

CMOS 8-Bit Microcontroller

TMP87CH21F, TMP87CH21BF, TMP87CM21F TMP87CH21DF, TMP87CH21BDF, TMP87CM21DF

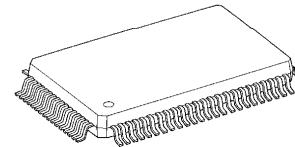
The TMP87CH21/H21B/M21 are the high speed and high performance 8-bit single chip microcomputers. These MCU contain, large ROM, RAM, input/output ports, LCD driver, 8-bit AD converter, four multi-function timer/counters, two serial interfaces, and two clock generators on chip.

Part No.	ROM	RAM	Package	OTP MCU
TMP87CH21F	16K x 8-bit	1K x 8-bit	P-QFP80-1420-0.80B	TMP87PP21F
TMP87CH21BF				
TMP87CM21F	32K x 8-bit			
TMP87CH21DF	16K x 8-bit		P-LQFP80-1212-0.50A	TMP87PP21DF
TMP87CH21BDF	32K x 8-bit			
TMP87CM21DF				

Features

- ◆ 8-bit single chip microcomputer TLCS-870 Series
- ◆ Instruction execution time: $0.5 \mu s$ (at 8 MHz),
 $122 \mu s$ (at 32.768 kHz)
- ◆ 129 types and 412 basic instructions
 - Multiplication and Division (8 bits x 8 bits, 16 bits ÷ 8 bits)
 $: 3.5 \mu s$ (at 8 MHz)
 - Bit manipulations
 (Set/Clear/Complement/Load/Store/Test/Exclusive OR)
 - 16-bit data operations
 - 1-byte jump/call (Short relative jump / Vector call)
- ◆ 14 interrupt sources (External: 5, Internal: 9)
 - All sources have independent latches each, and nested interrupt control is available
 - 4 edge-selectable external interrupts with noise reject
 - High-speed task switching by register bank changeover

P-QFP80-1420-0.80B


 TMP87CH21F
 TMP87CH21BF
 TMP87CM21F

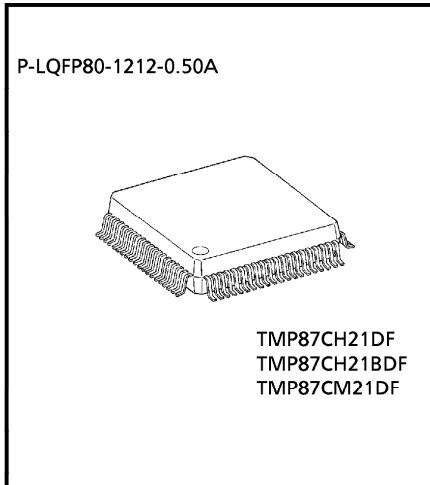
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- The information contained herein is subject to change without notice.

- ◆ 10 Input/Output ports (Max 52 pins)
- ◆ Two 16-bit Timer/Counters
 - Timer, Event counter, Frequency measurement, Pulse width measurement modes
- ◆ Two 8-bit Timer/Counters
 - Timer, Event counter, Capture (Pulse width/duty measurement), PWM output, PDO modes
- ◆ Time Base Timer (Interrupt frequency: 1 Hz to 16348 Hz)
- ◆ Divider output function (frequency: 1 kHz to 8 kHz)
- ◆ Watchdog Timer
- ◆ Two 8-bit Serial Interfaces
 - Each 8 bytes transmit/receive data buffer
 - Internal/external serial clock, and 4/8-bit mode
- ◆ LCD driver
 - With display memory
 - LCD direct drive capability (Max 32 seg x 4 com)
 - 1/4, 1/3, 1/2 duty or static drive are programmably selectable
- ◆ 8-bit successive approximate type AD converter with sample and hold
 - 8 analog inputs
 - Conversion time: 23 μ s / 92 μ s (at 8 MHz)
 - Conversion accuracy

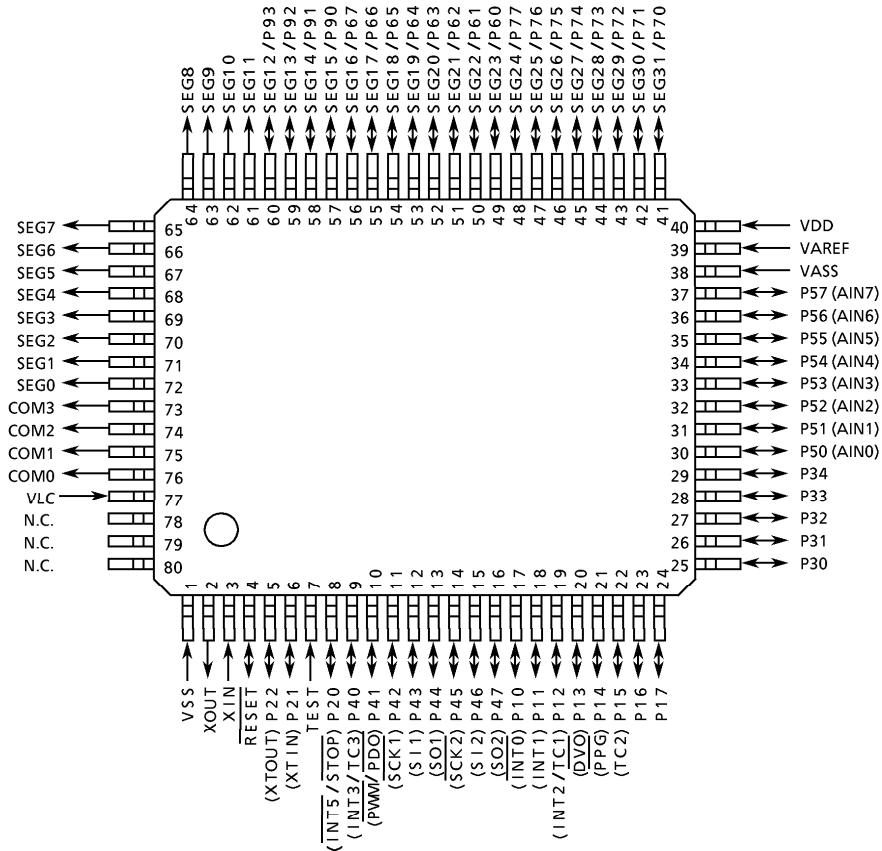
	Full Scale Error	Total Error	Unit
TMP87CH21/M21	± 1	± 2	
TMP87CH21B	+ 2, - 1	+ 3, - 2	LSB

- ◆ Dual clock operation
- ◆ Five Power saving operating modes
 - STOP mode: Oscillation stops. Battery/Capacitor back-up. Port output hold/high-impedance.
 - SLOW mode: Low power consumption operation using low-frequency clock (32.768 kHz).
 - IDLE1 mode: CPU stops, and Peripherals operate using high-frequency clock. Release by interrupts.
 - IDLE2 mode: CPU stops, and Peripherals operate using high and low frequency clock. Release by interrupts.
 - SLEEP mode: CPU stops, and Peripherals operate using low-frequency clock. Release by interrupts.
- ◆ Operating Voltage: 2.7 to 5.5 V at 4.2 MHz / 32.768 kHz, 4.5 to 5.5 V at 8 MHz / 32.768 kHz
- ◆ Emulation Pod: BM87CP23F0A



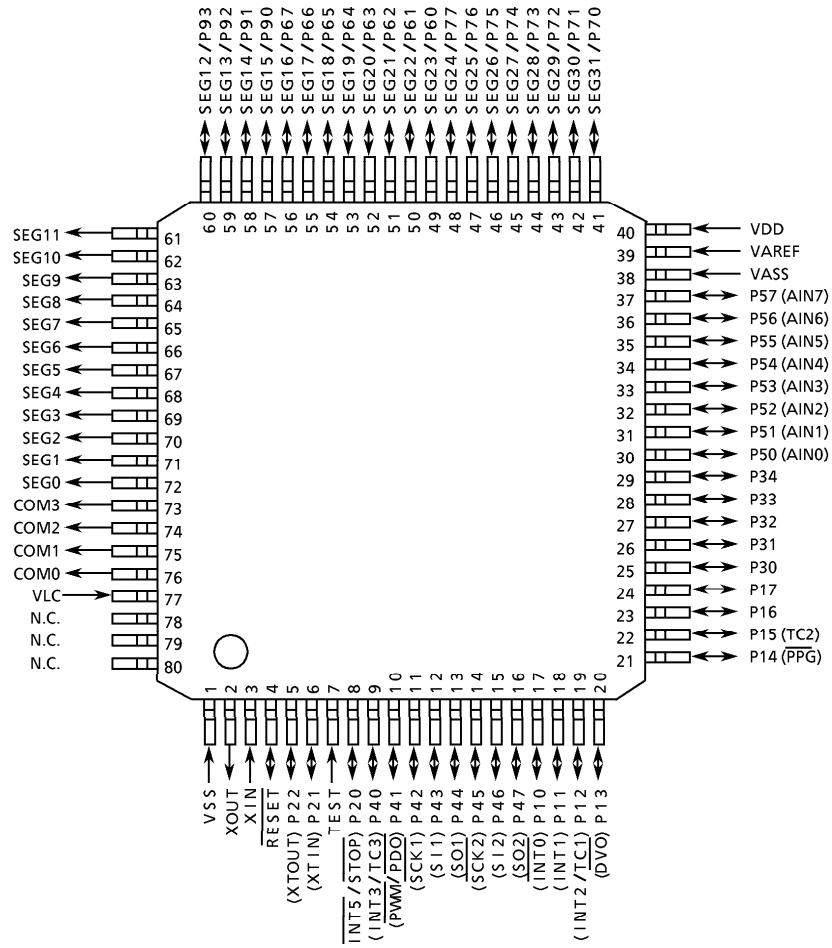
Pin Assignments (Top View)

P-QFP80-1420-0.80B

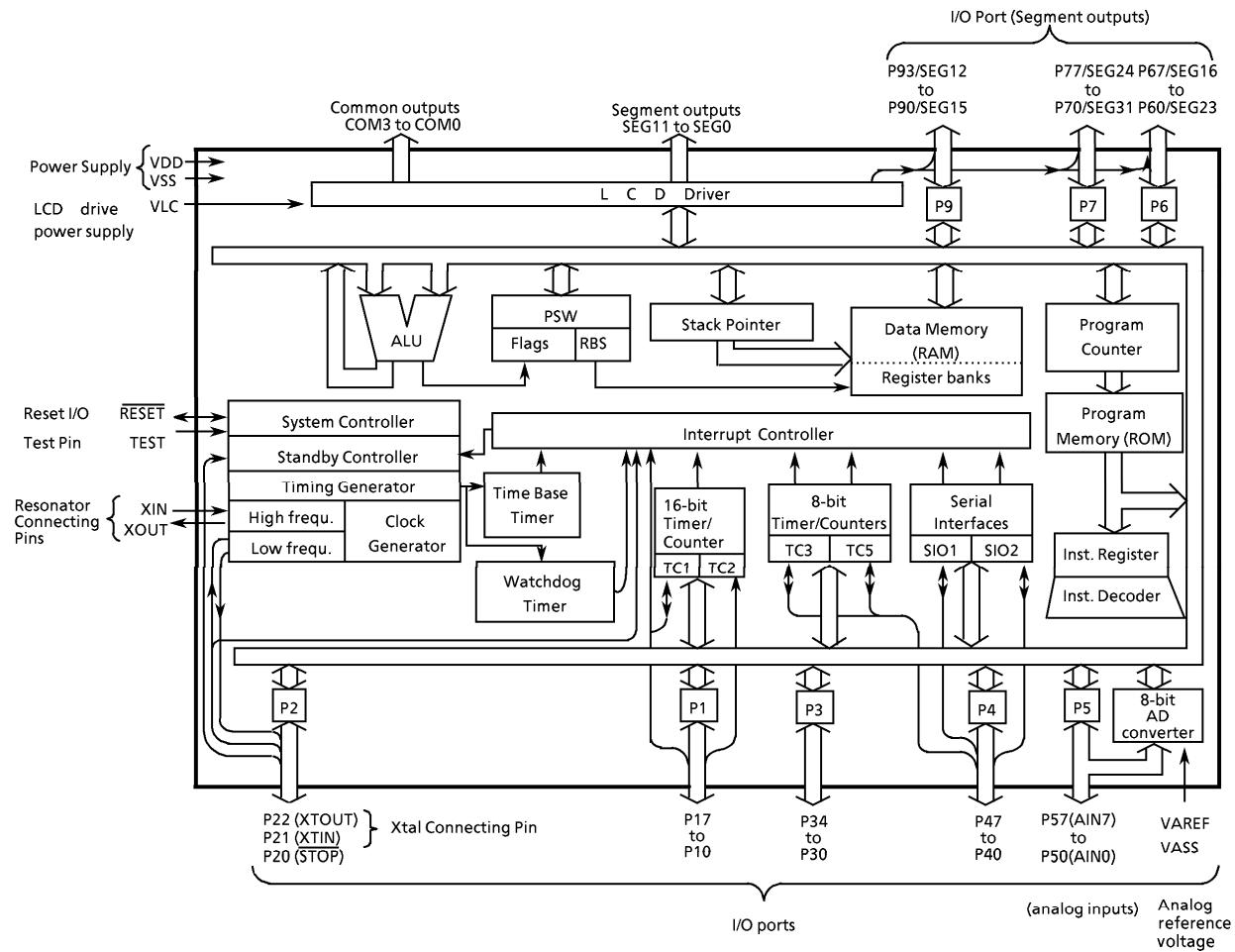


Pin Assignments (Top View)

P-LQFP80-1212-0.50A



Block Diagram



Pin Function

Pin Name	Input / Output	Function	
P17, P16	I/O	8-bit programmable input/output port (tri-state).	
P15 (TC2)	I/O (Input)		Timer/Counter 2 input
P14 (PPG)	I/O (Output)	Each bit of these ports can be individually configured as an input or an output under software control.	Programmable pulse generator output
P13 (DVO)			Divider output
P12 (INT2 / TC1)			External interrupt input 2 or Timer/Counter 1 input
P11 (INT1)	I/O (Input)	When used as timer/counter in or external interrupt input, the latch must be set to "0". When used as PPG output or divider output, the latch must be set to "1".	External interrupt input 1
P10 (INT0)			External interrupt input 0
P22 (XTOUT)	I/O (Output)	3-bit input/output port with latch.	Resonator connecting pins (32.768 kHz). For inputting external clock, XTIN is used and XTOUT is opened.
P21 (XTIN)	I/O (Input)	When used as an input port, the latch must be set to "1".	External interrupt input 5 or STOP mode release signal input
P20 (INT5/STOP)			
P34 to P30	I/O	5-bit input/output port with latch. When used as input port, the latch must be set to "1".	
P47 (SO2)	I/O (Output)	8-bit input/output port with latch. When used as input port or a SIO input/output, PWM/PDO output or external interrupt input, the latch must be set to "1".	SIO2 serial data output
P46 (SI2)	I/O (Input)		SIO2 serial data input
P45 (SCK2)	I/O (I/O)		SIO2 serial clock input/output
P44 (SO1)	I/O (Output)		SIO1 serial data output
P43 (SI1)	I/O (Input)		SIO1 serial data input
P42 (SCK1)	I/O (I/O)		SIO1 serial clock input/output
P41 (PWM/PDO)	I/O (Output)		8-bit PWM output, 8-bit programmable divider output
P40 (INT3/TC3)	I/O (Input)		External interrupt input 3, Timer/Counter 3 input
P57 (AIN07) to P50 (AIN00)	I/O (Input)	8-bit programmable input/output port (tri-state). Each bit of the port can be individually configured as an input or an output under software control. When used as analog input, the latch must be set to "0".	AD converter analog inputs
SEG31 (P70) to SEG24 (P77)	Output (I/O)	8-bit input/output port with latch. When used as an input port, the latch must be set to "1".	LCD segment outputs. When used as segment output, the control register of P6, P7 and P9 must be set to "1".
SEG23 (P60) to SEG16 (P67)	Output (I/O)		
SEG15 (P90) to SEG12 (P93)	Output (I/O)		
SEG11 to SEG0	Output	LCD segment outputs	
COM3 to COM0	Output	LCD common outputs	
XIN, XOUT	Input, Output	Resonator connecting pins for high-frequency clock. For inputting external clock, XIN is used and XOUT is opened.	
RESET	I/O	Reset signal input or watchdog timer output/address-trap-reset output	
TEST	Input	Test pin for out-going test. Be fixed to low.	
VDD, VSS	Power Supply	2.7 to 5.5 V, 0 V (GND)	
VAREF, VASS		Analog reference voltage inputs (High, Low)	
VLC		LCD drive power supply.	

Operational Description

1. CPU Core Functions

The CPU core consists of a CPU, a system clock controller, an interrupt controller, and a watchdog timer. This section provides a description of the CPU core, the program memory (ROM), the data memory (RAM), and the reset circuit.

1.1 Memory Address Maps

The TLCS-870 Series is capable of addressing 64 K bytes of memory. Figure 1-1 shows the memory address maps of the TMP87CH21/H21B/M21. In the TLCS-870 Series, the memory is organized 4 address spaces (ROM, RAM, SFR, and DBR). It uses a memory mapped I/O system, and all I/O registers are mapped in the SFR/DBR address spaces. There are 16 banks of general-purpose registers. The register banks are also assigned to the first 128 bytes of the RAM address space.

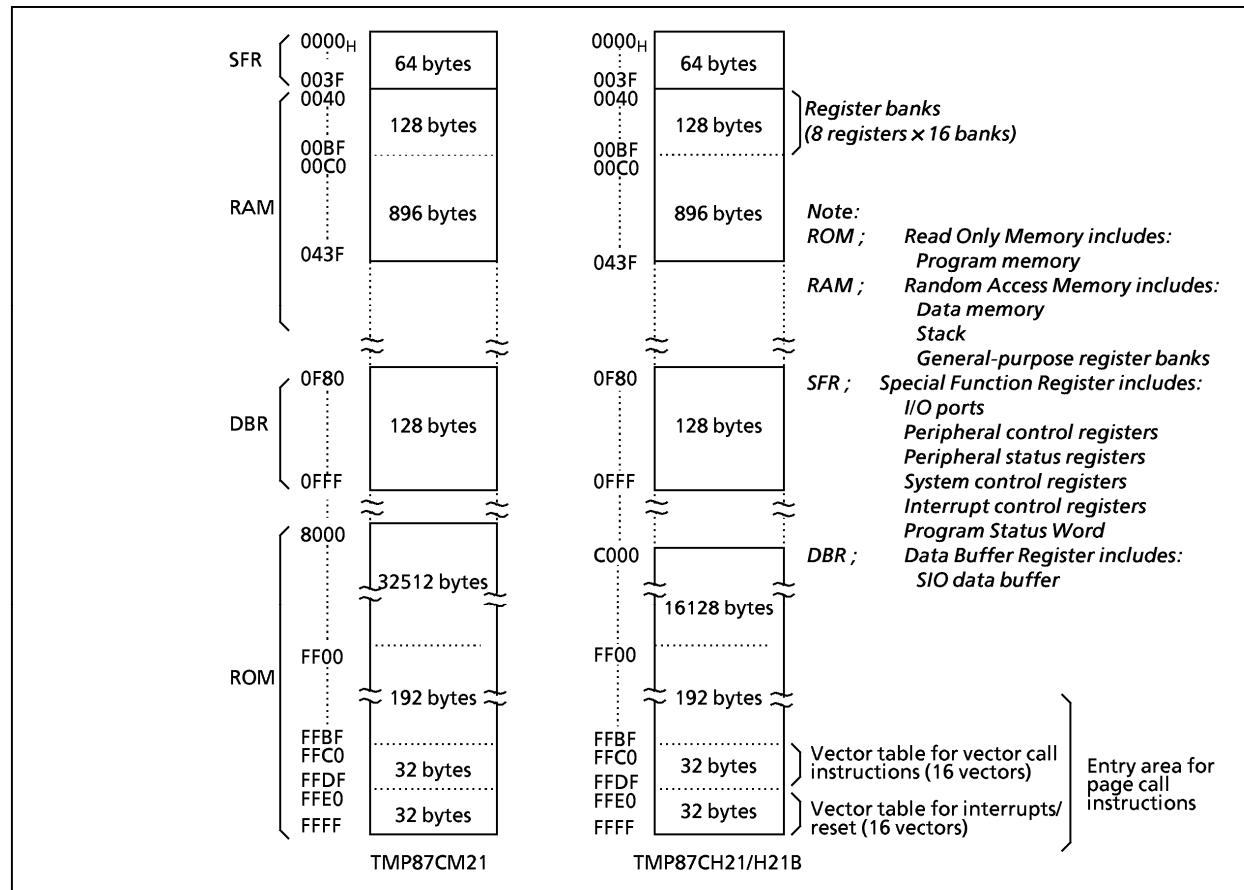


Figure 1-1. Memory Address Maps

1.2 Program Memory (ROM)

The TMP87CH21/H21B has a $16K \times 8$ -bit (addresses $C000_H$ to $FFFF_H$), and the TMP87CM21 has a $32K \times 8$ -bit (address 8000_H to $FFFF_H$) of program memory (mask programmed ROM).

Addresses $FF00_H$ to $FFFF_H$ in the program memory can also be used for special purposes.

(1) Interrupt / Reset vector table (addresses $FFE0_H$ to $FFFF_H$)

This table consists of a reset vector and 15 interrupt vectors (2 bytes/vector). These vectors store a reset start address and interrupt service routine entry addresses.

(2) Vector table for vector call instructions (addresses $FFC0_H$ to $FFDF_H$)

This table stores call vectors (subroutine entry address, 2 bytes/vector) for the vector call instructions [CALLV n]. There are 16 vectors. The CALLV instruction increases memory efficiency when utilized for frequently used subroutine calls (called from 3 or more locations).

(3) Entry area (addresses $FF00_H$ to $FFFF_H$) for page call instructions

This is the subroutine entry address area for the page call instructions [CALLP n]. Addresses $FF00_H$ to $FFBF_H$ are normally used because address $FFC0_H$ to $FFFF_H$ are used for the vector tables.

Programs and fixed data are stored in the program memory. The instruction to be executed next is read from the address indicated by the current contents of the program counter (PC). There are relative jump and absolute jump instructions. The concepts of page or bank boundaries are not used in the program memory concerning any jump instruction.

Example: The relationship between the jump instructions and the PC.

① 5-bit PC-relative jump [JRS cc, \$ + 2 + d]

E8C4H: JRS T, \$ + 2 + 08H

When JF = 1, the jump is made to E8CEH, which is 08H added to the contents of the PC. (The PC contains the address of the instruction being executed + 2; therefore, in this case, the PC contents are E8C4H + 2 = E8C6H.)

② 8-bit PC-relative jump [JR cc, \$ + 2 + d]

E8C4H: JR Z, \$ + 2 + 80H

When ZF = 1, the jump is made to E846H, which is FF80H (-128) added to the current contents of the PC.

③ 16-bit absolute jump [JP a]

E8C4H: JP 0C235H

An unconditional jump is made to address C235H. The absolute jump instruction can jump anywhere within the entire 64 K-bytes space.

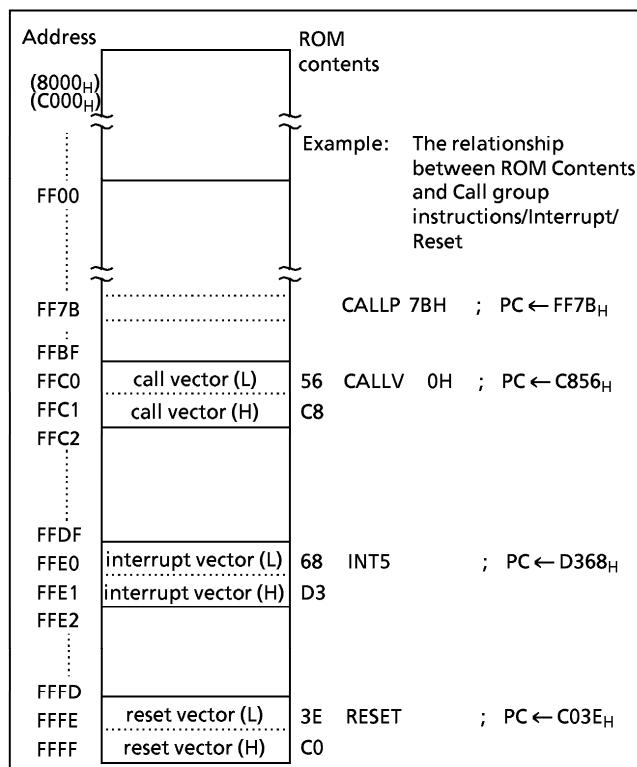


Figure 1-2. Program Memory Map

In the TLCS-870 Series, the same instruction used to access the data memory (e.g. [LD A, (HL)]) is also used to read out fixed data (ROM data) stored in the program memory. The register-offset PC-relative addressing (PC + A) instructions can also be used, and the code conversion, table look-up and n-way multiple jump processing can easily be programmed.

Example 1: Loads the ROM contents at the address specified by the HL register pair contents into the accumulator (TMP87CH21: $HL \geq C000_H$):

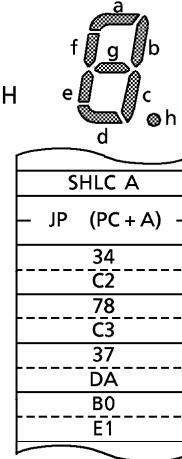
LD A, (HL) ; $A \leftarrow \text{ROM}(HL)$

Example 2: Converts BCD to 7-segment code (common anode LED). When $A = 05_H, 92_H$ is output to port P6 after executing the following program:

```
ADD A, TABLE - $ - 4 ; P6  $\leftarrow \text{ROM}(\text{TABLE} + A)$ 
LD (P6), (PC + A)
JRS T, SNEXT
TABLE: DB 0C0H, 0F9H, 0A4H, 0B0H, 99H, 92H, 82H, 0D8H, 80H, 98H
SNEXT:
```

Note 1: "\$" is a header address of ADD instruction.

Note 2: DB is a byte data definition instruction.



Example 3: N-way multiple jump in accordance with the contents of accumulator ($0 \leq A \leq 3$):

```
SHLC A ; if  $A = 00_H$  then  $\text{PC} \leftarrow C234_H$ 
JP (PC + A) if  $A = 01_H$  then  $\text{PC} \leftarrow C378_H$ 
if  $A = 02_H$  then  $\text{PC} \leftarrow DA37_H$ 
if  $A = 03_H$  then  $\text{PC} \leftarrow E1B0_H$ 
DW 0C234H, 0C378H, 0DA37H, 0E1B0H
```

Note: DW is a word data definition instruction.

1.3 Program Counter (PC)

The program counter (PC) is a 16-bit register which indicates the program memory address where the instruction to be executed next is stored. After reset, the user defined reset vector stored in the vector table (addresses $FFFF_H$ and $FFFE_H$) is loaded into the PC; therefore, program execution is possible from any desired address. For example, when $C0_H$ and $3E_H$ are stored at addresses $FFFF_H$ and $FFFE_H$, respectively, the execution starts from address $C03E_H$ after reset.

The TLCS-870 Series utilizes pipelined processing (instruction pre-fetch); therefore, the PC always indicates 2 addresses in advance. For example, while a 1-byte instruction stored at address $C123_H$ is being executed, the PC contains $C125_H$.

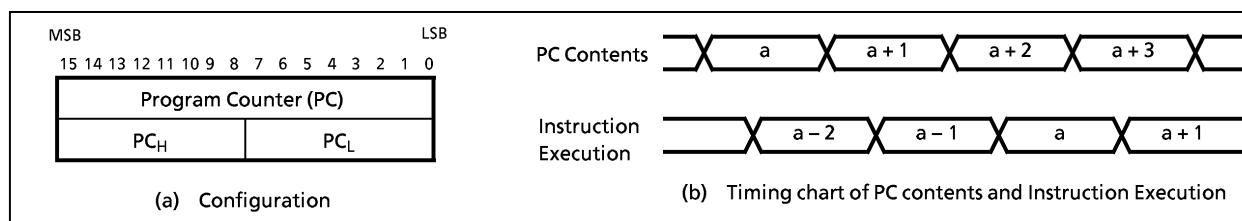


Figure 1-3. Program Counter

1.4 Data Memory (RAM)

The TMP87CH21/H21B/M21 have a $1K \times 8$ -bit (addresses 0040_H to $043F_H$) of data memory (static RAM). Figure 1-4 shows the data memory map.

Addresses 0000_H to $00FF_H$ are used as a direct addressing area to enhance instructions which utilize this addressing mode; therefore, addresses 0040_H to $00FF_H$ in the data memory can also be used for user flags or user counters.

Example 1: If bit 2 at data memory address $00C0_H$ is "1", 00_H is written to data memory at address $00E3_H$; otherwise, FF_H is written to the data memory at address $00E3_H$.

```
TEST    (00C0H).2      ;  if (00C0H) 2=0 then jump
JRS    T,SZERO
CLR    (00E3H)          ;  (00E3H) ← 00H
JRS    T,SNEXT
SZERO : LD    (00E3H),0FFH  ;  (00E3H) ← FFH
SNEXT :
```

Example 2: Increments the contents of data memory at address $00F5_H$, and clears to 00_H when 10_H is exceeded.

```
INC    (00F5H)          ;  (00F5H) ← (00F5H) + 1
AND    (00F5H),00F      ;  (00F5H) ← (00F5H)  $\wedge$  0F
```

General-purpose register banks (8 registers \times 16 banks) are also assigned to the 128 bytes of addresses 0040_H - $00BF_H$. Access as data memory is still possible even when being used for registers. For example, when the contents of the data memory at address 0040_H is read out, the contents of the accumulator in the bank 0 are also read out. The stack can be located anywhere within the data memory except the register bank area. The stack depth is limited only by the free data memory size. For more details on the stack, see section "1.7 Stack and Stack Pointer".

With the TMP87CH21/H21B/M21, programs in data memory cannot be executed. If the program counter indicates a specific data memory address (addresses 0040_H to $043F_H$), an address-trap-reset is generated due to bus error. (Output from the $\overline{\text{RESET}}$ pin goes low.)

Example 1: Clears RAM to "00_H" except the bank 0 (TMP87CH21/H21B/M21)

```
LD    HL, 0048H          ;  Sets start address to HL register pair
LD    A, H                ;  Sets initial data (00H) to A register
LD    BC, 03F7H          ;  Sets number of byte to BC register pair
SRAMCLR : LD (HL +), A
DEC   BC
JRS   F, SRAMCLR
```

Note: The data memory contents become unstable when the power supply is turned on; therefore, the data memory should be initialized by an initialization routine. Note that the general-purpose registers are mapped in the RAM; therefore, do not clear RAM at the current bank addresses.

Address	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0040H											Register bank 0		Register bank 1			
0050											Register bank 2		Register bank 3			
0060											Register bank 4		Register bank 5			
0070											Register bank 6		Register bank 7			
0080											Register bank 8		Register bank 9			
0090											Register bank 10		Register bank 11			
00A0											Register bank 12		Register bank 13			
00B0											Register bank 14		Register bank 15			
00C0																
00D0																
00E0																
00F0																
0100																
0110																
0120																
0130																
0140																
0430																
0440																
0830																

Figure 1-4. Data Memory Map

Direct addressing area

Note: The TMP87CH21/H21B/M21 does not have this area (0440H-083FH) of RAM

1.5 General-purpose Register Banks

General-purpose registers are mapped into addresses 0040_H to $00BF_H$ in the data memory as shown in Figure 1-4. There are 16 register banks, and each bank contains eight 8-bit registers W, A, B, C, D, E, H, and L. Figure 1-5 shows the general-purpose register banks configuration.

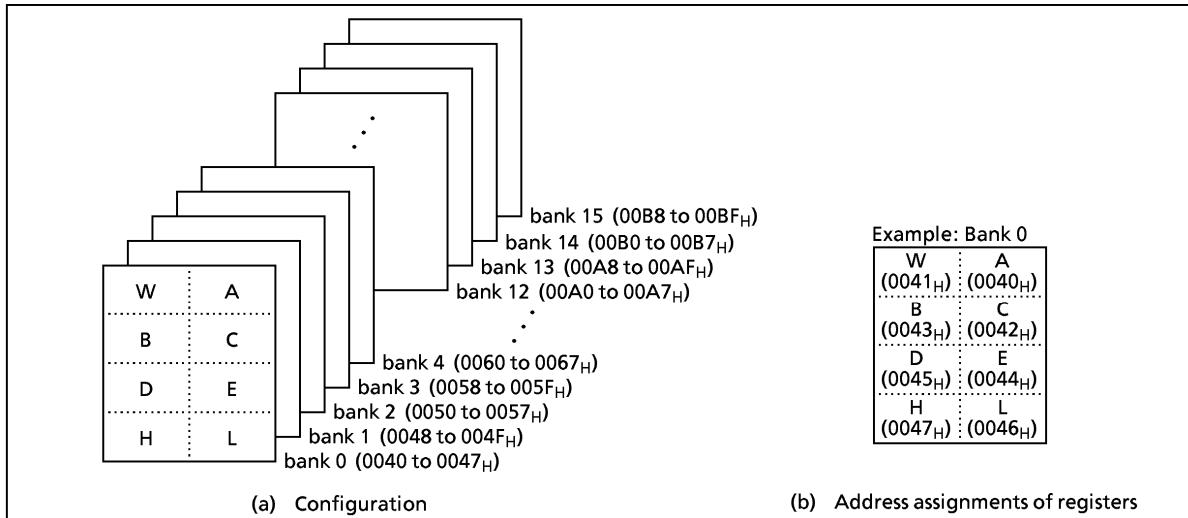


Figure 1-5. General-purpose Register Banks

In addition to access in 8-bit units, the registers can also be accessed in 16-bit units as the register pairs WA, BC, DE, and HL. Besides its function as a general-purpose register, the register also has the following functions:

(1) A, WA

The A register functions as an 8-bit accumulator and WA the register pair functions as a 16-bit accumulator (W is high byte and A is low byte). Registers other than A can also be used as accumulators for 8-bit operations.

Example 1: ADD A, B ; Adds B contents to A contents and stores the result into A.
 Example 2: SUB WA, 1234H ; Subtracts 1234H from WA contents and stores the result into WA.
 Example 3: SUB E, A ; Subtracts A contents from E contents, and stores the result into E.

(2) HL, DE

The HL and DE specify a memory address. The HL register pair functions as data pointer (HL) /index register (HL + d) /base register (HL + C), and the DE register pair function as a data pointer (DE). The HL also has an auto-post- increment and auto-pre-decrement functions. This function simplifies multiple digit data processing, software LIFO (last-in first-out) processing, etc.

Example 1: LD A, (HL) ; Loads the memory contents at the address specified by HL into A.
 Example 2: LD A, (HL + 52H) ; Loads the memory contents at the address specified by the value obtained by adding 52H to HL contents into A.
 Example 3: LD A, (HL + C) ; Loads the memory contents at the address specified by the value obtained by adding the register C contents to HL contents into A.
 Example 4: LD A, (HL +) ; Loads the memory contents at the address specified by HL into A. Then increments HL.
 Example 5: LD A, (-HL) ; Decrements HL. Then loads the memory contents at the address specified by new HL into A.

The TLCS-870 Series can transfer data directly memory to memory, and operate directly between memory data and memory data. This facilitates the programming of block processing.

Example 6: Block transfer

```

LD   B, n - 1    ; Sets (number of bytes to transfer) - 1 to B
LD   HL, DSTA   ; Sets destination address to HL
LD   DE, SRCA   ; Sets source address to DE
SLOOP : LD   (HL), (DE) ; HL ← DE
          INC  HL      ; HL ← HL + 1
          INC  DE      ; DE ← DE + 1
          DEC  B       ; B ← B - 1
          JRS  F, SLOOP ; if B ≥ 0 then loop

```

(3) B, C, BC

Registers B and C can be used as 8-bit buffers or counters, and the BC register pair can be used as a 16-bit buffer or counter. The C register functions as an offset register for register-offset index addressing (refer to example 1 ③ above) and as a divisor register for the division instruction [DIV gg, C].

Example 1: Repeat processing

```

LD   B, n      ; Sets n as the number of repetitions to B
SREPEAT : [processing] ; (n + 1 times processing)
          DEC  B
          JRS  F, SREPEAT

```

Example 2: Unsigned integer division (16-bit ÷ 8-bit)

```

DIV  WA, C      ; Divides the WA contents by the C contents, places the
                  quotient in A and the remainder in W.

```

The general-purpose register banks are selected by the 4-bit register bank selector (RBS). During reset, the RBS is initialized to "0". The bank selected by the RBS is called the current bank.

Together with the flag, the RBS is assigned to address 003FH in the SFR as the program status word (PSW). There are 3 instructions [LD RBS, n], [PUSH PSW], [POP PSW] to access the PSW. The PSW can be also operated by the memory access instruction.

Example 1: Incrementing the RBS

```

INC  (003FH)    ; RBS ← RBS + 1

```

Example 2: Reading the RBS

```

LD   A, (003FH) ; A ← PSW (A3-0 ← RBS, A7-4 ← Flags)

```

Highly efficient programming and high-speed task switching are possible by using bank changeover to save registers during interrupt and to transfer parameters during subroutine processing.

During interrupt, the PSW is automatically saved onto the stack. The bank used before the interrupt was accepted is restored automatically by executing an interrupt return instruction [RETI]/[RETN] ; therefore, there is no need for the RBS save/restore software processing.

The TLCS-870 Series supports a maximum of 15 interrupt sources. One bank is assigned to the main program, and one bank can be assigned to each source. Also, to increase the efficiency of data memory usage, assign the same bank to interrupt sources which are not nested.

Example: Saving /restoring registers during interrupt task using bank changeover.

```

PINT1 : LD   RBS, n      ; RBS ← n (Bank changeover)
          [interrupt processing]
          RETI           ; Maskable interrupt return (Bank restoring)

```

1.6 Program Status Word (PSW)

The program status word (PSW) consists of a register bank selector (RBS) and four flags, and the PSW is assigned to address $003F_H$ in the SFR.

The RBS can be read and written using the memory access instruction (e. g. [LD A, (003FH)], [LD (003FH), A]), however the flags can only be read. When writing to the PSW, the change specified by the instruction is made without writing data to the flags. For example, when the instruction [LD (003FH), 05H] is executed, "5" is written to the RBS and the JF is set to "1", but the other flags are not affected.

[PUSH PSW] and [POP PSW] are the PSW access instructions.

1.6.1 Register Bank Selector (RBS)

The register bank selector (RBS) is a 4-bit register used to select general-purpose register banks. For example, when RBS = 2, bank 2 is currently selected. During reset, the RBS is initialized to "0".

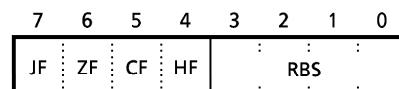


Figure 1-6. PSW (Flags, RBS) Configuration

1.6.2 Flags

The flags are configured with the upper 4 bits: a zero flag, a carry flag, a half carry flag and a jump status flag. The flags are set or cleared under conditions specified by the instruction. These flags except the half carry flag are used as jump condition "cc" for conditional jump instructions [JR cc, \$ + 2 + d]/[JRS cc, \$ + 2 + d]. After reset, the jump status flag is initialized to "1", other flags are not affected.

(1) Zero flag (ZF)

The ZF is set to "1" if the operation result or the transfer data is 00_H (for 8-bit operations and data transfers)/ 0000_H (for 16-bit operations); otherwise the ZF is cleared to "0".

During the bit manipulation instructions [SET, CLR, and CPL], the ZF is set to "1" if the contents of the specified bit is "0"; otherwise the ZF is cleared to "0".

This flag is set to "1" when the upper 8 bits of the product are 00_H during the multiplication instruction [MUL], and when 00_H for the remainder during the division instruction [DIV]; otherwise it is cleared to "0".

(2) Carry flag (CF)

The CF is set to "1" when a carry out of the MSB (most significant bit) of the result occurred during addition or when a borrow into the MSB of the result occurred during subtraction; otherwise the CF is cleared to "0". During division, this flag is set to "1" when the divisor is 00_H (divided by zero error), or when the quotient is 100_H or higher (overflow error); otherwise it is cleared. The CF is also affected during the shift/rotate instructions [SHLC, SHRC, ROLC, and RORC]. The data shifted out from a register is set to the CF.

This flag is also a 1-bit register (a boolean accumulator) for the bit manipulation instructions.

Set/clear/complement are possible with the CF manipulation instructions.

Example: Bit manipulation (The result of exclusive-OR between bit 5 content of address 07_H and bit 0 content of address $9A_H$ is written to bit 2 of address 01_H)

```
LD CF, (0007H) . 5 ; (0001H)2 ← (0007H)5 ⊕ (009AH)0
XOR CF, (009AH) . 0
LD (0001H) . 2, CF
```

(3) Half carry flag (HF)

The HF is set to "1" when a carry occurred between bits 3 and 4 of the operation result during an 8-bit addition, or when a borrow occurred from bit 4 into bit 3 of the result during an 8-bit subtraction; otherwise the HF is cleared to "0". This flag is useful in the decimal adjustment for BCD operations (adjustments using the [DAA r], or [DAS r] instructions).

Example: BCD operation

(The A becomes 47_H after executing the following program when $A = 19_H$, $B = 28_H$)

ADD A, B ; $A \leftarrow 41_H$, HF $\leftarrow 1$

DAA A ; $A \leftarrow 41_H + 06_H = 47_H$ (decimal-adjust)

(4) Jump status flag (JF)

Zero or carry information is set to the JF after operation (e. g. INC, ADD, CMP, TEST).

The JF provides the jump condition for conditional jump instructions [JR T/F, \$ + 2 + d], [JRS T/F, \$ + 2 + d] (T or F is a condition code). Jump is performed if the JF is "1" for a true condition (T), or the JF is "0" for a false condition (F).

The JF is set to "1" after executing the load/exchange/swap/nibble rotate/jump instruction, so that [JRS T, \$ + 2 + d] and [JR T, \$ + 2 + d] can be regarded as an unconditional jump instruction.

Example: Jump status flag and conditional jump instruction

INC A	
JRS T, SLABLE1	; Jump when a carry is caused by the immediately
:	operation instruction.
LD A, (HL)	
JRS T, SLABLE2	; JF is set to "1" by the immediately preceding instruction,
:	making it an unconditional jump instruction.

Example: The accumulator and flags become as shown below after executing the following instructions when the WA register pair, the HL register pair, the data memory at address $00C5_H$, the carry flag and the half carry flag contents being " $219A_H$ ", " $00C5_H$ ", " $D7_H$ ", "1" and "0", respectively.

Instruction	Acc. after execution	Flag after execution			
		JF	ZF	CF	HF
ADDC A, (HL)	72	1	0	1	1
SUBB A, (HL)	C2	1	0	1	0
CMP A, (HL)	9A	0	0	1	0
AND A, (HL)	92	0	0	1	0
LD A, (HL)	D7	1	0	1	0
ADD A, 66H	00	1	1	1	1

Instruction	Acc. after execution	Flag after execution			
		JF	ZF	CF	HF
INC A	9B	0	0	1	0
ROL C A	35	1	0	1	0
ROR C A	CD	0	0	0	0
ADD WA, 0F508H	16A2	1	0	1	0
MUL W, A	13DA	0	0	1	0
SET A.5	BA	1	1	1	0

1.7 Stack and Stack Pointer

1.7.1 Stack

The stack provides the area in which the return address or status, etc. are saved before a jump is performed to the processing routine during the execution of a subroutine call instruction or the acceptance of an interrupt. On a subroutine call instruction [CALL a] / [CALLP n] / [CALLV n], the contents of the PC (the return address) is saved; on an interrupt acceptance, the contents of the PC and the PSW are saved (the PSW is pushed first, followed by PC_H and PC_L). Therefore, a subroutine call occupies two bytes on the stack; an interrupt occupies three bytes.

When returning from the processing routine, executing a subroutine return instruction [RET] restores the contents to the PC from the stack; executing an interrupt return instruction [RETI] / [RETN] restores the contents to the PC and the PSW (the PC_L is popped first, followed by PC_H and PSW).

The stack can be located anywhere within the data memory space except the register bank area, therefore the stack depth is limited only by the free data memory size.

1.7.2 Stack Pointer (SP)

The stack pointer (SP) is a 16-bit register containing the address of the next free locations on the stack.

The SP is post-decremented when a subroutine call or a push instruction is executed, or when an interrupt is accepted; and the SP is pre-incremented when a return or a pop instruction is executed. Figure 1-8 shows the stacking order.

The SP is not initialized hardware-wise but requires initialization by an initialize routine (sets the highest stack address). [LD SP, mn], [LD SP, gg] and [LD gg, SP] are the SP access instructions (mn ; 16-bit immediate data, gg ; register pair).

Example 1: To initialize the SP

LD SP, 043FH ; SP←043FH

Example 2: To read the SP

LD HL, SP ; HL←SP

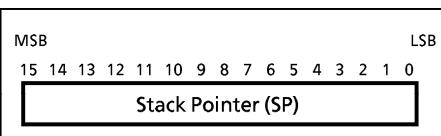


Figure 1-7. Stack Pointer

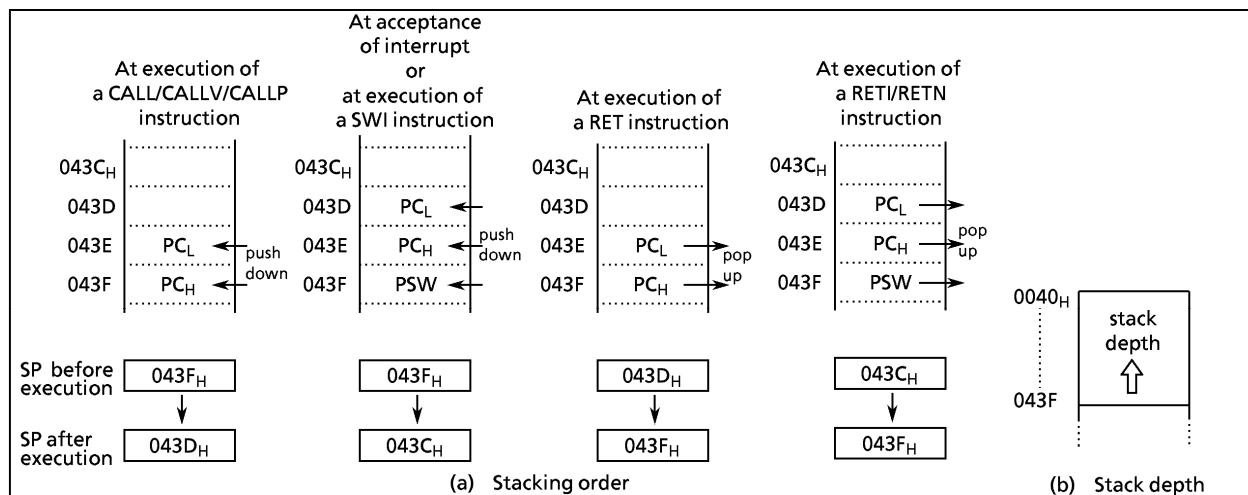


Figure 1-8. Stack

1.8 System Clock Controller

The system clock controller consists of a clock generator, a timing generator, and a stand-by controller.

