TOSHIBA

TOSHIBA Original CMOS 8-Bit Microcontroller

TLCS-870 Series

TMP87CM53FG

TOSHIBA CORPORATION

Semiconductor Company

Document Change Notification

The purpose of this notification is to inform customers about the launch of the Pb-free version of the device. The introduction of a Pb-free replacement affects the datasheet. Please understand that this notification is intended as a temporary substitute for a revision of the datasheet.

Changes to the datasheet may include the following, though not all of them may apply to this particular device.

1. Part number

   Example: TMPxxxxxxF → TMPxxxxxxFG

   All references to the previous part number were left unchanged in body text. The new part number is indicated on the prelims pages (cover page and this notification).

2. Package code and package dimensions

   Example: LQFP100-P-1414-0.50C → LQFP100-P-1414-0.50F

   All references to the previous package code and package dimensions were left unchanged in body text. The new ones are indicated on the prelims pages.

3. Addition of notes on lead solderability

   Now that the device is Pb-free, notes on lead solderability have been added.

4. RESTRICTIONS ON PRODUCT USE

   The previous (obsolete) provision might be left unchanged on page 1 of body text. A new replacement is included on the next page.

5. Publication date of the datasheet

   The publication date at the lower right corner of the prelims pages applies to the new device.

1. Part number

2. Package code and dimensions

Previous Part Number (in Body Text)	Previous Package Code (in Body Text)	New Part Number	New Package Code	OTP
TMP87CM53F	QFP80-P-1420-0.80B	TMP87CM53FG	QFP80-P-1420-0.80B	TMP87PM53FG

*: For the dimensions of the new package, see the attached Package Dimensions diagram.

3. Addition of notes on lead solderability

The following solderability test is conducted on the new device.

Lead solderability of Pb-free devices (with the G suffix)

Test	Test Conditions	Remark
Solderability	(1) Use of Lead (Pb) ·solder bath temperature = 230°C ·dipping time = 5 seconds ·the number of times = once ·use of R-type flux (2) Use of Lead (Pb)-Free ·solder bath temperature = 245°C ·dipping time = 5 seconds ·the number of times = once ·use of R-type flux	Leads with over 95% solder coverage till lead forming are acceptable.

4. RESTRICTIONS ON PRODUCT USE

The following replaces the "RESTRICTIONS ON PRODUCT USE" on page 1 of body text.

RESTRICTIONS ON PRODUCT USE 20070701-EN

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- For a discussion of how the reliability of microcontrollers can be predicted, please refer to Section 1.3 of the chapter entitled Quality and Reliability Assurance/Handling Precautions.

5. Publication date of the datasheet

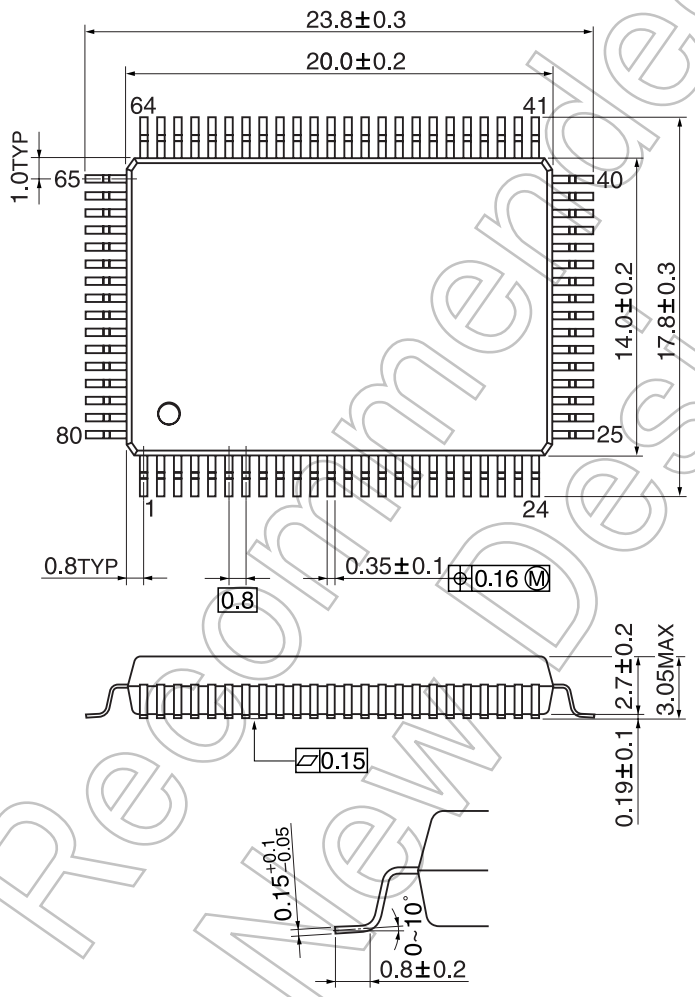
The publication date of this datasheet is printed at the lower right corner of this notification.

(Annex)

Package Dimensions

QFP80-P-1420-0.80B

Unit: mm



CMOS 8-Bit Microcontroller

TMP87CM53F

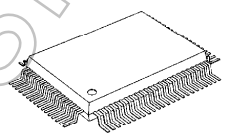
The 87CM53 is the high speed and high performance 8-bit single chip microcomputers. These MCU contain CPU core, ROM, RAM, input/output ports, an A/D converter, DTMF generator, multi-function timer/counters, two serial interfaces, and two clock generators on a chip. The 87CM53 provides high current output capability for LED direct drive.

Part No.	ROM	RAM	Package	OTP MCU
TMP87CM53F	32 K × 8-bit	1024 × 8-bit	P-QFP80-1420-0.80B	TMP87PM53F

Features

- ◆8-bit single chip microcomputer TLCS-870 Series
- ◆Instruction execution time: 0.5 μs (at 8 MHz, gear ratio1/1), 122 μs(at 32.768 kHz)
- ◆412 basic instructions
  - Multiplication and Division (8 bits × 8 bits , 16 bits ÷ 8 bits)
  - Bit manipulations (Set/Clear/Complement/Move/Test/Exclusive or)
  - 16-bit data operations
  - 1-byte jump/subroutine-call (Short relative jump / Vector call)
- ◆15 interrupt sources (External: 5, Internal: 10)
  - All sources have independent latches each, and nested interrupt control is available.
  - edge-selectable external interrupts with noise reject
  - High-speed task switching by register bank changeover
- ◆10 Input/Output ports (72 pins)
  - High current output: 7 pins (typ. 20 mA)
- ◆Two 16-bit Timer/Counters
  - Timer, Event counter, Programmable pulse generator output, Pulse width measurement, External trigger timer, Window modes
- ◆Two 8-bit Timer/Counters
  - Timer, Event counter, Capture (Pulse width/duty measurement), PWM output, Programmable divider output modes
- ◆Time Base Timer (Interrupt frequenc: 0.95 Hz to 16384 Hz)
- ◆Divider output function (frequency: 0.976 kHz to 8.192 kHz)
- ◆Tone generator
  - Single tone / Dual tone (DTMF) output function
  - Melody (sine wave / square wave) output function
- ◆Watchdog Timer
- ◆8-bit Serial Interface
  - 8 bytes transmit/receive data buffer
  - Internal/external serial clock, and 4/8-bit mode
- ◆UART
- ◆8-bit successive approximate type A/D converter with sample and hold
  - 8 analog inputs
  - Conversion time:23 μs or 92 μs (at 8 MHz, gear ratio1/1)

P-QFP80-1420-0.80B



TMP87CM53F
TMP87PM53F

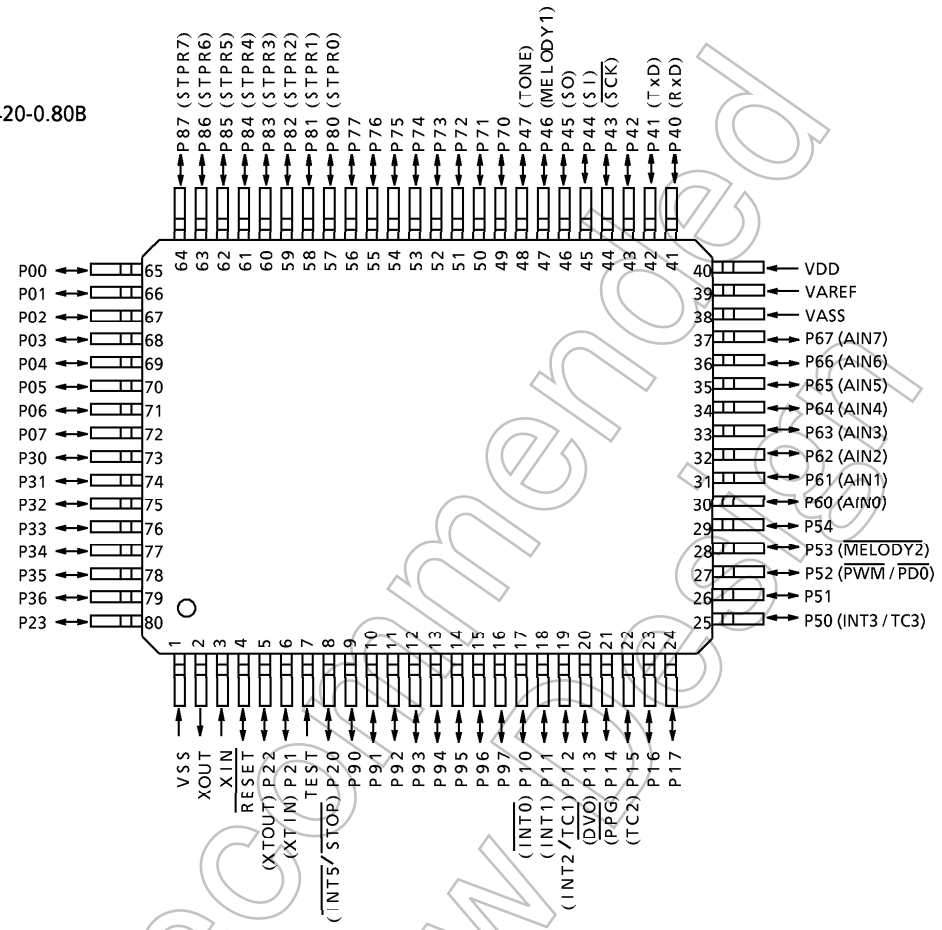
980910EBP1

◆Key on Wake-Up
◆Dual clock operation
◆Internal clock select mode (fc, fc/2, fc/4, fc/8) Initial fc/8 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 (32.768kHz).
- 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.

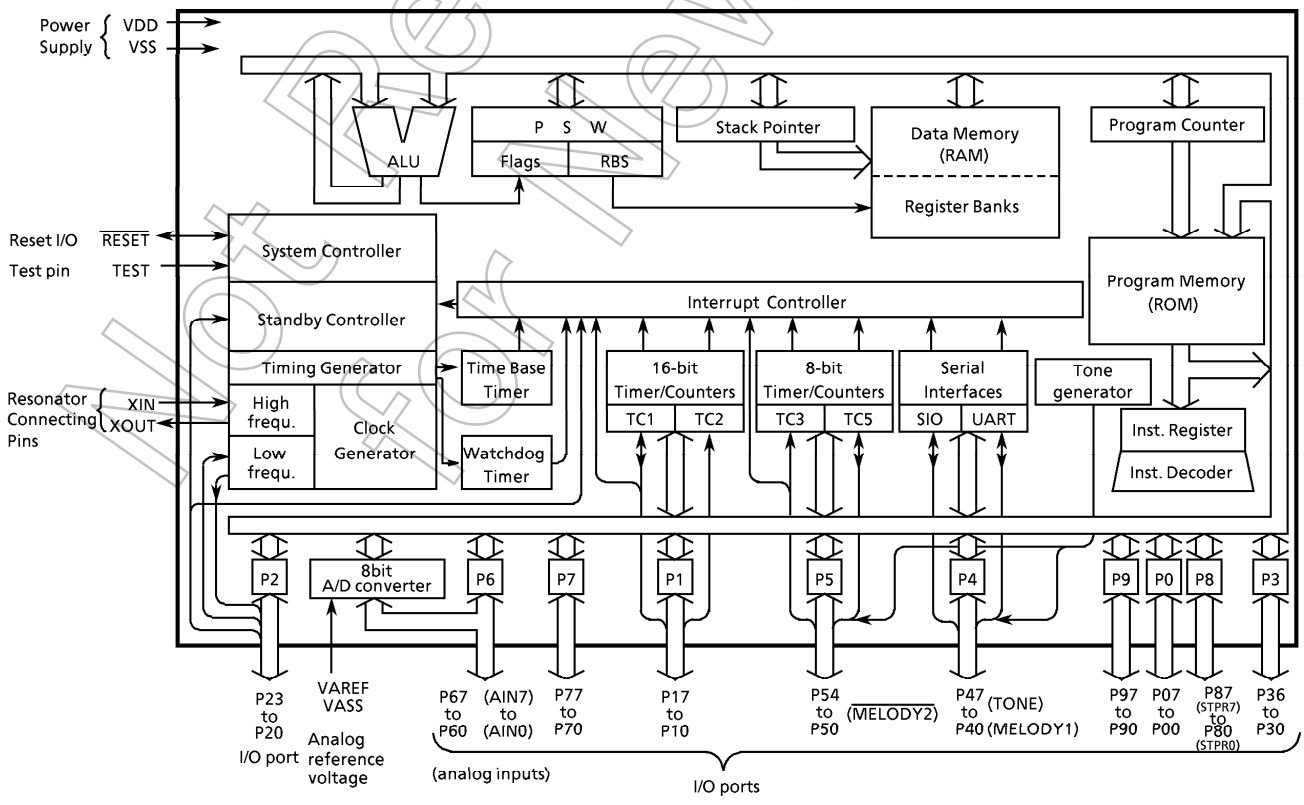
◆Wide operating voltage: 2.2 to 5.5 V at [3.58 MHz] [3.84 MHz] [4.0 MHz] [4.19 MHz] / 32.768 kHz,
4.5 to 5.5 V at 8 MHz / 32.768 kHz
◆Emulation Pod: BM87CM53F0A

Pin Assignments (Top View)

P-QFP80-1420-0.80B



Block Diagram



Pin Function

Pin Name	Input / Output	Function	
P07 to P00	I/O	Two 8-bit programmable input/output ports (tri-state). Each bit of these ports can be individually configured as an input or an output under software control. During reset, all bits are configured as input. When used as a divider output or a PPG output, the latch must be set to "1".	
P17, P16	I/O		
P15 (TC2)	I/O (Input)		Timer/Counter 2 input
P14 ($\overline{PPG}$)	I/O (Output)		Programmable pulse generator output
P13 ($\overline{DVO}$)			Divider output
P12 (INT2 / TC1)	I/O (Input)		External interrupt input 2 or Timer/Counter 1 input
P11 (INT1)			External interrupt input 1
P10 ($\overline{INT0}$)			External interrupt input 0
P23	I/O	4-bit input/output port with latch. When used as an input port, the latch must be set to "1".	
P22 (XTOUT)	I/O (Output)		Resonator connecting pins (32.768kHz). For inputting external clock, XTIN is used and XTOUT is opened.
P21 (XTIN)	I/O (Input)		
P20 ($\overline{INT5}$ / $\overline{STOP}$)			External interrupt input 5 or STOP mode release signal input
P36 to P30	I/O	7-bit input/output port (high current output) with latch. When used as an input port, the latch must be set to "1".	
P47 (Tone)	I/O (Output)	8-bit programmable input/output port (tri-state). Each bit of the port can be individually configured as an input or an output or a port option under software control. During reset, all bits are configured as input. When used as an input port or a SIO input/output, the latch must be set to "1".	Tone output
P46 (Melody1)	I/O (Output)		Melody1 output (sine wave)
P45 (SO)	I/O (Output)		SIO serial data output
P44 (SI)	I/O (Input)		SIO serial data input
P43 ($\overline{SCK}$)	I/O (I/O)		SIO serial clock input/output
P42	I/O		
P41 (TxD)	I/O (Output)		SIO serial data output (asynchronous only)
P40 (RxD)	I/O (Input)		SIO serial data input (asynchronous only)
P54	I/O	5-bit programmable input/output port (tri-state). Each bit of the port can be individually configured as an input or an output or a port option under software control. During reset, all bits are configured as input. When used as an input port, an external interrupt input, or a PWM/PDO output, the latch must be set to "1".	
P53 ($\overline{Melody2}$)	I/O (Output)		$\overline{Melody2}$ output (square wave)
P52 ($\overline{PWM}$/$\overline{PDO}$)	I/O (Output)		8-bit PWM output or 8-bit programmable divider output
P51	I/O		
P50 (INT3/TC3)	I/O (Input)		External interrupt input 3 or Timer/Counter 3 input
P67 (AIN7) to P60 (AIN0)	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.	A/D converter analog inputs
P77 to P70	I/O	8-bit programmable input/output port (tri-state). Each bit of the port can be individually configured as an input or an output or a port option under software control. During reset, all bits are configured as input.	
P97 to P90	I/O		
P87 (STPR7) to P80 (STPR0)	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 or a pull-up resister under software control. During reset, all bits are configared as an input.	
XIN, XOUT	Input, Output	Resonator connecting pins for high-frequency clock. For inputting external clock, XIN is used and XOUT is opened.	
$\overline{RESET}$	I/O	Reset signal input or watchdog timer output/address-trap-reset output/system-clock-reset output.	
TEST	Input	Test pin for out-going test. Be tied to low.	
VDD, VSS	Power Supply	+ 5 V, 0 V (GND)	
VAREF, VASS		Analog reference voltage inputs (High, Low)	

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 Map

The TLCS-870 Series is capable of addressing 64K bytes of memory. Figure 1-1 shows the memory address maps of the 87CM53. 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.

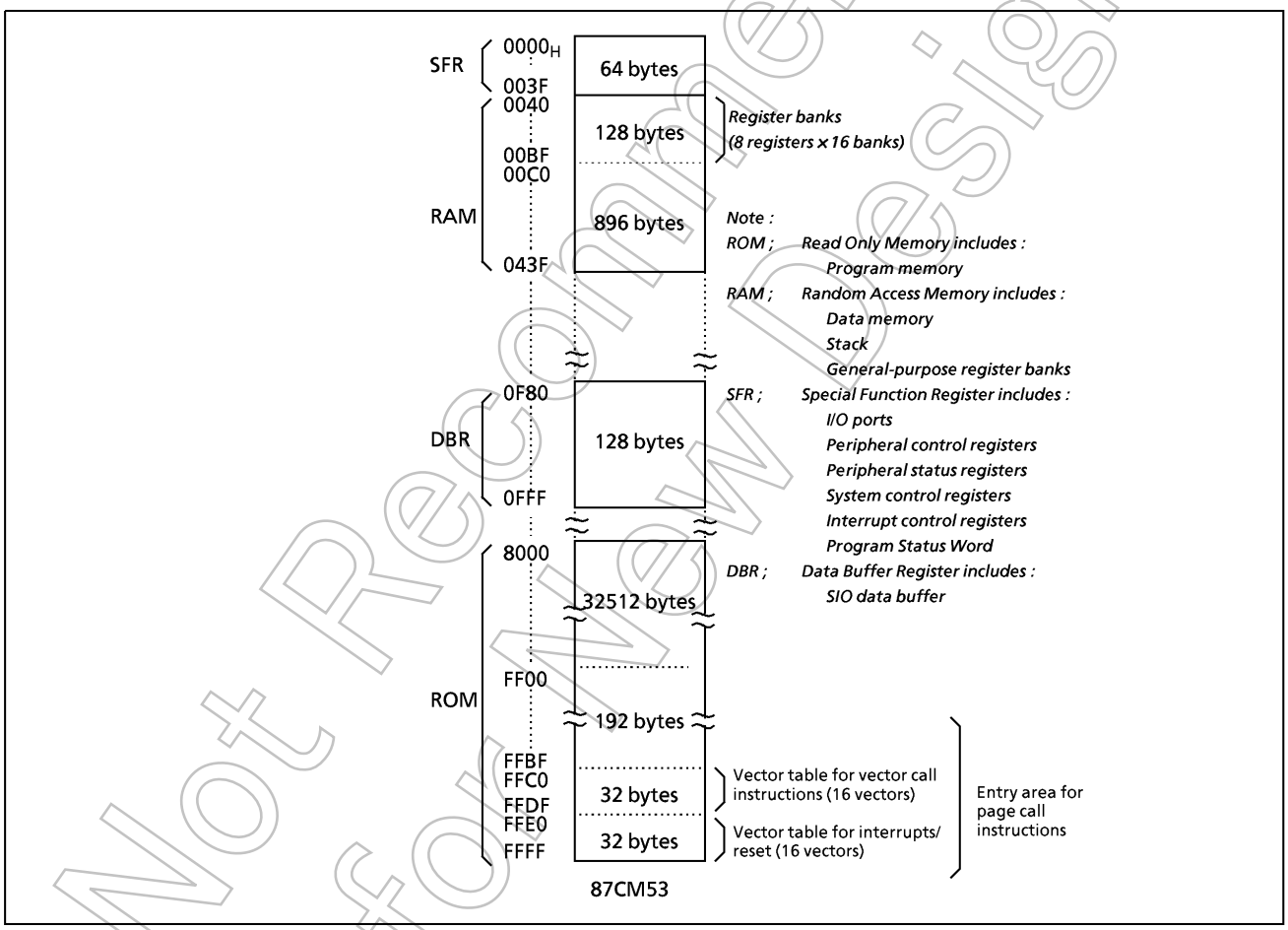


Figure 1-1. Memory Address Maps

1.2 Program Memory (ROM)

The 87CM53 has a 32K × 8-bit (address 8000_H-$FFFF_H$) of program memory (mask programmed ROM). Addresses $FF00_H$-$FFFF_H$ in the program memory can also be used for special purposes.

(1) **Interrupt** / **Reset** vector table (addresses $FFE0_H$-$FFFF_H$)
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 $FFC0_H$-$FFDF_H$)
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 $FF00_H$-$FFFF_H$) for **page call** instructions
This is the subroutine entry address area for the page call instructions [CALLP n]. Addresses $FF00_H$-$FFBF_H$ are normally used because address $FFC0_H$-$FFFF_H$ 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 $E8CE_H$, which is 08_H 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 $E8C4_H + 2 = E8C6_H$.)

② 8-bit PC-relative jump [JR cc, $ + 2 + d]
E8C4H : JR Z, $ + 2 + 80H
When ZF = 1, the jump is made to $E846_H$, which is $FF80_H$ (– 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 $C235_H$. The absolute jump instruction can jump anywhere within the entire 64K-bytes space.

