	Word Data Access M	Internal Operation N
Bcc	BRA d:16 (BT d:16)	2					2
	BRN d:16 (BF d:16)	2					2
	BHI d:16	2					2
	BLS d:16	2					2
	BCC d:16 (BHS d:16)	2					2
	BCS d:16 (BLO d:16)	2					2
	BNE d:16	2					2
	BEQ d:16	2					2
	BVC d:16	2					2
	BVS d:16	2					2
	BPL d:16	2					2
	BMI d:16	2					2
	BGE d:16	2					2
	BLT d:16	2					2
	BGT d:16	2					2
	BLE d:16	2					2
BCLR	BCLR #xx:3, Rd	1					
	BCLR #xx:3, @ERd	2			2		
	BCLR #xx:3, @aa:8	2			2		
	BCLR Rn, Rd	1					
	BCLR Rn, @ERd	2			2		
	BCLR Rn, @aa:8	2			2		
BIAND	BIAND #xx:3, Rd	1					
	BIAND #xx:3, @ERd	2			1		
	BIAND #xx:3, @aa:8	2			1		
BILD	BILD #xx:3, Rd	1					
	BILD #xx:3, @ERd	2			1		
	BILD #xx:3, @aa:8	2			1		
BIOR	BIOR #xx:8, Rd	1					
	BIOR #xx:8, @ERd	2			1		
	BIOR #xx:8, @aa:8	2			1		
BIST	BIST #xx:3, Rd	1					
	BIST #xx:3, @ERd	2			2		
	BIST #xx:3, @aa:8	2			2		
BIXOR	BIXOR #xx:3, Rd	1					
	BIXOR #xx:3, @ERd	2			1		
	BIXOR #xx:3, @aa:8	2			1		
BLD	BLD #xx:3, Rd	1					
	BLD #xx:3, @ERd	2			1		
	BLD #xx:3, @aa:8	2			1		

Table A-3 Number of Cycles per Instruction (cont)

Instruction	Mnemonic		Instruction Fetch I	Branch Addr. Read J	Stack Operation K	Byte Data Access L	Word Data Access M	Internal Operation N
BNOT	BNOT #xx:3, Rd		1					
	BNOT #xx:3, @ERd		2			2		
	BNOT #xx:3, @aa:8		2			2		
	BNOT Rn, Rd		1					
	BNOT Rn, @ERd		2			2		
	BNOT Rn, @aa:8		2			2		
BOR	BOR #xx:3, Rd		1					
	BOR #xx:3, @ERd		2			1		
	BOR #xx:3, @aa:8		2			1		
BSET	BSET #xx:3, Rd		1					
	BSET #xx:3, @ERd		2			2		
	BSET #xx:3, @aa:8		2			2		
	BSET Rn, Rd		1					
	BSET Rn, @ERd		2			2		
	BSET Rn, @aa:8		2			2		
BSR	BSR d:8	Normal*1	2		1			
		Advanced	2		2			
	BSR d:16	Normal*1	2		1			2
		Advanced	2		2			2
BST	BST #xx:3, Rd		1					
	BST #xx:3, @ERd		2			2		
	BST #xx:3, @aa:8		2			2		
BTST	BTST #xx:3, Rd		1					
	BTST #xx:3, @ERd		2			1		
	BTST #xx:3, @aa:8		2			1		
	BTST Rn, Rd		1					
	BTST Rn, @ERd		2			1		
	BTST Rn, @aa:8		2			1		
BXOR	BXOR #xx:3, Rd		1					
	BXOR #xx:3, @ERd		2			1		
	BXOR #xx:3, @aa:8		2			1		
CMP	CMP.B #xx:8, Rd		1					
	CMP.B Rs, Rd		1					
	CMP.W #xx:16, Rd		2					
	CMP.W Rs, Rd		1					
	CMP.L #xx:32, ERd		3					
	CMP.L ERs, ERd		1					
DAA	DAA Rd		1					
DAS	DAS Rd		1					

Table A-3 Number of Cycles per Instruction (cont)

Instruction	Mnemonic		Instruction Fetch I	Branch Addr. Read J	Stack Operation K	Byte Data Access L	Word Data Access M	Internal Operation N
DEC	DEC.B Rd		1					
	DEC.W #1/2, Rd		1					
	DEC.L #1/2, ERd		1					
DIVXS	DIVXS.B Rs, Rd		2					12
	DIVXS.W Rs, ERd		2					20
DIVXU	DIVXU.B Rs, Rd		1					12
	DIVXU.W Rs, ERd		1					20
EEPMOV	EEPMOV.B		2			2n + 2*2		
	EEPMOV.W		2			2n + 2*2		
EXTS	EXTS.W Rd		1					
	EXTS.L ERd		1					
EXTU	EXTU.W Rd		1					
	EXTU.L ERd		1					
INC	INC.B Rd		1					
	INC.W #1/2, Rd		1					
	INC.L #1/2, ERd		1					
JMP	JMP @ERn		2					
	JMP @aa:24		2					2
	JMP @@aa:8	Normal*1	2	1				2
		Advanced	2	2				2
JSR	JSR @ERn	Normal*1	2		1			
		Advanced	2		2			
	JSR @aa:24	Normal*1	2		1			2
		Advanced	2		2			2
	JSR @@aa:8	Normal*1	2	1	1			
		Advanced	2	2	2			
LDC	LDC #xx:8, CCR		1					
	LDC Rs, CCR		1					
	LDC @ERs, CCR		2				1	
	LDC @(d:16, ERs), CCR		3				1	
	LDC @(d:24, ERs), CCR		5				1	
	LDC @ERs+, CCR		2				1	2
	LDC @aa:16, CCR		3				1	
	LDC @aa:24, CCR		4				1	

Table A-3 Number of Cycles per Instruction (cont)

Instruction	Mnemonic	Instruction Fetch I	Branch Addr. Read J	Stack Operation K	Byte Data Access L	Word Data Access M	Internal Operation N
MOV	MOV.B #xx:8, Rd	1					
	MOV.B Rs, Rd	1					
	MOV.B @ERs, Rd	1			1		
	MOV.B @(d:16, ERs), Rd	2			1		
	MOV.B @(d:24, ERs), Rd	4			1		
	MOV.B @ERs+, Rd	1			1		2
	MOV.B @aa:8, Rd	1			1		
	MOV.B @aa:16, Rd	2			1		
	MOV.B @aa:24, Rd	3			1		
	MOV.B Rs, @ERd	1			1		
	MOV.B Rs, @(d:16, ERd)	2			1		
	MOV.B Rs, @(d:24, ERd)	4			1		
	MOV.B Rs, @–ERd	1			1		2
	MOV.B Rs, @aa:8	1			1		
	MOV.B Rs, @aa:16	2			1		
	MOV.B Rs, @aa:24	3			1		
	MOV.W #xx:16, Rd	2					
	MOV.W Rs, Rd	1					
	MOV.W @ERs, Rd	1				1	
	MOV.W @(d:16, ERs), Rd	2				1	
	MOV.W @(d:24, ERs), Rd	4				1	
	MOV.W @ERs+, Rd	1				1	2
	MOV.W @aa:16, Rd	2				1	
	MOV.W @aa:24, Rd	3				1	
	MOV.W Rs, @ERd	1				1	
	MOV.W Rs, @(d:16, ERd)	2				1	
	MOV.W Rs, @(d:24, ERd)	4				1	
	MOV.W Rs, @–ERd	1				1	2
	MOV.W Rs, @aa:16	2				1	
	MOV.W Rs, @aa:24	3				1	
	MOV.L #xx:32, ERd	3					
	MOV.L ERs, ERd	1					
	MOV.L @ERs, ERd	2				2	
	MOV.L @(d:16, ERs), ERd	3				2	
	MOV.L @(d:24, ERs), ERd	5				2	
	MOV.L @ERs+, ERd	2				2	2
	MOV.L @aa:16, ERd	3				2	
	MOV.L @aa:24, ERd	4				2	
	MOV.L ERs, @ERd	2				2	
	MOV.L ERs, @(d:16, ERd)	3				2	
	MOV.L ERs, @(d:24, ERd)	5				2	
	MOV.L ERs, @–ERd	2				2	2
	MOV.L ERs, @aa:16	3				2	
	MOV.L ERs, @aa:24	4				2	

Table A-3 Number of Cycles per Instruction (cont)

Instruction	Mnemonic	Instruction Fetch I	Branch Addr. Read J	Stack Operation K	Byte Data Access L	Word Data Access M	Internal Operation N
MOVFPE	MOVFPE @aa:16, Rd*3	2			1*3		
MOVTPE	MOVTPE Rs, @aa:16*3	2			1*3		
MULXS	MULXS.B Rs, Rd	2					12
	MULXS.W Rs, ERd	2					20
MULXU	MULXU.B Rs, Rd	1					12
	MULXU.W Rs, ERd	1					20
NEG	NEG.B Rd	1					
	NEG.W Rd	1					
	NEG.L ERd	1					
NOP	NOP	1					
NOT	NOT.B Rd	1					
	NOT.W Rd	1					
	NOT.L ERd	1					
OR	OR.B #xx:8, Rd	1					
	OR.B Rs, Rd	1					
	OR.W #xx:16, Rd	2					
	OR.W Rs, Rd	1					
	OR.L #xx:32, ERd	3					
	OR.L ERs, ERd	2					
ORC	ORC #xx:8, CCR	1					
POP	POP.W Rn	1				1	2
	POP.L ERn	2				2	2
PUSH	PUSH.W Rn	1				1	2
	PUSH.L ERn	2				2	2
ROTL	ROTL.B Rd	1					
	ROTL.W Rd	1					
	ROTL.L ERd	1					
ROTR	ROTR.B Rd	1					
	ROTR.W Rd	1					
	ROTR.L ERd	1					
ROTXL	ROTXL.B Rd	1					
	ROTXL.W Rd	1					
	ROTXL.L ERd	1					
ROTXR	ROTXR.B Rd	1					
	ROTXR.W Rd	1					
	ROTXR.L ERd	1					
RTE	RTE	2		2			2

Table A-3 Number of Cycles per Instruction (cont)

Instruction	Mnemonic		Instruction Fetch I	Branch Addr. Read J	Stack Operation K	Byte Data Access L	Word Data Access M	Internal Operation N
RTS	RTS	Normal*1	2		1			2
		Advanced	2		2			2
SHAL	SHAL.B Rd		1					
	SHAL.W Rd		1					
	SHAL.L ERd		1					
SHAR	SHAR.B Rd		1					
	SHAR.W Rd		1					
	SHAR.L ERd		1					
SHLL	SHLL.B Rd		1					
	SHLL.W Rd		1					
	SHLL.L ERd		1					
SHLR	SHLR.B Rd		1					
	SHLR.W Rd		1					
	SHLR.L ERd		1					
SLEEP	SLEEP		1					
STC	STC CCR, Rd		1					
	STC CCR, @ERd		2				1	
	STC CCR, @(d:16, ERd)		3				1	
	STC CCR, @(d:24, ERd)		5				1	
	STC CCR, @–ERd		2				1	2
	STC CCR, @aa:16		3				1	
	STC CCR, @aa:24		4				1	
SUB	SUB.B Rs, Rd		1					
	SUB.W #xx:16, Rd		2					
	SUB.W Rs, Rd		1					
	SUB.L #xx:32, ERd		3					
	SUB.L ERs, ERd		1					
SUBS	SUBS #1/2/4, ERd		1					
SUBX	SUBX #xx:8, Rd		1					
	SUBX Rs, Rd		1					
TRAPA	TRAPA #x:2	Normal*1	2	1	2			4
		Advanced	2	2	2			4
XOR	XOR.B #xx:8, Rd		1					
	XOR.B Rs, Rd		1					
	XOR.W #xx:16, Rd		2					
	XOR.W Rs, Rd		1					
	XOR.L #xx:32, ERd		3					
	XOR.L ERs, ERd		2					
XORC	XORC #xx:8, CCR		1					

Notes: 1. n is the value set in register R4L or R4. The source and destination are accessed n + 1 times each.
2. For the number of states required for data access, refer to the relevant hardware manual.
3. Not available in the H8/3003.

Appendix B Register Field

B.1 Register Addresses and Bit Names

Address (low)	Register Name	Data Bus Width	Bit Names								Module Name
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
H'1C											
H'1D											
H'1E											
H'1F											
H'20	MAR0AR	8									DMAC channel 0A
H'21	MAR0AE	8									
H'22	MAR0AH	8									
H'23	MAR0AL	8									
H'24	ETCR0AH	8									
H'25	ETCR0AL	8									
H'26	IOAR0A	8									
H'27	DTCR0A	8	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0	Short address mode
			DTE	DTSZ	SAID	SAIDE	DTIE	DTS2A	DTS1A	DTS0A	Full address mode
H'28	MAR0BR	8									DMAC channel 0B
H'29	MAR0BE	8									
H'2A	MAR0BH	8									
H'2B	MAR0BL	8									
H'2C	ETCR0BH	8									
H'2D	ETCR0BL	8									
H'2E	IOAR0B	8									
H'2F	DTCR0B	8	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0	Short address mode
			DTME	—	DAID	DAIDE	TMS	DTS2B	DTS1B	DTS0B	Full address mode

Legend
DMAC: DMA controller

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(Continued from preceding page)

Address (low)	Register Name	Data Bus Width	Bit Names								Module Name
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
H'30	MAR1AR	8									DMAC channel 1A
H'31	MAR1AE	8									
H'32	MAR1AH	8									
H'33	MAR1AL	8									
H'34	ETCR1AH	8									
H'35	ETCR1AL	8									
H'36	IOAR1A	8									
H'37	DTCR1A	8	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0	Short address mode
			DTE	DTSZ	SAID	SAIDE	DTIE	DTS2A	DTS1A	DTS0A	Full address mode
H'38	MAR1BR	8									DMAC channel 1B
H'39	MAR1BE	8									
H'3A	MAR1BH	8									
H'3B	MAR1BL	8									
H'3C	ETCR1BH	8									
H'3D	ETCR1BL	8									
H'3E	IOAR1B	8									
H'3F	DTCR1B	8	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0	Short address mode
			DTME	—	DAID	DAIDE	TMS	DTS2B	DTS1B	DTS0B	Full address mode
H'40	MAR2AR	8									DMAC channel 2A
H'41	MAR2AE	8									
H'42	MAR2AH	8									
H'43	MAR2AL	8									
H'44	ETCR2AH	8									
H'45	ETCR2AL	8									
H'46	IOAR2A	8									
H'47	DTCR2A	8	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0	Short address mode
			DTE	DTSZ	SAID	SAIDE	DTIE	DTS2A	DTS1A	DTS0A	Full address mode

Legend
DMAC: DMA controller

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Address (low)	Register Name	Data Bus Width	Bit Names								Module Name
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
H'48	MAR2BR	8									DMAC channel 2B
H'49	MAR2BE	8									
H'4A	MAR2BH	8									
H'4B	MAR2BL	8									
H'4C	ETCR2BH	8									
H'4D	ETCR2BL	8									
H'4E	IOAR2B	8									
H'4F	DTCR2B	8	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0	Short address mode
			DTME	—	DAID	DAIDE	TMS	DTS2B	DTS1B	DTS0B	Full address mode
H'50	MAR3AR	8									DMAC channel 3A
H'51	MAR3AE	8									
H'52	MAR3AH	8									
H'53	MAR3AL	8									
H'54	ETCR3AH	8									
H'55	ETCR3AL	8									
H'56	IOAR3A	8									
H'57	DTCR3A	8	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0	Short address mode
			DTE	DTSZ	SAID	SAIDE	DTIE	DTS2A	DTS1A	DTS0A	Full address mode
H'58	MAR3BR	8									DMAC channel 3B
H'59	MAR3BE	8									
H'5A	MAR3BH	8									
H'5B	MAR3BL	8									
H'5C	ETCR3BH	8									
H'5D	ETCR3BL	8									
H'5E	IOAR3B	8									
H'5F	DTCR3B	8	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0	Short address mode
			DTME	—	DAID	DAIDE	TMS	DTS2B	DTS1B	DTS0B	Full address mode

Legend
DMAC: DMA controller

(Continued on next page)

(Continued from preceding page)

Address (low)	Register Name	Data Bus Width	Bit Names								Module Name
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
H'60	TSTR	8	—	—	—	STR4	STR3	STR2	STR1	STR0	ITU (all channels)
H'61	TSNC	8	—	—	—	SYNC4	SYNC3	SYNC2	SYNC1	SYNC0	
H'62	TMDR	8		MDF	FDIR	PWM4	PWM3	PWM2	PWM1	PWM0	
H'63	TFCR	8	—	—	CMD1	CMD0	BFB4	BFA4	BFB3	BFA3	
H'64	TCR0	8	—	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	ITU channel 0
H'65	TIOR0	8	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0	
H'66	TIER0	8	—	—	—	—	—	OVIE	IMIEB	IMIEA	
H'67	TSR0	8	—	—	—	—	—	OVF	IMFB	IMFA	
H'68	TCNT0H	16									
H'69	TCNT0L										
H'6A	GRA0H	16									
H'6B	GRA0L										
H'6C	GRB0H	16									
H'6D	GRB0L										
H'6E	TCR1	8	—	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	ITU channel 1
H'6F	TIOR1	8	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0	
H'70	TIER1	8	—	—	—	—	—	OVIE	IMIEB	IMIEA	
H'71	TSR1	8	—	—	—	—	—	OVF	IMFB	IMFA	
H'72	TCNT1H	16									
H'73	TCNT1L										
H'74	GRA1H	16									
H'75	GRA1L										
H'76	GRB1H	16									
H'77	GRB1L										
H'78	TCR2	8	—	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	ITU channel 2
H'79	TIOR2	8	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0	
H'7A	TIER2	8	—	—	—	—	—	OVIE	IMIEB	IMIEA	
H'7B	TSR2	8	—	—	—	—	—	OVF	IMFB	IMFA	
H'7C	TCNT2H	16									
H'7D	TCNT2L										
H'7E	GRA2H	16									
H'7F	GRA2L										
H'80	GRB2H	16									
H'81	GRB2L										

Legend
ITU: 16-bit integrated timer unit

(Continued on next page)

(Continued from preceding page)

Address (low)	Register Name	Data Bus Width	Bit Names								Module Name
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
H'82	TCR3	8	—	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	ITU channel 3
H'83	TIOR3	8	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0	
H'84	TIER3	8	—	—	—	—	—	OVIE	IMIEB	IMIEA	
H'85	TSR3	8	—	—	—	—	—	OVF	IMFB	IMFA	
H'86	TCNT3H	16									
H'87	TCNT3L										
H'88	GRA3H	16									
H'89	GRA3L										
H'8A	GRB3H	16									
H'8B	GRB3L										
H'8C	BRA3H	16									
H'8D	BRA3L										
H'8E	BRB3H	16									
H'8F	BRB3L										
H'90	TOER	8	—	—	EXB4	EXA4	EB3	EB4	EA4	EA3	ITU (all channels)
H'91	TOCR	8	—	—	—	$\overline{\text{XTGD}}$	—	—	OLS4	OLS3	
H'92	TCR4	8	—	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0	ITU channel 4
H'93	TIOR4	8	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0	
H'94	TIER4	8	—	—	—	—	—	OVIE	IMIEB	IMIEA	
H'95	TSR4	8	—	—	—	—	—	OVF	IMFB	IMFA	
H'96	TCNT4H	16									
H'97	TCNT4L										
H'98	GRA4H	16									
H'99	GRA4L										
H'9A	GRB4H	16									
H'9B	GRB4L										
H'9C	BRA4H	16									
H'9D	BRA4L										
H'9E	BRB4H	16									
H'9F	BRB4L										

Legend
ITU: 16-bit integrated timer unit

(Continued on next page)

(Continued from preceding page)

Address (low)	Register Name	Data Bus Width	Bit Names								Module Name
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
H'A0	TPMR	8	—	—	—	—	G3NOV	G2NOV	G1NOV	G0NOV	TPC
H'A1	TPCR	8	G3CMS1	G3CMS0	G2CMS1	G2CMS0	G1CMS1	G1CMS0	G0CMS1	G0CMS0	
H'A2	NDERB	8	NDER15	NDER14	NDER13	NDER12	NDER11	NDER10	NDER9	NDER8	
H'A3	NDERA	8	NDER7	NDER6	NDER5	NDER4	NDER3	NDER2	NDER1	NDER0	
H'A4	NDRB*1	8	NDR15	NDR14	NDR13	NDR12	NDR11	NDR10	NDR9	NDR8	
		8	NDR15	NDR14	NDR13	NDR12	—	—	—	—	
H'A5	NDRA*1	8	NDR7	NDR6	NDR5	NDR4	NDR3	NDR2	NDR1	NDR0	
		8	NDR7	NDR6	NDR5	NDR4	—	—	—	—	
H'A6	NDRB*1	8	—	—	—	—	—	—	—	—	
		8	—	—	—	—	NDR11	NDR10	NDR9	NDR8	
H'A7	NDRA*1	8	—	—	—	—	—	—	—	—	
		8	—	—	—	—	NDR3	NDR2	NDR1	NDR0	
H'A8	TCSR*2	8	OVF	WT/$\overline{\text{IT}}$	TME	—	—	CKS2	CKS1	CKS0	WDT
H'A9	TCNT*2	8									
H'AA	—		—	—	—	—	—	—	—	—	
H'AB	RSTCSR*3	8	WRST	RSTOE	—	—	—	—	—	—	
H'AC	RFSHCR	8	SRFMD	PSRAME	DRAME	CAS/$\overline{\text{WE}}$	M9/$\overline{\text{M8}}$	PFSHE	—	RCYCE	Refresh controller
H'AD	RTMCSR	8	CMF	CMIE	CKS2	CKS1	CKS0	—	—	—	
H'AE	RTCNT	8									
H'AF	RTCOR	8									
H'B0	SMR	8	C/$\overline{\text{A}}$	CHR	PE	O/$\overline{\text{E}}$	STOP	MP	CKS1	CKS0	SCI channel 0
H'B1	BRR	8									
H'B2	SCR	8	TIE	RIE	TE	RE	MPIE	TEIE	CKE1	CKE0	
H'B3	TDR	8									
H'B4	SSR	8	TDRE	RDRF	ORER	FER	PER	TEND	MPB	MPBT	
H'B5	RDR	8									
H'B6	—		—	—	—	—	—	—	—	—	
H'B7	—		—	—	—	—	—	—	—	—	

Notes: 1. The address depends on the output trigger setting.
2. For write access to TCSR and TCNT, see section 12.2.4, Notes on Register Access.
3. For write access to RSTCSR, see section 12.2.4, Notes on Register Access.

Legend
TPC: Programmable timing pattern controller
WDT: Watchdog timer
SCI: Serial communication interface

(Continued on next page)

(Continued from preceding page)

Address (low)	Register Name	Data Bus Width	Bit Names								Module Name
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
H'B8	SMR	8	C/$\overline{A}$	CHR	PE	O/$\overline{E}$	STOP	MP	CKS1	CKS0	SCI channel 1
H'B9	BRR	8									
H'BA	SCR	8	TIE	RIE	TE	RE	MPIE	TEIE	CKE1	CKE0	
H'BB	TDR	8									
H'BC	SSR	8	TDRE	RDRF	ORER	FER	PER	TEND	MPB	MPBT	
H'BD	RDR	8									
H'BE	—		—	—	—	—	—	—	—	—	
H'BF	—		—	—	—	—	—	—	—	—	
H'C0	—		—	—	—	—	—	—	—	—	
H'C1	—		—	—	—	—	—	—	—	—	
H'C2	—		—	—	—	—	—	—	—	—	
H'C3	—		—	—	—	—	—	—	—	—	
H'C4	—		—	—	—	—	—	—	—	—	
H'C5	P4DDR	8	$P4_7$DDR	$P4_6$DDR	$P4_5$DDR	$P4_4$DDR	$P4_3$DDR	$P4_2$DDR	$P4_1$DDR	$P4_0$DDR	Port 4
H'C6	—		—	—	—	—	—	—	—	—	
H'C7	P4DR	8	$P4_7$	$P4_6$	$P4_5$	$P4_4$	$P4_3$	$P4_2$	$P4_1$	$P4_0$	Port 4
H'C8	P5DDR	8	$P5_7$DDR	$P5_6$DDR	$P5_5$DDR	$P5_4$DDR	$P5_3$DDR	$P5_2$DDR	$P5_1$DDR	$P5_0$DDR	Port 5
H'C9	P6DDR	8	—	$P6_6$DDR	$P6_5$DDR	$P6_4$DDR	$P6_3$DDR	$P6_2$DDR	$P6_1$DDR	$P6_0$DDR	Port 6
H'CA	P5DR	8	$P5_7$	$P5_6$	$P5_5$	$P5_4$	$P5_3$	$P5_2$	$P5_1$	$P5_0$	Port 5
H'CB	P6DR	8	—	$P6_6$	$P6_5$	$P6_4$	$P6_3$	$P6_2$	$P6_1$	$P6_0$	Port 6
H'CC	—		—	—	—	—	—	—	—	—	
H'CD	P8DDR	8	—	—	—	$P8_4$DDR	$P8_3$DDR	$P8_2$DDR	$P8_1$DDR	$P8_0$DDR	Port 8
H'CE	P7DR	8	$P7_7$	$P7_6$	$P7_5$	$P7_4$	$P7_3$	$P7_2$	$P7_1$	$P7_0$	Port 7
H'CF	P8DR	8	—	—	—	$P8_4$	$P8_3$	$P8_2$	$P8_1$	$P8_0$	Port 8
H'D0	P9DDR	8	—	—	$P9_5$DDR	$P9_4$DDR	$P9_3$DDR	$P9_2$DDR	$P9_1$DDR	$P9_0$DDR	Port 9
H'D1	PADDR	8	PA_7DDR	PA_6DDR	PA_5DDR	PA_4DDR	PA_3DDR	PA_2DDR	PA_1DDR	PA_0DDR	Port A
H'D2	P9DR	8	—	—	$P9_5$	$P9_4$	$P9_3$	$P9_2$	$P9_1$	$P9_0$	Port 9
H'D3	PADR	8	PA_7	PA_6	PA_5	PA_4	PA_3	PA_2	PA_1	PA_0	Port A
H'D4	PBDDR	8	PB_7DDR	PB_6DDR	PB_5DDR	PB_4DDR	PB_3DDR	PB_2DDR	PB_1DDR	PB_0DDR	Port B
H'D5	PCDDR	8	PC_7DDR	PC_6DDR	PC_5DDR	PC_4DDR	PC_3DDR	PC_2DDR	PC_1DDR	PC_0DDR	Port C
H'D6	PBDR	8	PB_7	PB_6	PB_5	PB_4	PB_3	PB_2	PB_1	PB_0	Port B
H'D7	PCDR	8	PC_7	PC_6	PC_5	PC_4	PC_3	PC_2	PC_1	PC_0	Port C

Legend
SCI: Serial communication interface

(Continued on next page)

(Continued from preceding page)

Address (low)	Register Name	Data Bus Width	Bit Names								Module Name
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
H'D8	—		—	—	—	—	—	—	—	—	
H'D9	—		—	—	—	—	—	—	—	—	
H'DA	P4PCR	8	$P4_7$PCR	$P4_6$PCR	$P4_5$PCR	$P4_4$PCR	$P4_3$PCR	$P4_2$PCR	$P4_1$PCR	$P4_0$PCR	Port 4
H'DB	P5PCR	8	$P5_7$PCR	$P5_6$PCR	$P5_5$PCR	$P5_4$PCR	$P5_3$PCR	$P5_2$PCR	$P5_1$PCR	$P5_0$PCR	Port 5
H'DC	—		—	—	—	—	—	—	—	—	
H'DD	—		—	—	—	—	—	—	—	—	
H'DE	—		—	—	—	—	—	—	—	—	
H'DF	—		—	—	—	—	—	—	—	—	
H'E0	ADDRAH	8	AD9	AD8	AD7	AD6	AD5	AD4	AD3	AD2	A/D
H'E1	ADDRAL	8	AD1	AD0	—	—	—	—	—	—	
H'E2	ADDRBH	8	AD9	AD8	AD7	AD6	AD5	AD4	AD3	AD2	
H'E3	ADDRBL	8	AD1	AD0	—	—	—	—	—	—	
H'E4	ADDRCH	8	AD9	AD8	AD7	AD6	AD5	AD4	AD3	AD2	
H'E5	ADDRCL	8	AD1	AD0	—	—	—	—	—	—	
H'E6	ADDRDH	8	AD9	AD8	AD7	AD6	AD5	AD4	AD3	AD2	
H'E7	ADDRDL	8	AD1	AD0	—	—	—	—	—	—	
H'E8	ADCSR	8	ADF	ADIE	ADST	SCAN	CKS	CH2	CH1	CH0	
H'E9	ADCR	8	TRGE	—	—	—	—	—	—	—	
H'EA	—		—	—	—	—	—	—	—	—	
H'EB	—		—	—	—	—	—	—	—	—	
H'EC	ABWCR	8	ABW7	ABW6	ABW5	ABW4	ABW3	ABW2	ABW1	ABW0	Bus controller
H'ED	ASTCR	8	AST7	AST6	AST5	AST4	AST3	AST2	AST1	AST0	
H'EE	WCR	8	—	—	—	—	WMS1	WMS0	WC1	WC0	
H'EF	WCER	8	WCE7	WCE6	WCE5	WCE4	WCE3	WCE2	WCE1	WCE0	