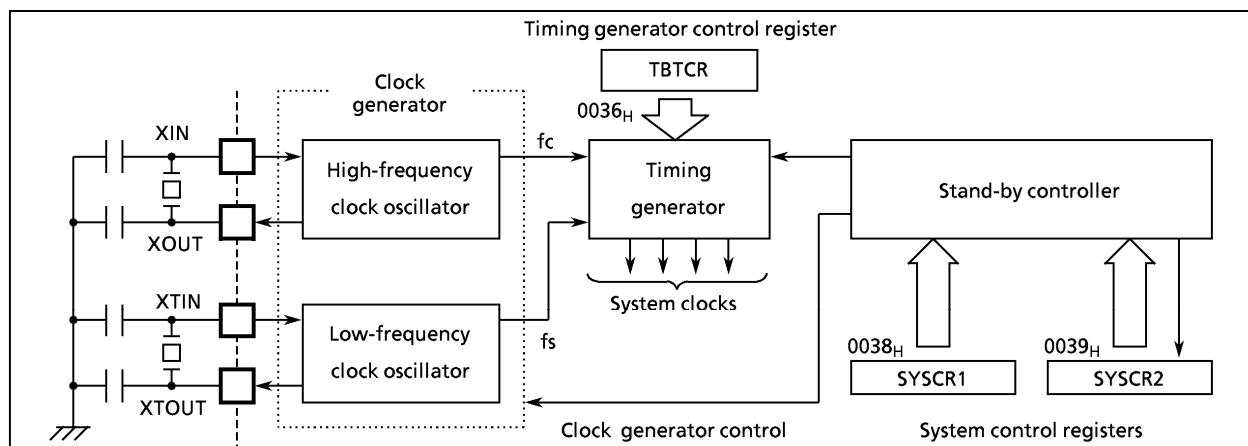


Figure 1-9. System Clock Controller

1.8.1 Clock Generator

The clock generator generates the basic clock which provides the system clocks supplied to the CPU core and peripheral hardware. It contains two oscillation circuits: one for the high-frequency clock and one for the low-frequency clock. Power consumption can be reduced by switching of the system clock controller to low-power operation based on the low-frequency clock.

The high-frequency (fc) and low-frequency (fs) clocks can be easily obtained by connecting a resonator between the XIN/XOUT and XTIN/XTOUT pins, respectively. Clock input from an external oscillator is also possible. In this case, external clock is applied to the XIN/XTIN pin with the XOUT/XTOUT pin not connected. The TMP87CH21/H21B/M21 are not provided an RC oscillation.

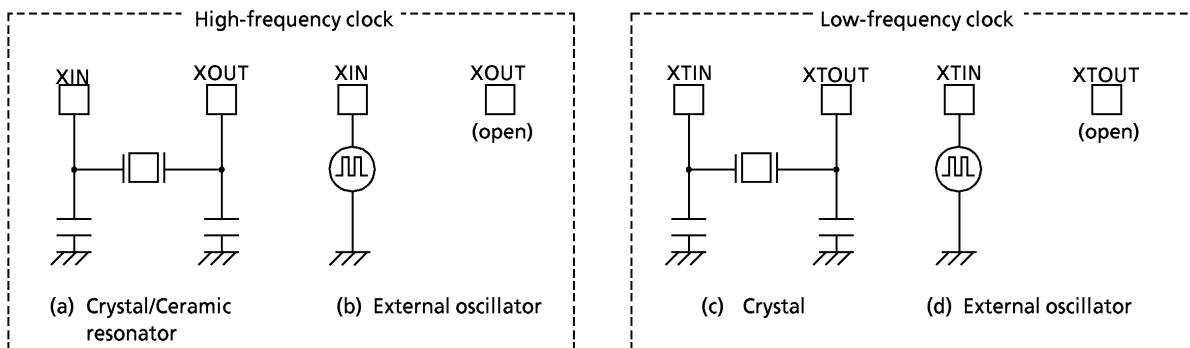


Figure 1-10. Examples of Resonator Connection

Note: Accurate Adjustment of the Oscillation Frequency:

Although no hardware to externally and directly monitor the basic clock pulse is not provided, the oscillation frequency can be adjusted by making the program to output fixed frequency pulses to the port while disabling all interrupts and monitoring this pulse. With a system requiring adjustment of the oscillation frequency, the adjusting program must be created beforehand.

1.8.2 Timing Generator

The timing generator generates from the basic clock the various system clocks supplied to the CPU core and peripheral hardware. The timing generator provides the following functions:

- ① Generation of main system clock
- ② Generation of divider output (\overline{DVO}) pulses
- ③ Generation of source clocks for time base timer
- ④ Generation of source clocks for watchdog timer
- ⑤ Generation of internal source clocks for timer/counters TC1 to TC3 and TC5
- ⑥ Generation of internal clocks for serial interfaces SIO1 and SIO2
- ⑦ Generation of warm-up clocks for releasing STOP mode
- ⑧ Generation of clocks for releasing reset output
- ⑨ Generation of base clocks for LCD driver/controller

(1) Configuration of Timing Generator

The timing generator consists of a 21-stage divider with a divided-by-4 prescaler, a main system clock generator, and machine cycle counters. An input clock to the 7th stage of the divider depends on the operating mode and DV7CK (bit 4 in TBTCR) shown in Figure 1-11 as follows.

During reset and at releasing STOP mode, the divider is cleared to "0", however, the prescaler is not cleared.

① In the single-clock mode

A divided-by-256 of high-frequency clock ($fc/28$) is input to the 7th stage of the divider.
Do not set DV7CK to "1" in the single-clock mode.

② In the dual-clock mode

During NORMAL2 or IDLE2 mode ($SYSCK = 0$), an input clock to the 7th stage of the divider can be selected either " $fc/28$ " or " fs " with DV7CK.

During SLOW or SLEEP mode ($SYSCK = 1$), fs is automatically input to the 7th stage. To input clock to the 1st stage is stopped ; output from the 1st to 6th stages is also stopped.

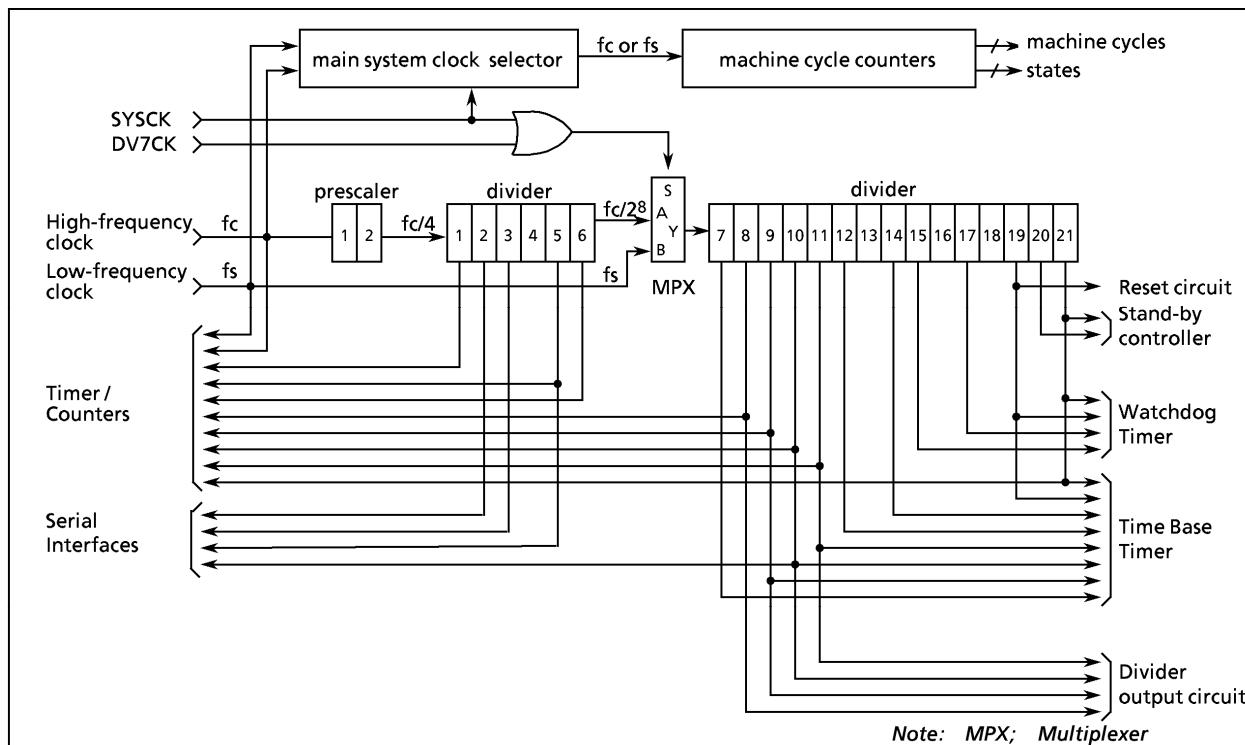


Figure 1-11. Configuration of Timing Generator

TBTCR (0036H)	7	6	5	4	3	2	1	0	(Initial value: 0**0 0***)
	(DVOEN)	(DVOCK)	DV7CK	(TBTCEN)	(TBTCK)				
	DV7CK	Selection of input clock to the 7th stage of the divider	0: $fc/28$ [Hz] 1: fs						R/W

Note 1: fc ; high-frequency clock [Hz], fs ; low-frequency clock [Hz], * ; Don't care
Note 2: Do not set DV7CK to "1" in the single-clock mode.
Note 3: Do not set DV7CK to "1" before low-frequency clock is stable in the dual-clock mode.

Figure 1-12. Timing Generator Control Register

(2) Machine Cycle

Instruction execution and peripheral hardware operation are synchronized with the main system clock. The minimum instruction execution unit is called an "machine cycle". There are a total of 10 different types of instructions for the TLCS-870 Series: ranging from 1-cycle instructions which require one machine cycle for execution to 10-cycle instructions which require 10 machine cycles for execution. A machine cycle consists of 4 states (S0 to S3), and each state consists of one main system clock.

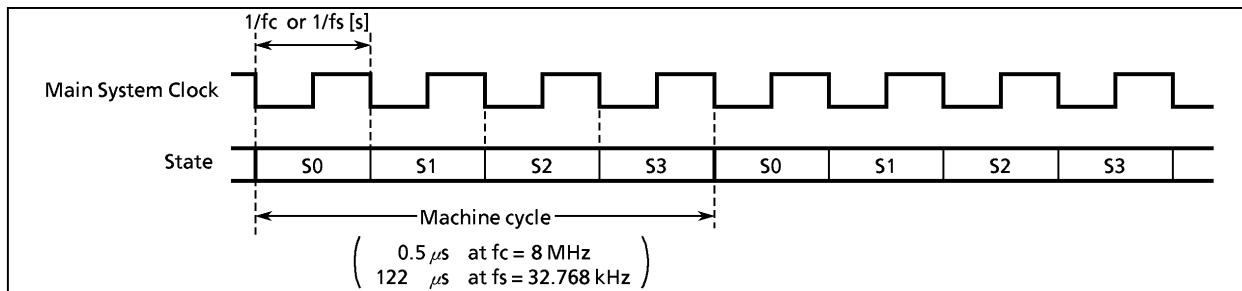


Figure 1-13. Machine Cycle

1.8.3 Stand-by Controller

The stand-by controller starts and stops the oscillation circuits for the high-frequency and low-frequency clocks, and switches the main system clock. There are two operating modes: single-clock and dual-clock. These modes are controlled by the system control registers (SYSCR1, SYSCR2).

Figure 1-14 shows the operating mode transition diagram and Figure 1-15 shows the system control registers. Either the single-clock or the dual-clock mode can be selected by an option during reset.

TMP87PP21 is fixed on the single-clock mode after reset release. (when using the dual-clock mode, turn on the oscillation circuits for the low-frequency clocks at the beginning of program.)

(1) Single-clock mode

Only the oscillation circuit for the high-frequency clock is used, and P21 (XTIN) and P22 (XTOUT) pins are used as input/output ports. In the single-clock mode, the machine cycle time is $4/fc$ [s] ($0.5 \mu s$ at $fc = 8 \text{ MHz}$).

① NORMAL1 mode

In this mode, both the CPU core and on-chip peripherals operate using the high-frequency clock. In the case where the single-clock mode has been selected as an option, the TMP87CH21/H21B/M21 are placed in this mode after reset.

② IDLE1 mode

In this mode, the internal oscillation circuit remains active, and the CPU and the watchdog timer are halted; however, on-chip peripherals remain active (operate using the high-frequency clock). IDLE1 mode is started by setting IDLE bit in the system control register 2 (SYSCR2), and IDLE1 mode is released to NORMAL1 mode by an interrupt request from on-chip peripherals or external interrupt inputs. When IMF (interrupt master enable flag) is "1" (interrupt enable), the execution will resume upon acceptance of the interrupt, and the operation will return to normal after the interrupt service is completed. When IMF is "0" (interrupt disable), the execution will resume with the instruction which follows IDLE mode start instruction.

③ STOP1 mode

In this mode, the internal oscillation circuit is turned off, causing all system operations to be halted. The internal status immediately prior to the halt is held with the lowest power consumption during this mode. The output status of all output ports can be set to either output hold or high-impedance under software control.

STOP1 mode is started by setting STOP bit in the system control register 1 (SYSCR1), and STOP1 mode is released by an input (either level-sensitive or edge-sensitive can be programmably selected) to the STOP pin. After the warming-up period is completed, the execution resumes with the next instruction which follows the STOP mode start instruction.

(2) Dual-clock mode

Both high-frequency and low-frequency oscillation circuits are used in this mode. Pins P21 (XTIN) and P22 (XTOUT) cannot be used as input/output ports. The main system clock is obtained from the high-frequency clock in NORMAL2 and IDLE2 modes, and is obtained from the low-frequency clock in SLOW and SLEEP modes. The machine cycle time is $4/f_c$ [s] (0.5 μ s at $f_c = 8$ MHz) in NORMAL2 and IDLE2 modes, and $4/f_s$ [s] (122 μ s at $f_s = 32.768$ kHz) in SLOW and SLEEP modes. Note that the TMP87PP21 is placed in the single-clock mode during reset.

To use the dual-clock mode, the low-frequency oscillator should be turned on by executing [SET (SYSCR2).XTEN] instruction.

① NORMAL2 mode

In this mode, the CPU core operates using the high-frequency clock. On-chip peripherals operate using the high-frequency clock and/or low-frequency clock. In case that the dual-clock mode has been selected by an option, the TMP87CH21/H21B/M21 are placed in this mode after reset.

② SLOW mode

This mode can be used to reduce power-consumption by turning off oscillation of the high-frequency clock. The CPU core and on-chip peripherals operate using the low-frequency clock.

Switching back and forth between NORMAL2 and SLOW modes is performed by the system control register 2.

③ IDLE2 mode

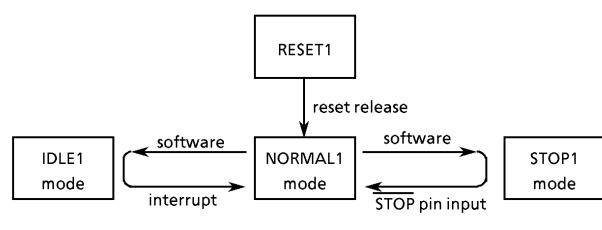
In this mode, the internal oscillation circuits remain active. The CPU and the watchdog timer are halted; however, on-chip peripherals remain active (operate using the high-frequency clock and/or the low-frequency clock). Starting and releasing of IDLE2 mode are the same as for IDLE1 mode, except that operation returns to NORMAL2 mode.

④ SLEEP mode

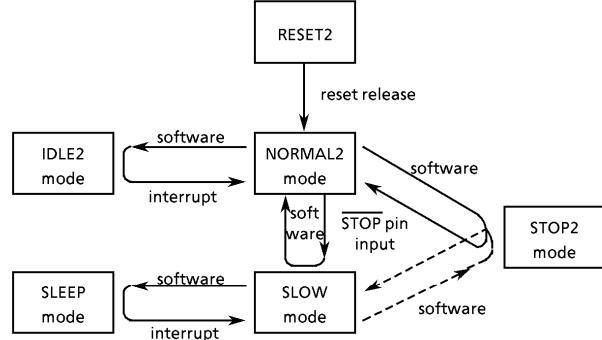
In this mode, the internal oscillation circuit of the low-frequency clock remains active. The CPU, the watchdog timer, and the internal oscillation circuit of the high-frequency clock are halted; however, on-chip peripherals remain active (operate using the low-frequency clock). Starting and releasing of SLEEP mode is the same as for IDLE1 mode, except that operation returns to SLOW mode.

⑤ STOP2 mode

As in STOP1 mode, all system operations are halted in this mode.



(a) Single-clock mode



(b) Dual-clock mode

Note 1: *NORMAL1 and NORMAL2 modes are generically called NORMAL; STOP1 and STOP2 are called STOP; and IDLE1, IDLE2 and SLEEP are called IDLE.*

Note 2: *There is no RESET2 mode in TMP87PP21.*

Operating mode		Frequency		CPU core	On-chip Peripherals	Machine cycle time
		High-frequency	Low-frequency			
Single-Clock	RESET1	turning on oscillation	turning off oscillation	reset	reset	4/fc [s]
	NORMAL1			operate	operate	
	IDLE1			halt	—	
	STOP1	turning off oscillation		halt		—
Dual-Clock	RESET2	turning on oscillation	turning on oscillation	reset	reset	4/fc [s]
	NORMAL2			High-frequency	operate (High and/or Low)	
	IDLE2		turning off oscillation	halt	4/fs [s]	
	SLOW			Low-frequency	Low-frequency	
	SLEEP		turning off oscillation	halt	—	
	STOP2			halt		—

Figure 1-14. Operating Mode Transition Diagram

System Control Register 1

SYSCR1 (0038 _H)								(Initial value: 0000 00**)		
7	6	5	4	3	2	1	0			
STOP	RELM	RETM	OUTEN	WUT						
STOP	STOP mode start					0: CPU core and peripherals remain active 1: CPU core and peripherals are halted (start STOP mode)				
RELM	Release method for STOP mode					0: Edge-sensitive release 1: Level-sensitive release				
RETM	Operating mode after STOP mode					0: Return to NORMAL mode 1: Return to SLOW mode				
OUTEN	Port output control during STOP mode					0: High-impedance 1: Remain unchanged				
WUT	Warming-up time at releasing STOP mode					00: 3 × 2 ¹⁹ /fc or 3 × 2 ¹³ /fs [s] 01: 2 ¹⁹ /fc or 2 ¹³ /fs 1*: Reserved				

Note 1: Always set RETM to "0" when transitioning from NORMAL1 mode to STOP1 mode and from NORMAL2 mode to STOP2 mode. Always set RETM to "1" when transitioning from SLOW mode to STOP2 mode.

Note 2: When STOP mode is released with RESET pin input, a return is made to NORMAL mode regardless of the RETM contents.

Note 3: fc ; high-frequency clock [Hz]
fs ; low-frequency clock [Hz]
* ; Don't care

Note 4: Bits 1 and 0 in SYSCR1 are read in as undefined data when a read instruction is executed.

Note 5: When the STOP mode is started by specifying OUTEN = "0", the internal input of port is fixed to "0" and the interrupt of the falling edge may be set.

System Control Register 2

SYSCR2 (0039 _H)								(Initial value: 10/100 ****)		
7	6	5	4	3	2	1	0			
XEN	High-frequency oscillator control					0: Turn off oscillation 1: Turn on oscillation				
XTEN	Low-frequency oscillator control					0: Turn off oscillation 1: Turn on oscillation				
SYSCK	Main system clock select (write)/main system clock monitor (read)					0: High-frequency clock 1: Low-frequency clock				
IDLE	IDLE mode start					0: CPU and watchdog timer remain active 1: CPU and watchdog timer are stopped (start IDLE mode)				

Note 1: A reset is applied (RESET pin output goes low) if both XEN and XTEN are cleared to "0".

Note 2: Do not clear XEN to "0" when SYSCK = 0, and do not clear XTEN to "0" when SYSCK = 1.

Note 3: WDT; watchdog timer, * ; Don't care

Note 4: Bits 3 - 0 in SYSCR2 are always read in as "1" when a read instruction is executed.

Note 5: An optional initial value can be selected for XTEN. Always specify when ordering ES (engineering sample).

XTEN	operating mode after reset
0	Single-clock mode (NORMAL1)
1	Dual-clock mode (NORMAL2)

Note 6: The instruction for specifying Masking Option (Operating Mode) in ES Order Sheet is described in ADDITIONAL INFORMATION "Notice for Masking Option of TLCS-870 series" section 8.

Figure 1-15. System Control Registers

1.8.4 Operating Mode Control

(1) STOP mode (STOP1, STOP2)

STOP mode is controlled by the system control register 1 (SYSCR1) and the STOP pin input. The STOP pin is also used both as a port P20 and an INT5 (external interrupt input 5) pin. STOP mode is started by setting STOP (bit 7 in SYSCR1) to "1". During STOP mode, the following status is maintained.

- ① Oscillations are turned off, and all internal operations are halted.
- ② The data memory, registers (except for DBR) and port output latches are all held in the status in effect before STOP mode was entered. The port output can be select either output hold or high-impedance by setting OUTEN (bit 4 in SYSCR1).
- ③ The divider of the timing generator is cleared to "0".
- ④ The program counter holds the address of the instruction following the instruction which started the STOP mode.

STOP mode includes a level-sensitive release mode and an edge-sensitive release mode, either of which can be selected with RELM (bit 6 in SYSCR1).

Note: In STOP Mode changes in external interrupt signals may cause interrupt latches to be set to 1 and interrupt routines to be started immediately after exiting STOP Mode. Therefore be sure to enter STOP Mode only after disabling interrupts. Also, when enabling interrupts after exiting STOP Mode, be sure to first clear interrupt latches for interrupts not to be used.

a. Level-sensitive release mode (RELM = 1)

In this mode, STOP mode is released by setting the STOP pin high. This mode is used for capacitor back-up when the main power supply is cut off and long term battery back-up.

When the STOP pin input is high, executing an instruction which starts the STOP mode will not place in STOP mode but instead will immediately start the release sequence (warm-up). Thus, to start STOP mode in the level-sensitive release mode, it is necessary for the program to first confirm that the STOP pin input is low. The following method can be used for confirmation:

- Using an external interrupt input INT5 (INT5 is a falling edge-sensitive input).

Example: Starting STOP mode with an INT5 interrupt.

```

PINT5 : TEST (P2) .0 ; To reject noise, the STOP mode does not start if
                      ; port P20 is at high
JRS F, SINT5
LD (SYSCR1), 01000000B ; Sets up the level-sensitive release mode.
SET (SYSCR1) .7 ; Starts STOP mode
LDW (IL),1110011101010111B ; IL12, 11, 7, 5, 3 ← 0
SINT5 : RETI

```

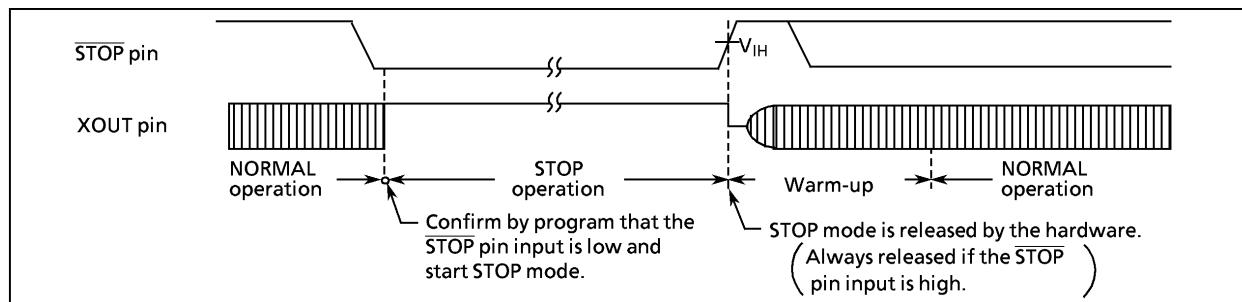


Figure 1-16. Level-sensitive Release Mode

Note 1: After warm-up start, even if STOP pin input is low again, STOP mode does not restart.

Note 2: When changing to the level-sensitive release mode from the edge-sensitive release mode, the release mode is not switched until a rising edge of the STOP pin input is detected.

b. Edge-sensitive release mode (RELM = 0)

In this mode, STOP mode is released by a rising edge of the $\overline{\text{STOP}}$ pin input. This is used in applications where a relatively short program is executed repeatedly at periodic intervals. This periodic signal (for example, a clock from a low-power consumption oscillator) is input to the $\overline{\text{STOP}}$ pin.

In the edge-sensitive release mode, STOP mode is started even when the $\overline{\text{STOP}}$ pin input is high.

Example: Starting STOP mode operation in the edge-sensitive release mode
LD (SYSCR1), 10000000B

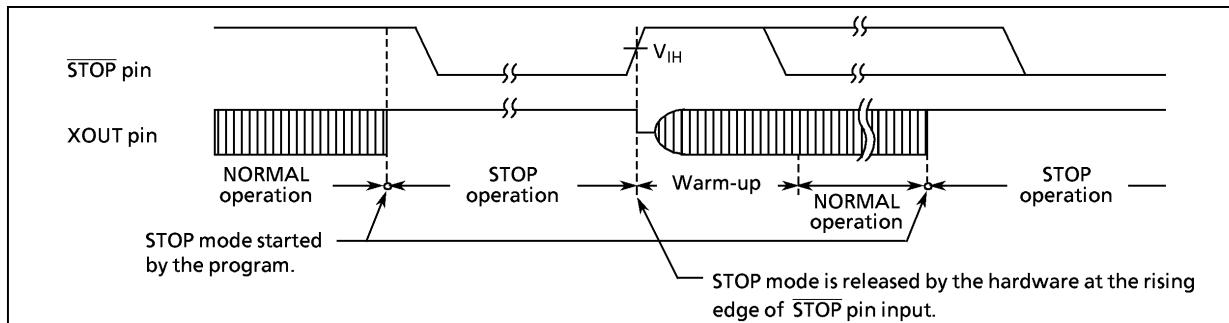


Figure 1-17. Edge-sensitive Release Mode

STOP mode is released by the following sequence:

- ① When returning to NORMAL2, both the high-frequency and low-frequency clock oscillators are turned on ; when returning to SLOW mode, only the low-frequency clock oscillator is turned on. When returning to NORMAL 1, only the high-frequency clock oscillator is turned on.
- ② A warming-up period is inserted to allow oscillation time to stabilize. During warm-up, all internal operations remain halted. Two different warming-up times can be selected with WUT (bits 2 and 3 in SYSCR1) as determined by the resonator characteristics.
- ③ When the warming-up time has elapsed, normal operation resumes with the instruction following the STOP mode start instruction (e.g. [SET (SYSCR1). 7]). The start is made after the divider of the timing generator is cleared to "0".

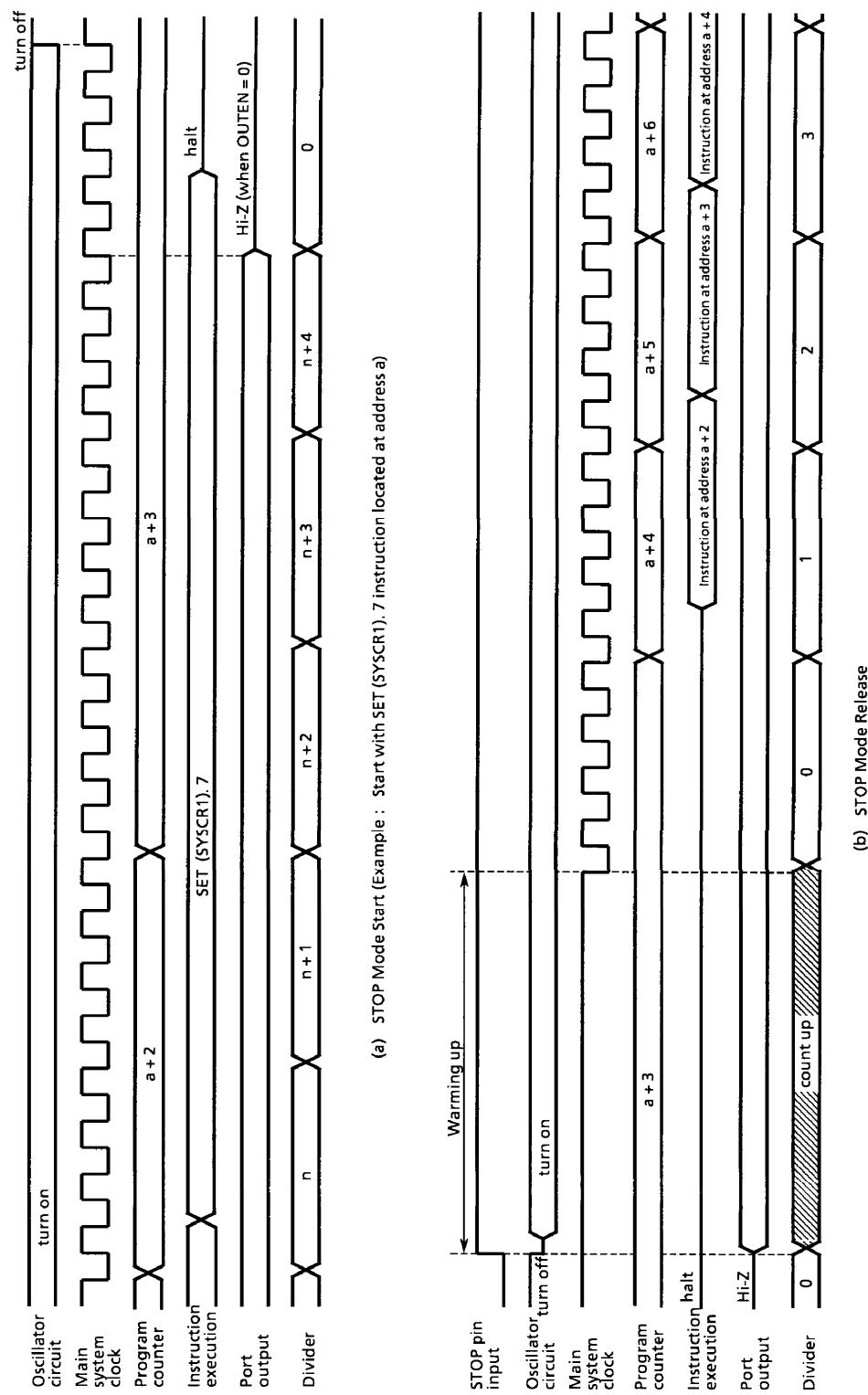
Table 1-1. Warming-up Time example

Return to NORMAL1 mode			Return to SLOW mode	
WUT	At $f_c = 4.194304$ MHz	At $f_c = 8$ MHz	WUT	At $f_s = 32.768$ kHz
$3 \times 2^{19}/f_c$ [s] $2^{19}/f_c$	375 [ms] 125	196.6 [ms] 65.5	$3 \times 2^{13}/f_s$ [s] $2^{13}/f_s$	750 [ms] 250

Note: The warming-up time is obtained by dividing the basic clock by the divider: therefore, the warming-up time may include a certain amount of error if there is any fluctuation of the oscillation frequency when STOP mode is released. Thus, the warming-up time must be considered an approximate value.

STOP mode can also be released by setting the $\overline{\text{RESET}}$ pin low, which immediately performs the normal reset operation.

After reset, the TMP87CH21/H21B/M21 are placed in NORMAL mode (the TMP87PP21 is placed in NORMAL1 mode).



Note: When STOP mode is released with a low hold voltage, the following cautions must be observed.

The power supply voltage must be at the operating voltage level before releasing STOP mode. The $\overline{\text{RESET}}$ pin input must also be high, rising together with the power supply voltage. In this case, if an external time constant circuit has been connected, the $\overline{\text{RESET}}$ pin input voltage will increase at a slower rate than the power supply voltage. At this time, there is a danger that a reset may occur if input voltage level of the $\overline{\text{RESET}}$ pin drops below the non-inverting high-level input voltage (hysteresis input).

(2) IDLE mode (IDLE1, IDLE2, SLEEP)

IDLE mode is controlled by the system control register 2 and maskable interrupts. The following status is maintained during IDLE mode.

- ① Operation of the CPU and watchdog timer is halted. On-chip peripherals continue to operate.
- ② The data memory, CPU registers and port output latches are all held in the status in effect before IDLE mode was entered.
- ③ The program counter holds the address of the instruction following the instruction which started IDLE mode.

Example: Starting IDLE mode.

SET (SYSCR2).4

IDLE mode includes a normal release mode and an interrupt release mode. Selection is made with the interrupt master enable flag (IMF). Releasing the IDLE mode returns from IDLE1 to NORMAL1, from IDLE2 to NORMAL2, and from SLEEP to SLOW mode.

a. Normal release mode (IMF = "0")

IDLE mode is released by any interrupt source enabled by the individual interrupt enable flag (EF) or an external interrupt 0 ($\overline{\text{INT0}}$ pin) request.

Execution resumes with the instruction following the IDLE mode start instruction (e.g. [SET (SYSCR2).4]). The interrupt latch (IL) of the interrupt source for releasing the IDLE mode must be cleared to "0" by load instruction.

b. Interrupt release mode (IMF = "1")

IDLE mode is released and interrupt processing is started by any interrupt source enabled with the individual interrupt enable flag (EF) or an external interrupt 0 ($\overline{\text{INT0}}$ pin) request. After the interrupt is processed, the execution resumes from the instruction following the instruction which started IDLE mode.

IDLE mode can also be released by setting the $\overline{\text{RESET}}$ pin low, which immediately performs the reset operation. After reset, the TMP87CH21/H21B/M21 are placed in NORMAL mode (the TMP87PP21 is placed in NORMAL1 mode).

Note: When a watchdog timer interrupt is generated immediately before the IDLE mode is started, the watchdog timer interrupt will be processed but IDLE mode will not be started.

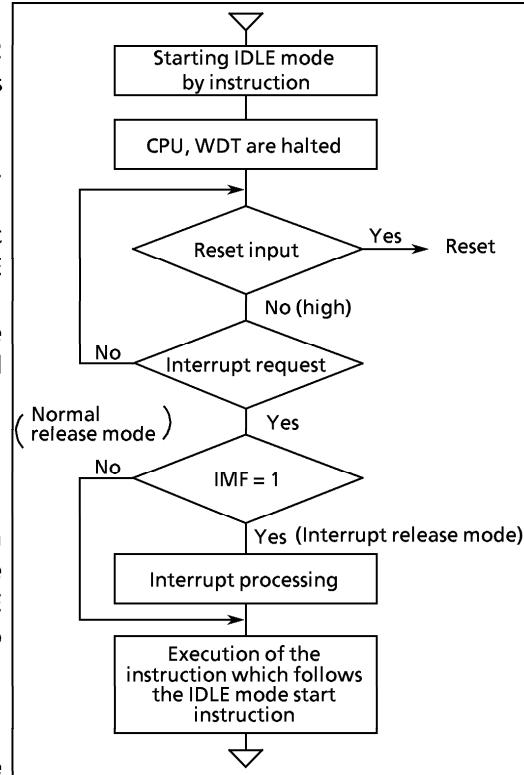


Figure 1-19. IDLE Mode

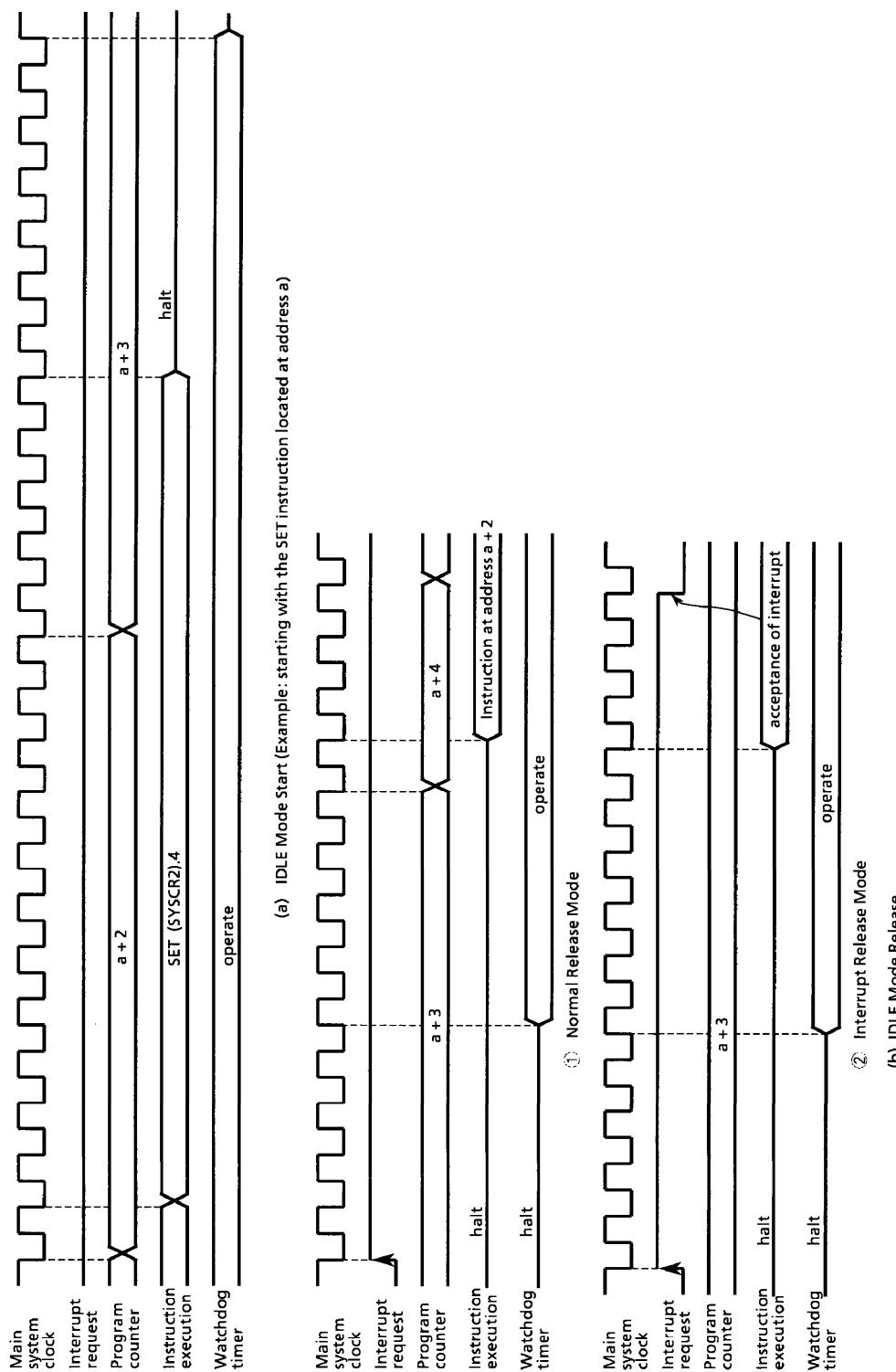


Figure 1-20. IDLE Mode Start/Release

(3) SLOW mode

SLOW mode is controlled by the system control register 2 (SYSCR2) and the timer/counter 2 (TC2).

a. Switching from NORMAL2 mode to SLOW mode

First, set SYSCK (bit 5 in SYSCR2) to switch the main system clock to the low-frequency clock. Next, clear XEN (bit 7 in SYSCR2) to turn off high-frequency oscillation.

When the low-frequency clock oscillation is unstable, wait until oscillation stabilizes before performing the above operations. The timer/counter 2 (TC2) can conveniently be used to confirm that low-frequency clock oscillation has stabilized.

Note: The high frequency clock can be continued oscillation in order to return to NORMAL2 mode from SLOW mode quickly. Always turn off oscillation of high frequency clock when switching from SLOW mode to STOP mode.

Example1: Switching from NORMAL2 mode to SLOW mode.

```
SET (SYSCR2) .5 ; SYSCK←1 (Switches the main system clock to the
                   low-frequency clock)
CLR (SYSCR2) .7 ; XEN←0 (turns off high-frequency oscillation)
```

Example2: Switching to SLOW mode after low-frequency clock oscillation has stabilized.

```
LD (TC2CR), 14H ; Sets TC2 mode
                  (timer mode, source clock: fs)
LDW (TREG2), 8000H ; Sets warming-up time
                  (according to Xtal characteristics)
SET (EIRH), EF14 ; Enables INTTC2
LD (TC2CR), 34H ; Starts TC2
:
PINTTC2: LD (TC2CR), 10H ; Stops TC2
SET (SYSCR2) .5 ; SYSCK←1
CLR (SYSCR2) .7 ; XEN←0
RETI
:
VINTTC2: DW PINTTC2 ; INTTC2 vector table
```

b. Switching from SLOW mode to NORMAL2 mode

First, set XEN (bit 7 in SYSCR2) to turn on the high-frequency oscillation. When time for stabilization (warm-up) has been taken by the timer/counter 2 (TC2), clear SYSCK (bit 5 in SYSCR2) to switch the main system clock to the high-frequency clock.

Note1: After the SYSCK is cleared to "0", the CPU core operate using low frequency clock when the main system clock is switching from low frequency clock to high frequency clock.

Note2: SLOW mode can also be released by setting the RESET pin low, which immediately performs the reset operation. After reset, the TMP87CH21/H21B/M21 are placed in NORMAL mode. (The TMP87PP21 is placed in NORMAL1 mode)

Example: Switching from SLOW mode to NORMAL2 mode
(fc = 8 MHz, warming-up time is about 7.9 ms).

```
SET  (SYSCR2).7      ; XEN←1      (turns on high-frequency oscillation)
LD   (TC2CR), 10H    ; Sets TC2 mode
                           (timer mode, source clock: fc)
LD   (TREG2 + 1), 0F8H ; Sets the warming-up time
                           (according to frequency and resonator characteristics)
SET  (EIRH), EF14     ; Enables INTTC2
LD   (TC2CR), 30H     ; Starts TC2
:
PINTTC2 : LD   (TC2CR), 10H    ; Stops TC2
CLR  (SYSCR2).5      ; SYSCK←0  (Switches the main system clock to the
                           high-frequency clock)
RETI
:
VINTTC2 : DW  PINTTC2      ; INTTC2 vector table
```

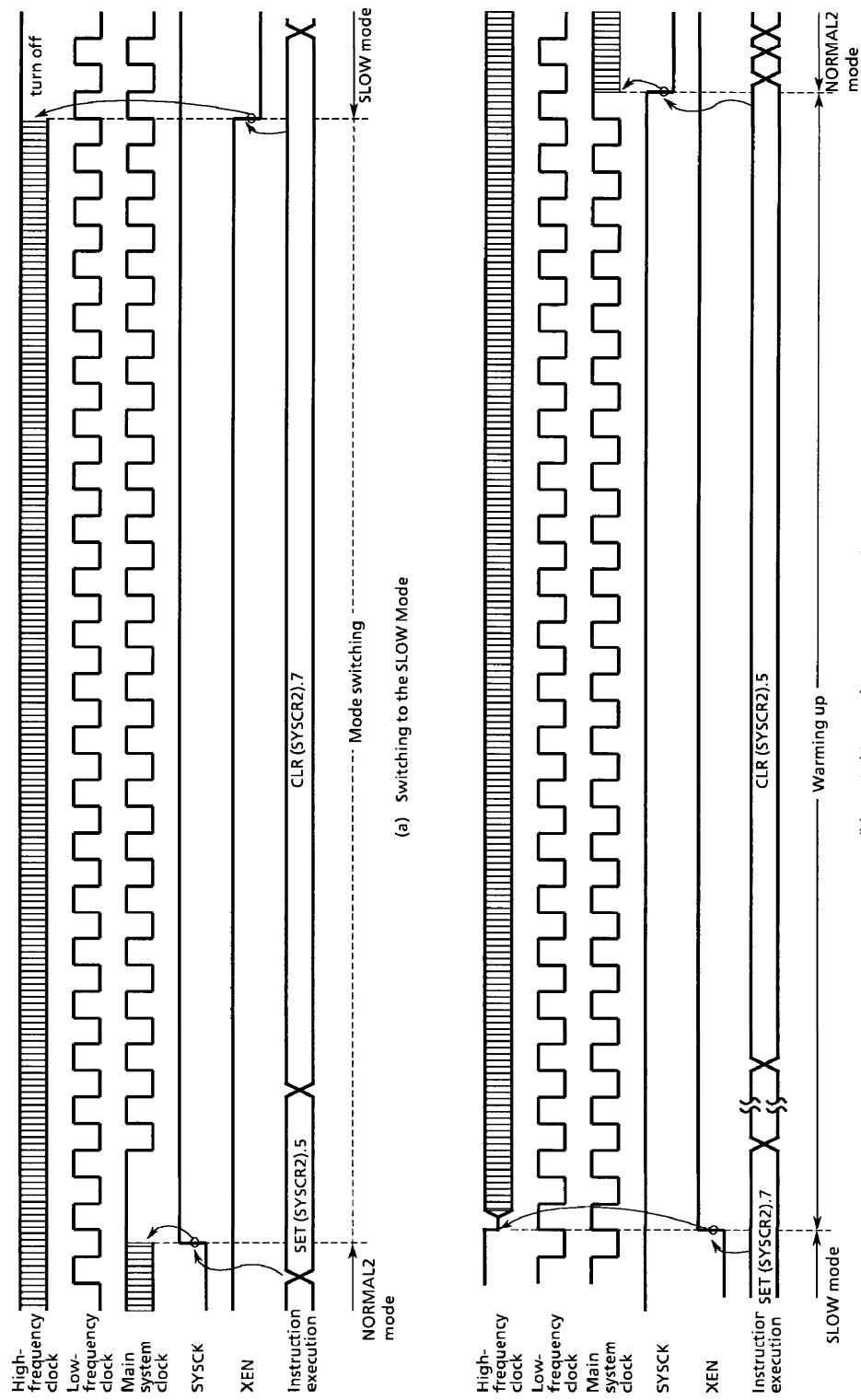


Figure 1-21. Switching between the NORMAL2 and SLOW Modes

1.9 Interrupt Controller

The TMP87CH21/H21B/M21 each have a total of 14 interrupt sources: 5 externals and 9 internals. Nested interrupt control with priorities is also possible. Two of the internal sources are pseudo non-maskable interrupts; the remainder are all maskable interrupts.

Interrupt latches (IL) that hold the interrupt requests are provided for interrupt sources. Each interrupt vector is independent.

The interrupt latch is set to "1" when an interrupt request is generated and requests the CPU to accept the interrupt. The acceptance of maskable interrupts can be selectively enabled and disabled by the program using the interrupt master enable flag (IMF) and the individual interrupt enable flags (EF). When two or more interrupts are generated simultaneously, the interrupt is accepted in the highest priority order as determined by the hardware. Figure 1-22 shows the interrupt controller.