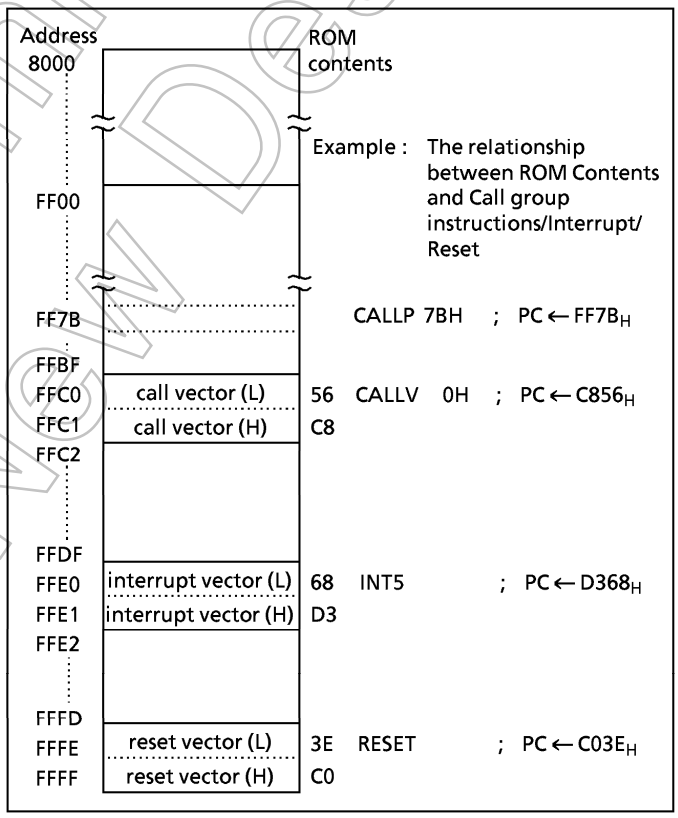


Figure 1-2. Program Memory Map

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.

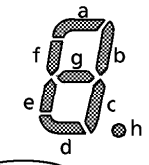
Example 1 : Loads the ROM contents at the address specified by the HL register pair contents into the accumulator (HL ≧ 8000_H):

```
LD      A, (HL)          ; A←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←ROM (TABLE + A)
        LD      (P6), (PC + A)
        JRS     T, SNEXT
TABLE : DB      0C0H, 0F9H, 0A4H, 0B0H, 99H, 92H, 82H, 0D8H, 80H, 98H
SNEXT :
```

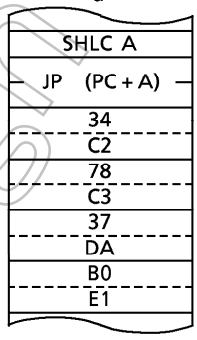
Notes : "$" is a header address of ADD instruction.
DB is a byte data difinition instruction.



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

```
        SHLC    A
        JP      (PC + A)     ; if A = 00H then PC←C234H
                             ; if A = 01H then PC←C378H
                             ; if A = 02H then PC←DA37H
                             ; if A = 03H then PC←E1B0H
        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 $C125_H$.

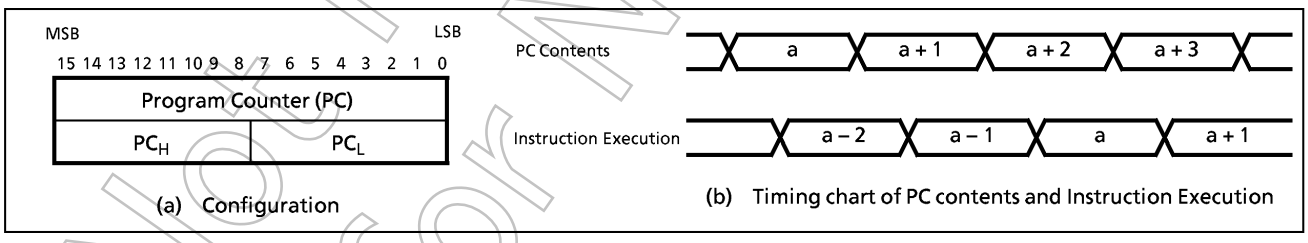


Figure 1-3. Program Counter

1.4 Data Memory (RAM)

The 87CM53 has a 1K × 8-bit (addresses 0040_H-$043F_H$) of data memory (static RAM). Figure 1-4 shows the data memory map.

Addresses 0000_H-$00FF_H$ are used as a direct addressing area to enhance instructions which utilize this addressing mode; therefore, addresses 0040_H-$00FF_H$ 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), 0FH    ;  (00F5H) ← (00F5H) ∧ 0FH
```

General-purpose register banks (8 registers × 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 87CM53, programs in data memory cannot be executed. If the program counter indicates a data memory address, an address-trap-reset is generated due to due to bus error. (Output from the $\overline{RESET}$ pin goes low.)

Example 1 : Clears RAM to "00_H" except the bank 0

```
        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 1 : 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 2 : The general-purpuse registers are mapped in the RAM ; therefore, do not clear RAM at the current bank addresses.

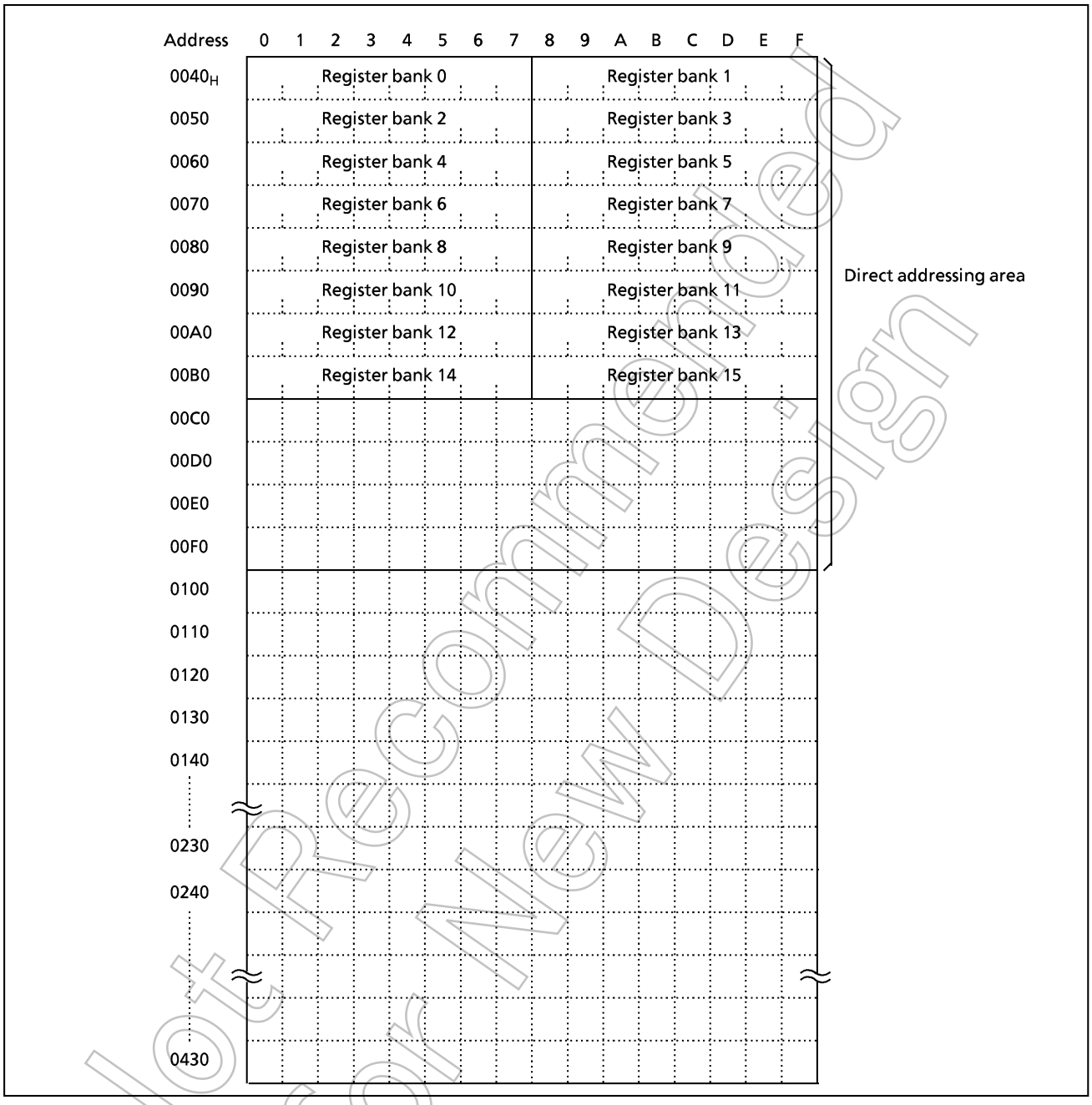


Figure 1-4. Data Memory Map

1.5 General-purpose Register Banks

General-purpose registers are mapped into addresses 0040_H-$00BF_H$ 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 bank configuration.

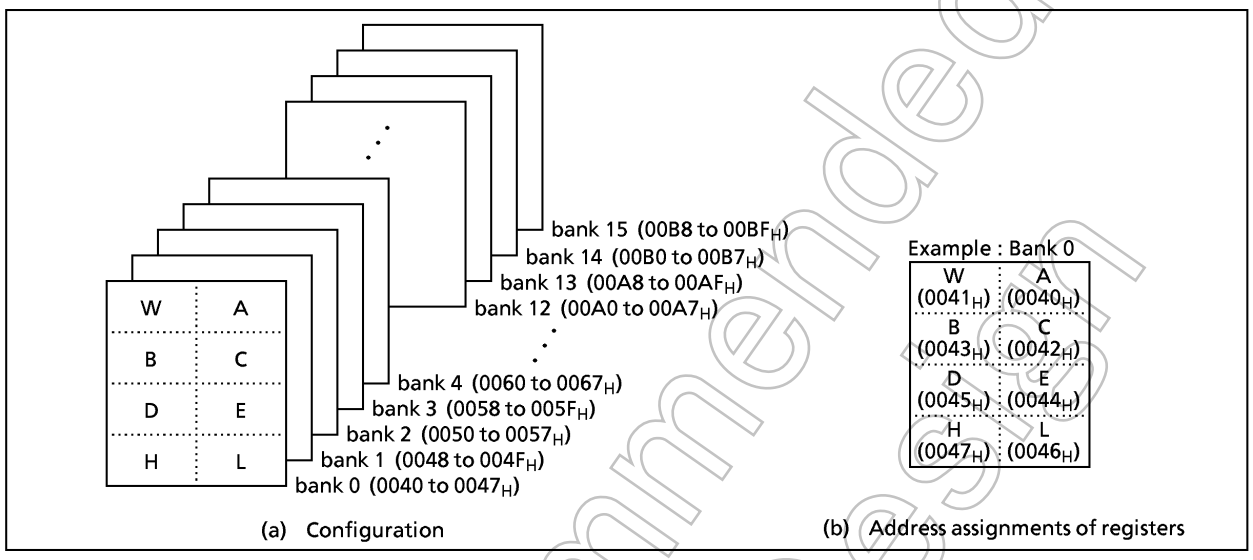


Figure 1-5. General-purpose Register Banks

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.

```
Examples :  ①   ADD  A, B          ; Adds B contents to A contents and stores the result into A.
            ②   SUB  WA, 1234H     ; Subtracts 1234H from WA contents and stores the result into WA.
            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 :  ①   LD   A, (HL)        ; Loads the memory contents at the address specified by HL into A.
             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.
             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.
             ④   LD   A, (HL + )     ; Loads the memory contents at the address specified by HL into A.
                                     Then increments HL.
             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 2 : Block transfer

```
        LD      B, m            ; m = n – 1 (n : number of bytes to transfer)
        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 $003F_H$ 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".

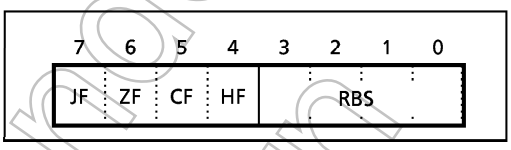


Figure 1-6. PSW (Flags, RBS) Configuration

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.

Example1 : 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 ← 41H, HF ← 1, CF ← 0
DAA     A           ;  A ← 41H + 06H = 47H (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
 ⋮                        preceding 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
ROLC A	35	1	0	1	0
RORC 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.

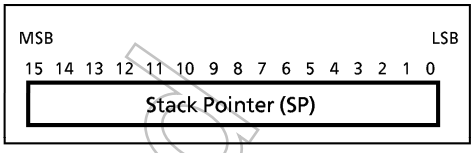


Figure 1-7. Stack Pointer

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←043F_H
```

Example 2 : To read the SP

```
LD      HL, SP          ; HL←SP
```

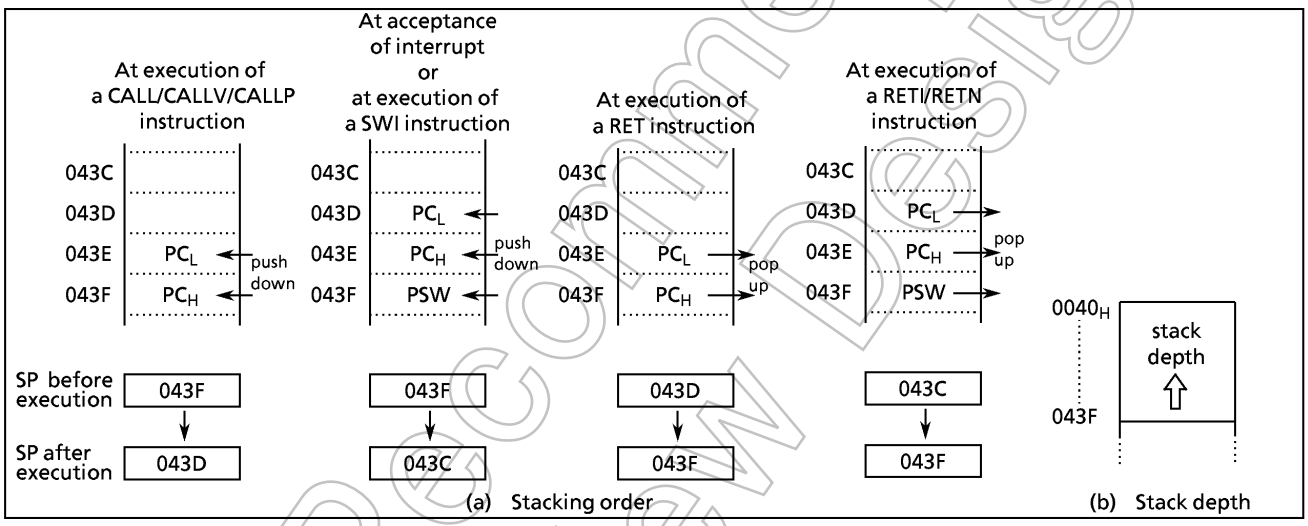


Figure 1-8. Stack

1.8 System Clock Controller

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

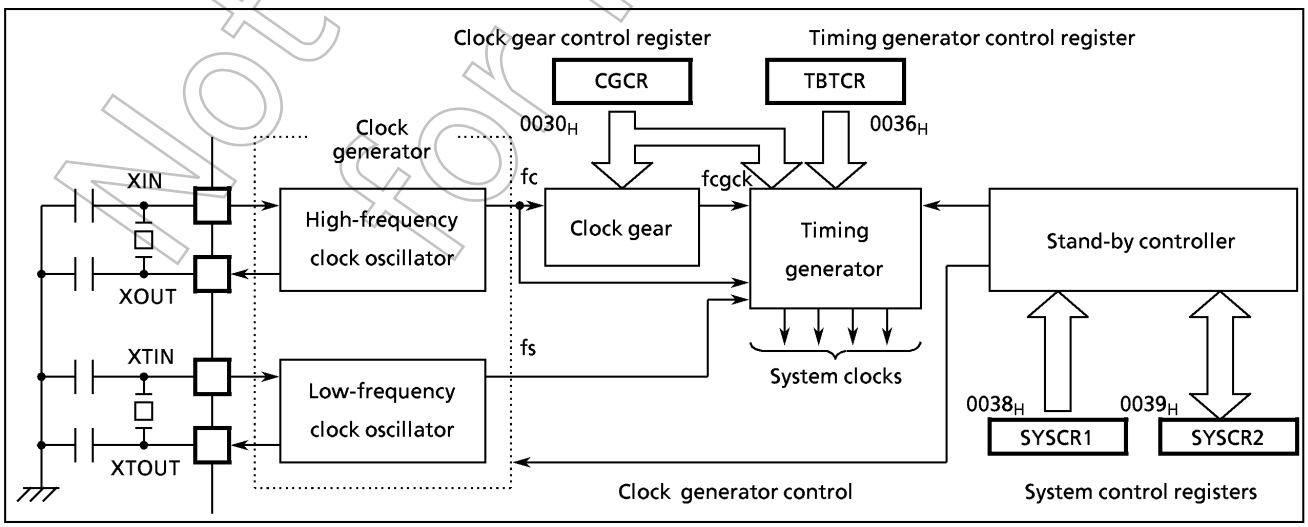


Figure 1-9. System Clock Controller

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 87CM53 is not provided an RC oscillation.

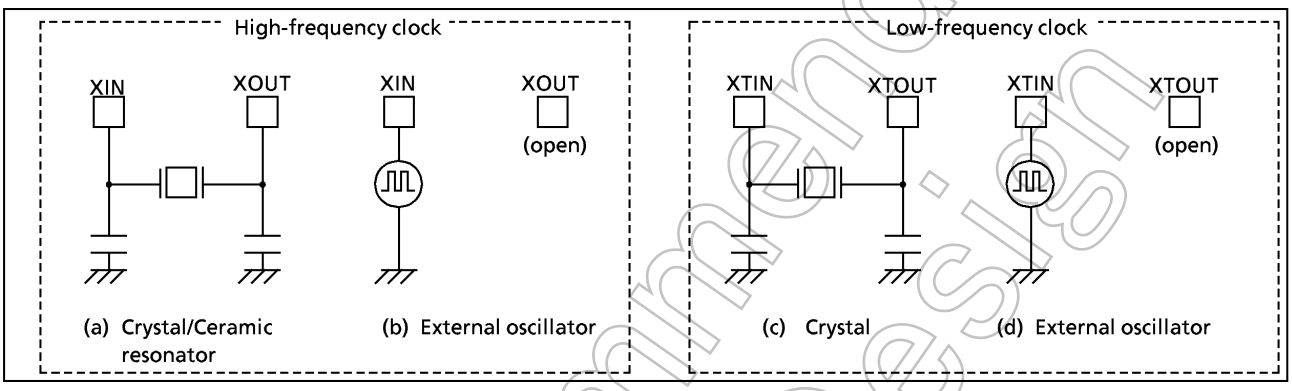


Figure 1-10. Examples of Resonator Connection

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 the watchdog timer and monitoring this pulse. With a system requiring adjustment of the oscillation frequency, the adjusting program must be created beforehand.

1.8.2 Clock Gear

The clock gear is a circuit to select a gear clock fcgck, that is the basis of the main system clock supplied to the timing generator, from high-frequency clock fc, or the divided clock fc/2, fc/4, or fc/8. Power consumption can be reduced by switching of the gear clock from fc to fc/2, fc/4, and fc/8 with the clock gear using.

The clock gear consists of a 3-stage prescaler with a multiplexer.

Note : The gear clock fcgck is specified to be fc/8 after reset release.

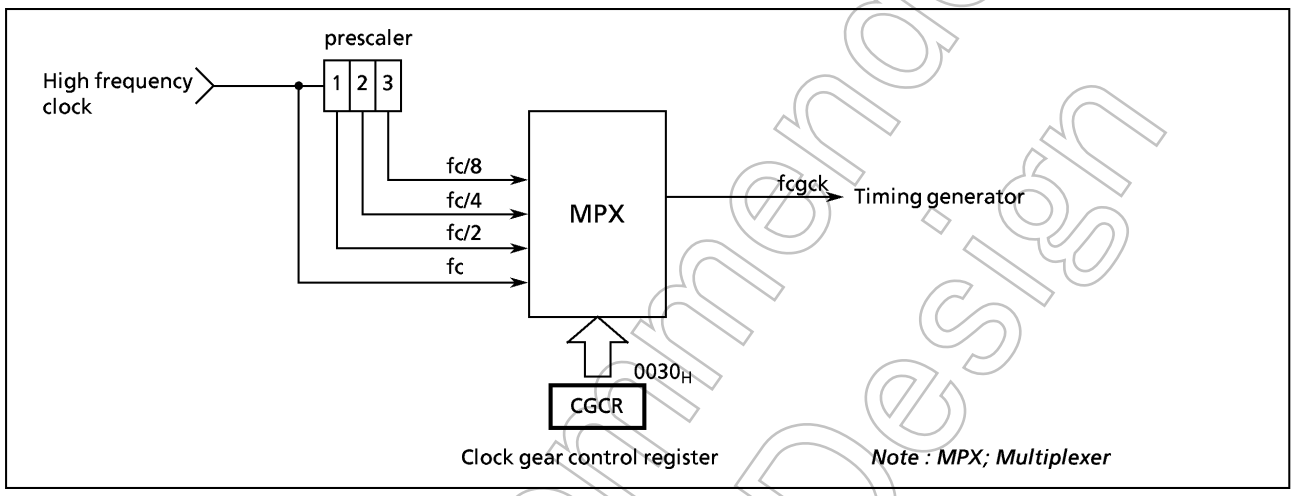


Figure 1-11. Configuration of Clock Gear

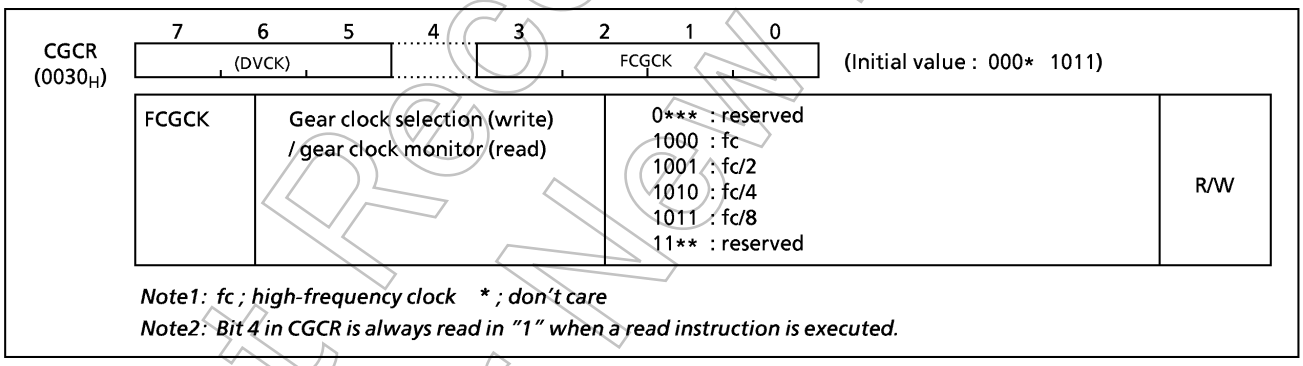


Figure 1-12. Clock Gear Control Register

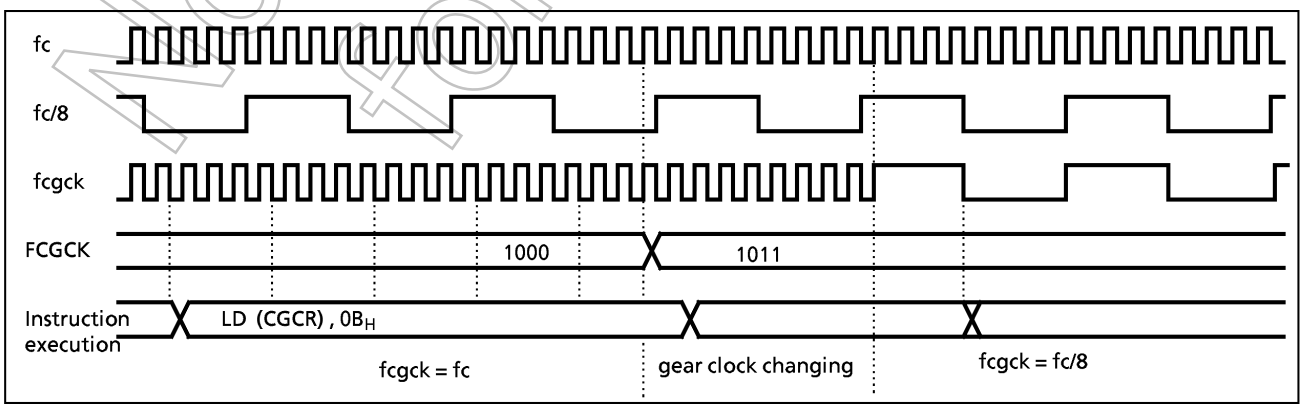


Figure 1-13. Example of Clock Exchangeable Timing by Clock Gear

1.8.3 Timing Generator

The timing generator generates the various system clocks supplied to the CPU core and peripheral hardware from the gear clock (fcgck) or the basic clock (fc or fs). The timing generator provides the following functions.