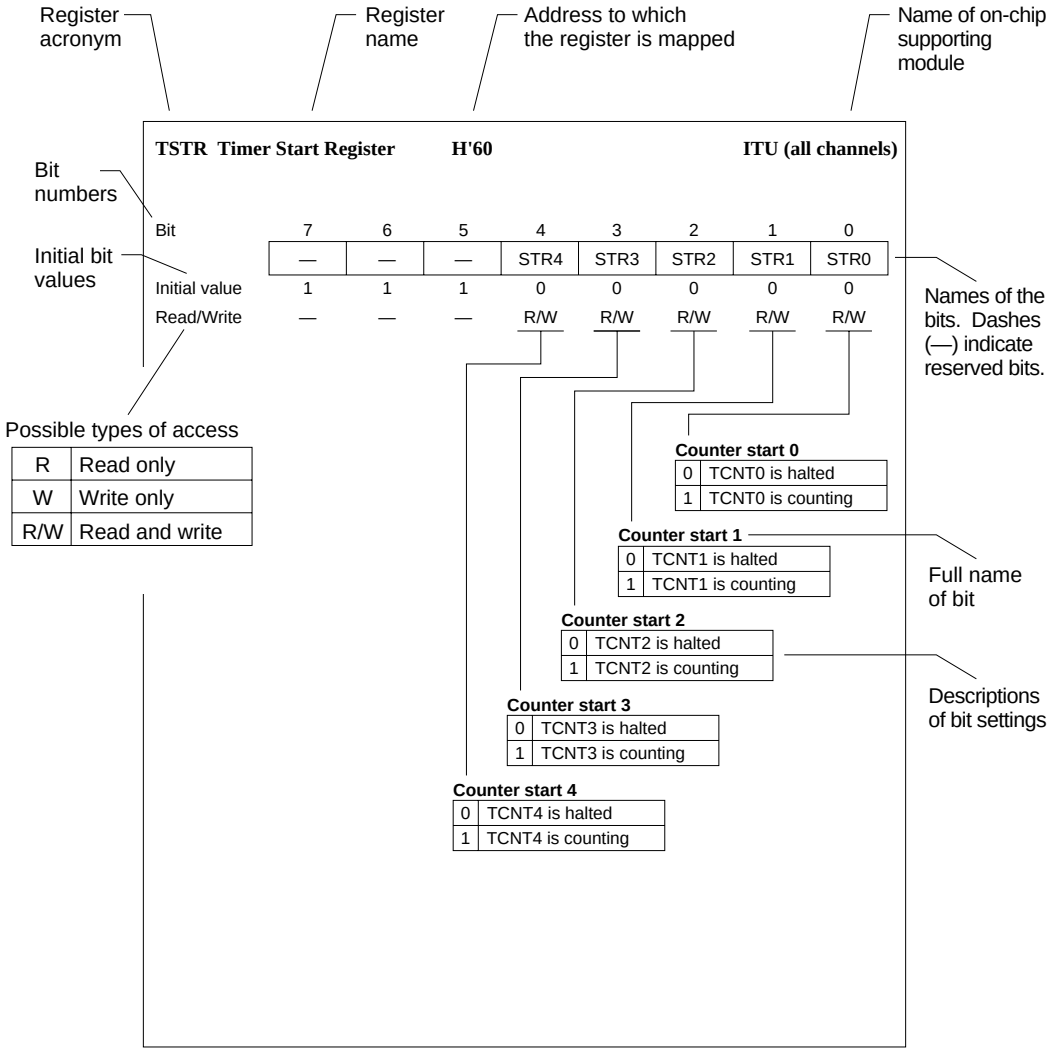
Legend
A/D: A/D converter

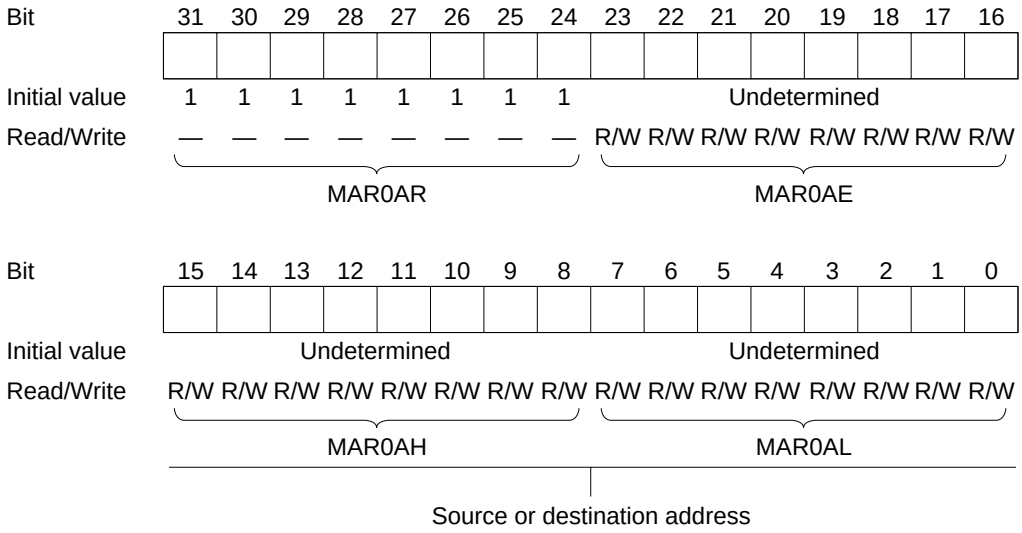
(Continued on next page)

(Continued from preceding page)

Address (low)	Register Name	Data Bus Width	Bit Names								Module Name
			Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	
H'F0	—		—	—	—	—	—	—	—	—	
H'F1	MDCR	8	—	—	—	—	—	MDS2	MDS1	MDS0	System control
H'F2	SYSCR	8	SSBY	STS2	STS1	STS0	UE	NMIEG	—	RAME	
H'F3	BRCR	8	—	—	—	—	—	—	—	BRLE	Bus controller
H'F4	ISCR	8	IRQ7SC	IRQ6SC	IRQ5SC	IRQ4SC	IRQ3SC	IRQ2SC	IRQ1SC	IRQ0SC	Interrupt controller
H'F5	IER	8	IRQ7E	IRQ6E	IRQ5E	IRQ4E	IRQ3E	IRQ2E	IRQ1E	IRQ0E	
H'F6	ISR	8	IRQ7F	IRQ6F	IRQ5F	IRQ4F	IRQ3F	IRQ2F	IRQ1F	IRQ0F	
H'F7	—		—	—	—	—	—	—	—	—	
H'F8	IPRA	8	IPRA7	IPRA6	IPRA5	IPRA4	IPRA3	IPRA2	IPRA1	IPRA0	Interrupt controller
H'F9	IPRB	8	IPRB7	IPRB6	IPRB5	IPRB4	IPRB3	IPRB2	IPRB1	—	
H'FA	—		—	—	—	—	—	—	—	—	
H'FB	—		—	—	—	—	—	—	—	—	
H'FC	—		—	—	—	—	—	—	—	—	
H'FD	—		—	—	—	—	—	—	—	—	
H'FE	—		—	—	—	—	—	—	—	—	
H'FF	—		—	—	—	—	—	—	—	—	

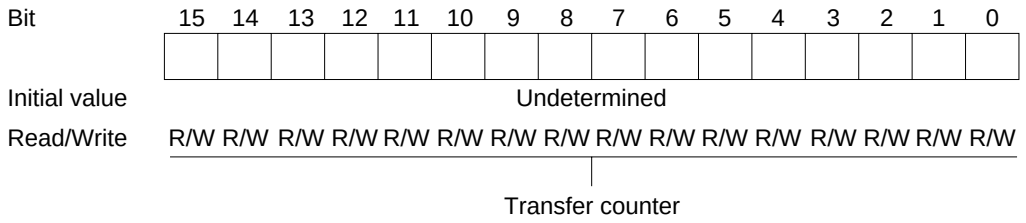
B.2 Register Descriptions



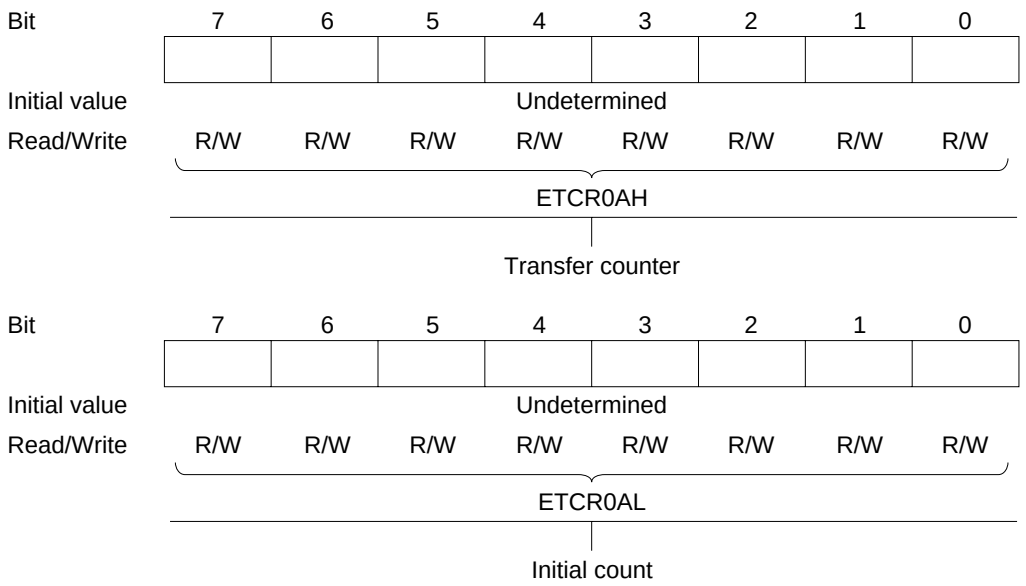

Bit
31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16
Initial value
1 1 1 1 1 1 1 1 Undetermined
Read/Write
— — — — — — — — R/W R/W R/W R/W R/W R/W R/W R/W
MAR0AR
MAR0AE
Bit
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Initial value
Undetermined Undetermined
Read/Write
R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W
MAR0AH
MAR0AL
Source or destination address

- Short address mode

I/O mode and idle mode

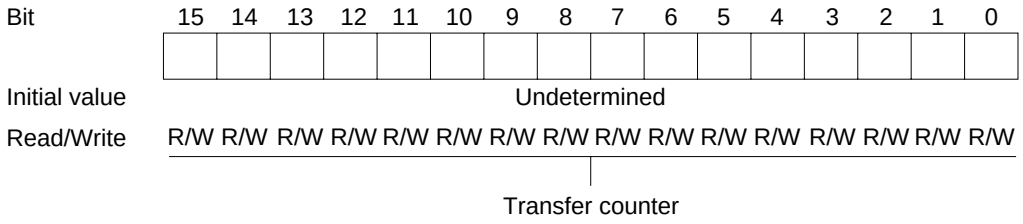


Repeat mode

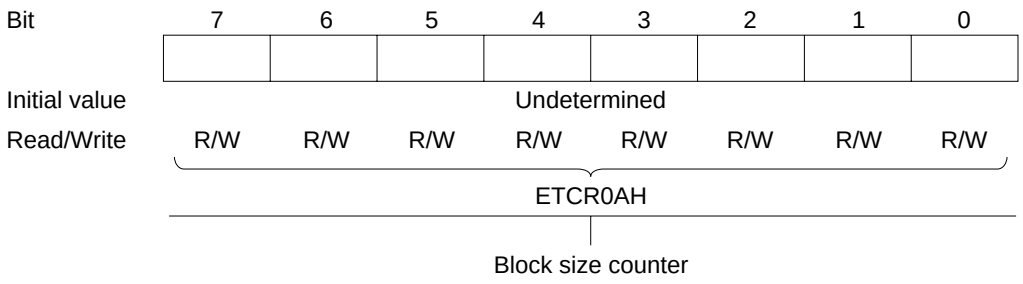


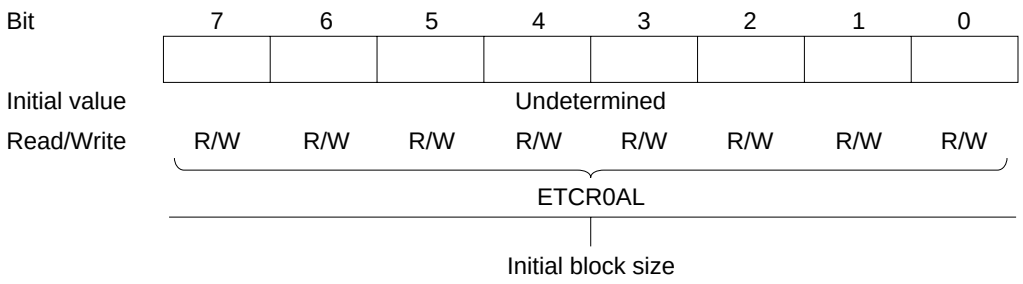
- Full address mode

Normal mode

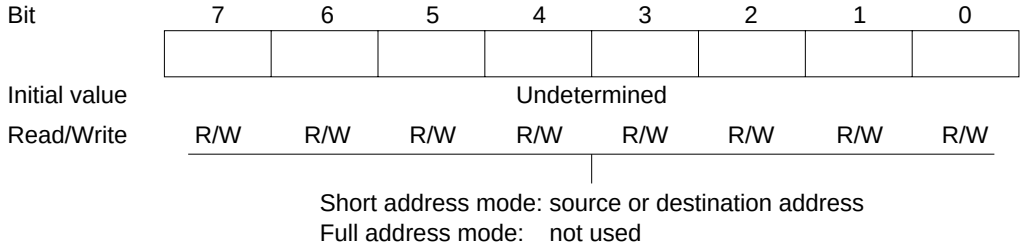


Block transfer mode





IOAR0A—I/O Address Register 0A **H'26** **DMAC0**



- Short address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data transfer select

Bit 2	Bit 1	Bit 0	
DTS2	DTS1	DTS0	Data Transfer Activation Source
0	0	0	Compare match/input capture A interrupt from ITU channel 0
		1	Compare match/input capture A interrupt from ITU channel 1
	1	0	Compare match/input capture A interrupt from ITU channel 2
		1	Compare match/input capture A interrupt from ITU channel 3
1	0	0	SCI transmit-data-empty interrupt
		1	SCI receive-data-full interrupt
	1	*	Transfer in full address mode

Data transfer interrupt enable

0	Interrupt requested by DTE bit is disabled
1	Interrupt requested by DTE bit is enabled

Repeat enable

RPE	DTIE	Description
0	0	I/O mode
	1	
1	0	Repeat mode
	1	Idle mode

Data transfer increment/decrement

0	Incremented: If DTSZ = 0, MAR is incremented by 1 after each transfer If DTSZ = 1, MAR is incremented by 2 after each transfer
1	Decremented: If DTSZ = 0, MAR is decremented by 1 after each transfer If DTSZ = 1, MAR is decremented by 2 after each transfer

Data transfer size

0	Byte-size transfer
1	Word-size transfer

Data transfer enable

0	Data transfer is disabled
1	Data transfer is enabled

- Full address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	SAID	SAIDE	DTIE	DTS2A	DTS1A	DTS0A
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data transfer select 0A

0	Normal mode
1	Block transfer mode

Data transfer select 2A and 1A

Set both bits to 1

Data transfer interrupt enable

0	Interrupt request by DTE bit is disabled
1	Interrupt request by DTE bit is enabled

Source address increment/decrement

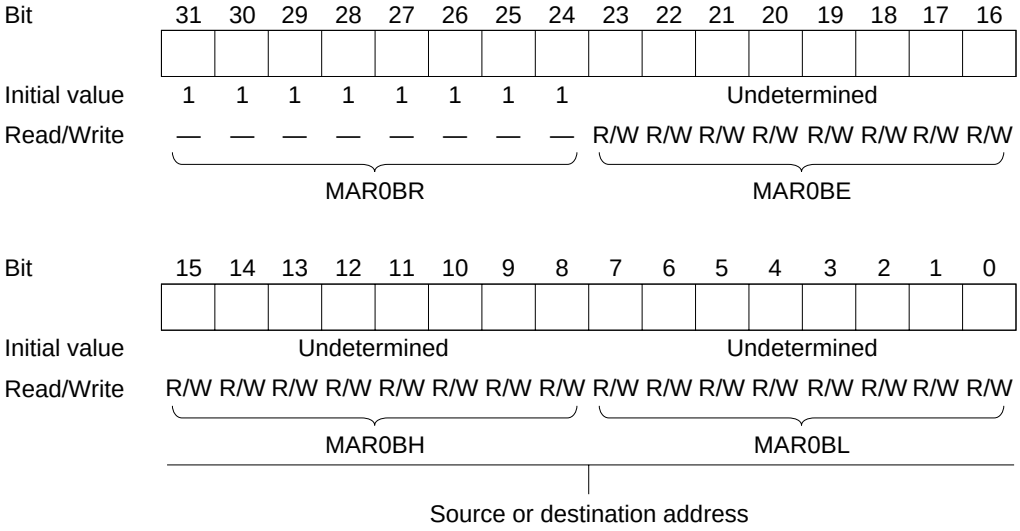
Bit 5	Bit 4	
SAID	SAIDE	Increment/Decrement Enable
0	0	MARA is held fixed
	1	Incremented: If DTSZ = 0, MARA is incremented by 1 after each transfer If DTSZ = 1, MARA is incremented by 2 after each transfer
1	0	MARA is held fixed
	1	Decremented: If DTSZ = 0, MARA is decremented by 1 after each transfer If DTSZ = 1, MARA is decremented by 2 after each transfer

Data transfer size

0	Byte-size transfer
1	Word-size transfer

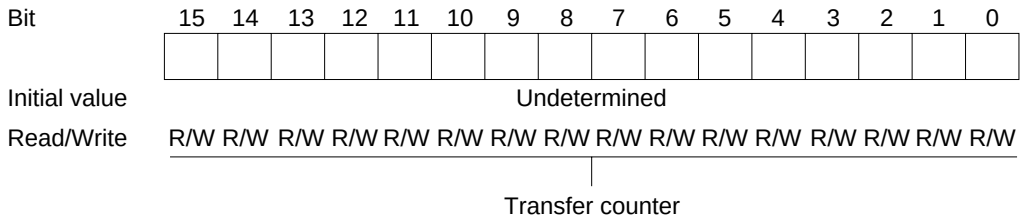
Data transfer enable

0	Data transfer is disabled
1	Data transfer is enabled

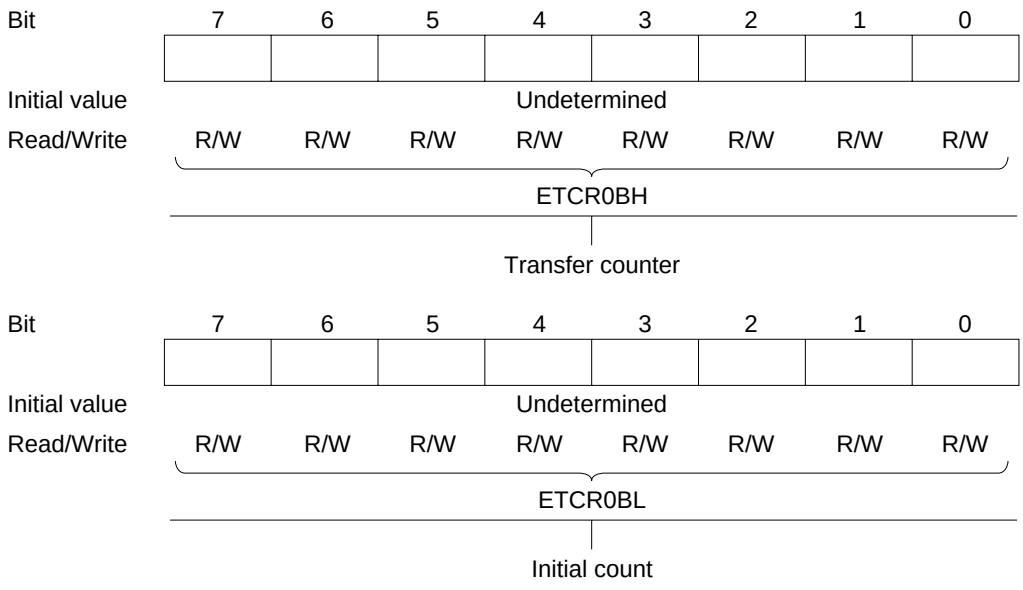

Bit
31 30 29 28 27 26 25 24 23 22 21 20 19 18 17 16
Initial value
1 1 1 1 1 1 1 1 Undetermined
Read/Write
— — — — — — — — R/W R/W R/W R/W R/W R/W R/W R/W
MAR0BR
MAR0BE
Bit
15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Initial value
Undetermined Undetermined
Read/Write
R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W R/W
MAR0BH
MAR0BL
Source or destination address

- Short address mode

I/O mode and idle mode

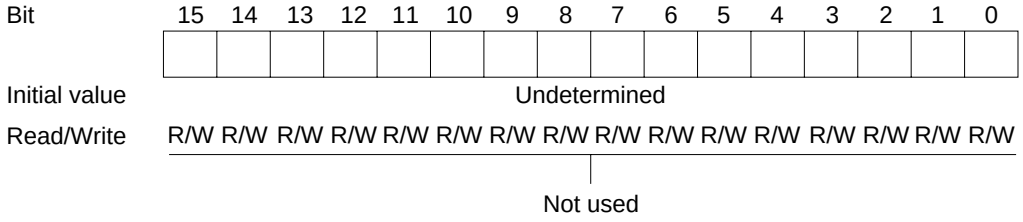


Repeat mode

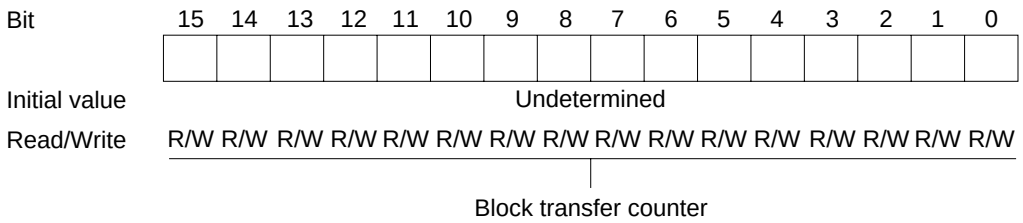


- Full address mode

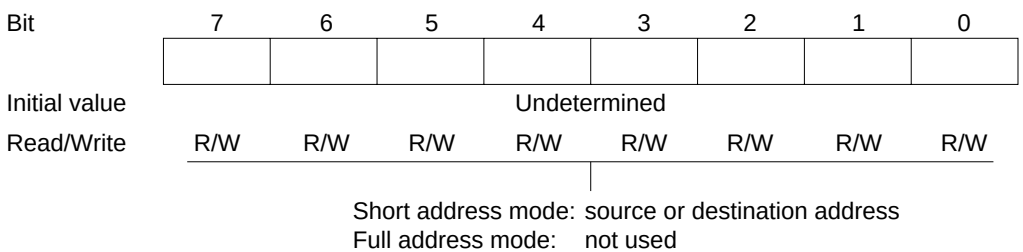
Normal mode



Block transfer mode



IOAR0B—I/O Address Register 0B **H'2E** **DMAC0**



- Short address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data transfer select

Bit 2	Bit 1	Bit 0	
DTS2	DTS1	DTS0	Data Transfer Activation Source
0	0	0	Compare match/input capture A interrupt from ITU channel 0
		1	Compare match/input capture A interrupt from ITU channel 1
	1	0	Compare match/input capture A interrupt from ITU channel 2
		1	Compare match/input capture A interrupt from ITU channel 3
1	0	0	SCI transmit-data-empty interrupt
		1	SCI receive-data-full interrupt
	1	0	Falling edge of $\overline{\text{DREQ}}$ input
		1	Low level of $\overline{\text{DREQ}}$ input

Data transfer interrupt enable

0	Interrupt requested by DTE bit is disabled
1	Interrupt requested by DTE bit is enabled CPU interrupt requested when DTE = 0

Repeat enable

RPE	DTIE	Description
0	0	I/O mode
	1	
1	0	Repeat mode
	1	Idle mode

Data transfer increment/decrement

0	Incremented: If DTSZ = 0, MAR is incremented by 1 after each transfer If DTSZ = 1, MAR is incremented by 2 after each transfer
1	Decremented: If DTSZ = 0, MAR is decremented by 1 after each transfer If DTSZ = 1, MAR is decremented by 2 after each transfer

Data transfer size

0	Byte-size transfer
1	Word-size transfer

Data transfer enable

0	Data transfer is disabled
1	Data transfer is enabled

- Full address mode

Bit	7	6	5	4	3	2	1	0
	DTME	—	DAID	DAIDE	TMS	DTS2B	DTS1B	DTS0B
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data transfer select 2B to 0B

Bit 2	Bit 1	Bit 0	Data Transfer Activation Source	
DTS2B	DTS1B	DTS0B	Normal Mode	Block Transfer Mode
0	0	0	Auto-request (burst mode)	Compare match/input capture A from ITU channel 0
		1	Not available	Compare match/input capture A from ITU channel 1
	1	0	Auto-request (cycle-steal mode)	Compare match/input capture A from ITU channel 2
		1	Not available	Compare match/input capture A from ITU channel 3
1	0	0	Not available	Not available
		1	Not available	Not available
	1	0	Falling edge of $\overline{\text{DREQ}}$	Falling edge of $\overline{\text{DREQ}}$
		1	Low level input at $\overline{\text{DREQ}}$	Not available

Transfer mode select

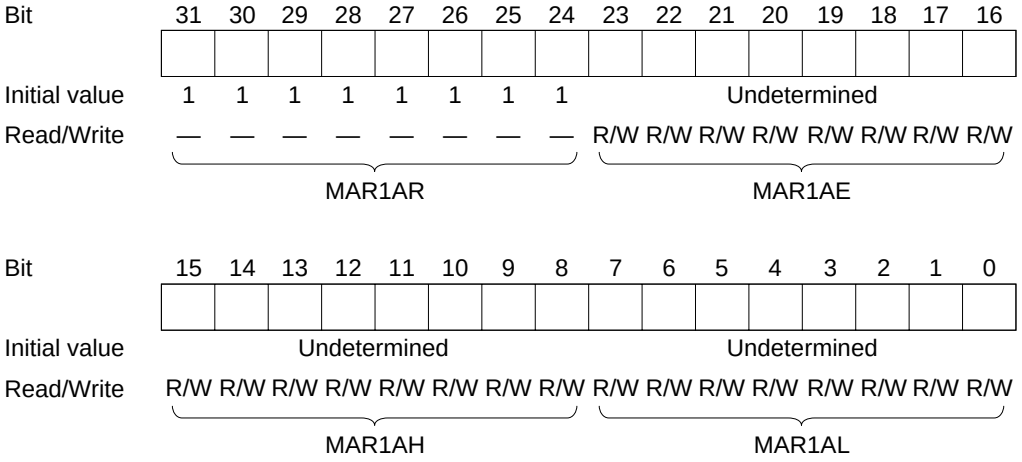
0	Destination is the block area in block transfer mode
1	Source is the block area in block transfer mode

Destination address increment/decrement

Bit 5	Bit 4	
DAID	DAIDE	Increment/Decrement Enable
0	0	MARB is held fixed
	1	Incremented: If DTSZ = 0, MARB is incremented by 1 after each transfer If DTSZ = 1, MARB is incremented by 2 after each transfer
1	0	MARB is held fixed
	1	Decremented: If DTSZ = 0, MARB is decremented by 1 after each transfer If DTSZ = 1, MARB is decremented by 2 after each transfer

Data transfer master enable

0	Data transfer is disabled
1	Data transfer is enabled



Note: Bit functions are the same as for DMAC0.

ETCR1A H/L—Execute Transfer Count Register 1A H/L H'34, H'35 DMAC1

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	Undetermined															
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

ETCR1AH

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

ETCR1AL

Note: Bit functions are the same as for DMAC0.

IOAR1A—I/O Address Register 1A H'36 DMAC1

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

- Short address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

- Full address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	SAID	SAIDE	DTIE	DTS2A	DTS1A	DTS0A
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

MAR1B R/E/H/L—Memory Address Register 1B R/E/H/L **H'38, H'39, H'3A, H'3B** **DMAC1**

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Initial value	1	1	1	1	1	1	1	1	Undetermined							
Read/Write	—	—	—	—	—	—	—	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR1BR								MAR1BE							

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	Undetermined								Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR1BH								MAR1BL							

Note: Bit functions are the same as for DMAC0.

ETCR1B H/L—Execute Transfer Count Register 1B H/L **H'3C, H'3D** **DMAC1**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	Undetermined															
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

ETCR1BH

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

ETCR1BL

Note: Bit functions are the same as for DMAC0.