Table 1-2. Interrupt Sources

Interrupt Source		Enable Condition	Interrupt Latch	Vector Table Address	Priority
Internal/External	(Reset)	Non-Maskable	—	FFFE _H	High 0
Internal	INTSW (Software interrupt)	Pseudo non-maskable	—	FFFC _H	1
Internal	INTWDT (Watchdog Timer interrupt)		IL ₂	FFFA _H	2
External	INT0 (External interrupt 0)	IMF = 1, INT0EN = 1	IL ₃	FFF8 _H	3
Internal	INTTC1 (16-bit TC1 interrupt)	IMF · EF ₄ = 1	IL ₄	FFF6 _H	4
External	INT1 (External interrupt 2)	IMF · EF ₅ = 1	IL ₅	FFF4 _H	5
Internal	INTTBT (Time Base Timer interrupt)	IMF · EF ₆ = 1	IL ₆	FFF2 _H	6
External	INT2 (External interrupt 2)	IMF · EF ₇ = 1	IL ₇	FFF0 _H	7
Internal	INTTC3 (8-bit TC3 interrupt)	IMF · EF ₈ = 1	IL ₈	FFEE _H	8
Internal	INTSIO1 (Serial Interface 1 interrupt)	IMF · EF ₉ = 1	IL ₉	FFEC _H	9
Internal	INTTC5 (8-bit TC5 interrupt)	IMF · EF ₁₀ = 1	IL ₁₀	FFEA _H	10
External	INT3 (External interrupt 3)	IMF · EF ₁₁ = 1	IL ₁₁	FFE8 _H	11
	reserved	IMF · EF ₁₂ = 1	IL ₁₂	FFE6 _H	12
Internal	INTSIO2 (Serial Interface 2 interrupt)	IMF · EF ₁₃ = 1	IL ₁₃	FFE4 _H	13
Internal	INTTC2 (16-bit TC2 interrupt)	IMF · EF ₁₄ = 1	IL ₁₄	FFE2 _H	14
External	INT5 (External interrupt 5)	IMF · EF ₁₅ = 1	IL ₁₅	FFE0 _H	Low 15

(1) Interrupt Latches (IL₁₅ to 2)

Interrupt latches are provided for each source, except for a software interrupt. The latch is set to "1" when an interrupt request is generated, and requests the CPU to accept the interrupt. The latch is cleared to "0" just after the interrupt is accepted. All interrupt latches are initialized to "0" during reset.

The interrupt latches are assigned to addresses 003C_H and 003D_H in the SFR. Each latch can be cleared to "0" individually by an instruction; however, the read-modify-write instruction such as bit manipulation or operation instructions cannot be used (Do not clear the IL₂ for a watchdog timer interrupt to "0"). Thus, interrupt requests can be cancelled and initialized by the program. Note that interrupt latches cannot be set to "1" by any instruction.

The contents of interrupt latches can be read out by an instruction. Therefore, testing interrupt requests by software is possible.

Example 1: Clears interrupt latches

LDW (IL), 1110100000111111B ; IL₁₂, IL₁₀ to IL₆ ← 0

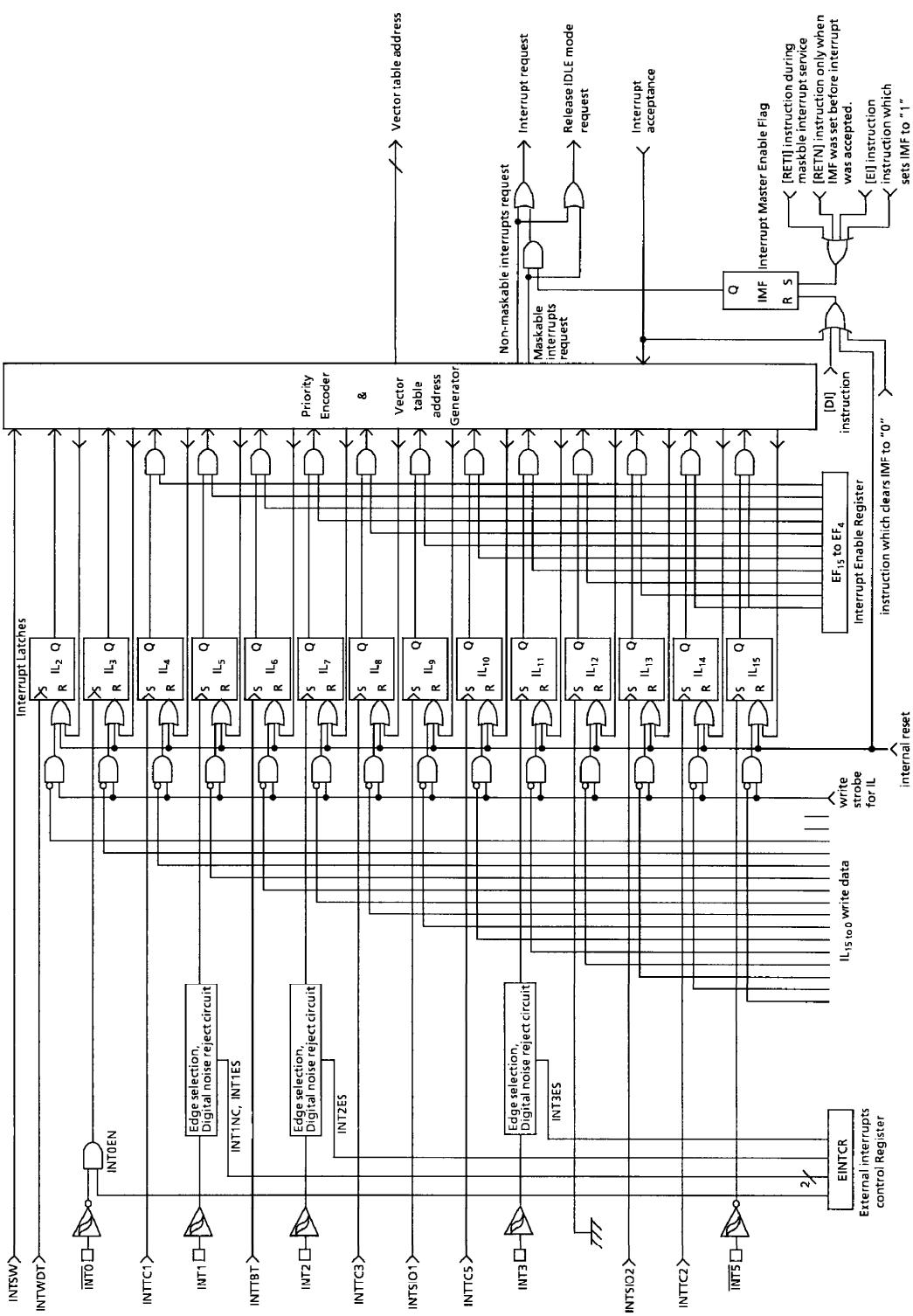


Figure 1-22. Interrupt Controller Block Diagram

Example 2: Reads interrupt latches

LD WA, (IL) ; W←IL_H, A←IL_L

Example 3: Tests an interrupt latch

TEST (IL).7 ; if IL₇ = 1 then jump
JR F, SSET

(2) Interrupt Enable Register (EIR)

The interrupt enable registers (EIR) enable and disable the acceptance of interrupts except for the pseudo non-maskable interrupts (software and watchdog timer interrupts). Pseudo non-maskable interrupts are accepted regardless of the contents of the EIR; however, the pseudo non-maskable interrupts cannot be nested more than once at the same time.

The EIR consists of an interrupt master enable flag (IMF) and individual interrupt enable flags (EF). These registers are assigned to addresses 003A_H and 003B_H in the SFR, and can be read and written by an instruction (including read-modify-write instructions such as bit manipulation instructions).

① Interrupt Master enable Flag (IMF)

The interrupt master enable flag (IMF) enables and disables the acceptance of all interrupts, except for pseudo non-maskable interrupts. Clearing this flag to "0" disables the acceptance of all maskable interrupts. Setting to "1" enables the acceptance of interrupts.

When an interrupt is accepted, this flag is cleared to "0" to temporarily disable the acceptance of maskable interrupts. After execution of the interrupt service program, this flag is set to "1" by the maskable interrupt return instruction [RETI] to again enable the acceptance of interrupts. If an interrupt request has already been occurred, interrupt service starts immediately after execution of the [RETI] instruction.

Pseudo non-maskable interrupts are returned by the [RETN] instruction. In this case, the IMF is set to "1" only when pseudo non-maskable interrupt service is started with interrupt acceptance enabled (IMF = 1). Note that IMF remains "0" when cleared by the interrupt service program.

The IMF is assigned to bit 0 at address 003A_H in the SFR, and can be read and written by an instruction. IMF is normally set and cleared by the [EI] and [DI] instructions, and the IMF is initialized to "0" during reset.

② Individual interrupt enable flags (EF₁₅ to EF₄)

Each of these flags enables and disables the acceptance of its maskable interrupt. Setting the corresponding bit of an individual interrupt enable flag to "1" enables acceptance of its interrupt, and setting the bit to "0" disables acceptance. The individual interrupt enable flags (EF₁₅ to EF₄) are located on EIRL to EIRH (address: 003A_H to 003B_H in SFR), and can be read and written by an instruction. During reset, all the individual interrupt enable flags (EF₁₅ to EF₄) are initialized to "0" and all maskable interrupts are not accepted until they are set to "1".

Example 1: Sets individual interrupt enable flags

DI ; IMF←0
LDW (EIRL), 1110100010100000B ; EF₁₅ to 13, EF₁₁, EF₇, EF₅←1
Note: Do not set IMF

EI ; IMF←1

Example 2: Example of description in C

```
unsigned int __io(3AH) EIRL; /* 3AH: address for EIRL */
__DI()
__EIRL=10100000B;
__EI();
```

Interrupt Latches																							
IL	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0							
(003C, 003DH)	IL ₁₅	IL ₁₄	IL ₁₃	IL ₁₂	IL ₁₁	IL ₁₀	IL ₉	IL ₈	IL ₇	IL ₆	IL ₅	IL ₄	IL ₃	IL ₂								
IL _H (003DH)								IL _L (003CH)															
(Initial value: 00000000 000000**)																							
Interrupt Enable Registers																							
EIR	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0							
(003A, 003BH)	EF ₁₅	EF ₁₄	EF ₁₃	EF ₁₂	EF ₁₁	EF ₁₀	EF ₉	EF ₈	EF ₇	EF ₆	EF ₅	EF ₄	IMF								
EIR _H (003BH)								EIR _L (003AH)															
(Initial value: 00000000 0000****0)																							
Note 1: Do not clear IL ₂ to "0" by an instruction.																							
Note 2: Do not clear IL with read-modify-write instructions such as bit operations.																							
Note 3: Before you set EF, be sure to clear IMF (to disable interrupt).																							
Note 4: * ; Don't care																							
Note 5: Do not set IMF to 1 simultaneously with EF.																							
Note 6: Do not set IMF to "1" during non-maskable interrupt service program.																							

Figure 1-23. Interrupt Latch (IL) and Interrupt Enable Register (EIR)

1.9.1 Interrupt Sequence

An interrupt request is held until the interrupt is accepted or the interrupt latch is cleared to "0" by a reset or an instruction. Interrupt acceptance sequence requires 8 machine cycles (4 μ s at $f_c = 8$ MHz in NORMAL mode) after the completion of the current instruction execution. The interrupt service task terminates upon execution of an interrupt return instruction [RETI] (for maskable interrupts) or [RETN] (for pseudo non-maskable interrupts).

(1) Interrupt acceptance processing

Interrupt acceptance processing is as follows:

- ① The interrupt master enable flag (IMF) is cleared to "0" to temporarily disable the acceptance of any following maskable interrupts. When a non-maskable interrupt is accepted, the acceptance of any following interrupts is temporarily disabled.
- ② The interrupt latch (IL) for the interrupt source accepted is cleared to "0".
- ③ The contents of the program counter (PC) and the program status word (PSW) are saved (pushed) onto the stack. (pushed down in order of PSW, PC_H, PC_L). The stack pointer (SP) is three decrements.
- ④ The entry address of the interrupt service program is read from the vector table address corresponding to the interrupt source, and the entry address is loaded to the program counter.
- ⑤ The instruction stored at the entry address of the interrupt service program is executed.

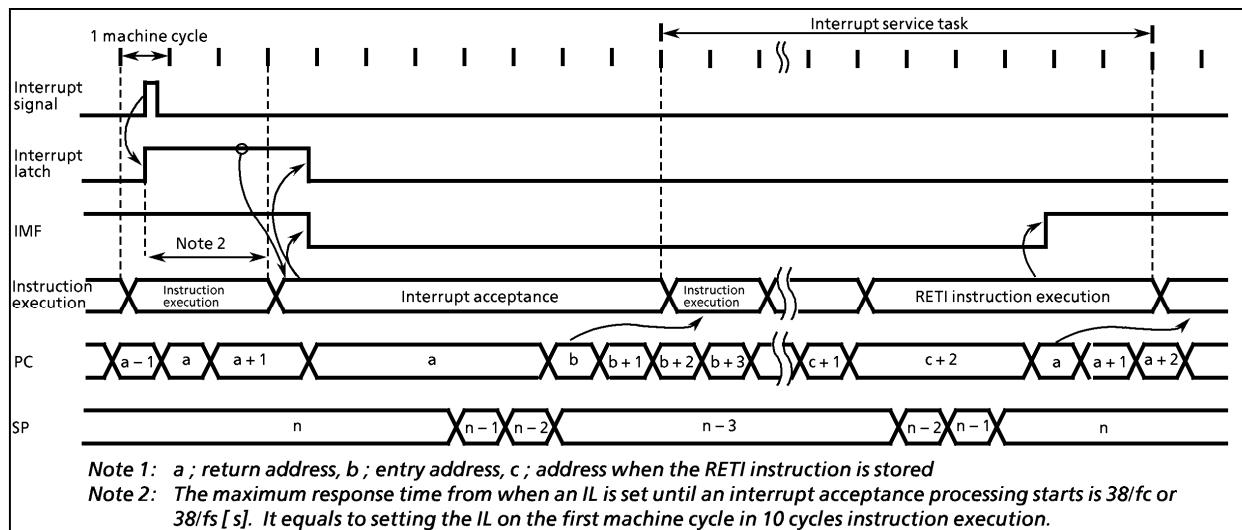
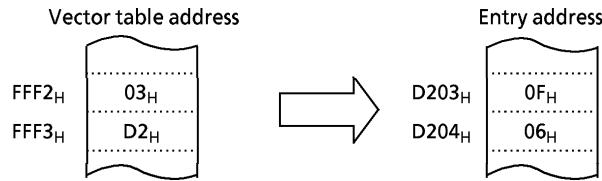


Figure 1-24. Timing Chart of Interrupt Acceptance and Interrupt Return Instruction

Example: Correspondence between vector table address for INTTB and the entry address of the interrupt service program.



A maskable interrupt is not accepted until the IMF is set to "1" even if a maskable interrupt of higher priority than that of the current interrupt being serviced.

When nested interrupt service is necessary, the IMF is set to "1" in the interrupt service program. In this case, acceptable interrupt sources are selectively enabled by the individual interrupt enable flags. However, an acceptance of external interrupt 0 cannot be disabled by the EF; therefore, if disablement is necessary, either the external interrupt function must be disabled in the external interrupt control register (INT0EN) or interrupt processing must be avoided by the program. (When INT0EN=0, the interrupt latch IL3 is not set, therefore, the falling edge of the INT0 pin input cannot be detected.)

Example 1: Disables an external interrupt 0 using INT0EN:

```
CLR      (EINTCR), INT0EN ; INT0EN←0
```

Example 2: Disables the processing of external interrupt 0 under the software control (using bit 0 at address 00F0H as the interrupt processing disable switch):

```
PINT0 : TEST    (00F0H).0      ; Returns without interrupt processing if (00F0H)0=1
        JRS     T, SINT0
        RETI
SINT0 : Interrupt processing
        RETI
        .
VINT0 : DW      PINT0
```

(2) General-purpose register save/restore processing

During interrupt acceptance processing, the program counter and the program status word are automatically saved on the stack, but not the accumulator and other registers. These registers are saved by the program if necessary. Also, when nesting multiple interrupt services, it is necessary to avoid using the same data memory area for saving registers.

The following method is used to save/restore the general-purpose registers:

① General-purpose register save/restore by register bank changeover:

General-purpose registers can be saved at high-speed by switching to a register bank that is not in use. Normally, bank 0 is used for the main task and banks 1 to 15 are assigned to interrupt service tasks. To increase the efficiency of data memory utilization, the same bank is assigned for interrupt sources which are not nested.

The switched bank is automatically restored by executing an interrupt return instruction [RETI] or [RETN]. Therefore, it is not necessary for a program to save the RBS.

Example: Register Bank Changeover

```
PINTxx : LD RBS, n ; Switches to bank n (1μs at 8 MHz)
          [interrupt processing]
          RETI ; Restores bank and Returns
```

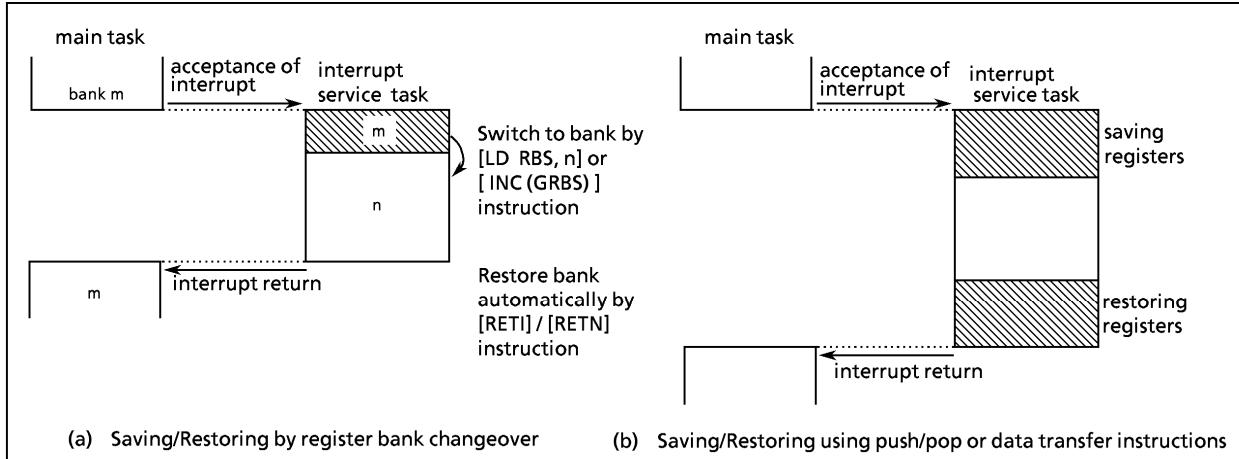
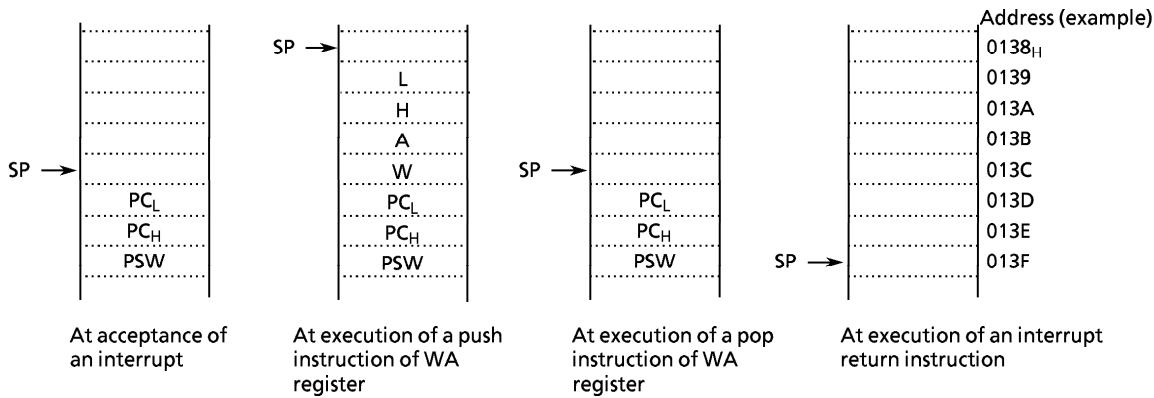


Figure 1-25. Saving/Restoring General-purpose Registers

② General-purpose register save/restore using push and pop instructions:

To save only a specific register, and when the same interrupt source occurs more than once, the general-purpose registers can be saved/restored using push/pop instructions.

```
PINTxx : PUSH WA ; Save WA register pair
          PUSH HL ; Save HL register pair
          [interrupt processing]
          POP HL ; Restore HL register pair
          POP WA ; Restore WA register pair
          RETI ; Return
```



③ General-purpose registers save/restore using data transfer instruction:
Data transfer instructions can be used to save only a specific general-purpose register during processing of a single interrupt.

Example: Saving/restoring a register using data transfer instructions

```
PINTxx : LD      (GSAVA), A      ; Save A register
          :Interrupt processing:
          LD      A, (GSAVA)      ; Restore A register
          RETI                 ; Return
```

The interrupt return instructions [RETI] / [RETN] perform the following operations.

[RETI] Maskable interrupt return	[RETN] Non-maskable interrupt return
<p>① The contents of the program counter and the program status word are restored from the stack.</p> <p>② The stack pointer is incremented 3 times.</p> <p>③ The interrupt master enable flag is set to "1".</p>	<p>① The contents of the program counter and program status word are restored from the stack.</p> <p>② The stack pointer is incremented 3 times.</p> <p>③ The interrupt master enable flag is set to "1" only when a non-maskable interrupt is accepted in interrupt enable status. However, the interrupt master enable flag remains at "0" when so clear by an interrupt service program.</p>

Interrupt requests are sampled during the final cycle of the instruction being executed. Thus, the next interrupt can be accepted immediately after the interrupt return instruction is executed.

Note: When the interrupt processing time is longer than the interrupt request generation time, the interrupt service task is performed but not the main task.

1.9.2 Software Interrupt (INTSW)

Executing the [SWI] instruction generates a software interrupt and immediately starts interrupt processing (INTSW is highest prioritized interrupt). However, if processing of a non-maskable interrupt is already underway, executing the SWI instruction will not generate a software interrupt but will result in the same operation as the [NOP] instruction. Thus, the [SWI] instruction behaves like the [NOP] instruction.

Note: Software interrupt generates during non-maskable interrupt processing to use SWI instruction for software break in a development tool.

Use the [SWI] instruction only for detection of the address error or for debugging.

- ① Address Error Detection
 FF_H is read if for some cause such as noise the CPU attempts to fetch an instruction from a non-existent memory address. Code FF_H is the SWI instruction, so a software interrupt is generated and an address error is detected. The address error detection range can be further expanded by writing FF_H to unused areas of the program memory. Address trap reset is generated for instruction fetch from a part of RAM area (address 0040_H to $043F_H$) or SFR area (0000_H to $003F_H$).
- ② Debugging
Debugging efficiency can be increased by placing the SWI instruction at the software break point setting address.

Note: The fetch date from addresses $7F80_H$ to $7FFF_H$ (test ROM area) is not "FF_H".

1.9.3 External Interrupts

The TMP87CH21/H21B/M21 has five external interrupts (INT0 to INT5: $\overline{\text{INT0}}$, INT1, INT2, INT3, $\overline{\text{INT5}}$). Three of these (INT1, INT2, INT3) have digital noise cancellation circuits (pulse inputs of less than a fixed time are cancelled as noise). Edge selection is possible with pins INT1, INT2, and INT3.

The $\overline{\text{INT0}}/\text{P10}$ pin can be selected either as an external interrupt input pin or as an I/O port. At reset, it is initialized as an input port.

Edge selection, noise cancellation control, and $\overline{\text{INT0}}/\text{P10}$ pin function selection are performed by the external interrupt control register (#0037H: EINTCR).

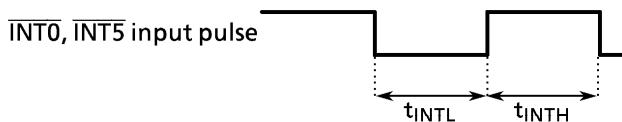
The both-edge detect function of the INT3 pin is selected by the external interrupt control register (#0037H: EINTCR and #001FH: EINT3).

Table 1-3 (a) lists enable conditions, edge select, noise cancellation conditions. The following are notes on the usage of external interrupts:

Notes on usage of external interrupts:

Note 1: When INT0 to INT5 ($\overline{\text{INT0}}$, INT1, INT2, INT3, $\overline{\text{INT5}}$) are used in SLOW or SLEEP mode, the noise cancellation function is disabled. Noise cancellation time for a pulse input during operating mode transition is indeterminate.

Note 2: Input pulse width for $\overline{\text{INT0}}$ and $\overline{\text{INT5}}$ must be one machine cycle or more at both high and low levels.



$$t_{INTL}, t_{INTH} > t_{cyc}$$

$$t_{cyc} = 4/fc [s] \text{ (at NORMAL 1/2 and IDLE 1/2 modes)}$$

$$4/fs [s] \text{ (at SLOW and SLEEP modes)}$$

Note 3: If a signal without noise is input to the external interrupt pin in NORMAL 1/2 or IDLE 1/2 mode, the maximum times from input signal edge to input latch set are as described below:

- ① INT1 pin $49/fc [s]$ (when INT1NC = 1)
 $193/fc [s]$ (when INT1NC = 0)
- ② INT2 pin $25/fc [s]$
- ③ INT3 pin $25/fc [s]$ (when #0037H: INT3W = 0, falling or rising edge)
 $25/fc [s]$ (when #0037H: INT3W = 1 and #001FH: NCS (0, 0, 0))
 $(26/fc) \times 8.5 + 19/fc [s]$ (when #0037H: INT3W = 1 and #001FH: NCS (0, 0, 1))
 $(27/fc) \times 8.5 + 19/fc [s]$ (when #0037H: INT3W = 1 and #001FH: NCS (0, 1, 0))
 $(28/fc) \times 8.5 + 19/fc [s]$ (when #0037H: INT3W = 1 and #001FH: NCS (0, 1, 1))
 $(29/fc) \times 8.5 + 19/fc [s]$ (when #0037H: INT3W = 1 and #001FH: NCS (1, 0, 0))
 $(210/fc) \times 8.5 + 19/fc [s]$ (when #0037H: INT3W = 1 and #001FH: NCS (1, 0, 1))
 $(211/fc) \times 8.5 + 19/fc [s]$ (when #0037H: INT3W = 1 and #001FH: NCS (1, 1, 0))
 $(212/fc) \times 8.5 + 19/fc [s]$ (when #0037H: INT3W = 1 and #001FH: NCS (1, 1, 1))

Note 4: Noise cancellation/pulse receive conditions for timer/counter are as described below:

- ① TC1 pin: Less than $7/fc [s]$ (noise cancellation) and $24/fc [s]$ or more (pulse receive)
- ② TC3 pin: When INT3W = 0, less than $7/fc [s]$ (noise cancellation) and $24/fc [s]$ or more (pulse receive).

For when INT3W = 1, see Table 1-3 (b).

Note 5: When INT0EN = 0, interrupt latch IL3 is not set even if a falling edge is detected for $\overline{\text{INT0}}$ pin input.

Note 6: Change EINTCR only when IMF=0. After changing EINTCR, interrupt latches of external interrupt inputs must be cleared to "0" using load instruction.

Example: Changes INT2 edge selection from rising edge to falling edge

DI	; IMF ← 0 (disables interrupt service)
LD (EINTCR), 10000110B	; INT2ES ← 1 (changes edge selection)
LD (ILL), 01111111B	; IL7 ← 0 (clears interrupt latch)
EI	; IMF ← 1 (enables interrupt service)

Note 7: If changing the contents of INT1ES during NORMAL1/2 mode, interrupt latch of external interrupt input INT1 must be cleared after 14 machine cycles (when INT1NC=1) or 50 machine cycles (when INT1NC=0) from the time of changing. During SLOW mode, 3 machine cycles are required.

Note 8: In order to change of external interrupt input by rewriting the contents of INT2ES during NORMAL1/2 mode, clear interrupt latches of external interrupt inputs (INT2, INT3 and INT4) after 8 machine cycles from the time of rewriting. During SLOW mode, 3 machine cycles are required.

Note 9: In order to change an edge of timer counter input by rewriting the contents of INT2ES during NORMAL1/2 mode, rewrite the contents after timer counter is stopped (TC1S=00), that is, interrupt disable state. Then, clear interrupt latches of external interrupt inputs (INT2, INT3 and INT4) after 8 machine cycles from the time of rewriting to change to interrupt enable state. Finally, start timer counter. During SLOW mode, 3 machine cycles are required.

Example: When changing TC1 pin inputs edge in external trigger timer mode from rising edge to falling edge.

LD (TC1CR), 01001000B	; TC1S ← 00 (stop TC1)
DI	; IMF ← 0 (disable interrupt service)
LD (EINTCR), 00000100B	; INT2ES ← 1 (change edge selection)
<hr/>	
8 machine cycles	
NOP	
:	
NOP	
<hr/>	
LD (ILL), 01111111B	; IL7 ← 0 (clear interrupt latch)
EI	; IMF ← 1 (enable interrupt service)
LD (TC1CR), 01111000B	; TC1S ← 11 (start TC1)

Note 10: When high-impedance is specified for port output in stop mode, port input is forcibly fixed to low level internally. Thus, interrupt latches of external interrupt inputs except INT5 (P20/STOP) which are also used as ports may be set to "1". To specify high-impedance for port output in stop mode, first disable interrupt service (IMF=0), activate stop mode. After releasing stop mode, clear interrupt latches using load instruction, then, enable interrupt service.

Example: Activating stop mode

LD (SYSCR1), 01000000B	; OUTEN ← 0 (specifies high-impedance)
DI	; IMF ← 0 (disables interrupt service)
SET (SYSCR1).STOP	; STOP ← 1 (activates stop mode)
LDW (IL), 1111011101010111B	; IL11, 7, 5, 3 ← 0 (clears interrupt latches)
EI	; IMF ← 1 (enables interrupt service)

Table 1-3 (a). External Interrupts

Source	Pin	Secondary function	Enable Condition	Edge			Digital noise reject
				rising	falling	both	
INT0	INT0	P10	IMF = 1, INT0EN = 1	—	○	—	— (hysteresis input)
INT1	INT1	P11	IMF · EF ₅ = 1	INT1ES = 0	INT1ES = 1	—	Note 1
INT2	INT2	P12 / TC1	IMF · EF ₇ = 1	INT2ES = 0	INT2ES = 1	—	Note 2
INT3	INT3	P40 / TC3	IMF · EF ₁₁ = 1, INT3W = 0	INT3ES = 0	INT3ES = 1	—	Note 3
			IMF · EF ₁₁ = 1, INT3W = 1	—	—	INT3W = 1 (Note)	Note 4
INT5	INT5	P20 / STOP	IMF · EF ₁₅ = 1	—	○	—	— (hysteresis input)

Note 1: Pulses less than 15/fc [s] or 63/fc [s] are cancelled as noise. Pulses equal to or more than 48/fc [s] or 192/fc [s] are regarded as signals.

Note 2: Pulses less than 7/fc [s] are cancelled as noise. Pulses equal to or more than 24/fc [s] are regarded as signals. Same applies to pin TC1.

Note 3: For falling or rising edge, pulses less than 7/fc [s] are cancelled as noise. Pulses equal to or more than 24/fc [s] are regarded as signals. Same applies to pin TC3 (at one edge).

Note 4: Noise cancellation conditions are as listed in Table 1-3 (b). They are applied to the INT3 pin when it is used for both-edge interrupts.

Note: To detect the edge at which an interrupt is generated, read bit 7 (INTEDT) in EINT3CR (#001FH), that is, at the beginning of the interrupt processing routine.

INTEDT is valid only for both-edge interrupts (INT3W = 1). INTEDT is set to 1 by an interrupt as the non-selected edge; cleared to 0 after read automatically.

For both-edge interrupts, rising or falling edge is selected by setting/modifying bit 3 (INT3ES) in EINTCR (#0037H).

When rising edge is selected (INT3ES = 0), bit 7 in INTEDT (#001FH) is set to 1 when a falling edge is detected at the INT3 pin. (That is, remains 0 if rising edge is detected.)

When falling edge is selected (INT3ES = 1), bit 7 in INTEDT: #001FH is set to 1 when a rising edge is detected at the INT3 pin. (That is, remains 0 at falling edge.)

Table 1-3 (b). Noise reject condition for INT3 (both-edge interrupt)

#001FH			max pulse width for noise reject	min pulse width for immediate signal		
NCS2	NCS1	NCS0				
0	0	0	– (hysteresis input)			
0	0	1	$(2^6/fc) \times 7 - 6/fc$	$(2^6/fc) \times 8 + 5/fc$		
0	1	0	$(2^7/fc) \times 7 - 6/fc$	$(2^7/fc) \times 8 + 5/fc$		
0	1	1	$(2^8/fc) \times 7 - 6/fc$	$(2^8/fc) \times 8 + 5/fc$		
1	0	0	$(2^9/fc) \times 7 - 6/fc$	$(2^9/fc) \times 8 + 5/fc$		
1	0	1	$(2^{10}/fc) \times 7 - 6/fc$	$(2^{10}/fc) \times 8 + 5/fc$		
1	1	0	$(2^{11}/fc) \times 7 - 6/fc$	$(2^{11}/fc) \times 8 + 5/fc$		
1	1	1	$(2^{12}/fc) \times 7 - 6/fc$	$(2^{12}/fc) \times 8 + 5/fc$		

Note: In SLOW mode, set (NCS) = (0, 0, 0).
In SLOW mode, the digital noise filter in the above table is disabled.

External interrupt Control Register 1

EINTCR (0037H)	7	6	5	4	3	2	1	0	(initial value: 00** 0000)
	INT1 NC	INT0 EN			INT3 ES	INT2 ES	INT1 ES	INT3W	

INT1NC	Noise reject time select	0: Pulses of less than $63/fc$ [s] are eliminated as noise 1: " $15/fc$ [s] "	R/W
INT0EN	P10/INT0 pin configuration	0: P10 input/output 1: INT0 pin (port P10 should be set to an input mode)	
INT3ES INT2ES INT1ES	INT3 to INT1 edge select	0: rising edge 1: falling edge	
INT3W	INT3 both edge selection	0: refer to INT3ES 1: both edge detection	

Note: fc ; High-frequency clock [Hz] * ; Don't care

Figure 1-26 (a). External Interrupt Control Register

External interrupt Control Register 2

EINT3CR (001FH)	7	6	5	4	3	2	1	0	(initial value: 0000 0***)
	INT EDT		NCS		INT3 DET				

INTEDT	Flag indicating an interrupt at selected edge/non-selected edge, when INT3W = 1 (for both-edge interrupts).	0: Interrupt at selected edge or no interrupt 1: Interrupt at non-selected edge	R
NCS	Noise cancellation time select for INT3 digital noise filter (valid only when INT3W = 1)	000: No noise cancellation 001: Cancels $(2^6/fc) \times 7 - 6/fc$ as noise. 010: Cancels $(2^7/fc) \times 7 - 6/fc$ " 011: Cancels $(2^8/fc) \times 7 - 6/fc$ " 100: Cancels $(2^9/fc) \times 7 - 6/fc$ " 101: Cancels $(2^{10}/fc) \times 7 - 6/fc$ " 110: Cancels $(2^{11}/fc) \times 7 - 6/fc$ " 111: Cancels $(2^{12}/fc) \times 7 - 6/fc$ "	R/W
INT3DET	INT3 interrupt detection flag	0: No interrupt 1: Interrupt	R

Note: INTEDT and NCS are valid only when the INT3W bit in EINTCR (#0037H) is set to 1.
Therefore, when INT3W = 0, the digital noise filter set by the NCS bit is disabled.

Figure 1-26 (b). External Interrupt Control Register 2

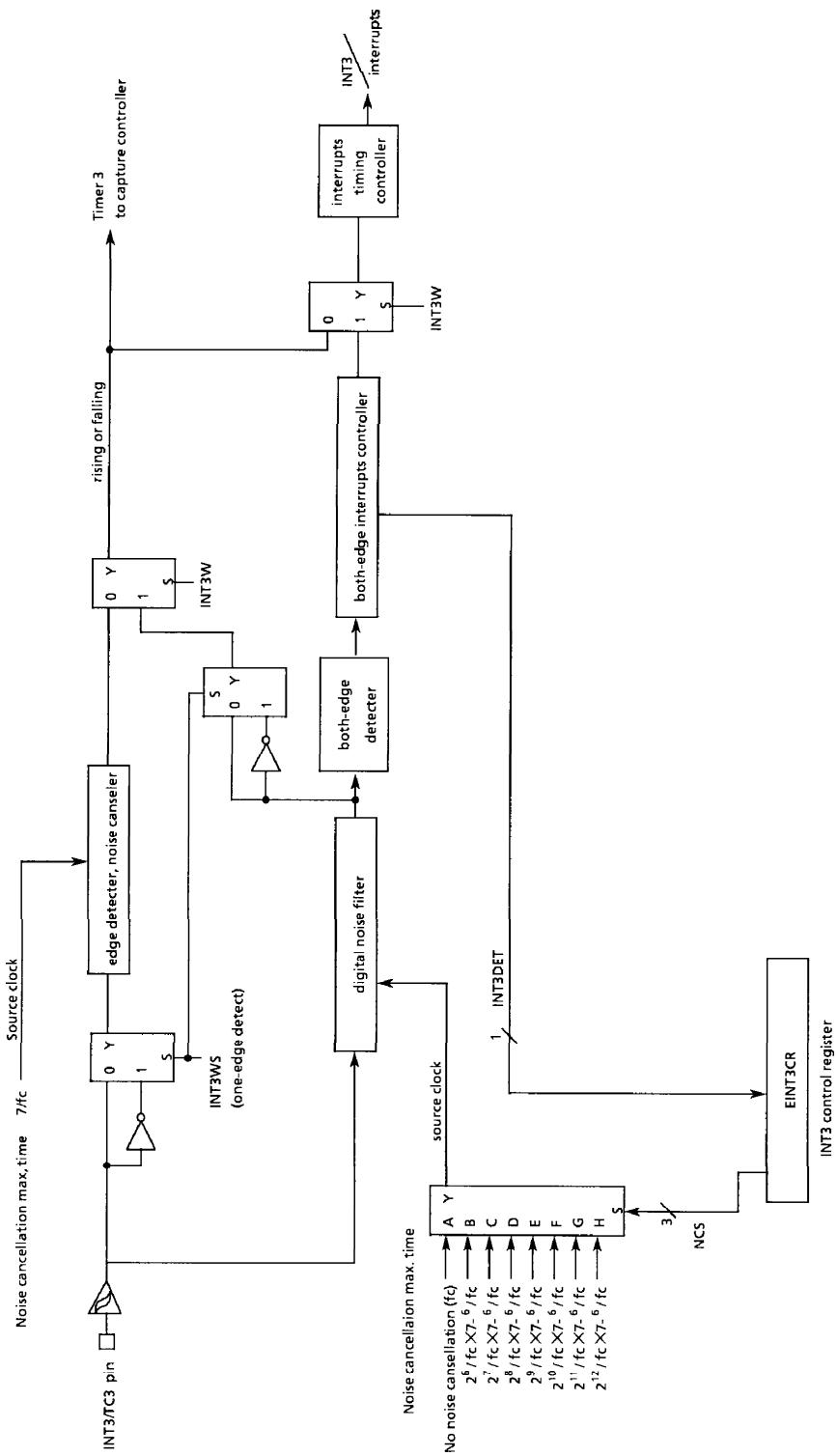


Figure 1-26 (C). Bother One Edge Detictor of INT3/TC3 Pin

Notes on the usage of INT3 pin (external interrupt)

1. In the case of using the INT3 pin for one edge (either rising or falling).

Note: *In order to set/rewrite external interrupt control register(EINTCR), set/rewrite external interrupt register in the interrupt disable state (IMF=0). Then, enable interrupt acceptance after interrupt latch cleared.*

2. In the case of using the INT3 pin for both edge (rising and falling).

Note 1: *When using the INT3 pin for both edges (rising and falling), set bit 0 (INT3W) in EINTCR (#0037H) to 1.*

Note 2: *To detect the edge at which an interrupt is generated, read bit 7 (INTEDT) in EINT3CR (#001FH), that is, at the beginning of the interrupt processing routine.*

Note 3: *INTEDT is valid only for both-edge interrupts (INT3W = 1). INTEDT is set to 1 by an interrupt as the non-selected edge; cleared to 0 after read automatically.*

When rising edge is selected (INT3ES = 0), bit 7 (INTEDT) in EINT3CR (#001FH) is set to 1 when a falling edge is detected at the INT3 pin. (That is, remains 0 if rising edge is detected.)

When falling edge is selected (INT3ES = 1), bit 7 (INTEDT) in EINT3CR (#001FH) is set to 1 when a rising edge is detected at the INT3 pin. (That is, remains 0 at falling edge.)

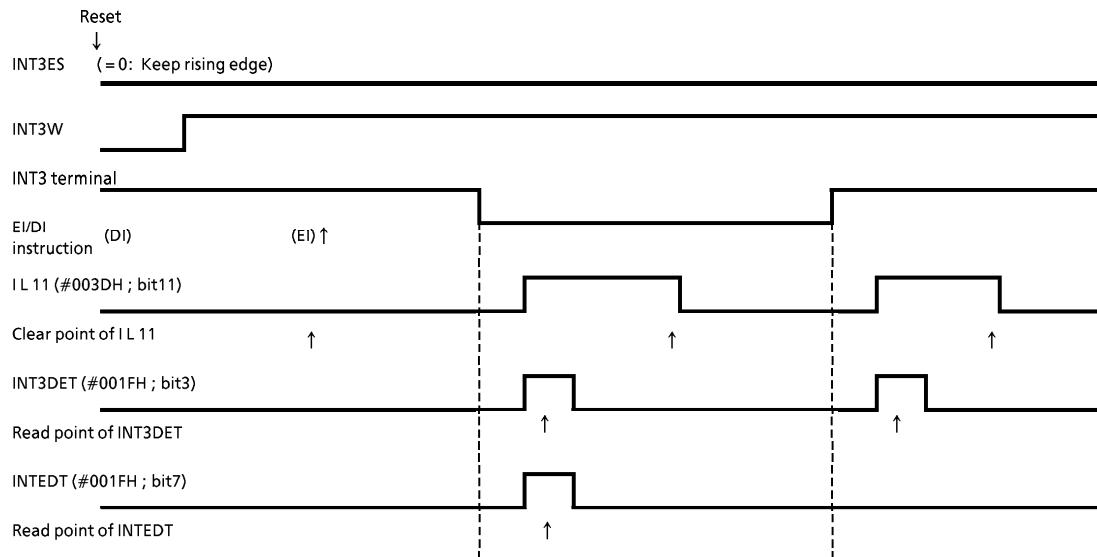
Note 4: *In order to set/rewrite external interrupt control register(EINTCR), set/rewrite external interrupt register in the interrupt disable state (IMF=0). Then, enable interrupt acceptance after interrupt latch cleared.*

Operation description for INT3 (both-edge interrupt) in use:

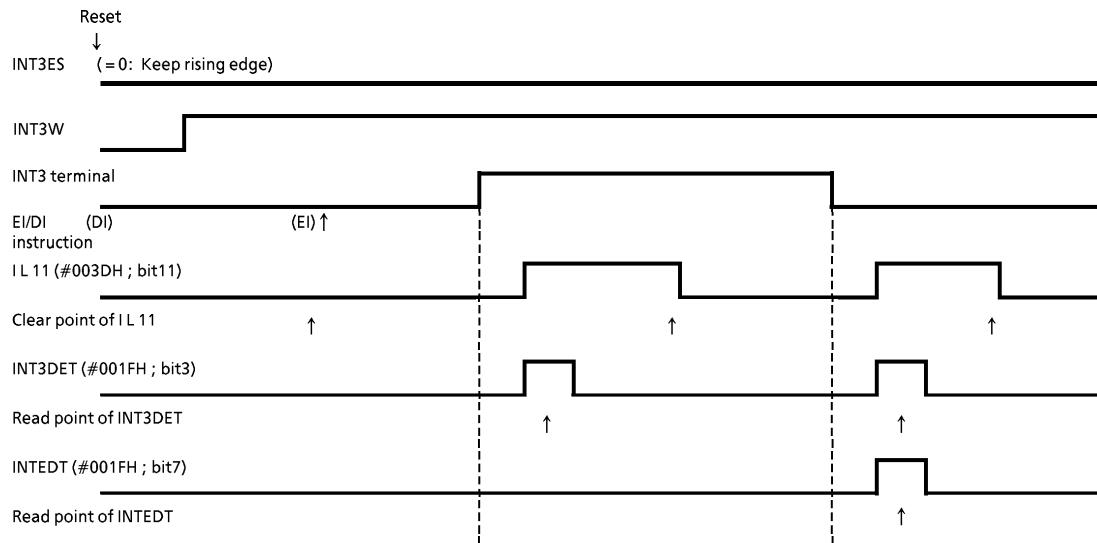
1. Operation without setting/modifying external interrupt control register (EINTCR) after reset:

For both-edge interrupts, rising edge is selected (INT3ES = 0) and fixed.