① Generation of main system clock (fm)
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-TC3, TC5
⑥ Generation of warm-up clocks for releasing STOP mode

(1) Configuration of timing generator

The timing generator consists of a 2-stage prescaler, a 21-stage divider, a main system clock generator, and machine cycle counters.

The clock fc/4, that is output from the 2nd stage of the prescaler.

Even if the main system clock is changed by the clock gear, the output from the divider is not changed. The peripheral circuit using high-speed divider output (1st to 4th output) can not be used when the main system clock slows down. In this case, setting DVCK (bits 7, 6 and 5 in CGCR) can change high-speed divider output to low-speed divider output. The DVCK should be set according to the lowest speed of the clock gear and divider output used for the peripheral circuit prior to starting the peripheral circuits. Do not change the set value after setting.

An input clock to the 7th stage of the divider depends on the operating mode, DV7CK(bit 4 in TBTCR), that is shown in Table 1-2. As reset and STOP mode started/canceled, The prescaler and the divider are cleared to "0".

Table 1-1. Divider Output Capability

DVCK	Gear clock frequency	Divider output capability			
		DV1G	DV2G	DV3G	DV4
000	fcgck = fc	D	E	E	E
	fcgck = fc/2	D	D	E	E
	fcgck = fc/4	D	D	D	E
	fcgck = fc/8	D	D	D	D
010	fcgck = fc	E	E	E	E
	fcgck = fc/2	D	D	E	E
	fcgck = fc/4	D	D	D	E
	fcgck = fc/8	D	D	D	D
100	fcgck = fc	E	E	E	E
	fcgck = fc/2	E	E	E	E
	fcgck = fc/4	D	D	D	E
	fcgck = fc/8	D	D	D	D
110	fcgck = fc	E	E	E	E
	fcgck = fc/2	E	E	E	E
	fcgck = fc/4	E	E	E	E
	fcgck = fc/8	D	D	D	D

Note : D = disable, E = enable

Table1-2. Input Clock to 7th Stage of the Divider

Single-clock mode	Dual-clock mode		
NORMAL1, IDLE1 mode	NORMAL2, IDLE2 mode (SYSCK = 0)		SLOW, SLEEP mode (SYSCK = 1)
	DV7CK = 0	DV7CK = 1	
$fc/2^8$	$fc/2^8$	fs	fs

Note 1 : Do not set DV7CK to "1" in the single clock mode.
Note 2 : In SLOW and SLEEP mode, the input clock to the 1st stage of the divider is stopped; output from the 1st to 6th stages is also stopped.
Note 3 : D = disable, E = enable
Note 4 : TC1CK 10 : DV1G TC5CK 011 : DV1G
TC2CK 011 : DV1G SCK 010 : DV3G
(SIO) 011 : DV2G

① In the single-clock mode
A divided-by-256 of high-frequency clock ($fc/2^8$) is input to the 7th stage of the divider.
Do not set DVCK 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 "$fc/2^8$" 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.

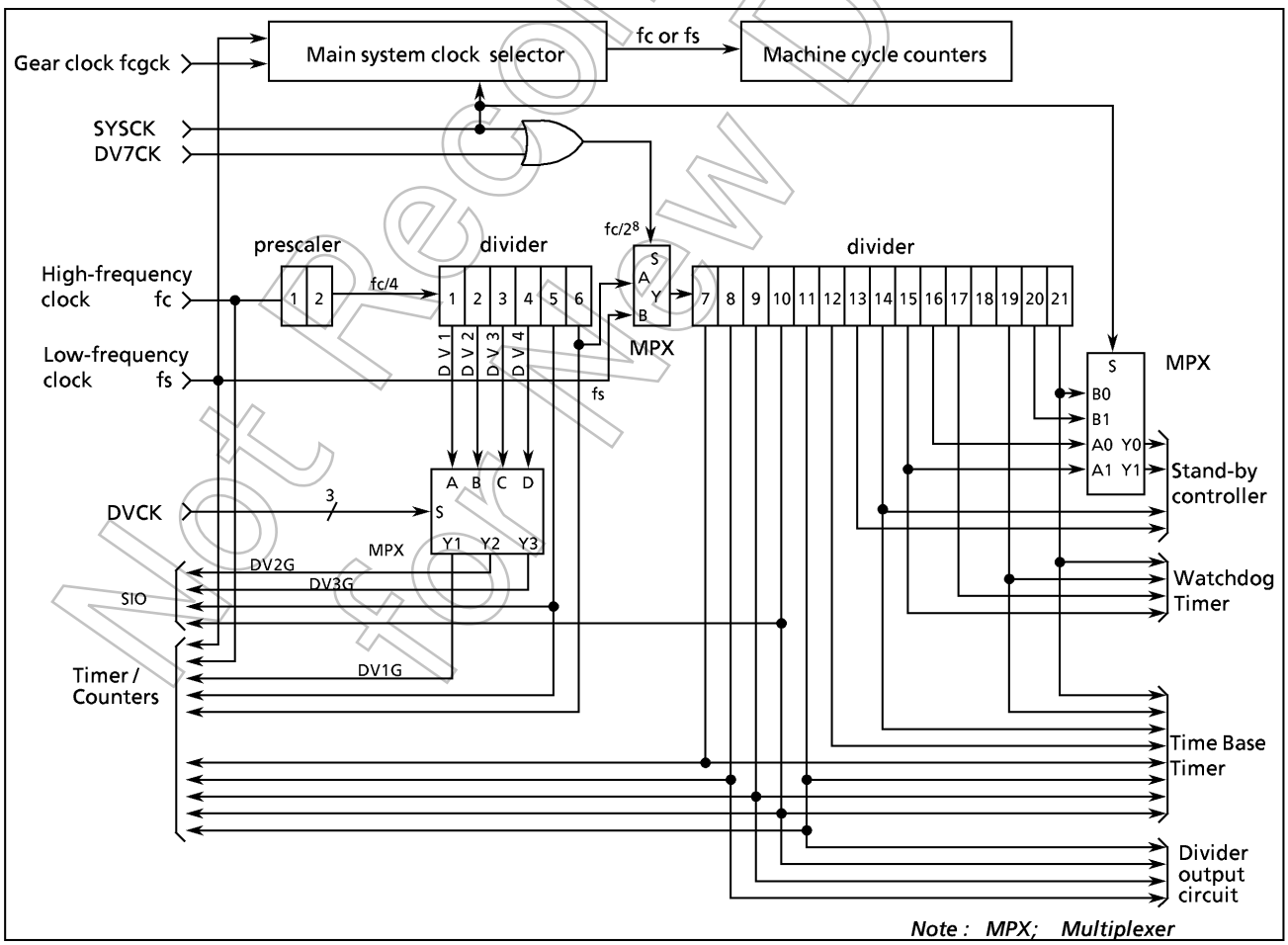


Figure 1-14. Configuration of Timing Generator

CGCR (00030_H)

7	6	5	4	3	2	1	0
DVCK				(FCGCK)			

(Initial value 000* 1011)

		DV1G	DV2G	DV3G	
DVCK	Divider output DV1G to DV3G	000 :	–	$fc/2^4$	$fc/2^5$	R/W
		010 :	$fc/2^4$	$fc/2^4$	$fc/2^5$	
		100 :	$fc/2^5$	$fc/2^5$	$fc/2^5$	
		110 :	$fc/2^6$	$fc/2^6$	$fc/2^6$	

*Note 1 : fc ; High-frequency clock [Hz] * ; don't care*

Note 2 : Bit 4 in CGCR is always read in "1" when a read instruction is executed.

Figure 1-15. Clock Gear Control Register

TBTCR (0036_H)

7	6	5	4	3	2	1	0
(DVOEN)	(DVOCK)		DV7CK	(TBTEN)	(TBTCK)		

(Initial value: 0000 0000)

DV7CK	Selection of input clock to the 7th stage of the divider	0 : $fc/2^8$ [Hz] 1 : fs	R/W

*Note1 : 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 1-16. 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 - S3), and each state consists of one main system clock.

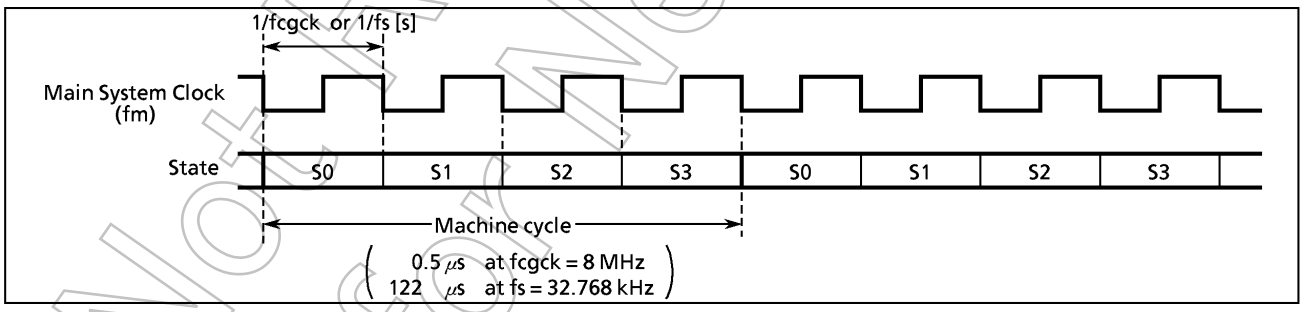


Figure 1-17. Machine Cycle

1.8.4 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 1-18 shows the operating mode transition diagram and Figure 1-19 shows the system control registers. Either the single-clock or the dual-clock mode can be selected by an option during reset.

(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/fcgck [s].

① NORMAL1 mode

In this mode, both the CPU core and on-chip peripherals operate using the high-frequency clock. In the case when the single-clock mode has been selected as an option, the 87CM53 is 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 $\overline{\text{STOP}}$ 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/fcgck [s] (0.5 μs at fcgck = 8 MHz) in NORMAL2 and IDLE2 modes, and 4/fs [s] (122 μs at fs = 32.768 kHz) in SLOW and SLEEP modes.

Note : The 87PM53 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 87CM53 is 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

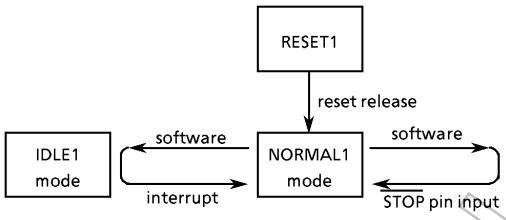
In this mode, the internal oscillation circuits remain active. The CPU and the watchdog timer are halted; however, on-chip peripherals remain active (operate using the high-frequency clock and/or the low-frequency clock). Starting and releasing of IDLE2 mode are the same as for IDLE1 mode, except that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

④ SLEEP mode

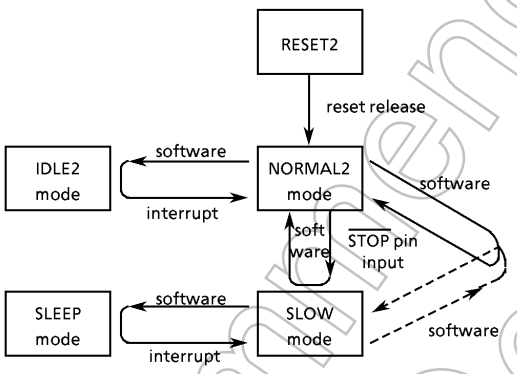
In this mode, the internal oscillation circuit of the low-frequency clock remains active. The CPU, the watchdog timer, and the internal oscillation circuit of the high- frequency clock are halted; however, on-chip peripherals remain active (operate using the low-frequency clock). Starting and releasing 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 : The 87PM53 doesn't have RESET2 mode.

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/fcgck [s]
	NORMAL1			operate	operate	
	IDLE1			halt		
	STOP1	turning off oscillation			halt	—
Dual-Clock	RESET2	turning on oscillation	turning on oscillation	reset	reset	4/fcgck [s]
	NORMAL2			High-frequency	operate (High and/or Low)	
	IDLE2			halt		
	SLOW	turning off oscillation		Low-frequency	Low-frequency	4/fs [s]
	SLEEP			halt		
	STOP2		turning off oscillation		halt	—

Figure 1-18. Operating Mode Transition Diagram

System Control Register 1

SYSCR1 (0038_H)

7	6	5	4	3	2	1	0
STOP	RELM	RETM	OUTEN	WUT			

(Initial value: 0000 00**)

STOP	STOP mode start	0 : CPU core and peripherals remain active 1 : CPU core and peripherals are halted (start STOP mode)			R/W
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		Return to NORMAL made	Return to SLOW made	
		00	3×2^{16} / fc	3×2^{13} / fs	
		01	2^{16} / fc	2^{13} / fs	
		10	3×2^{14} / fc	–	
		11	2^{14} / fc	–	

Note 1 : Always set RETM to "0" when transitting from NORMAL1 mode to STOP1 mode and from NOMAL2 mode to STOP2 mode. Always set RETM to "1" when transitting from SLOW mode to STOP2 mode.

Note 2 : When STOP mode is released with $\overline{\text{RESET}}$ 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 "1" data when a read instruction is executed.

Note 5 : When the stop operation is set by OUTEN = "0", the internal input is fired to "0". Interrupts may be set at the falling edge.

Note 6 : When the Key on wake-up is used, the edge release can not function according to some conditions. It is recommended to set the level release (RELM = "0").

System Control Register 2

SYSCR2 (0039_H)

7	6	5	4	3	2	1	0
XEN	XTEN	SYSCK	IDLE				

(Initial value: 10/100 ****)

XEN	High-frequency oscillator control	0 : Turn off oscillation 1 : Turn on oscillation	R/W
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 ($\overline{\text{RESET}}$ 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) is ES Order Sheet is described in ADDITIONAL INFORMATION "Notice for Masking Option of TLCS-870 series" section 8.

Figure 1-19. System Control Registers

1.8.5 Operating Mode Control

(1) **STOP** mode (STOP1, STOP2)

STOP mode is controlled by the system control register 1 (SYSCR1) and the $\overline{\text{STOP}}$ pin input. The $\overline{\text{STOP}}$ pin is also used both as a port P20 and an $\overline{\text{INT5}}$ (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 (except for DBR), 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).

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

In this mode, STOP mode is released by setting the $\overline{\text{STOP}}$ 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 $\overline{\text{STOP}}$ 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 $\overline{\text{STOP}}$ pin input is low. The following method can be used for confirmation:

- Using an external interrupt input $\overline{\text{INT5}}$ ($\overline{\text{INT5}}$ 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
          JRS    F, SINT5                 port P20 is at high
          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
```

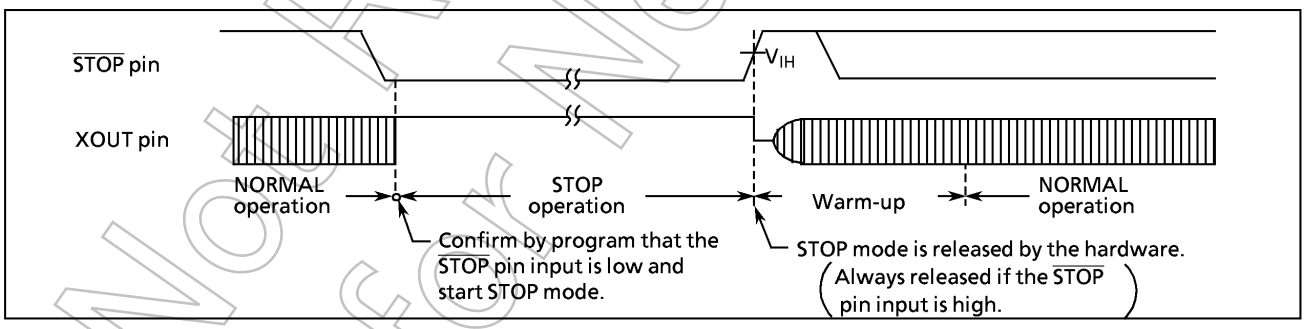


Figure 1-20. Level-sensitive Release Mode

Note 1 : After warm-up start, even if $\overline{\text{STOP}}$ 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 $\overline{\text{STOP}}$ pin input is detected.

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

In this mode, STOP mode is released by a rising edge of the $\overline{STOP}$ 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 $\overline{STOP}$ pin.

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

Example : Starting STOP mode operation in the edge-sensitive release mode

```
LD          (SYSCR1), 10000000B
```

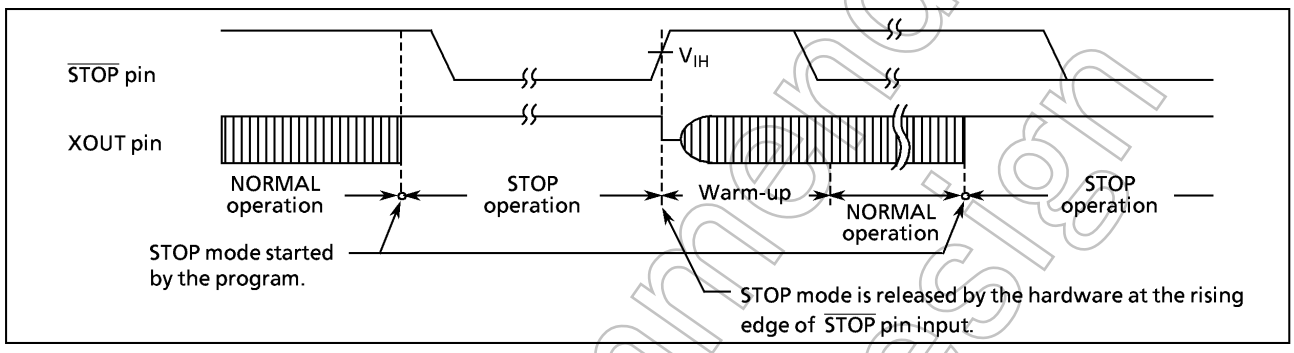


Figure 1-21. Edge-sensitive Release Mode

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. Four (two in SLOW mode) 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 1-3. Warming-up Time (example at fcgck = 8 MHz, fs = 32.768 kHz)

WUT	Warming-up Time [ms]	
	Return to NORMAL mode	Return to SLOW mode
00	24.576	750
01	8.192	250
10	6.144	–
11	2.048	–

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 $\overline{RESET}$ pin low, which immediately performs the normal reset operation.

In this case, even if the setting is to return to the SLOW mode, it starts from the NORMAL mode. (If the initial XTEN of 87CM53 is set to "1" by mask option, they start from the NORMAL2 mode. In case of 87PM53, starts from NORMAL1 mode.)

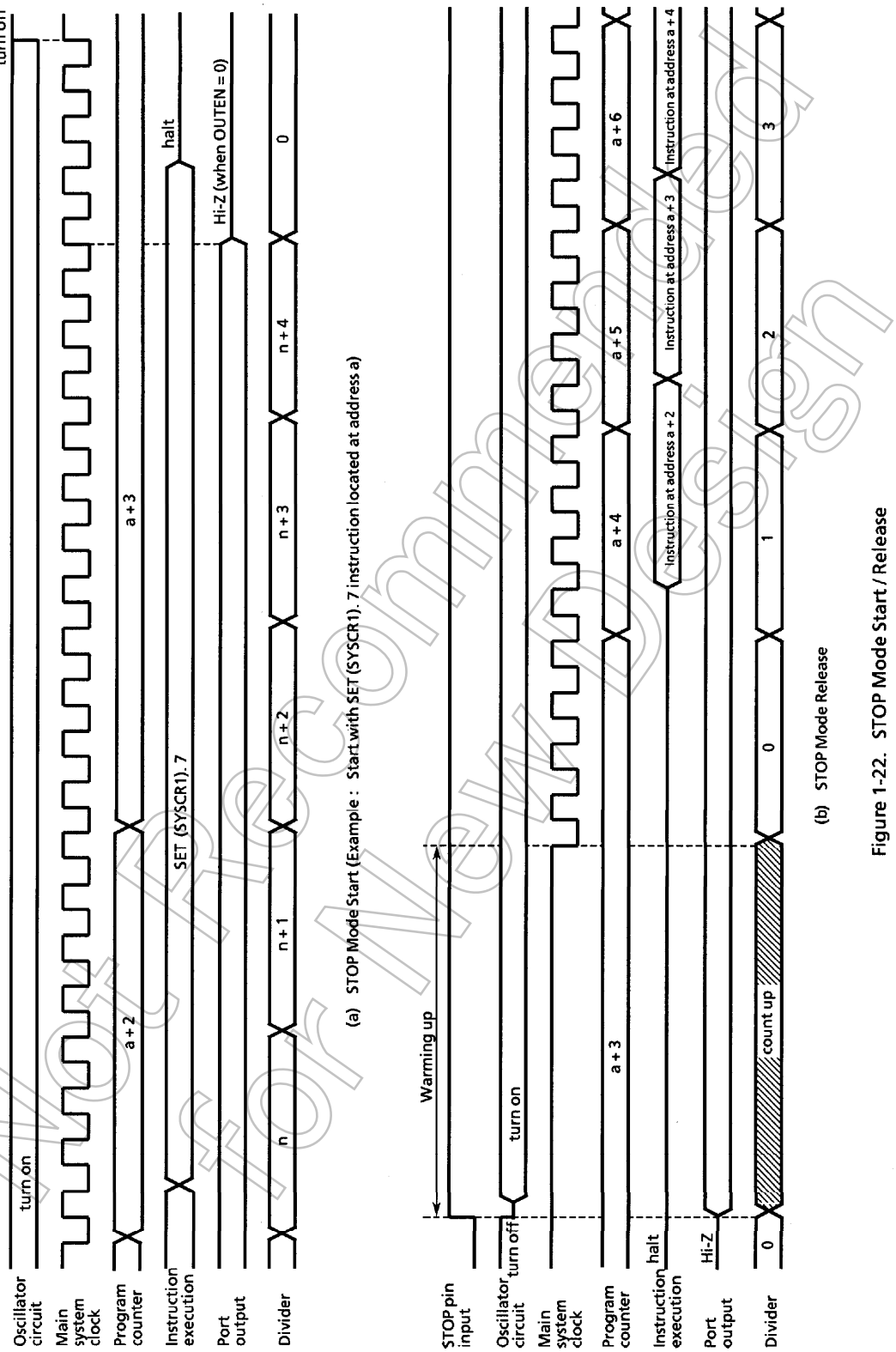


Figure 1-22. STOP Mode Start / Release

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
```

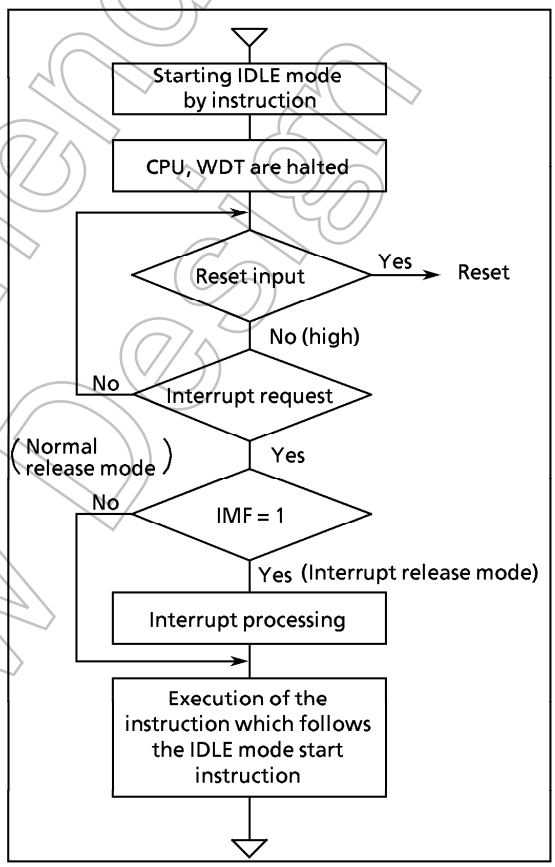


Figure 1-23. IDLE Mode

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 87CM53 are placed in NORMAL mode (the 87PM53 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.