IOAR1B—I/O Address Register 1B **H'3E** **DMAC1**

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

DTCR1B—Data Transfer Control Register 1B **H'3F** **DMAC1**

- Short address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

- Full address mode

Bit	7	6	5	4	3	2	1	0
	DTME	—	DAID	DAIDE	TMS	DTS2B	DTS1B	DTS0B
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

MAR2A R/E/H/L—Memory Address Register 2A R/E/H/L **H'40, H'41, H'42, H'43** **DMAC2**

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Initial value	1	1	1	1	1	1	1	1	Undetermined							
Read/Write	—	—	—	—	—	—	—	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR2AR								MAR2AE							

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	Undetermined								Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR2AH								MAR2AL							

Note: Bit functions are the same as for DMAC0.

ETCR2A H/L—Execute Transfer Count Register 2A H/L H'44, H'45 DMAC2

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	Undetermined															
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

ETCR2AH

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

ETCR2AL

Note: Bit functions are the same as for DMAC0.

IOAR2A—I/O Address Register 2A H'46 DMAC2

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

- Short address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

- Full address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	SAID	SAIDE	DTIE	DTS2A	DTS1A	DTS0A
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

MAR2B R/E/H/L—Memory Address Register 2B R/E/H/L **H'48, H'49, H'4A, H'4B** **DMAC2**

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Initial value	1	1	1	1	1	1	1	1	Undetermined							
Read/Write	—	—	—	—	—	—	—	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR2BR								MAR2BE							

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	Undetermined								Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR2BH								MAR2BL							

Note: Bit functions are the same as for DMAC0.

ETCR2B H/L—Execute Transfer Count Register 2B H/L **H'4C, H'4D** **DMAC2**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	Undetermined															
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

ETCR2BH

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

ETCR2BL

Note: Bit functions are the same as for DMAC0.

IOAR2B—I/O Address Register 2B **H'4E** **DMAC2**

Bit	7	6	5	4	3	2	1	0
Initial value	Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

DTCR2B—Data Transfer Control Register 2B **H'4F** **DMAC2**

- Short address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

- Full address mode

Bit	7	6	5	4	3	2	1	0
	DTME	—	DAID	DAIDE	TMS	DTS2B	DTS1B	DTS0B
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

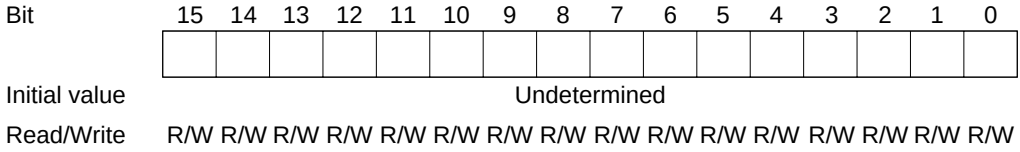
MAR3A R/E/H/L—Memory Address Register 3A R/E/H/L **H'50, H'51, H'52, H'53** **DMAC3**

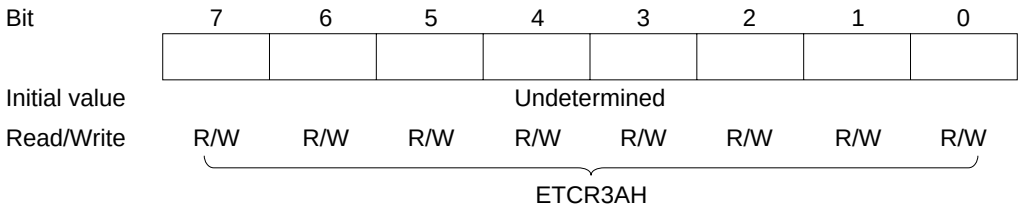
Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Initial value	1	1	1	1	1	1	1	1	Undetermined							
Read/Write	—	—	—	—	—	—	—	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR3AR								MAR3AE							

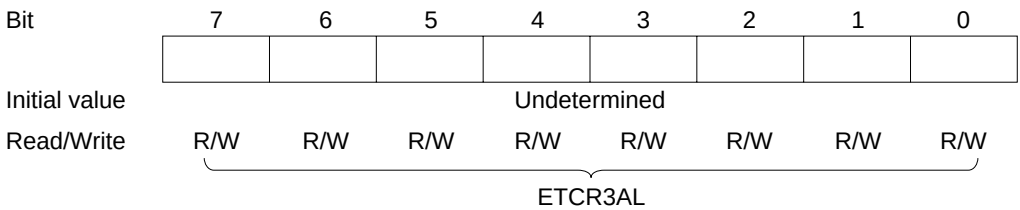
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	Undetermined								Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR3AH								MAR3AL							

Note: Bit functions are the same as for DMAC0.

ETCR3A H/L—Execute Transfer Count Register 3A H/L **H'54, H'55** **DMAC3**

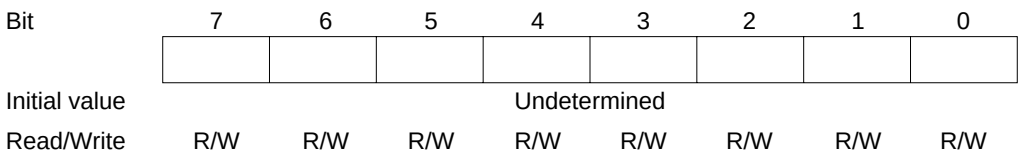






Note: Bit functions are the same as for DMAC0.

IOAR3A—I/O Address Register 3A **H'56** **DMAC3**



Note: Bit functions are the same as for DMAC0.

- Short address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

- Full address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	SAID	SAIDE	DTIE	DTS2A	DTS1A	DTS0A
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

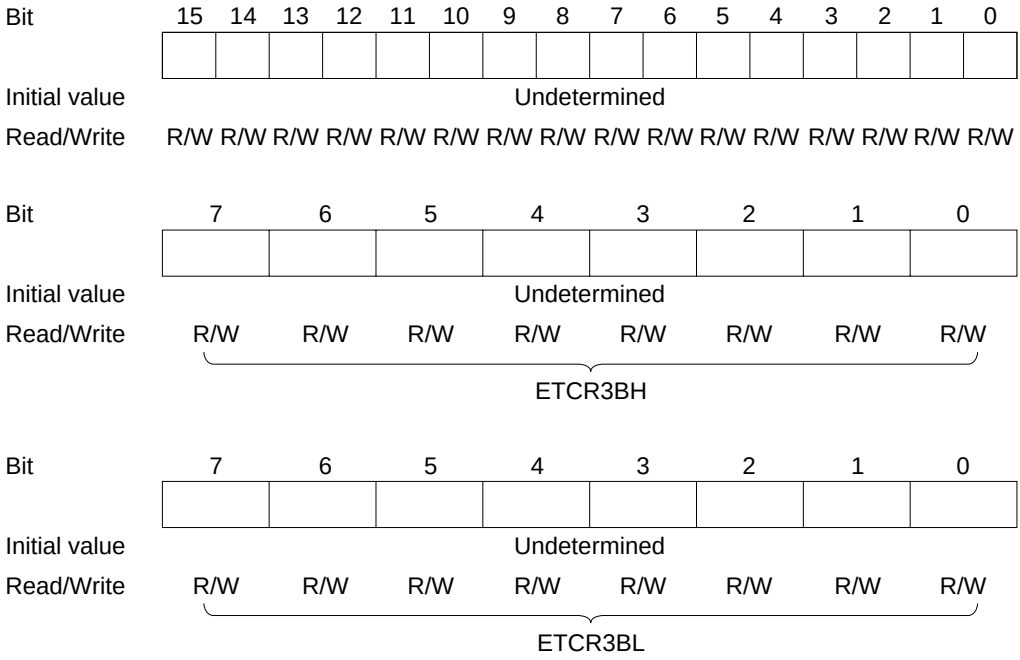
MAR3B R/E/H/L—Memory Address Register 3B R/E/H/L **H'58, H'59, H'5A, H'5B** **DMAC3**

Bit	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
Initial value	1	1	1	1	1	1	1	1	Undetermined							
Read/Write	—	—	—	—	—	—	—	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR3BR								MAR3BE							

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	Undetermined								Undetermined							
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
	MAR3BH								MAR3BL							

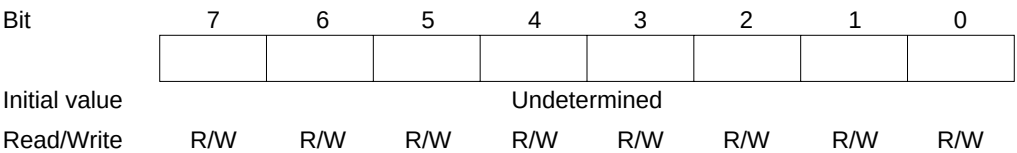
Note: Bit functions are the same as for DMAC0.

ETCR3B H/L—Execute Transfer Count Register 3B H/L **H'5C, H'5D** **DMAC3**



Note: Bit functions are the same as for DMAC0.

IOAR3B—I/O Address Register 3B **H'5E** **DMAC3**



Note: Bit functions are the same as for DMAC0.

- Short address mode

Bit	7	6	5	4	3	2	1	0
	DTE	DTSZ	DTID	RPE	DTIE	DTS2	DTS1	DTS0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

- Full address mode

Bit	7	6	5	4	3	2	1	0
	DTME	—	DAID	DAIDE	TMS	DTS2B	DTS1B	DTS0B
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for DMAC0.

Bit	7	6	5	4	3	2	1	0
	—	—	—	STR4	STR3	STR2	STR1	STR0
Initial value	1	1	1	0	0	0	0	0
Read/Write	—	—	—	R/W	R/W	R/W	R/W	R/W

Counter start 0

0	TCNT0 is halted
1	TCNT0 is counting

Counter start 1

0	TCNT1 is halted
1	TCNT1 is counting

Counter start 2

0	TCNT2 is halted
1	TCNT2 is counting

Counter start 3

0	TCNT3 is halted
1	TCNT3 is counting

Counter start 4

0	TCNT4 is halted
1	TCNT4 is counting

TSNC—Timer Synchro Register **H'61** **ITU (all channels)**

Bit	7	6	5	4	3	2	1	0
	—	—	—	SYNC4	SYNC3	SYNC2	SYNC1	SYNC0
Initial value	1	1	1	0	0	0	0	0
Read/Write	—	—	—	R/W	R/W	R/W	R/W	R/W

Timer sync 0

0	TCNT0 operates independently
1	TCNT0 is synchronized

Timer sync 1

0	TCNT1 operates independently
1	TCNT1 is synchronized

Timer sync 2

0	TCNT2 operates independently
1	TCNT2 is synchronized

Timer sync 3

0	TCNT3 operates independently
1	TCNT3 is synchronized

Timer sync 4

0	TCNT4 operates independently
1	TCNT4 is synchronized

Bit	7	6	5	4	3	2	1	0
	—	MDF	FDIR	PWM4	PWM3	PWM2	PWM1	PWM0
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W

PWM mode 0

0	Channel 0 operates normally
1	Channel 0 operates in PWM mode

PWM mode 1

0	Channel 1 operates normally
1	Channel 1 operates in PWM mode

PWM mode 2

0	Channel 2 operates normally
1	Channel 2 operates in PWM mode

PWM mode 3

0	Channel 3 operates normally
1	Channel 3 operates in PWM mode

PWM mode 4

0	Channel 4 operates normally
1	Channel 4 operates in PWM mode

Flag direction

0	OVF is set to 1 in TSR2 when TCNT2 overflows or underflows
1	OVF is set to 1 in TSR2 when TCNT2 overflows

Phase counting mode flag

0	Channel 2 operates normally
1	Channel 2 operates in phase counting mode

Bit	7	6	5	4	3	2	1	0
	—	—	CMD1	CMD0	BFB4	BFA4	BFB3	BFA3
Initial value	1	1	0	0	0	0	0	0
Read/Write	—	—	R/W	R/W	R/W	R/W	R/W	R/W

Buffer mode A3

0	GRA3 operates normally
1	GRA3 is buffered by BRA3

Buffer mode B3

0	GRB3 operates normally
1	GRB3 is buffered by BRB3

Buffer mode A4

0	GRA4 operates normally
1	GRA4 is buffered by BRA4

Buffer mode B4

0	GRB4 operates normally
1	GRB4 is buffered by BRB4

Combination mode 1 and 0

Bit 5	Bit 4	
CMD1	CMD0	Operating Mode of Channels 3 and 4
0	0	Channels 3 and 4 operate normally
	1	
1	0	Channels 3 and 4 operate together in complementary PWM mode
	1	Channels 3 and 4 operate together in reset-synchronized PWM mode

Bit	7	6	5	4	3	2	1	0
	—	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Timer prescaler 2 to 0

Bit 2	Bit 1	Bit 0	
TPSC2	TPSC1	TPSC0	TCNT Clock Source
0	0	0	Internal clock: ø
		1	Internal clock: ø/2
	1	0	Internal clock: ø/4
		1	Internal clock: ø/8
1	0	0	External clock A: TCLKA input
		1	External clock B: TCLKB input
	1	0	External clock C: TCLKC input
		1	External clock D: TCLKD input

Clock edge 1 and 0

Bit 4	Bit 3	
CKEG1	CKEG0	Counted Edges of External Clock
0	0	Rising edges counted
	1	Falling edges counted
1	—	Both edges counted

Counter clear 1 and 0

Bit 6	Bit 5	
CCLR1	CCLR0	TCNT Clear Source
0	0	TCNT is not cleared
	1	TCNT is cleared by GRA compare match or input capture
1	0	TCNT is cleared by GRB compare match or input capture
	1	Synchronous clear: TCNT is cleared in synchronization with other synchronized timers

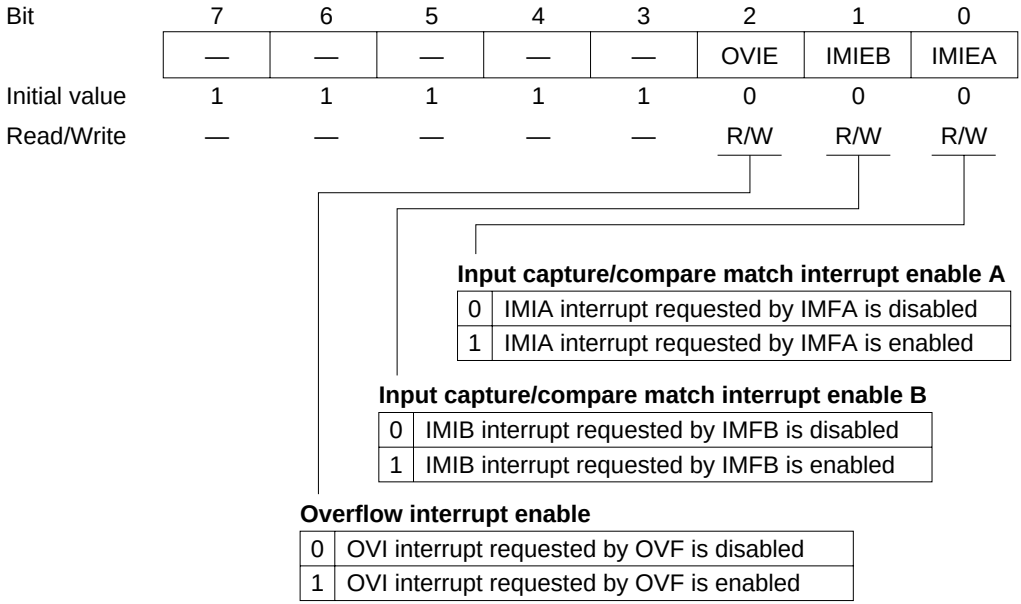
Bit	7	6	5	4	3	2	1	0
	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0
Initial value	1	0	0	0	1	0	0	0
Read/Write	—	R/W	R/W	R/W	—	R/W	R/W	R/W

I/O control A2 to A0

Bit 2	Bit 1	Bit 0		
IOA2	IOA1	IOA0	GRA Function	
0	0	0	GRA is an output compare register	No output at compare match
		1		0 output at GRA compare match
	1	0		1 output at GRA compare match
		1		Output toggles at GRA compare match
1	0	0	GRA is an input capture register	GRA captures rising edge of input
		1		GRA captures falling edge of input
	1	0		GRA captures both edges of input
		1		

I/O control B2 to B0

Bit 6	Bit 5	Bit 4		
IOB2	IOB1	IOB0	GRB Function	
0	0	0	GRB is an output compare register	No output at compare match
		1		0 output at GRB compare match
	1	0		1 output at GRB compare match
		1		Output toggles at GRB compare match
1	0	0	GRB is an input capture register	GRB captures rising edge of input
		1		GRB captures falling edge of input
	1	0		GRB captures both edges of input
		1		


Bit
7
6
5
4
3
2
1
0
—
—
—
—
—
OVIE
IMIEB
IMIEA
Initial value
1
1
1
1
1
0
0
0
Read/Write
—
—
—
—
—
R/W
R/W
R/W
Input capture/compare match interrupt enable A
0
IMIA interrupt requested by IMFA is disabled
1
IMIA interrupt requested by IMFA is enabled
Input capture/compare match interrupt enable B
0
IMIB interrupt requested by IMFB is disabled
1
IMIB interrupt requested by IMFB is enabled
Overflow interrupt enable
0
OVI interrupt requested by OVF is disabled
1
OVI interrupt requested by OVF is enabled

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	OVF	IMFB	IMFA
Initial value	1	1	1	1	1	0	0	0
Read/Write	—	—	—	—	—	R/(W)*	R/(W)*	R/(W)*

Input capture/compare match flag A

0	[Clearing condition] Read IMFA when IMFA = 1, then write 0 in IMFA
1	[Setting conditions] TCNT = GRA when GRA functions as a compare match register. TCNT value is transferred to GRA by an input capture signal, when GRA functions as an input capture register.

Input capture/compare match flag B

0	[Clearing condition] Read IMFB when IMFB = 1, then write 0 in IMFB
1	[Setting conditions] TCNT = GRB when GRB functions as a compare match register. TCNT value is transferred to GRB by an input capture signal, when GRB functions as an input capture register.

Overflow flag

0	[Clearing condition] Read OVF when OVF = 1, then write 0 in OVF
1	[Setting condition] TCNT overflowed from H'FFFF to H'0000

Note: * Only 0 can be written, to clear the flag.

TCNT0 H/L—Timer Counter 0 H/L **H'68, H'69** **ITU0**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Up-counter

GRA0 H/L—General Register A0 H/L **H'6A, H'6B** **ITU0**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Output compare or input capture register

GRB0 H/L—General Register B0 H/L **H'6C, H'6D** **ITU0**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Output compare or input capture register

TCR1—Timer Control Register 1 **H'6E** **ITU1**

Bit	7	6	5	4	3	2	1	0
	—	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TIOR1—Timer I/O Control Register 1 **H'6F** **ITU1**

Bit	7	6	5	4	3	2	1	0
	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0
Initial value	1	0	0	0	1	0	0	0
Read/Write	—	R/W	R/W	R/W	—	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TIER1—Timer Interrupt Enable Register 1 **H'70** **ITU1**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	OVIE	IMIEB	IMIEA
Initial value	1	1	1	1	1	0	0	0
Read/Write	—	—	—	—	—	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TSR1—Timer Status Register 1 **H'71** **ITU1**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	OVF	IMFB	IMFA
Initial value	1	1	1	1	1	0	0	0
Read/Write	—	—	—	—	—	R/(W)*	R/(W)*	R/(W)*

Notes: Bit functions are the same as for ITU0.
* Only 0 can be written, to clear the flag.

TCNT1 H/L—Timer Counter 1 H/L **H'72, H'73** **ITU1**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

GRA1 H/L—General Register A1 H/L **H'74, H'75** **ITU1**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

GRB1 H/L—General Register B1 H/L **H'76, H'77** **ITU1**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TCR2—Timer Control Register 2 **H'78** **ITU2**

Bit	7	6	5	4	3	2	1	0
	—	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Notes: 1. Bit functions are the same as for ITU0.
2. When channel 2 is used in phase counting mode, the counter clock source selection by bits TPSC2 to TPSC0 is ignored.

TIOR2—Timer I/O Control Register 2 **H'79** **ITU2**

Bit	7	6	5	4	3	2	1	0
	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0
Initial value	1	0	0	0	1	0	0	0
Read/Write	—	R/W	R/W	R/W	—	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TIER2—Timer Interrupt Enable Register 2 **H'7A** **ITU2**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	OVIE	IMIEB	IMIEA
Initial value	1	1	1	1	1	0	0	0
Read/Write	—	—	—	—	—	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TSR2—Timer Status Register 2 **H'7B** **ITU2**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	OVF	IMFB	IMFA
Initial value	1	1	1	1	1	0	0	0
Read/Write	—	—	—	—	—	R/(W)*	R/(W)*	R/(W)*

Bit functions are the same as for ITU0.

Overflow flag

0	[Clearing condition] Read OVF when OVF = 1, then write 0 in OVF
1	[Setting condition] TCNT overflowed from H'FFFF to H'0000 or underflowed from H'0000 to H'FFFF

Note: * Only 0 can be written, to clear the flag.

TCNT2 H/L—Timer Counter 2 H/L **H'7C, H'7D** **ITU2**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Phase counting mode: up/down counter
Other modes: up-counter

GRA2 H/L—General Register A2 H/L **H'7E, H'7F** **ITU2**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

GRB2 H/L—General Register B2 H/L **H'80, H'81** **ITU2**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TCR3—Timer Control Register 3 **H'82** **ITU3**

Bit	7	6	5	4	3	2	1	0
	—	CCLR1	CCLR0	CKEG1	CLEG0	TPSC2	TPSC1	TPSC0
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TIOR3—Timer I/O Control Register 3 **H'83** **ITU3**

Bit	7	6	5	4	3	2	1	0
	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0
Initial value	1	0	0	0	1	0	0	0
Read/Write	—	R/W	R/W	R/W	—	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TIER3—Timer Interrupt Enable Register 3 **H'84** **ITU3**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	OVIE	IMIEB	IMIEA
Initial value	1	1	1	1	1	0	0	0
Read/Write	—	—	—	—	—	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TSR3—Timer Status Register 3 **H'85** **ITU3**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	OVF	IMFB	IMFA
Initial value	1	1	1	1	1	0	0	0
Read/Write	—	—	—	—	—	R/(W)*	R/(W)*	R/(W)*

Bit functions are the same as for ITU0

Overflow flag

0	[Clearing condition] Read OVF when OVF = 1, then write 0 in OVF
1	[Setting condition] TCNT overflowed from H'FFFF to H'0000 or underflowed from H'0000 to H'FFFF

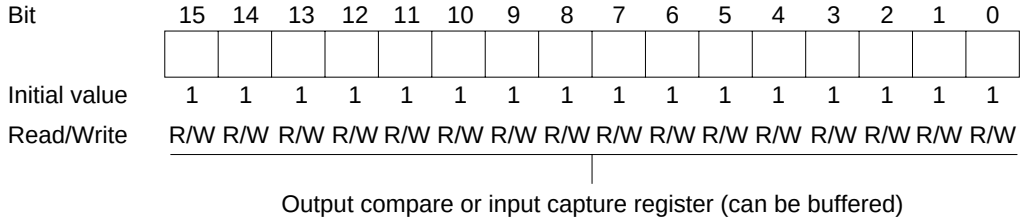
Note: * Only 0 can be written, to clear the flag.

TCNT3 H/L—Timer Counter 3 H/L **H'86, H'87** **ITU3**

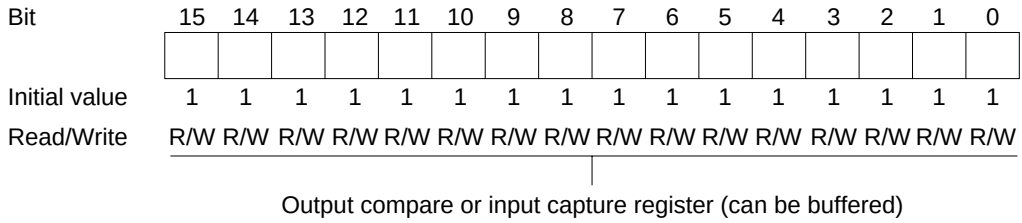
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Complementary PWM mode: up/down counter
Other modes: up-counter

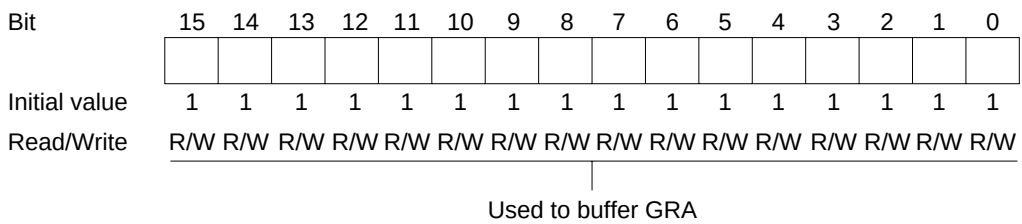
GRA3 H/L—General Register A3 H/L **H'88, H'89** **ITU3**



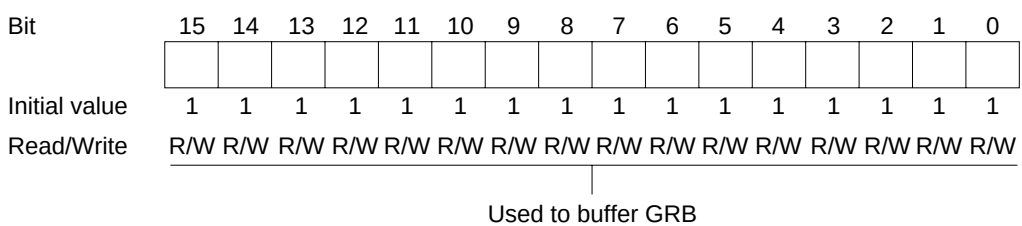
GRB3 H/L—General Register B3 H/L **H'8A, H'8B** **ITU3**



BRA3 H/L—Buffer Register A3 H/L **H'8C, H'8D** **ITU3**



BRB3 H/L—Buffer Register B3 H/L **H'8E, H'8F** **ITU3**



Bit	7	6	5	4	3	2	1	0
	—	—	EXB4	EXA4	EB3	EB4	EA4	EA3
Initial value	1	1	1	1	1	1	1	1
Read/Write	—	—	R/W	R/W	R/W	R/W	R/W	R/W

Master enable TIOCA3

0	$TIOCA_3$ output is disabled regardless of TIOR3, TMDR, and TFCR settings
1	$TIOCA_3$ is enabled for output according to TIOR3, TMDR, and TFCR settings

Master enable TIOCA4

0	$TIOCA_4$ output is disabled regardless of TIOR4, TMDR, and TFCR settings
1	$TIOCA_4$ is enabled for output according to TIOR4, TMDR, and TFCR settings

Master enable TIOCB4

0	$TIOCB_4$ output is disabled regardless of TIOR4 and TFCR settings
1	$TIOCB_4$ is enabled for output according to TIOR4 and TFCR settings

Master enable TIOCB3

0	$TIOCB_3$ output is disabled regardless of TIOR3 and TFCR settings
1	$TIOCB_3$ is enabled for output according to TIOR3 and TFCR settings

Master enable TOCXA4

0	$TOCXA_4$ output is disabled regardless of TFCR settings
1	$TOCXA_4$ is enabled for output according to TFCR settings

Master enable TOCXB4

0	$TOCXB_4$ output is disabled regardless of TFCR settings
1	$TOCXB_4$ is enabled for output according to TFCR settings

Bit	7	6	5	4	3	2	1	0
	—	—	—	XTGD	—	—	OLS4	OLS3
Initial value	1	1	1	1	1	1	1	1
Read/Write	—	—	—	R/W	—	—	R/W	R/W

Output level select 3

0	$TIOCB_3$, $TOCXA_4$, and $TOCXB_4$ outputs are inverted
1	$TIOCB_3$, $TOCXA_4$, and $TOCXB_4$ outputs are not inverted

Output level select 4

0	$TIOCA_3$, $TIOCA_4$, and $TIOCB_4$ outputs are inverted
1	$TIOCA_3$, $TIOCA_4$, and $TIOCB_4$ outputs are not inverted

External trigger disable

0	Input capture A in channel 1 is used as an external trigger signal in reset-synchronized PWM mode and complementary PWM mode*
1	External triggering is disabled

Note: * When an external trigger occurs, bits 5 to 0 in TOER are cleared to 0, disabling ITU output.

TCR4—Timer Control Register 4 **H'92** **ITU4**

Bit	7	6	5	4	3	2	1	0
	—	CCLR1	CCLR0	CKEG1	CKEG0	TPSC2	TPSC1	TPSC0
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TIOR4—Timer I/O Control Register 4 **H'93** **ITU4**

Bit	7	6	5	4	3	2	1	0
	—	IOB2	IOB1	IOB0	—	IOA2	IOA1	IOA0
Initial value	1	0	0	0	1	0	0	0
Read/Write	—	R/W	R/W	R/W	—	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TIER4—Timer Interrupt Enable Register 4 **H'94** **ITU4**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	OVIE	IMIEB	IMIEA
Initial value	1	1	1	1	1	0	0	0
Read/Write	—	—	—	—	—	R/W	R/W	R/W

Note: Bit functions are the same as for ITU0.

TSR4—Timer Status Register 4 **H'95** **ITU4**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	OVF	IMFB	IMFA
Initial value	1	1	1	1	1	0	0	0
Read/Write	—	—	—	—	—	R/(W)*	R/(W)*	R/(W)*

Notes: Bit functions are the same as for ITU0.
* Only 0 can be written, to clear the flag.