1) Case1: When the initial state of the INT3 pin is high after reset:

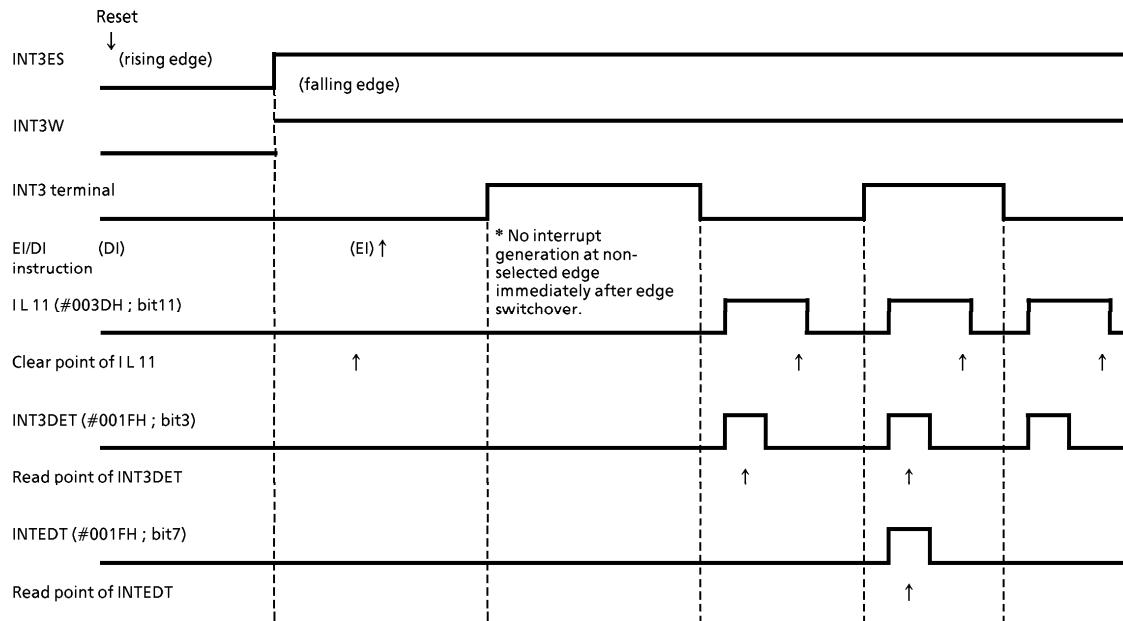


2) Case2: When the initial state of the INT3 pin is low after reset:

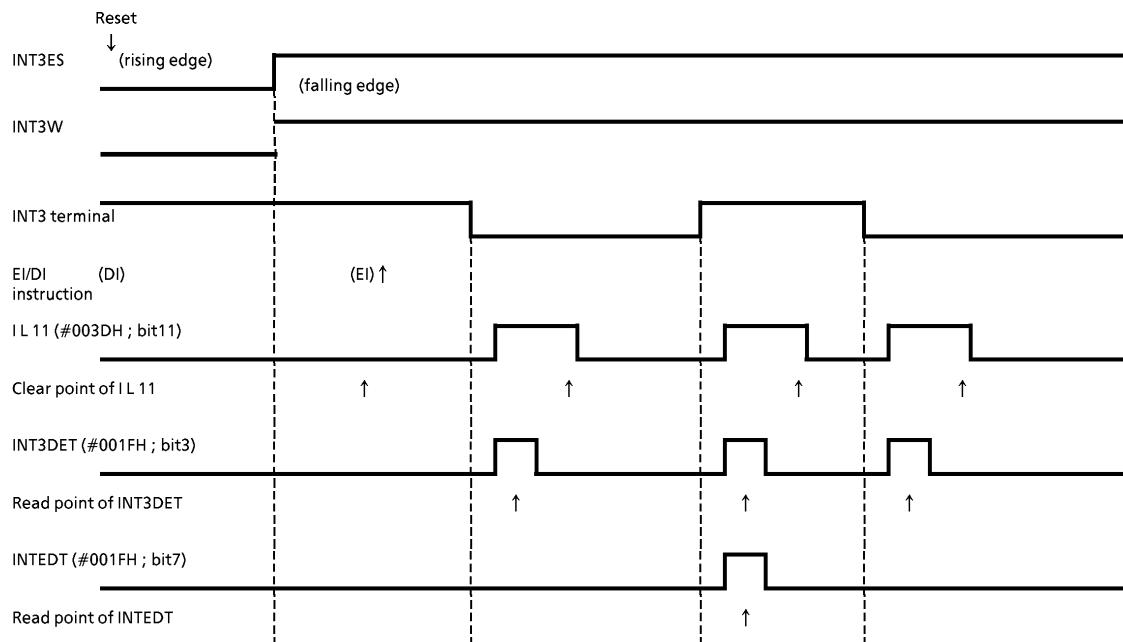


2. Operation with setting/modifying external interrupt control register (EINTCR) after reset:

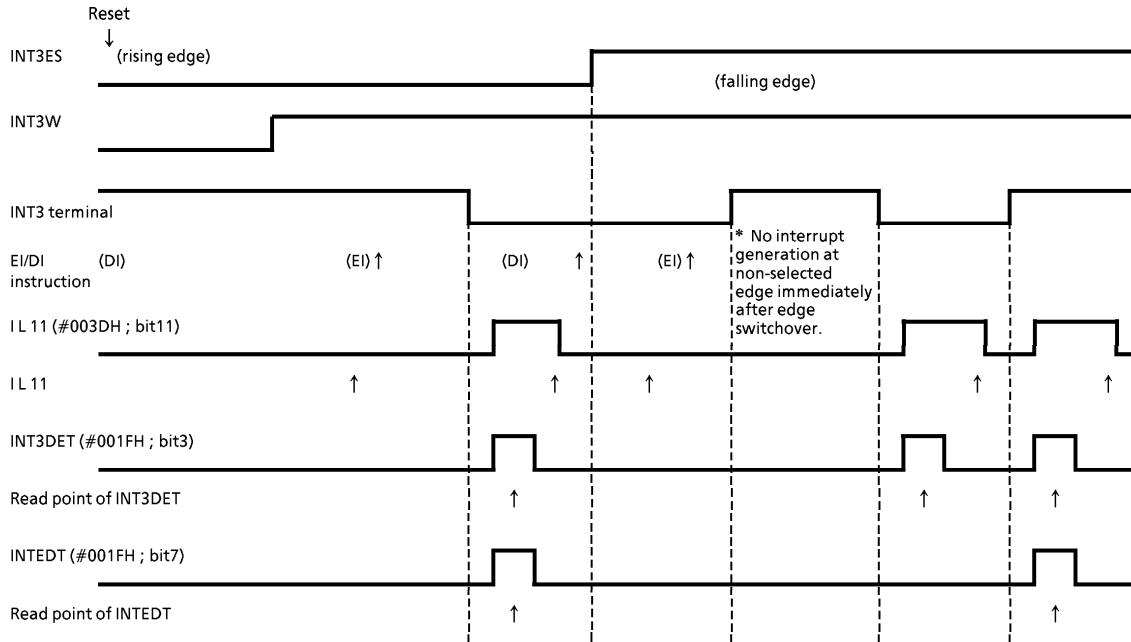
1) Case3: When the initial state of the INT3 pin is low after reset/low at edge switchover from rising to falling:



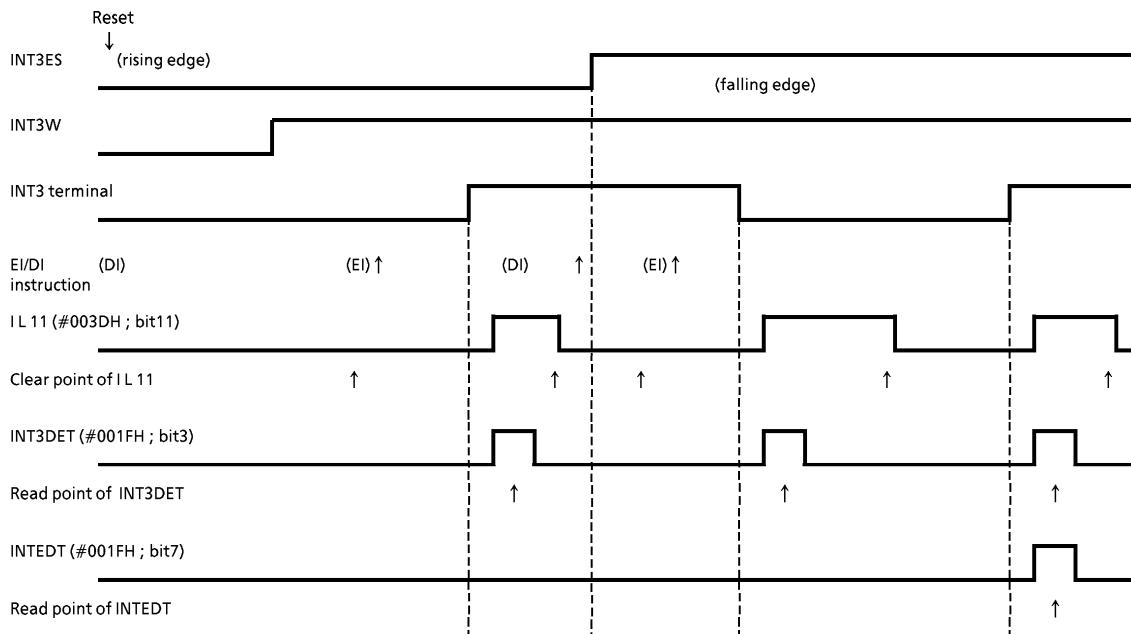
2) Case4: When the initial state of the INT3 pin is high after reset/high at edge switchover from rising to falling:



3) Case5: Case 5: When the initial state of the INT3 pin is high after reset/low at edge switchover from rising to falling:



4) Case6: When the initial state of the INT3 pin is low after reset/high at edge switchover from rising to falling:



1.10 Watchdog Timer (WDT)

The watchdog timer rapidly detects the CPU malfunction such as endless looping caused by noise or the like, and resumes the CPU to the normal state.

The watchdog timer signal for detecting malfunction can be selected either a reset output or a non-maskable interrupt request. However, selection is possible only once after reset. At first the reset output is selected.

When the watchdog timer is not being used for malfunction detection, it can be used as a timer to generate an interrupt at fixed intervals.

Note: Adequate care must be given when designing systems so as to eliminate disturbing noise. Otherwise the Watchdog Timer may not exhibit its full functionality.

1.10.1 Watchdog Timer Configuration

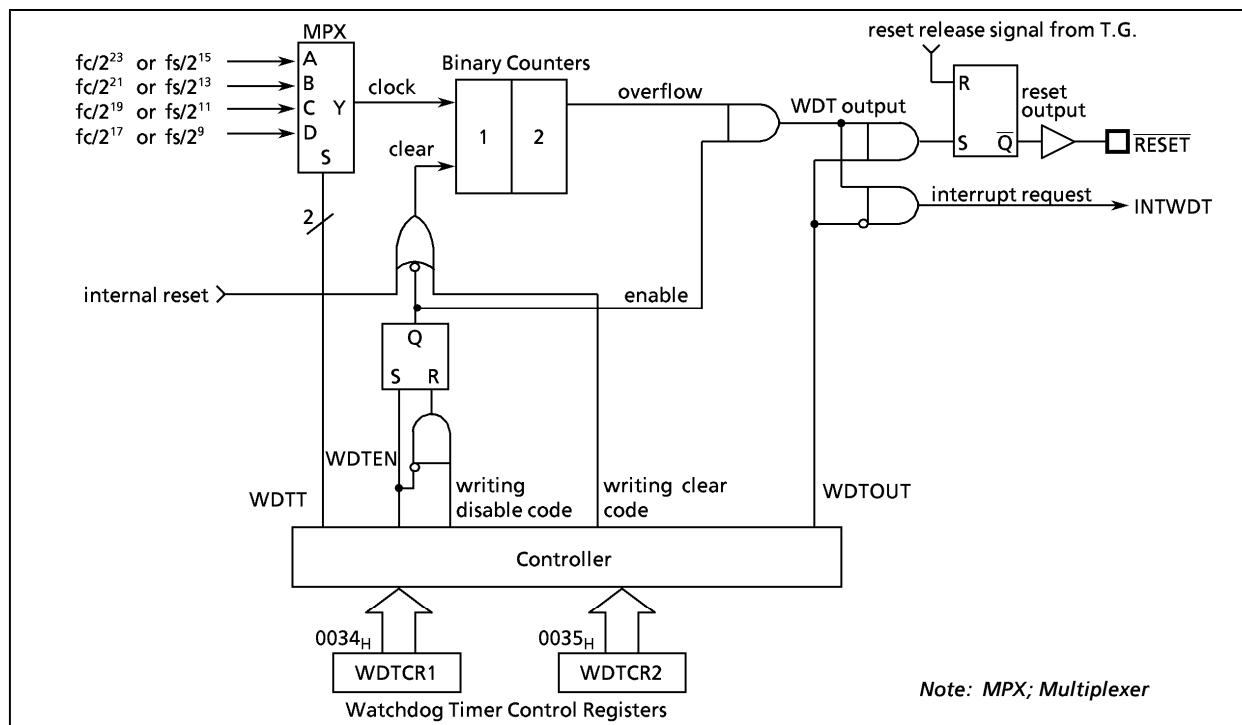


Figure 1-27. Watchdog Timer Configuration

1.10.2 Watchdog Timer Control

Figure 1-28 shows the watchdog timer control registers (WDTCR1, WDTCR2). The watchdog timer is automatically enabled after reset.

(1) Malfunction detection methods using the watchdog timer

The CPU malfunction is detected as follows.

- ① Setting the detection time, selecting output, and clearing the binary counter.
- ② Repeatedly clearing the binary counter within the setting detection time.

If the CPU malfunction occurs for any cause, the watchdog timer output will become active at the rising of an overflow from the binary counters unless the binary counters are cleared. At this time, when WDTOUT = 1 a reset is generated, which drives the RESET pin low to reset the internal hardware and the external circuits. When WDTOUT = 0, a watchdog timer interrupt (INTWDT) is generated.

The watchdog timer temporarily stops counting in the STOP mode including warm-up or IDLE mode, and automatically restarts (continues counting) when the STOP/IDLE mode is released.

Example: Sets the watchdog timer detection time to $2^{21}/fc$ [s] and resets the CPU malfunction.

```

LD  (WDTCR2), 4EH      ; Clears the binary counters
LD  (WDTCR1), 00001101B ; WDTT←10, WDTOUT←1
Within WDT
detection time  LD  (WDTCR2), 4EH      ; Clears the binary counters
                  (always clear immediately after changing WDTT)
Within WDT
detection time  LD  (WDTCR2), 4EH      ; Clears the binary counters
LD  (WDTCR2), 4EH      ; Clears the binary counters

```

Watchdog Timer Control Register 1

WDTCR1 (0034H)	7	6	5	4	3	2	1	0	(Initial value: **** 1001)
					WDT EN	WDTT		WDT OUT	

WDTEN	Watchdog timer enable/disable	0: Disable (It is necessary to write the disable code to WDTCR2) 1: Enable	Write only
WDTT	Watchdog timer detection time	00: $2^{25}/fc$ or $2^{17}/fs$ [s] 01: $2^{23}/fc$ or $2^{15}/fs$ 10: $2^{21}/fc$ or $2^{13}/fs$ 11: $2^{19}/fc$ or $2^{11}/fs$	
WDTOUT	Watchdog timer output select	0: Interrupt request 1: Reset output	

Note 1: *WDTOUT cannot be set to "1" by program after clearing WDTOUT to "0".*

Note 2: *fc ; High-frequency clock [Hz] fs ; Low-frequency clock [Hz] * ; Don't care*

Note 3: *WDTCR1 is a write-only register and must not be used with any of read-modify-write instructions.*

Note 4: *Disable the watchdog timer or clear the counter just before switching to STOP mode. When the counter is cleared just before switching to STOP mode, clear the counter again subsequently to releasing STOP mode.*

Watchdog Timer Control Register 2

WDTCR2 (0035H)	7	6	5	4	3	2	1	0	(Initial value: **** ****)

WDTCR2	Watchdog timer control code write register	4EH: Watchdog timer binary counter clear (clear code) B1H: Watchdog timer disable (disable code) others: Invalid	Write only
--------	--	--	------------

Note 1: *The disable code is invalid unless written when WDTEN = 0.*

Note 2: ** ; Don't care*

Note 3: *Since WDTCR2 is a write-only register, read-modify-write instructions (e. g., bit manipulating instructions such as SET or CLR and arithmetic instructions such as AND or OR) cannot be used for read/write to this register.*

Note 4: *To clear the binary counter doesn't initialize the source clock, therefore, it is recommended to clear the binary counter within 3/4 of the detection period.*

Figure 1-28. Watchdog Timer Control Registers

Table 1-4. Watchdog Timer Detection Time

Operating mode			Detection time	
NORMAL1	NORMAL2	SLOW	At $f_c = 8$ MHz	At $f_s = 32.768$ kHz
$2^{25}/f_c$ [s]	$2^{25}/f_c, 2^{17}/f_s$	$2^{17}/f_s$	4.194 s	4 s
$2^{23}/f_c$	$2^{23}/f_c, 2^{15}/f_s$	$2^{15}/f_s$	1.048 ms	1 s
$2^{21}/f_c$	$2^{21}/f_c, 2^{13}/f_s$	—	262.1 ms	250 ms
$2^{19}/f_c$	$2^{19}/f_c, 2^{11}/f_s$	—	65.5 ms	62.5 ms

(2) Watchdog Timer Enable

The watchdog timer is enabled by setting WDTEN (bit 3 in WDTCR1) to "1". WDTEN is initialized to "1" during reset, so the watchdog timer operates immediately after reset is released.

Example: Enables watchdog timer
 LD (WDTCR1), 00001000B ; WDTEN←1

(3) Watchdog Timer Disable

The watchdog timer is disabled by writing the disable code (B1H) to WDTCR2 after clearing WDTEN (bit 3 in WDTCR1) to "0". The watchdog timer is not disabled if this procedure is reversed and the disable code is written to WDTCR2 before WDTEN is cleared to "0".

During disabling the watchdog timer, the binary counters are cleared to "0".

Example: Disables watchdog timer
 LDW (WDTCR1), 0B101H ; WDTEN←0, WDTCR1←disable code

1.10.3 Watchdog Timer Interrupt (INTWDT)

This is a pseudo non-maskable interrupt which can be accepted regardless of the contents of the EIR. If a watchdog timer interrupt or a software interrupt is already accepted, however, the new watchdog timer interrupt waits until the previous interrupt processing is completed (the end of the [RETN] instruction execution).

The stack pointer (SP) should be initialized before using the watchdog timer output as an interrupt source with WDTOUT.

Example: Watchdog timer interrupt setting up.

LD SP, 023FH ; Sets the stack pointer
 LD (WDTCR1), 00001000B ; WDTOUT←0

1.10.4 Watchdog Timer Reset

If the watchdog timer output becomes active, a reset is generated, which drives the $\overline{\text{RESET}}$ pin low to reset the internal hardware. The reset output time is $2^{20}/\text{fc}$ [s] (131 ms at $\text{fc}=8$ MHz). The $\overline{\text{RESET}}$ pin is sink open drain input / output with pull-up resistor.

Note: The high-frequency clock oscillator also turns on when a watchdog timer reset is generated in SLOW mode. Thus, the reset output time is $2^{20}/\text{fc}$.

The reset output time include a certain amount of error if there is any fluctuation of the oscillation frequency when the high-frequency clock oscillator turns on. Thus, the reset output time must be considered approximate value.

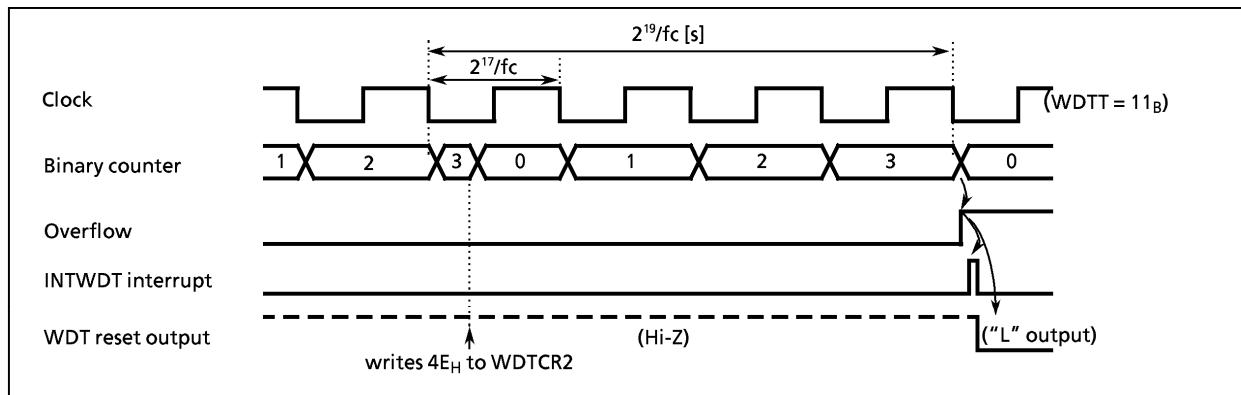


Figure 1-29. Watchdog Timer Interrupt / Reset

1.11 Reset Circuit

The TMP87CH21/H21B/M21 each have four types of reset generation procedures: an external reset input, an address trap reset, a watchdog timer reset and a system clock reset. Table 1-5 shows on-chip hardware initialization by reset action. The internal source reset circuit (watchdog timer reset, address trap reset, and system clock reset) is not initialized when power is turned on. Thus, output from the $\overline{\text{RESET}}$ pin may go low ($2^{20}/\text{fc}$ [s] (131 ms at 8 MHz) when power is turned on.

Table 1-5. Initializing Internal Status by Reset Action

On-chip Hardware	Initial Value	On-chip Hardware	Initial Value
Program counter (PC)	(FFFF _H) · (FFFE _H)	Divider of Timing generator	0
Register bank selector (RBS)	0	Watchdog timer	Enable
Jump status flag (JF)	1	Output latches of I/O ports	Refer to I/O port circuitry
Interrupt master enable flag (IMF)	0	Control registers	Refer to each of control register
Interrupt individual enable flags (EF)	0		
Interrupt latches (IL)	0		

1.11.1 External Reset Input

When the **RESET** pin is held at low for at least 3 machine cycles ($12/fc$ [s]) with the power supply voltage within the operating voltage range and oscillation stable, a reset is applied and the internal state is initialized.

When the **RESET** pin input goes high, the reset operation is released and the program execution starts at the vector address stored at addresses $FFFFH$ - $FFFFH$. The **RESET** pin contains a Schmitt trigger (hysteresis) with an internal pull-up resistor. A simple power-on-reset can be applied by connecting an external capacitor and a diode.

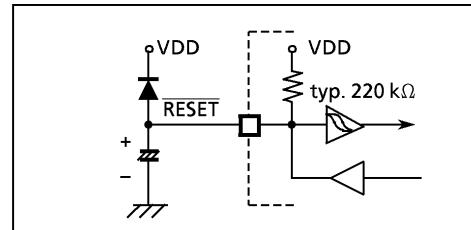


Figure 1-30. Simple Power-on-Reset Circuitry

1.11.2 Address-Trap-Reset

An address-trap-reset is one of fail-safe function that detects CPU malfunction caused by noise or the like, and returns the CPU to the normal state. If the CPU attempts to fetch an instruction from a part of RAM or SFR (address $0000H$ to $043FH$ for TMP87CH21/H21B/M21), an address-trap-reset will be generated. Then, the **RESET** pin output will go low. The reset time is $220/fc$ [s] (131 ms at 8 MHz).

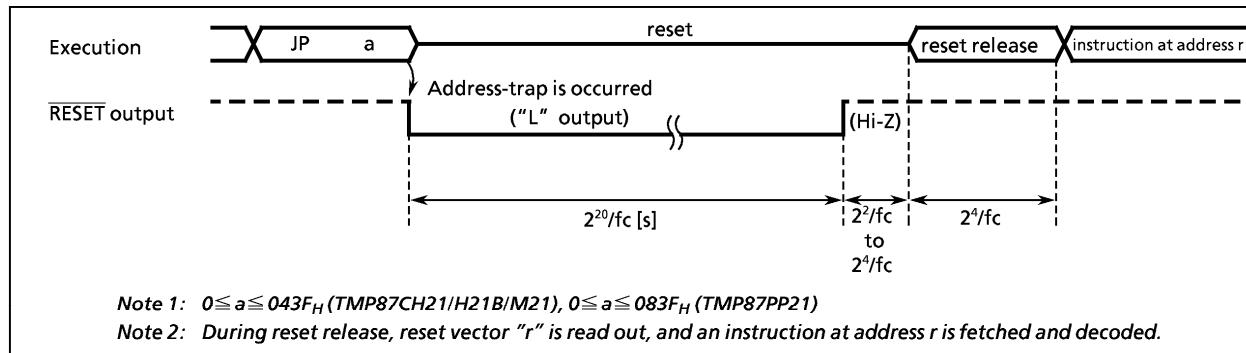


Figure 1-31. Address-Trap-Reset

1.11.3 Watchdog Timer Reset

Refer to Section "1.10 Watchdog Timer".

1.11.4 System-Clock-Reset

Clearing both XEN and XTEN (bits 7 and 6 in SYSCR2) to "0" stops both high-frequency and low-frequency oscillation, and causes the MCU to deadlock. This can be prevented by automatically generating a reset signal whenever $XEN = XTEN = 0$ is detected to continue the oscillation. Then, the **RESET** pin output goes low from high-impedance. The reset time is $220/fc$ [s] (131 ms at 8 MHz).

2. Peripheral Hardware Functions

2.1 Special Function Registers (SFR) and Data Buffer Registers (DBR)

The TLCS-870 Series uses the memory mapped I/O system, and all peripherals control and data transfers are performed through the special function registers (SFR) and data buffer registers (DBR).

The SFR are mapped to addresses 0000_H to $003F_H$ and the DBR to addresses $0F80_H$ to $0FFF_H$.

Figure 2-1 shows the TMP87CH21/H21B/M21 SFRs and DBRs.

Address	Read	Write	Address	Read	Write
0000_H	reserved		0020_H	SIO1SR (SIO1 status)	SIOCR1 (SIO1 control)
01	P1 Port		21	—	SIOCR2
02	P2 Port		22	SIO2SR (SIO2 status)	SIOCR1 (SIO2 control)
03	P3 Port		23	—	SIOCR2
04	P4 Port		24	reserved	
05	P5 Port		25	reserved	
06	P6 Port		26	reserved	
07	P7 Port		27	reserved	
08	reserved		28	—	LCDCR (LCD control)
09	P9 Port		29	—	P6CR (P6 I/O control)
0A	reserved		2A	—	P7CR (P7 I/O control)
0B	—	P1CR (P1 I/O control)	2B	—	reserved
0C	—	P4CR1 (P4 I/O control)	2C	—	P9CR (P9 I/O control)
0D	—	P5CR (P5 I/O control)	2D	—	P4CR2 (P4 I/O control)
0E	ADCCR (AD converter control)		2E	—	reserved
0F	ADCDR (AD conv. result)	—	2F	—	reserved
10	—	TREG1A _L (Timer register 1A)	30	—	reserved
11	—	TREG1A _H	31	—	reserved
12	TREG1B _L	(Timer register 1B)	32	—	reserved
13	TREG1B _H		33	—	reserved
14	—	TC1CR (TC1 control)	34	—	WDTCR1 (WDT control)
15	—	TC2CR (TC2 control)	35	—	WDTCR2
16	—	TREG2 _L (Timer register 2)	36	—	TBTCR (TBT / TG / DVO control)
17	—	TREG2 _H	37	EINTCR (External interrupt control)	
18	—	TREG3A (Timer register 3A)	38	—	SYSCR1 (system control)
19	TREG3B (Timer register 3B)	—	39	—	SYSCR2
1A	—	TC3CR (TC3 control)	3A	EIR _L	(interrupt enable register)
1B	—	reserved	3B	EIR _H	
1C	—	reserved	3C	IL _L	(interrupt latch)
1D	—	TREG5 (Timer register 5)	3D	IL _H	
1E	—	TC5CR (TC 5 control)	3E	—	reserved
1F	—	EINT3CR	3F	PSW (program status word)	RBS (register bank selector)

(a) Special Function Registers

Address	Read	Write
$0F80_H$	LCD display data buffer	
$0F8F$	reserved	
$0F90$	—	
$0FEF$	—	
$0FF0$	SIO1 transmit and receive data buffer	
$0FF7$	—	
$0FF8$	SIO2 transmit and receive data buffer	
$0FFF$	—	

Note 1: Do not access reserved areas by the program.
 Note 2: When defining address $003F_H$ with assembler symbols, use GPSW and GRBS.
 Note 3: — ; do not access.
 Note 4: Operations specified to writing registers and interrupt latches by read modifying write instructions (bit operation instructions such as SET, CLR, etc., or operation instructions such as AND, OR, etc.) are not effective.

Figure 2-1. SFR & DBR

2.2 I/O Ports

The TMP87CH21/H21B/M21 have 8 parallel input/output ports (52pins) each as follows:

	Primary Function	Secondary Functions
Port P1	8-bit I/O port	external interrupt input, timer/counter input/output, and divider output
Port P2	3-bit I/O port	low-frequency resonator connections, external interrupt input, and STOP mode release signal input
Port P3	5-bit I/O port	—
Port P4	8-bit I/O port	serial interface, timer/counter input/output, external interrupt input
Port P5	8-bit I/O port	analog input
Port P6	8-bit I/O port	segment output
Port P7	8-bit I/O port	segment output
Port P9	4-bit I/O port	segment output

Each output port contains a latch, which holds the output data. All input ports do not have latches, so the external input data should either be held externally until read or reading should be performed several times before processing. Figure 2-2 shows input/output timing examples.

External data is read from an I/O port in the S1 state of the read cycle during execution of the read instruction. This timing can not be recognized from outside, so that transient input such as chattering must be processed by the program.

Output data output changes in the S2 state of the write cycle during execution of the instruction which writes to an I/O port.

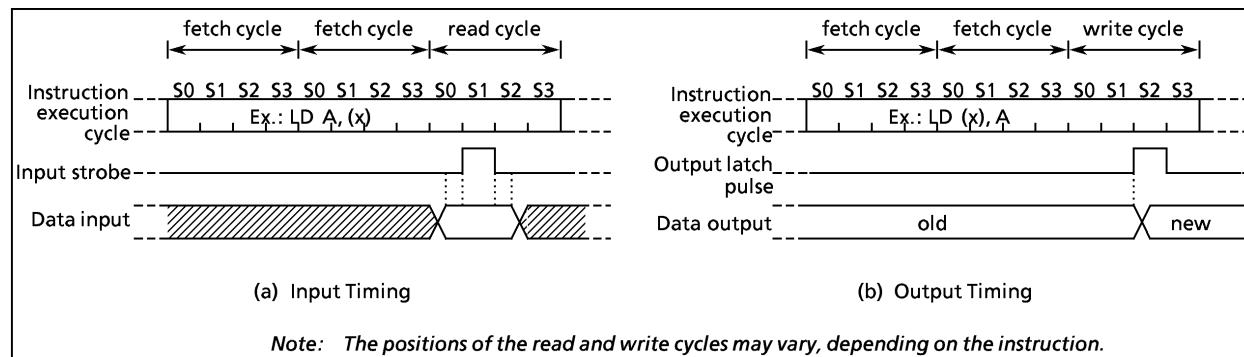


Figure 2-2. Input/Output Timing (Example)

When reading an I/O port except programmable I/O ports, whether the pin input data or the output latch contents are read depends on the instructions, as shown below:

(1) Instructions that read the output latch contents

① XCH r, (src)	⑤ LD (pp).b, CF
② CLR/SET/CPL (src).b	⑥ ADDADD/SUB/SUBB/AND/OR/XOR (src), n
③ CLR/SET/CPL (pp).g	⑦ (src) side of ADDADD/SUB/SUBB/AND/OR/XOR (src), (HL)
④ LD (src).b, CF	

(2) Instructions that read the pin input data

① Instructions other than the above (1)
② (HL) side of ADDADD/SUB/SUBB/AND/OR/XOR (src), (HL)

2.2.1 Port P1 (P17 to P10)

Port P1 is an 8-bit input/output port which can be configured as an input or an output in one-bit unit under software control. Input/output mode is specified by the corresponding bit in the port P1 input/output control register (P1CR). Port P1 is configured as an input if its corresponding P1CR bit is cleared to "0", and as an output if its corresponding P1CR bit is set to "1". During reset, the P1CR is initialized to "0", which configures port P1 as an input. The P1 output latches are also initialized to "0". Port P1 is also used as an external interrupt input, a timer/counter input, and a divider output. When used as secondary function pin, the input pins should be set to the input mode, and the output pins should be set to the output mode and beforehand the output latch should be set to "1".

It is recommended that pins P11 and P12 should be used as external interrupt inputs, timer/counter input, or input ports. The interrupt latch is set at the rising or falling edge of the output when used as output ports.

Pin P10 (INT0) can be configured as either an I/O port or an external interrupt input with INT0EN (bit 6 in EINTCR). During reset, pin P10 (INT0) is configured as an input port P10.

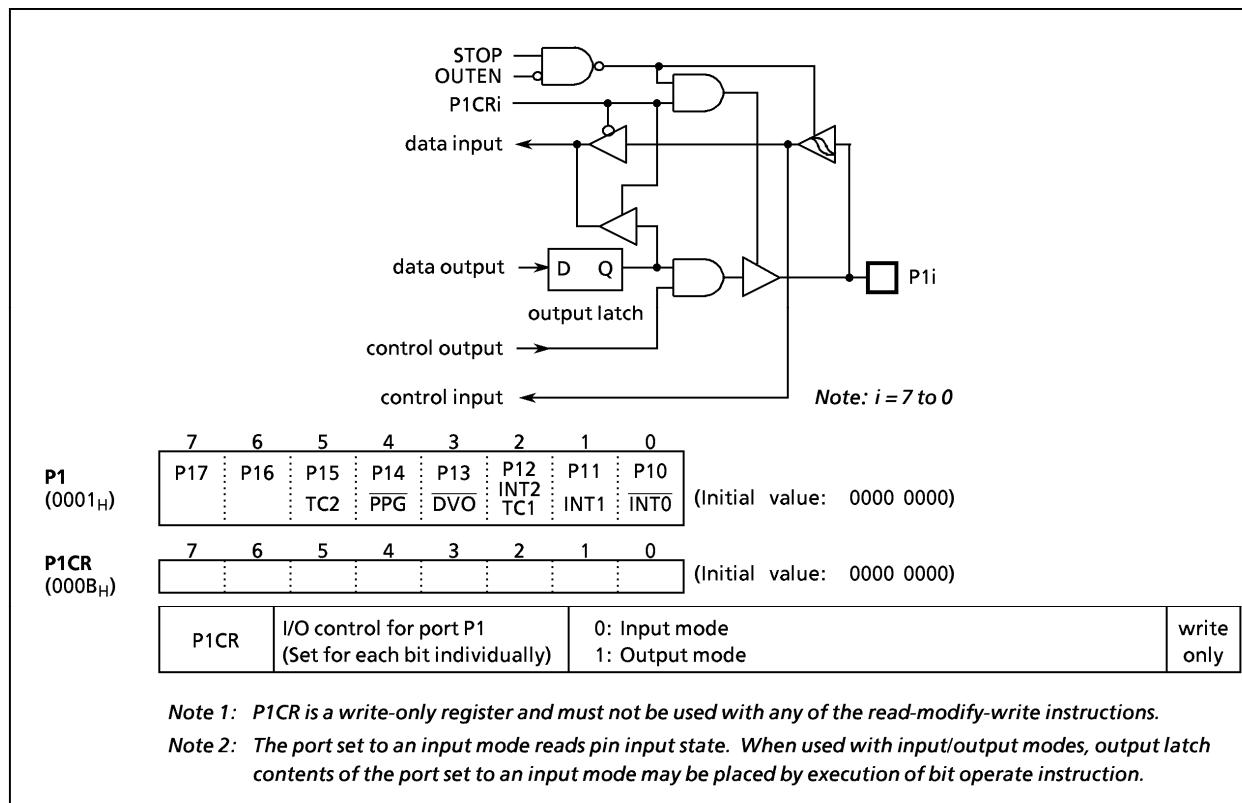


Figure 2-3. Port P1 and P1CR

Example: Sets P17, P16 and P14 as output ports, P13 and P11 as input ports, and the others as function pins. Internal output data is "1" for the P17 and P14 pins, and "0" for the P16 pin.

```

LD  (EINTCR), 0100000B ; INT0EN←1
LD  (P1), 1011111B      ; P17←1, P14←1, P16←0
LD  (P1CR), 1101000B
  
```

2.2.2 Port P2 (P22 to P20)

The P2 port is a 3-bit input/output port which is shared with external interrupt input, STOP mode clearing signal input, and low-frequency resonator connecting pin.

When using this port as one of these functional pins or an input port, set the output latch to "1". When reset, the output latch is initialized to "1".

A low-frequency crystal (32.768 kHz) is connected to pins P21 (XTIN) and P22 (XTOUT) in the dual-clock mode. In the single-clock mode, pins P21 and P22 can be used as normal input/output ports.

It is recommended that the P20 pin be used as external interrupt input, STOP mode clearing signal input, or an input port. (If this pin is used as an output port, the interrupt latch is set at a falling edge of the output pulse.)

When a read instruction is executed for port P2, bits 7 to 3 read in as indefinite.

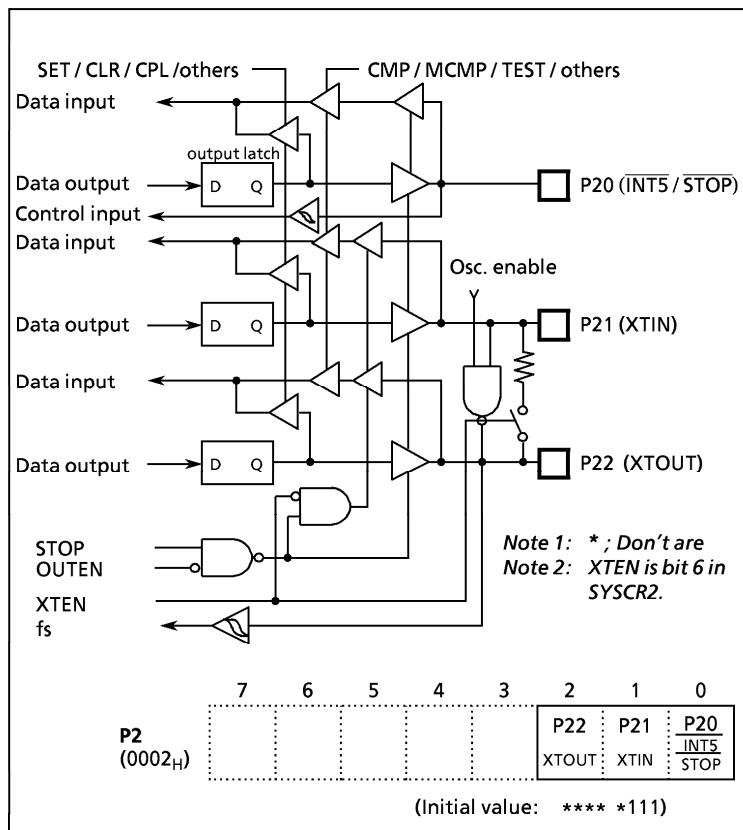


Figure 2-4. Port P2

2.2.3 Port P3 (P34 to P30)

Port P3 is an 5-bit input/output port. When used as an input port, the output latch should be set to "1". The output latches are initialized to "1" during reset.

Example 1: Output the immediate data 1AH to the P3 port.

LD (P3), 1AH; P3 \leftarrow 1AH

Example 2: Inverts the output of the lower 4bits (P33 to P30) of the P3 port.

XOR (P3), 00001111B
; P33 to P30 \leftarrow ~P33 to P30

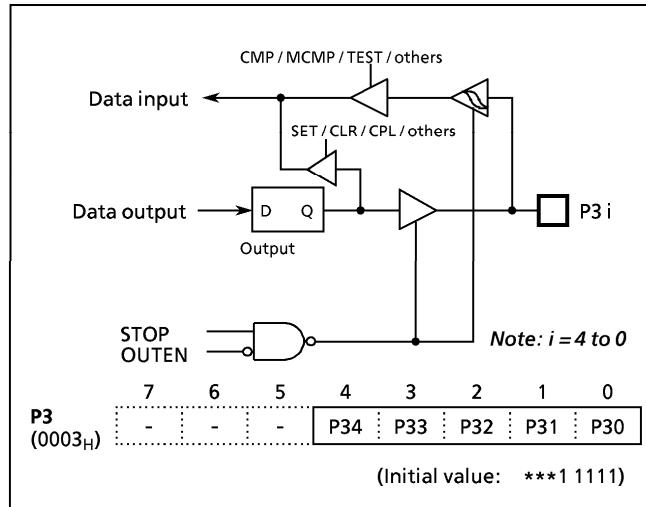


Figure 2-5. Port P3

2.2.4 Port P4 (P47 to P40)

The P4 port is an 8-bit general-purpose input/output port, each bit of which can be set for input or output and its output state can be selected individually. When used as secondary function pin, the input pins should be set to the input mode, and the output pins should be set to the output mode and beforehand the output latch should be set to "1". This port is shared with external interrupt input, timer-counter input/output, and serial interface input/output. Use the P4 port input/output control register 1 (P4CR1) to direct this port for input or output. For the output state of this port, use the P4 port input/output control register 2 (P4CR2) to choose "open-drain" or "push-pull". When reset, P4CR1 is set to "1", so that the P4 port is directed for output. Also, the P4 port's output latch is initialized to "1".

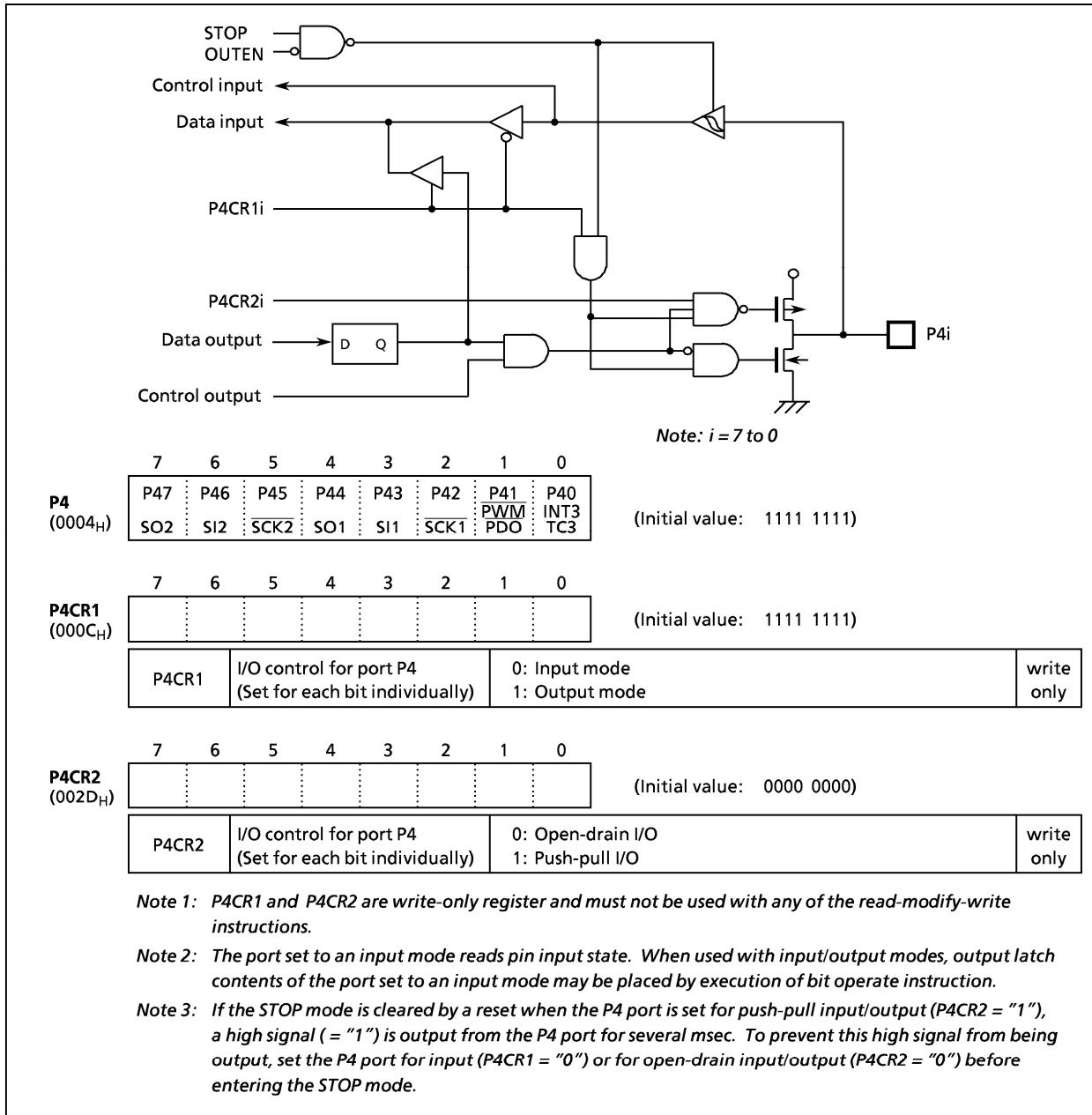


Figure 2-6. Port P4

2.2.5 Port P5 (P57 to P50)

Port P5 is a general-purpose 8-bit I/O port that can be specified bitwise. It is also used for analog input. Specify input or output using the P5 I/O control register (P5CR) and AINDS (bit 4 of ADCCR). At reset, the P5CR is set to 0; AINDS, to 1, setting port P5 to analog input. At reset, the output latch of port P5 is initialized to 0. The P5CR is write-only register. The pins of port P5 not specified for analog input can be used as an I/O port; to maintain accuracy, do not use them for output instructions during AD conversion. While the AD converter is operating, executing an input instruction writes "1" to pins specified for analog input; "1" or "0", to pins not specified for analog input depending on the pin input level.

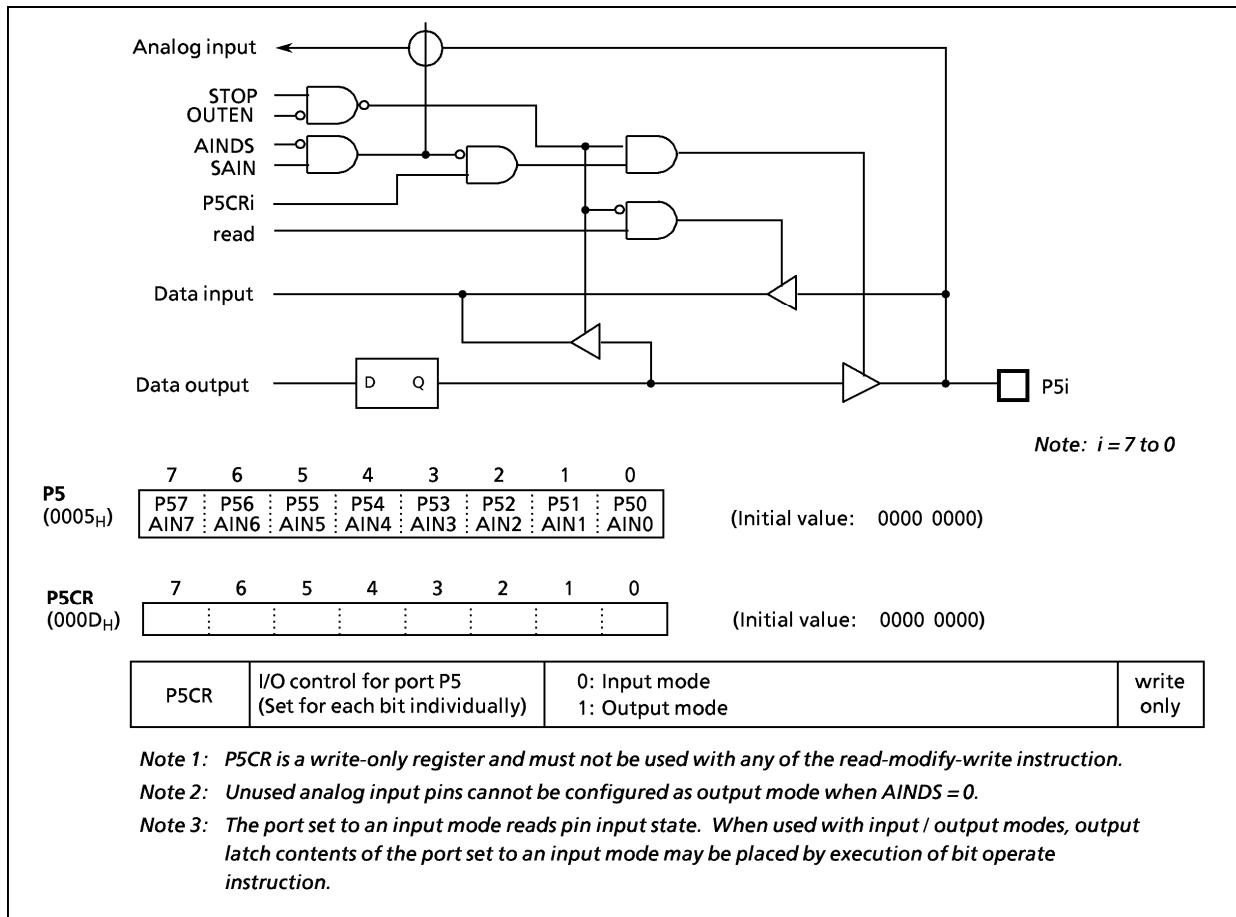


Figure 2-7. Port P5

2.2.6 Ports P6 (P67 to P60), P7 (P77 to P70), P9 (P93 to P90)

The P6, P7 and P9 ports are 8-bit or 4-bit input/output ports which are shared with the LCD driver's segment output. Use each port's control register (P6CR, P7CR, P9CR) to specify whether each port be used as an input/output port or for segment output.

When reset, each port's control register is cleared to "0", so that each port functions as an input/output port. To use these ports as an input port, set their output latch to "1". When reset, each port's output latch is initialized to "1".