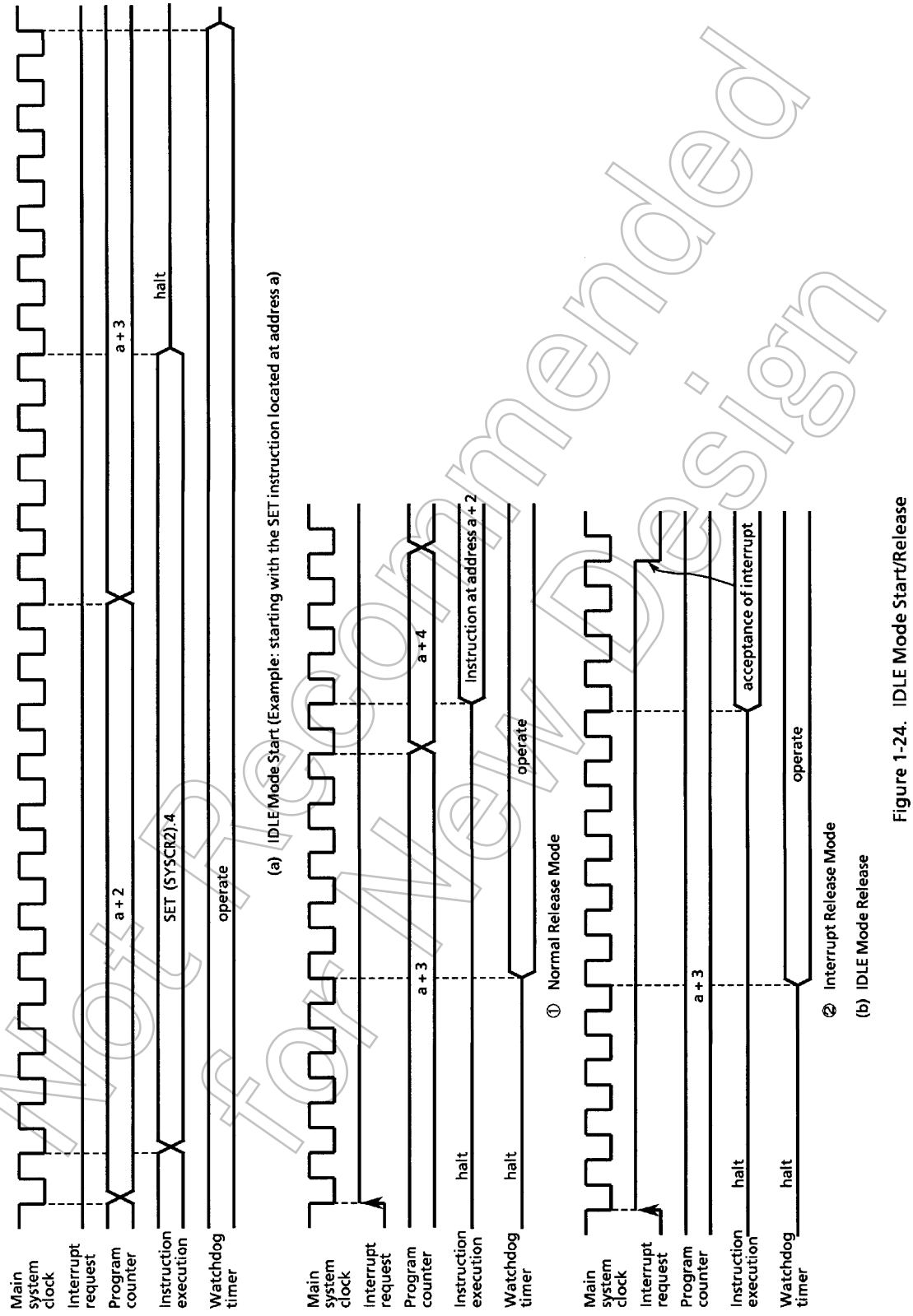


Figure 1-24. IDLE Mode Start/Release

(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        ; Enable 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 $\overline{\text{RESET}}$ pin low, which immediately performs the reset operation. After reset, the 87CM53 is placed in NORMAL mode. (The PM53 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        ; enable 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 clcok)
                RETI
                 ⋮
VINTTC2 :       DW      PINTTC2             ; INTTC2 vector table
```

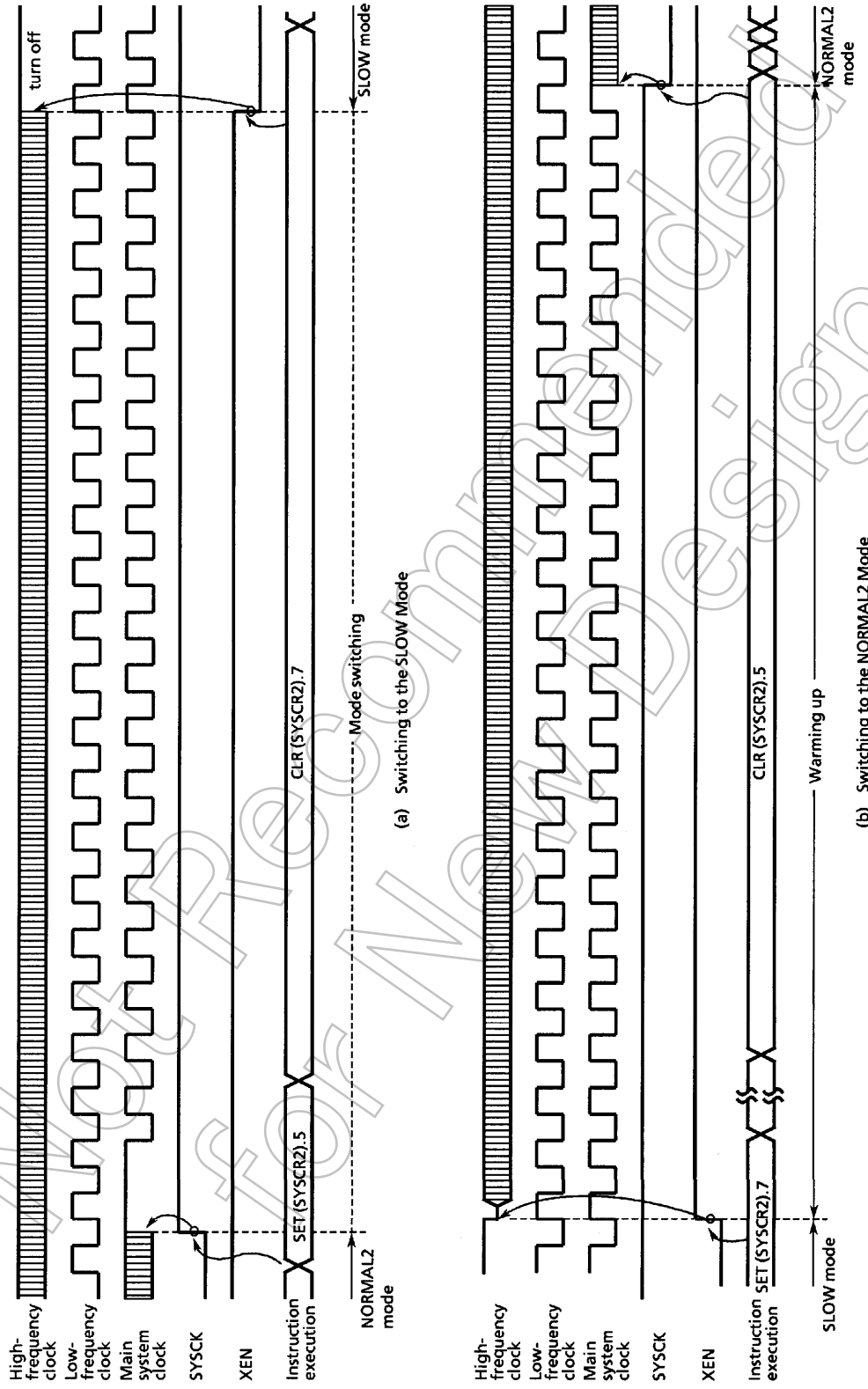


Figure 1-25. Switching between the NORMAL2 and SLOW Modes

1.9 Interrupt Controller

The 87CM53 has a total of 15 interrupt sources: 5 externals and 10 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 1-26 shows the interrupt controller.

Table 1-4. 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 1)	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	INTSIO	(Serial Interface 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
Internal	INTRX	(UART receive interrupt)	IMF · EF_{12} = 1	IL_{12}	$FFE6_H$	12
Internal	INTTX	(UART transmit 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 ($IL_{15\ to\ 2}$)

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
```

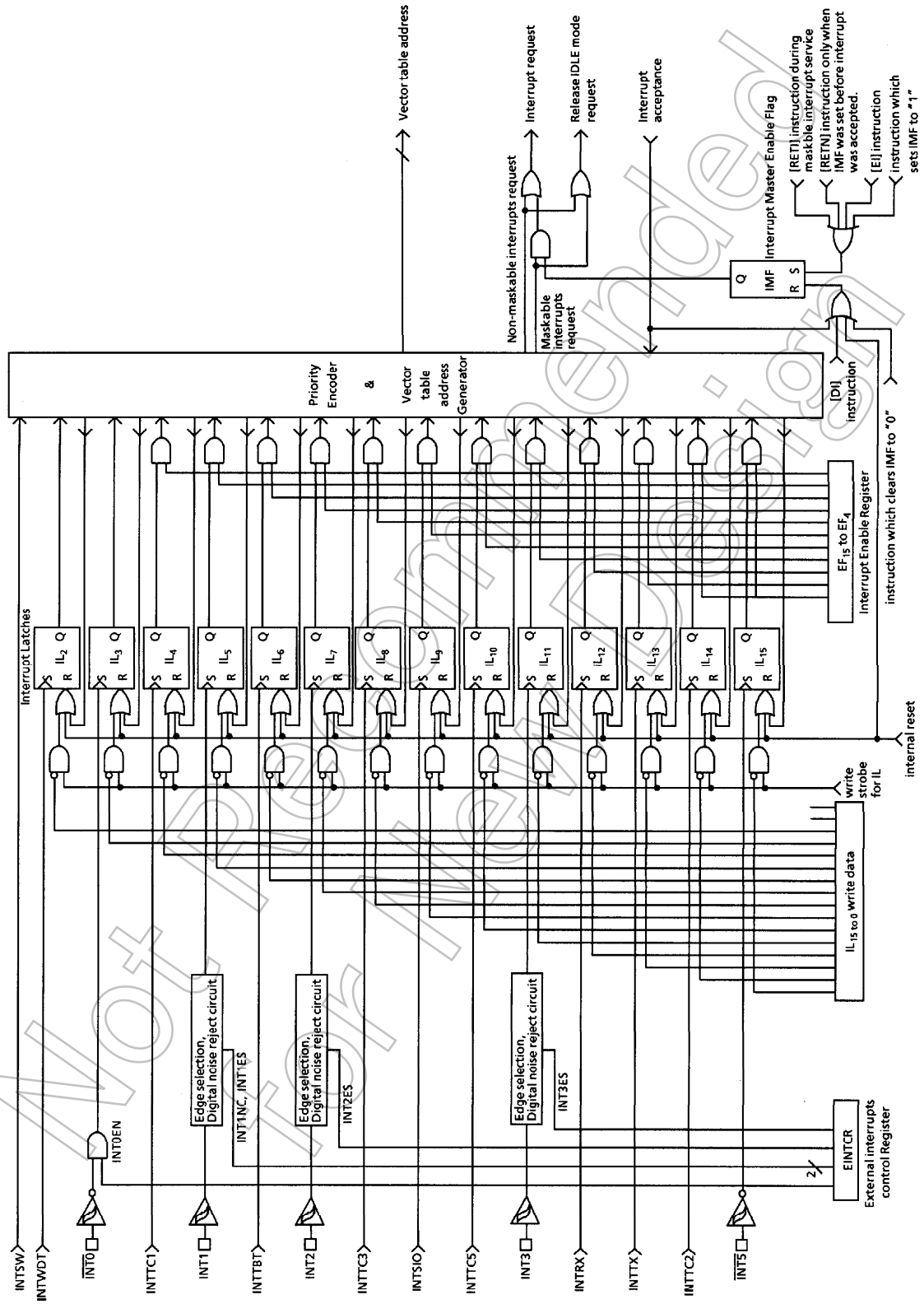


Figure 1-26. Interrupt Controller Block Diagram

Example 2 : Reads interrupt latches

```
LD      WA, (IL)        ; W←IL_H, A←IL_L
```

Example 3: Tests an interrupt latch

```
TEST    (IL).7          ; if IL_7 = 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 in 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** (EF_{15} to EF_4)

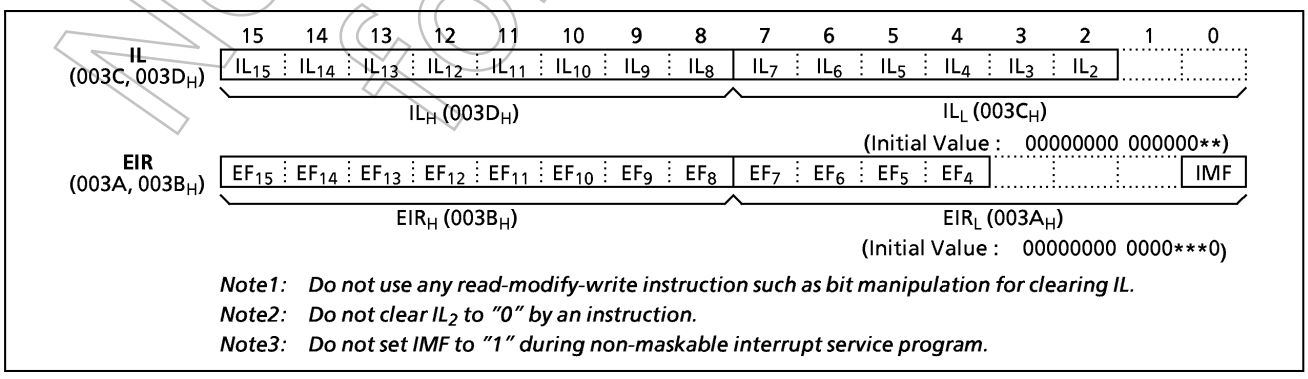
These flags enable and disable the acceptance of individual maskable interrupts, except for an external interrupt 0. Setting the corresponding bit of an individual interrupt enable flag to "1" enables acceptance of an interrupt, setting the bit to "0" disables acceptance.

Example 1 : Sets EF for individual interrupt enable, and sets IMF to "1".

```
LDW     (EIR), 1110100010100001B    ;   EF15 to EF13, EF11, EF7, EF5, IMF←1
```

Example 2 : Sets an individual interrupt enable flag to "1".

```
SET     (EIRH).4                    ;   EF12←1
```



Note1: Do not use any read-modify-write instruction such as bit manipulation for clearing IL.
Note2: Do not clear IL_2 to "0" by an instruction.
Note3: Do not set IMF to "1" during non-maskable interrupt service program.

Figure 1-27. Interrupt Latch (IL) and Interrupt Enable Register (EIR)

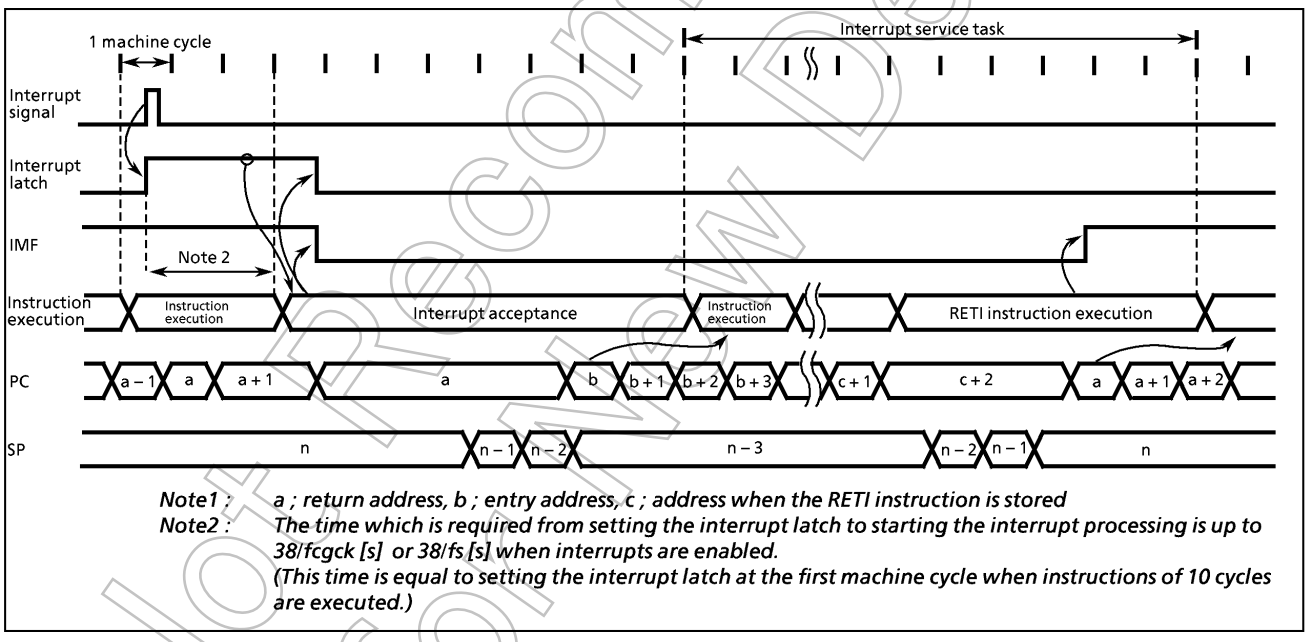
1.9.1 Interrupt Sequence

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 μs at fc = 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:

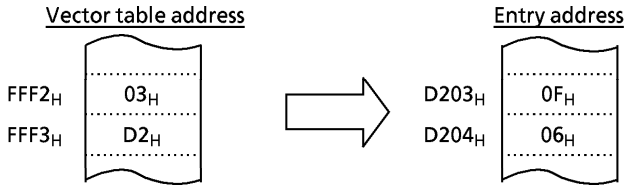
① The interrupt master enable flag (IMF) is cleared to "0" to temporarily disable the acceptance of any following maskable interrupts. When a non-maskable interrupt is accepted, the acceptance of any following interrupts is temporarily disabled.
② The interrupt latch (IL) for the interrupt source accepted 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. The contents of Stack Pointer is decreased by 3.
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.



Note1 : a ; return address, b ; entry address, c ; address when the RETI instruction is stored
Note2 : The time which is required from setting the interrupt latch to starting the interrupt processing is up to 38/fcgck [s] or 38/fs [s] when interrupts are enabled.
(This time is equal to setting the interrupt latch at the first machine cycle when instructions of 10 cycles are executed.)

Figure 1-28. Timing Chart of Interrupt Acceptance and Interrupt Return Instruction

Example : Correspondence between vector table address for INTTBT 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 $\overline{INT0}$ 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 $00F0_H$ 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:

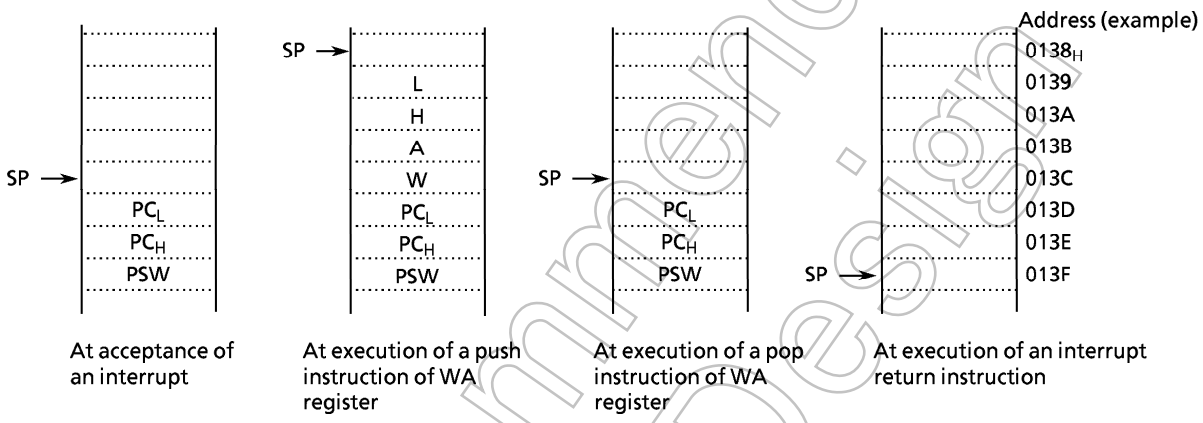
① General-purpose register save/restore by register bank changeove:
General-purpose registers can be saved at high-speed by switching to a register bank that is not in use. Normally, bank 0 is used for the main task and banks 1 to 15 are assigned to interrupt service tasks. To increase the efficiency 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
```