TCNT4 H/L—Timer Counter 4 H/L **H'96, H'97** **ITU4**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU3.

GRA4 H/L—General Register A4 H/L **H'98, H'99** **ITU4**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU3.

GRB4 H/L—General Register B4 H/L **H'9A, H'9B** **ITU4**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU3.

BRA4 H/L—Buffer Register A4 H/L **H'9C, H'9D** **ITU4**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU3.

BRB4 H/L—Buffer Register B4 H/L **H'9E, H'9F** **ITU4**

Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for ITU3.

TPMR—TPC Output Mode Register **H'A0** **TPC**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	G3NOV	G2NOV	G1NOV	G0NOV
Initial value	1	1	1	1	0	0	0	0
Read/Write	—	—	—	—	R/W	R/W	R/W	R/W

Group 0 non-overlap

0	Normal TPC output in group 0. Output values change at compare match A in the selected ITU channel.
1	Non-overlapping TPC output in group 0, controlled by compare match A and B in the selected ITU channel

Group 1 non-overlap

0	Normal TPC output in group 1. Output values change at compare match A in the selected ITU channel.
1	Non-overlapping TPC output in group 1, controlled by compare match A and B in the selected ITU channel

Group 2 non-overlap

0	Normal TPC output in group 2. Output values change at compare match A in the selected ITU channel.
1	Non-overlapping TPC output in group 2, controlled by compare match A and B in the selected ITU channel

Group 3 non-overlap

0	Normal TPC output in group 3. Output values change at compare match A in the selected ITU channel.
1	Non-overlapping TPC output in group 3, controlled by compare match A and B in the selected ITU channel

Bit	7	6	5	4	3	2	1	0
	G3CMS1	G3CMS0	G2CMS1	G2CMS0	G1CMS1	G1CMS0	G0CMS1	G0CMS0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Group 0 compare match select 1 and 0

Bit 1	Bit 0	
G0CMS1	G0CMS0	ITU Channel Selected as Output Trigger
0	0	TPC output group 0 (TP_3 to TP_0) is triggered by compare match in ITU channel 0
	1	TPC output group 0 (TP_3 to TP_0) is triggered by compare match in ITU channel 1
1	0	TPC output group 0 (TP_3 to TP_0) is triggered by compare match in ITU channel 2
	1	TPC output group 0 (TP_3 to TP_0) is triggered by compare match in ITU channel 3

Group 1 compare match select 1 and 0

Bit 3	Bit 2	
G1CMS1	G1CMS0	ITU Channel Selected as Output Trigger
0	0	TPC output group 1 (TP_7 to TP_4) is triggered by compare match in ITU channel 0
	1	TPC output group 1 (TP_7 to TP_4) is triggered by compare match in ITU channel 1
1	0	TPC output group 1 (TP_7 to TP_4) is triggered by compare match in ITU channel 2
	1	TPC output group 1 (TP_7 to TP_4) is triggered by compare match in ITU channel 3

Group 2 compare match select 1 and 0

Bit 5	Bit 4	
G2CMS1	G2CMS0	ITU Channel Selected as Output Trigger
0	0	TPC output group 2 (TP_{11} to TP_8) is triggered by compare match in ITU channel 0
	1	TPC output group 2 (TP_{11} to TP_8) is triggered by compare match in ITU channel 1
1	0	TPC output group 2 (TP_{11} to TP_8) is triggered by compare match in ITU channel 2
	1	TPC output group 2 (TP_{11} to TP_8) is triggered by compare match in ITU channel 3

Group 3 compare match select 1 and 0

Bit 7	Bit 6	
G3CMS1	G3CMS0	ITU Channel Selected as Output Trigger
0	0	TPC output group 3 (TP_{15} to TP_{12}) is triggered by compare match in ITU channel 0
	1	TPC output group 3 (TP_{15} to TP_{12}) is triggered by compare match in ITU channel 1
1	0	TPC output group 3 (TP_{15} to TP_{12}) is triggered by compare match in ITU channel 2
	1	TPC output group 3 (TP_{15} to TP_{12}) is triggered by compare match in ITU channel 3

NDERB—Next Data Enable Register B **H'A2** **TPC**

Bit	7	6	5	4	3	2	1	0
	NDER15	NDER14	NDER13	NDER12	NDER11	NDER10	NDER9	NDER8
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Next data enable 15 to 8

Bits 7 to 0	
NDER15 to NDER8	Description
0	TPC outputs TP_{15} to TP_8 are disabled (NDR15 to NDR8 are not transferred to PB_7 to PB_0)
1	TPC outputs TP_{15} to TP_8 are enabled (NDR15 to NDR8 are transferred to PB_7 to PB_0)

NDERA—Next Data Enable Register A **H'A3** **TPC**

Bit	7	6	5	4	3	2	1	0
	NDER7	NDER6	NDER5	NDER4	NDER3	NDER2	NDER1	NDER0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Next data enable 7 to 0

Bits 7 to 0	
NDER7 to NDER0	Description
0	TPC outputs TP_7 to TP_0 are disabled (NDR7 to NDR0 are not transferred to PA_7 to PA_0)
1	TPC outputs TP_7 to TP_0 are enabled (NDR7 to NDR0 are transferred to PA_7 to PA_0)

- Same output trigger for TPC output groups 2 and 3

Address H'FFA4

Bit	7	6	5	4	3	2	1	0
	NDR15	NDR14	NDR13	NDR12	NDR11	NDR10	NDR9	NDR8
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Next output data for TPC output group 3

Next output data for TPC output group 2

Address H'FFA6

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	—	—	—
Initial value	1	1	1	1	1	1	1	1
Read/Write	—	—	—	—	—	—	—	—

- Different output triggers for TPC output groups 2 and 3

Address H'FFA4

Bit	7	6	5	4	3	2	1	0
	NDR15	NDR14	NDR13	NDR12	—	—	—	—
Initial value	0	0	0	0	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	—	—	—	—

Next output data for TPC output group 3

Address H'FFA6

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	NDR11	NDR10	NDR9	NDR8
Initial value	1	1	1	1	0	0	0	0
Read/Write	—	—	—	—	R/W	R/W	R/W	R/W

Next output data for TPC output group 2

- Same output trigger for TPC output groups 0 and 1

Address H'FFA5

Bit	7	6	5	4	3	2	1	0
	NDR7	NDR6	NDR5	NDR4	NDR3	NDR2	NDR1	NDR0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Next output data for TPC output group 1

Next output data for TPC output group 0

Address H'FFA7

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	—	—	—
Initial value	1	1	1	1	1	1	1	1
Read/Write	—	—	—	—	—	—	—	—

- Different output triggers for TPC output groups 0 and 1

Address H'FFA5

Bit	7	6	5	4	3	2	1	0
	NDR7	NDR6	NDR5	NDR4	—	—	—	—
Initial value	0	0	0	0	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	—	—	—	—

Next output data for TPC output group 1

Address H'FFA7

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	NDR3	NDR2	NDR1	NDR0
Initial value	1	1	1	1	0	0	0	0
Read/Write	—	—	—	—	R/W	R/W	R/W	R/W

Next output data for TPC output group 0

Bit	7	6	5	4	3	2	1	0
	OVF	WT/$\overline{IT}$	TME	—	—	CKS2	CKS1	CKS0
Initial value	0	0	0	1	1	0	0	0
Read/Write	R/(W)*	R/W	R/W	—	—	R/W	R/W	R/W

Timer enable

0	Timer disabled • TCNT is initialized to H'00 and halted
1	Timer enabled • TCNT is counting • CPU interrupt requests are enabled

Clock select 2 to 0

0	0	0	ø/2
		1	ø/32
	1	0	ø/64
		1	ø/128
1	0	0	ø/256
		1	ø/512
	1	0	ø/2048
		1	ø/4096

Timer mode select

0	Interval timer: requests interval timer interrupts
1	Watchdog timer: generates a reset signal

Overflow flag

0	[Clearing condition] Read OVF when OVF = 1, then write 0 in OVF
1	[Setting condition] TCNT changes from H'FF to H'00

Note: * Only 0 can be written, to clear the flag.

TCNT—Timer Counter **H'A9 (read), H'A8 (write)** **WDT**

Bit	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Count value

RSTCSR—Reset Control/Status Register **H'AB (read), H'AA (write)** **WDT**

Bit	7	6	5	4	3	2	1	0
	WRST	RSTOE	—	—	—	—	—	—
Initial value	0	0	1	1	1	1	1	1
Read/Write	R/(W)*	R/W	—	—	—	—	—	—

Reset output enable

0	Reset signal is not output externally
1	Reset signal is output externally

Watchdog timer reset

0	[Clearing condition] Reset signal input at $\overline{\text{RES}}$ pin, or 0 written by software
1	[Setting condition] TCNT overflow generates a reset signal

Note: * Only 0 can be written in bit 7, to clear the flag.

Bit	7	6	5	4	3	2	1	0
	SRFMD	PSRAME	DRAME	CAS/$\overline{WE}$	M9/$\overline{M8}$	RFSHE	—	RCYCE
Initial value	0	0	0	0	0	0	1	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	—	R/W

Refresh cycle enable

0	Refresh cycles are disabled
1	Refresh cycles are enabled for area 3

Refresh pin enable

0	Refresh signal output at the $\overline{RFSH}$ pin is disabled
1	Refresh signal output at the $\overline{RFSH}$ pin is enabled

Address multiplex mode select

0	8-bit column address mode
1	9-bit column address mode

Strobe mode select

0	2 $\overline{WE}$ mode
1	2 $\overline{CAS}$ mode

PSRAM enable, DRAM enable

Bit 6	Bit 5	
PSRAME	DRAME	RAM Interface
0	0	Can be used as an interval timer
	1	DRAM can be connected
1	0	PSRAM can be connected
	1	Illegal setting

Self-refresh mode

0	DRAM or PSRAM self-refresh is disabled in software standby mode
1	DRAM or PSRAM self-refresh is enabled in software standby mode

Bit	7	6	5	4	3	2	1	0
	CMF	CMIE	CKS2	CKS1	CKS0	—	—	—
Initial value	0	0	0	0	0	1	1	1
Read/Write	R/(W)*	R/W	R/W	R/W	R/W	—	—	—

Clock select 2 to 0

Bit 5	Bit 4	Bit 3	
CKS2	CKS1	CKS0	Counter Clock Source
0	0	0	Clock input is disabled
		1	ø/2
	1	0	ø/8
		1	ø/32
1	0	0	ø/128
		1	ø/512
	1	0	ø/2048
		1	ø/4096

Compare match interrupt enable

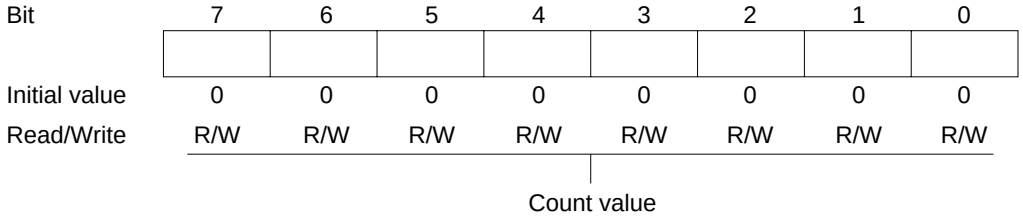
0	The CMI interrupt requested by CMF is disabled
1	The CMI interrupt requested by CMF is enabled

Compare match flag

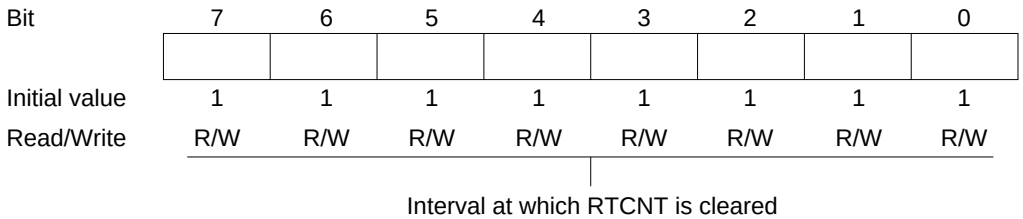
0	[Clearing condition] Read CMF when CMF = 1, then write 0 in CMF
1	[Setting condition] RTCNT = RTCOR

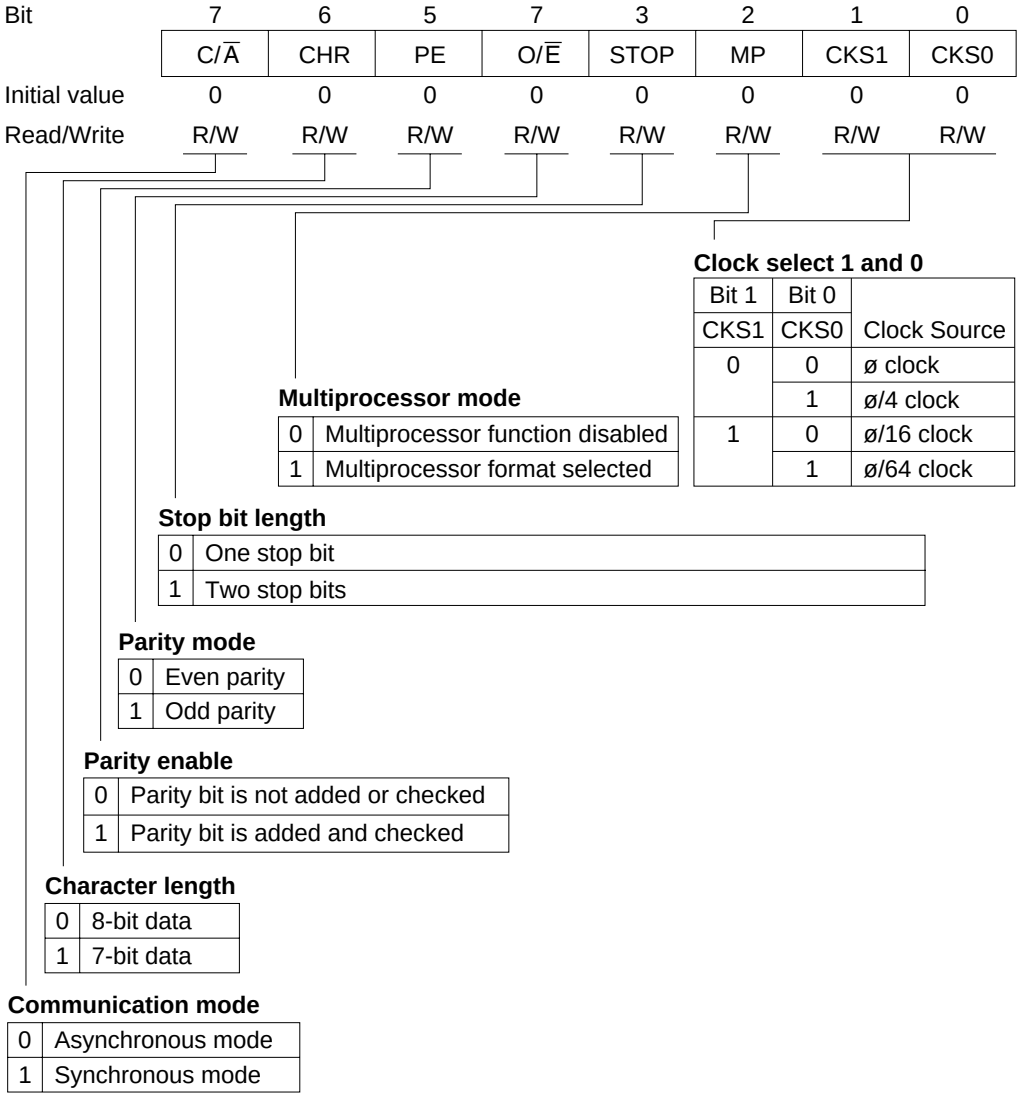
Note: * Only 0 can be written, to clear the flag.

RTCNT—Refresh Timer Counter **H'AE** **Refresh controller**

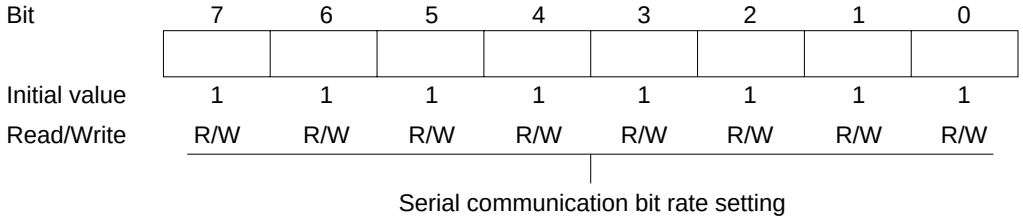


RTCOR—Refresh Time Constant Register **H'AF** **Refresh controller**




Bit
7 6 5 7 3 2 1 0
C/$\overline{A}$ CHR PE O/$\overline{E}$ STOP MP CKS1 CKS0
Initial value
0 0 0 0 0 0 0 0
Read/Write
R/W R/W R/W R/W R/W R/W R/W R/W
Clock select 1 and 0
Bit 1 Bit 0
CKS1 CKS0 Clock Source
0 0 ø clock
1 ø/4 clock
1 0 ø/16 clock
1 ø/64 clock
Multiprocessor mode
0 Multiprocessor function disabled
1 Multiprocessor format selected
Stop bit length
0 One stop bit
1 Two stop bits
Parity mode
0 Even parity
1 Odd parity
Parity enable
0 Parity bit is not added or checked
1 Parity bit is added and checked
Character length
0 8-bit data
1 7-bit data
Communication mode
0 Asynchronous mode
1 Synchronous mode

BRR—Bit Rate Register **H'B1** **SCI0**



Bit	7	6	5	4	3	2	1	0
	TIE	RIE	TE	RE	MPIE	TEIE	CKE1	CKE0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Clock enable 1 and 0

Bit 1	Bit 0		
CKE1	CKE0	Clock Selection and Output	
0	0	Asynchronous mode	Internal clock, SCK pin available for generic input output
		Synchronous mode	Internal clock, SCK pin used for serial clock output
	1	Asynchronous mode	Internal clock, SCK pin used for clock output
		Synchronous mode	Internal clock, SCK pin used for serial clock output
1	0	Asynchronous mode	External clock, SCK pin used for clock input
		Synchronous mode	External clock, SCK pin used for serial clock input
	1	Asynchronous mode	External clock, SCK pin used for clock input
		Synchronous mode	External clock, SCK pin used for serial clock input

Transmit-end interrupt enable

0	Transmit-end interrupt requests (TEI) are disabled
1	Transmit-end interrupt requests (TEI) are enabled

Multiprocessor interrupt enable

0	Multiprocessor interrupts are disabled (normal receive operation)
1	Multiprocessor interrupts are enabled

Receive enable

0	Transmitting is disabled
1	Transmitting is enabled

Transmit enable

0	Transmitting is disabled
1	Transmitting is enabled

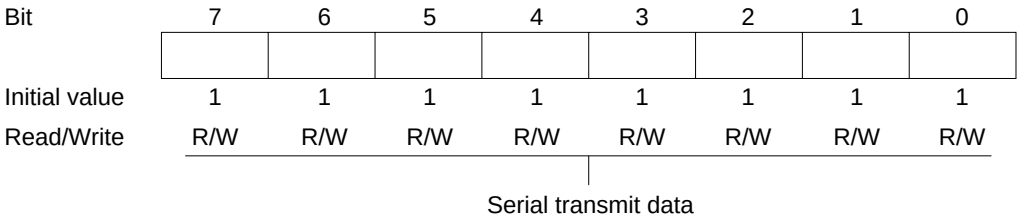
Receive interrupt enable

0	Receive-end (RXI) and receive-error (ERI) interrupt requests are disabled
1	Receive-end (RXI) and receive-error (ERI) interrupt requests are enabled

Transmit interrupt enable

0	Transmit-data-empty interrupt request (TXI) is disabled
1	Transmit-data-empty interrupt request (TXI) is enabled

TDR—Transmit Data Register **H'B3** **SCI0**



SSR—Serial Status Register **H'B4** **SCI0**

Bit	7	6	5	4	3	2	1	0
	TDRE	RDRF	ORER	FER	PER	TEND	MPB	MPBT
Initial value	1	0	0	0	0	1	0	0
Read/Write	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R	R	R/W

Multiprocessor bit

0	Multiprocessor bit value in receive data is 0
1	Multiprocessor bit value in receive data is 1

Multiprocessor bit transfer

0	Multiprocessor bit value in transmit data is 0
1	Multiprocessor bit value in transmit data is 1

Transmit end

0	[Clearing conditions] Read TDRE when TDRE = 1, then write 0 in TDRE. The DMAC writes data in TDR.
1	[Setting conditions] Reset or transition to standby mode. TE is cleared to 0 in SCR. TDRE is 1 when last bit of serial character is transmitted.

Parity error

0	[Clearing conditions] Reset or transition to standby mode. Read PER when PER = 1, then write 0 in PER.
1	[Setting condition] Parity error: (parity of receive data does not match parity setting of O/$\overline{E}$ in SMR)

Framing error

0	[Clearing conditions] Reset or transition to standby mode. Read FER when FER = 1, then write 0 in FER.
1	[Setting condition] Framing error (stop bit is 0)

Overrun error

0	[Clearing conditions] Reset or transition to standby mode. Read ORER when ORER = 1, then write 0 in ORER.
1	[Setting condition] Overrun error (reception of next serial data ends when RDRF = 1)

Receive data register full

0	[Clearing conditions] Reset or transition to standby mode. Read RDRF when RDRF = 1, then write 0 in RDRF. The DMAC reads data from RDR.
1	[Setting condition] Serial data is received normally and transferred from RSR to RDR

Transmit data register empty

0	[Clearing conditions] Read TDRE when TDRE = 1, then write 0 in TDRE. The DMAC writes data in TDR.
1	[Setting conditions] Reset or transition to standby mode. TE is 0 in SCR Data is transferred from TDR to TSR, enabling new data to be written in TDR.

Note: * Only 0 can be written, to clear the flag.

RDR—Receive Data Register **H'B5** **SCI0**

Bit	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R	R	R	R	R	R	R	R

Serial receive data

SMR—Serial Mode Register **H'B8** **SCI1**

Bit	7	6	5	4	3	2	1	0
	C/$\overline{A}$	CHR	PE	O/$\overline{E}$	STOP	MP	CKS1	CKS0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for SCI0.

BRR—Bit Rate Register **H'B9** **SCI1**

Bit	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for SCI0.

SCR—Serial Control Register **H'BA** **SCI1**

Bit	7	6	5	4	3	2	1	0
	TIE	RIE	TE	RE	MPIE	TEIE	CKE1	CKE0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for SCI0.

TDR—Transmit Data Register **H'BB** **SCI1**

Bit	7	6	5	4	3	2	1	0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Note: Bit functions are the same as for SCI0.

SSR—Serial Status Register **H'BC** **SCI1**

Bit	7	6	5	4	3	2	1	0
	TDRE	RDRF	ORER	FER	PER	TEND	MPB	MPBT
Initial value	1	0	0	0	0	1	0	0
Read/Write	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R	R	R/W

Notes: Bit functions are the same as for SCI0.
* Only 0 can be written, to clear the flag.

RDR—Receive Data Register **H'BD** **SCI1**

Bit	7	6	5	4	3	2	1	0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R	R	R	R	R	R	R	R

Note: Bit functions are the same as for SCI0.

P4DDR—Port 4 Data Direction Register **H'C5** **Port 4**

Bit	7	6	5	4	3	2	1	0
	$P4_7DDR$	$P4_6DDR$	$P4_5DDR$	$P4_4DDR$	$P4_3DDR$	$P4_2DDR$	$P4_1DDR$	$P4_0DDR$
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port 4 input/output select

0	Generic input pin
1	Generic output pin

P4DR—Port 4 Data Register **H'C7** **Port 4**

Bit	7	6	5	4	3	2	1	0
	$P4_7$	$P4_6$	$P4_5$	$P4_4$	$P4_3$	$P4_2$	$P4_1$	$P4_0$
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data for port 4 pins

P5DDR—Port 5 Data Direction Register **H'C8** **Port 5**

Bit		7	6	5	4	3	2	1	0
		$P5_7DDR$	$P5_6DDR$	$P5_5DDR$	$P5_4DDR$	$P5_3DDR$	$P5_2DDR$	$P5_1DDR$	$P5_0DDR$
Mode 1, 2	Initial value	0	0	0	0	1	1	1	1
	Read/Write	W	W	W	W	—	—	—	—
Mode 3, 4	Initial value	1	1	1	1	1	1	1	1
	Read/Write	—	—	—	—	—	—	—	—

Port 5 input/output select

0	Generic input
1	Generic output

P6DDR—Port 6 Data Direction Register **H'C9** **Port 6**

Bit	7	6	5	4	3	2	1	0
	—	$P6_6DDR$	$P6_5DDR$	$P6_4DDR$	$P6_3DDR$	$P6_2DDR$	$P6_1DDR$	$P6_0DDR$
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	W	W	W	W	W	W	W

Port 6 input/output select

0	Generic input
1	Generic output

P5DR—Port 5 Data Register **H'CA** **Port 5**

Bit	7	6	5	4	3	2	1	0
	$P5_7$	$P5_6$	$P5_5$	$P5_4$	$P5_3$	$P5_2$	$P5_1$	$P5_0$
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data for port 5 pins

P6DR—Port 6 Data Register **H'CB** **Port 6**

Bit	7	6	5	4	3	2	1	0
	—	$P6_6$	$P6_5$	$P6_4$	$P6_3$	$P6_2$	$P6_1$	$P6_0$
Initial value	1	0	0	0	0	0	0	0
Read/Write	—	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data for port 6 pins

P8DDR—Port 8 Data Direction Register **H'CD** **Port 8**

Bit	7	6	5	4	3	2	1	0
	—	—	—	$P8_4DDR$	$P8_3DDR$	$P8_2DDR$	$P8_1DDR$	$P8_0DDR$
Initial value	1	1	1	1	0	0	0	0
Read/Write	—	—	—	W	W	W	W	W

Port 8 input/output select

0	Generic input
1	$\overline{CS}$ output

Port 8 input/output select

0	Generic input
1	Generic output

P7DR—Port 7 Data Register **H'CE** **Port 7**

Bit	7	6	5	4	3	2	1	0
	$P7_7$	$P7_6$	$P7_5$	$P7_4$	$P7_3$	$P7_2$	$P7_1$	$P7_0$
Initial value	—*	—*	—*	—*	—*	—*	—*	—*
Read/Write	R	R	R	R	R	R	R	R

Data for port 7 pins

Note: * Determined by pins $P7_7$ to $P7_0$.

P8DR—Port 8 Data Register **H'CF** **Port 8**

Bit	7	6	5	4	3	2	1	0
	—	—	—	$P8_4$	$P8_3$	$P8_2$	$P8_1$	$P8_0$
Initial value	1	1	1	0	0	0	0	0
Read/Write	—	—	—	R/W	R/W	R/W	R/W	R/W

Data for port 8 pins

P9DDR—Port 9 Data Direction Register **H'D0** **Port 9**

Bit	7	6	5	4	3	2	1	0
	—	—	$P9_5DDR$	$P9_4DDR$	$P9_3DDR$	$P9_2DDR$	$P9_1DDR$	$P9_0DDR$
Initial value	1	1	0	0	0	0	0	0
Read/Write	—	—	W	W	W	W	W	W

Port 9 input/output select

0	Generic input
1	Generic output

PADDR—Port A Data Direction Register **H'D1** **Port A**

Bit	7	6	5	4	3	2	1	0
	PA_7DDR	PA_6DDR	PA_5DDR	PA_4DDR	PA_3DDR	PA_2DDR	PA_1DDR	PA_0DDR
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port A input/output select

0	Generic input
1	Generic output

P9DR—Port 9 Data Register **H'D2** **Port 9**

Bit	7	6	5	4	3	2	1	0
	—	—	$P9_5$	$P9_4$	$P9_3$	$P9_2$	$P9_1$	$P9_0$
Initial value	1	1	0	0	0	0	0	0
Read/Write	—	—	R/W	R/W	R/W	R/W	R/W	R/W

Data for port 9 pins

PADR—Port A Data Register **H'D3** **Port A**

Bit	7	6	5	4	3	2	1	0
	PA_7	PA_6	PA_5	PA_4	PA_3	PA_2	PA_1	PA_0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data for port A pins

PBDDR—Port B Data Direction Register **H'D4** **Port B**

Bit	7	6	5	4	3	2	1	0
	PB_7DDR	PB_6DDR	PB_5DDR	PB_4DDR	PB_3DDR	PB_2DDR	PB_1DDR	PB_0DDR
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port B input/output select

0	Generic input
1	Generic output

PCDDR—Port C Data Direction Register **H'D5** **Port C**

Bit	7	6	5	4	3	2	1	0
	PC_7DDR	PC_6DDR	PC_5DDR	PC_4DDR	PC_3DDR	PC_2DDR	PC_1DDR	PC_0DDR
Initial value	0	0	0	0	0	0	0	0
Read/Write	W	W	W	W	W	W	W	W

Port C input/output select

0	Generic input
1	$\overline{CS}$ output

Port C input/output select

0	Generic input
1	Generic output

PBDR—Port B Data Register **H'D6** **Port B**

Bit	7	6	5	4	3	2	1	0
	PB_7	PB_6	PB_5	PB_4	PB_3	PB_2	PB_1	PB_0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data for port B pins

PCDR—Port C Data Register **H'D7** **Port C**

Bit	7	6	5	4	3	2	1	0
	PC_7	PC_6	PC_5	PC_4	PC_3	PC_2	PC_1	PC_0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Data for port C pins

P4PCR—Port 4 Input Pull-Up Control Register **H'DA** **Port 4**

Bit	7	6	5	4	3	2	1	0
	$P4_7$PCR	$P4_6$PCR	$P4_5$PCR	$P4_4$PCR	$P4_3$PCR	$P4_2$PCR	$P4_1$PCR	$P4_0$PCR
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Port 4 input pull-up control 7 to 0

0	Input pull-up transistor is off
1	Input pull-up transistor is on

Note: Valid when the corresponding P4DDR bit is cleared to 0 (designating generic input).