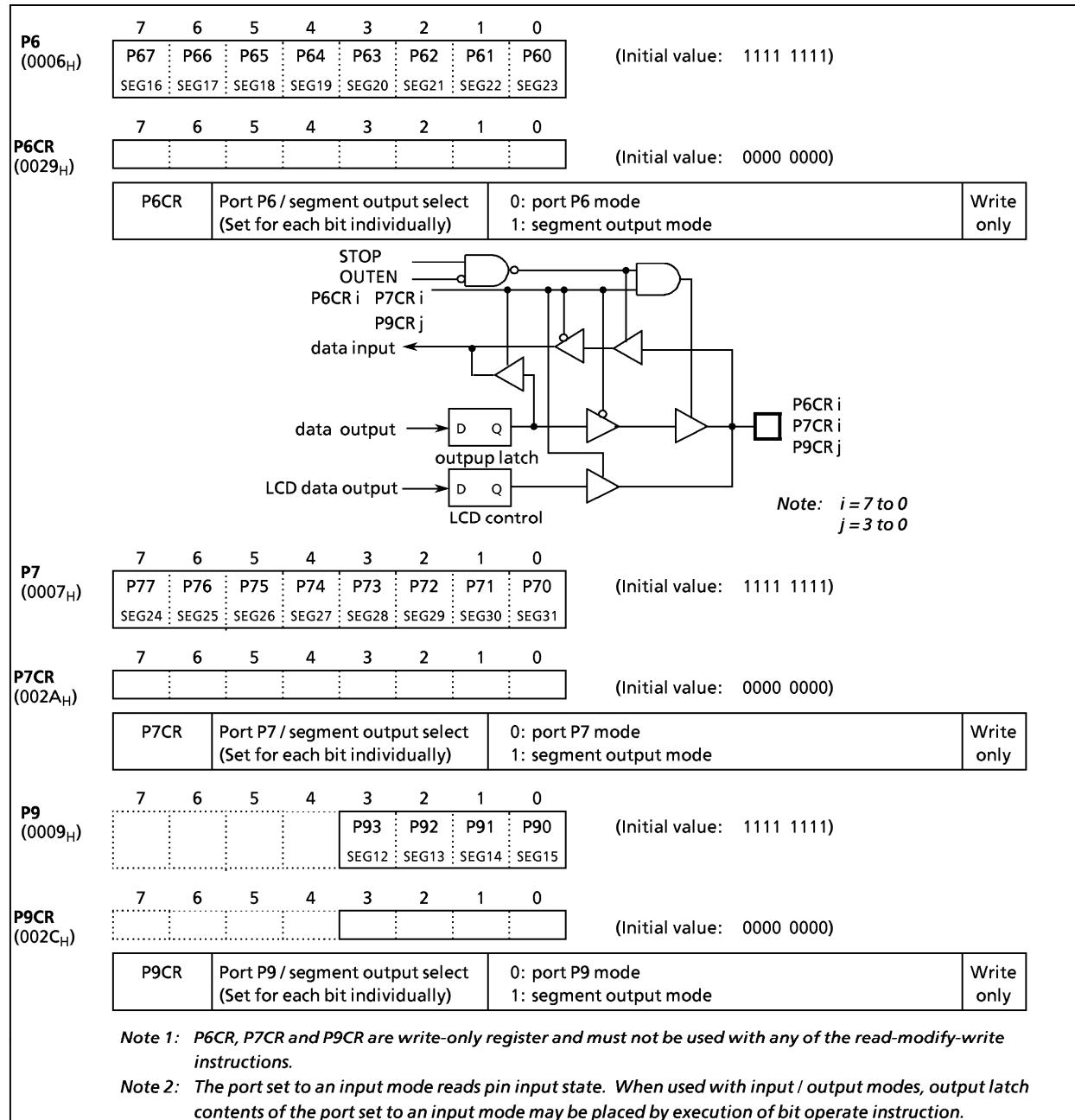


Figure 2-8. Port P6, P7, P9

Example: Setting the upper 2 bits of port P6 as a segment output port, and the others as input/output port.

LD (P6CR), 11000000B

2.3 Time Base Timer (TBT)

The time base timer is a timer for generating the base time, which generates a time base timer interrupt (INTTBT) per fixed period.

An INTTBT is generated on the first rising edge of the source clock (the divider output of the timing generator selected by TBTCR<TBTC>) after the time base timer is enabled.

Note 1: Because the divider is not cleared by the program, only the first interrupt may be generated ahead of the set interrupt period (Figure 2-9).

Note 2: Select the interrupt frequency with the time base timer disabled. (Do not also change the interrupt frequency when the time base timer is changed from enabled state to disabled state.)

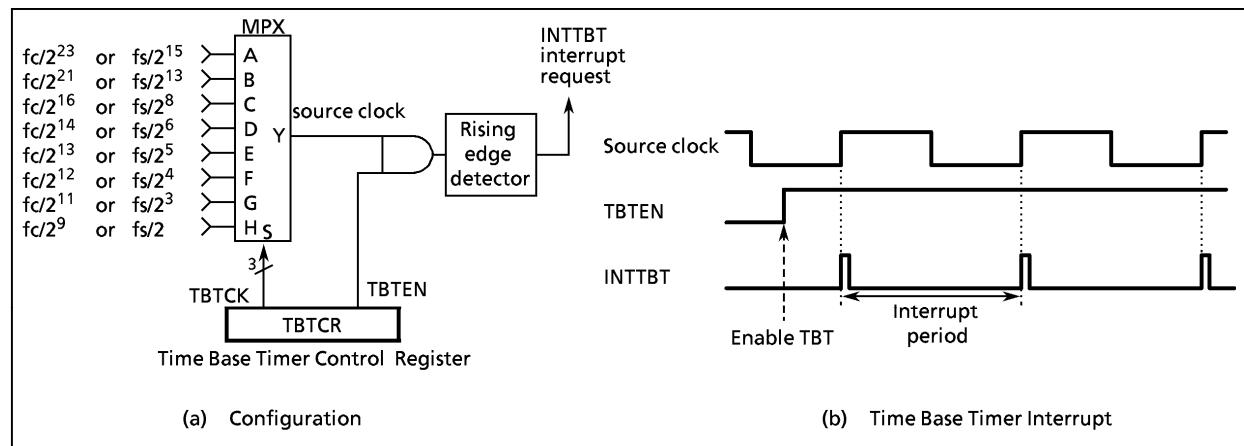


Figure 2-9. Time Base Timer

TBTCR (0036H)								(Initial value: 0**0 0***)
7	6	5	4	3	2	1	0	
(DVOEN)		(DVQCK)		(DV7CK)	TBTEN	TBTCK		
TBTEN		Time base timer enable/disable		0: Disable 1: Enable				
TBTCK		Time base timer interrupt frequency select		000: $fc/2^{23}$ or $fs/2^{15}$ [Hz] 001: $fc/2^{21}$ or $fs/2^{13}$ 010: $fc/2^{16}$ or $fs/2^8$ 011: $fc/2^{14}$ or $fs/2^6$ 100: $fc/2^{13}$ or $fs/2^5$ 101: $fc/2^{12}$ or $fs/2^4$ 110: $fc/2^{11}$ or $fs/2^3$ 111: $fc/2^9$ or $fs/2$				R/W

*Note: fc; High-frequency clock [Hz], fs; Low-frequency clock [Hz], *; Don't care*

Figure 2-10. Time Base Timer and Divider Output Control Register

Example: Set the time base timer interrupt frequency to $fc/2^{16}$ [Hz] and enable on INTTBT interrupt.

LD (TBTCR), 00001010B
SET (EIRL). 6

Table 2-1. Time Base Timer Interrupt Frequency

TBTCK	NORMAL1/2, IDLE1/2 mode		SLOW, SLEEP mode	Interrupt Frequency	
	DV7CK = 0	DV7CK = 1		At $f_c = 8$ MHz	At $f_s = 32.768$ kHz
000	$f_c/2^{23}$	$f_s/2^{15}$	$f_s/2^{15}$	0.95 Hz	1 Hz
001	$f_c/2^{21}$	$f_s/2^{13}$	$f_s/2^{13}$	3.81	4
010	$f_c/2^{16}$	$f_s/2^8$	–	122.07	128
011	$f_c/2^{14}$	$f_s/2^6$	–	488.28	512
100	$f_c/2^{13}$	$f_s/2^5$	–	976.56	1024
101	$f_c/2^{12}$	$f_s/2^4$	–	1953.12	2048
110	$f_c/2^{11}$	$f_s/2^3$	–	3906.25	4096
111	$f_c/2^9$	$f_s/2$	–	15625	16384

2.4 Divider Output (DVO)

TBTCR (0036H)								(Initial value: 0**0 0***)
7	6	5	4	3	2	1	0	
DVOEN	DVOCK	(DV7CK)	(TB7EN)		(TB7CK)			
DVOEN	Divider output enable/disable	0: Disable 1: Enable						R/W
DVOCK	Divider output (DVO) frequency selection	00: $fc/2^{13}$ or $fs/2^5$ [Hz] 01: $fc/2^{12}$ or $fs/2^4$ 10: $fc/2^{11}$ or $fs/2^3$ 11: $fc/2^{10}$ or $fs/2^2$						R/W

*Note: fc; High-frequency clock [Hz], fs; Low-frequency clock [Hz], *; Don't care*

Figure 2-11. Divider Output Control Register

A 50% duty pulse can be output using the divider output circuit, which is useful for piezo-electric buzzer drive. Divider output is from pin P13 (DVO). The P13 output latch should be set to "1" and then the P13 should be configured as an output mode.

Divider output circuit is controlled by the control register (TBTCR) shown in Figure 2-11.

Note: Selection of divider output frequency must be made while divider output is disabled.

Example: Approximate 1 kHz pulse output (at $fc = 8$ MHz)

```
SET (P1).3 ; P13 output latch ← 1
LD (P1CR), 00001000B ; Configures P13 as an output mode
LD (TBTCR), 10000000B ; DVOEN←1, DVOCK←00
```

Table 2-2. Frequency of Divider Output

DVOCK	Frequency of Divider Output	At $fc = 4.194304$ MHz	At $fc = 8$ MHz	At $fs = 32.768$ kHz
00	$fc/2^{13}$ or $fs/2^5$	0.512 [kHz]	0.976 [kHz]	1.024 [kHz]
01	$fc/2^{12}$ or $fs/2^4$	1.024	1.953	2.048
10	$fc/2^{11}$ or $fs/2^3$	2.048	3.906	4.096
11	$fc/2^{10}$ or $fs/2^2$	4.096	7.812	8.192

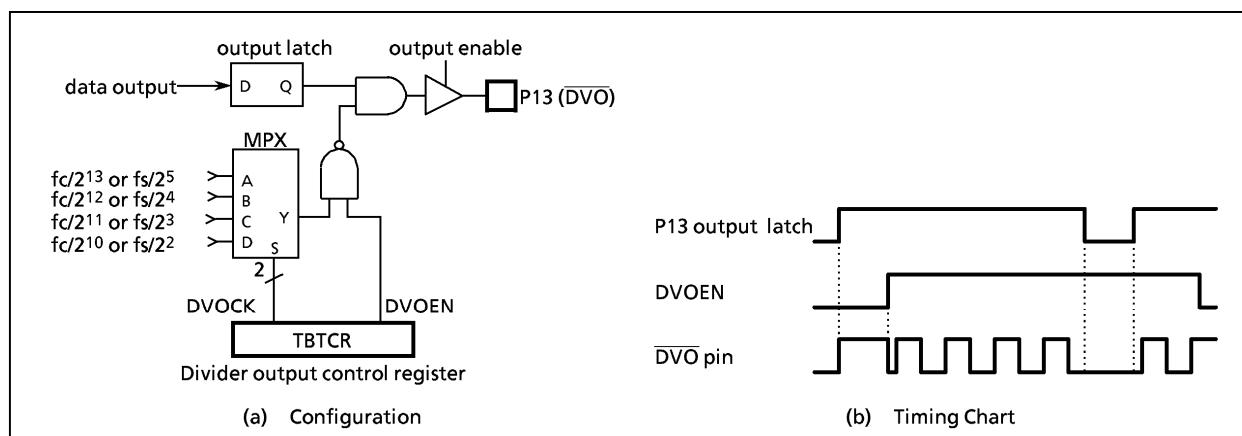


Figure 2-12. Divider Output

2.5 16-bit Timer/Counter 1 (TC1)

2.5.1 Configuration

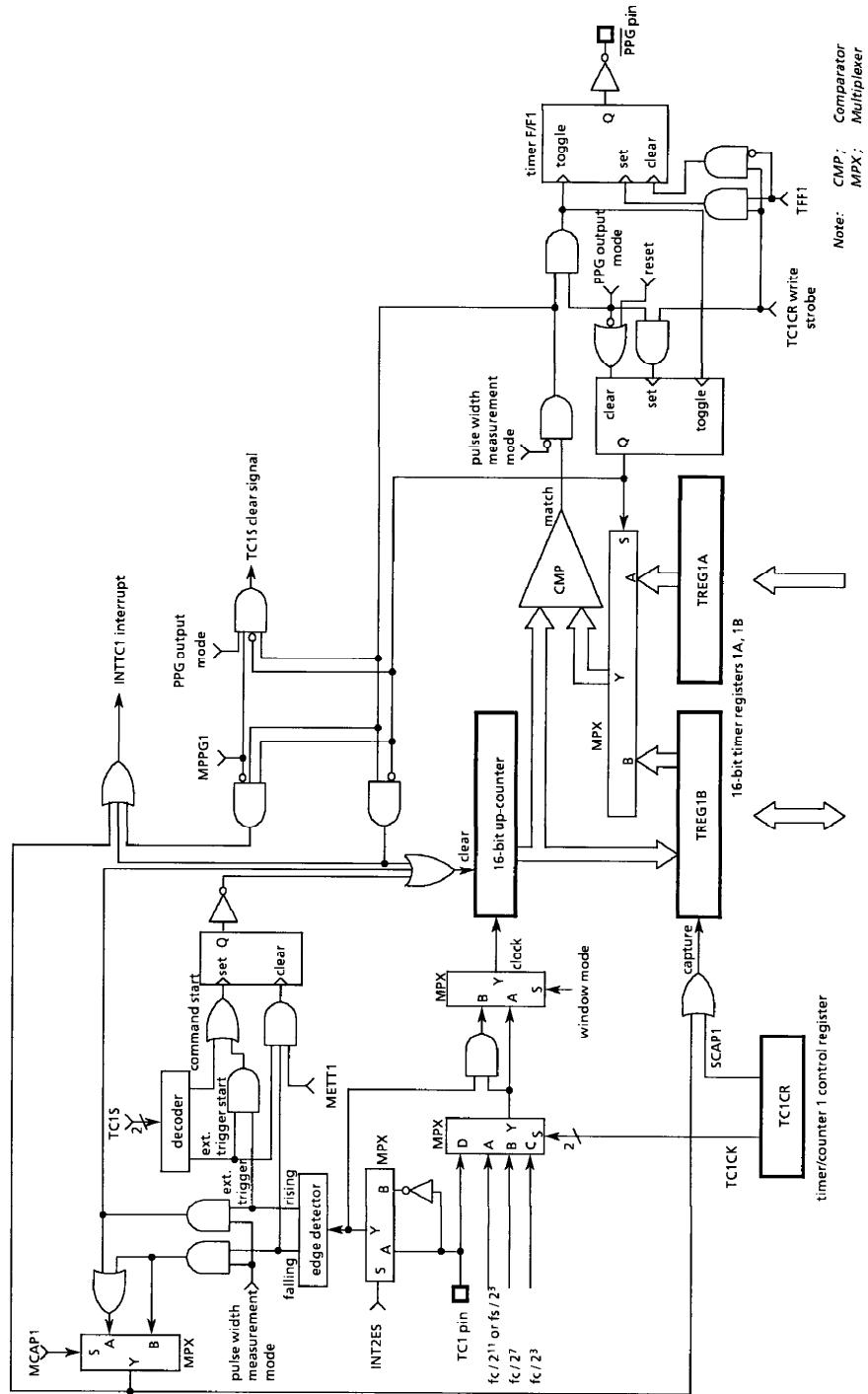


Figure 2-13. Timer/Counter 1 (TC1)

2.5.2 Control

The timer/counter 1 is controlled by a timer/counter 1 control register (TC1CR) and two 16-bit timer registers (TREG1A and TREG1B). Reset does not affect TREG1A and TREG1B.

<table border="1"> <tr> <td colspan="16" style="text-align: center;">15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0</td></tr> <tr> <td colspan="8" style="text-align: center;">TREG1A_H (0011_H)</td><td colspan="8" rowspan="2" style="text-align: center;">TREG1A_L (0010_H)</td></tr> <tr> <td colspan="16" style="text-align: center;">Write only</td></tr> <tr> <td colspan="8" style="text-align: center;">TREG1B_H (0013_H)</td><td colspan="8" rowspan="2" style="text-align: center;">TREG1B_L (0012_H)</td></tr> <tr> <td colspan="16" style="text-align: center;">Read / Write (Write available in only PPG output mode)</td></tr> <tr> <td colspan="2" style="text-align: center;">TC1CR (0014_H)</td><td colspan="2" style="text-align: center;">TFF1</td><td colspan="2" rowspan="9" style="text-align: center;">SCAP1 MCAP1 METT1 MPPG1</td><td colspan="2" style="text-align: center;">TC1S</td><td colspan="2" rowspan="9" style="text-align: center;">TC1CK</td><td colspan="2" rowspan="9" style="text-align: center;">TC1M</td><td colspan="8" style="text-align: center;">(Initial value: 0000 0000)</td></tr> <tr> <td colspan="2" style="text-align: center;">TC1M</td><td colspan="4" style="text-align: center;">TC1 mode select</td><td colspan="10"> 00: timer / external trigger timer / event counter mode 01: window mode 10: pulse width measurement mode 11: PPG output mode </td><td rowspan="8" style="vertical-align: middle; text-align: center;">Write only</td></tr> <tr> <td colspan="2" style="text-align: center;">TC1CK</td><td colspan="4" style="text-align: center;">TC1 source clock select</td><td colspan="12"> 00: internal clock $fc/2^{11}$ or $fs/2^3$ [Hz] 01: internal clock $fc/2^7$ 10: internal clock $fc/2^3$ 11: external clock (TC1 pin input) </td></tr> <tr> <td colspan="2" style="text-align: center;">TC1S</td><td colspan="4" style="text-align: center;">TC1 start control</td><td colspan="11"> 00: stop & counter clear 01: command start 10: reserved 11: external trigger start </td></tr> <tr> <td colspan="2" style="text-align: center;">SCAP1</td><td colspan="4" style="text-align: center;">software capture control</td><td colspan="11"> 0: - 1: software capture trigger (Note 3) </td></tr> <tr> <td colspan="2" style="text-align: center;">MCAP1</td><td colspan="4" style="text-align: center;">pulse width measurement control</td><td colspan="11"> 1: double edge capture 1: single edge capture </td></tr> <tr> <td colspan="2" style="text-align: center;">METT1</td><td colspan="4" style="text-align: center;">external trigger timer control</td><td colspan="11"> 0: trigger start 1: trigger start & stop </td></tr> <tr> <td colspan="2" style="text-align: center;">MPPG1</td><td colspan="4" style="text-align: center;">PPG output control</td><td colspan="11"> 0: continuous pulse 1: single pulse </td></tr> <tr> <td colspan="2" style="text-align: center;">TFF1</td><td colspan="4" style="text-align: center;">timer F/F1 control for PPG output mode</td><td colspan="11"> 0: clear 1: set </td></tr> </table>	15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0																TREG1A _H (0011 _H)								TREG1A _L (0010 _H)								Write only																TREG1B _H (0013 _H)								TREG1B _L (0012 _H)								Read / Write (Write available in only PPG output mode)																TC1CR (0014 _H)		TFF1		SCAP1 MCAP1 METT1 MPPG1		TC1S		TC1CK		TC1M		(Initial value: 0000 0000)								TC1M		TC1 mode select				00: timer / external trigger timer / event counter mode 01: window mode 10: pulse width measurement mode 11: PPG output mode										Write only	TC1CK		TC1 source clock select				00: internal clock $fc/2^{11}$ or $fs/2^3$ [Hz] 01: internal clock $fc/2^7$ 10: internal clock $fc/2^3$ 11: external clock (TC1 pin input)												TC1S		TC1 start control				00: stop & counter clear 01: command start 10: reserved 11: external trigger start											SCAP1		software capture control				0: - 1: software capture trigger (Note 3)											MCAP1		pulse width measurement control				1: double edge capture 1: single edge capture											METT1		external trigger timer control				0: trigger start 1: trigger start & stop											MPPG1		PPG output control				0: continuous pulse 1: single pulse											TFF1		timer F/F1 control for PPG output mode				0: clear 1: set										
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TFF1		timer F/F1 control for PPG output mode				0: clear 1: set																																																																																																																																																																																																																																							
<p>Note 1: fc; High-frequency clock [Hz], fs; Low-frequency clock [Hz]</p> <p>Note 2: Writing to the low-byte of the timer registers (TREG1A_L, TREG1B_L), the comparison is inhibited until the high-byte (TREG1A_H, TREG1B_H) is written. (Only the low-byte of the timer registers cannot be changed.) After writing to the high-byte, the comparison of 1 machine cycle(during instruction execution) is ignored.</p> <p>Note 3: Set the mode, source clock, edge (INT2ES), PPG control and timer F/F control when TC1 stops (TC1S = 00).</p> <p>Note 4: Software capture can be used in only timer and event counter modes. SCAP1 is automatically cleared to "0" after software capture.</p> <p>Note 5: Values to be loaded to timer registers must satisfy the following condition. $TREG1A > TREG1B > 0$ (PPG output mode) ; $TREG1A > 0$ (others) </p> <p>Note 6: Always write "0" to TFF1 except the PPG output mode.</p> <p>Note 7: TREG1B cannot be written after setting to PPG output mode.</p> <p>Note 8: TC1CR is a write-only register, which cannot be accessed by any read-modify-write instruction such as bit operate, etc.</p> <p>Note 9: When selecting $fc/2^3$ source clock in the pulse width measurement mode, the last bit (bit 0) of counter value (TREG1B) to be read is always "0". The other source clock can be read the counter value corresponded to the counting.</p>																																																																																																																																																																																																																																													

Figure 2-14. Timer Registers and TC1 Control Register

2.5.3 Function

Timer/counter 1 has six operating modes: timer, external trigger timer, event counter, window, pulse width measurement, programmable pulse generator output mode.

(1) Timer Mode

In this mode, counting up is performed using the internal clock. The contents of TREG1A are compared with the contents of up-counter. If a match is found, an INTTC1 interrupt is generated, and the counter is cleared to "0". Counting up resumes after the counter is cleared. The current contents of up-counter can be transferred to TREG1B by setting SCAP1 (bit 6 in TC1CR) to "1" (software capture function). SCAP1 is automatically cleared to "0" after capturing.

Table 2-3. Timer/Counter 1 Source Clock (Internal Clock)

Source clock		Resolution		Maximum time setting	
NORMAL1/2, IDLE1/2 modes					
DV7CK = 0	DV7CK = 1	SLOW, SLEEP modes	At $f_c = 8$ MHz	At $f_s = 32.768$ kHz	At $f_c = 8$ MHz
$f_c/2^{11}$	$f_s/2^3$	$f_s/2^3$ [Hz]	256 μ s	244.14 μ s	16.8 s
$f_c/2^7$	$f_c/2^7$	—	16 μ s	—	1.0 s
$f_c/2^3$ [Hz]	$f_c/2^3$ [Hz]	—	1 μ s	—	65.5 ms

Example 1: Sets the timer mode with source clock $f_s/2^3$ [Hz] and generates an interrupt 1 s. later (at $f_s = 32.768$ kHz).

```

LD   (TC1CR), 00000000B ; Sets the TC1 mode and source clock
LDW  (TREG1A), 1000H      ; Sets the timer register (1 s ÷ 23/fs = 1000H)
SET  (EIRL).EF4          ; enable INTTC1
EI
LD   (TC1CR), 00010000B ; Starts TC1

```

Note: TC1CR is a write-only register, which cannot start by [SET(TC1CR).4] instruction.

Example 2: Software capture

```

LD   (TC1CR), 01010000B ; SCAP1←1 (Captures)
LD   WA, (TREG1B)        ; Reads captured value

```

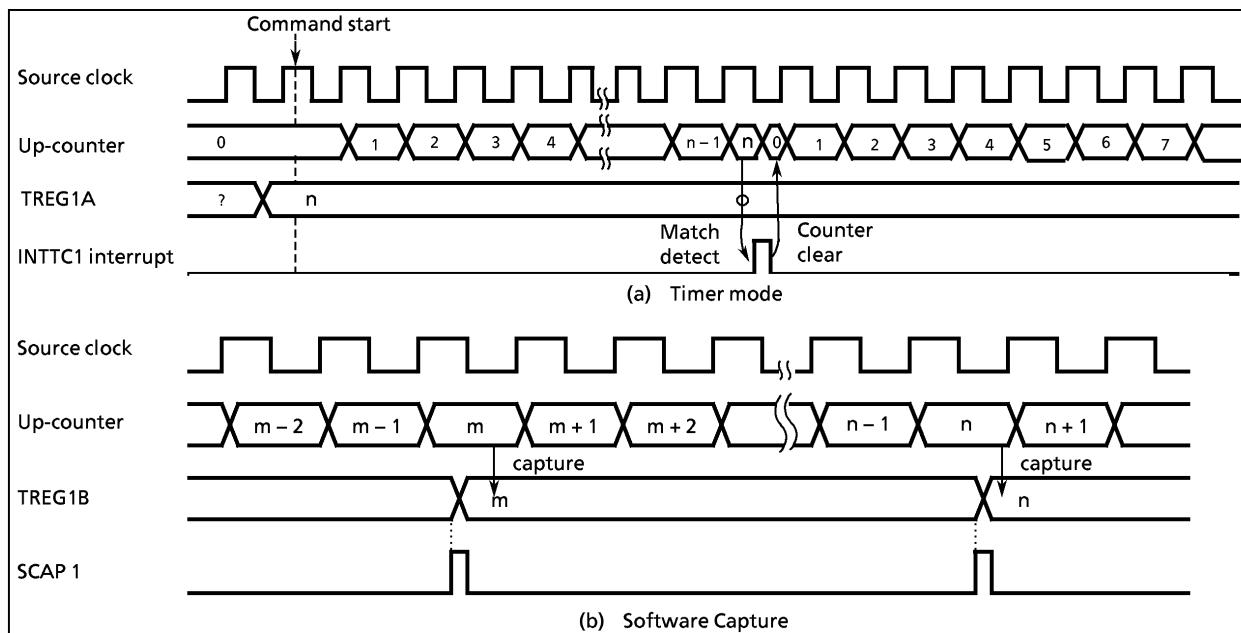


Figure 2-15. Timer Mode Timing Chart

(2) External Trigger Timer mode

In this mode, counting up is started by an external trigger. This trigger is the edge of the TC1 pin input. Either the rising or falling edge can be selected with INT2ES. Edge selection is the same as for the external interrupt input INT2 pin. Source clock is used an internal clock selected with TC1CK. The contents of TREG1A is compared with the contents of up-counter. If a match is found, an INTTC1 interrupt is generated, and the counter is cleared to "0" and halted. The counter is restarted by the selected edge of the TC1 pin input.

When the edge input is opposite to the edge input way of the count start trigger at METTI (bit 6 in TC1CR) = 1, the counter is cleared, and count stops. In this mode, pulse input with a constant pulse width generates interrupt. When METT1 is "0", the opposite edge input is ignored. The edge of TC1 pin input before match detection is also ignored.

The TC1 pin input has the same noise rejection as the INT2 pin; therefore, pulses of $7/fc$ [s] or less are rejected as noise. A pulse width of $24/fc$ [s] or more is required for edge detection in NORMAL1/2 or IDLE1/2 mode. The noise rejection circuit is turned off in SLOW and SLEEP modes. But, a pulse width of 1 machine cycle or more is required.

Example 1: Generates interrupt after $100 \mu s$ from TC1 pin input rising edge (at $fc = 8$ MHz).

```

LD  (EINTCR), 0000000B ; INT2ES←0 (rising edge)
LDW (TREG1A), 0064H    ;  $100 \mu s \div 2^3/fc = 64H$ 
SET (EIRL).EF4        ; Enables INTTC1 interrupt
EI
LD  (TC1CR), 00111000B ; Starts TC1 external trigger, METT = 0

```

Example 2: When "L" level pulses of 4 ms or more is input to TC1 pin, generates interrupt.
(at $f_c = 8$ MHz)

```

LD  (EINTCR), 00000100B ; INT2ES<-1 ("L" level)
LDW (TREG1A), 00FAH      ; 4 ms ÷ 27/ $f_c$  = FAH
SET (EIRL).EF4          ; Enables INTTC1 interrupt
EI
LD  (TC1CR), 01110100B ; Starts TC1 external trigger , METT = 1

```

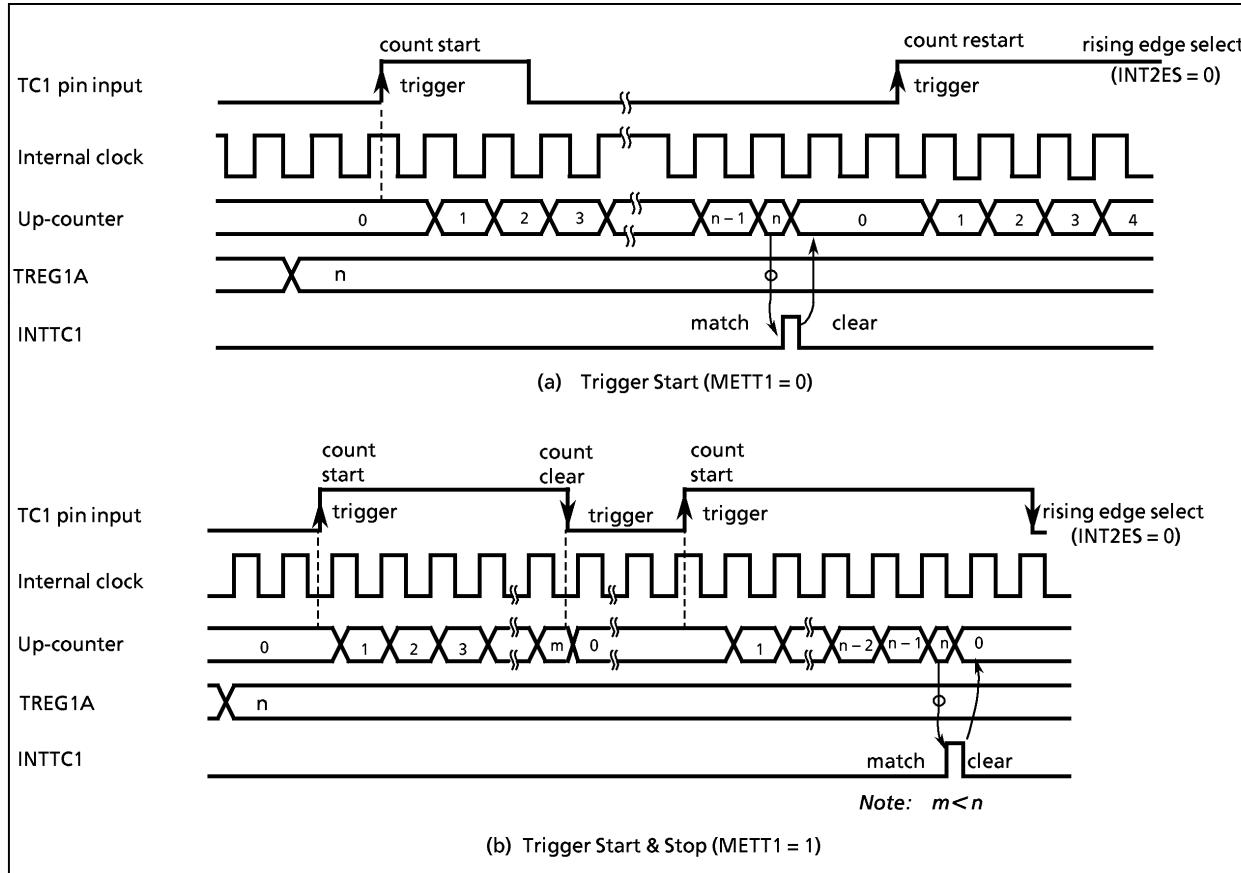


Figure 2-16. External Trigger Timer Mode Timing Chart

(3) Event Counter Mode

In this mode, events are counted on the edge of the TC1 pin input. Either the rising or falling edge can be selected with INT2ES in EINTCR. The contents of TREG1A are compared with the contents of up-counter. If a match is found, an INTTC1 interrupt is generated, and the counter is cleared. Counting up resumes after the counter is cleared. The maximum applied frequency is $f_c/2^4$ [Hz] in NORMAL1/2 or IDLE1/2 mode and $f_s/2^4$ [Hz] in SLOW or SLEEP mode.

Setting SCAP1 to "1" transfers the current contents of up-counter to TREG1B (software capture function). SCAP is automatically cleared after capturing.

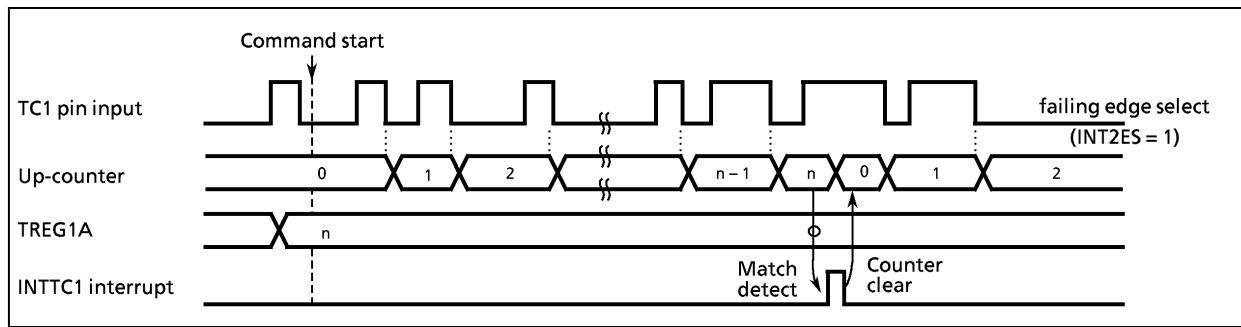


Figure 2-17. Event Counter Mode Timing Chart (INT2ES = 1)

(4) Window mode

Counting up is performed on the rising edge of the pulse that is the logical AND-ed product of the TC1 pin input (window pulse) and an internal clock. The contents of TREG1A are compared with the contents of up-counter. If a match is found, an INTTC1 interrupt is generated, and the counter is cleared. Positive or negative logic for the TC1 pin input can be selected with INT2ES. Setting SCAP1 to "1" transfers the current contents of up-counter to TREG1B. It is necessary that the maximum applied frequency (TC1 input) be such that the counter value can be analyzed by the program. That is, the frequency must be considerably slower than the selected internal clock.

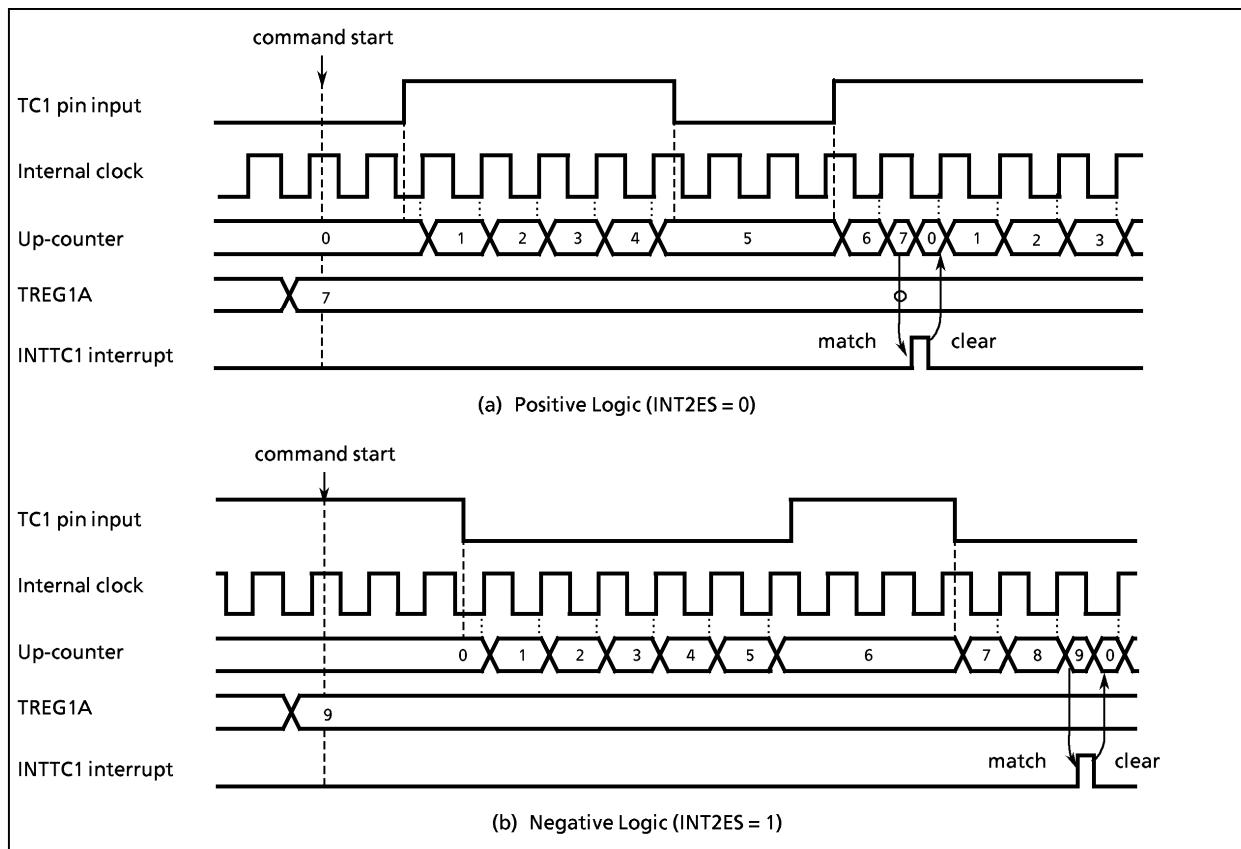


Figure 2-18. Window Mode Timing Chart

(5) Pulse width measurement mode

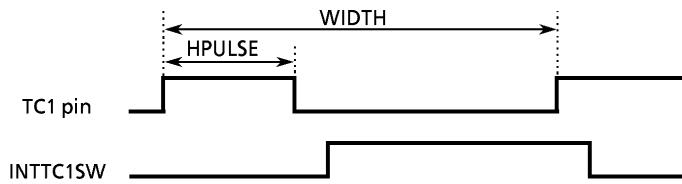
Counting is started by the external trigger (set to external trigger start by TC1S). The trigger can be selected either the rising or falling edge of the TC1 pin input. The source clock is used an internal clock. On the next falling (rising) edge, the counter contents are transferred to TREG1B and an INTTC1 interrupt is generated. The counter is cleared when the single edge capture mode is set. When double edge capture is set, the counter continues and, at the next rising (falling) edge, the counter contents are again transferred to TREG1B. If a falling (rising) edge capture value is required, it is necessary to read out TREG1B contents until a rising (falling) edge is detected. Falling or rising edge is selected with INT2ES, and single edge or double edge is selected with MCAP1 (bit 6 in TC1CR).

Example: Duty measurement (Resolution $fc/2^7$ [Hz])

```

CLR  (INTTC1SW).0          ; INTTC1 service switch initial setting
LD   (EINTCR), 0000000B    ; Sets the rise edge at the INT2 edge
LD   (TC1CR), 00000110B    ; Sets the TC1 mode and source clock
SET  (EIRL).4              ; Enables INTTC1
EI
LD   (TC1CR), 00110110B    ; Starts TC1 with an external trigger
:
PINTTC1 : CPL  (INTTC1SW).0          ; Complements INTTC1 service switch
JRS  F, SINTTC1
LD   (HPULSE), (TREG1BL)        ; Reads TREG1B
LD   (HPULSE + 1), (TREG1BH)
RETI
SINTTC1 : LD   (WIDTH), (TREG1BL)    ; Reads TREG1B (Period)
LD   (WIDTH + 1), (TREG1BH)
:
RETI
:
VINTTC1 : DW   PINTTC1

```



Note: When selecting $fc/2^3$ source clock in the pulse width measurement mode, the last bit (bit 0) of counter value (TREG1B) to be read is always "0". The other source clock can be read the counter value corresponded to the counting.

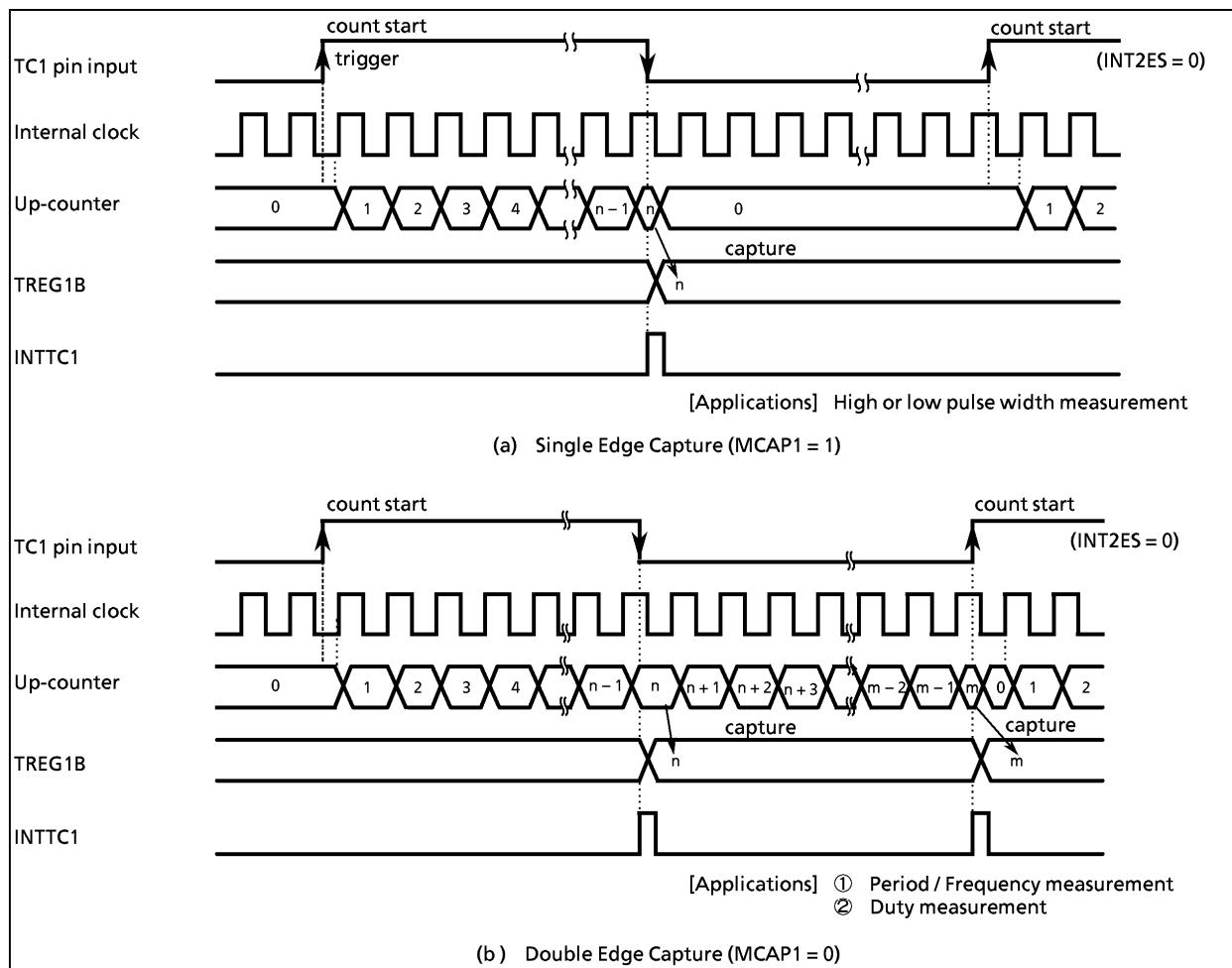


Figure 2-19. Pulse Width Measurement Mode Timing Chart

(6) Programmable Pulse Generate (PPG) output mode

Counting is started by an edge of the TC1 pin input (either the rising or falling edge can be selected by INT2ES of EINTCR) or by a command. The source clock is used an internal clock. First, the contents of TREG1B are compared with the contents of the up-counter. If a match is found, timer F/F1 output is toggled. Next, timer F/F1 is again toggled and the counter is cleared by matching with TREG1A. An INTTC1 interrupt is generated at this time. Timer F/F output is inverted and connected to the P14 (PPG) pin. In the case of PPG output, set the P14 output latch to "1" and configure as an output with P1CR4. Timer F/F1 is cleared to "0" during reset. The timer F/F1 value can also be set by program and either a positive or negative logic pulse output is available. Also, writing to the TREG1B is not possible unless the timer / counter 1 is set to the PPG output mode.