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
```

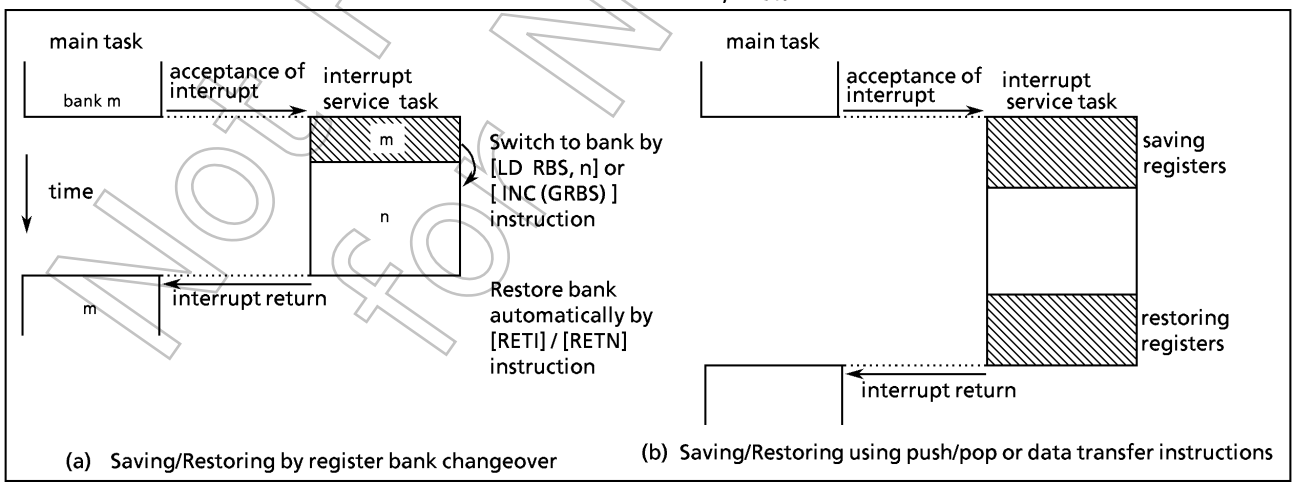


Figure 1-29. Saving/Restoring General-purpose Registers

(3) Interrupt return

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

[RETI] Maskable interrupt return	[RETN] Non-maskable interrupt return
① The contents of the program counter and the program status word are restored from the stack.	① The contents of the program counter and program status word are restored from the stack.
② The stack pointer is incremented 3 times.	② The stack pointer is incremented 3 times.
③ The interrupt master enable flag is set to "1".	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.

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-$043F_H$) or SFR area (0000_H-$003F_H$).

Note : The fetch data from addresses (test ROM area), $7H80_H$ to $7FFF_H$ for 87PM/CM53 is not FF_H.

② Debugging

Debugging efficiency can be increased by placing the SWI instruction at the software break point setting address.

1.9.3 External Interrupts

The 87CM53 has five external interrupts (INT0 to INT5 : $\overline{INT0}$, INT1, INT2, INT3, $\overline{INT5}$). 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 $\overline{INT0}$/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 $\overline{INT0}$/P10 pin function selection are performed by the external interrupt control register (#0037H : EINTCR).

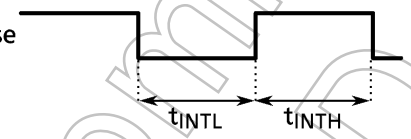
Table 1-5 lists enable conditions, edge select, noise cancellation conditions. The following are notes on the usage of external interrupts:

Notes on usage of external interrupts:

Note 1 : When INT1 to INT3 (INT1, INT2, INT3) 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. Input pulse must be 2 machine cycle or more at both "H" and "L" levels.

Note 2 : Input pulse width for $\overline{INT0}$ *and* $\overline{INT5}$ *must be 2 machine cycle or more at both "H" and "L" levels.*

$\overline{INT0}$, $\overline{INT5}$ input pulse



t_{INTL}, $t_{INTH} > 2t_{cyc}$

t_{cyc} = 4/fcgck [s] (at NORMAL 1/2 and IDLE 1/2 modes)
4/fs [s] (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 and INT3 pin 25/fc [s]*

Note 4 : Noise cancellation/pulse receive conditions for timer/counter are as described below:
TC1, 3 pin : Less than 7/fc [s] (noise cancellation) and 24/fc [s] or more (pulse receive)

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

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 an edge of timer counter input by rewriting the contents of INT2ES and INT3ES during NORMAL1/2 mode, rewrite the contents after timer counter is stopped (TC*S = 0), that is, interrupt disable state. Then, clear interrupt laches of external interrupt inputs (INT2 and INT3) 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)
                NOP
  8 machine       to
    cycles      NOP
                LD (ILL),01111111B       ;  IL7 ← 0 (clear interrupt latch)
                EI                       ;  IMF ← 1 (enable interrupt service)
                LD (TC1CR),01111000B     ;  TC1S ← 11 (start TC1)
```

Note 9 : 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 $\overline{\text{INT5}}$ *(P20/*$\overline{\text{STOP}}$*) 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 1-5. External Interrupts

SOURCE	Pin	Secondary function	Enable Condition	Edge			Digital noise reject
				rising	falling	both	
INT0	$\overline{INT0}$	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	P50 / TC3	IMF · EF_{11} = 1,	INT3ES = 0	INT3ES = 1	—	Note 3)
INT5	$\overline{INT5}$	P20 / $\overline{STOP}$	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. (This circuit is not applied for event counter mode)
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. (This circuit is not applied for event counter mode)

External interrupt Control Register 1

EINTCR (0037_H)

7	6	5	4	3	2	1	0
INT1NC	INT0EN		–	INT3ES	INT2ES	INT1ES	

(initial value 00*0 000*)

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 / $\overline{INT0}$ pin configuration	0 : P10 input/output 1 : $\overline{INT0}$ pin (port P10 should be set to an input mode)	
INT3ES INT2ES INT1ES	INT3 to INT1 edge select	0 : rising edge 1 : falling edge	

*Note1 : fc ; High-frequency clock [Hz] * ; don't care*

Figure 1-30. External Interrupt Control Register

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.

1.10.1 Watchdog Timer Configuration

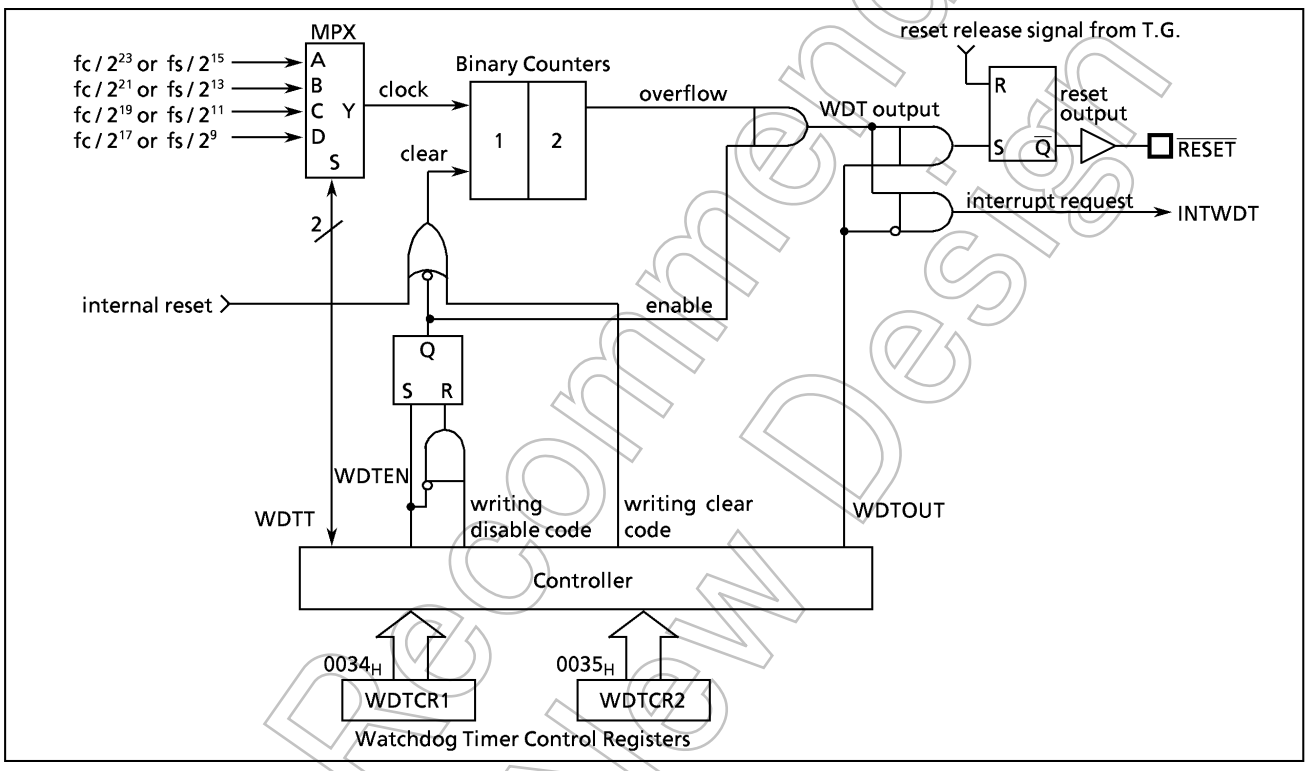


Figure 1-31. Watchdog Timer Configuration

1.10.2 Watchdog Timer Control

Figure 1-32 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 $\overline{\text{RESET}}$ 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 counter
        LD      (WDTCR1), 00001101B    ; WDTT←10, WDTOUT←1
        LD      (WDTCR2), 4EH          ; Clears the binary counters
                                       (always clear immediately after changing WDTT)
Within 3/4 of WDT
detection time
        LD      (WDTCR2), 4EH          ; Clears the binary counters
Within 3/4 of WDT
detection time
        LD      (WDTCR2), 4EH          ; Clears the binary counters
```

Watchdog Timer Control Register 1

WDTCR1 (0034_H)

7	6	5	4	3	2	1	0
				WDT EN	WDTT		WDT OUT

(Initial value : **** 1001)

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 (0035_H)

7	6	5	4	3	2	1	0

(Initial value : **** ****)

WDTCR2	Watchdog timer control code write register	$4E_H$: Watchdog timer binary counter clear (clear code) $B1_H$: 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 binary counter doesn't initialize the source clock, therefore, it is recommended to clear binary counter within 3/4 of the detection period.

Figure 1-32. Watchdog Timer Control Registers

Table 1-6. Watchdog Timer Detection Time

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

(3) Watchdog Timer Disable

The watchdog timer is disabled by writing the disable code ($B1_H$) 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^{16}/fc [s] (8.2 ms at 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^{16}/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.

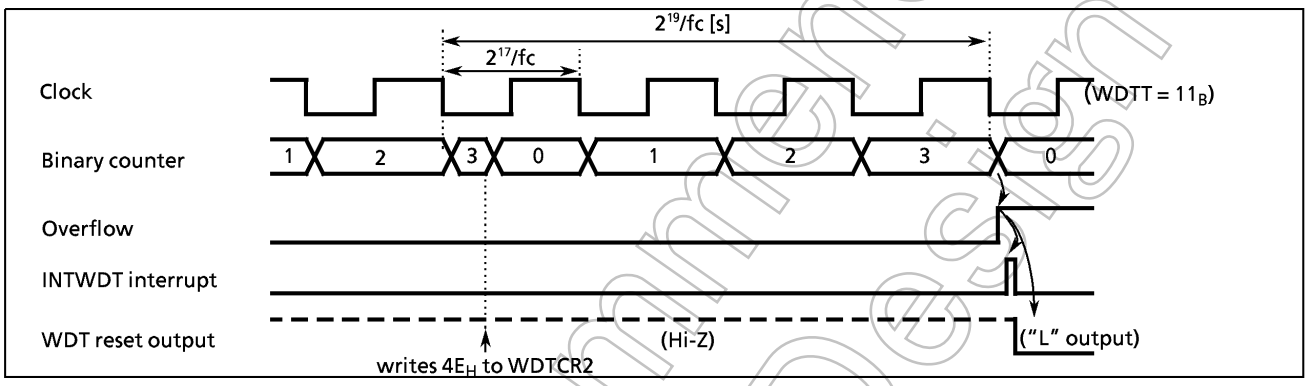


Figure 1-33. Watchdog Timer Interrupt / Reset

1.11 Reset Circuit

The 87CM53 has four types of reset generation procedures: an external reset input, an address trap reset, a watchdog timer reset and a system clock reset. Table 1-7 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^{16}/fc [s] (8.2 ms at 8 MHz) when power is turned on.

Table 1-7. Initializing Internal Status by Reset Action

On-chip Hardware		Initial Value	On-chip Hardware	Initial Value
Program counter	(PC)	$(FFFF_H) \cdot (FFFE_H)$	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 $\overline{\text{RESET}}$ pin is held at low for at least 3 machine cycles (12/fcgck [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 $\overline{\text{RESET}}$ pin input goes high, the reset operation is released and the program execution starts at the vector address stored at addresses $FFFE_H$ - $FFFF_H$.

The $\overline{\text{RESET}}$ 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.

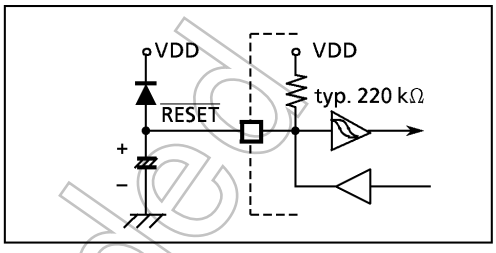
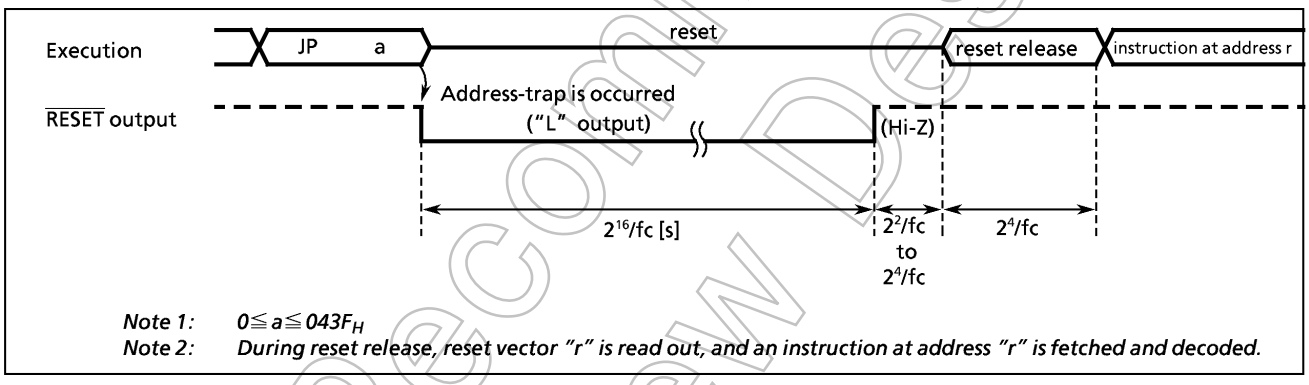


Figure 1-34. Simple Power-on-Reset Circuitry

1.11.2 Address-Trap-Reset

An address-trap-reset is one of fail-safe function that detects CPU malfunction such as endless looping 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, an address-trap-reset will be generated. Then, the $\overline{\text{RESET}}$ pin output will go low. The reset time is 2^{16}/fc [s] (8.2 ms at 8 MHz) .



Note 1: $0 \leqq a \leqq 043F_H$

Note 2: *During reset release, reset vector "r" is read out, and an instruction at address "r" is fetched and decoded.*

Figure 1-35. 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 $\overline{\text{RESET}}$ pin output goes low from high-impedance. The reset time is 2^{16}/fc [s] (8.2 ms at 8MHz).

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 – $003F_H$ and the DBR to addresses $0F80_H$ – $0FFF_H$.

Figure 2-1 shows the 87CM53 SFRs and DBRs.

Address	Read	Write
0000_H	P0 Port	
01	P1 Port	
02	P2 Port	
03	P3 Port	
04	P4 Port	
05	P5 Port	
06	P6 Port	
07	P7 Port	
08	P8 Port	
09	P9 Port	
0A		P0CR (P0 I/O control)
0B	–	P1CR (P1 I/O control)
0C		P6CR (P6 I/O control)
0D		P7CR1 (P7 I/O control1)
0E	ADCCR (A/D converter control)	
0F	ADCDR (A/D conv. result)	–
10	–	$TREG1A_L$ (Timer register 1A)
11	–	$TREG1A_H$
12	$TREG1B_L$ (Timer register 1B)	
13	$TREG1B_H$	
14	–	TC1CR (TC1 control)
15	–	TC2CR (TC2 control)
16	–	$TREG2_L$ (Timer register 2)
17	–	$TREG2_H$
18	TREG3A (Timer register 3A)	
19	TREG3B (Timer register 3B)	–
1A	–	TC3CR (TC 3 control)
1B	–	P4 CR1 (P4 I/O control1)
1C	P4 CR2 (P4 I/O control2)	
1D	–	TREG5 (Timer register5)
1E	–	TC5CR (TC 5 control)
1F	reserved	

Address	Read	Write
0020_H	SIOSR (SIO status)	SIOCR1 (SIO control)
21	–	SIOCR2
22	UARTSR(UART status)	UARTCR1 (UART control)
23	–	UARTCR2
24	RDBUF (UART receive data)	TDBUF (UART transmit data)
25		P5CR1 (P5 I/O control1)
26	P5CR2 (P5 I/O control2)	
27	P7CR2 (P7 I/O control2)	
28	–	P8CR (P8 I/O control)
29	P8 PUCR (P8 pull up control)	
2A	–	P9CR1 (P9 I/O control1)
2B	P9CR2 (P9 I/O control2)	
2C	–	GCCR (generator clock control)
2D	DTMFCR (DTMF control)	
2E	DTMFDR (DTMF data register)	
2F	STOPCR (releases stop mode control)	
30	CGCR (system clock control)	
31	reserved	
32	reserved	
33	reserved	
34	–	WDTCR1 (WDT control)
35	–	WDTCR2
36	TBTCR (TBT / TG / DVO control)	
37	EINTCR (External interrupt control)	
38	SYSCR1 (system control)	
39	SYSCR2	
3A	EIR_L (interrupt enable register)	
3B	EIR_H	
3C	IL_L (interrupt latch)	
3D	IL_H	
3E	reserved	
3F	PSW (program status word)	RBS (register bank selector)

(a) Special Function Registers

Address	Read	Write
$0F80_H$	reserved	
	"	
0FEF	"	
0FF0	SIO transmit and receive data buffer (8 byte)	
F1		
F2		
F3		
F4		
F5		
F6		
F7		
0FF8	reserved	
to	"	
0FFF		

(b) Data Buffer Registers

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.

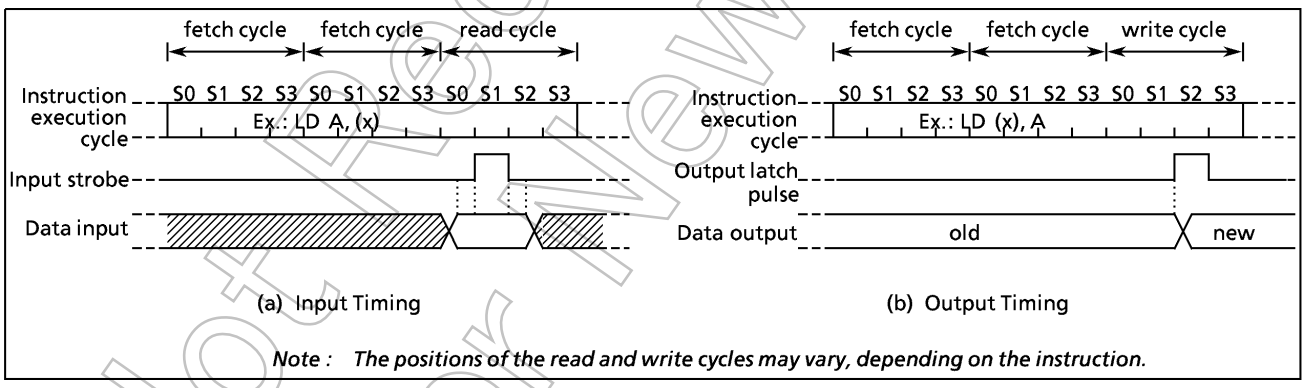
Figure 2-1. SFR & DBR

2.2 I/O Ports

The 87CM53 has 10 parallel input/output ports (72pins) each as follows:

	Primary Function	Secondary Functions
Port P0	8-bit I/O port	————
Port P1	8-bit I/O port	external interrupt input, timer/counter input/output, and divider output
Port P2	4-bit I/O port	low-frequency resonator connections, external interrupt input, and STOP mode release signal input
Port P3	7-bit I/O port	————
Port P4	8-bit I/O port	serial interface, TONE output, MELODY1 (sine wave) output
Port P5	5-bit I/O port	$\overline{\text{MELODY2}}$ (square wave) output, external interrupt input , timer/counter input/output
Port P6	8-bit I/O port	analog input
Port P7	8-bit I/O port	————
Port P8	8-bit I/O port	Key on wake up input
Port P9	8-bit I/O port	————

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.



Note : The positions of the read and write cycles may vary, depending on the instruction.

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

(2) Instructions that read the pin input data
① Instructions other than the above (1)
② (HL) side of ADD/ADDC/SUB/SUBB/AND/OR/XOR (src), (HL)

For the programmable Input/Output ports, when data are read from the port, pins set to the output mode read a value of the output latch.
The control output pins, and etc. are also set to the output mode. Thus a value of the output latch is read, which may be different from a value of the pins.

2.2.1 Port P0 (P07 - P00)

Port P0 is an 8-bit general-purpose input/output port which can be configured as either an input or an output in one-bit unit under software control. Input/output mode is specified by the corresponding bit in the port P0 input/output control register (P0CR). Port P0 is configured as an input if its corresponding P0CR bit is cleared to "0", and as an output if its corresponding P0CR bit is set to "1".
During reset, P0CR is initialized to "0", which configures port P0 as input. The P0 output latches are also initialized to "0". Data is written into the output latch regardless of the P0CR contents. Therefore initial output data should be written into the output latch before setting P0CR.

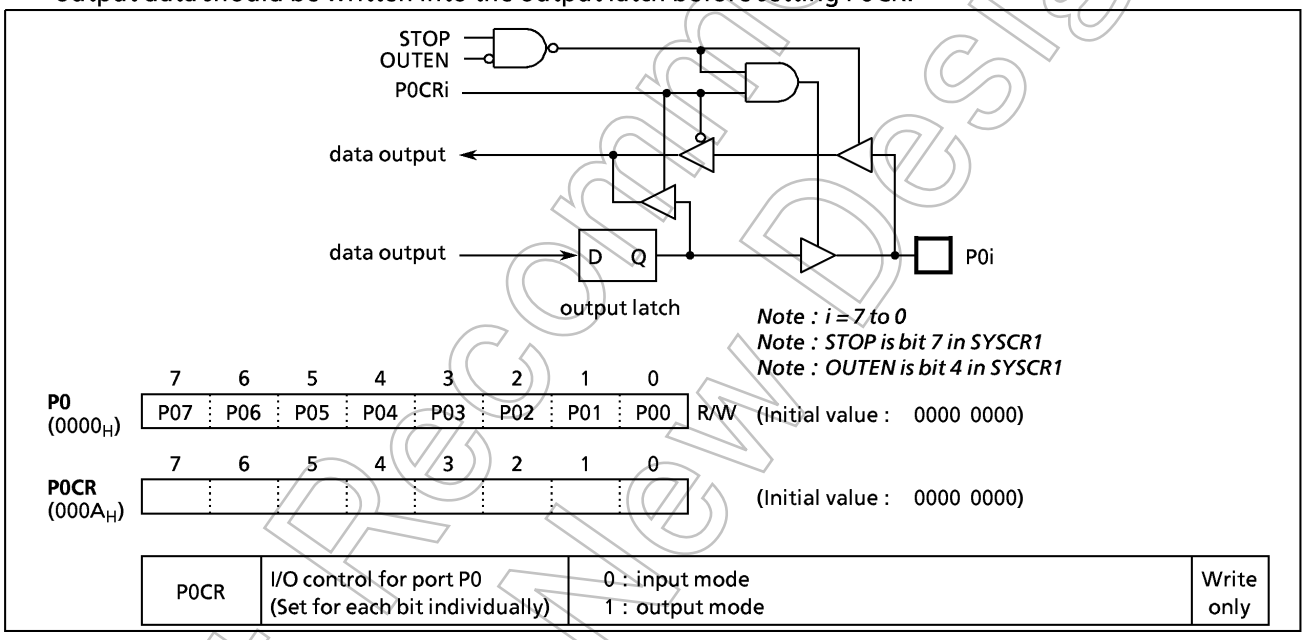


Figure 2-3. Port P0 and P0CR

Example : Setting the upper 4 bits of port P0 as an input port and the lower 4 bits as an output port (Initial output data are 1010_B).