P5PCR—Port 5 Input Pull-Up Control Register **H'DB** **Port 5**

Bit	7	6	5	4	3	2	1	0
	$P5_7PCR$	$P5_6PCR$	$P5_5PCR$	$P5_4PCR$	$P5_3PCR$	$P5_2PCR$	$P5_1PCR$	$P5_0PCR$
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Port 5 input pull-up control 7 to 4

0	Input pull-up transistor is off
1	Input pull-up transistor is on

Note: Valid when the corresponding P5DDR bit is cleared to 0 (designating generic input).

ADDRA H/L—A/D Data Register A H/L **H'E0, H'E1** **A/D**

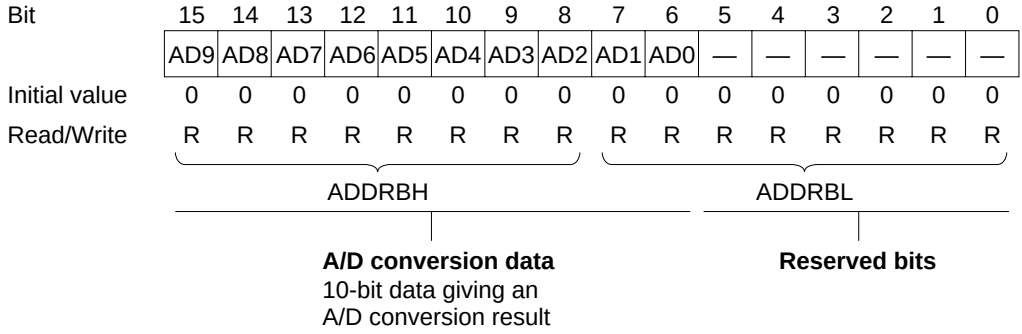
Bit	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
	AD9	AD8	AD7	AD6	AD5	AD4	AD3	AD2	AD1	AD0	—	—	—	—	—	—
Initial value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Read/Write	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R

ADDRAH ADDRAL

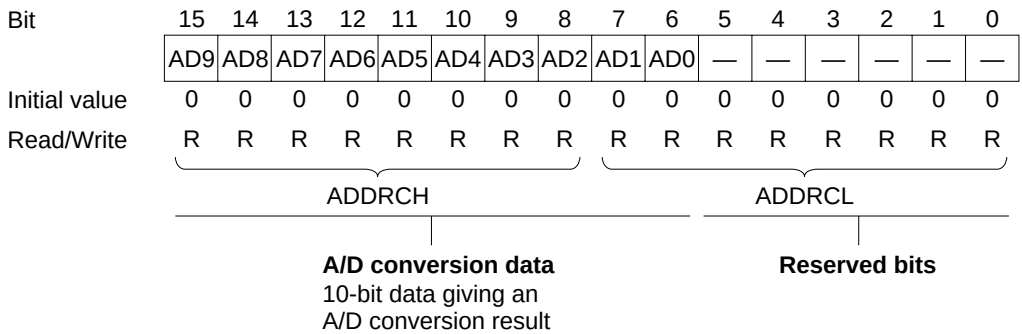
A/D conversion data
10-bit data giving an A/D conversion result

Reserved bits

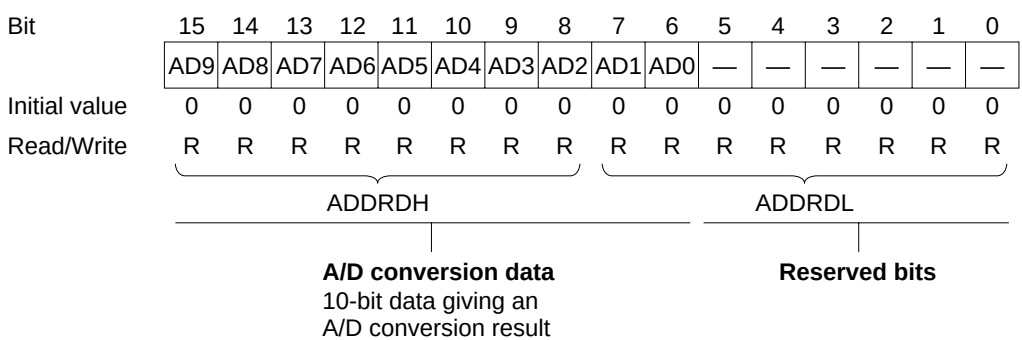
ADDRB H/L—A/D Data Register B H/L **H'E2, H'E3** **A/D**



ADDRC H/L—A/D Data Register C H/L **H'E4, H'E5** **A/D**



ADDRD H/L—A/D Data Register D H/L **H'E6, H'E7** **A/D**



Bit	7	6	5	4	3	2	1	0
	TRGE	—	—	—	—	—	—	—
Initial value	0	1	1	1	1	1	1	1
Read/Write	R/W	—	—	—	—	—	—	—

Trigger enable

0	A/D conversion cannot be externally triggered
1	A/D conversion starts at the fall of the external trigger signal ($\overline{\text{ADTRG}}$)

Bit	7	6	5	4	3	2	1	0
	ADF	ADIE	ADST	SCAN	CKS	CH2	CH1	CH0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/(W)*	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Clock select

0	Conversion time = 266 states (maximum)
1	Conversion time = 134 states (maximum)

Channel select 2 to 0

Group Selection	Channel Selection		Description	
CH2	CH1	CH0	Single Mode	Scan Mode
0	0	0	AN_0	AN_0
		1	AN_1	AN_0, AN_1
	1	0	AN_2	AN_0 to AN_2
		1	AN_3	AN_0 to AN_3
1	0	0	AN_4	AN_4
		1	AN_5	AN_4, AN_5
	1	0	AN_6	AN_4 to AN_6
		1	AN_7	AN_4 to AN_7

Scan mode

0	Single mode
1	Scan mode

A/D start

0	A/D conversion is stopped
1	Single mode: A/D conversion starts; ADST is automatically cleared to 0 when conversion ends Scan mode: A/D conversion starts and continues, cycling among the selected channels, until ADST is cleared to 0 by software, by a reset, or by a transition to standby mode

A/D interrupt enable

0	A/D end interrupt request is disabled
1	A/D end interrupt request is enabled

A/D end flag

0	[Clearing condition] Read ADF while ADF = 1, then write 0 in ADF
1	[Setting conditions] Single mode: A/D conversion ends Scan mode: A/D conversion ends in all selected channels

Note: * Only 0 can be written, to clear flag.

ABWCR—Bus Width Control Register **H'EC** **Bus controller**

Bit		7	6	5	4	3	2	1	0
		ABW7	ABW6	ABW5	ABW4	ABW3	ABW2	ABW1	ABW0
Initial value	Mode 1, 3	1	1	1	1	1	1	1	1
	Mode 2, 4	0	0	0	0	0	0	0	0
Read/Write		R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Area 7 to 0 bus width control

Bits 7 to 0	
AWB7 to AWB0	Bus Width of Access Area
0	Areas 7 to 0 are 16-bit access areas
1	Areas 7 to 0 are 8-bit access areas

ASTCR—Access State Control Register **H'ED** **Bus controller**

Bit	7	6	5	4	3	2	1	0
	AST7	AST6	AST5	AST4	AST3	AST2	AST1	AST0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Area 7 to 0 access state control

Bits 7 to 0	
AST7 to AST0	Number of States in Access Cycle
0	Areas 7 to 0 are two-state access areas
1	Areas 7 to 0 are three-state access areas

WCR—Wait Control Register H'EE Bus controller

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	WMS1	WMS0	WC1	WC0
Initial value	1	1	1	1	0	0	1	1
Read/Write	—	—	—	—	R/W	R/W	R/W	R/W

Wait mode select 1 and 0

Bit 3	Bit 2	
WMS1	WMS0	Wait Mode
0	0	Programmable wait mode
	1	No wait states inserted by wait-state controller
1	0	Pin wait mode
	1	Pin auto-wait mode

Wait count 1 and 0

Bit 1	Bit 0	
WC1	WC0	Number of Wait States
0	0	No wait states inserted by wait-state controller
	1	1 state inserted
1	0	2 states inserted
	1	3 states inserted

WCER—Wait Controller Enable Register H'EF Bus controller

Bit	7	6	5	4	3	2	1	0
	WCE7	WCE6	WCE5	WCE4	WCE3	WCE2	WCE1	WCE0
Initial value	1	1	1	1	1	1	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Wait state controller enable 7 to 0

0	Wait-state control is disabled (pin wait mode 0)
1	Wait-state control is enabled

MDCR—Mode Control Register **H'F1** **System control**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	MDS2	MDS1	MDS0
Initial value	1	1	0	0	0	—*	—*	—*
Read/Write	—	—	—	—	—	R	R	R

Mode select 2 to 0

Bit 2	Bit 1	Bit 0	
MD_2	MD_1	MD_0	Operating mode
0	0	0	—
		1	Mode 1
	1	0	Mode 2
		1	Mode 3
1	0	0	Mode 4
		1	—
	1	0	—
		1	—

Note: * Determined by the state of the mode pins (MD_2 to MD_0).

Bit	7	6	5	4	3	2	1	0
	SSBY	STS2	STS1	STS0	UE	NMIEG	—	RAME
Initial value	0	0	0	0	1	0	1	1
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	—	R/W

RAM enable

0	On-chip RAM is disabled
1	On-chip RAM is enabled

NMI edge select

0	An interrupt is requested at the falling edge of NMI
1	An interrupt is requested at the rising edge of NMI

User bit enable

0	CCR bit 6 (UI) is used as an interrupt mask bit
1	CCR bit 6 (UI) is used as a user bit

Standby timer select 2 to 0

Bit 6	Bit 5	Bit 4	
STS2	STS1	STS0	Standby Timer
0	0	0	Waiting time = 8192 states
		1	Waiting time = 16384 states
	1	0	Waiting time = 32768 states
		1	Waiting time = 65536 states
1	0	—	Waiting time = 131072 states
	1	—	Waiting time = 4 states

Software standby

0	SLEEP instruction causes transition to sleep mode
1	SLEEP instruction causes transition to software standby mode

BRCR—Bus Release Control Register **H'F3** **Bus controller**

Bit	7	6	5	4	3	2	1	0
	—	—	—	—	—	—	—	BRLE
Initial value	1	1	1	1	1	1	1	0
Read/Write	—	—	—	—	—	—	—	R/W

Bus release enable

0	The bus cannot be released to an external device
1	The bus can be released to an external device

ISCR—IRQ Sense Control Register **H'F4** **Interrupt controller**

Bit	7	6	5	4	3	2	1	0
	IRQ7SC	IRQ6SC	IRQ5SC	IRQ4SC	IRQ3SC	IRQ2SC	IRQ1SC	IRQ0SC
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

$\overline{\text{IRQ}_7}$ to $\overline{\text{IRQ}_0}$ sense control

0	Interrupts are requested when $\overline{\text{IRQ}_7}$ to $\overline{\text{IRQ}_0}$ inputs are low
1	Interrupts are requested by falling-edge input at $\overline{\text{IRQ}_7}$ to $\overline{\text{IRQ}_0}$

IER—IRQ Enable Register **H'F5** **Interrupt controller**

Bit	7	6	5	4	3	2	1	0
	IRQ7E	IRQ6E	IRQ5E	IRQ4E	IRQ3E	IRQ2E	IRQ1E	IRQ0E
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/(W)	R/(W)	R/(W)	R/(W)	R/(W)	R/(W)	R/(W)	R/(W)

IRQ_7 to IRQ_0 enable

0	IRQ_7 to IRQ_0 interrupts are disabled
1	IRQ_7 to IRQ_0 interrupts are enabled

Bit	7	6	5	4	3	2	1	0
	IRQ7F	IRQ6F	IRQ5F	IRQ4F	IRQ3F	IRQ2F	IRQ1F	IRQ0F
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*	R/(W)*

IRQ_7 to IRQ_0 flags

Bits 7 to 0 IRQ7F to IRQ0F	Setting and Clearing Conditions
0	[Clearing conditions] Read IRQnF when IRQnF = 1, then write 0 in IRQnF. IRQnSC = 0, $\overline{IRQn}$ input is high, and interrupt exception handling is carried out. IRQnSC = 1 and IRQn interrupt exception handling is carried out.
1	[Setting conditions] IRQnSC = 0 and $\overline{IRQn}$ input is low. IRQnSC = 1 and $\overline{IRQn}$ input changes from high to low.

(n = 7 to 0)

Note: * Only 0 can be written, to clear the flag.

IPRA—Interrupt Priority Register A **H'F8** **Interrupt controller**

Bit	7	6	5	4	3	2	1	0
	IPRA7	IPRA6	IPRA5	IPRA4	IPRA3	IPRA2	IPRA1	IPRA0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Priority level A7 to A0

0	Priority level 0 (low priority)
1	Priority level 1 (high priority)

- Interrupt sources controlled by each bit

	Bit 7 IPRA7	Bit 6 IPRA6	Bit 5 IPRA5	Bit 4 IPRA4	Bit 3 IPRA3	Bit 2 IPRA2	Bit 1 IPRA1	Bit 0 IPRA0
Interrupt source	IRQ_0	IRQ_1	IRQ_2, IRQ_3	IRQ_4 to IRQ_7	WDT, Refresh Controller	ITU channel 0	ITU channel 1	ITU channel 2

IPRB—Interrupt Priority Register B **H'F9** **Interrupt controller**

Bit	7	6	5	4	3	2	1	0
	IPRB7	IPRB6	IPRB5	IPRB4	IPRB3	IPRB2	IPRB1	IPRB0
Initial value	0	0	0	0	0	0	0	0
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Priority level B7 to B0 **Reserved bit**

0	Priority level 0 (low priority)
1	Priority level 1 (high priority)

- Interrupt sources controlled by each bit

	Bit 7 IPRB7	Bit 6 IPRB6	Bit 5 IPRB5	Bit 4 IPRB4	Bit 3 IPRB3	Bit 2 IPRB2	Bit 1 IPRB1	Bit 0 —
Interrupt source	ITU channel 3	ITU channel 4	DMAC group 0	DMAC group 1	SCI channel 0	SCI channel 1	A/D converter	—

Appendix C I/O Port Block Diagrams

C.1 Port 4 Block Diagram

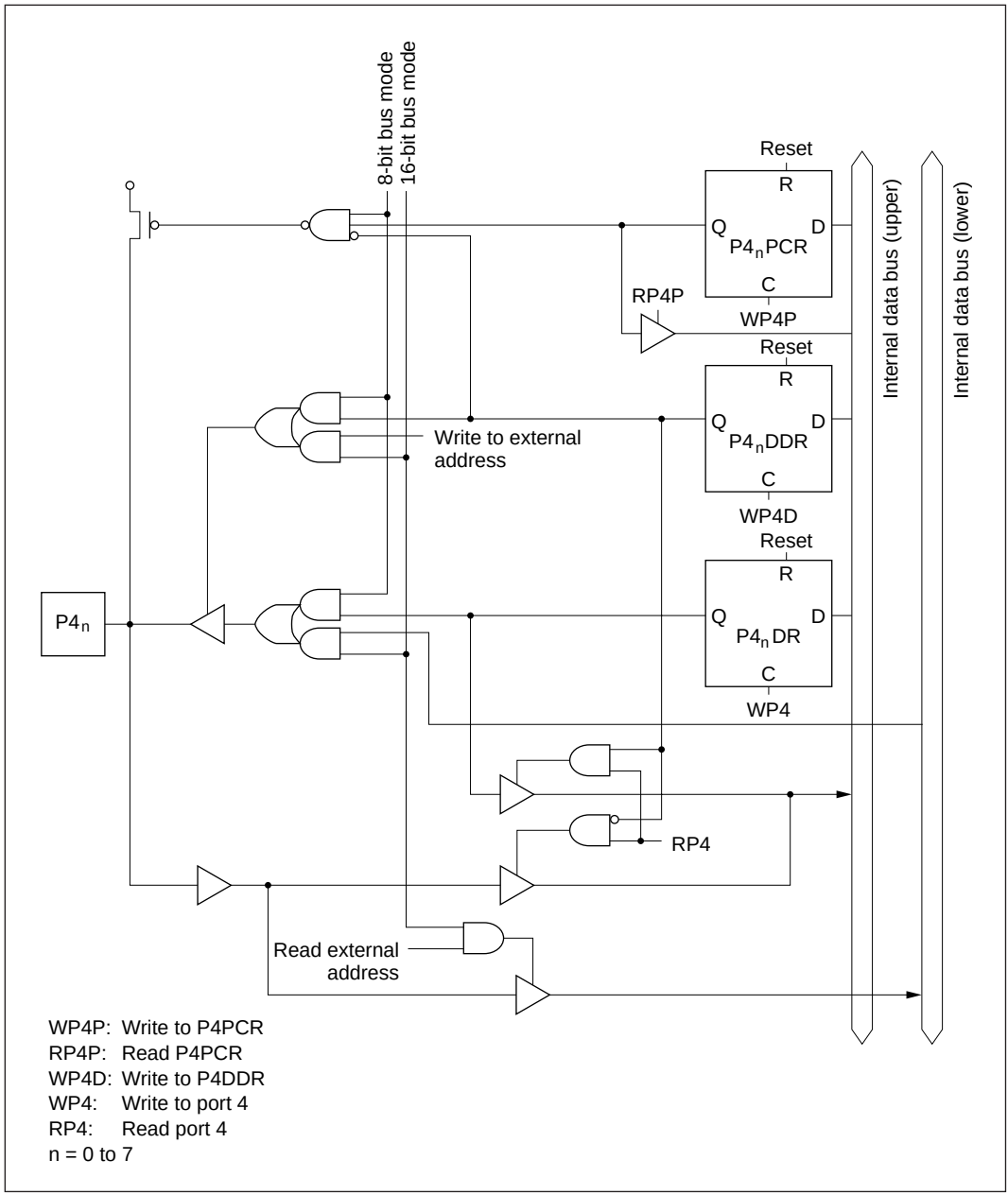


Figure C-1 Port 4 Block Diagram

C.2 Port 5 Block Diagram

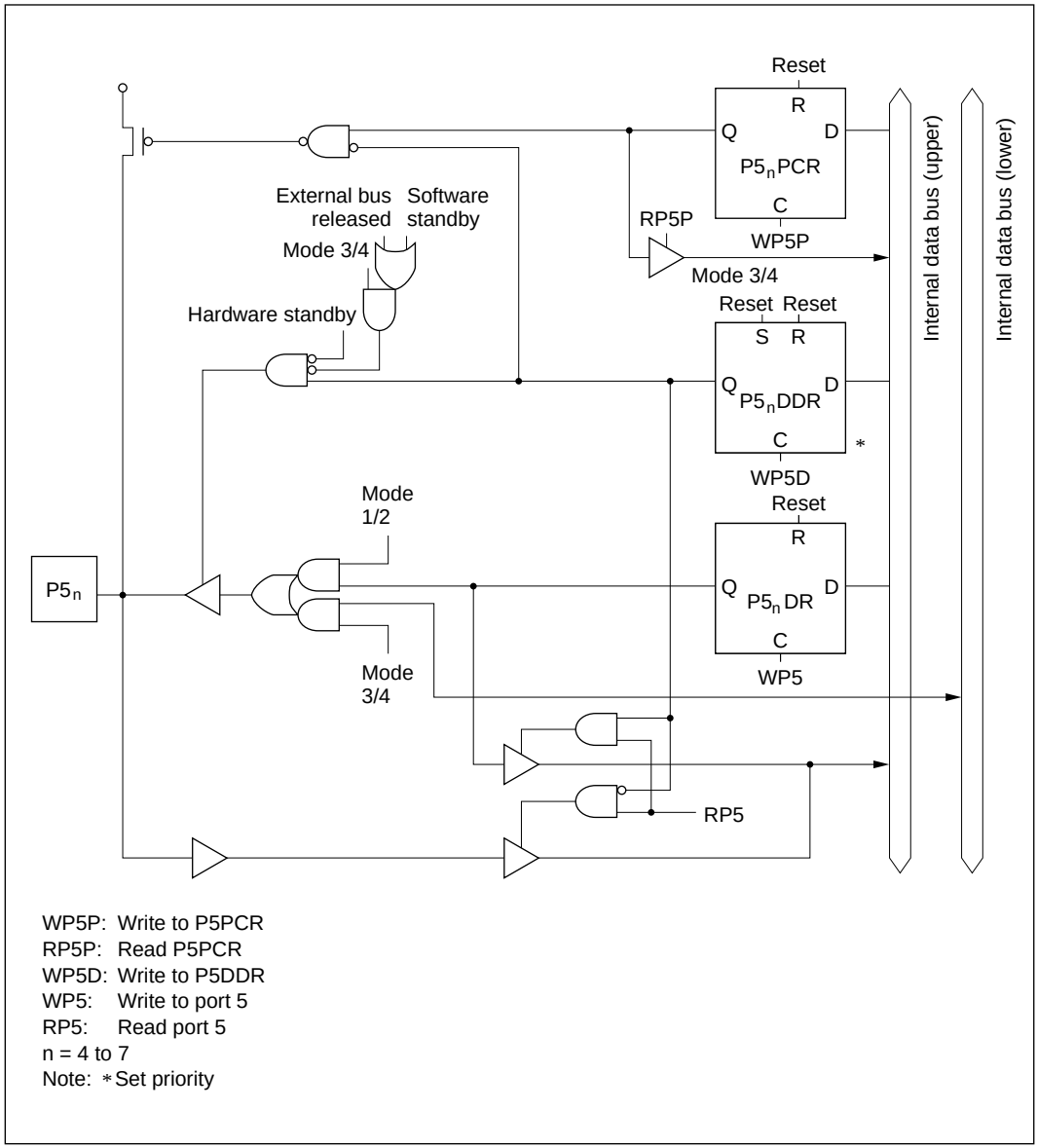


Figure C-2 Port 5 Block Diagram

C.3 Port 6 Block Diagrams

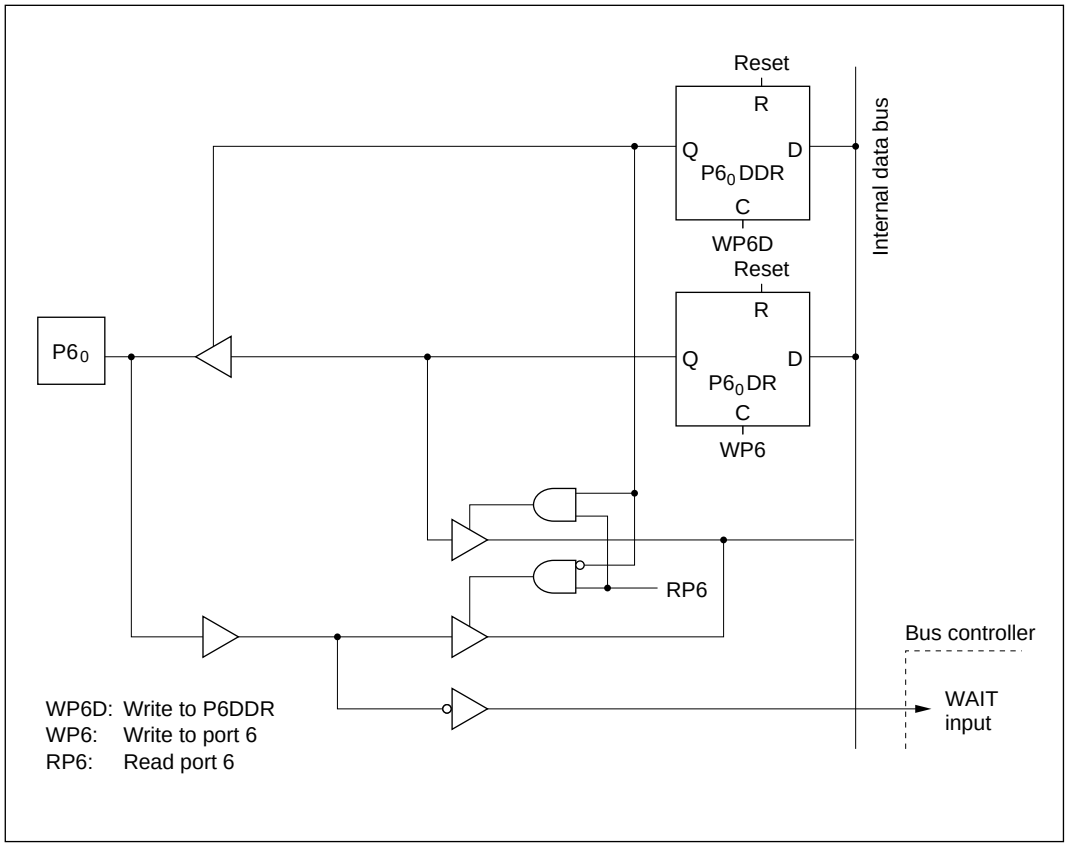


Figure C-3 (a) Port 6 Block Diagram (Pin P6$_0$)

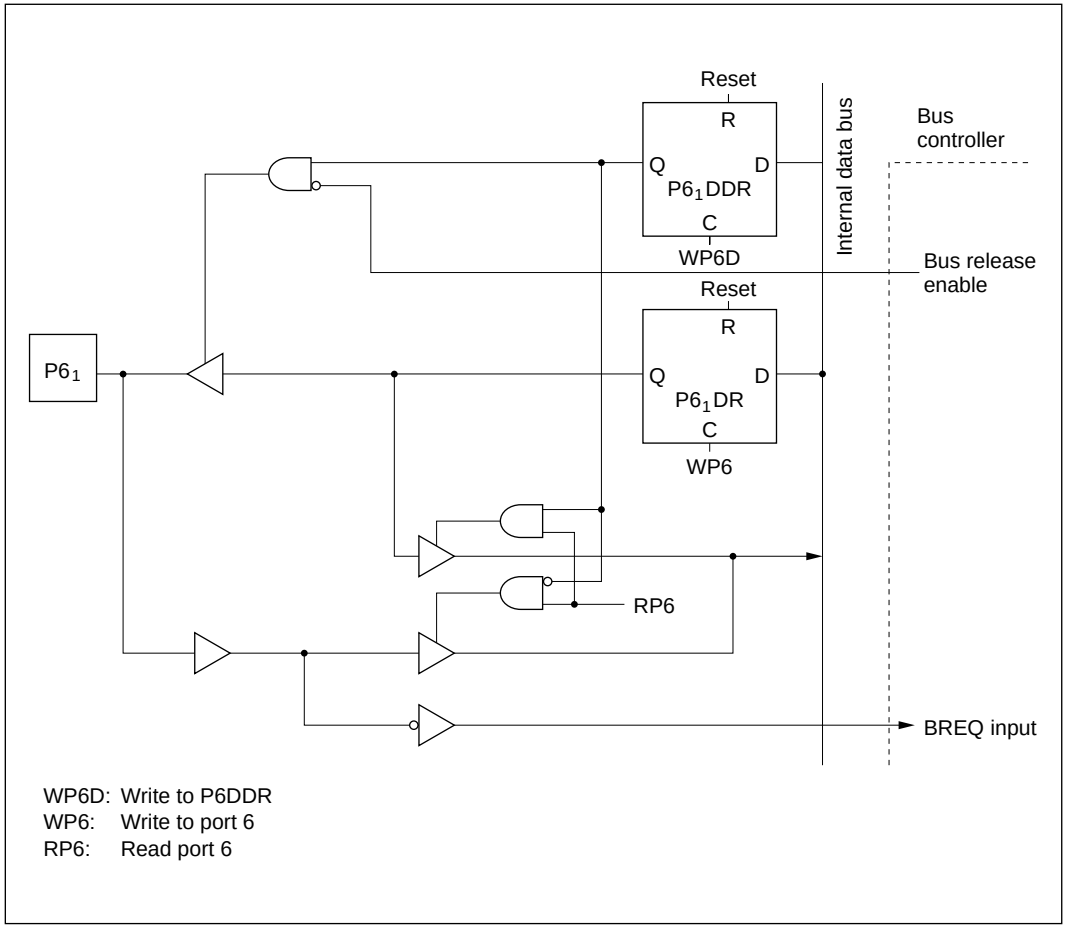


Figure C-3 (b) Port 6 Block Diagram (Pin P6$_1$)