Example: "H" level 800 μ s, "L" level 200 μ s pulse output at $f_c = 8$ MHz

```

SET  (P1).4          ; P14 output latch←1
LD   (P1CR), 00010000B ; Sets P14 to an output mode
LD   (TC1CR), 10001011B ; Sets PPG output mode
LDW  (TREG1A), 03E8H    ; Sets a period (1 ms ÷ 1  $\mu$ s = 03E8H)
LDW  (TREG1B), 00C8H    ; Sets "L" level pulse width (200  $\mu$ s ÷ 1  $\mu$ s = 00C8H)
LD   (TC1CR), 10010011B ; Start

```

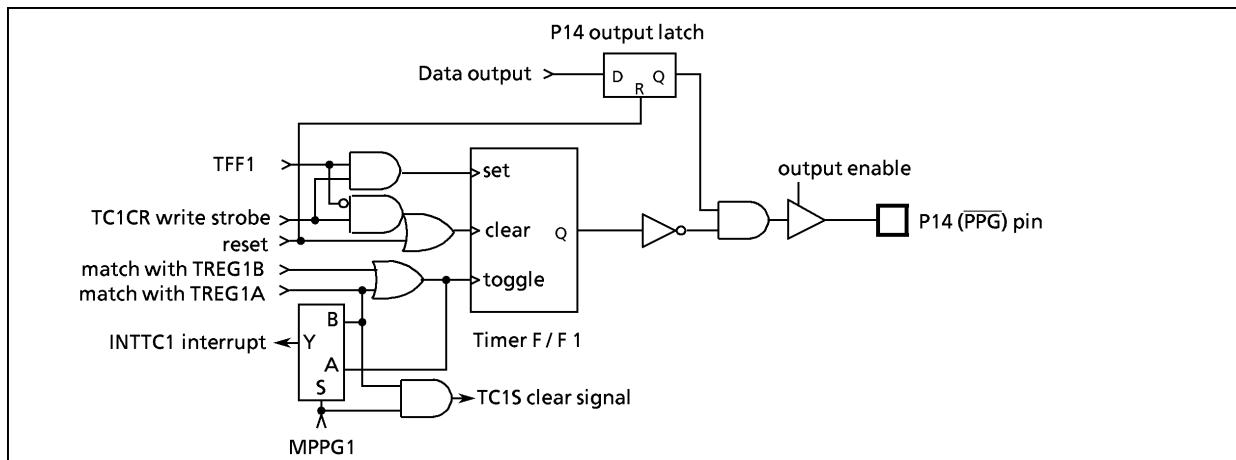
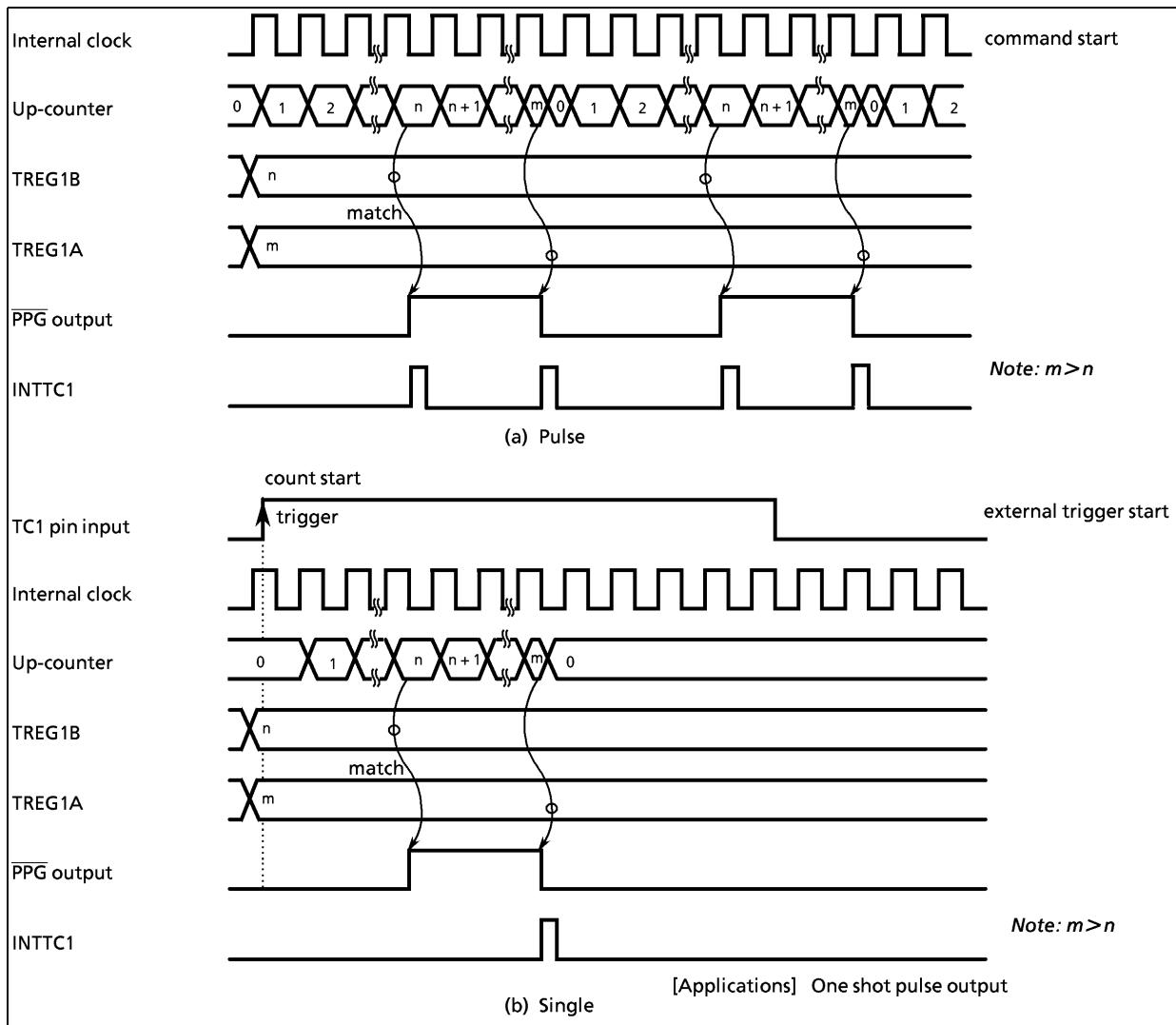
Figure 2-20. $\overline{\text{PPG}}$ Output

Figure 2-21. PPG Output Mode Timing Chart

2.6 16-bit Timer/Counter 2 (TC2)

2.6.1 Configuration

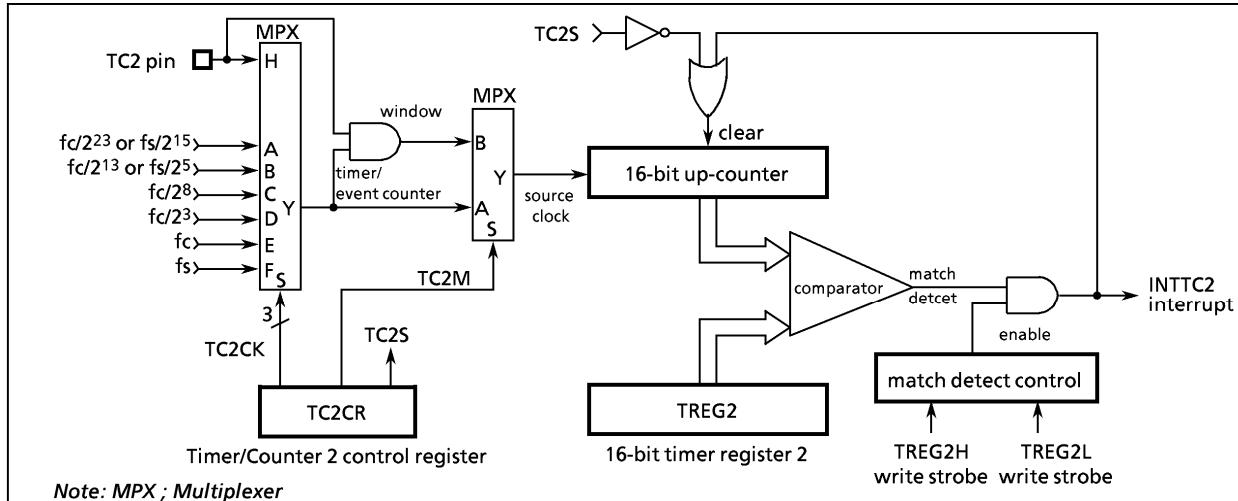


Figure 2-22. Timer/Counter 2 (TC2)

2.6.2 Control

The timer/counter 2 is controlled by a timer/counter 2 control register (TC2CR) and a 16-bit timer register 2 (TREG2). Reset does not affect TREG2.

TREG2 (0016, 0017 _H)																	
TREG2 _H (0017 _H)								TREG2 _L (0016 _H)									
write only																	
TC2CR (0015 _H)								(Initial value: **00 00*0)									
TC2M								0: Timer/Event counter mode 1: Window mode									
TC2CK								000: Internal clock fc/2 ²³ or fs/2 ¹⁵ [Hz] 001: " fc/2 ¹³ or fs/2 ⁵ 010: " fc/2 ⁸ 011: " fc/2 ³ 100: " fc (Note 5) 101: " fs 110: Reserved 111: External clock (TC2 pin input)								Write only	
TC2S								0: Stop and counter clear 1: Start									

Note 1: fc; High-frequency clock [Hz], fs; Low-frequency clock [Hz], *; Don't care
 Note 2: When writing to the low-byte of timer register 2 (TREG2_L), the comparison is inhibited until the high-byte (TREG2_H) is written.
 After writing to the high-byte, any match during 1 machine cycle (instruction execution cycle) is ignored.
 Note 3: Set the mode and source clock when timer/counter stops (TC2S = 0).
 Note 4: Values to be loaded to the timer register must satisfy the following condition.
 TREG2 > 0 (TREG2_{15 to 11} > 0 when warm-up).
 Note 5: "fc" can be selected as the source clock only in the timer mode during the SLOW mode.
 Note 6: TC2CR is a write-only register, which cannot access any of in read-modify-write instruction such as bit operate, etc.

Figure 2-23. Timer Register 2 and TC2 Control Register

2.6.3 Function

The timer/counter 2 has three operating modes: timer, event counter and window modes. Also timer/counter 2 is used for warm-up when switching from SLOW mode to NORMAL2 mode.

(1) Timer Mode

In this mode, the internal clock is used for counting up. The contents of TREG2 are compared with the contents of up-counter. If a match is found, a timer/counter 2 interrupt (INTTC2) is generated, and the counter is cleared. Counting up is resumed after the counter is cleared.

Also, when fc is selected as the source clock during SLOW mode, the lower 11 bits of TREG2 are ignored and an INTTC2 interrupt is generated by matching the upper 5 bits. Thus, in this case, only the TREG2_H setting is necessary.

Table 2-4. Source Clock (Internal Clock) for Timer/Counter 2

Source clock		Resolution		Maximum time setting	
NORMAL1/2, IDLE1/2 mode		SLOW mode	SLEEP mode	At fc = 8 MHz	At fs = 32.768 kHz
DV7CK = 0	DV7CK = 1				
fc/2 ²³ [Hz]	fs/2 ¹⁵ [Hz]	fs/2 ¹⁵ [Hz]	fs/2 ¹⁵ [Hz]	1.05 s	1 s
fc/2 ¹³	fs/2 ⁵	fs/2 ⁵	fs/2 ⁵	1.02 ms	1 ms
fc/2 ⁸	fc/2 ⁸	–	–	32 μ s	–
fc/2 ³	fc/2 ³	–	–	1 μ s	–
–	–	fc (Note)	–	125 ns	–
fs	fs	–	–	–	30.5 μ s
					–
					2 s

Note: "fc" can be used only in the timer mode. This is used for warm up when switching from SLOW mode to NORMAL2 mode.

Example: Sets the timer mode with source clock fc/2³ [Hz] and generates an interrupt every 25 ms (at fc = 8 MHz).

```

LD  (TC2CR), 00001100B ; Sets the TC2 mode and source clock
LDW (TREG2), 61A8H       ; Sets TREG2 (25ms ÷ 23/fc = 61A8H)
SET (EIRH).EF14          ; Enable INTTC2
EI
LD  (TC2CR), 00101100B ; Starts TC2

```

(2) Event Counter Mode

In this mode, events are counted on the rising edge of the TC2 pin input. The contents of TREG2 are compared with the contents of the up-counter. If a match is found, an INTTC2 interrupt is generated, and the counter is cleared. The maximum frequency applied to the TC2 pin is fc/2⁴ [Hz] in NORMAL1/2 or IDLE1/2 mode, and fs/2⁴ [Hz] in SLOW or SLEEP mode. But, a pulse width of 2 machine cycles or more is required for both "H" and "L" level.

Example: Sets the event counter mode and generates an INTTC2 interrupt 640 counts later.

```

LD  (TC2CR), 00011100B ; Sets the TC2 mode
LDW (TREG2), 640         ; Sets TREG2
SET (EIRH).EF14          ; Enable INTTC2
EI
LD  (TC2CR), 00111100B ; Starts TC2

```

(3) Window Mode

In this mode, counting up is performed on the rising edge of the pulse that is the logical AND-ed product of the TC2 pin input (window pulse) and an internal clock. The internal clock is selected with TC2CK. The contents of TREG2 are compared with the contents of up-counter. If a match is found, an INTTC2 interrupt is generated, and the up-counter is cleared to "0". It is necessary that the maximum applied frequency (TC2 input) be such that the counter value can be analyzed by the program. That is, the frequency must be considerably slower than the selected internal clock.

Example: Inputs "H" level pulse of 120 ms or more and generates interrupt. (at $f_c = 8$ MHz).

LDW (TREG2), 0078H ; Sets TREG2 ($120\text{ ms} \div 2^{13}/f_c = 0078_H$)

SET (EIRH).EF14 ; Enables INTTC2 interrupt

EI

LD (TC2CR), 00100101B ; Starts TC2

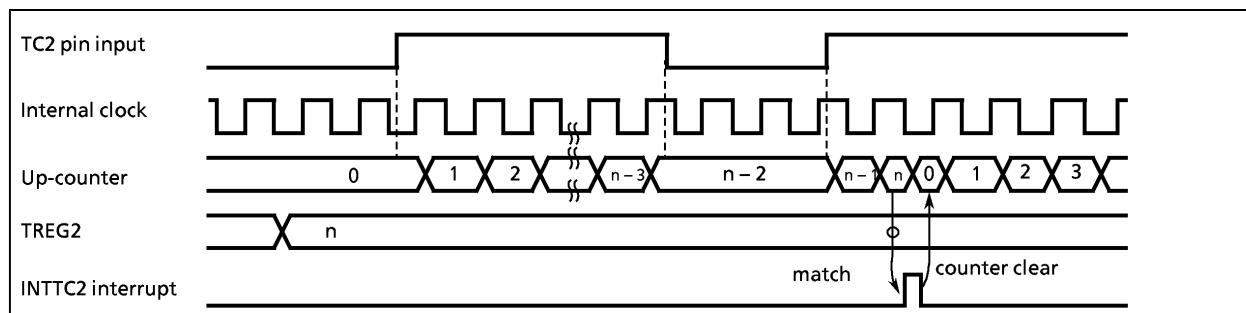


Figure 2-24. Window Mode Timing Chart

2.7 8-Bit Timer/Counter 3 (TC3)

2.7.1 Configuration

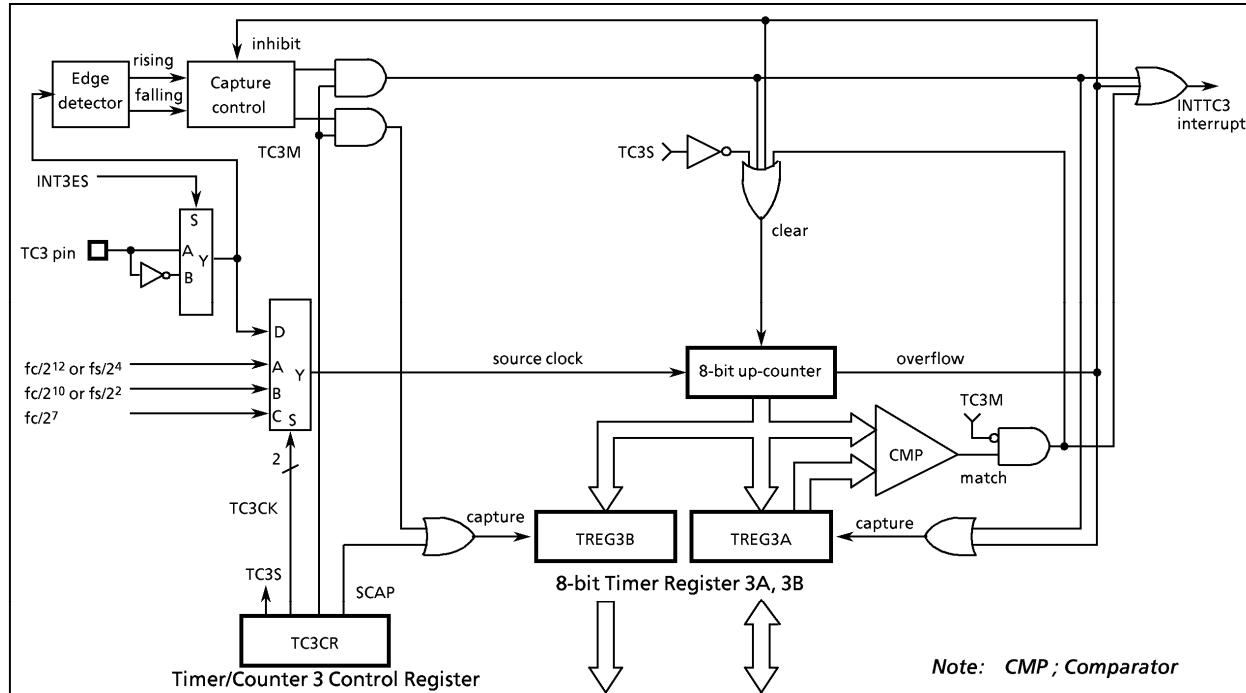


Figure 2-25. Timer/Counter 3

2.7.2 Control

The timer/counter 3 is controlled by a timer/counter 3 control register (TC3CR) and two 8-bit timer registers (TREG3A and TREG3B). Reset does not affect these timer registers.

TREG3A (0018 _H)	7 6 5 4 3 2 1 0	Read/Write
TREG3B (0019 _H)	7 6 5 4 3 2 1 0	Read only
TC3CR (001A _H)	7 6 5 4 3 2 1 0 SCAP TC3S TC3CK TC3M	(Initial value: *0*0 00*0)
TC3M	Timer/counter 3 operation mode set	0: Timer/event counter mode 1: Capture mode
TC3CK	Timer/counter 3 source clock select	00: Internal clock $fc/2^{12}$ or $fs/2^4$ [Hz] 01: Internal clock $fc/2^{10}$ or $fs/2^2$ 10: Internal clock $fc/2^7$ 11: External clock (TC3 pin input)
TC3S	Timer/counter 3 start select	0: Stop & clear 1: Start
SCAP	Software capture control	0: - 1: Software capture

*Note 1: fc; High-frequency clock [Hz] fs; Low-frequency clock [Hz] *; Don't care*
Note 2: Set the mode, the source clock and the edge selection (INT3ES) when the TC3 stops (TC3S = 0).
Note 3: Values to be loaded into timer register 3A must satisfy the following condition.
 $TREG3A > 0$ (in the timer/event counter mode)
Note 4: Software capture can be used in only timer and event counter mode.
Note 5: TC3CR is a write-only register, which cannot access any of in read-modify-write instruction such as bit operate, etc.

Figure 2-26. Timer Register 3A/3B and TC3 Control Register

2.7.3 Function

The timer/counter 3 has three operating modes: timer, event counter, and capture mode.

(1) Timer Mode

In this mode, the internal clock is used for counting up. The contents of TREG3A are compared with the contents of up-counter. If a match is found, a timer/counter 3 interrupt (INTTC3) is generated, and the up-counter is cleared. Counting up resumes after the up-counter is cleared. The current contents of up-counter are loaded into TREG3B by setting SCAP (bit 6 in TC3CR) to "1". SCAP is automatically cleared after capturing.

Table 2-5. Source Clock (Internal Clock) for Timer Counter 3

Source clock		Resolution		Maximum time setting	
NORMAL1/2, IDLE1/2 mode		SLOW, SLEEP mode	At $fc = 8$ MHz	At $fs = 32.768$ kHz	At $fc = 8$ MHz
DV7CK = 0	DV7CK = 1				At $fs = 32.768$ kHz
$fc/2^{12}$	$fs/2^4$ [Hz]	$fs/2^4$ [Hz]	$512 \mu s$	$488.28 \mu s$	131.1 ms
$fc/2^{10}$	$fs/2^2$	-	$128 \mu s$	$122.07 \mu s$	32.6 ms
$fc/2^7$		-	$16 \mu s$	-	4.1 ms

(2) Event Counter Mode

In this mode, the TC3 pin input pulses are used for counting up. Either the rising or falling edge can be selected with INT3ES (bit 3 in EINTCR). The contents of TREG3A are compared with the contents of the up-counter. If a match is found, an INTTC3 interrupt is generated and the counter is cleared. The maximum applied frequency is $fc/2^4$ [Hz] in the NORMAL1/2 or IDLE1/2 mode, and $fs/2^4$ [Hz] in SLOW or SLEEP mode. Two or more machine cycles are required for both the "H" and "L" levels of the pulse width.

The current contents of up-counter are loaded into TREG3B by setting SCAP (bit 6 in TC3CR) to "1". SCAP is automatically cleared after capturing.

Example: Generates an interrupt every 0.5 s, inputting 50Hz pulses to the TC3 pin.

```
LD  (TC3CR), 00001100B ; Sets TC3 mode and source clock
LD  (TREG3A), 19H        ; 0.5 s ÷ 1/50 = 25 = 19H
LD  (TC3CR), 00011100B ; Start TC3
```

(3) Capture Mode

The pulse width, period and duty of the TC3 pin input are measured in this mode, which can be used in decoding the remote control signals, etc. The counter is free running by the internal clock. On the rising (falling) edge of the TC3 pin input, the current contents of counter is loaded into TREG3A, then the up-counter is cleared and an INTTC3 interrupt is generated. On the falling (rising) edge of the TC3 pin input, the current contents of the counter is loaded into the TREG3B. In this case, counting continues. At the next rising (falling) edge of the TC3 pin input, the current contents of counter are loaded into TREG3A, then the counter is cleared again and an interrupt is generated. If the counter overflows before the edge is detected, FF_H is set to the TREG3A and an overflow interrupt (INTTC3) is generated. During interrupt processing, it can be determined whether or not there is an overflow by checking whether or not the TREG3A value is FF_H. Also, after an interrupt (capture to TREG3A, or overflow detection) is generated, capture and overflow detection are halted until TREG3A has been read out; however, the counter continues.

When the TREG3A has been read out, capture and overflow detection resumes.

Thus, it is general to read out TREG3B before reading out TREG3A.

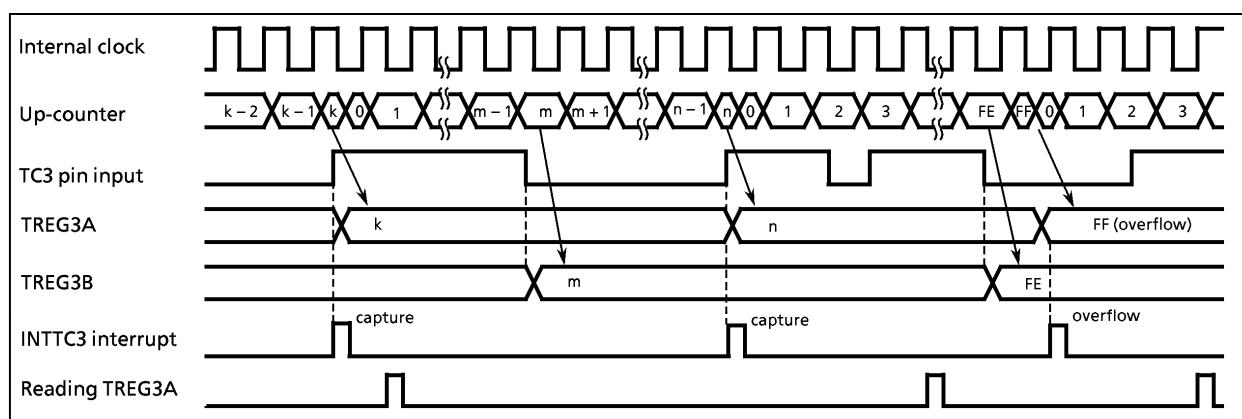


Figure 2-27. Timing Chart for Capture Mode (INT3ES = 0)

2.8 8-bit Timer/Counter 5 (TC5)

2.8.1 Configuration

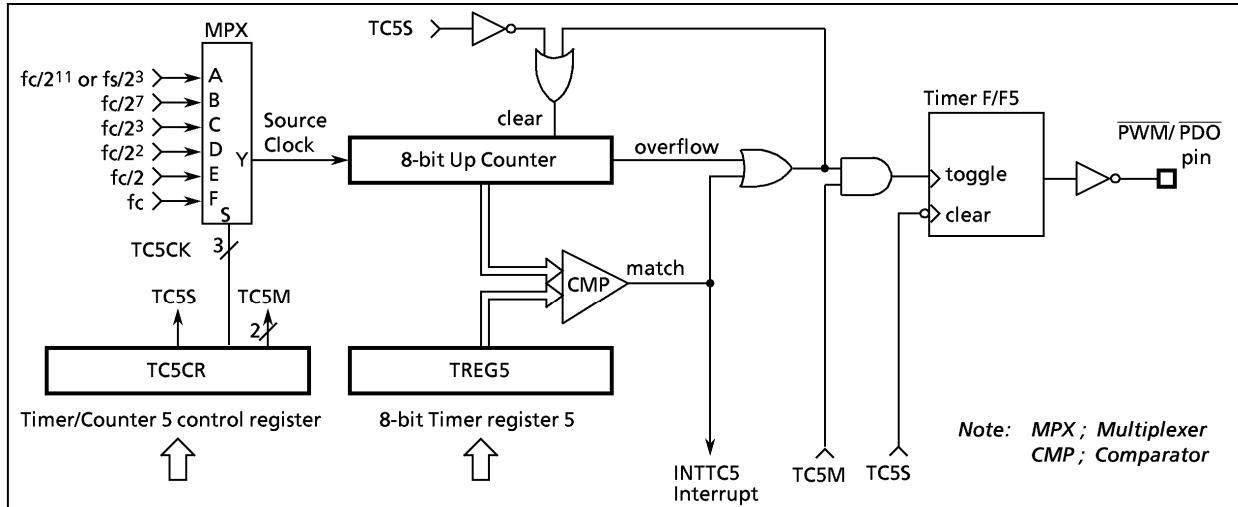


Figure 2-28. Timer/Counter 5 (TC5)

2.8.2 Control

The TC5 is controlled by a timer/counter 5 control register (TC5CR) and an 8-bit timer register 5 (TREG5).

Figure 2-29. Timer/Counter 5 Timer register, Control register

2.8.3 Function

TC5 has 3 operating modes: timer, programmable divider output, and pulse width modulation output mode.

(1) Timer mode

In this mode, the internal clock is used for counting up. The contents of the timer register 5 (TREG5) is compared with the contents of the up-counter. Matching with TREG5 generates a timer/counter 5 interrupt (INTTC5) and clears the counter. Counting up resumes after the counter is cleared.

Table 2-6. Source Clock (Internal clock) for TC5

Source clock		Resolution		Maximum setting time	
NORMAL1/2, IDLE1/2 mode		SLOW, SLEEP mode		fc = 8 MHz	fs = 32.768 kHz
DV7CK = 0	DV7CK = 1	fs/2 ¹¹ [Hz]	fs/2 ³ [Hz]	256 μ s	244.14 μ s
		fc/2 ⁷	–	16 μ s	4.1 ms
		fc/2 ³	–	1 μ s	255 μ s

(2) Programmable divider output (PDO) mode

The internal clock is used for counting up. The contents of the TREG5 are compared with the contents of the up-counter. The timer F/F5 output is toggled and the counter is cleared each time a match is found. The timer F/F5 output is inverted and output to the $\overline{\text{PDO}}$ (P41) pin. In the case of $\overline{\text{PDO}}$ output, set the P41 output latch to "1" and configure as an output with P4CR1. This mode can be used for 50% duty pulse output. INTTC5 interrupt is generated each time the $\overline{\text{PDO}}$ output is toggled.

Example: 1024 Hz pulse output (at $f_c = 4.194304$ MHz)

```

SET (P4).1 ; P41 output latch←1
LD (TC5CR), 00001010B ; Sets to TC5 modes and source clock
LD (TREG5), 10H ; 1/1024 × 1/2 ÷ 27/fc = 10H
LD (TC5CR), 00101010B ; Starts TC5

```

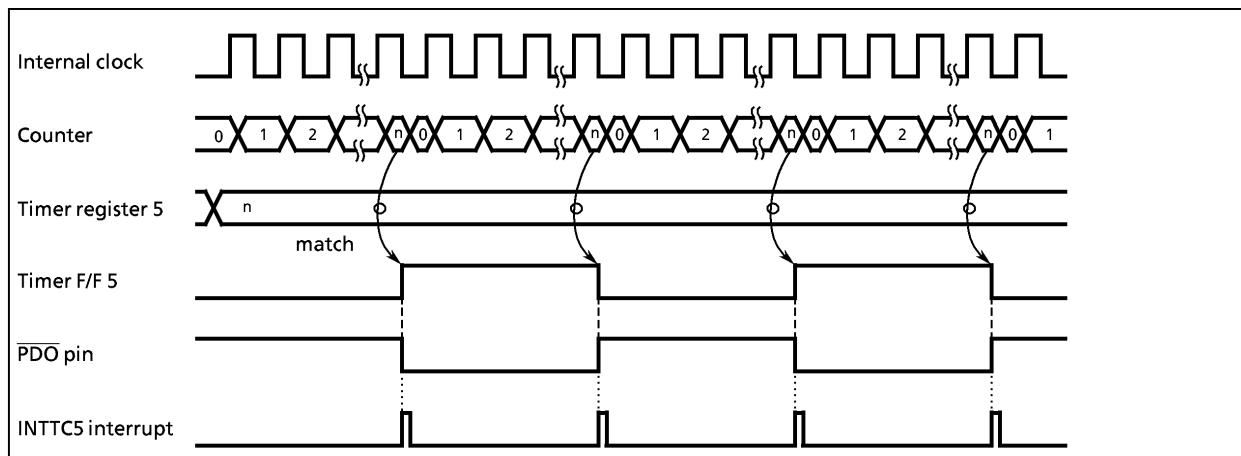


Figure 2-30. PDO Mode Timing Chart

(3) Pulse width modulation (PWM) output mode

PWM output with a resolution of 8-bits is possible. The internal clock is used for counting up. The contents of the TREG5 is compared with the contents of the up-counter. If a match is found, the timer F/F5 output is toggled. The counter continues counting and, when an overflow occurs, the timer F/F5 output is again toggled and the counter is cleared. The timer F/F5 output is inverted and output to the PWM (P41) pin. In the case of $\overline{\text{PWM}}$ output, set the P41 output latch to "1" and configure as an output with P4CR1. An INTTC5 interrupt is generated when an overflow occurs.

TREG5 is configured a 2-stage shift register and, during output, will not switch until one output cycle is completed even if TREG5 is overwritten; therefore, output can be altered continuously. Also, the first time, TREG5 is shifted by setting TC5S (bit 5 in TC5CR) to "1" after data are loaded to TREG5.

Note: PWM output mode can be used only in NORMAL1/2 or IDLE1/2 mode.

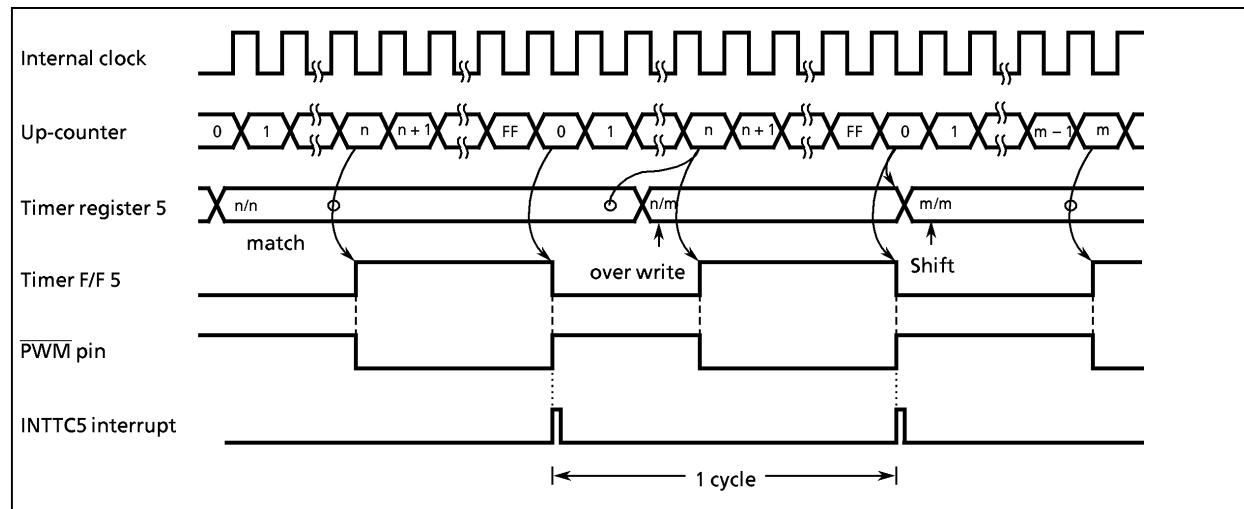


Figure 2-31. PWM Output Mode Timing Chart

Table 2-7. PWM Output Mode

Source clock		Resolution		Repeat cycle	
NORMAL1/2, IDLE1/2 mode		At $f_c = 8$ MHz	At $f_c = 4.194304$ MHz	At $f_c = 8$ MHz	At $f_c = 4.194304$ MHz
DV7CK = 0	DV7CK = 1				
$f_c/2^2$ [Hz]		500 ns	953.7 ns	$128 \mu s$	$244 \mu s$
$f_c/2$		250 ns	476.8 ns	$64 \mu s$	$122 \mu s$
f_c		125 ns	238.4 ns	$32 \mu s$	$61 \mu s$

2.9 Serial Interface (SIO1, SIO2)

The TMP87CH21/H21B/M21 each have two clocked-synchronous 8-bit serial interfaces (SIO1 and SIO2). Each serial interface has an 8-byte transmit and receive data buffer that can automatically and continuously transfer up to 64 bits of data.

The serial interfaces are connected to external devices via pins P44 (SO1), P43 (SI1), P42 (SCK1) for SIO1 and P47 (SO2), P46 (SI2), P45 (SCK2) for SIO2. The serial interface pins are also used as port P4. When used as serial interface pins, the output latches of these pins should be set to "1". In the transmit mode, pins P43 and P46 can be used as normal I/O ports, and in the receive mode, the pins P44 and P47 can be used as normal I/O ports.

2.9.1 Configuration

The SIO1 and SIO2 have the same configuration, except for the addresses/bit positions of the control/status registers and buffer registers.

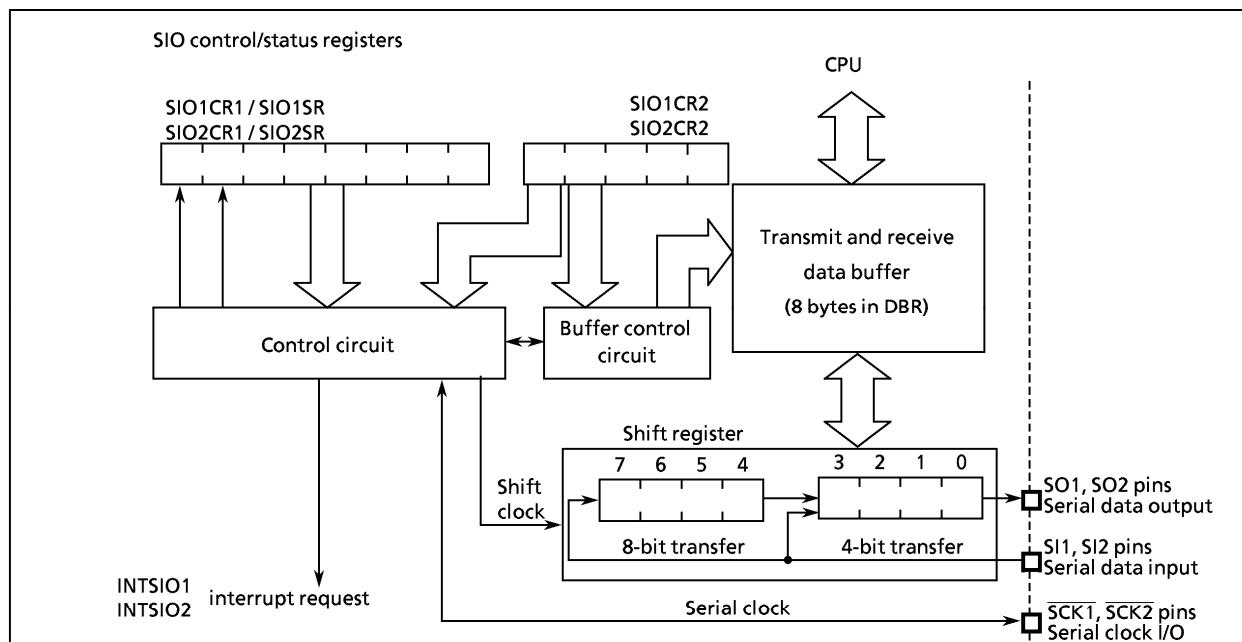


Figure 2-32. Serial Interfaces

2.9.2 Control

The serial interfaces are controlled by SIO control registers (SIO1CR1/SIO1CR2 or SIO2CR1/SIO2CR2). The serial interface status can be determined by reading SIO status registers (SIO1SR or SIO2SR).

The transmit and receive data buffer is controlled by the BUF (bits 2 to 0 in SIO1CR2/SIO2CR2). The data buffer is assigned to addresses $0FF0H$ to $0FF7H$ for SIO1 or $0FF8H$ to $0FFFH$ for SIO2 in the DBR area, and can continuously transfer up to 8 words (bytes or nibbles) at one time. When the specified number of words has been transferred, a buffer empty (in the transmit mode) or a buffer full (in the receive mode or transmit/receive mode) interrupt (INTSIO1 or INTSIO2) is generated.

When the internal clock is used as the serial clock in the 8-bit receive mode and the 8-bit transmit/receive mode, a fixed interval wait can be applied to the serial clock for each word transferred. Four different wait times can be selected with WAIT (bits 4 and 3 in SIO1CR2/SIO2CR2).

SIO1, SIO2 Control Registers 1

SIO1CR1 (0020 _H)								(Initial value: 0000 0000)
SIO2CR1 (0022 _H)								Write only
SIOS	SIOINH	SIOM	SCK					
SIOS	Indicate transfer start/stop				0: Stop	1: Start		
SIOINH	Continue/abort transfer				0: Continue transfer	1: Abort transfer (automatically cleared after abort)		
SIOM	Transfer mode select				000:8-bit transmit mode	010:4-bit transmit mode	100:8-bit transmit/receive mode	
SCK	Serial clock select				101:8-bit receive mode	110:4-bit receive mode	000:Internal clock $fc/2^{13}$ or $fs/2^5$ [Hz]	Output on SCK pin
					001:Internal clock $fc/2^8$	010:Internal clock $fc/2^6$	011:Internal clock $fc/2^5$	
					111:External clock (input from SCK pin)			

Note 1: fc ; High-frequency clock [Hz], fs ; Low-frequency clock [Hz]

Note 2: Set SIOS to "0" and SIOINH to "1" when setting the transfer mode or serial clock.

Note 3: SIO1CR1/SIO2CR1 are write-only registers, which cannot access any of in read-modify-write instruction such as bit operate, etc.

SIO1, SIO2 Status Registers

SIO1SR (0020 _H)							
SIO2SR (0022 _H)							
SIOF	SEF	"1"	"1"	"1"	"1"	"1"	"1"
SIOF	Serial transfer operating status monitor				0: Transfer terminated	1: Transfer in process	Read only
SEF	Shift operating status monitor				0: Shift operation terminated	1: Shift operation in process	

SIO1, SIO2 Control Registers 2

SIO1CR2 (0021 _H)								(Initial value: ***0 0000)
SIO2CR2 (0023 _H)								Write only
WAIT	BUF				Always sets "00" except 8-bit transmit/receive mode.	00: $T_f = T_D$ (non-wait)	01: $T_f = 2T_D$	
WAIT	Wait control				10: $T_f = 4T_D$	11: $T_f = 8T_D$	(wait)	
BUF	Number of transfer words				Buffer address used SIO1 SIO2			
					000:1 word transfer	OFF0 _H	OFF8 _H	Write only
					001:2 words transfer	OFF0 to OFF1 _H	OFF8 to OFF9 _H	
					010:3 words transfer	OFF0 to OFF2 _H	OFF8 to OFFA _H	
					011:4 words transfer	OFF0 to OFF3 _H	OFF8 to OFFB _H	
					100:5 words transfer	OFF0 to OFF4 _H	OFF8 to OFFC _H	
					101:6 words transfer	OFF0 to OFF5 _H	OFF8 to OFFD _H	
					110:7 words transfer	OFF0 to OFF6 _H	OFF8 to OFFE _H	
					111:8 words transfer	OFF0 to OFF7 _H	OFF8 to OFFF _H	

Figure 2-33. SIO Control Registers and Status Registers (1/2)

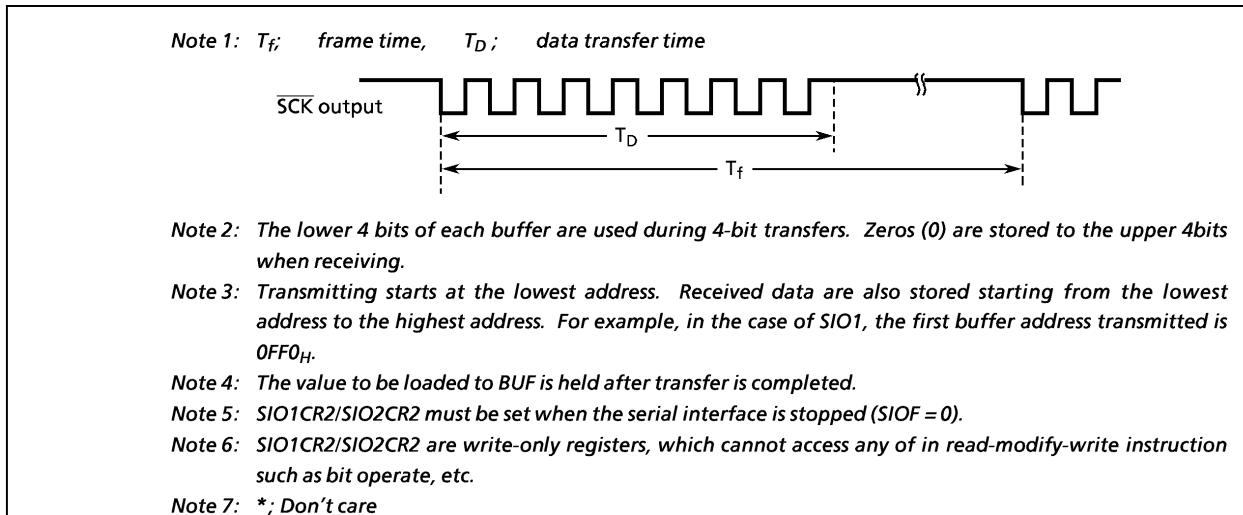


Figure 2-33. SIO Control Registers and Status Registers (2/2)

(1) Serial Clock

a. Clock Source

SCK (bits 2 to 0 in SIO1CR1/SIO2CR1) is able to select the following:

① Internal Clock

Any of four frequencies can be selected. The serial clock is output to the outside on the $\overline{SCK1}$ / $\overline{SCK2}$ pin. The SCK pin goes high when transfer starts.

When data writing (in the transmit mode) or reading (in the receive mode or the transmit/receive mode) cannot keep up with the serial clock rate, there is a wait function that automatically stops the serial clock and holds the next shift operation until the read/write processing is completed.

Table 2-8. Serial Clock Rate

Serial clock		Maximum transfer rate	
NORMAL1/2, IDLE1/2 mode		SLOW, SLEEP mode	At $f_c = 8$ MHz
DV7CK = 0	DV7CK = 1		At $f_s = 32.768$ kHz
$f_c / 2^{13}$ [Hz]	$f_s / 2^5$ [Hz]	$f_s / 2^5$ [Hz]	0.954 Kbit/s
$f_c / 2^8$	$f_c / 2^8$	—	30.5
$f_c / 2^6$	$f_c / 2^6$	—	122
$f_c / 2^5$	$f_c / 2^5$	—	244

Note: 1 Kbit = 1024 bit

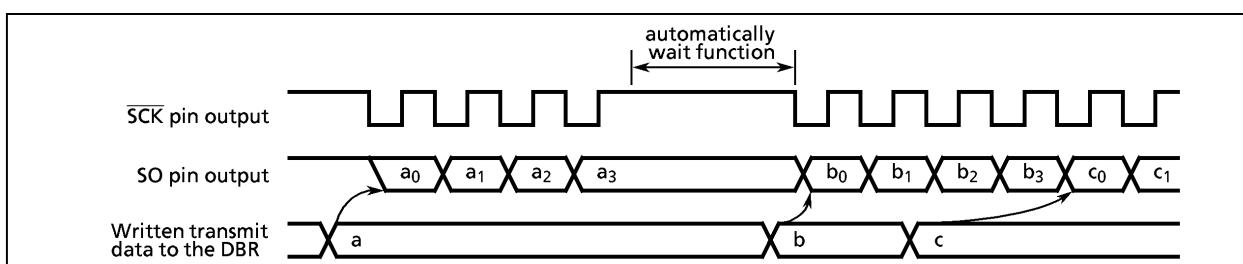
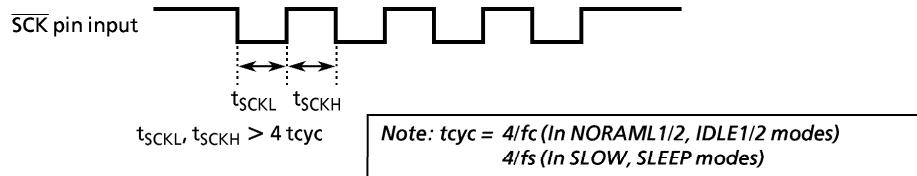


Figure 2-34. Clock Source (Internal Clock)

② External Clock

An external clock connected to the $\overline{\text{SCK1}} / \overline{\text{SCK2}}$ pin is used as the serial clock. In this case, the P42 ($\overline{\text{SCK1}}$) / P45 ($\overline{\text{SCK2}}$) output latch must be set to "1". To ensure shifting, a pulse width of at least 4 machine cycles is required. Thus, the maximum transfer speed is 244 Kbit/s. (at $\text{fc} = 8 \text{ MHz}$).



b. Shift edge

The leading edge is used to transmit, and the trailing edge is used to receive.

① Leading Edge

Transmitted data are shifted on the leading edge of the serial clock (falling edge of the $\overline{\text{SCK}}$ pin input/output).

② Trailing Edge

Received data are shifted on the trailing edge of the serial clock (rising edge of the $\overline{\text{SCK}}$ pin input/output).

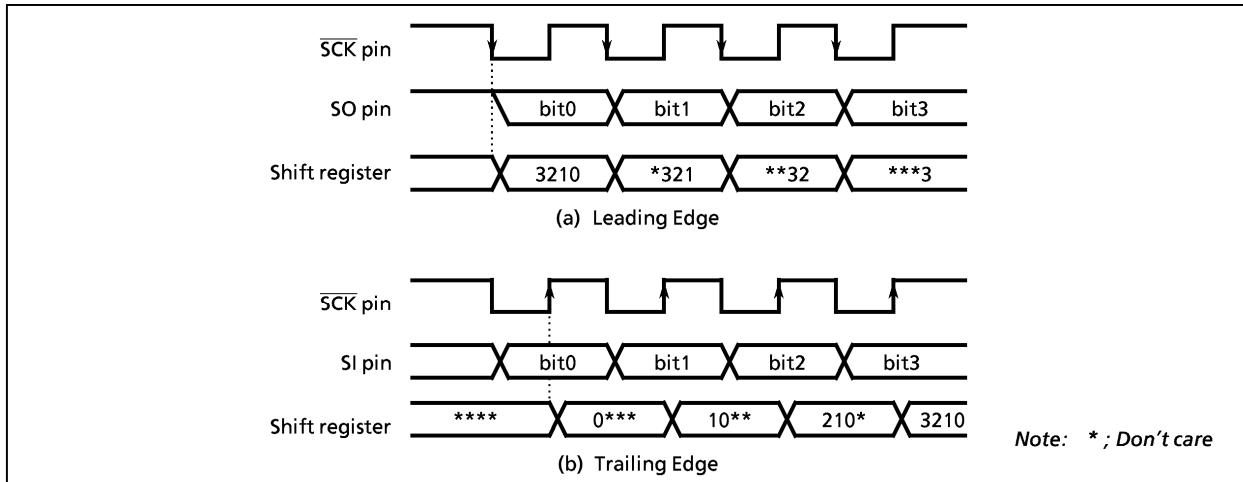


Figure 2-35. Shift Edge

(2) Number of Bits to Transfer

Either 4-bit or 8-bit serial transfer can be selected. When 4-bit serial transfer is selected, only the lower 4 bits of the transmit/receive data buffer register are used. The upper 4 bits are cleared to "0" when receiving.

The data is transferred in sequence starting at the least significant bit (LSB).

(3) Number of Words to Transfer

Up to 8 words consisting of 4 bits of data (4-bit serial transfer) or 8 bits (8-bit serial transfer) of data can be transferred continuously. The number of words to be transferred is loaded to BUF.