```
LD    (P0), 00001010B    ;  Sets initial data to P0 output latches
LD    (P0CR), 00001111B  ;  Sets the port P0 input/output mode
```

Note 1 : Ports set to the input mode read the pin input states. When input pin and output pin exist in Port P0 together, the contents of the output latch of ports set to the input mode may be rewritten by executing the bit manipulation instructions. Pins set to the output mode read a value of the output latch.

Note 2 : The P0CR is a write-only register. It can not be operated by the read-modify instruction (Bit manipulation instructions of SET, CLR, etc. and Arithmetic instructions of AND, OR, etc.)

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

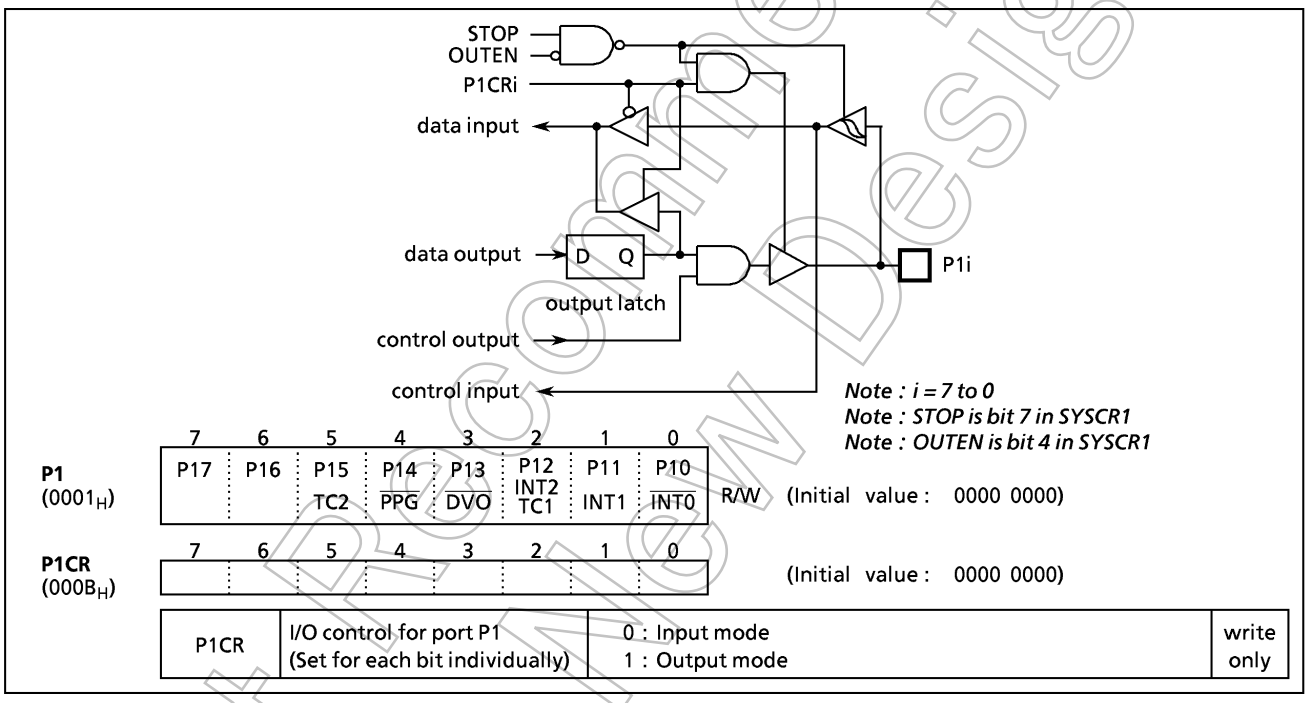


Figure 2-4. Port P1 and P1CR

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), 01000000B     ; INT0EN←1
LD      (P1), 10111111B         ; P17←1, P14←1, P16←0
LD      (P1CR), 11010000B
```

Note 1 : Ports set to the input mode read the pin states. When input pin and output pin exist in Port P1 together, the contents of the output latch of ports set to the input mode may be rewritten by executing the bit manipulation instructions. Pins set to the output mode read a value of the output latch.

Note 2 : The P1CR is a write-only register. It can not be operated by the read-modify instruction (Bit manipulation instructions of SET, CLR, etc. and Arithmetic instructions of AND, OR, etc.)

2.2.3 Port P2 (P23 to P20)

Port P2 is a 4-bit input/output port. It is also used as an external interrupt input, and low-frequency crystal connection pins When used as an input port, or a secondary function pin, the output latch should be set to "1". During reset , the output latches are 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 pin P20 should be used as an external interrupt input, a STOP mode release signal input, or an input port. If used as an output port, the interrupt latch is set on the falling edge of the output pulse.

When a read instruction is executed for port P2, bits 7 to 4 read in "1".

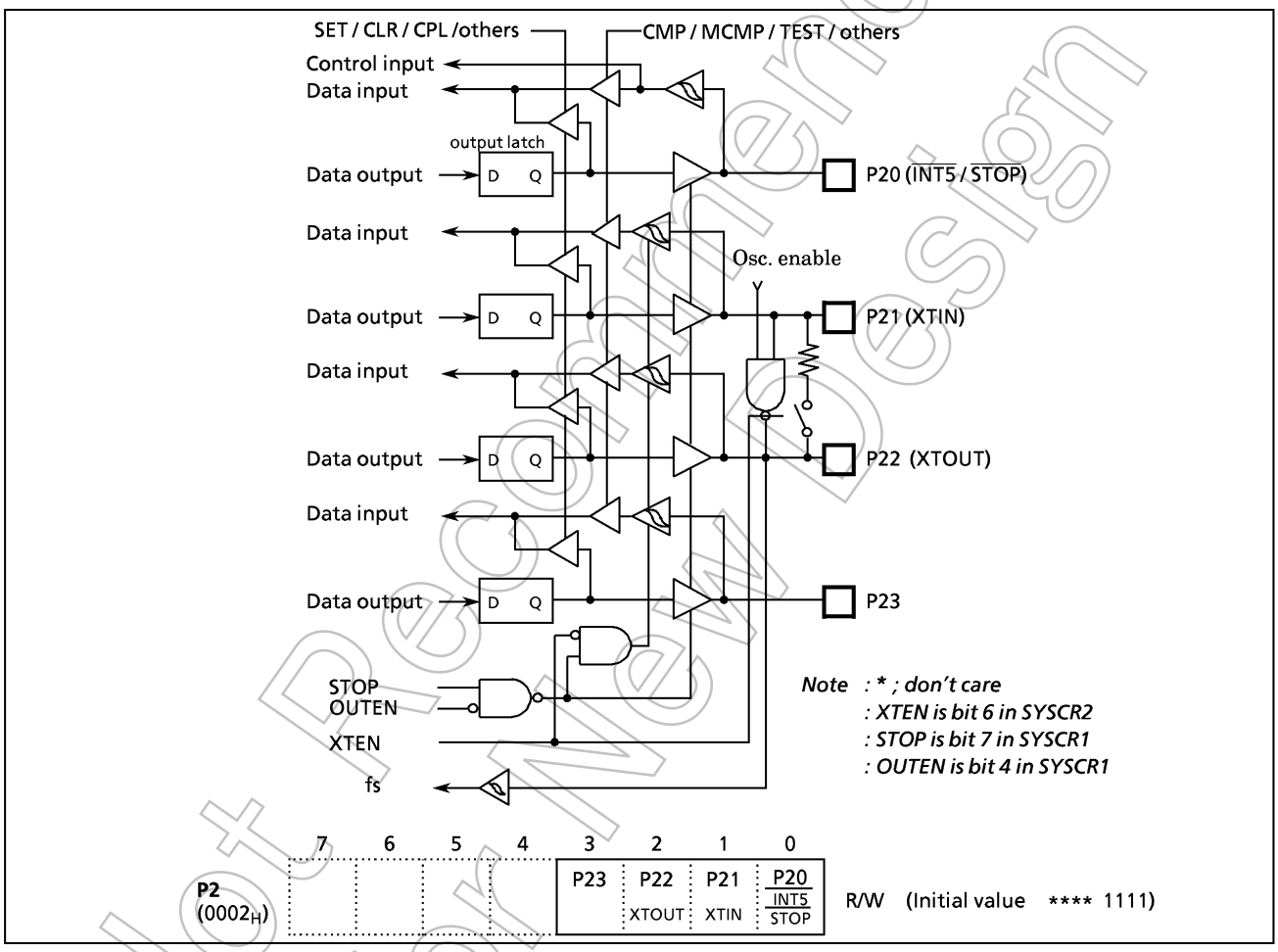


Figure 2-5. Port P2

Note : When using the P20 pin as an output port, the following cautions are needed. It is recommended that the P20 pin is used as the external interrupt input, STOP release signal input or the input port.

1) The interrupt latch of the INT5 is specified at the falling edge which the output of the P20 pin is changed from H to L.

2) When bit 4 (OUTEN) of the SYSCR1 (0038H) is "0" in the stop mode, the P20 pin is set to "Hi-Z".

Ex. : When the stop mode is released by the external RESET and the P20 pin is used as an output pin, malfunctions occur as follows:
When the P20 pin is set to the stop mode with "L" output, the output of the P20 pin is changed from "L" to "Hi-Z". (The voltage level is set to "H" due to external pull-up resistor.) The stop mode is released immediately after entering to the stop mode. Thus, the stop mode is released incorrectly before released by the external RESET. In this case, the P20 output must be set to "H" before entering to the stop mode. Additionally, the stop mode is set after setting bit 6 (RELM) of the SYSCR1 (0038H) to "0" (edge release).

3) When the stop mode is not used, note 1) mentioned above.

2.2.4 Port P3 (P36 to P30)

Port P3 is an 7-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.
When a read instruction is executed for port P3, bits 7 read in "1".

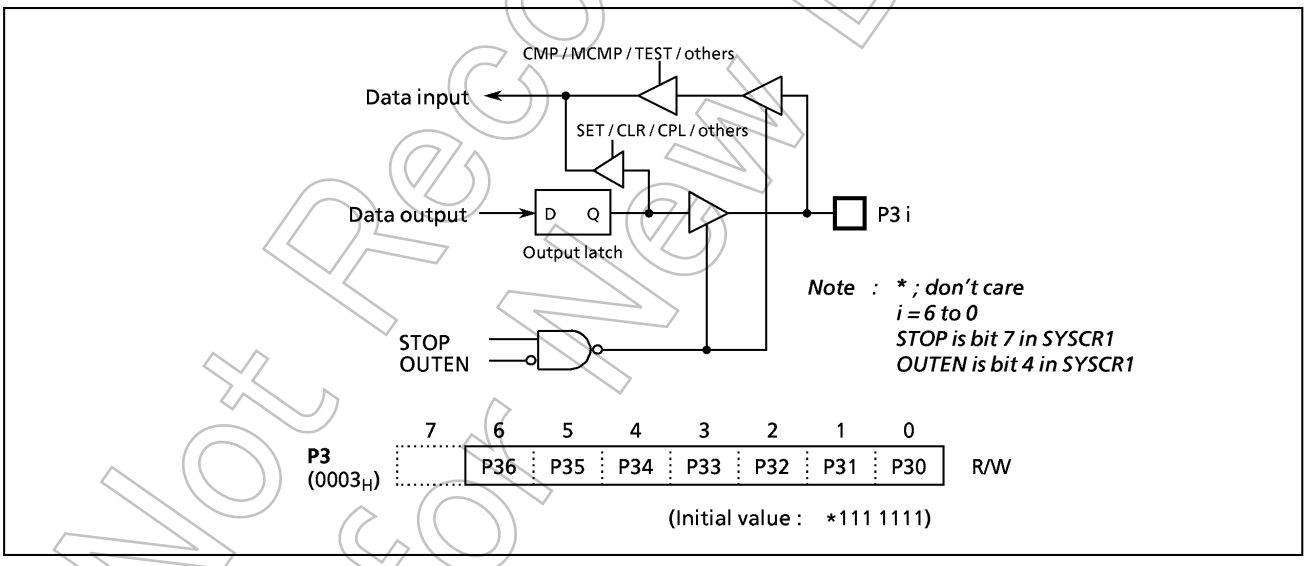


Figure 2-6. Port P3

Example 1: Output the immediate data $1A_H$ to the P3 port.

```
LD      (P3), 1AH          ;   P3←1AH
```

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

```
XOR     (P3), 00001111B    ;   P33 to P30←P33 to P30
```

2.2.5 Port P4 (P47 to P40)

Port P4 can specify input or output on a bit basis and select either the tri-state or the open drain.
It also functions as an 8-bit general-purpose I/O port, tone outputs (TONE, MLELODY1), UART I/Os, and SIO I/Os.
To use Port P4 as UART input or SIO input pin, set the input mode. To use Port P4 as UART output or SIO output pin, set the output mode after setting the output latch to "1".
To use Port P4 as TONE or MELODY1, set the output mode.
Port P4 is set to either input or output by the port P4 I/O control register 1 (P4CR1).
The tri-state or the open drain is specified by the port P4 I/O control register 2 (P4CR2).
At reset, the P4CR1 is initialized to "0", and it is set to the input mode. The P4CR2 is initialized to "1", and it is set to the tri-state. The latch of the port P4 is initialized to "1". The P4CR1 is a write only register.

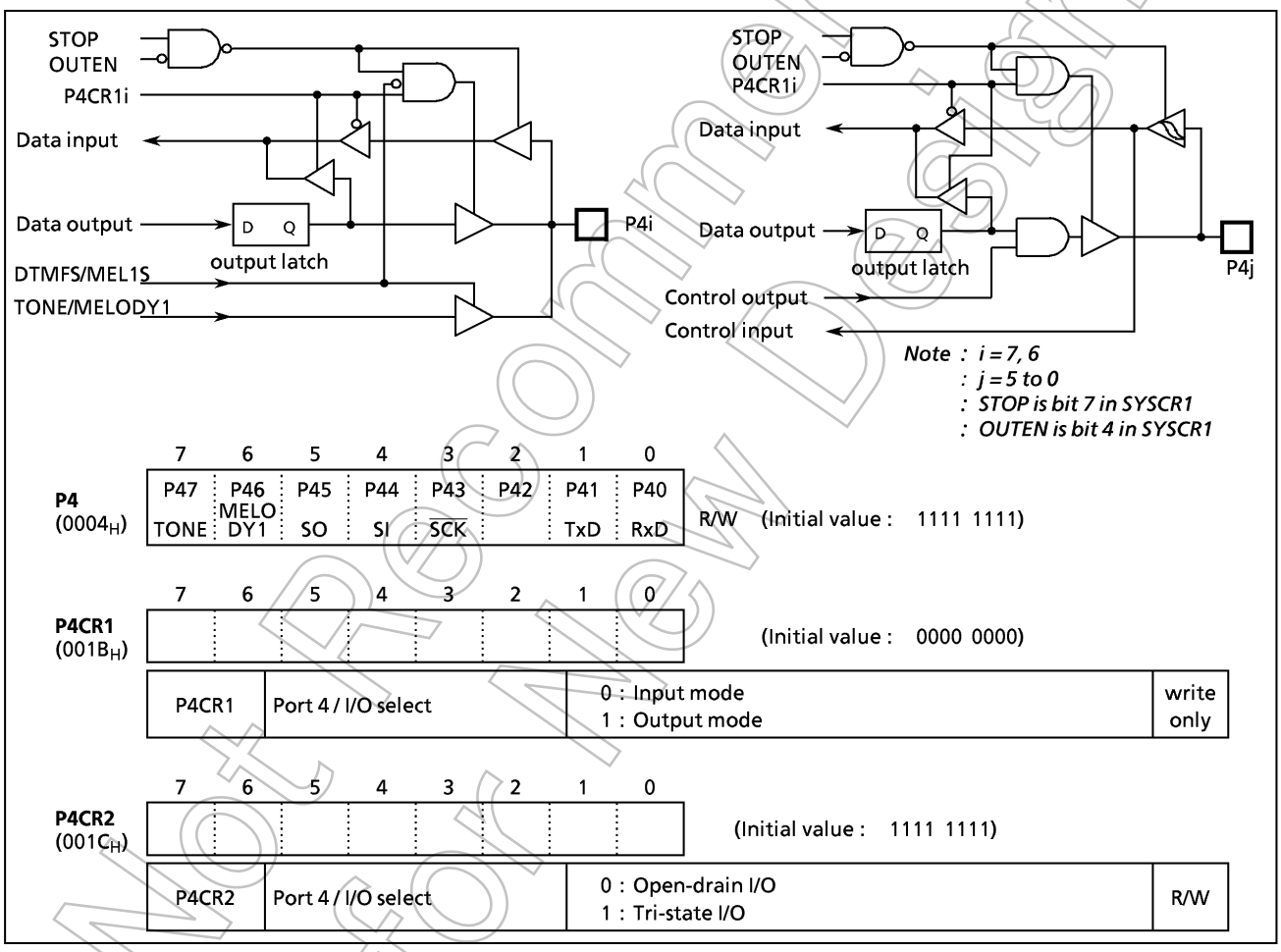


Figure 2-7. Port P4

Note 1 : Ports set to the input mode read the pin states. When input pin and output pin exist in Port P4 together, the contents of the output latch of ports set to the input mode may be rewritten by executing the bit manipulation instructions. Pins set to the output mode read a value of the output latch.

Note 2 : The P4CR1 is a write-only register. It can not be operated by the read-modify instruction (Bit manipulation instructions of SET, CLR, etc. and Arithmetic instructions of AND, OR, etc.)

2.2.6 Port P5 (P54 to P50)

Port P5 can specify input or output on a bit basis and select either the tri-state or the open drain.
It also functions as an 8-bit general-purpose I/O port, an external interrupt input, TC3 input, TC5 output (PWM, PDO), MLELODY2 output.
To use Port P5 as an external input or TC3 input pin, set the input mode. To use Port P5 as TC5 output pin, set the output mode after setting the output latch to "1".
To use Port P5 as MELODY2, set the output mode.
Port P5 is set to either input or output by the port P5 I/O control register 1 (P5CR1).
The tri-state or the open drain is specified by the port P5 I/O control register 2 (P5CR2).
At reset, the P5CR1 is initialized to "0", and it is set to the input mode. The P5CR2 is initialized to "1", and it is set to the tri-state. The latch of the port P5 is initialized to "1". The P5CR1 is a write only register.