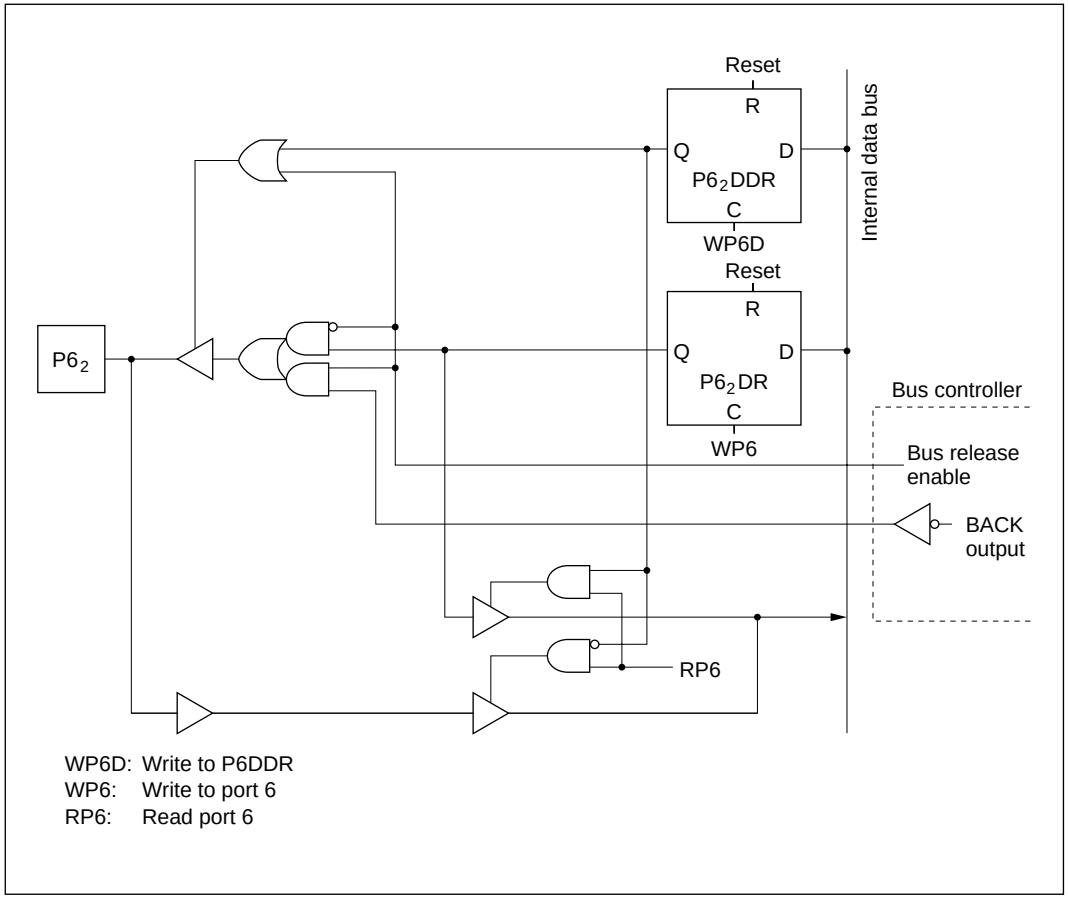


Figure C-3 (c) Port 6 Block Diagram (Pin P6$_2$)

C.4 Port 7 Block Diagram

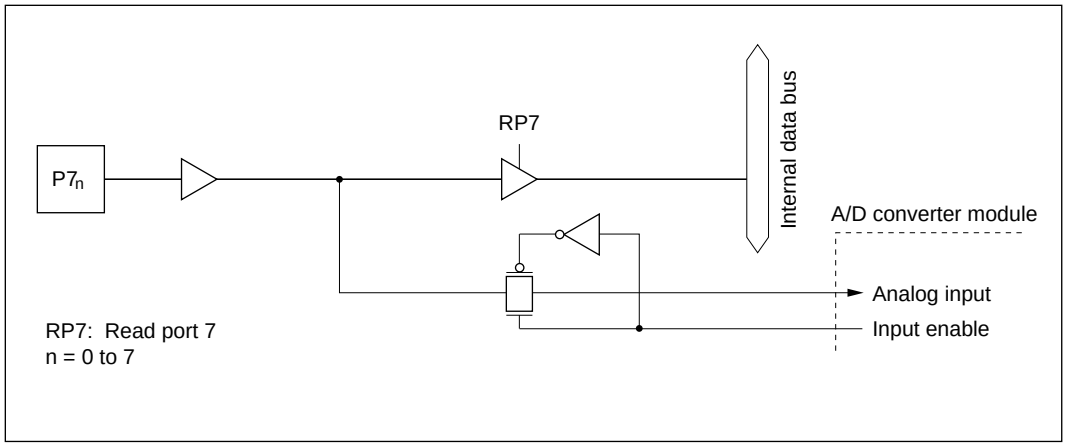


Figure C-4 Port 7 Block Diagram (Pin $P7_n$)

C.5 Port 8 Block Diagrams

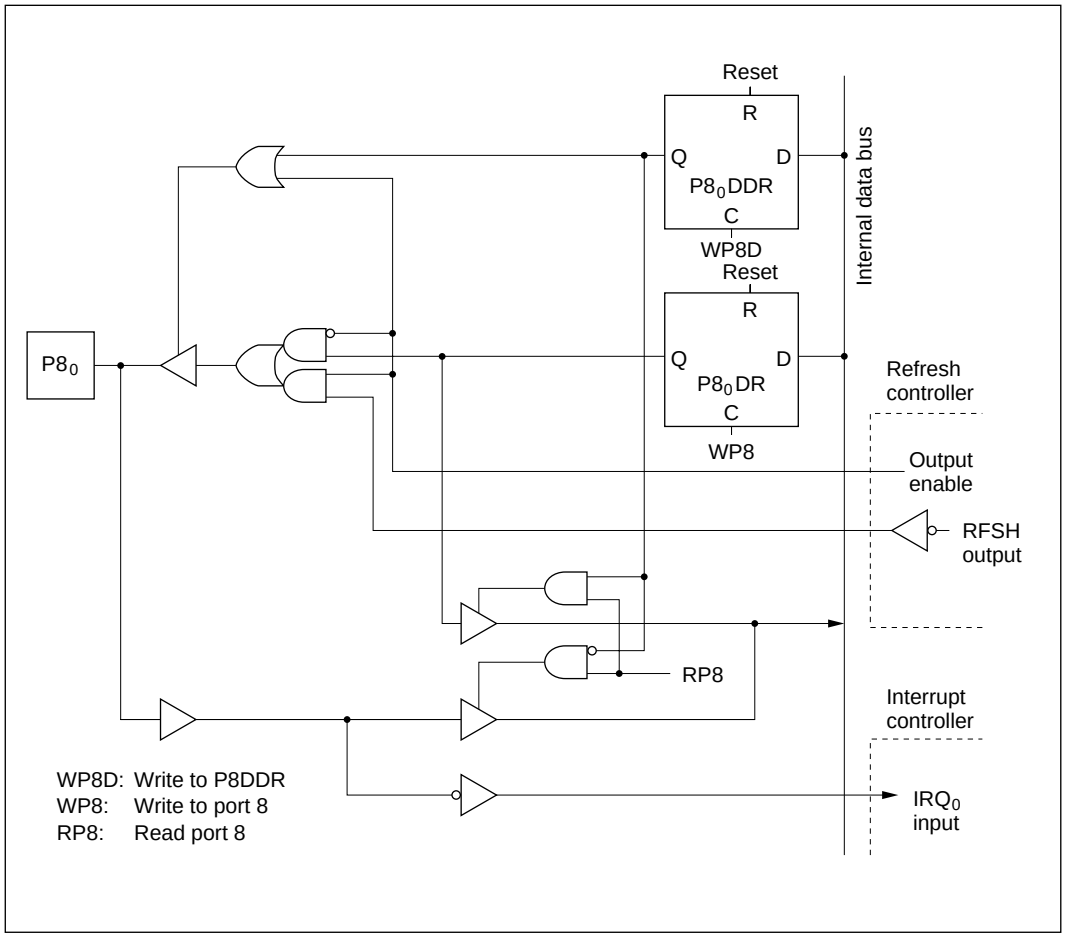


Figure C-5 (a) Port 8 Block Diagram (Pin P8$_0$)

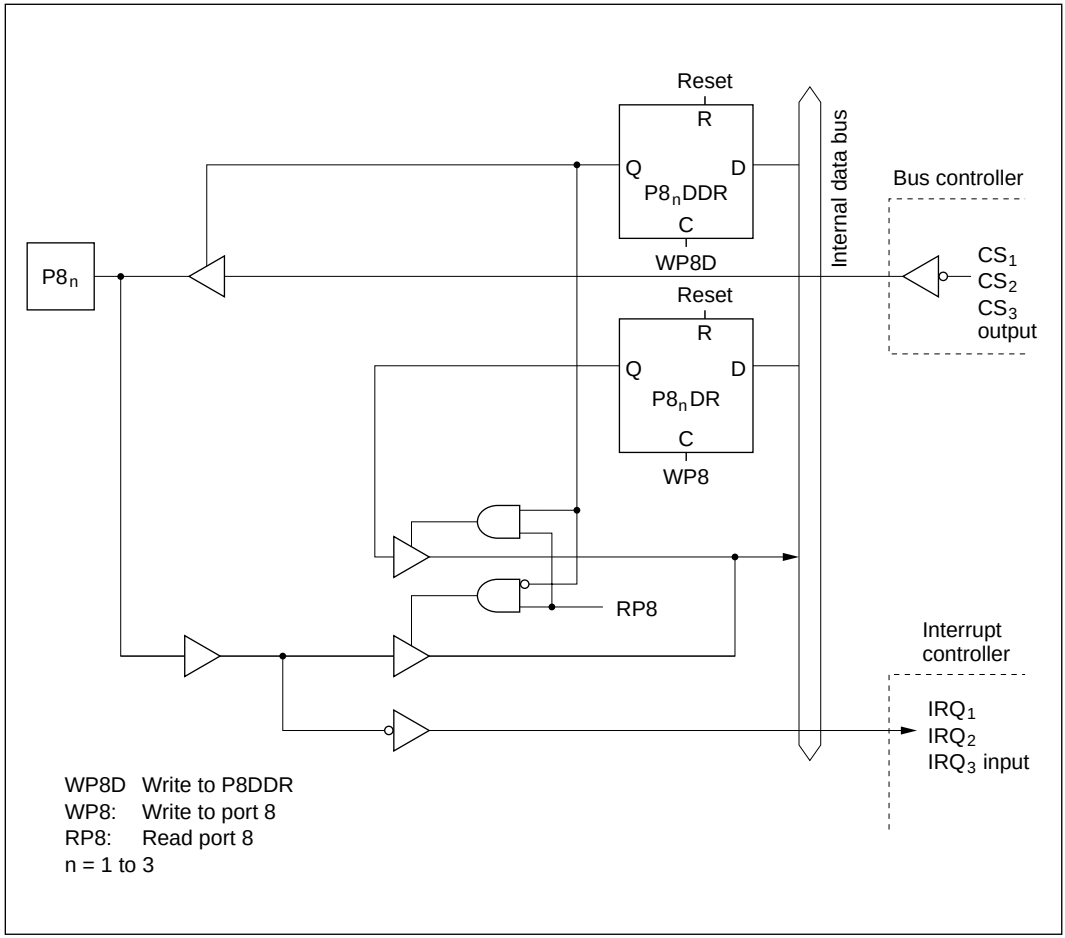


Figure C-5 (b) Port 8 Block Diagram (Pins $P8_1$, $P8_2$, $P8_3$)

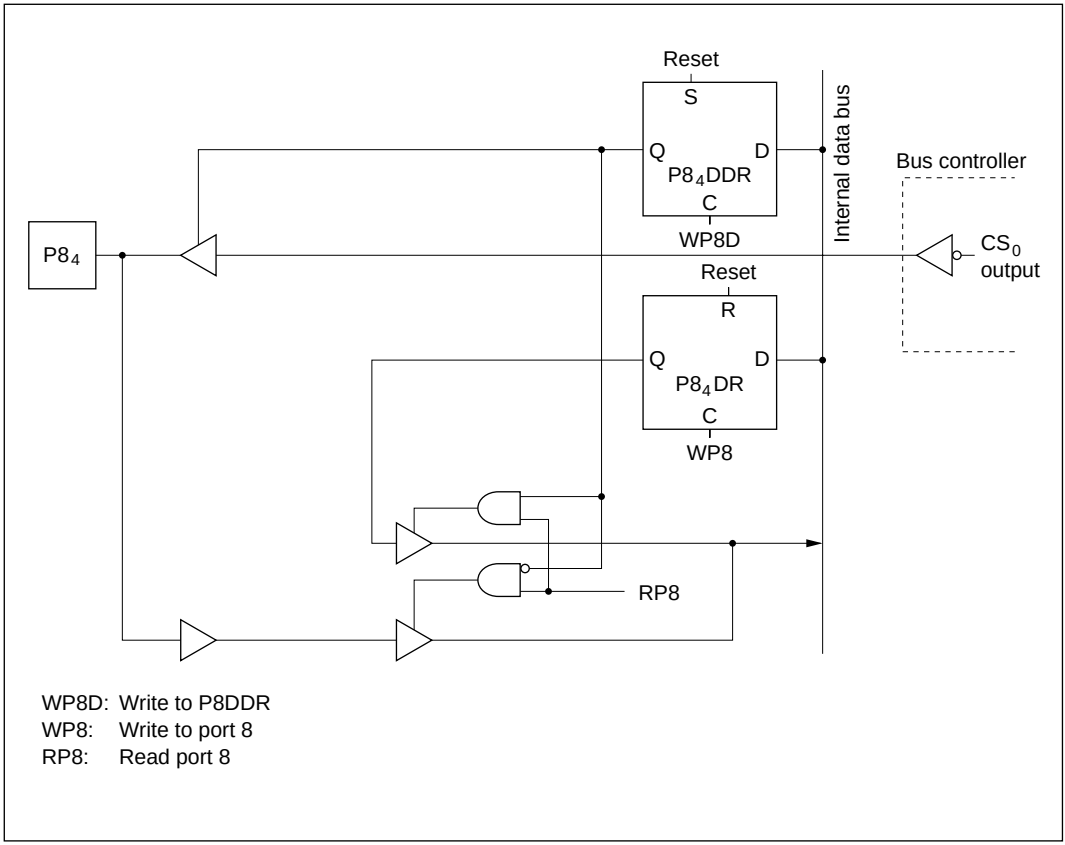


Figure C-5 (c) Port 8 Block Diagram (Pin P8$_4$)

C.6 Port 9 Block Diagrams

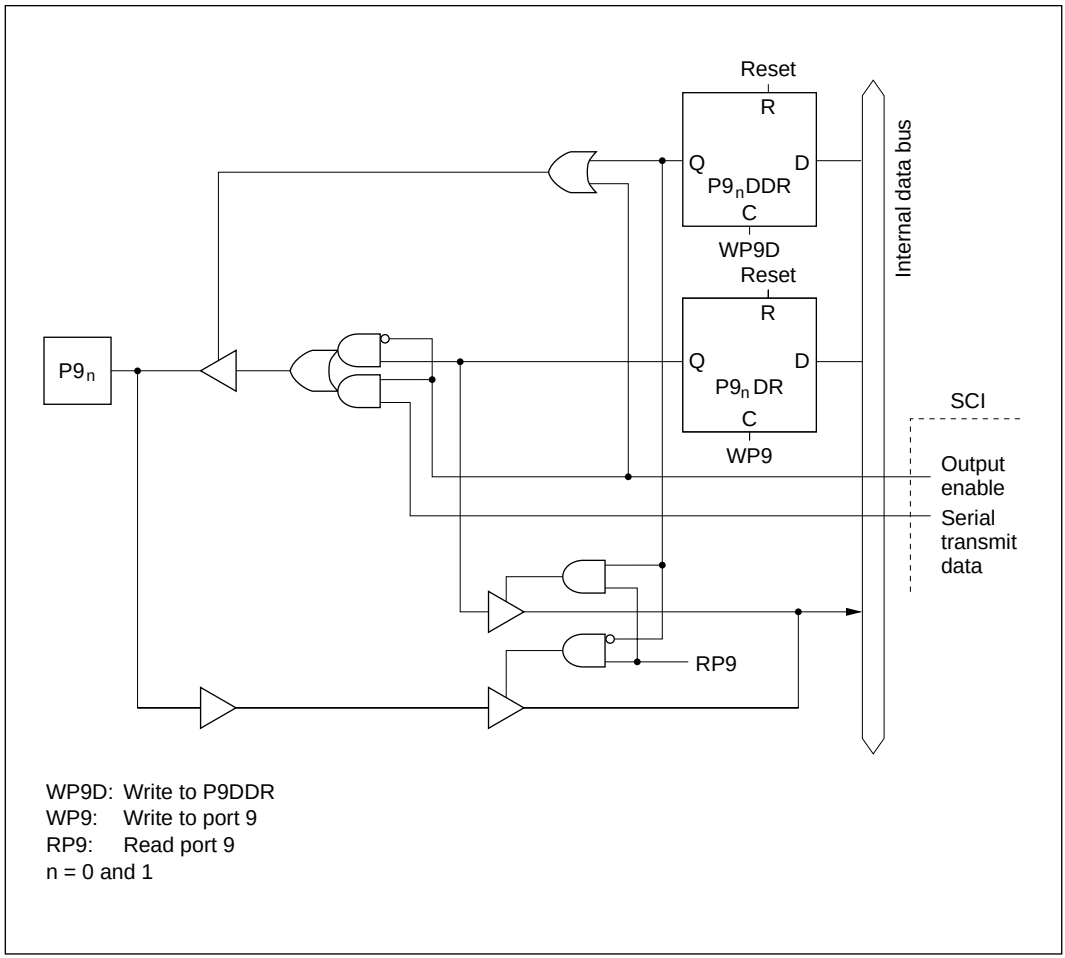


Figure C-6 (a) Port 9 Block Diagram (Pins $P9_0$, $P9_1$)

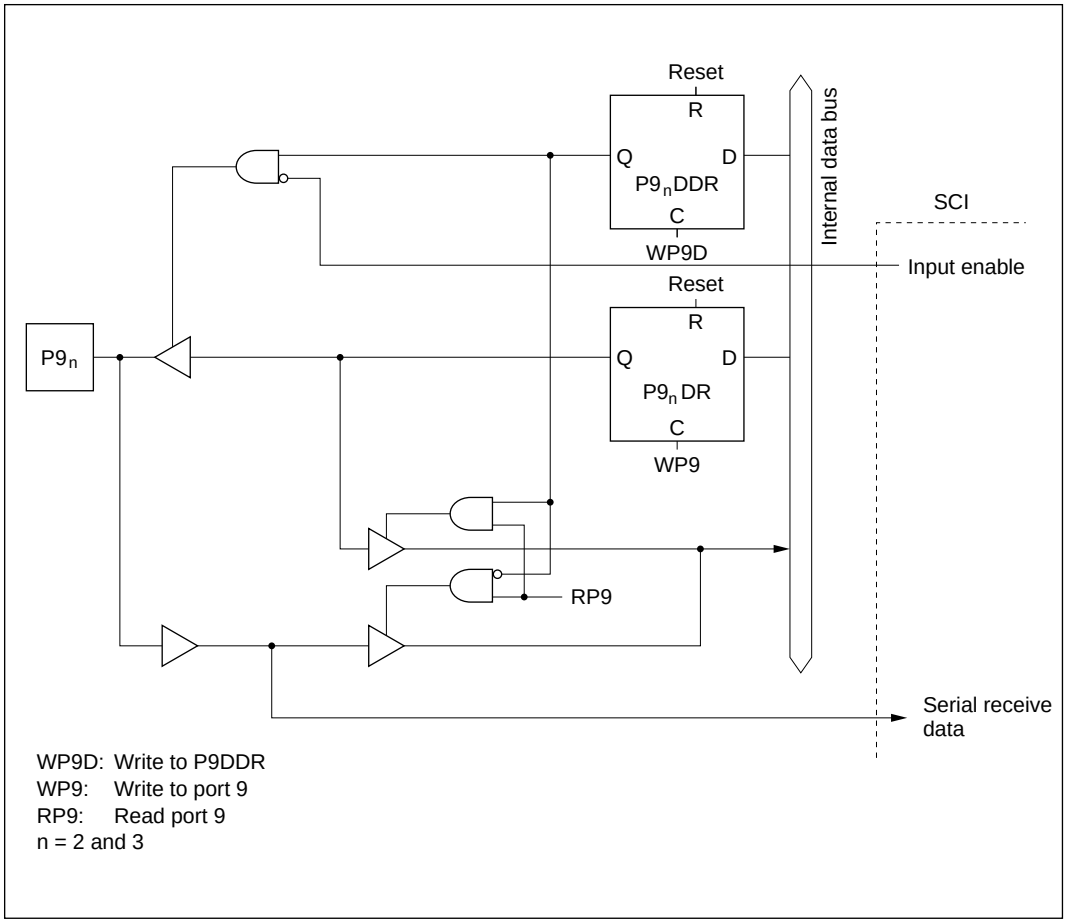


Figure C-6 (b) Port 9 Block Diagram (Pins $P9_2$, $P9_3$)

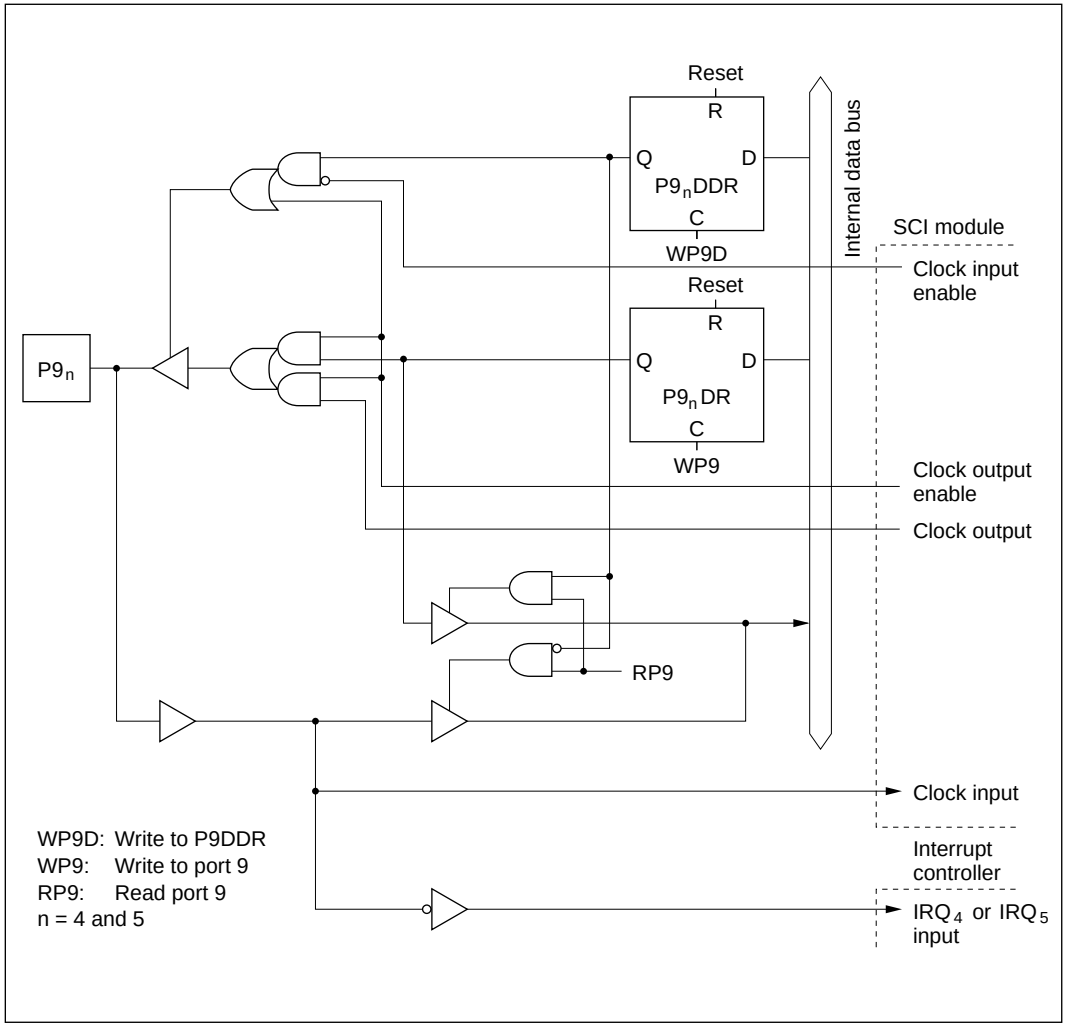


Figure C-6 (c) Port 9 Block Diagram (Pins $P9_4$, $P9_5$)

C.7 Port A Block Diagrams

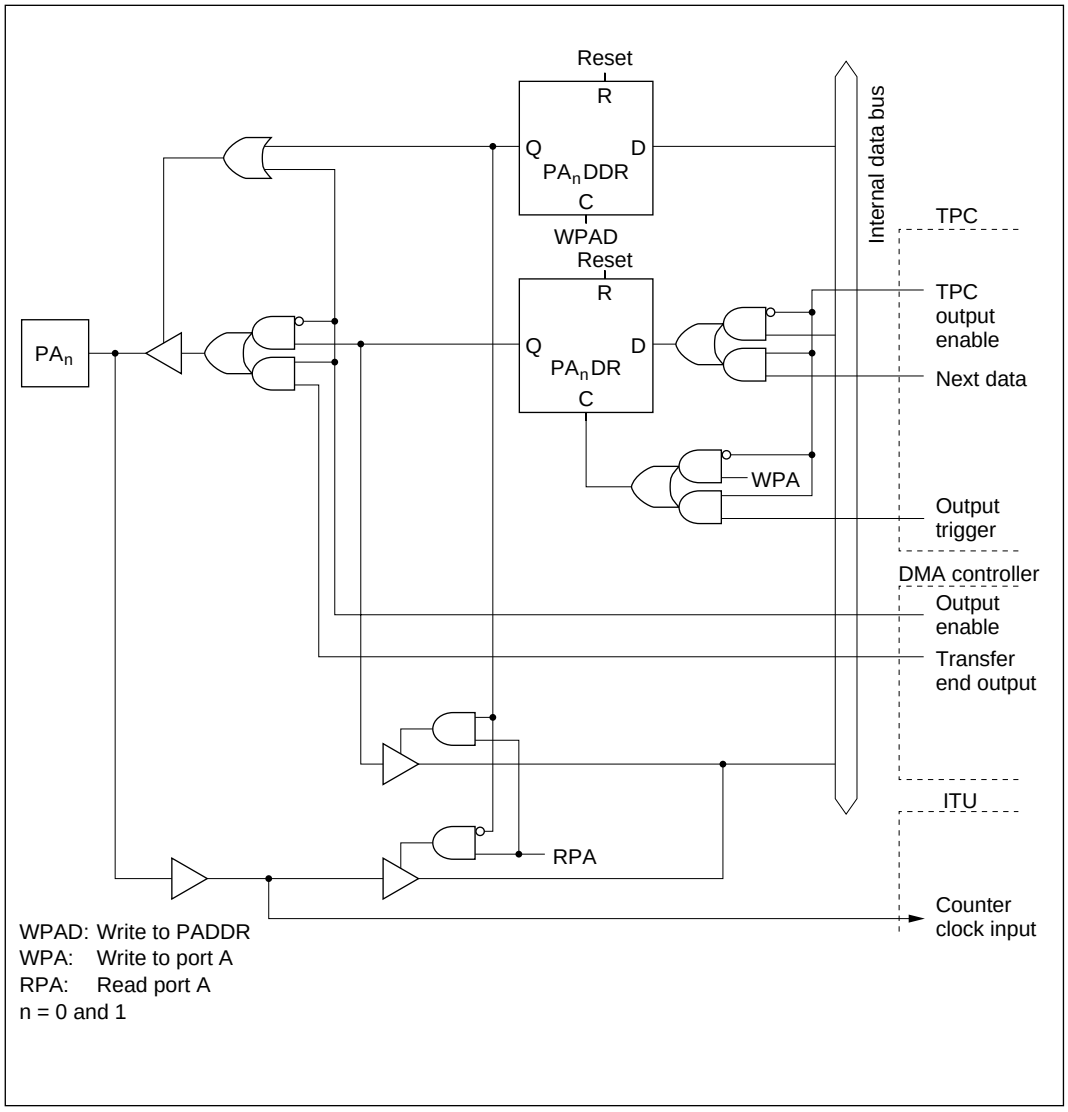


Figure C-7 (a) Port A Block Diagram (Pins PA_0, PA_1)