An INTSIO interrupt is generated when the specified number of words has been transferred. If the number of words is to be changed during transfer, the serial interface must be stopped before making the change. The number of words can be changed during automatic-wait operation of an internal clock. In this case, the serial interface is not required to be stopped.

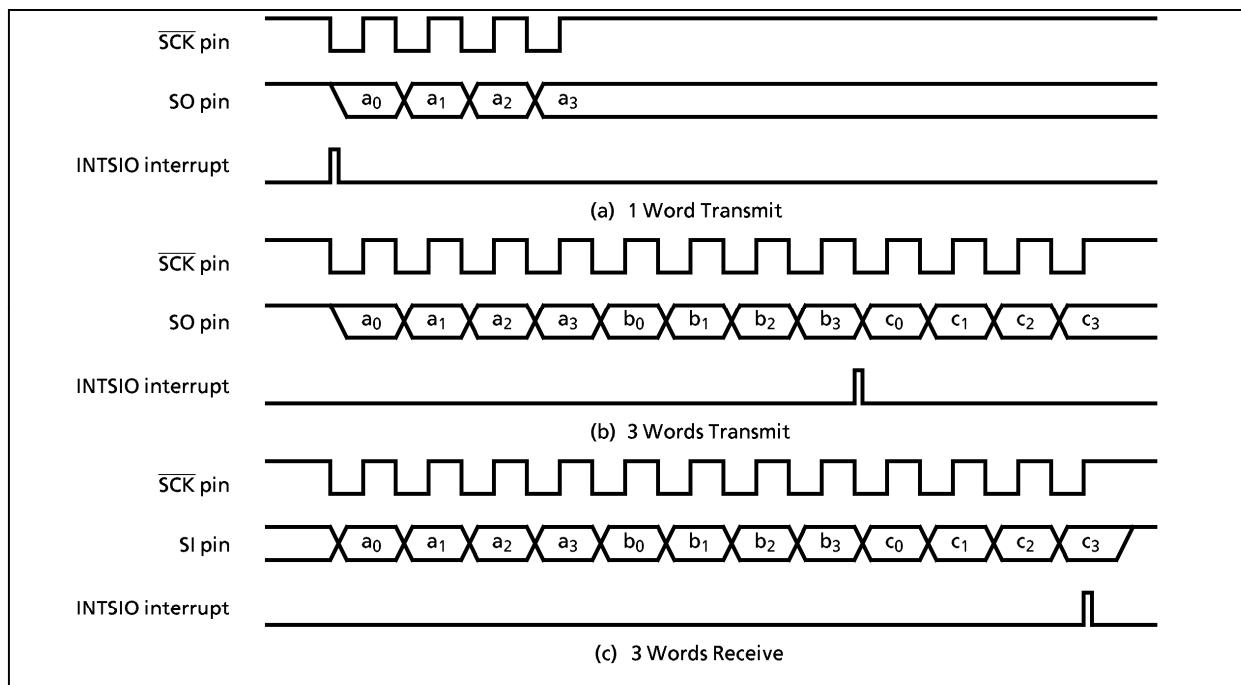


Figure 2-36. Number of words to Transfer (Example: 1word = 4-bit)

2.9.3 Transfer Mode

SIOM (bits 5 to 3 in SIO1CR1/SIO2CR1) is used to select the transmit, receive, or transmit/receive mode.

(1) 4-bit and 8-bit Transmit Modes

In these modes, the SIO1CR1/SIO2CR1 is set to the transmit mode and then the data to be transmitted first are written to the data buffer registers (DBR). After the data are written, the transmission is started by setting SIOS to "1". The data are then output sequentially to the SO pin in synchronous with the serial clock, starting with the least significant bit (LSB). As soon as the LSB has been output, the data are transferred from the data buffer register to the shift register. When the final data bit has been transferred and the data buffer register is empty, an INTSIO (buffer empty) interrupt is generated to request the next transmitted data.

When the internal clock is used, the serial clock will stop and an automatic-wait will be initiated if the next transmitted data are not loaded to the data buffer register by the time the number of data words specified with the BUF has been transmitted. Writing even one word of data cancels the automatic-wait; therefore, when transmitting two or more words, always write the next word before transmission of the previous word is completed.

Note: Automatic-waits are also canceled by writing to a DBR not being used as a transmit data buffer register; therefore, during SIO do not use such DBR for other applications. For example, when 3 words are transmitted, do not use the DBR of the remained 5 words.

When an external clock is used, the data must be written to the data buffer register before shifting next data. Thus, the transfer speed is determined by the maximum delay time from the generation of the interrupt request to writing of the data to the data buffer register by the interrupt service program.

In the TMP87CH21/M21 when the transmit is started, after the SIOF goes "high" output from the SO pin holds final bit of the last data until falling edge of the SCK. In the TMP87CH21B, it remains "1".

The transmission is ended by clearing SIOS to "0" or set SIOINH to "1" in buffer empty interrupt service program. That the transmission has ended can be determined from the status of SIOF (bit 7 in SIO1SR/SIO2SR) because SIOF is cleared to "0" when a transfer is completed. When SIOINH is set, the transmission is immediately ended and SIOF is cleared to "0".

When an external clock is used, it is also necessary to clear SIOS to "0" before shifting the next data; otherwise, dummy data will be transmitted and the operation will end.

If the number of words is to be changed, SIOS is cleared to "0". After confirmed that SIOF has been cleared to "0", BUF must be rewritten.

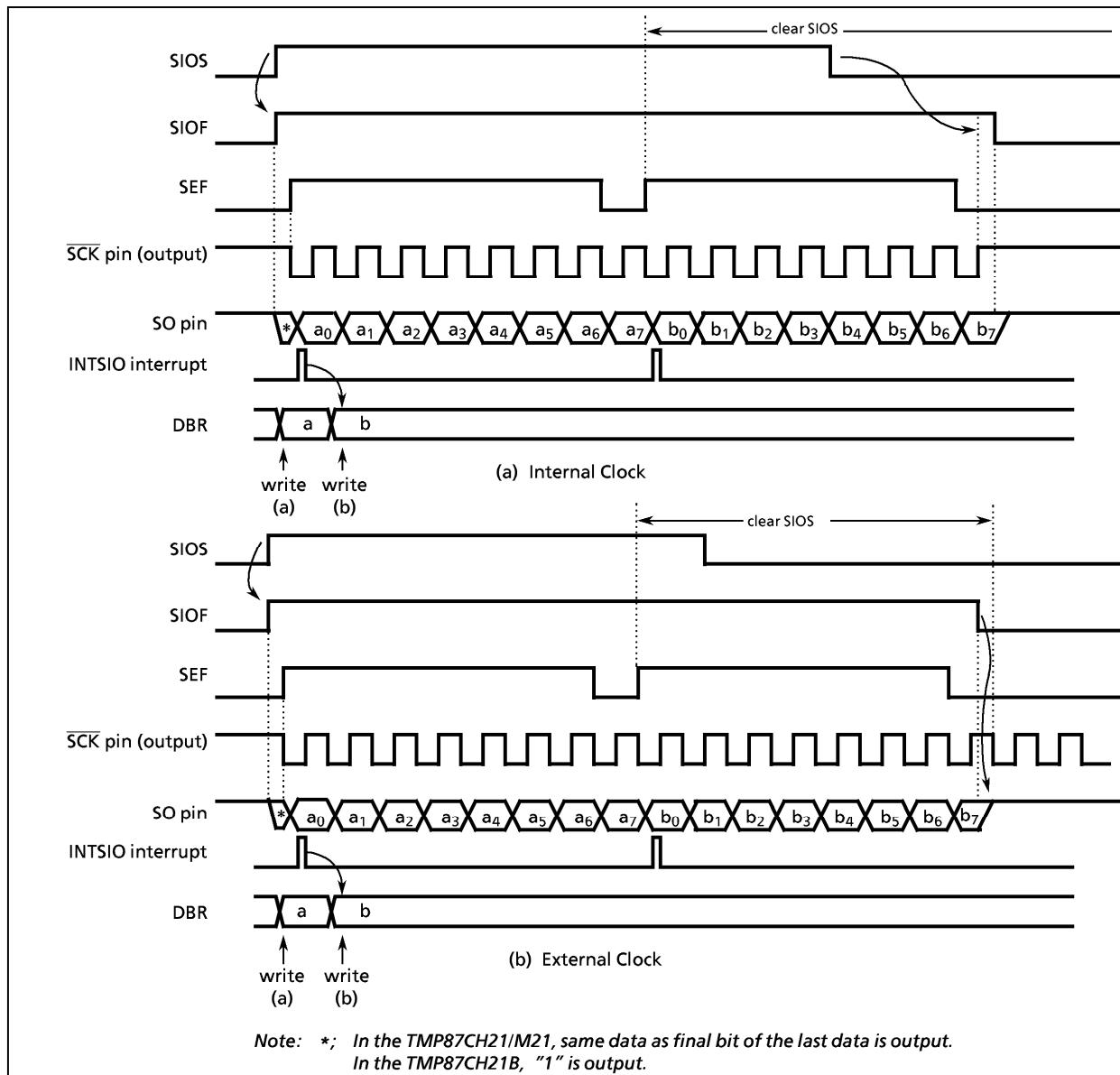


Figure 2-37. Transfer Mode (Example: 8-bit, 1 Word Transfer)

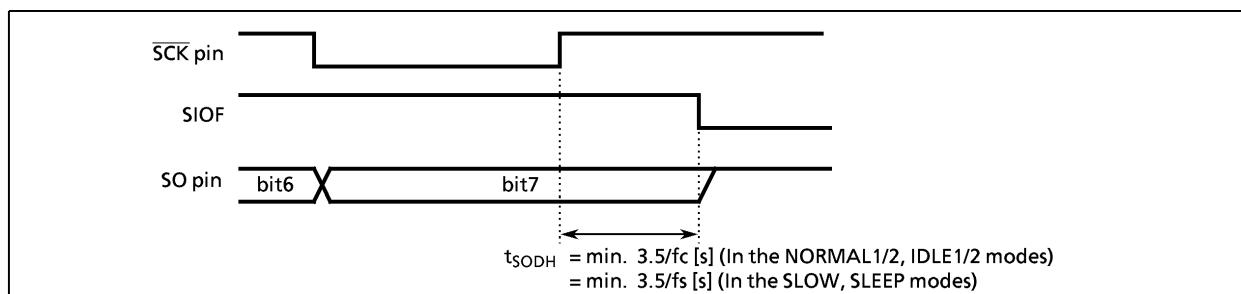


Figure 2-38. Transmitted Data Hold Time at end of transmit

(2) 4-bit and 8-bit Receive Modes

After setting the control registers to the receive mode, set SIOS to "1" to enable receiving. The data are then transferred to the shift register via the SI pin in synchronous with the serial clock. When one word of data has been received, it is transferred from the shift register to the data buffer register (DBR). When the number of words specified with the BUF has been received, an INTSIO (buffer full) interrupt is generated to request that these data be read out. The data are then read from the data buffer registers by the interrupt service program.

When the internal clock is used, and the previous data are not read from the data buffer register before the next data are received, the serial clock will stop and an automatic-wait will be initiated until the data are read. A wait will not be initiated if even one data word has been read.

Note: Waits are also canceled by reading a DBR not being used as a received data buffer register is read; therefore, during SIO do not use such DBR for other applications.

When an external clock is used, the shift operation is synchronized with the external clock; therefore, the previous data are read before the next data are transferred to the data buffer register. If the previous data have not been read, the next data will not be transferred to the data buffer register and the receiving of any more data will be canceled. When an external clock is used, the maximum transfer speed is determined by the delay between the time when the interrupt request is generated and when the data received have been read.

When the transmit is started, after the SIOF goes "1" output from the SO pin holds final bit of the last data until falling edge of the SCK.

Clear SIOS to "0" or SIOINH to "1" in buffer full interrupt service program to end receiving. When SIOS is cleared, the current data are transferred to the buffer. After SIOS cleared, the transmissions is ended at the time that the final bit of the data being shifted has been output. That the transmission has ended can be determined from the status of SIOF (bit 7 in SIO1SR / SIO2SR). SIOF is cleared to "0" when the transmission is ended. After confirmed the receiving termination, the final receiving data is read. When SIOINH is set, the transmission is immediately ended and SIOF is cleared to "0". (The received data is ignored, and it is not required to be read out.) If the number of words is to be changed during transfer, SIOS must be cleared to "0" and BUF is rewritten after SIOF is determined to be cleared to "0" during automatic-wait operation of an external clock operation. The number of words can be changed in an internal clock. In this case, BUF must be rewritten before the received data is read out.

Note: The buffer contents are lost when the transfer mode is switched. If it should become necessary to switch the transfer mode, end receiving by clearing SIOS to "0", read the last data and then switch the transfer mode.

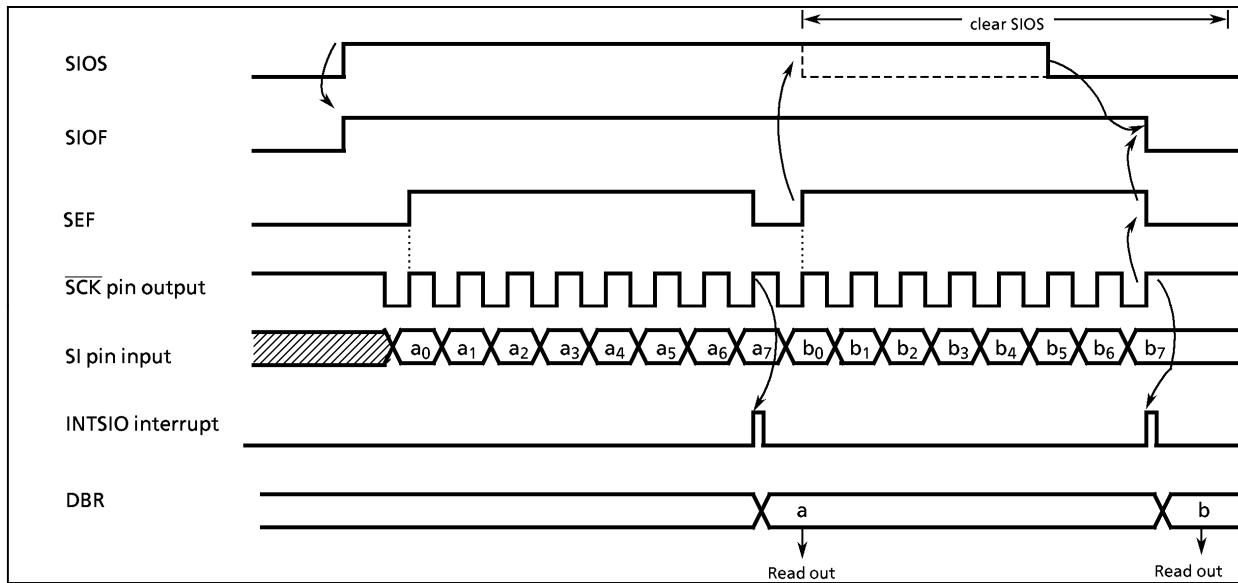


Figure 2-39. Receive Mode (Example: 8-bit, 1 word, internal clock)

(3) 8-bit Transmit/Receive Mode

After setting the control registers to the 8-bit transmit/receive mode, write the data to be transmitted first to the data buffer registers (DBR). After that, enable transceiving by setting SIOS to "1". When transmitting, the data are output from the SO pin at leading edges of the serial clock. When receiving, the data are input to the SI pin at the trailing edges of the serial clock. 8-bit data are transferred from the shift register to the data buffer register. An INTSIO interrupt is generated when the number of data words specified with the BUF has been transferred. The interrupt service program reads the received data from the data buffer register and then writes the data to be transmitted. The data buffer register is used for both transmitting and receiving; therefore, always write the data to be transmitted after reading the received data.

When the internal clock is used, a wait is initiated until the received data are read and the next data are written. A wait will not be initiated if even one data word has been written.

Note: Waits are also canceled by writing to a DBR not being used as the transmit/received data buffer register; therefore, do not use such DBR for other applications.

When an external clock is used, the shift operation is synchronized with the external clock; therefore, it is necessary to read the received data and write the data to be transmitted next before starting the next shift operation. When an external clock is used, the transfer speed is determined by the maximum delay between generation of an interrupt request and the received data are read and the data to be transmitted next are written.

In the TMP87CH21/M21 when the receive is started, after the SIOF goes "high" output from the SO pin holds final bit of the last data until falling edge of the \overline{SCK} . In the TMP87CH21B, it remains "1". The transmit / receive operation is ended by clearing SIOS to "0" or setting SIOINH to "1" in interrupt service program.

When SIOS is cleared, the current data are transferred to the data buffer register. The transmit/receive is ended at the time that the final bit of the data being shifted has been output. The end of transmit/receive can be determined from the status of SIOF (bit 7 in SIO1SR / SIO2SR). SIOF is cleared to "0" when the transmit/receive is ended. When SIOINH is set, the transmit/receive is immediately ended and SIOF is cleared to "0".

If the number of words is to be changed during transfer, SIOS must be cleared to "0" and BUF is rewritten after confirming that SIOF clearing to "0".

If it is necessary to change the number of words in external clock operation, SIOS should be cleared to "0", then BUF must be rewritten after confirming that SIOF has been cleared to "0".

If it is necessary to change the number of words in internal clock, during automatic-wait operation which occurs after completion of transmit/receive operation, BUF must be rewritten before reading and writing of the receive/transmit data.

Note: The buffer contents are lost when the transfer mode is switched. If it should become necessary to switch the transfer mode, end receiving by clearing SIOS to "0", read the last data and then switch the transfer mode.

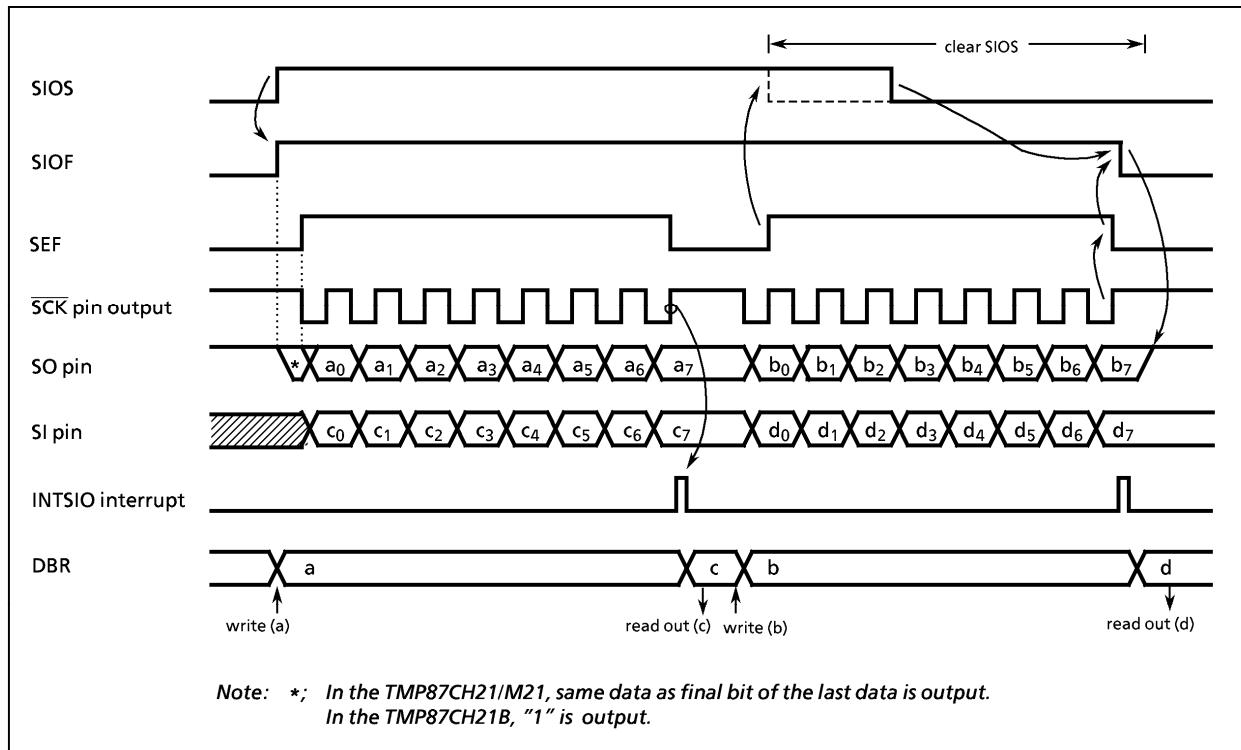


Figure 2-40. Transmit/Receive Mode (Example: 8-bit, 1word, internal clock)

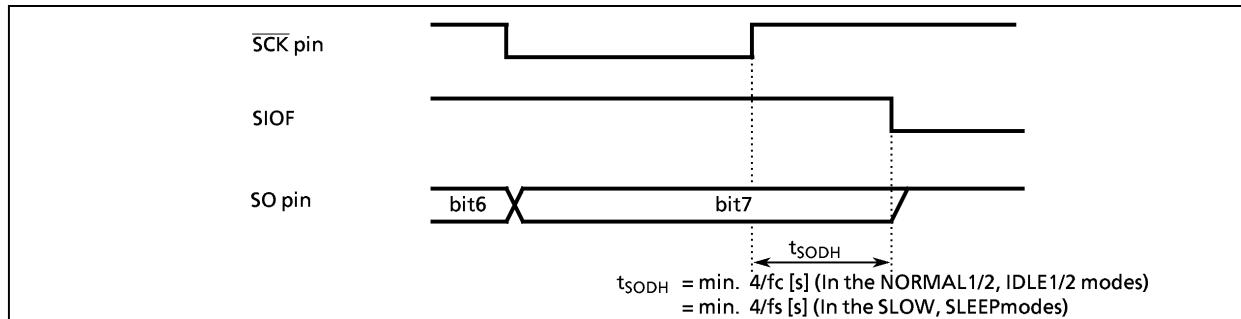


Figure 2-41. Transmitted Data Hold Time at end of transmit/receive

2.10 LCD Driver

The TMP87CH21/H21B/M21 each have a driver and control circuit to directly drive the liquid crystal device (LCD). The pins to be connected to LCD are as follows:

① Segment output port	12 pins (SEG11 to SEG0)
② Segment output or P6, P7, P9 input / output port	20 pins (SEG31 to SEG12)
③ Common output port	4 pins (COM3 to COM0)

In addition, VLC pin is provided as the drive power pins

The devices that can be directly driven is selectable from LCD of the following drive methods:

① 1/4 Duty (1/3 Bias) LCD	Max128 Segments (8-segment x 16 digits)
② 1/3 Duty (1/3 Bias) LCD	Max 96 Segments (8-segment x 12 digits)
③ 1/3 Duty (1/2 Bias) LCD	Max 96 Segments (8-segment x 12 digits)
④ 1/2 Duty (1/2 Bias) LCD	Max 64 Segments (8-segment x 8 digits)
⑤ Static LCD	Max 32 Segments (8-segment x 4 digits)

2.10.1 Configuration

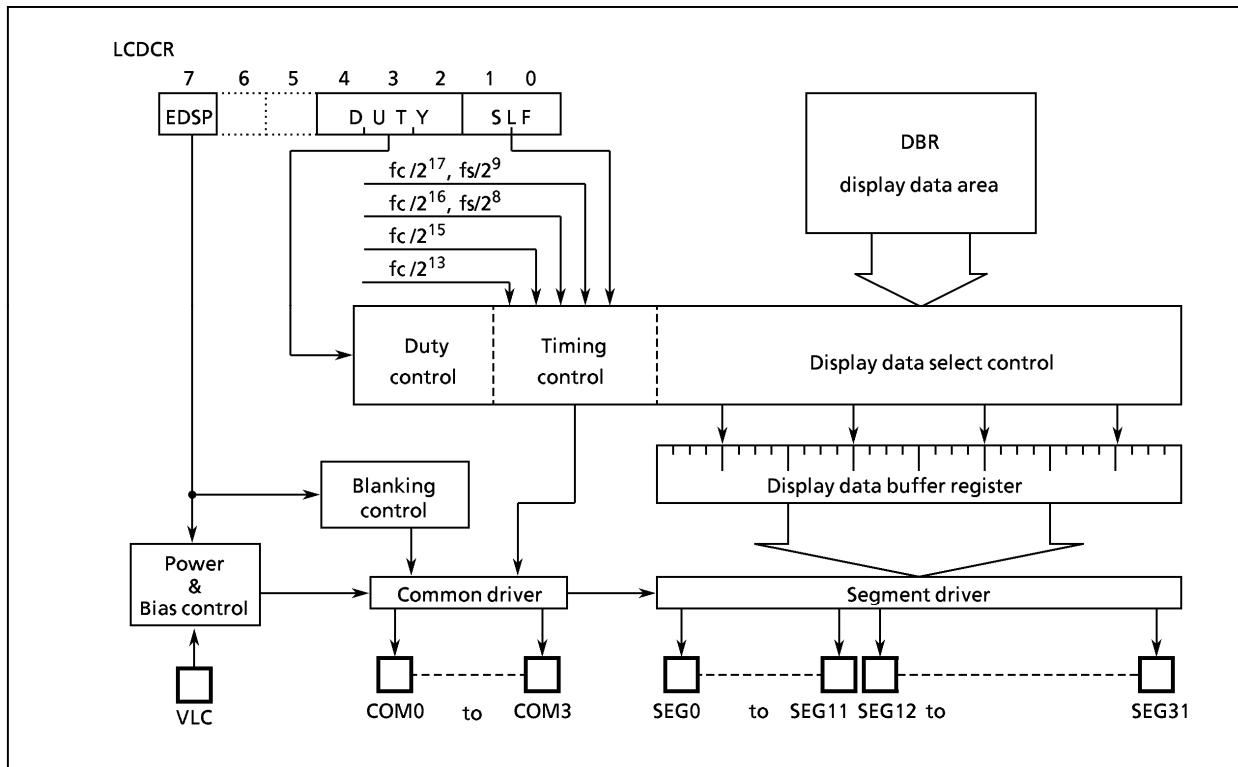


Figure 2-42. LCD driver

2.10.2 Control

The LCD driver is controlled by the LCD control register (LCDCR).

LCDCR (0028H)		7	6	5	4	3	2	1	0				
		EDSP	D U T Y			SLF	(Initial value: 0**0 0000)						
SLF		Selection of LCD base frequency				00: $fc/2^{17}$ or $fs/2^9$ [Hz] 01: $fc/2^{16}$ or $fs/2^8$ 10: $fc/2^{15}$				Write only			
DUTY		Selection of driving methods				000: 1/4 Duty (1/3 Bias) 001: 1/3 Duty (1/3 Bias) 010: 1/3 Duty (1/2 Bias) 011: 1/2 Duty (1/2 Bias) 100: Static 101: reserved 110: reserved 111: reserved				Write only			
EDSP		LCD Display Control				0: Blanking 1: Enables LCD display (Blanking is released)							

Note: fc: high-frequency clock, fs: low-frequency clock

Figure 2-43. LCD driver control register

(1) LCD driving methods

As for LCD driving method, 5 types can be selected by DUTY (bit 4 to bit 2 of LCDCR). The driving method is initialized in the initial program according to the LCD used.

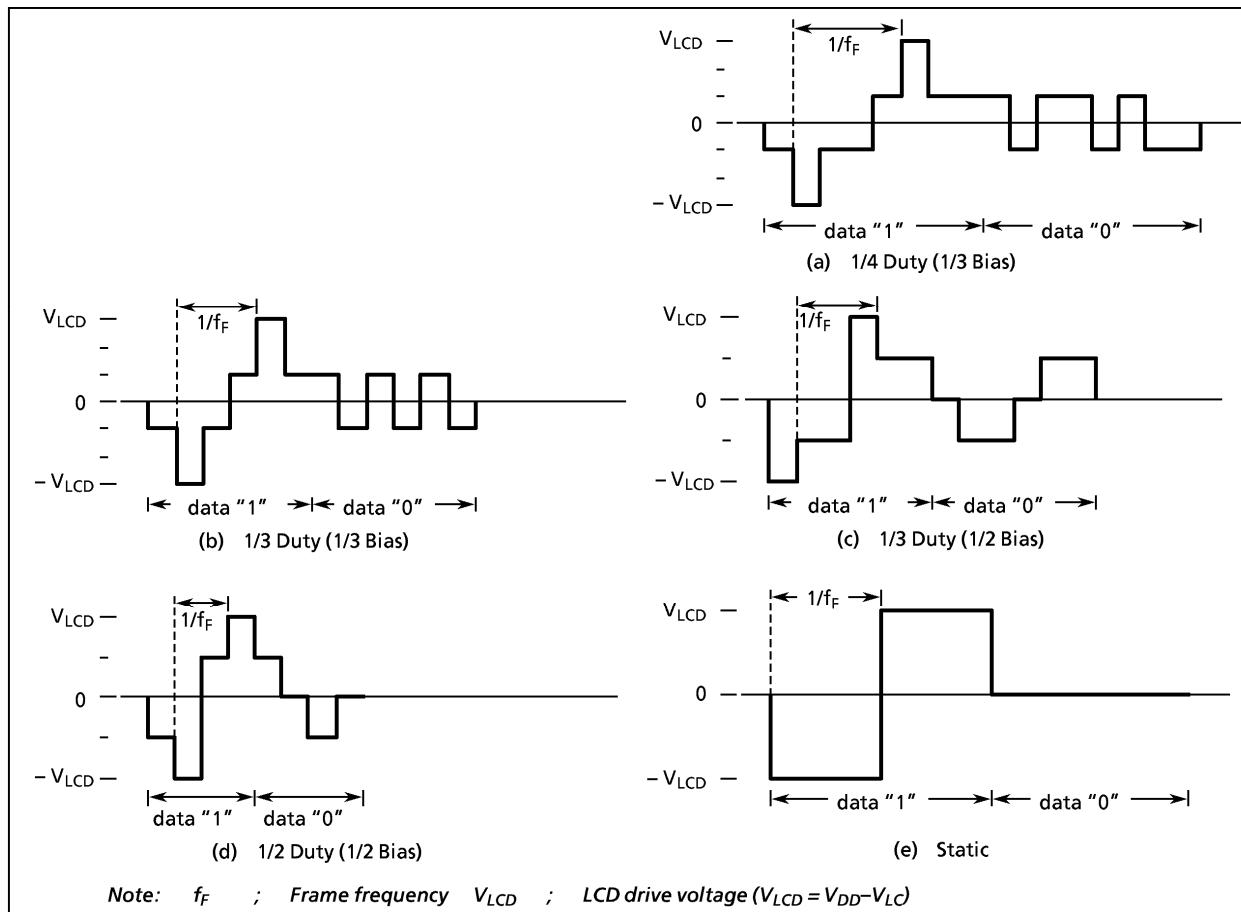


Figure 2-44. LCD drive waveform (COM - SEG pins)

(2) Frame frequency

Frame frequency (f_F) is set according to driving method and base frequency as shown in the following Table 2-9. The base frequency is selected by SLF (bit 1 and 0 of LCDCR) according to the frequency f_C and f_S of the basic clock to be used.

Table 2-9. Setting of LCD Frame Frequency

a. At the single clock mode or at the dual clock mode with DVCK7 = 0

SLF	Base frequency [Hz]	Frame frequency [Hz]			
		1/4 Duty	1/3 Duty	1/2 Duty	Static
00	$\frac{f_C}{2^{17}}$ ($f_C = 8 \text{ MHz}$)	$\frac{f_C}{2^{17}}$ 61	$\frac{4}{3} \cdot \frac{f_C}{2^{17}}$ 81	$\frac{4}{2} \cdot \frac{f_C}{2^{17}}$ 122	$\frac{f_C}{2^{17}}$ 61
01	$\frac{f_C}{2^{16}}$ ($f_C = 4 \text{ MHz}$)	$\frac{f_C}{2^{16}}$ 61	$\frac{4}{3} \cdot \frac{f_C}{2^{16}}$ 81	$\frac{4}{2} \cdot \frac{f_C}{2^{16}}$ 122	$\frac{f_C}{2^{16}}$ 61
10	$\frac{f_C}{2^{15}}$ ($f_C = 4 \text{ MHz}$)	$\frac{f_C}{2^{15}}$ 122	$\frac{4}{3} \cdot \frac{f_C}{2^{15}}$ 162	$\frac{4}{2} \cdot \frac{f_C}{2^{15}}$ 244	$\frac{f_C}{2^{15}}$ 122
11	$\frac{f_C}{2^{13}}$ ($f_C = 1 \text{ MHz}$)	$\frac{f_C}{2^{13}}$ 122	$\frac{4}{3} \cdot \frac{f_C}{2^{13}}$ 162	$\frac{4}{2} \cdot \frac{f_C}{2^{13}}$ 244	$\frac{f_C}{2^{13}}$ 122

Note: f_C ; High-frequency clock [Hz]

b. At the dual clock mode with DVCK7 = 1 or with SYSCK = 1

SLF	Base frequency [Hz]	Frame frequency [Hz]			
		1/4 Duty	1/3 Duty	1/2 Duty	Static
00	$\frac{f_S}{2^9}$ ($f_S = 32.768 \text{ kHz}$)	$\frac{f_S}{2^9}$ 64	$\frac{4}{3} \cdot \frac{f_S}{2^9}$ 85	$\frac{4}{2} \cdot \frac{f_S}{2^9}$ 128	$\frac{f_S}{2^9}$ 64
01	$\frac{f_S}{2^8}$ ($f_S = 32.768 \text{ kHz}$)	$\frac{f_S}{2^8}$ 128	$\frac{4}{3} \cdot \frac{f_S}{2^8}$ 171	$\frac{4}{2} \cdot \frac{f_S}{2^8}$ 256	$\frac{f_S}{2^8}$ 128

Note: f_S ; Low-frequency clock [Hz]

(3) LCD drive voltage

LCD driving voltage V_{LCD} is given as potential difference $V_{DD} - V_{LC}$ between pins VDD and VLC. Therefore, when the CPU voltage and LCD drive voltage are the same, VLC pin will be connected to VSS pin. The LCD lights when the potential difference between segment output and common output is $\pm V_{LCD}$. Otherwise it turns off.

During reset, the power switch of LCD driver is automatically turned off, shutting off the VLC voltage. At the same time, both segment outputs and common outputs become at GND level, turning off the LCD. The power switch is turned on to supply VLC voltage to LCD driver by setting with EDSP (bit 7 in LCDCR) to "1". After that, the power switch will not turn off even during blanking (clearing EDSP to "0") and the VLC voltage continues to flow. When STOP mode starts, the power switch will be turned off. Therefore, LCD light out, and stop operation is executed at low power consumption. When STOP mode is released the status is in effect immediately before the STOP operation is reinstated.

2.10.3 LCD Display Operation

(1) Display data setting

Display data is stored to the display data area (assigned to address 0F80 to 0F8FH) in the DBR. The display data which are stored in the display data area are automatically read out and sent to the LCD driver by the hardware. The LCD driver generates the segment signal and common signal according to the display data and driving method. Therefore, display patterns can be changed by only overwriting the contents of display data area by the program. Figure 2-45 shows the correspondence between the display data area and SEG/COM pins.

LCD light when display data is "1" and turn off when "0". According to the driving method of LCD, the number of pixels which can be driven becomes different, and the number of bits in the display data area which is used to store display data also becomes different.

Therefore, the bits which are not used to store display data as well as the data buffer which corresponds to the addresses not connected to LCD can be used to store general user process data (see Table 2-10.)

address	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
0F80H	SEG1				SEG0			
81	SEG3				SEG2			
82	SEG5				SEG4			
83	SEG7				SEG6			
84	SEG9				SEG8			
85	SEG11				SEG10			
86	SEG13				SEG12			
87	SEG15				SEG14			
88	SEG17				SEG16			
89	SEG19				SEG18			
8A	SEG21				SEG20			
8B	SEG23				SEG22			
8C	SEG25				SEG24			
8D	SEG27				SEG26			
8E	SEG29				SEG28			
8F	SEG31				SEG30			
	COM3	COM2	COM1	COM0	COM3	COM2	COM1	COM0

Table 2-10. Driving method and bit for display Data

Driving methods	bit 7/3	bit 6/2	bit 5/1	bit 4/0
1/4 Duty	COM3	COM2	COM1	COM0
1/3 Duty	-	COM2	COM1	COM0
1/2 Duty	-	-	COM1	COM0
Static	-	-	-	COM0

Note: - ; This bit is not used for display data

Figure 2-45. LCD display data area (DBR)

(2) Blanking

Blanking is enabled when EDSP is cleared to "0".

Blanking turns off LCD through outputting a non-selective level to COM pin. A signal level is continuously output to SEG pin according to display data and driving method. For static drive, lights-out by data (clearing display data to "0") does not apply any voltage between pins COM and SEG. On the other hand, lights-out by blanking makes the output to COM pin at a constant $V_{LCD}/2$ level, so that the part between pins COM and SEG becomes in the state driven by $V_{LCD}/2$.

2.10.4 Control Method of LCD Driver

(1) Initial setting

Figure 2-46 shows the flowchart of initialization.

Example: To operate a 1/4 duty LCD of 32 segments \times 4 commons at frame frequency $fc/2^{16}$ [Hz]

```

LD  (LCDR),00000001B ; Sets LCD driving method and
                       frame frequency.
LD  (P6CR),0FFH        ; Sets P6 port, P7 port and P9 port
                       as segment output.
LD  (P7CR),0FFH
LD  (P9CR),0FFH
...   ...           ; Sets the initial value of display
...   ...           data.
LD  (LCDR),10000001B ; Display enable

```

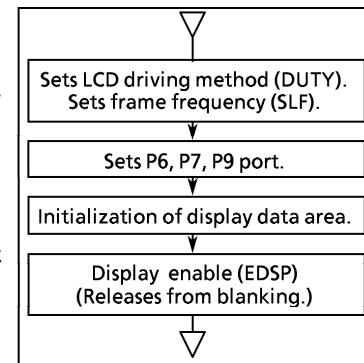


Figure 2-46. Initial Setting of LCD Driver

(2) Store of display data

Generally, display data are prepared as fixed data in program memory (ROM) and stored in display data area by load command.

Example 1: To display using 1/4 duty LCD a numerical value which corresponds to the LCD data stored in data memory at address 80H (when pins COM and SEG are connected to LCD as in Figure 2-47), display data become as shown in Table 2-11.

```

LD  A, (80H)
ADD A, TABLE - $ - 5
LD  HL,0F80H
LD  (HL),(PC + A)
RET
TABLE: DB  11011111B, 00000110B, 11100011B, 10100111B, 00110110B, 10110101B,
       11110101B, 00010111B, 11110111B, 10110111B

```

Note: DB is a byte data definition instruction.



Figure 2-47. Example of COM, SEG Pin Connection (1/4 Duty)

Table 2-11. Example of Display Data (1/4 Duty)

No.	display	display data	No.	display	display data
0	0.	11011111	5	5	10110101
1	!	00000110	6	5	11110101
2	2	11100011	7	7	00000111
3	3	10100111	8	8	11110111
4	4	00110110	9	9	10110111

Example 2: Table 2-12 shows an example of display data which are displayed using 1/2 duty LCD in the same way as Table 2-11. The connection between pins COM and SEG are the same as shown in Figure 2-48.

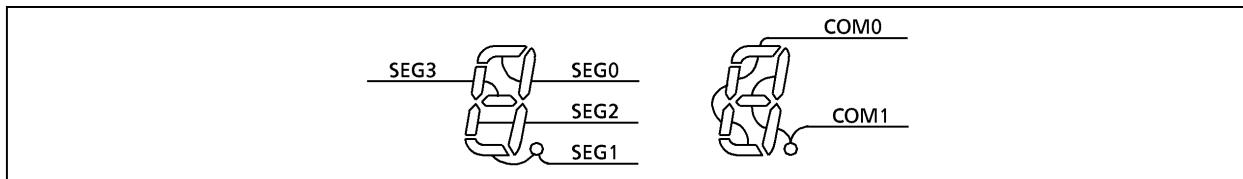


Figure 2-48. Example of COM, SEG Pin Connection

Table 2-12. Example of Display Data (1/2 Duty)

Number	display data		Number	display data	
	High order address	Low order address		High order address	Low order address
0	**01**11	**01**11	5	**11**10	**01**01
1	**00**10	**00**10	6	**11**11	**01**01
2	**10**01	**01**11	7	**01**10	**00**11
3	**10**10	**01**11	8	**11**11	**01**11
4	**11**10	**00**10	9	**11**10	**01**11

Note: *; Don't care

(3) Example of LCD drive output

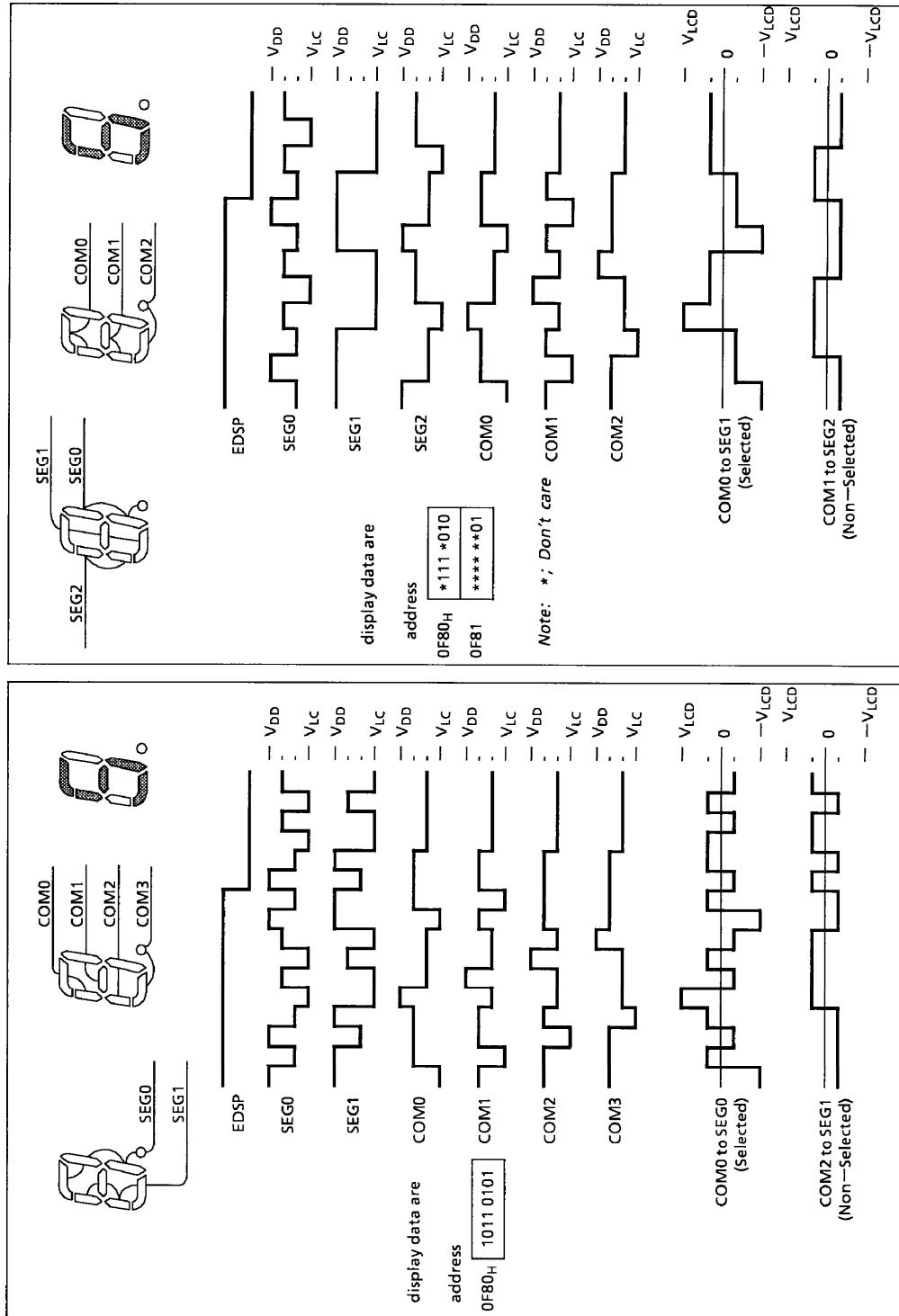


Figure 2-49. 1/4 Duty (1/3 Bias) Drive

Figure 2-50. 1/3 Duty (1/3 Bias) Drive

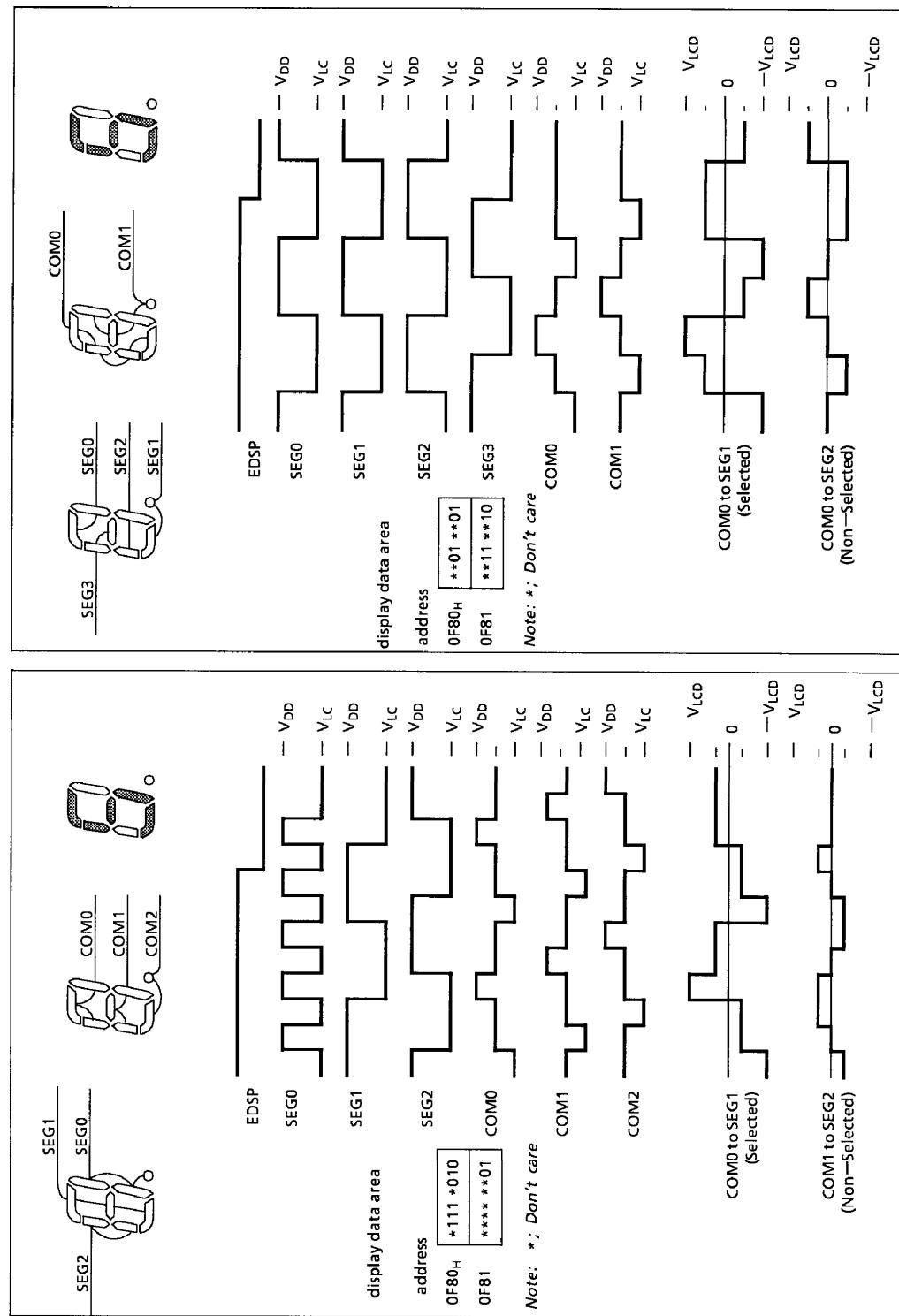


Figure 2-51. 1/3 Duty (1/2 Bias) Drive

Figure 2-52. 1/2 Duty (1/2 Bias) Drive

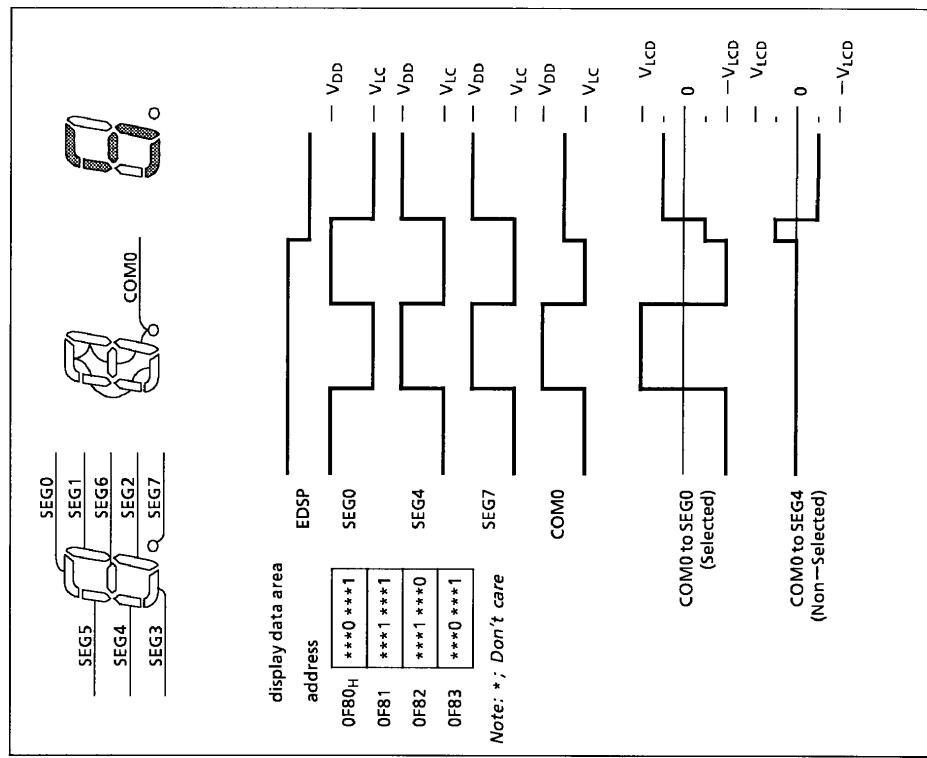


Figure 2-53. Static Drive

2.11 8-bit AD Converter (ADC)

The TMP87CH21/H21B/M21 each have an 8-channel multiplexed-input 8-bit successive approximate type AD converter with sample and hold.