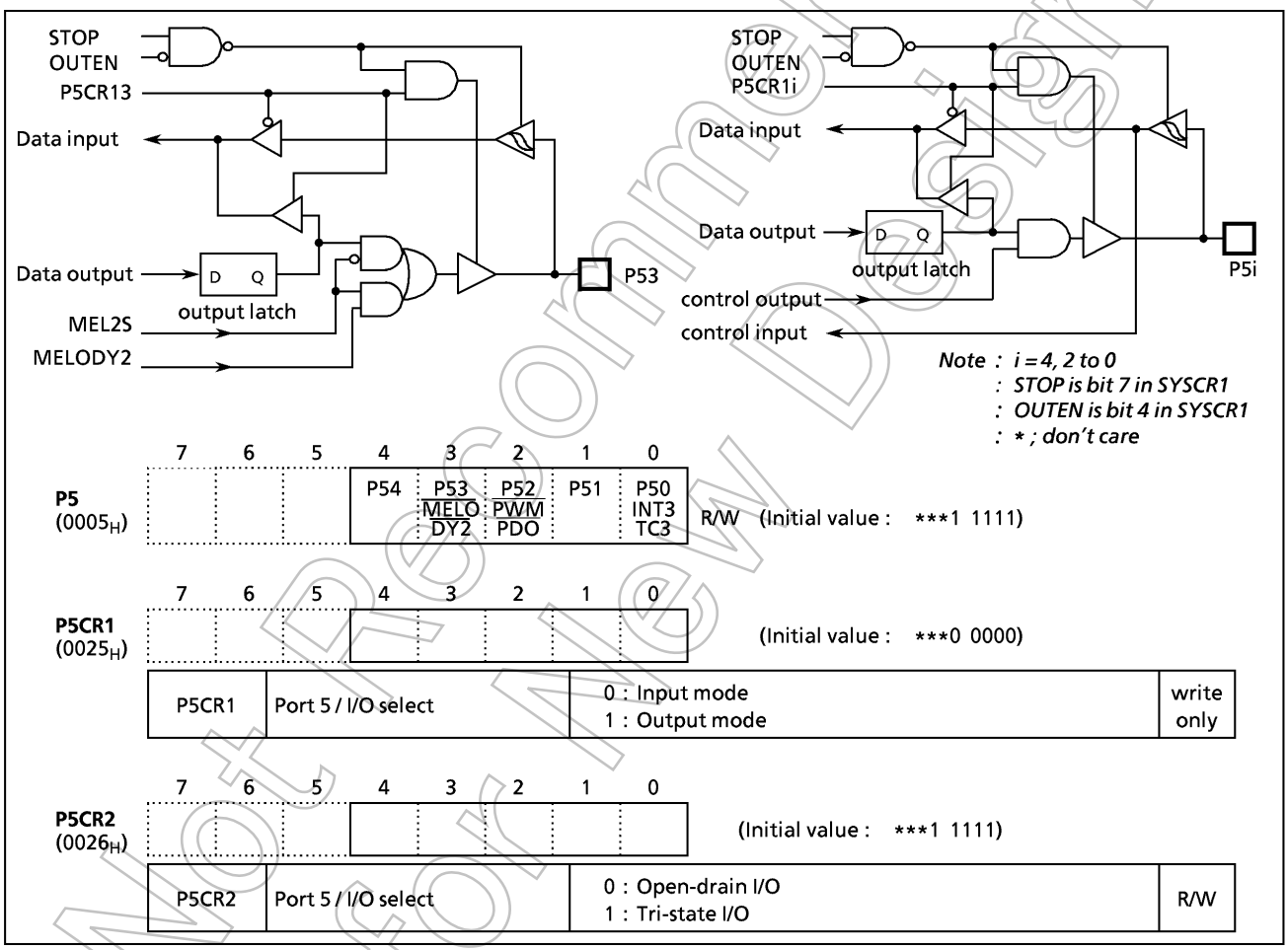


Figure 2-8. Port P5

Note 1 : Ports set to the input mode read the pin states. When input pin and output pin exist in Port P5 together, the contents of the output latch of ports set to the input mode may be rewritten by executing the bit manipulation instructions. Pins set to the output mode read a value of the output latch.

Note 2 : The P5CR1 is a write-only register. It can not be operated by the read-modify instruction (Bit manipulation instructions of SET, CLR, etc. and Arithmetic instructions of AND, OR, etc.)

2.2.7 Port P6 (P67 to P60)

Port P6 is an 8-bit input/output port which can be configured as an input or an output in one-bit unit under software control.

It also functions as an 8-bit general-purpose I/O port, an analog input for the A/D converter.

To use Port P6 as an analog input pin, set the input mode.

Port P6 is set to either input or output by the port P6 I/O control register 1 (P6CR).

At reset, the P6CR is initialized to "0", and it is set to the input mode.

The latch of the port P6 is initialized to "0". The P6CR is a write only register.

When a read instruction is executed for the port P6, pins set to the output mode read a value of the output latch. Pins set to the input mode read an external input value. (They read "0" at level "L" and "1" at level "H".)

When the AINDS (bit 4 of the ADCCR) of the A/D converter control register (ADCCR) is "0", a pin selected by the SAIN (bit 0 to 3 of the ADCCR) are set to "1" without reading an external input value.

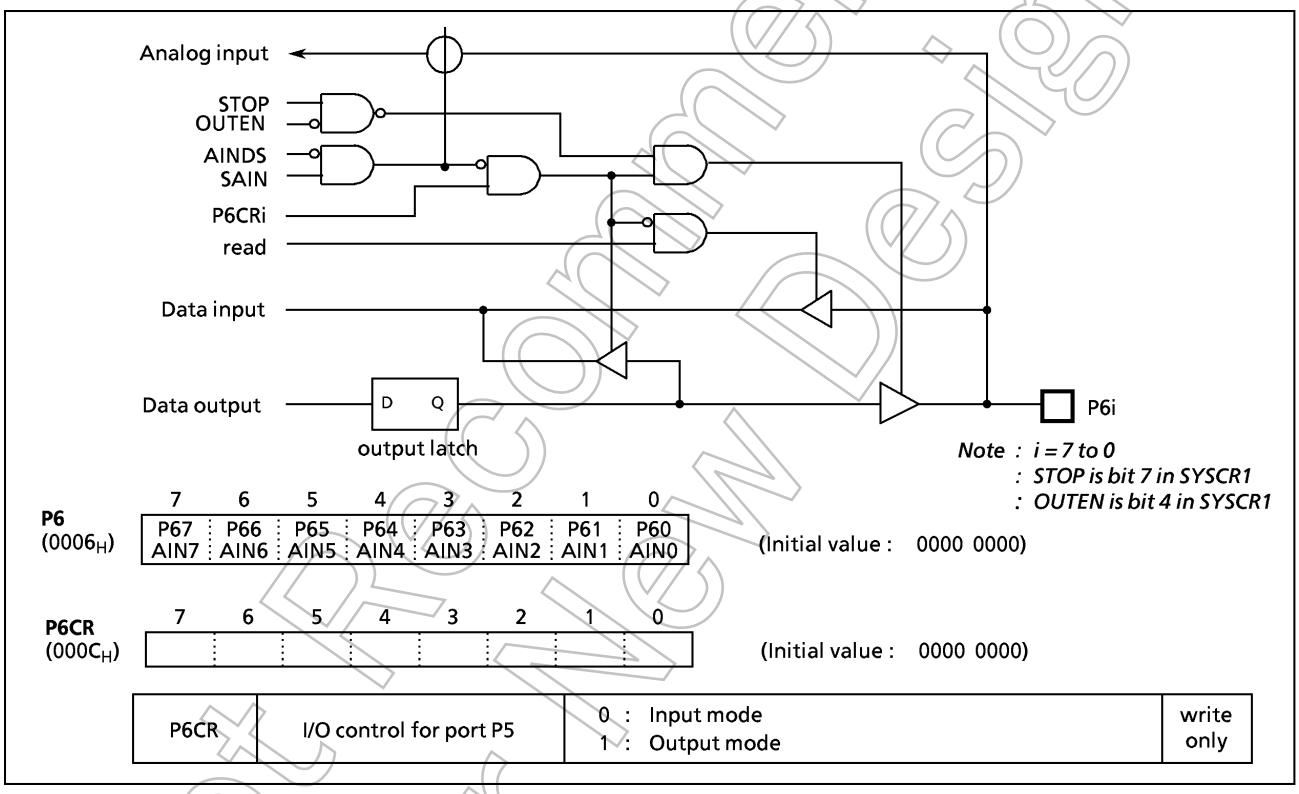


Figure 2-9. Port P6

Note 1 : Ports set to the input mode read the pin states. When input pin and output pin exist in Port P6 together, the contents of the output latch of ports set to the input mode may be rewritten by executing the bit manipulation instructions. Pins set to the output mode read a value of the output latch.

Note 2 : The P6CR is a write-only register. It can not be operated by the read-modify instruction (Bit manipulation instructions of SET, CLR, etc. and Arithmetic instructions of AND, OR, etc.)

Note 3 : Unused analog input pins cannot be configured as output mode when AINDS = 0.

2.2.8 Ports P7 (P77 - P70)

Port P7 can specify input or output on a bit basis and select either the tri-state or the open drain.
It also functions as an 8-bit general-purpose I/O port.
Port P7 is set to either input or output by the port P7 I/O control register 1 (P7CR1).
The tri-state or the open drain is specified by the port P7 I/O control register 2 (P7CR2).
At reset, the P7CR1 is initialized to "0", and it is set to the input mode. The P7CR2 is initialized to "1", and it is set to the tri-state. The latch of the port P7 is initialized to "0". The P7CR1 is a write only register.

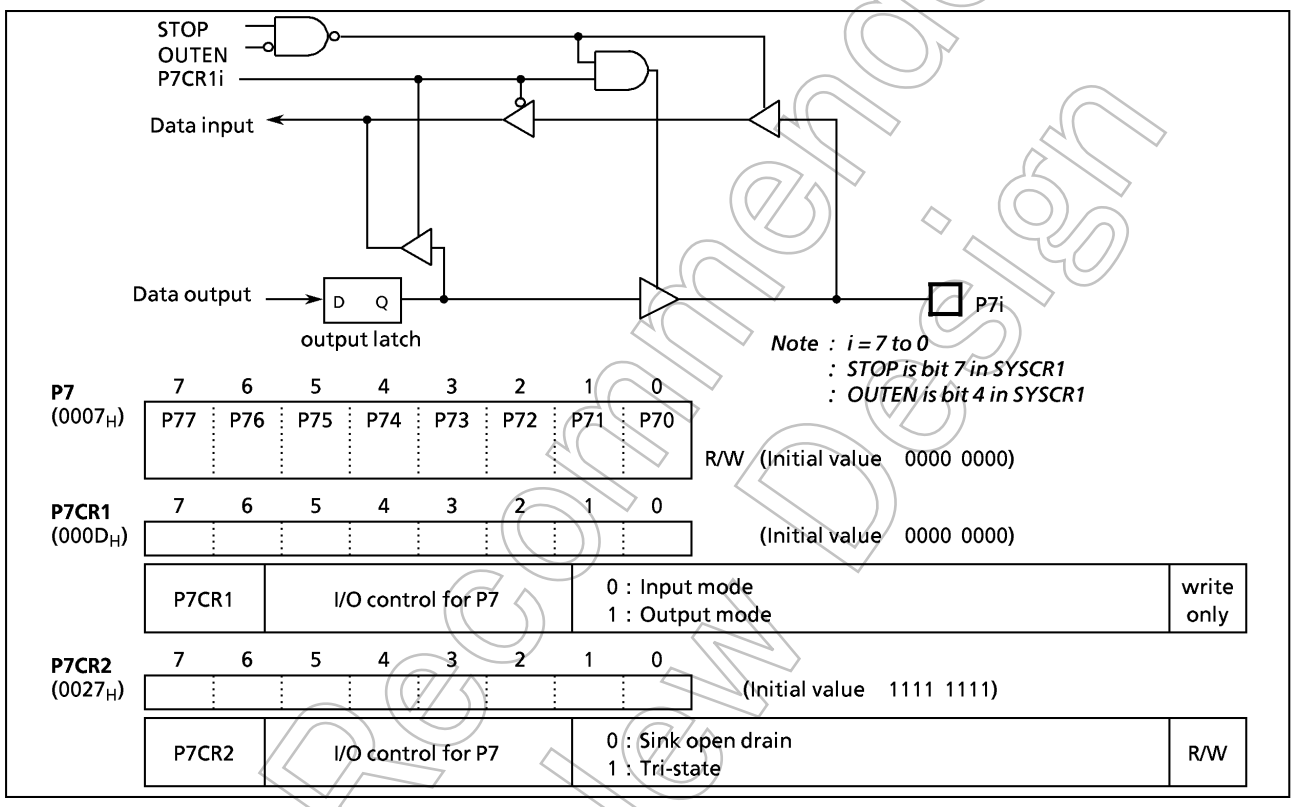


Figure 2-10. Port 7 and P7CR

Note 1 : Ports set to the input mode read the pin states. When input pin and output pin exist in Port P7 together, the contents of the output latch of ports set to the input mode may be rewritten by executing the bit manipulation instructions. Pins set to the output mode read a value of the output latch.

Note 2 : The P7CR1 is a write-only register. It can not be operated by the read-modify instruction (Bit manipulation instructions of SET, CLR, etc. and Arithmetic instructions of AND, OR, etc.)

2.2.9 Port P8 (P87 to P80)

Port P8 can specify input or output on a bit basis and select either the pull-up resistor is set or not.
It also functions as an 8-bit general-purpose I/O port, Key on wake-up.
To use Port P8 as Key on wake-up pin, set the input mode.
Port P8 is set to either input or output by the port P8 I/O control register (P8CR).
Port P8 is set to pull-up resistor or not is specified by the port P8 pull-up resistor control register (P8PUCR).
At reset, the P8CR is initialized to "0", and it is set to the input mode. The P8PUCR is initialized to "0".
The latch of the port P8 is initialized to "0". The P8CR is a write only register.

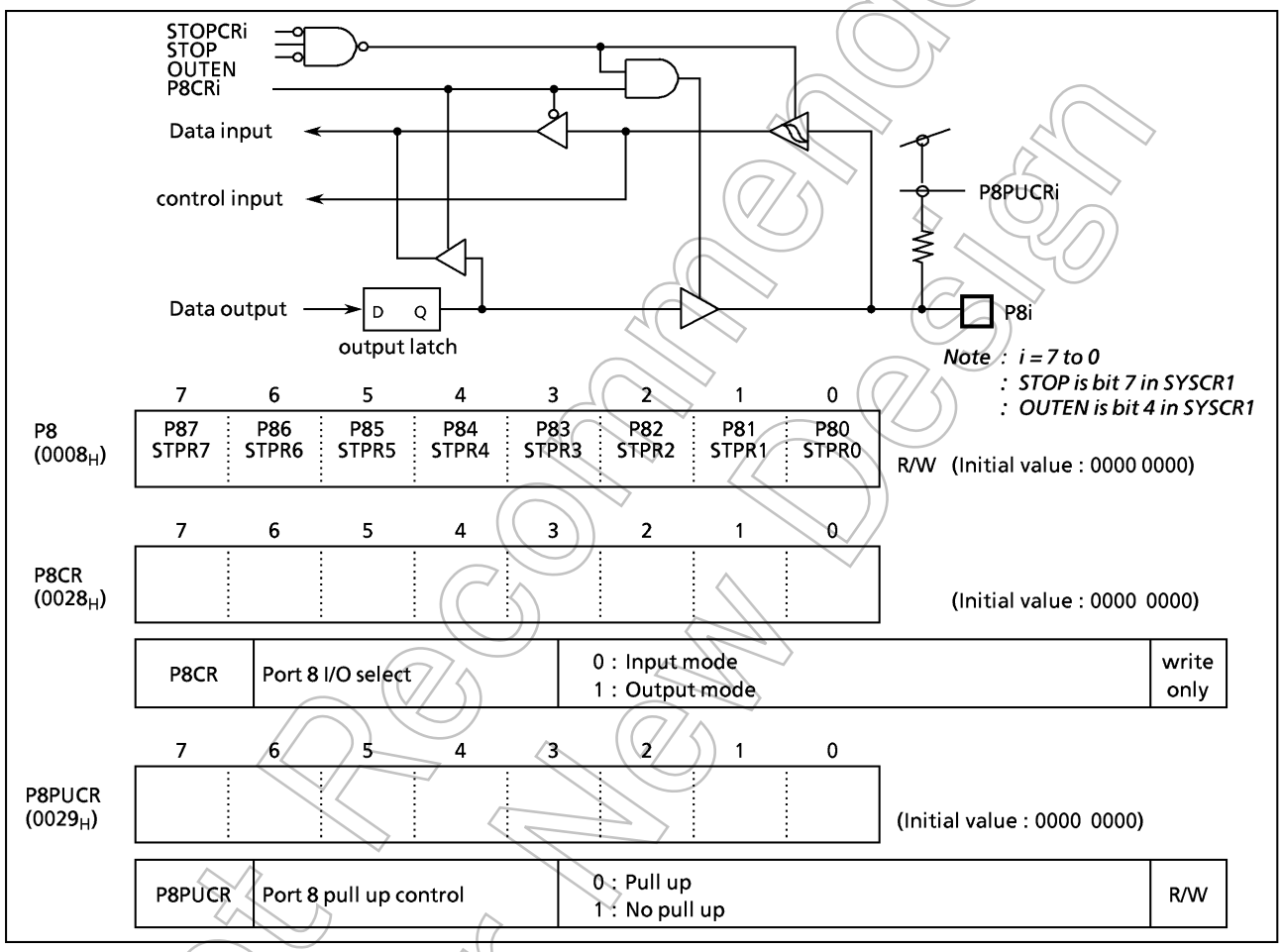


Figure 2-11. Port 8 and P8CR

Note 1 : Ports set to the input mode read the pin states. When input pin and output pin exist in Port P8 together, the contents of the output latch of ports set to the input mode may be rewritten by executing the bit manipulation instructions. Pins set to the output mode read a value of the output latch.

Note 2 : The P8CR is a write-only register. It can not be operated by the read-modify instruction (Bit manipulation instructions of SET, CLR, etc. and Arithmetic instructions of AND, OR, etc.)

2.2.10 Ports P9 (P97 - P90)

Port P9 can specify input or output on a bit basis and select either the tri-state or the open drain.
It also functions as an 8-bit general-purpose I/O port.
Port P9 is set to either input or output by the port P9 I/O control register 1 (P9CR1).
The tri-state or the open drain is specified by the port P9 I/O control register 2 (P9CR2).
At reset, the P9CR1 is initialized to "0", and it is set to the input mode. The P9CR2 is initialized to "1", and it is set to the tri-state. The latch of the port P9 is initialized to "0". The P9CR1 is a write only register.

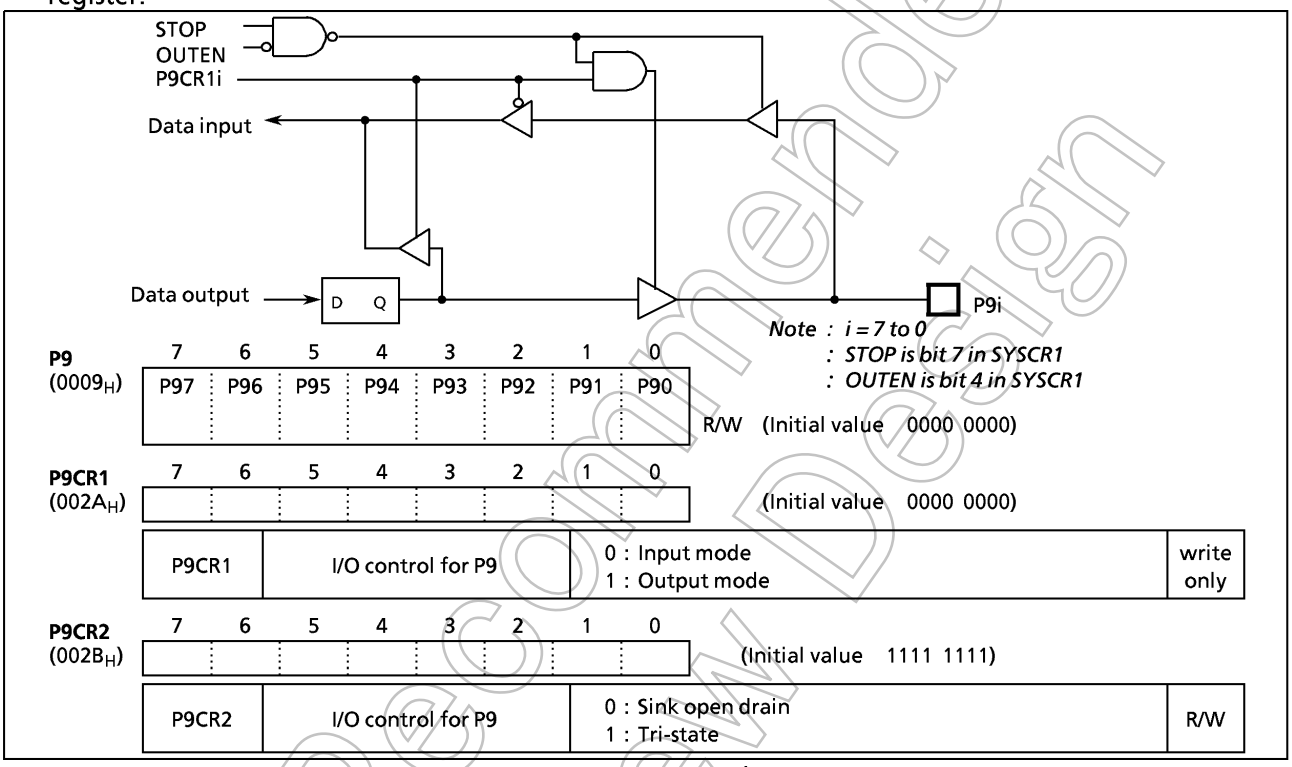


Figure 2-12. Port 9 and P9CR

Note 1 : Ports set to the input mode read the pin states. When input pin and output pin exist in Port P9 together, the contents of the output latch of ports set to the input mode may be rewritten by executing the bit manipulation instructions. Pins set to the output mode read a value of the output latch.

Note 2 : The P9CR1 is a write-only register. It can not be operated by the read-modify instruction (Bit manipulation instructions of SET, CLR, etc. and Arithmetic instructions of AND, OR, etc.)

2.3 Time Base Timer (TBT)

The time-base timer is used to generate the base time for key scan and dynamic display processing. For this purpose, it generates a time-base timer interrupt (INTTBT) at predetermined intervals.

This interrupt is generated beginning with the first rising edge of the source clock (the timing generator's divider output selected by TBTCK) after the time-base timer is enabled. Note that since the divider cannot be cleared by a program, the first interrupt only may occur earlier than the set interrupt period. (See Figure 2-13. (b).)

When selecting the interrupt frequency, make sure the time-base timer is disabled. (Do not change the selected interrupt frequency when disabling the active timer either.) However, you can select the interrupt frequency simultaneously when enabling the timer.

Example : Sets the time base timer frequency to fc/2^{16} [Hz] and enables an INTTBT interrupt.