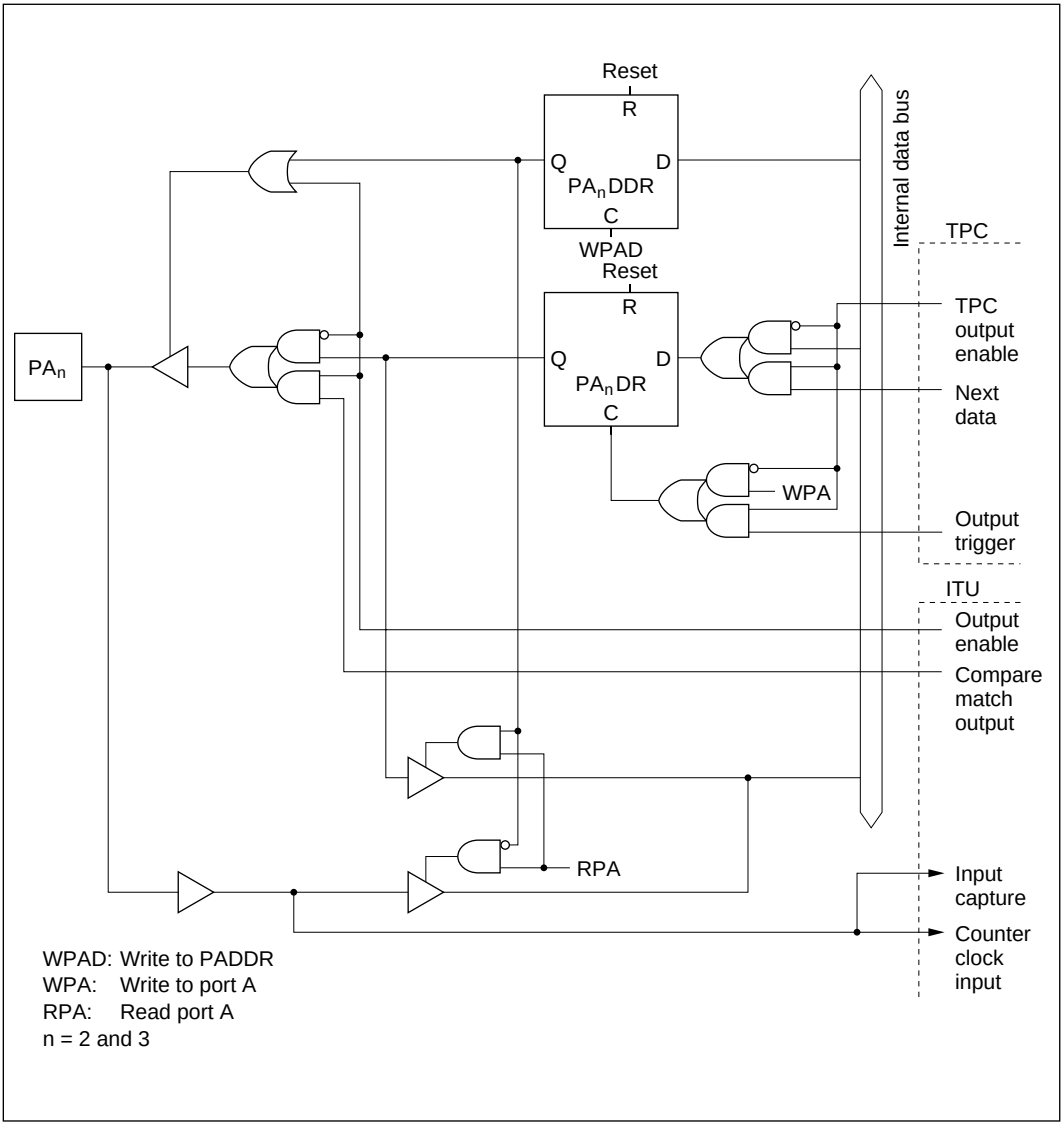


Figure C-7 (b) Port A Block Diagram (Pins PA_2, PA_3)

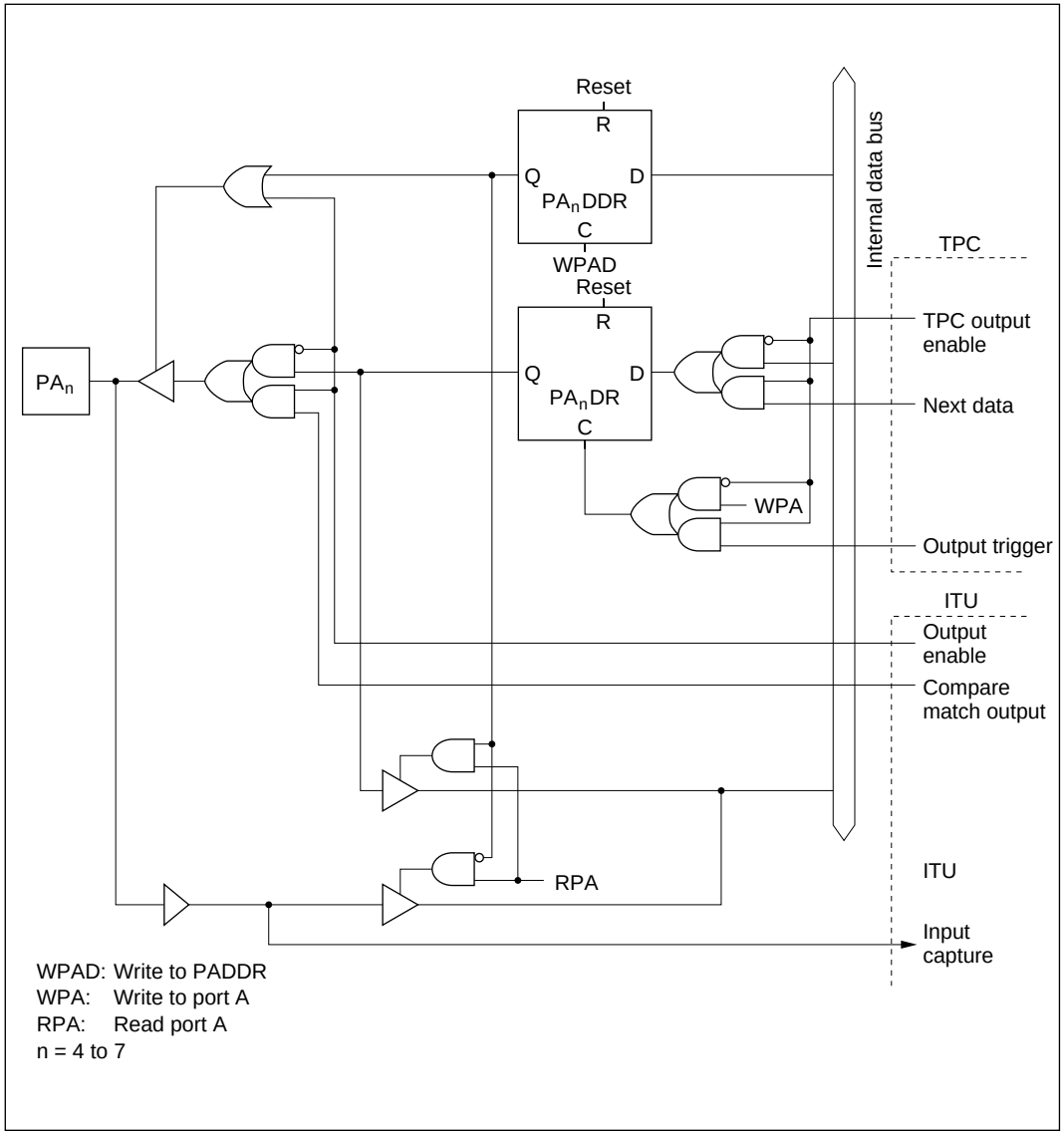


Figure C-7 (c) Port A Block Diagram (Pins PA_4 to PA_7)

C.8 Port B Block Diagrams

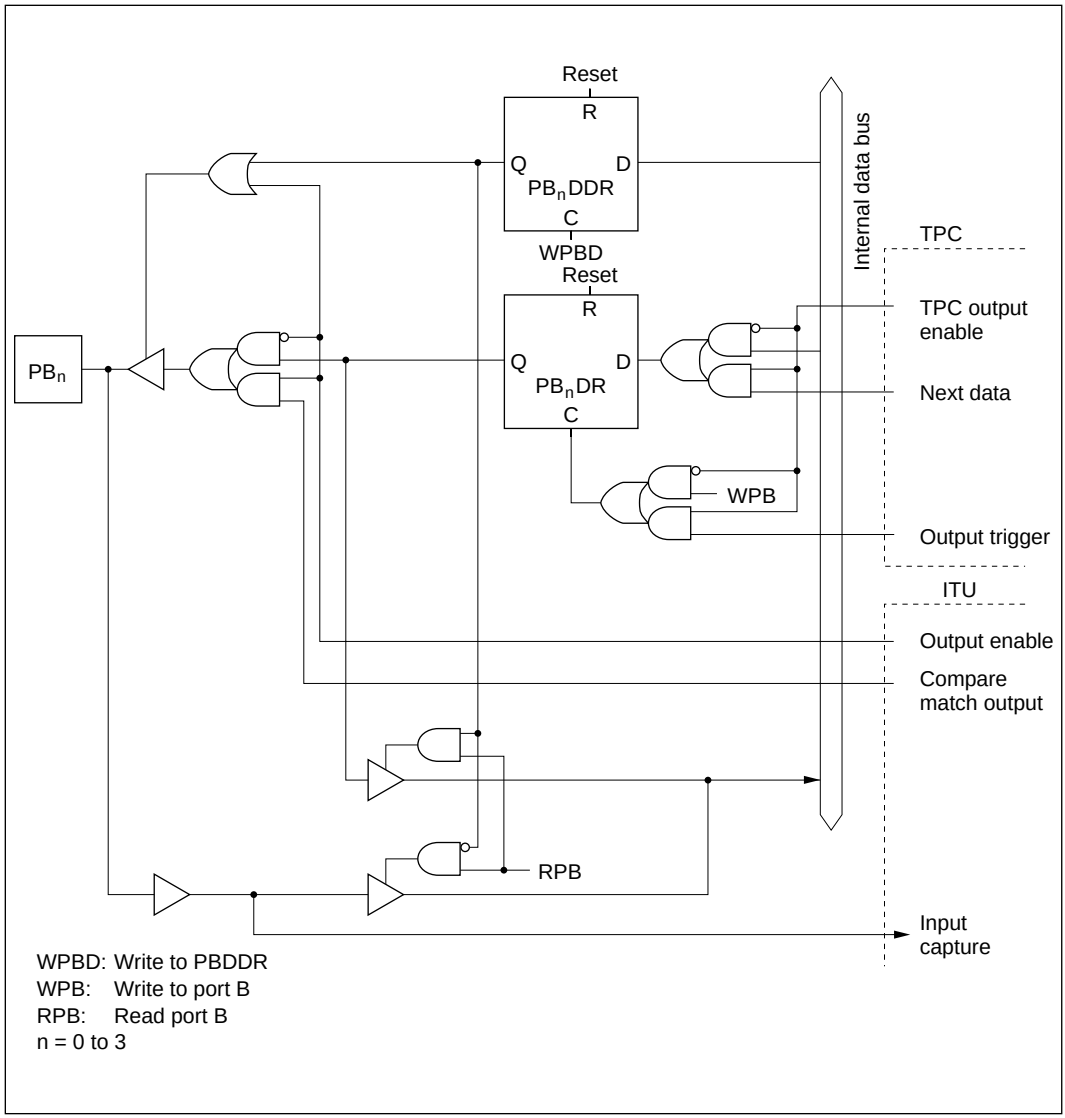


Figure C-8 (a) Port B Block Diagram (Pins PB_0 to PB_3)

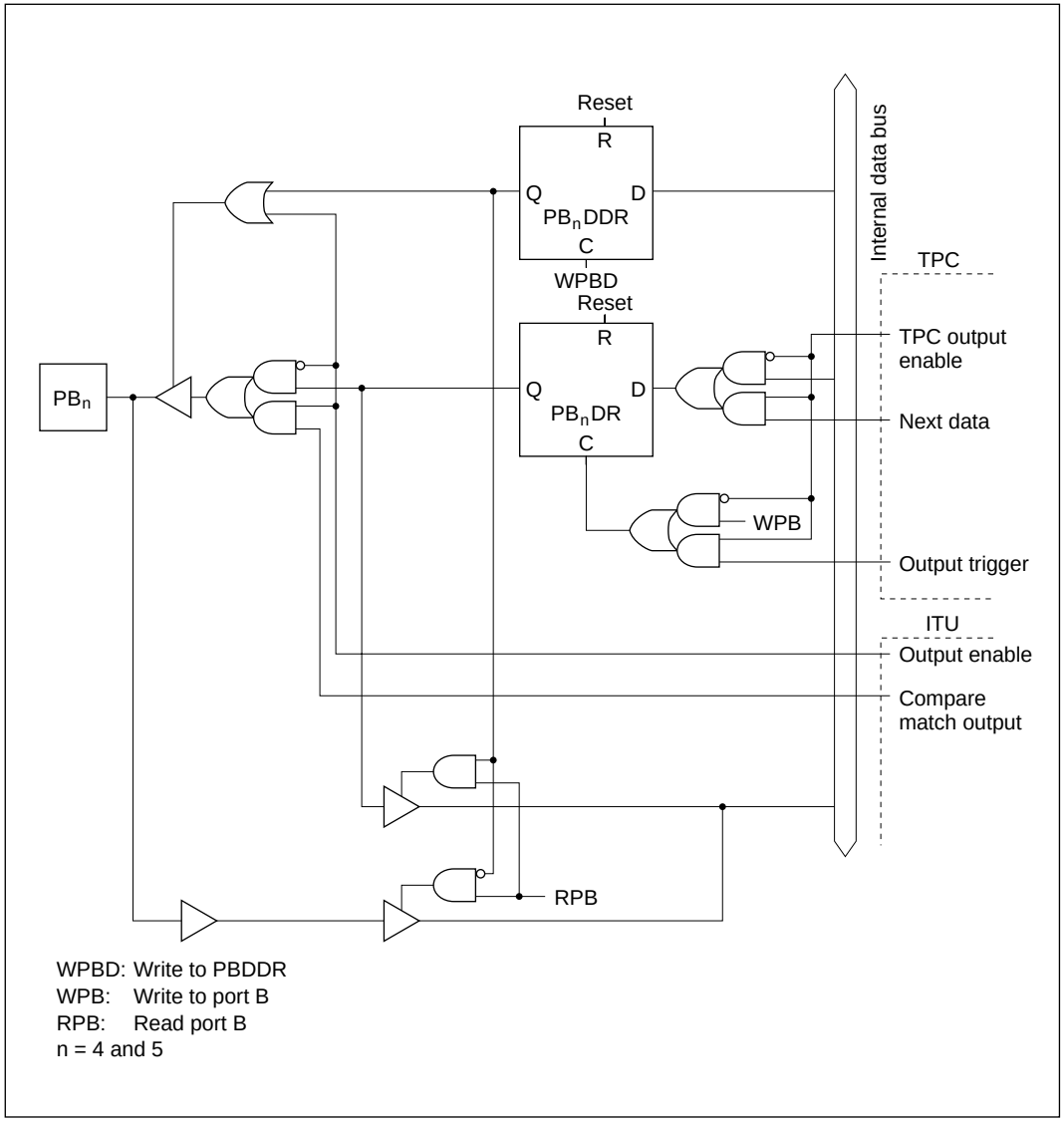


Figure C-8 (b) Port B Block Diagram (Pins PB_4, PB_5)

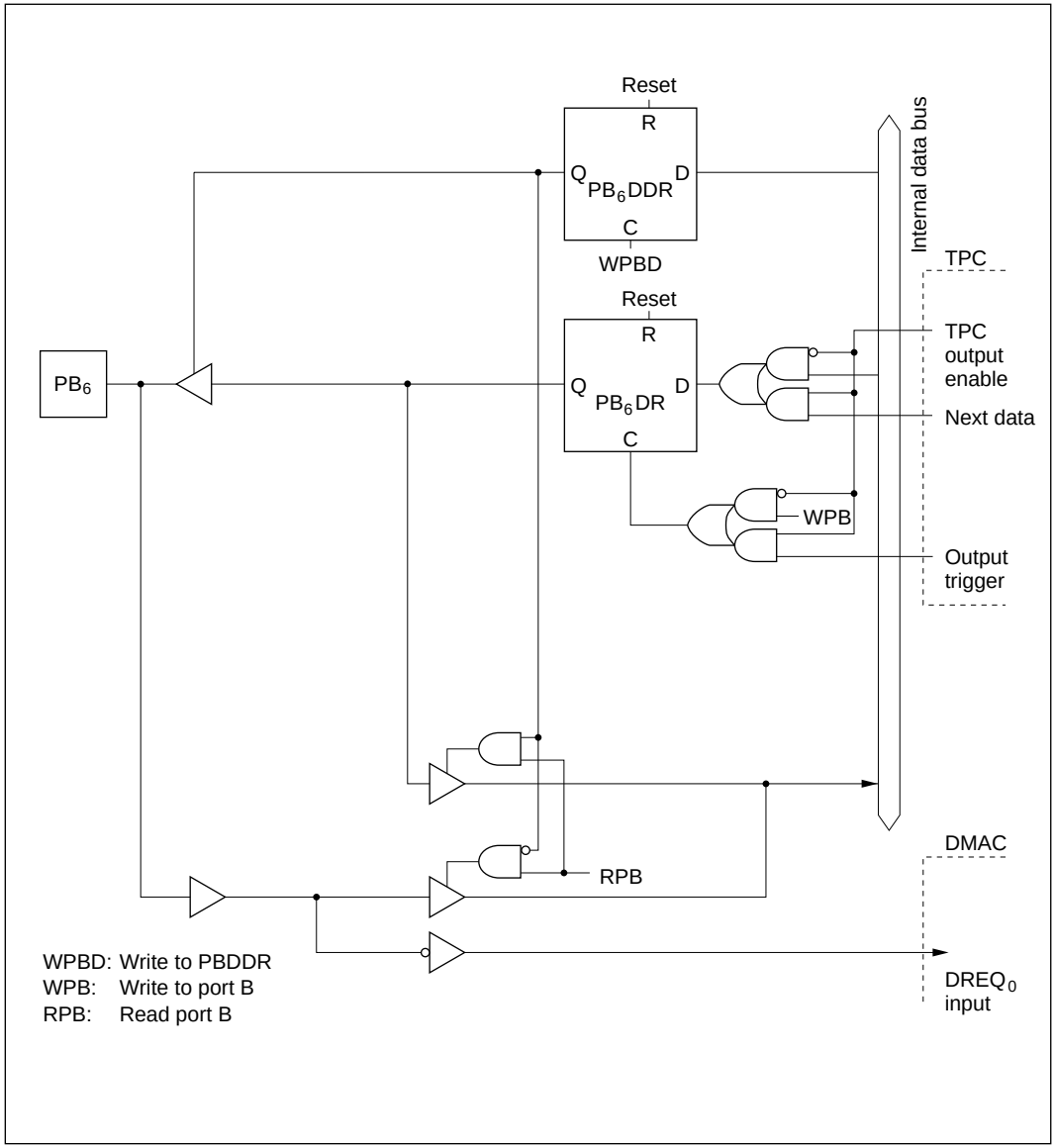


Figure C-8 (c) Port B Block Diagram (Pin PB_6)

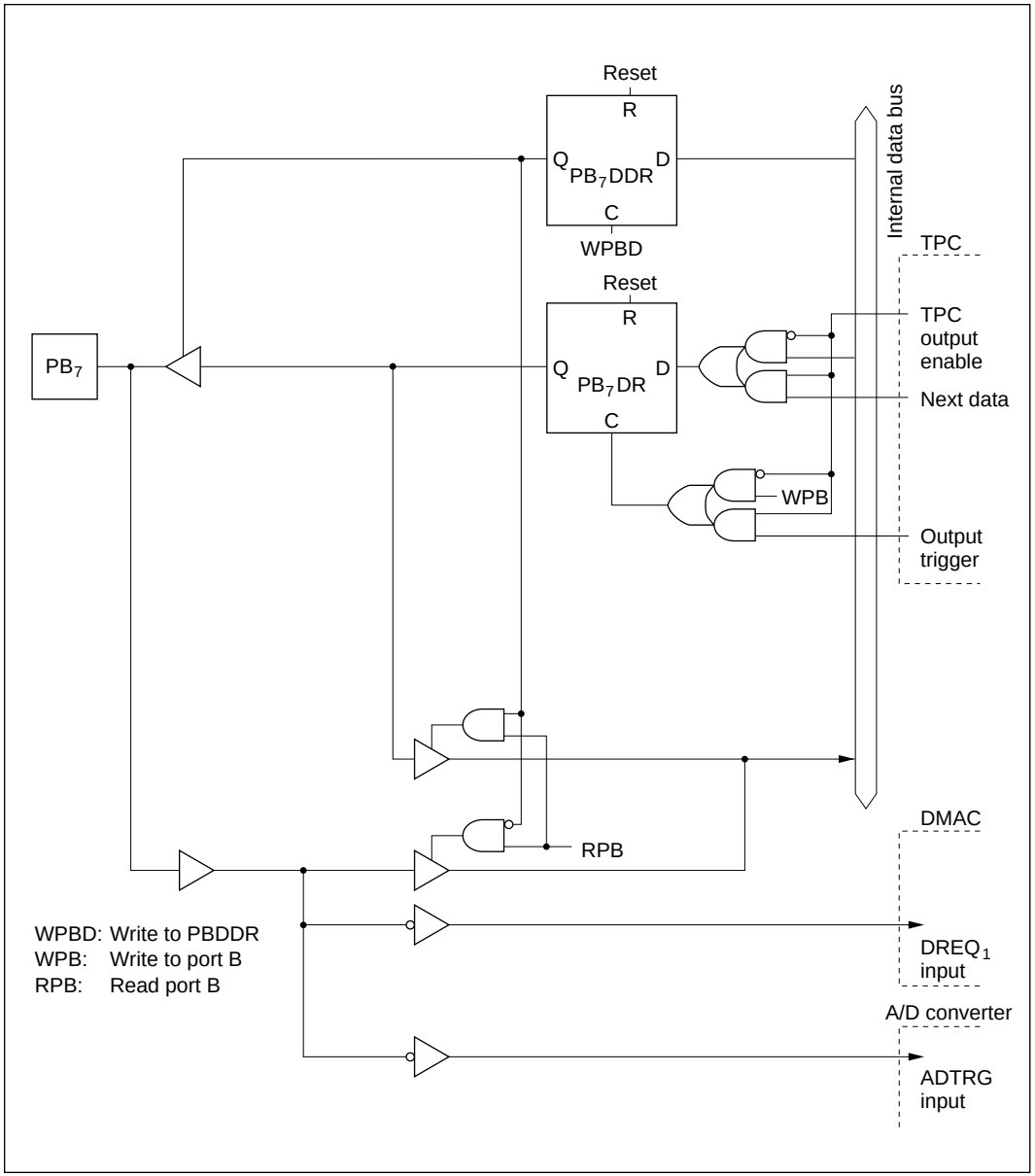


Figure C-8 (d) Port B Block Diagram (Pin PB_7)

C.9 Port C Block Diagrams

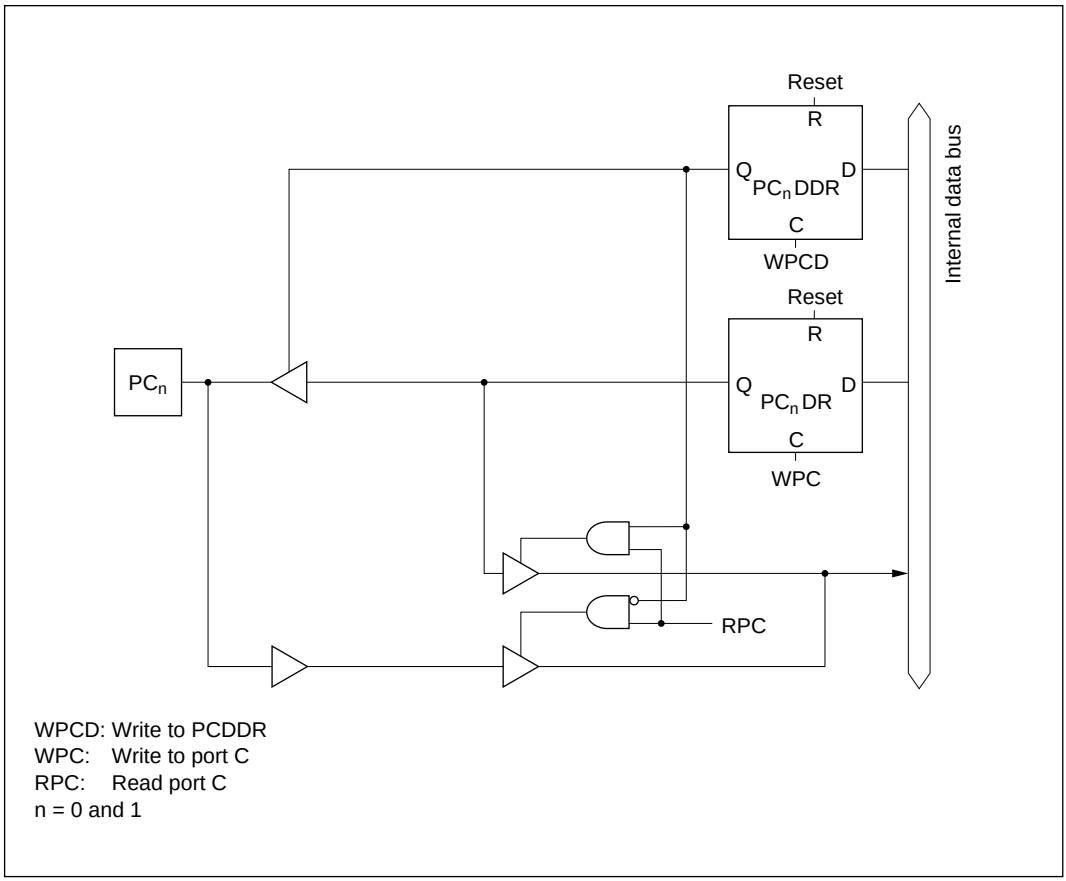


Figure C-9 (a) Port C Block Diagram (Pins PC_0, PC_1)

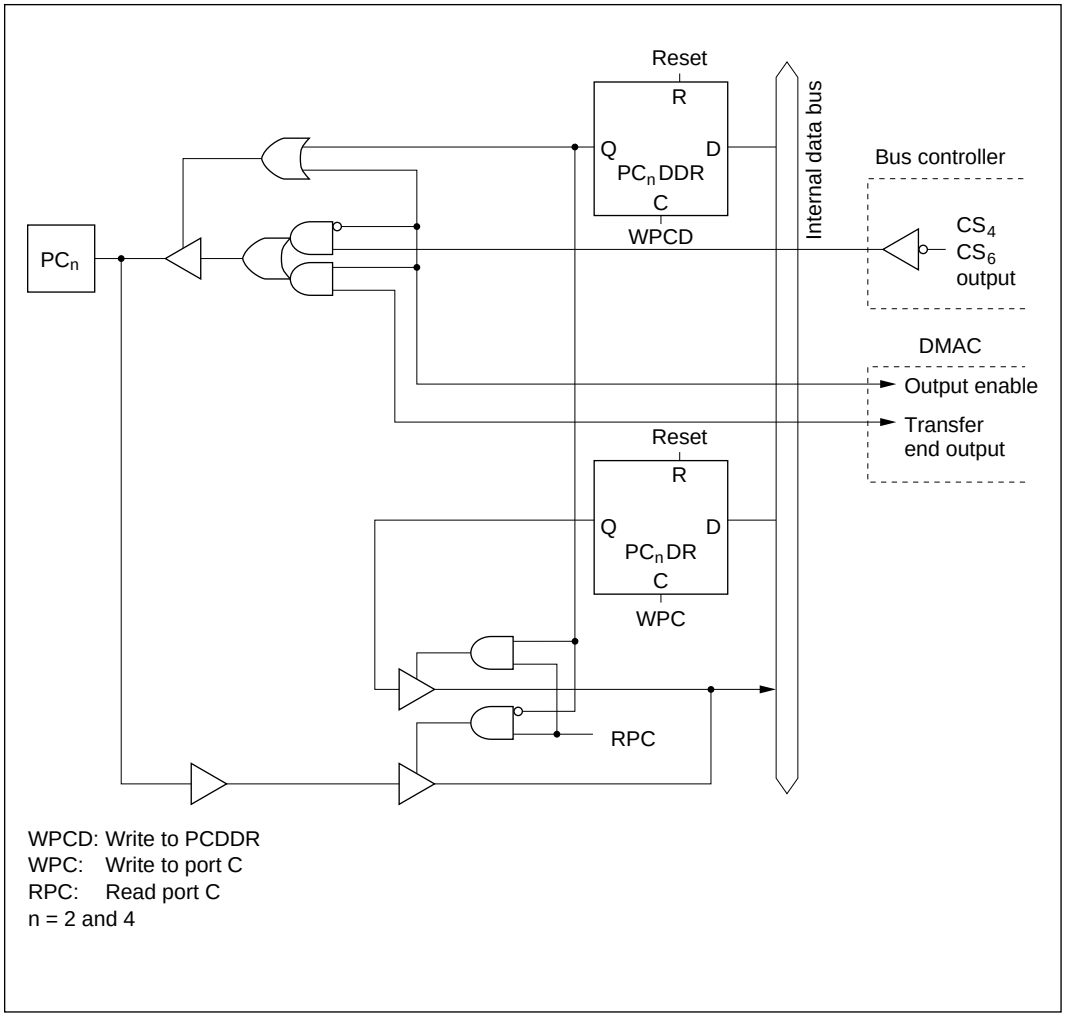


Figure C-9 (b) Port C Block Diagram (Pins PC_2, PC_4)