The conversion accuracy differs between the TMP87CH21/CM21 and the TMP87CH21B. (Please refer to the Electrical Characteristics.)

2.11.1 Configuration

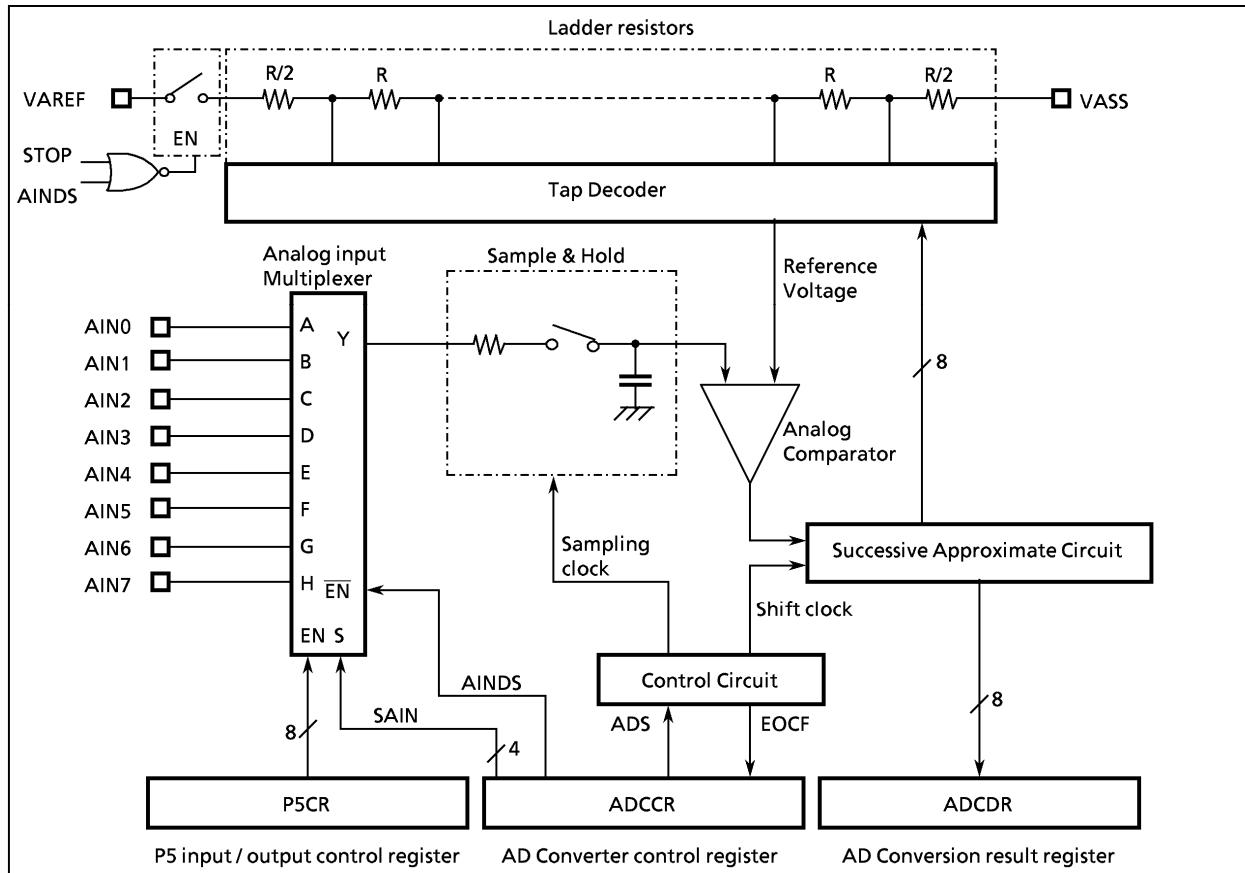


Figure 2-54. AD Converter

2.11.2 Control

The AD converter is controlled by the AD converter control register (ADCCR). Reading EOCF in ADCCR determines the AD converter operating state; reading the AD conversion value register (ADCDR) determines the AD conversion value.

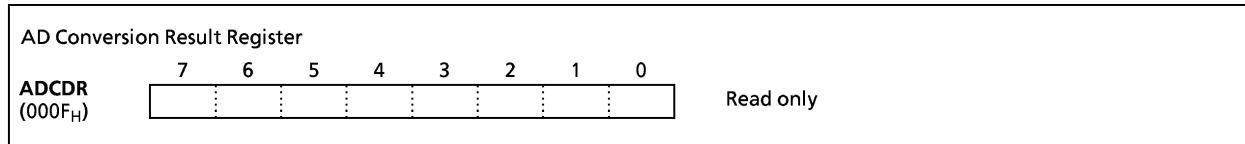


Figure 2-55. AD Converter Result Register

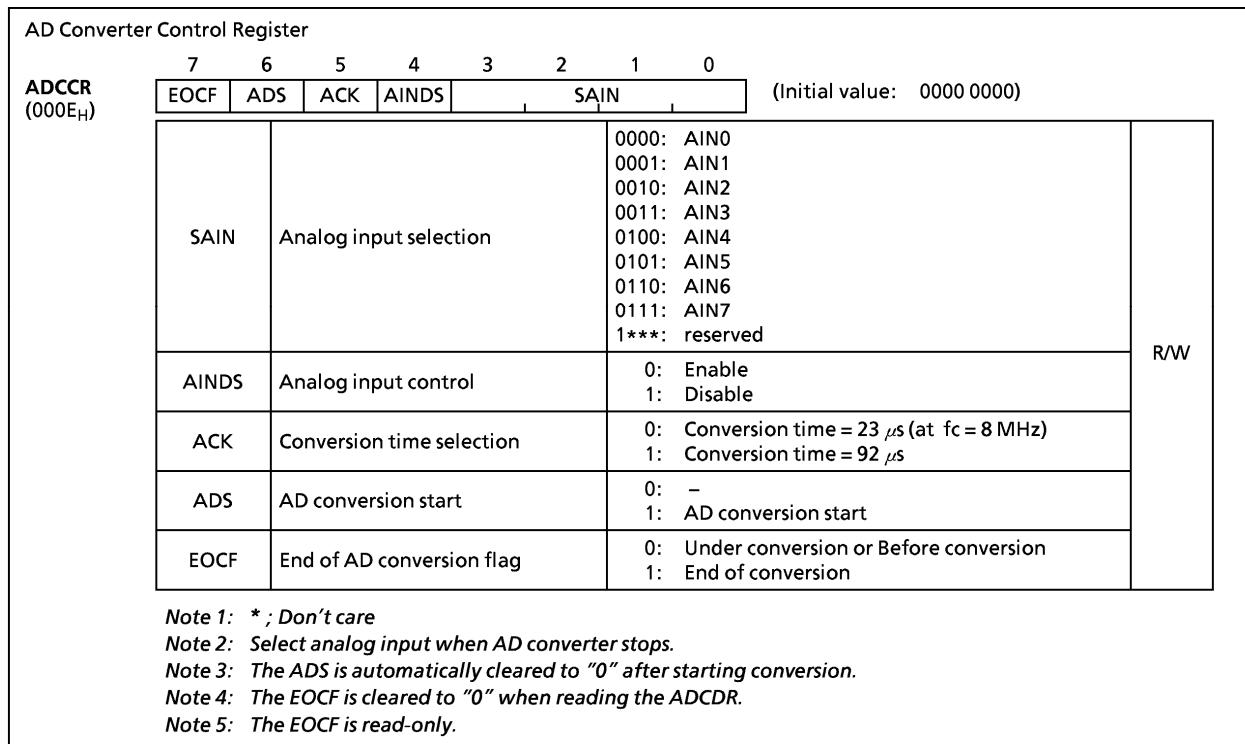


Figure 2-56. AD converter control register and AD conversion result register

2.11.3 Operation

The high side of an analog reference voltage is applied to VAREF pin, and the low side is applied to VASS pin. The reference voltage between VAREF and VASS is divided into the voltage corresponding with bits by radar resistance. The reference voltage is compared with an analog input voltage and AD conversion is performed.

(1) Start of AD conversion

Prior to AD conversion start, select one pin among analog input channels (AIN7 to AIN0) using the SAIN (bit 3 to 0 in ADCCR). Clear AINDS (bit 4 in ADCCR) to 0 and clear the channel to be used for analog input using the P5 I/O control register (P5CR).

Note: The pin that is not used as an analog input can be used as regular input/output pins. During conversion, do not perform output instruction to maintain a precision for all of the pins.

Set AD conversion time using the ACK (bit 5 in ADCCR).

To start AD conversion, set AD conversion to "1" using the ADS (bit 6 in ADCCR).

AD conversion time is from AD conversion start to AD conversion result being set in ADCDR. When ACK = 0, $184/fc$ [s] (46 machine cycles) is necessary. That is, when $fc = 8$ MHz, the AD conversion time is $23\ \mu s$.

After AD conversion, the EOCF (bit 7 in ADCCR) is set to "1" indicating end of conversion.

Setting the ADS to "1" during AD conversion resumes conversion from the beginning.

The analog input voltage is sampled every 4 machine cycles after AD conversion start.

Note: To keep the same level of an analog input during 4 machine cycle time is necessary for charging the electron to the sample hold circuit which has a resistor (typ. $5\ k\Omega$) and a capacitor (typ. $12\ pF$).

(2) Reading of AD conversion result

After the end of conversion, read the conversion result from the ADCDR.

The EOCF is automatically cleared to "0" when reading the ADCDR. When the conversion result is read out during AD conversion, the invalid value is read out.

(3) AD conversion in STOP mode

When the MCU places in the STOP mode during the AD conversion, the conversion is terminated and the AD conversion value become indefinite. Thus EOCF is maintained to "0" after returned from the STOP mode.

However, if the STOP mode is started after the end of conversion (EOCF = 1), the ADCDR contents are held.

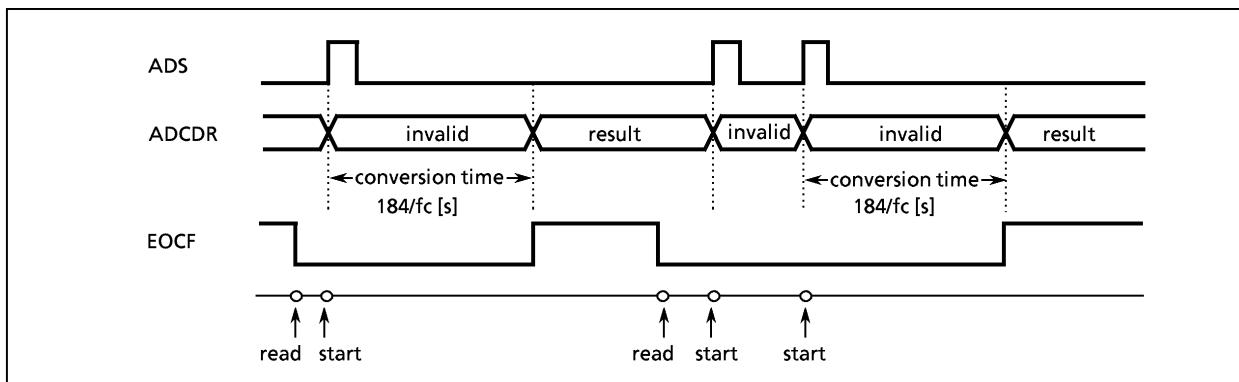


Figure 2-57. AD conversion Timing chart

Example: After AIN pin 4 is selected as an analog input channel, AD conversion is started. EOCF is confirmed and the converted result is read out. It is saved to address $009EH$ in RAM.

```

; AIN SELECT
LD  (ADCCR), 00000100B ; selects AIN4
; AD CONVERT START
SET (ADCCR).6           ; ADS = 1
SLOOP: TEST (ADCCR).7    ; EOCF = 1 ?
JRS  T, SLOOP
; RESULT DATA READ
LD  (9EH), (ADCDR)

```

Figure 2-58 shows the relationship between An analog input voltage and AD converted 8-bit digital value.

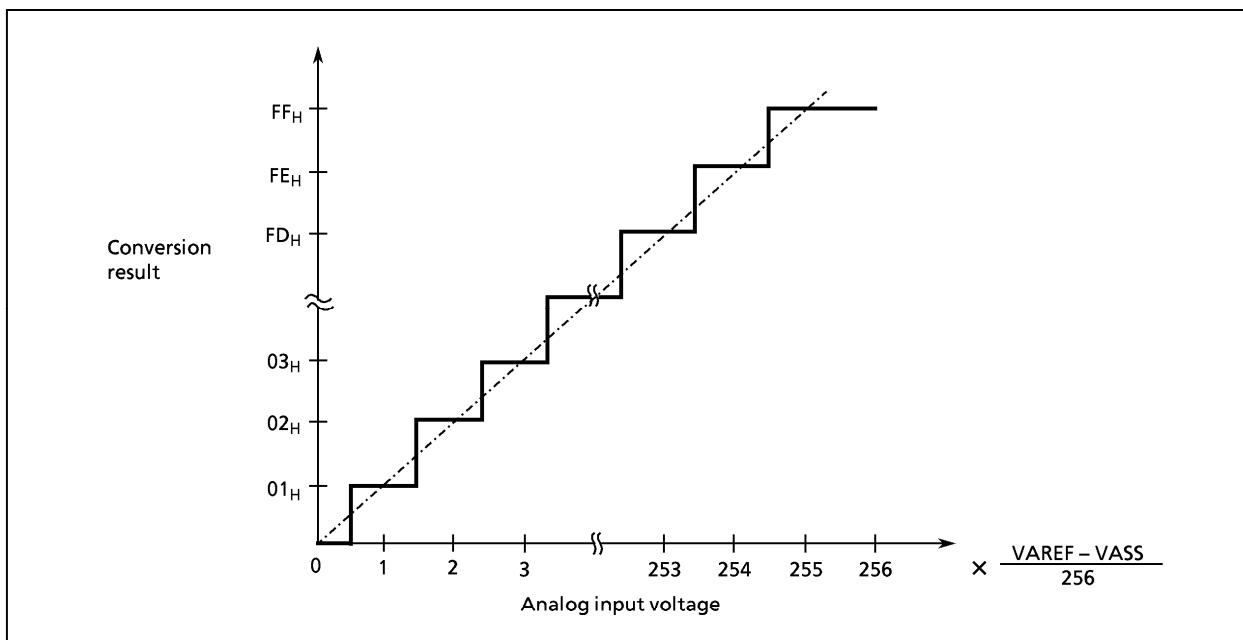


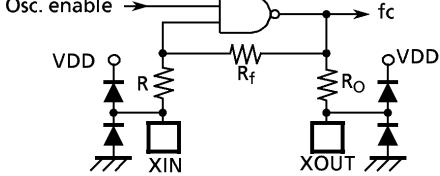
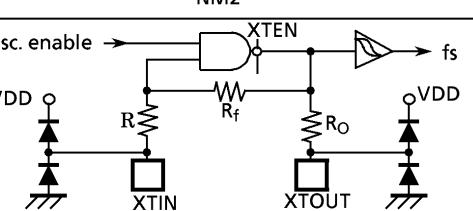
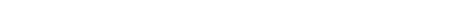
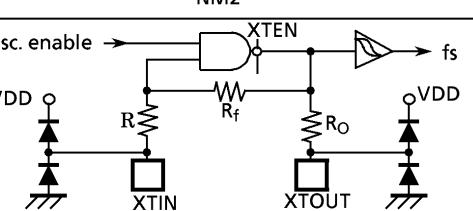
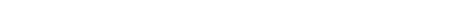
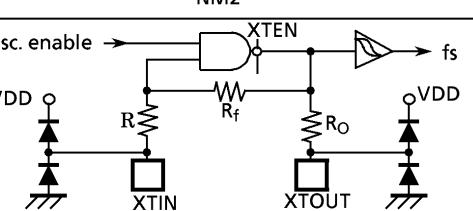
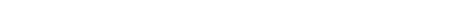
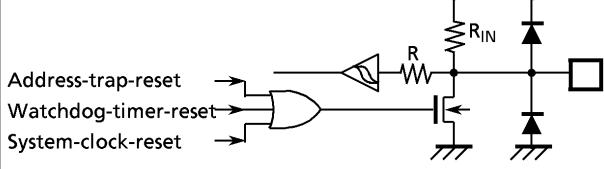
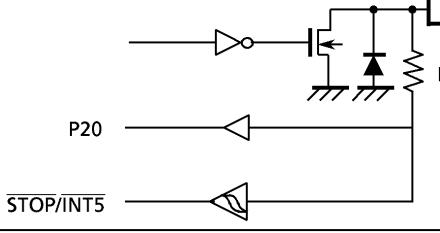
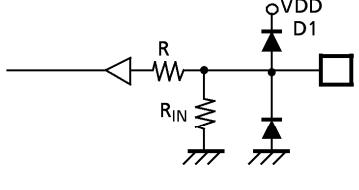
Figure 2-58. Analog input voltage vs AD conversion result (typ.)

Input / Output Circuitry

(1) Control pins

The input / output circuitries of the TMP87CH21/H21B/M21 control pins are shown below.

Please specify either the single-clock mode or the dual-clock mode by a code (NM1 or NM2) as an option for an operating mode during reset.

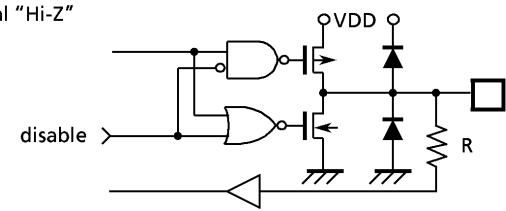
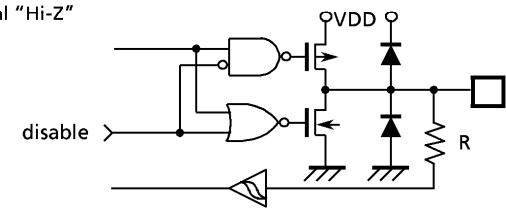
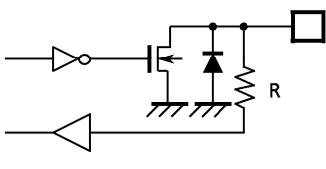
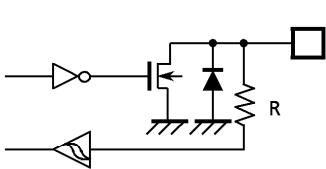
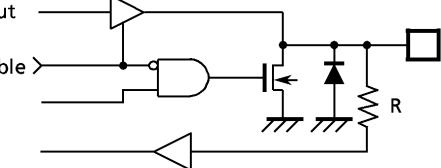
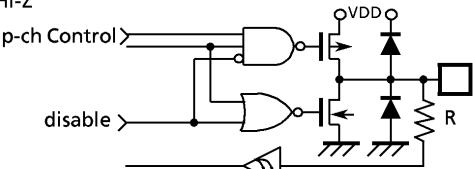
Control Pin	I/O	Input / Output Circuitry and Code		Remarks						
XIN XOUT	Input Output			Resonator connecting pins (high-frequency) $R_f = 1.2 \text{ M}\Omega$ (typ.) $R_o = 1.5 \text{ k}\Omega$ (typ.) $R = 1 \text{ k}\Omega$ (typ.)						
XTIN (P21) XTOUT (P22)	Input Output	<table border="1"> <tr> <td>Refer to port P2</td> <td>NM1</td> <td>NM2</td> </tr> <tr> <td></td> <td>  </td> <td>  </td> </tr> </table>	Refer to port P2	NM1	NM2					Resonator connecting pins (low-frequency) $R_f = 6 \text{ M}\Omega$ (typ.) $R_o = 220 \text{ k}\Omega$ (typ.) $R = 1 \text{ k}\Omega$ (typ.)
Refer to port P2	NM1	NM2								
										
RESET	I/O			Sink open drain output Hysteresis input Pull-up resistor $R_{IN} = 220 \text{ k}\Omega$ (typ.) $R = 1 \text{ k}\Omega$ (typ.)						
STOP/INT5 (P20)	Input			Hysteresis input $R = 1 \text{ k}\Omega$ (typ.)						
TEST	Input			Pull-down resistor $R_{IN} = 70 \text{ k}\Omega$ (typ.) $R = 1 \text{ k}\Omega$ (typ.)						

Note 1: The TEST pin of the TMP87PP21 does not have a pull-down resistor (R_{IN}) and a diode (D1). Be sure to fix the TEST pin to low level in MCU mode.

Note 2: The TMP87PP21 is placed in the single-clock mode during reset, and the input/output circuitries are the code NM1 type.

(2) Input/Output Ports

The input/output circuitries of the TMP87CH21/H21B/M21 input/output ports are shown below.

Port	I/O	Input / Output Circuitry and Code	Remarks
P5	I/O	<p>initial "Hi-Z"</p> 	<p>Tri-state I/O</p> <p>$R = 1 \text{ k}\Omega$ (typ.)</p>
P1	I/O	<p>initial "Hi-Z"</p> 	<p>Tri-state I/O</p> <p>Hysteresis input</p> <p>$R = 1 \text{ k}\Omega$ (typ.)</p>
P2	I/O	<p>initial "Hi-Z"</p> 	<p>Sink open drain output</p> <p>$R = 1 \text{ k}\Omega$ (typ.)</p>
P3	I/O	<p>initial "Hi-Z"</p> 	<p>Sink open drain output</p> <p>$R = 1 \text{ k}\Omega$ (typ.)</p>
P6 P7 P9	I/O	<p>initial "Hi-Z"</p> <p>Segment output</p> 	<p>Sink open drain or Segment output</p> <p>$R = 1 \text{ k}\Omega$ (typ.)</p>
P4	I/O	<p>initial "Hi-Z"</p> <p>p-ch Control</p> 	<p>Push-pull I/O</p> <p>P41 High current output</p> <p>$R = 1 \text{ k}\Omega$ (typ.)</p>

Note: P4 port enables the control of ON/OFF operation of the Pch transistor by using the command register.

Electrical Characteristics

(1) TMP87CH21/M21

Absolute Maximum Ratings		(V _{SS} = 0 V)		
Parameter	Symbol	Pins	Ratings	Unit
Supply Voltage	V _{DD}		- 0.3 to 6.5	V
Input Voltage	V _{IN}		- 0.3 to V _{DD} + 0.3	V
Output Voltage	V _{OUT}		- 0.3 to V _{DD} + 0.3	V
Output Current (Per 1 pin)	I _{OUT1}	Ports P0, P1, P2, P3, P5, P6, P7, P8, P9, P4 (except P41)	3.2	mA
	I _{OUT2}	P41	30	
Output Current (Total)	Σ I _{OUT1}	Ports P0, P1, P2, P3, P5, P6, P7, P8, P9, P4 (except P41)	120	mA
	Σ I _{OUT2}	P41	30	
Power Dissipation [Topr = 70°C]	PD		350	mW
Soldering Temperature (time)	T _{sld}		260 (10 s)	°C
Storage Temperature	T _{stg}		- 55 to 125	°C
Operating Temperature	Topr		- 30 to 70	°C

Note: The absolute maximum ratings are rated values which must not be exceeded during operation, even for an instant. Any one of the ratings must not be exceeded. If any absolute maximum rating is exceeded, a device may break down or its performance may be degraded, causing it to catch fire or explode resulting in injury to the user. Thus, when designing products which include this device, ensure that no absolute maximum rating value will ever be exceeded.

Recommended Operating Conditions		(V _{SS} = 0 V, Topr = - 30 to 70°C)					
Parameter	Symbol	Pins	Conditions		Min	Max	Unit
Supply Voltage	V _{DD}		fc = 8 MHz	NORMAL1, 2 mode	4.5	5.5	V
				IDLE1, 2 mode			
			fc = 4.2 MHz	NORMAL1, 2 mode			
				IDLE1, 2 mode			
			fs = 32.768 kHz	SLOW mode	2.7		
Input High Voltage	V _{IH1}	Except hysteresis input	V _{DD} ≥ 4.5 V		V _{DD} × 0.70	V _{DD}	V
	V _{IH2}	Hysteresis input			V _{DD} × 0.75		
	V _{IH3}		V _{DD} < 4.5 V		V _{DD} × 0.90		
Input Low Voltage	V _{IL1}	Except hysteresis input	V _{DD} ≥ 4.5 V			V _{DD} × 0.30	V
	V _{IL2}	Hysteresis input					
	V _{IL3}		V _{DD} < 4.5 V				
Clock Frequency	fc	XIN, XOUT	V _{DD} = 4.5 to 5.5 V		0	8.0	MHz
					0.4		
	fs	XTIN, XTOUT	V _{DD} = 2.7 to 5.5 V		30.0	4.2	

Note 1: The recommended operating conditions for a device are operating conditions under which it can be guaranteed that the device will operate as specified. If the device is used under operating conditions other than the recommended operating conditions (supply voltage, operating temperature range, specified AC/DC values etc.), malfunction may occur. Thus, when designing products which include this device, ensure that the recommended operating conditions for the device are always adhered to.

Note 2: Clock frequency fc: Supply voltage range is specified in NORMAL1/2 mode and IDLE1/2 mode.

DC Characteristics			(V _{SS} = 0 V, Topr = -30 to 70°C)						
Parameter	Symbol	Pins	Conditions	Min	Typ.	Max	Unit		
Hysteresis Voltage	V _{HS}	Hysteresis inputs		—	0.9	—	V		
Input Current	I _{IN1}	TEST	V _{DD} = 5.5 V V _{IN} = 5.5 V / 0 V	—	—	± 2	μA		
	I _{IN2}	Open drain ports and tri-state ports							
	I _{IN3}	RESET, STOP							
Input Low Current	I _{IL}	Push-pull ports	V _{DD} = 5.5 V, V _{IN} = 0.4 V	—	—	-2	mA		
Input Resistance	R _{IN2}	RESET		100	220	450	kΩ		
Output Leakage Current	I _{LO}	Open drain ports, Tri-state ports	V _{DD} = 5.5 V, V _{OUT} = 5.5 V	—	—	2	μA		
Output High Voltage	V _{OH1}	Push-pull ports P4 ports	V _{DD} = 4.5 V, I _{OH} = -200 μA	2.4	—	—	V		
	V _{OH2}	Tri-state ports P1, P5 ports	V _{DD} = 4.5 V, I _{OH} = -0.7 mA	4.1	—	—			
Output Low Voltage	V _{OL}	Except XOUT and P41	V _{DD} = 4.5 V, I _{OL} = 1.6 mA	—	—	0.4	V		
Output Low Current	I _{OL3}	P41	V _{DD} = 4.5 V, V _{OL} = 1.0 V	—	20	—	mA		
Supply Current in NORMAL 1, 2 mode	I _{DD}		V _{DD} = 5.5 V V _{IN} = 5.3 V/0.2 V fc = 8 MHz fs = 32.768 kHz	—	10	16	mA		
Supply Current in IDLE 1, 2 mode					6	10	mA		
Supply Current in SLOW mode			V _{DD} = 3.0 V V _{IN} = 2.8 V/0.2 V fs = 32.768 kHz LCD driver is not enable	—	30	60	μA		
Supply Current in SLEEP mode					15	30	μA		
Supply Current in STOP mode			V _{DD} = 5.5 V V _{IN} = 5.3 V/0.2 V	—	0.5	10	μA		
Segment Output Low Resistance	R _{OS1}	SEG31 to SEG0	—	20	—	kΩ			
Common Output Low Resistance	R _{OC1}	COM3 to COM0	V _{DD} = 5 V, V _{DD} - V _{LC} = 3 V	—	200		—		
Segment Output High Resistance	R _{OS2}	SEG31 to SEG0			3.8	4.0	4.2		
Common Output High Resistance	R _{OC2}	COM3 to COM0			3.3	3.5	3.7		
Segment/Common Output Voltage	V _{O2/3}	SEG31 to SEG0 and COM3 to COM0			2.8	3.0	3.2		
	V _{O1/2}				V				
	V _{O1/3}								

Note 1: Typical values show those at Topr = 25°C, V_{DD} = 5 V.

Note 2: Input Current ; The current through pull-up or pull-down resistor is not included.

Note 3: I_{DD} ; Except for I_{REF}

Note 4: Output resistors Ros, Roc indicate "on" when switching levels.

Note 5: V_{O2/3} indicates an output voltage at the 2/3 level when operating in the 1/4 or 1/3 duty mode.

Note 6: V_{O1/2} indicates an output voltage at the 1/2 level when operating in the 1/2 duty or static mode.

Note 7: V_{O1/3} indicates an output voltage at the 1/3 level when operating in the 1/4 or 1/3 duty mode.

Note 8: When using LCD, it is necessary to consider values of Ros1/2 and Roc1/2.

Note 9: Times for SEG/COM output switching on: Ros1, Roc1: 2⁶/fc, 2/fs(s)
Ros2, Roc2: 1/(n, f_F)
(1/n: duty, f_F: frame frequency)

AD Conversion Characteristics		(V _{SS} = 0 V, V _{DD} = 2.7 to 5.5 V, Topr = -30 to 70°C)				
Parameter	Symbol	Conditions	Min	Typ.	Max	Unit
Analog Reference Voltage	V _{AREF}	V _{AREF} - V _{ASS} ≥ 2.5 V	2.7	—	V _{DD}	V
	V _{ASS}		V _{SS}	—	1.5	
Analog Input Voltage	V _A		V _{ASS}	—	V _{AREF}	V
Analog Supply Current	I _{REF}	V _{AREF} = 5.5 V, V _{ASS} = 0.0 V	—	0.5	1.0	mA
Nonlinearity Error		V _{DD} = 5.0 V, V _{SS} = 0.0 V V _{AREF} = 5.000 V V _{ASS} = 0.000 V or	—	—	± 1	LSB
Zero Point Error			—	—	± 1	
Full Scale Error			—	—	± 1	
Total Error		V _{DD} = 2.7 V, V _{SS} = 0.0 V V _{AREF} = 2.700 V V _{ASS} = 0.000 V	—	—	± 2	

Note 1: Quantizing error is not contained in those errors.

Note 2: Full Scale Error and Total Error are different from those with the TMP87CH21B.

	TMP87CH21B	Unit
Full Scale Error	+2, -1	
Total Error	+3, -2	LSB

AC Characteristics - 1

(V_{SS} = 0 V, V_{DD} = 4.5 to 5.5 V, Topr = -30 to 70°C)

Parameter	Symbol	Conditions	Min	Typ.	Max	Unit	
Machine Cycle Time	t _{cy}	In NORMAL 1, 2 mode	0.5	—	10	μs	
		In IDLE 1, 2 mode					
		In SLOW mode	117.6	—	133.3		
		In SLEEP mode					
High Level Clock Pulse Width	t _{WCH}	For external clock operation (XIN input), f _c = 8 MHz	50	—	—	ns	
Low Level Clock Pulse Width	t _{WCL}						
High Level Clock Pulse Width	t _{WSH}	For external clock operation (XTIN input), f _s = 32.768 kHz	14.7	—	—	μs	
Low Level Clock Pulse Width	t _{WSL}						

AC Characteristics - 2

(V_{SS} = 0 V, V_{DD} = 2.7 to 5.5 V, Topr = -30 to 70°C)

Parameter	Symbol	Conditions	Min	Typ.	Max	Unit	
Machine Cycle Time	t _{cy}	In NORMAL 1, 2 mode	0.95	—	10	μs	
		In IDLE 1, 2 mode					
		In SLOW mode	117.6	—	133.3		
		In SLEEP mode					
High Level Clock Pulse Width	t _{WCH}	For external clock operation (XIN input), f _c = 4.2 MHz	110	—	—	ns	
Low Level Clock Pulse Width	t _{WCL}						
High Level Clock Pulse Width	t _{WSH}	For external clock operation (XTIN input), f _s = 32.768 kHz	14.7	—	—	μs	
Low Level Clock Pulse Width	t _{WSL}						

Electrical Characteristics

(2) TMP87CH21B

Absolute Maximum Ratings		$(V_{SS} = 0 \text{ V})$		
Parameter	Symbol	Conditions	Ratings	Unit
Supply Voltage	V_{DD}		- 0.3 to 6.5	V
Input Voltage	V_{IN}		- 0.3 to $V_{DD} + 0.3$	V
Output Voltage	V_{OUT}		- 0.3 to $V_{DD} + 0.3$	V
Output Current (Per 1 pin)	I_{OUT1}	Ports P0, P1, P2, P3, P5, P6, P7, P8, P9, P4 (except P41)	3.2	mA
	I_{OUT2}	P41	30	
Output Current (Total)	ΣI_{OUT1}	Ports P0, P1, P2, P3, P5, P6, P7, P8, P9, P4 (except P41)	120	mA
	ΣI_{OUT2}	P41	30	
Power Dissipation [Topr = 70°C]	PD		350	mW
Soldering Temperature (time)	Tsld		260 (10 s)	°C
Storage Temperature	Tstg		- 55 to 125	°C
Operating Temperature	Topr		- 30 to 70	°C

Note: The absolute maximum ratings are rated values which must not be exceeded during operation, even for an instant. Any one of the ratings must not be exceeded. If any absolute maximum rating is exceeded, a device may break down or its performance may be degraded, causing it to catch fire or explode resulting in injury to the user. Thus, when designing products which include this device, ensure that no absolute maximum rating value will ever be exceeded.

Recommended Operating Conditions		$(V_{SS} = 0 \text{ V}, \text{Topr} = - 30 \text{ to } 70 \text{ °C})$					
Parameter	Symbol	Pins	Conditions		Min	Max	Unit
Supply Voltage	V_{DD}		$f_c = 8 \text{ MHz}$	NORMAL1, 2 mode	4.5	5.5	V
				IDLE1, 2 mode			
			$f_c = 4.2 \text{ MHz}$	NORMAL1, 2 mode			
				IDLE1, 2 mode			
			$f_s = 32.768 \text{ kHz}$	SLOW mode	2.7		
Input High Voltage	V_{IH1}	Except hysteresis input	$V_{DD} \geq 4.5 \text{ V}$		$V_{DD} \times 0.70$	V_{DD}	V
	V_{IH2}	Hysteresis input			$V_{DD} \times 0.75$		
	V_{IH3}		$V_{DD} < 4.5 \text{ V}$		$V_{DD} \times 0.90$		
Input Low Voltage	V_{IL1}	Except hysteresis input	$V_{DD} \geq 4.5 \text{ V}$			0	V
	V_{IL2}	Hysteresis input					
	V_{IL3}		$V_{DD} < 4.5 \text{ V}$				
Clock Frequency	f_c	XIN, XOUT	$V_{DD} = 4.5 \text{ to } 5.5 \text{ V}$			1.0	MHz
			$V_{DD} = 2.7 \text{ to } 5.5 \text{ V}$				
	f_s	XTIN, XTOUT			30.0	34.0	kHz

Note 1: The recommended operating conditions for a device are operating conditions under which it can be guaranteed that the device will operate as specified. If the device is used under operating conditions other than the recommended operating conditions (supply voltage, operating temperature range, specified AC/DC values etc.), malfunction may occur. Thus, when designing products which include this device, ensure that the recommended operating conditions for the device are always adhered to.

Note 2: Clock frequency f_c : Supply voltage range is specified in NORMAL1/2 mode and IDLE1/2 mode.

DC Characteristics			(V _{SS} = 0 V, Topr = -30 to 70°C)					
Parameter	Symbol	Pins	Conditions	Min	Typ.	Max	Unit	
Hysteresis Voltage	V _{HS}	Hysteresis inputs		—	0.9	—	V	
Input Current	I _{IN1}	TEST	V _{DD} = 5.5 V V _{IN} = 5.5 V / 0 V	—	—	± 2	μA	
	I _{IN2}	Open drain ports and tri-state ports						
	I _{IN3}	RESET, STOP						
Input Low Current	I _{IL}	Push-pull ports	V _{DD} = 5.5 V, V _{IN} = 0.4 V	—	—	-2	mA	
Input Resistance	R _{IN2}	RESET		100	220	450	kΩ	
Output Leakage Current	I _{LO}	Open drain ports, Tri-state ports	V _{DD} = 5.5 V, V _{OUT} = 5.5 V	—	—	2	μA	
Output High Voltage	V _{OH1}	Push-pull ports P4 ports	V _{DD} = 4.5 V, I _{OH} = -200 μA	2.4	—	—	V	
	V _{OH2}	Tri-state ports P1, P5 ports	V _{DD} = 4.5 V, I _{OH} = -0.7 mA	4.1	—	—		
Output Low Voltage	V _{OL}	Except XOUT and P41	V _{DD} = 4.5 V, I _{OL} = 1.6 mA	—	—	0.4	V	
Output Low Current	I _{OL3}	P41	V _{DD} = 4.5 V, V _{OL} = 1.0 V	—	20	—	mA	
Supply Current in NORMAL 1, 2 mode	I _{DD}		V _{DD} = 5.5 V	—	6	9	mA	
Supply Current in IDLE 1, 2 mode			V _{IN} = 5.3 V/0.2 V	—	3	4.5	mA	
Supply Current in SLOW mode			f _c = 8 MHz	—	30	60	μA	
Supply Current in SLEEP mode			f _s = 32.768 kHz	—	15	30	μA	
Supply Current in STOP mode			LCD driver is not enable	—	0.5	10	μA	
Segment Output Low Resistance	R _{O1}	SEG31 to SEG0	V _{DD} = 5 V, V _{DD} - V _{LC} = 3 V	—	20	—	kΩ	
Common Output Low Resistance	R _{O2}	COM3 to COM0		—	200	—	kΩ	
Segment Output High Resistance	R _{O3}	SEG31 to SEG0		3.8	4.0	4.2	V	
Common Output High Resistance	R _{O4}	COM3 to COM0		3.3	3.5	3.7		
Segment/Common Output Voltage	V _{O2/3}	SEG31 to SEG0 and COM3 to COM0		2.8	3.0	3.2		
	V _{O1/2}							
	V _{O1/3}							

Note 1: Typical values show those at Topr = 25°C, V_{DD} = 5 V.

Note 2: Input Current ; The current through pull-up or pull-down resistor is not included.

Note 3: I_{DD} ; Except for I_{REF}

Note 4: Output resistors Ros, Roc indicate "on" when switching levels.

Note 5: V_{O2/3} indicates an output voltage at the 2/3 level when operating in the 1/4 or 1/3 duty mode.

Note 6: V_{O1/2} indicates an output voltage at the 1/2 level when operating in the 1/2 duty or static mode.

Note 7: V_{O1/3} indicates an output voltage at the 1/3 level when operating in the 1/4 or 1/3 duty mode.

Note 8: When using LCD, it is necessary to consider values of Ros1/2 and Roc1/2.

Note 9: Times for SEG/COM output switching on: Ros1, Roc1: 2⁶/f_c, 2/f_s(s)
Ros2, Roc2: 1/(n, f_F)
(1/n: duty, f_F: frame frequency)

AD Conversion Characteristics		$(V_{SS} = 0 \text{ V}, V_{DD} = 2.7 \text{ to } 5.5 \text{ V}, Topr = -30 \text{ to } 70^\circ\text{C})$				
Parameter	Symbol	Conditions	Min	Typ.	Max	Unit
Analog Reference Voltage	V_{AREF}	$V_{AREF} - V_{ASS} \geq 2.5 \text{ V}$	2.7	—	V_{DD}	V
	V_{ASS}		V_{SS}	—	1.5	
Analog Input Voltage	V_{AIN}	$V_{AREF} = 5.5 \text{ V}, V_{ASS} = 0.0 \text{ V}$	V_{ASS}	—	V_{AREF}	V
Analog Supply Current	I_{REF}		—	0.5	1.0	mA
Nonlinearity Error		$V_{DD} = 5.0 \text{ V}, V_{SS} = 0.0 \text{ V}$ $V_{AREF} = 5.000 \text{ V}$ $V_{ASS} = 0.000 \text{ V}$ or $V_{DD} = 2.7 \text{ V}, V_{SS} = 0.0 \text{ V}$ $V_{AREF} = 2.700 \text{ V}$ $V_{ASS} = 0.000 \text{ V}$	—	—	± 1	LSB
Zero Point Error			—	—	± 1	
Full Scale Error			—	—	$+2, -1$	
Total Error			—	—	$+3, -2$	

Note 1: Quantizing error is not contained in those errors.

Note 2: Full Scale Error and Total Error are different from those with the TMP87CH21/CM21/PP21.

	TMP87CH21/CM21/PP21	Unit
Full Scale Error	± 1	
Total Error	± 2	LSB

AC Characteristics - 1

$(V_{SS} = 0 \text{ V}, V_{DD} = 4.5 \text{ to } 5.5 \text{ V}, Topr = -30 \text{ to } 70^\circ\text{C})$

Parameter	Symbol	Conditions	Min	Typ.	Max	Unit
Machine Cycle Time	t_{cy}	In NORMAL 1, 2 mode	0.5	—	4	μs
		In IDLE 1, 2 mode		—	—	
		In SLOW mode	117.6	—	133.3	
		In SLEEP mode		—	—	
High Level Clock Pulse Width	t_{WCH}	For external clock operation (XIN input), $f_c = 8 \text{ MHz}$	50	—	—	ns
Low Level Clock Pulse Width	t_{WCL}			—	—	
High Level Clock Pulse Width	t_{WSH}	For external clock operation (XTIN input), $f_s = 32.768 \text{ kHz}$	14.7	—	—	μs
Low Level Clock Pulse Width	t_{WSL}			—	—	

AC Characteristics - 2

$(V_{SS} = 0 \text{ V}, V_{DD} = 2.7 \text{ to } 5.5 \text{ V}, Topr = -30 \text{ to } 70^\circ\text{C})$

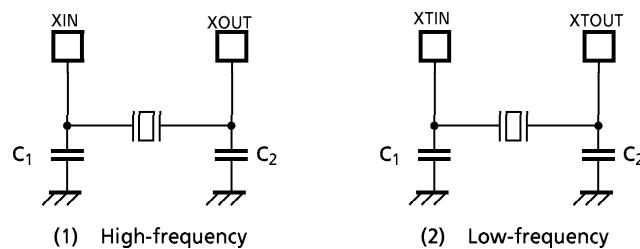
Parameter	Symbol	Conditions	Min	Typ.	Max	Unit
Machine Cycle Time	t_{cy}	In NORMAL 1, 2 mode	0.95	—	4	μs
		In IDLE 1, 2 mode		—	—	
		In SLOW mode	117.6	—	133.3	
		In SLEEP mode		—	—	
High Level Clock Pulse Width	t_{WCH}	For external clock operation (XIN input), $f_c = 4.2 \text{ MHz}$	110	—	—	ns
Low Level Clock Pulse Width	t_{WCL}			—	—	
High Level Clock Pulse Width	t_{WSH}	For external clock operation (XTIN input), $f_s = 32.768 \text{ kHz}$	14.7	—	—	μs
Low Level Clock Pulse Width	t_{WSL}			—	—	

Recomended Oscillating Condition-1 (VSS = 0 V, VDD = 4.5 to 5.5 V, Topr = -30 to 70°C)

Parameter	Oscillator	Frequency	Recommender Oscillator	Recommended Condition	
				C ₁	C ₂
High-frequency	Ceramic Resonator	8 MHz	KYOCERA KBR8.0M	30 pF	30 pF
			Standard/Lead Type (MURATA) CSA8.00MTZ CST8.00MTW	built-in 30 pF	built-in 30 pF
			Standard/SMP Type (MURATA) CSAC8.00MT	30 pF	30 pF
		4 MHz	Standard/Small Chip Type (MURATA) CSTS8.00MT	built-in 30 pF	built-in 30 pF
	Crystal Oscillator	8 MHz	KYOCERA KBR4.0MS	30 pF	30 pF
		4 MHz	TOYOCOM 210B 8.0000	20 pF	20 pF
Low-frequency	Crystal Oscillator	32.768 kHz	NDK MX-38T	15 pF	15 pF

Recomended Oscillating Condition-2 (VSS = 0 V, VDD = 2.7 to 5.5 V, Topr = -30 to 70°C)

Parameter	Oscillator	Frequency	Recommender Oscillator	Recommended Condition	
				C ₁	C ₂
High-frequency	Ceramic Resonator	4 MHz	Standard/Lead Type (MURATA) CSA4.00MG CST4.00MGW	30 pF	30 pF
			built-in 30 pF	built-in 30 pF	
			Standard/SMD Type (MURATA) CSA4.00MGC CSAC4.00MGCM CSTC4.00MG	30 pF	30 pF
			built-in 30 pF	built-in 30 pF	
			Standard/Small Chip Type CSTCS4.00MG	built-in 10 pF	built-in 10 pF



Note: When used in high electric field such as a picture tube, the package is recommended to be electrically shielded to maintain a regular operation.