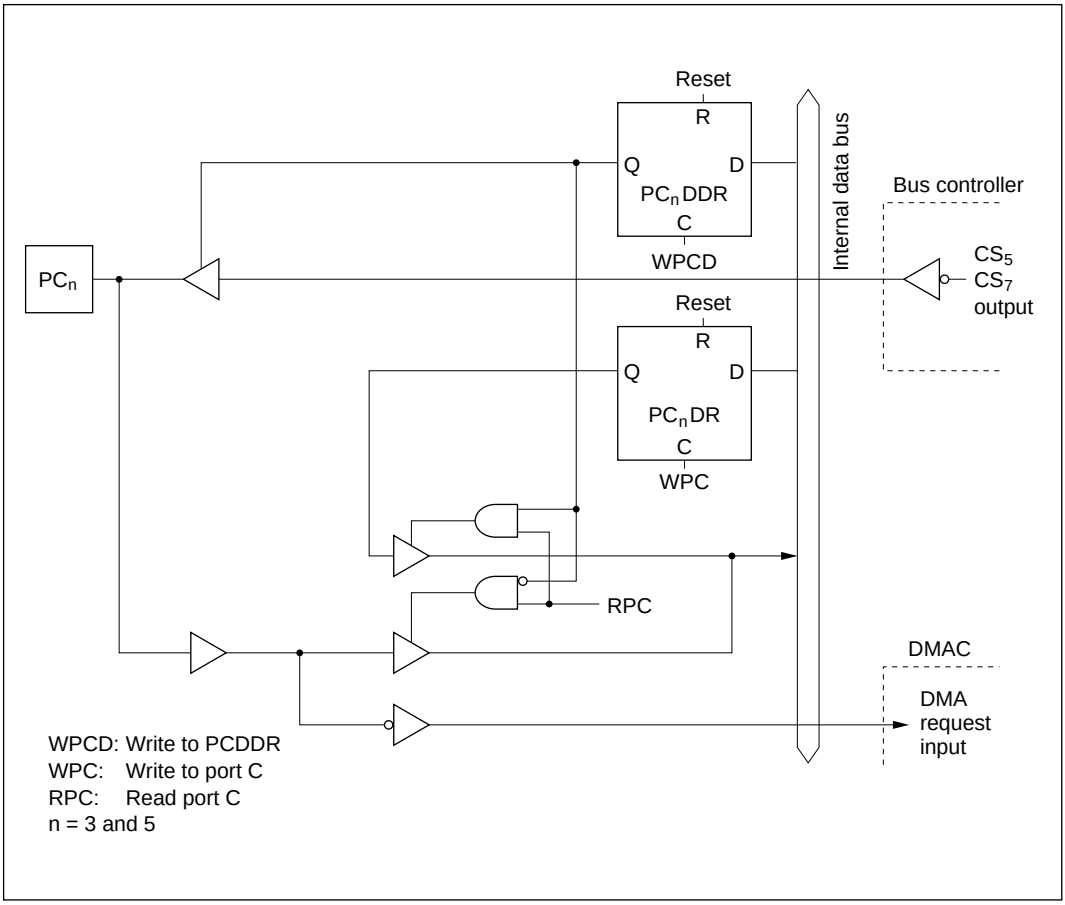


Figure C-9 (c) Port C Block Diagram (Pins PC_3, PC_5)

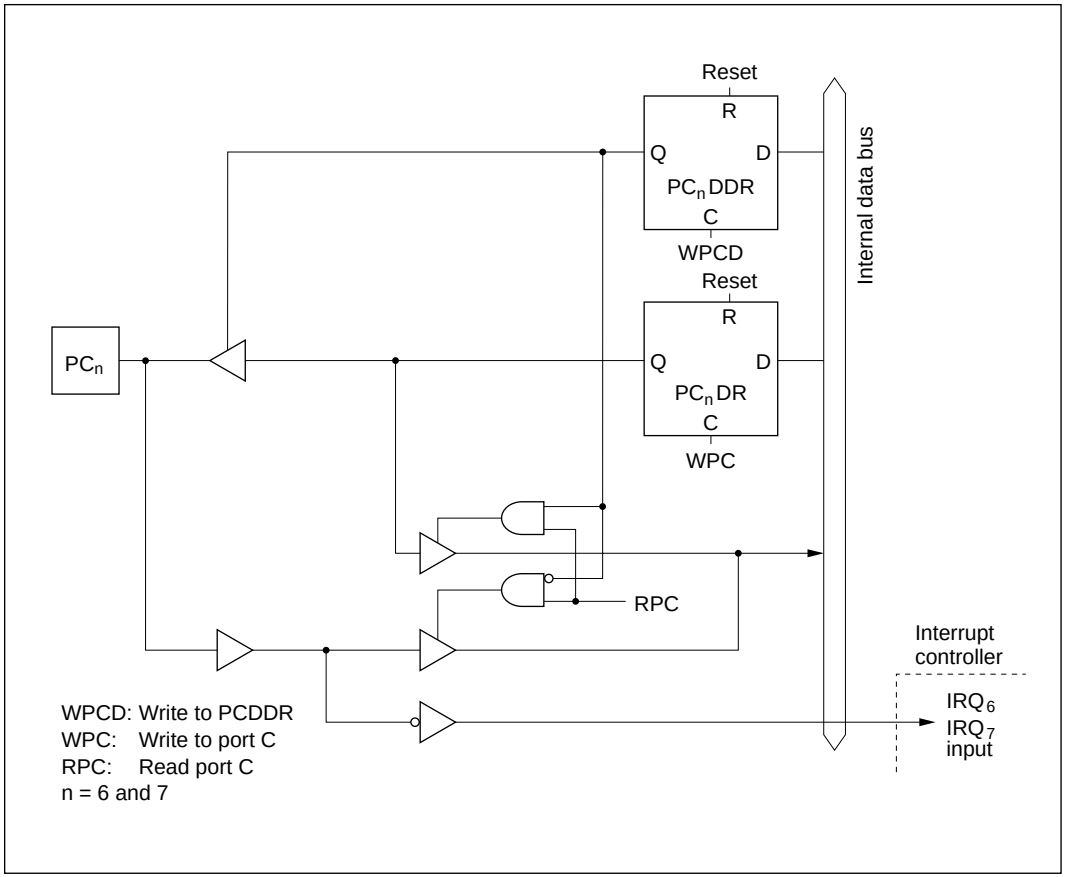


Figure C-9 (d) Port C Block Diagram (Pins PC_6, PC_7)

Appendix D Pin States

D.1 Port States in Each Mode

Table D-1 Port States

Pin Name	Mode		Reset State	Hardware Standby Mode	Software Standby Mode	Bus-Released Mode	Program Execution Sleep Mode
ø	—		Clock output	T	H	Clock output	Clock output
A_{19} to A_0	1 to 4		L	T	T	T	A_{19} to A_0
D_{15} to D_8	1 to 4		T	T	T	T	D_{15} to D_0
$\overline{AS}$, $\overline{RD}$, $\overline{HWR}$, $\overline{LWR}$	1 to 4		H	T	T	T	$\overline{AS}$, $\overline{RD}$, $\overline{HWR}$, $\overline{LWR}$
$P4_7$ to $P4_0$	1 to 4	8-bit bus	T	T	keep	keep	I/O port
D_7 to D_0		16-bit bus			T	T	D_7 to D_0
$P5_7$ to $P5_4$	1, 2		T	T	keep	keep	I/O port
$A2_3$ to $A2_0$	3, 4		L	T	T	T	A_{23} to A_{20}
$P6_0$	1 to 4		T	T	keep	keep	I/O port*1 $\overline{WAIT}$
$P6_1$	1 to 4		T	T	(BRLE = 0) keep (BRLE = 1) T	T	I/O port $\overline{BREQ}$
$P6_2$	1 to 4		T	T	(BRLE = 0) keep (BRLE = 1) H	L	I/O port (BRLE = 0) or $\overline{BACK}$ (BRLE = 1)
$P7_7$ to $P7_0$	1 to 4		T	T	T	T	Input port

Note: * Do not set the DDR bit to 1.

Legend

H: High

L: Low

T: High-impedance state

keep: Input pins are in the high-impedance state; output pins maintain their previous state.

DDR: Data direction register bit

Table D-1 Port States (cont)

Pin Name	Mode	Reset State	Hardware Standby Mode	Software Standby Mode	Bus-Released Mode	Program Execution Sleep Mode
$P8_0$	1 to 4	T	T	(RFSHE = 0) keep (RFSHE = 1) $\overline{RFSH}$	(RFSHE = 0) keep (RFSHE = 1) H	I/O port (RFSHE = 0) or $\overline{RFSH}$ (RFSHE = 1)
$P8_3$ to $P8_1$	1 to 4	T	T	(DDR = 0) T (DDR = 1) H	keep	Input port (DDR = 0) or $\overline{CS_3}$ to $\overline{CS_1}$ (DDR = 1)
$P8_4$	1 to 4	L	T	(DDR = 0) T (DDR = 1) L	keep	Input port (DDR = 0) or $\overline{CS_0}$ (DDR = 1)
$P9_5$ to $P9_0$	1 to 4	T	T	keep	keep	I/O port
PA_7 to PA_0	1 to 4	T	T	keep	keep	I/O port
PB_7 to PB_0	1 to 4	T	T	keep	keep	I/O port
PC_7, PC_6 PC_1, PC_0	1 to 4	T	T	keep	keep	I/O port
PC_5 to PC_2	1 to 4	T	T	(DDR = 0) keep (DDR = 1) H	keep	Input port (DDR = 0) or $\overline{CS_7}$ to $\overline{CS_4}$ (DDR = 1)

Legend
H: High
L: Low
T: High-impedance state
keep: Input pins are in the high-impedance state; output pins maintain their previous state.
DDR: Data direction register bit

D.2 Pin States at Reset

Reset in T_1 State: Figure D-1 is a timing diagram for the case in which $\overline{RES}$ goes low during the T_1 state of an external memory access cycle. As soon as $\overline{RES}$ goes low, all ports are initialized to the input state. $\overline{AS}$, $\overline{RD}$, $\overline{HWR}$, and $\overline{LWR}$ go high, and the data bus goes to the high-impedance state. The address bus is initialized to the low output level 0.5 state after the low level of $\overline{RES}$ is sampled. Sampling of $\overline{RES}$ takes place at the fall of the system clock (ø).

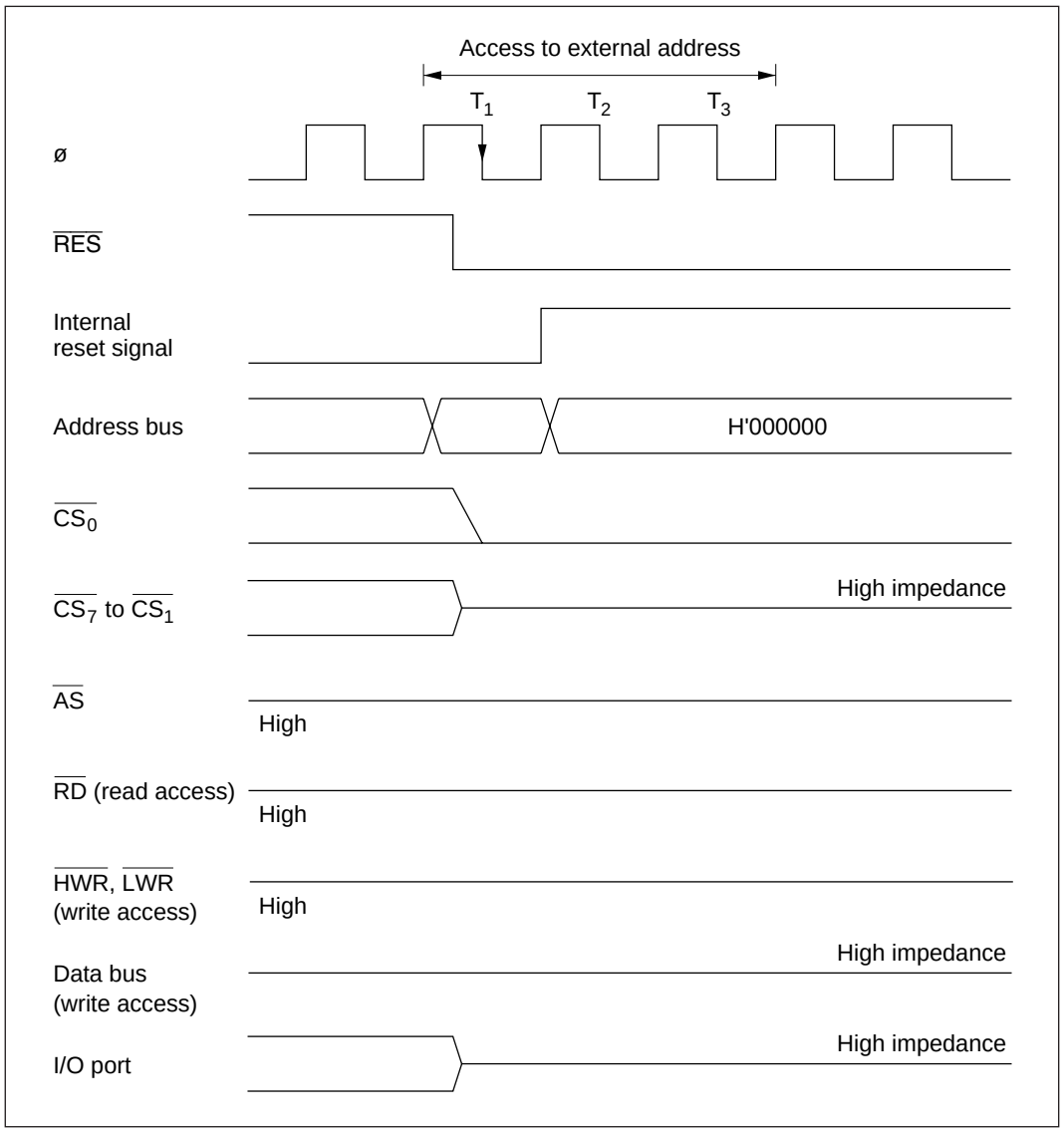


Figure D-1 Reset during Memory Access (Reset during T_1 State)

Reset in T_2 State: Figure D-2 is a timing diagram for the case in which $\overline{RES}$ goes low during the T_2 state of an external memory access cycle. As soon as $\overline{RES}$ goes low, all ports are initialized to the input state. $\overline{AS}$, $\overline{RD}$, $\overline{HWR}$, and $\overline{LWR}$ go high, and the data bus goes to the high-impedance state. The address bus is initialized to the low output level 0.5 state after the low level of $\overline{RES}$ is sampled. The same timing applies when a reset occurs during a wait state (T_W).

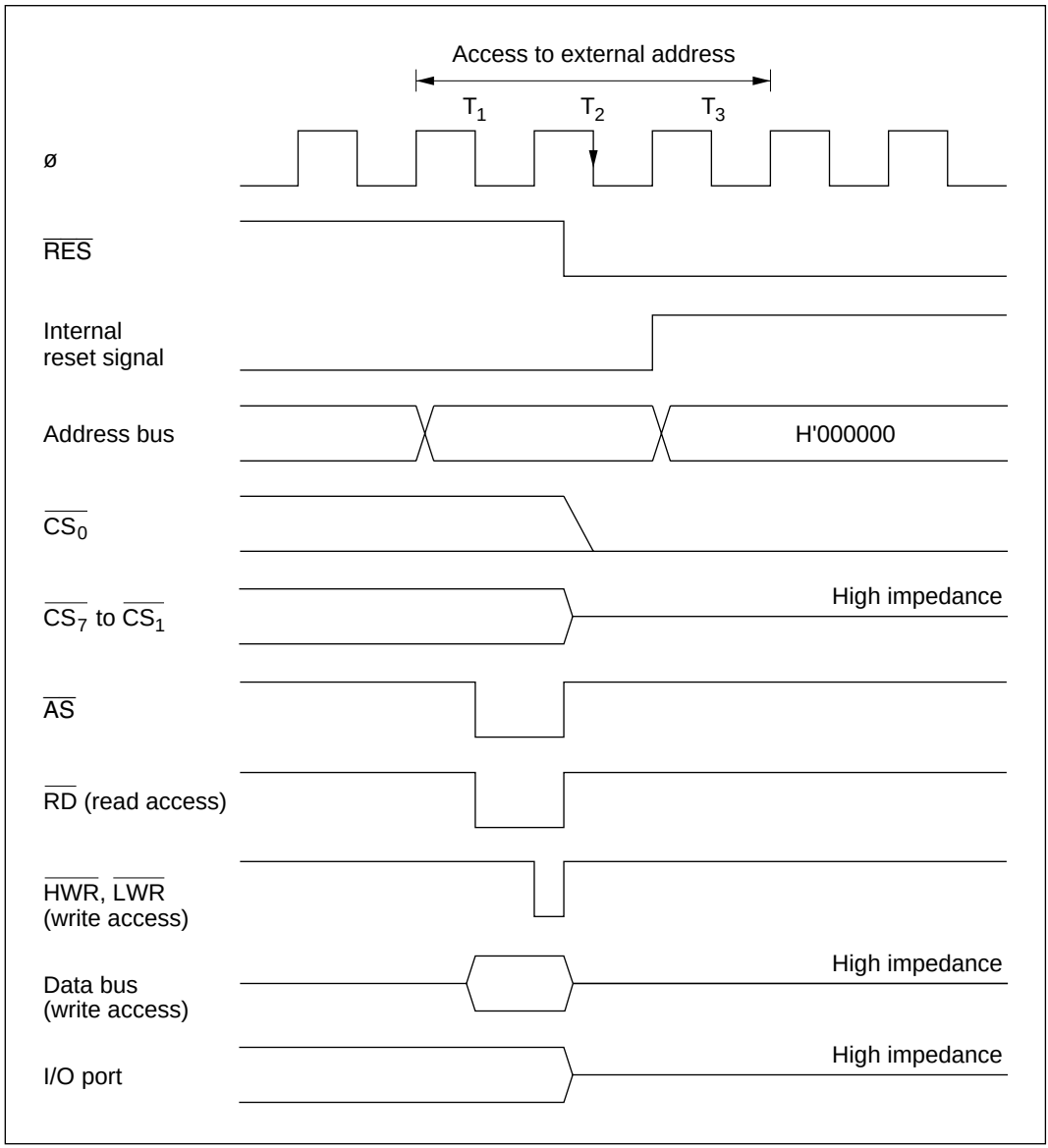


Figure D-2 Reset during Memory Access (Reset during T_2 State)

Reset in T_3 State: Figure D-3 is a timing diagram for the case in which $\overline{RES}$ goes low during the T_3 state of an external memory access cycle. As soon as $\overline{RES}$ goes low, all ports are initialized to the input state. $\overline{AS}$, $\overline{RD}$, $\overline{HWR}$, and $\overline{LWR}$ go high, and the data bus goes to the high-impedance state. The address bus outputs are held during the T_3 state.The same timing applies when a reset occurs in the T_2 state of an access cycle to a two-state-access area.

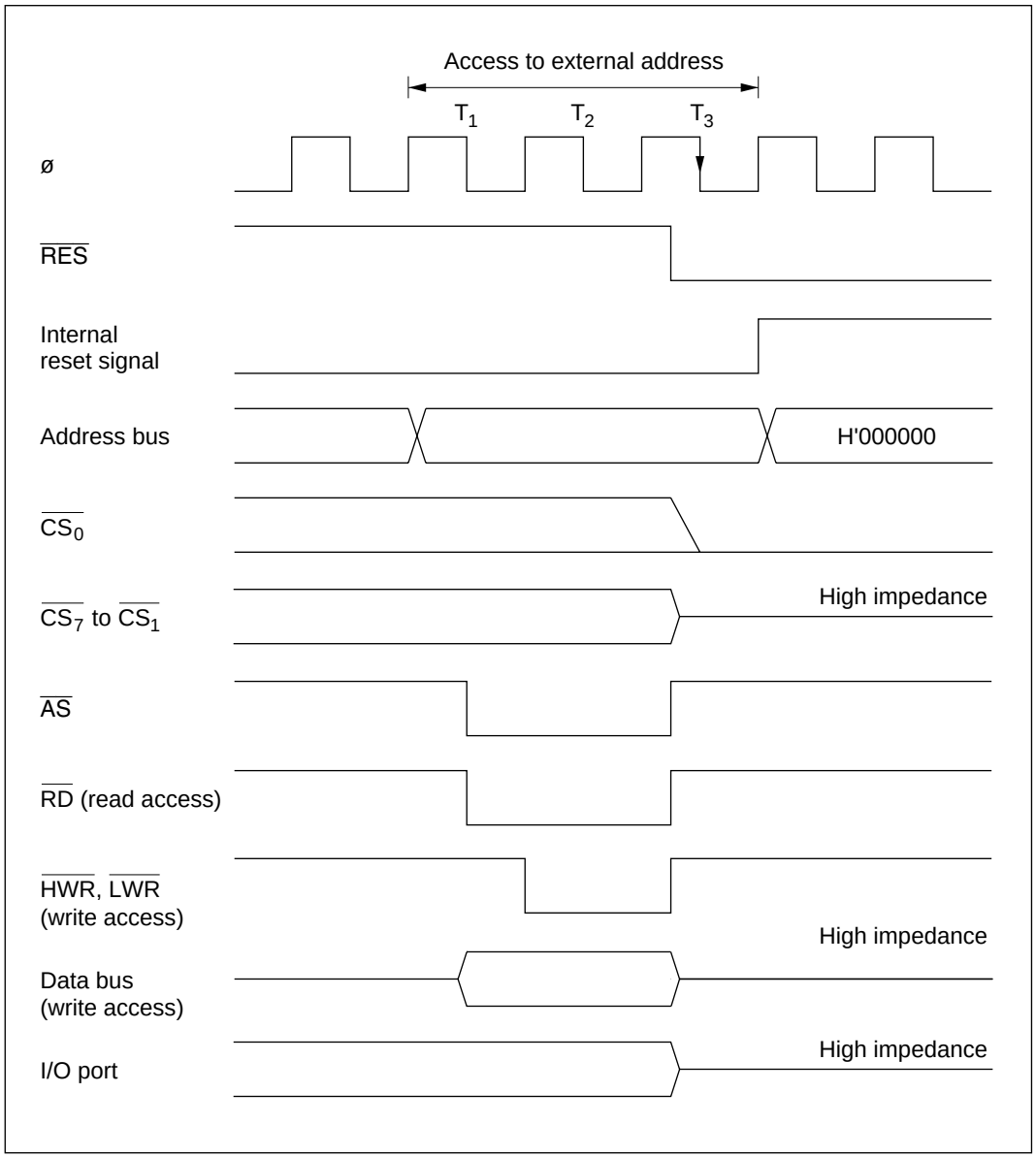
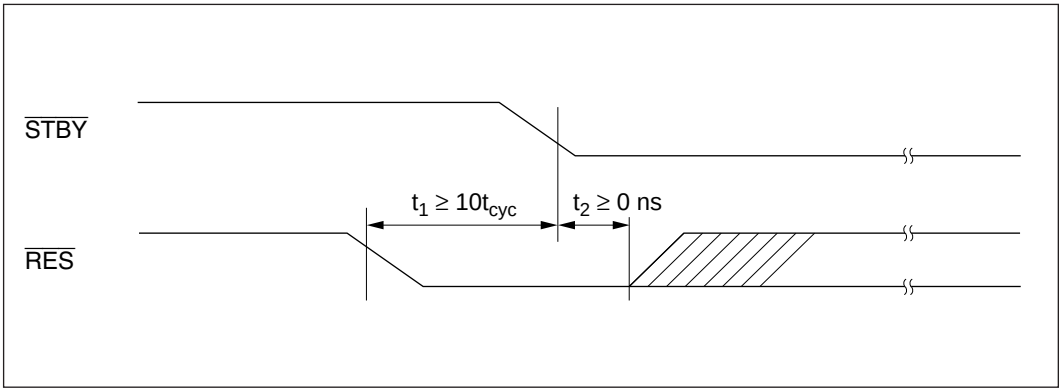


Figure D-3 Reset during Memory Access (Reset during T_3 State)

Appendix E Timing of Transition to and Recovery from Hardware Standby Mode

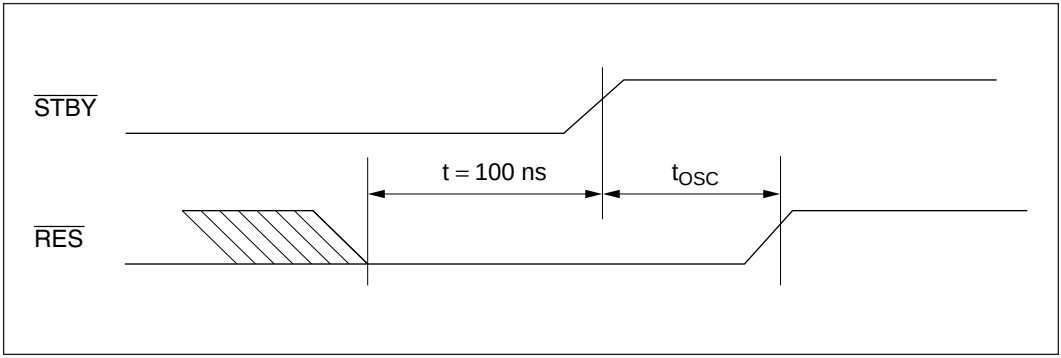
Timing of Transition to Hardware Standby Mode

(1) To retain RAM contents with the RAME bit set to 1 in SYSCR, drive the $\overline{\text{RES}}$ signal low 10 system clock cycles before the $\overline{\text{STBY}}$ signal goes low, as shown below. $\overline{\text{RES}}$ must remain low until $\overline{\text{STBY}}$ goes low (minimum delay from $\overline{\text{STBY}}$ low to $\overline{\text{RES}}$ high: 0 ns).



(2) To retain RAM contents with the RAME bit cleared to 0 in SYSCR, $\overline{\text{RES}}$ does not have to be driven low as in (1).

Timing of Recovery from Hardware Standby Mode: Drive the $\overline{\text{RES}}$ signal low approximately 100 ns before $\overline{\text{STBY}}$ goes high.



Appendix F Package Dimensions

Figure E-1 shows the QFP-112 package dimensions of the H8/3003.

Unit: mm

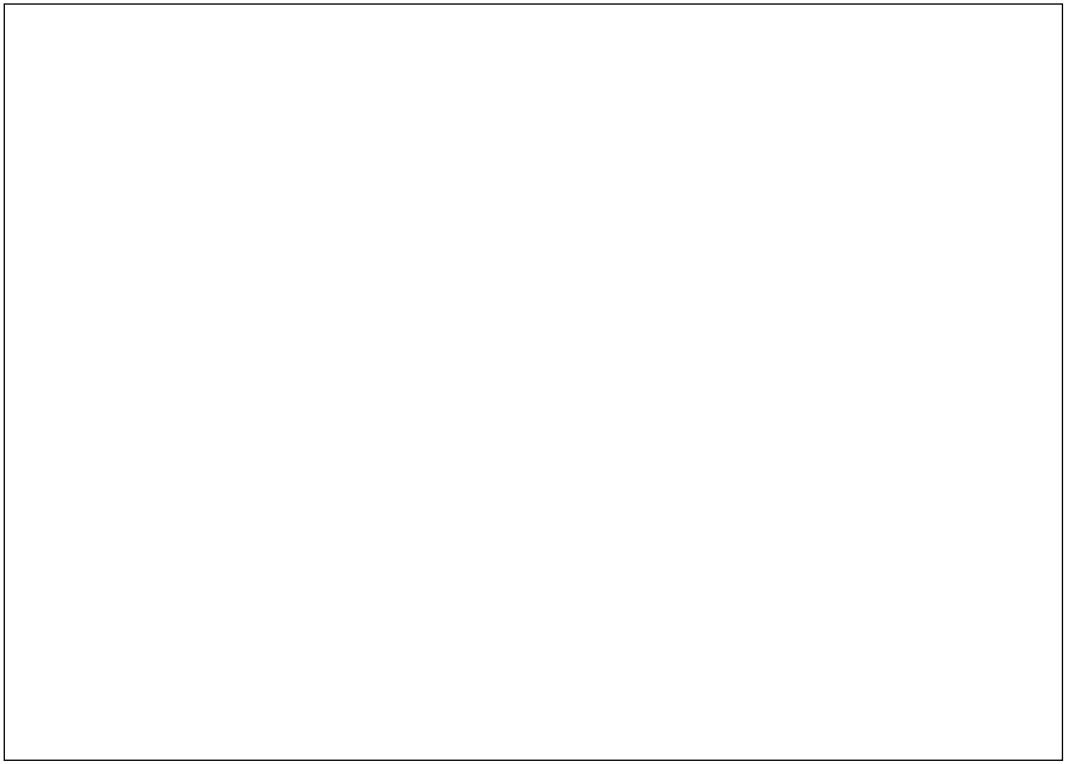


Figure F-1 Package Dimensions (QFP-112)