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

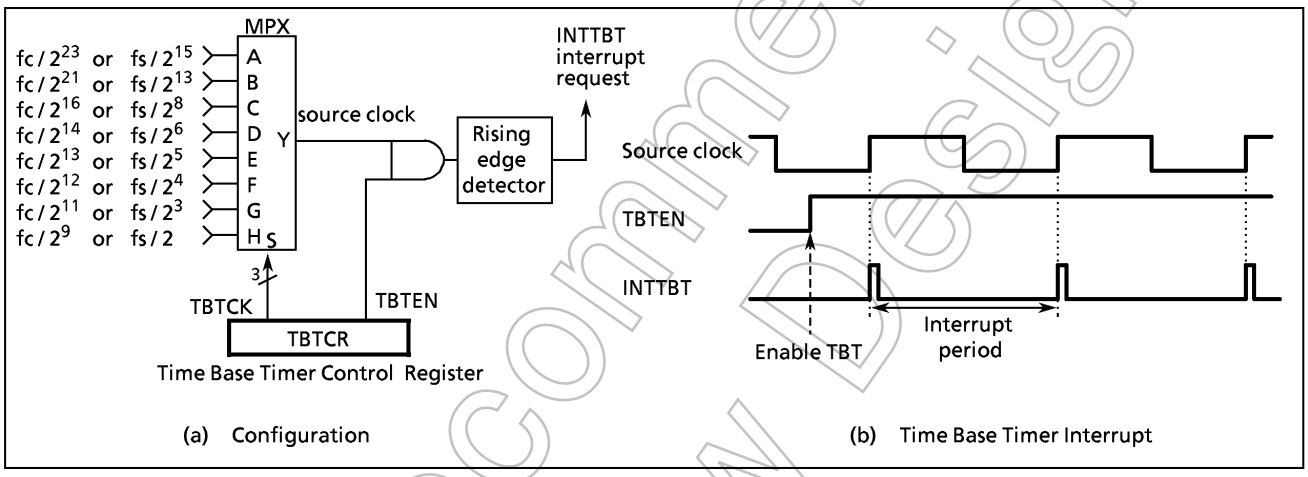
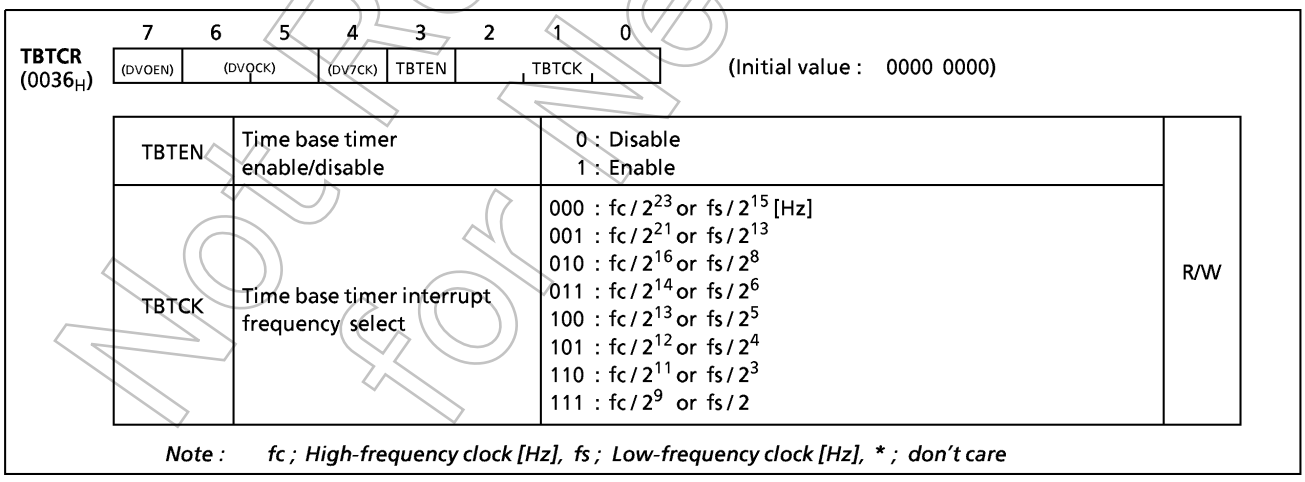


Figure 2-13. Time Base Timer



TBTEN	Time base timer enable/disable	0 : Disable 1 : Enable	R/W
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	

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

Figure 2-14. Time Base Timer and Divider Output Control Register

Table 2-1. Time Base Timer Interrupt Frequency

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

2.4 Divider Output ($\overline{DVO}$)

TBTCR (0036_H)

7	6	5	4	3	2	1	0
DVOEN	DVOCK		(DV7CK)	(TBTEN)	(TBTCK)		

(Initial value : 0000 0000)

DVOEN	Divider output enable/disable	0 : Disable 1 : Enable	R/W
DVOCK	Divider output ($\overline{DVO}$) 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 $fs/2^{2}$	

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

Figure 2-15. 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 ($\overline{DVO}$). 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.

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

```
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	$fc/2^{12}$ $fs/2^{4}$	1.024	1.953	2.048
10	$fc/2^{11}$ $fs/2^{3}$	2.048	3.906	4.096
11	$fc/2^{10}$ $fs/2^{2}$	4.096	7.812	8.192

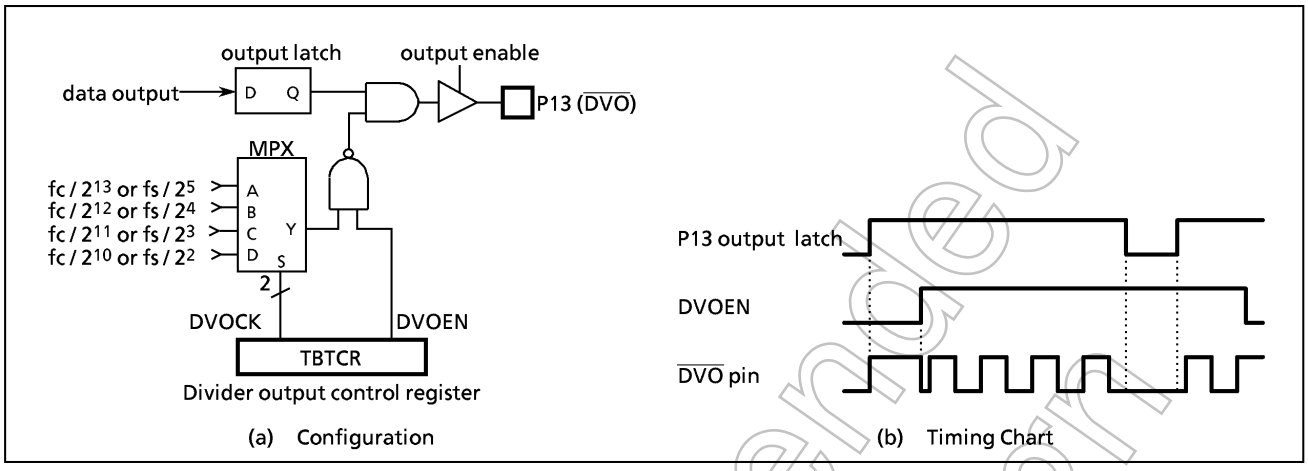


Figure 2-16. Divider Output

2.5 16-bit Timer/Counter 1 (TC1)

2.5.1 Configuration

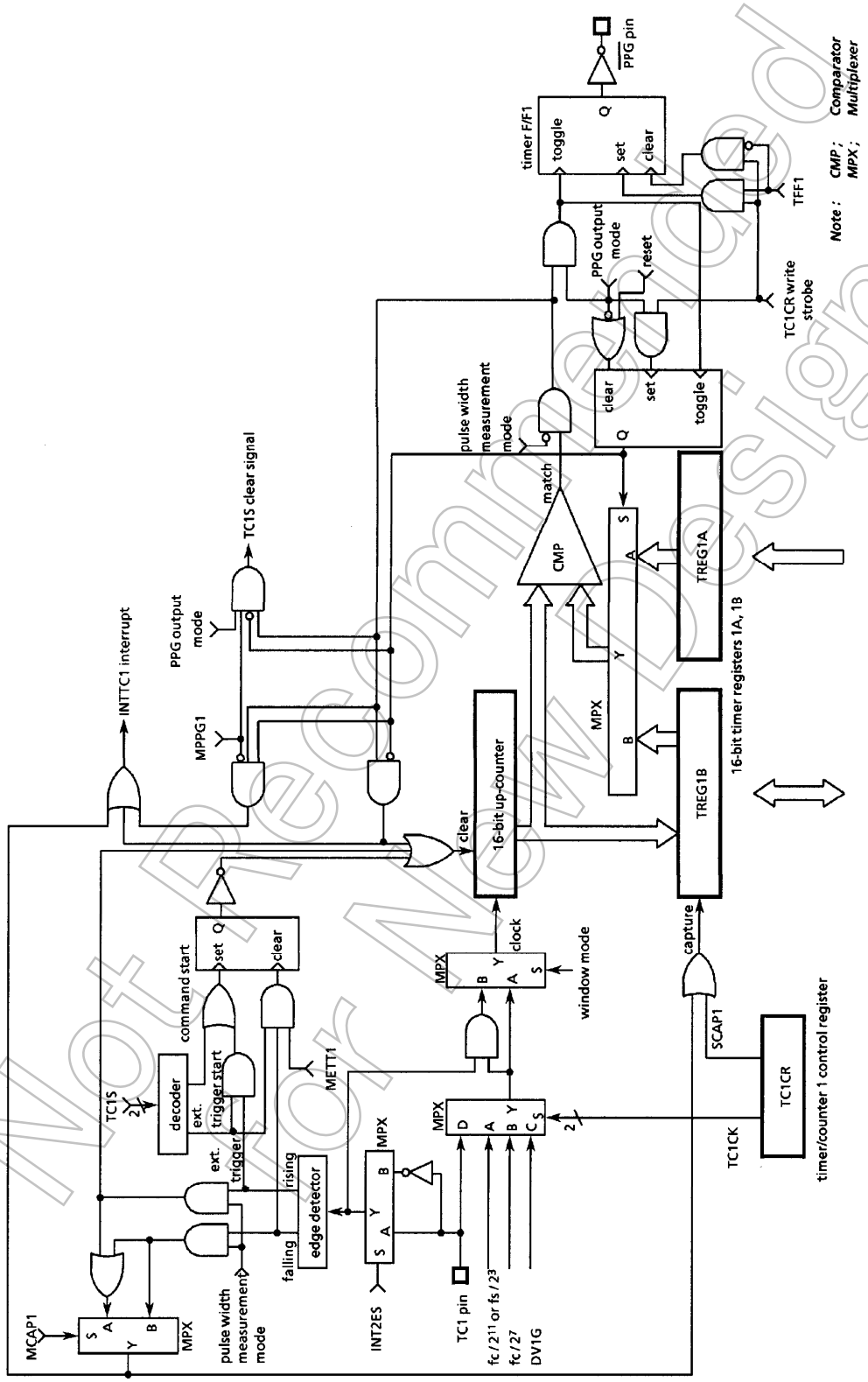
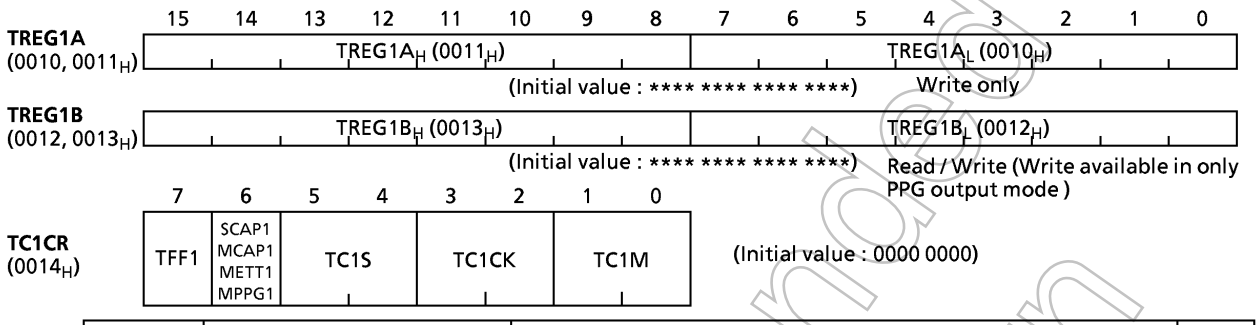


Figure 2-17. Timer/Counter 1

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.



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 DV1G (fc/2^4, fc/2^5, fc/2^6) 11 : external clock (TC1 pin input)	
TC1S	TC1 start control	00 : stop & counter clear 01 : command start 10 : reserved 11 : external trigger srart	
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 srart 1 : trigger start & stop	
MPPG1	PPG output control	0 : cotinuous pulse 1 : single pulse	
TFF1	timer F/F1 control for PPG output mode	0 : clear 1 : set	

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

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 within 1 cycle(during instruction execution) is ignored.

Note 3 : Set the mode, source clock, edge (INT2ES), PPG control and timer F/F control when TC1 stops (TC1S = 00). After writing to the high-byte, the comparison of 1 machine cycle (during instruction execution) is ignored.

Note 4 : Software capture can be used in only timer and event counter modes. SCAP1 is automatically cleared to "0" after software capture.

Note 5 : Values to be loaded to timer registers must satisfy the following condition.
TREG1A > TREG1B > 0 (PPG output mode) ; TREG1A > 0 (others)

Note 6 : Always write "0" to TFF1 except the PPG output mode.

Note 7 : TREG1B can be written only in PPG output mode.

Note 8 : TC1CR is a write-only register, which cannot access any of in read-modify-write instruction such as bit operate, etc.

Note 9 : The DV1G can be set to either fc/2^4, fc/2^5 or fc/2^6 by the DVCR of the clock gear control register (CGCR). When DV1G is used, it must be set to fc/2^4, fc/2^5 or fc/2^6 at the gear ratio = 1/1, to fc/2^5 or fc/2^6 at gear ratio = 1/2, and to fc/2^6 at gear ratio = 1/4. When it is set to other values or the gear ratio is set to 1/8, DV1G (TC1CK = 10) can not operate correctly.

Figure 2-18. 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 transfered to TREG1B by setting SCAP1 (bit 6 in TC1CR) to "1" (software capture function). SCAP1 is automatically cleared to "0" after capaturing.

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

Source clock			Resolution		Maximum time setting	
NORMAL1/2, IDLE1/2 modes		SLOW, SLEEP modes				
DV7CK = 0	DV7CK = 1		At fc = 8 MHz	At fs = 32.768 kHz	At fc = 8 MHz	At fs = 32.768 kHz
$fc / 2^{11}$	$fs / 2^3$ [Hz]	$fs / 2^3$ [Hz]	256 μs	244.14 μs	16.8 s	16.0 s
$fc / 2^7$	$fc / 2^7$	–	16 μs	–	1.0 s	–
$fc / 2^6$	$fc / 2^6$	–	8 μs	–	524.2 ms	–
$fc / 2^5$	$fc / 2^5$	–	4 μs	–	262.1 ms	–
$fc / 2^4$ [Hz]	$fc / 2^4$	–	2 μs	–	131.1 ms	–

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

```
LD      (TC1CR), 00000000B      ; Sets the TC1 mode and source clock
LDW     (TREG1A), 1000H         ; Sets the timer register (1 s ÷ 2^3 / 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
```

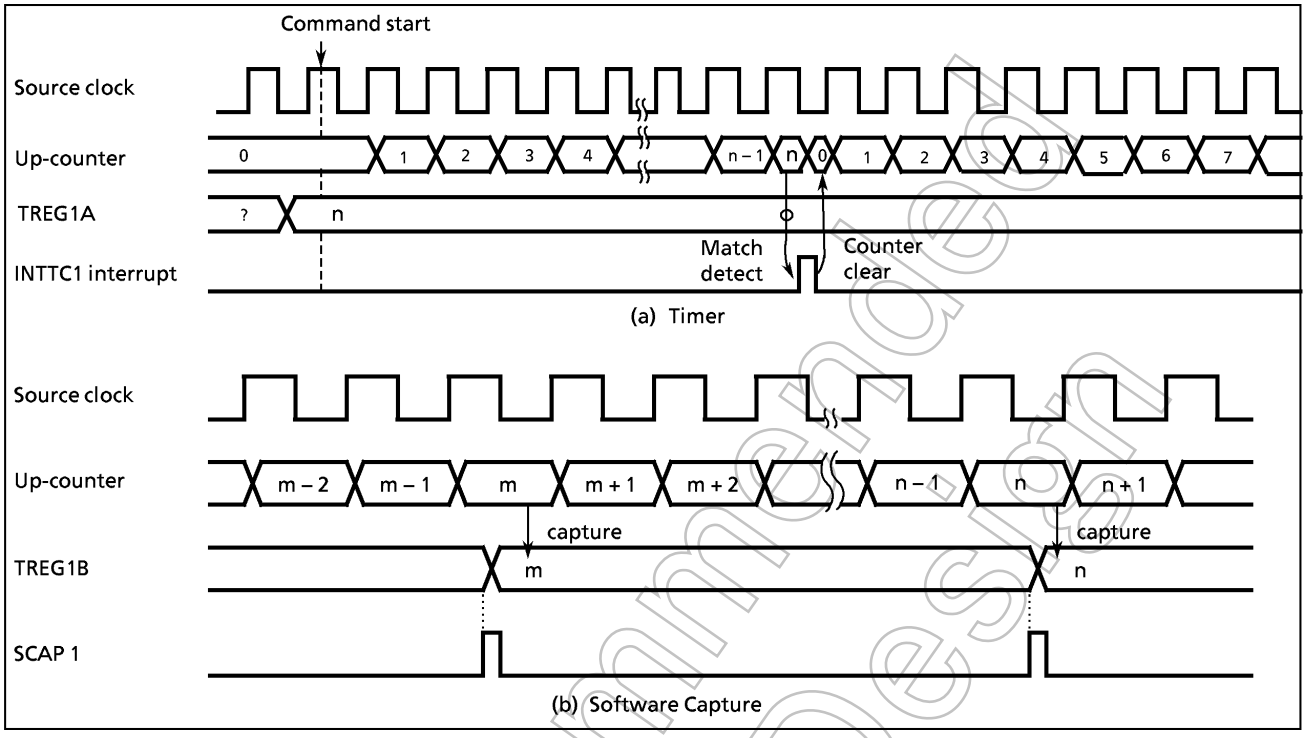


Figure 2-19. Timer Mode Timing Chart

(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 for both "H" and "L" level.

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 2 machine cycle or more is required.

Example 1 : Generates interrupt after 100 μs from TC1 pin input rising edge
(at fc = 8 MHz, DVCK in CGCR = "010").

```
LD      (EINTCR), 00000000B     ;  INT2ES←0 (rising edge)
LDW     (TREG1A), 0032H         ;  100 μs ÷ 2^4 / fc = 32H
SET     (EIRL).EF4              ;  Enables INTTC1 interrupt
EI
LD      (TC1CR), 00111000B      ;  Starts TC1 external trigger, METT = 0
```

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

```
LD      (EINTCR), 00000100B     ;  INT2ES←1 ("L" level)
LDW     (TREG1A), 00FAH         ;  4 ms ÷ 2^7 / fc = FA_H
SET     (EIRL).EF4              ;  Enables INTTC1 interrupt
EI
LD      (TC1CR), 01110100B      ;  Starts TC1 external trigger , METT = 1
```

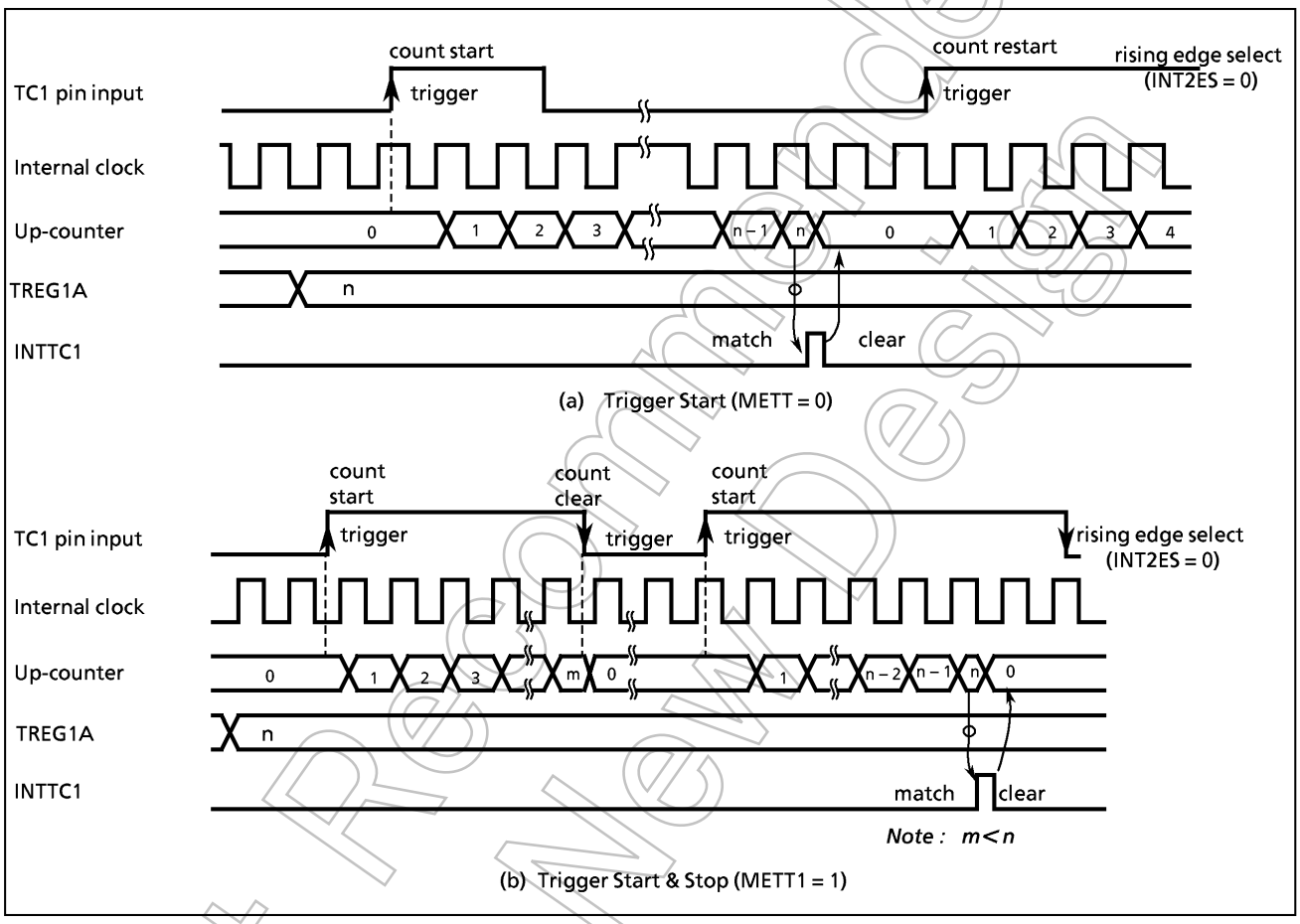


Figure 2-20. External Trigger Timer Mode Timing Chart

(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 fcgck/2^4 [Hz] in NORMAL1/2 or IDLE1/2 mode and fs/2^4 [Hz] in SLOW or SLEEP mode. But, a pulse width of 2 machine cycles or more is required for both "H" and "L" level.

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

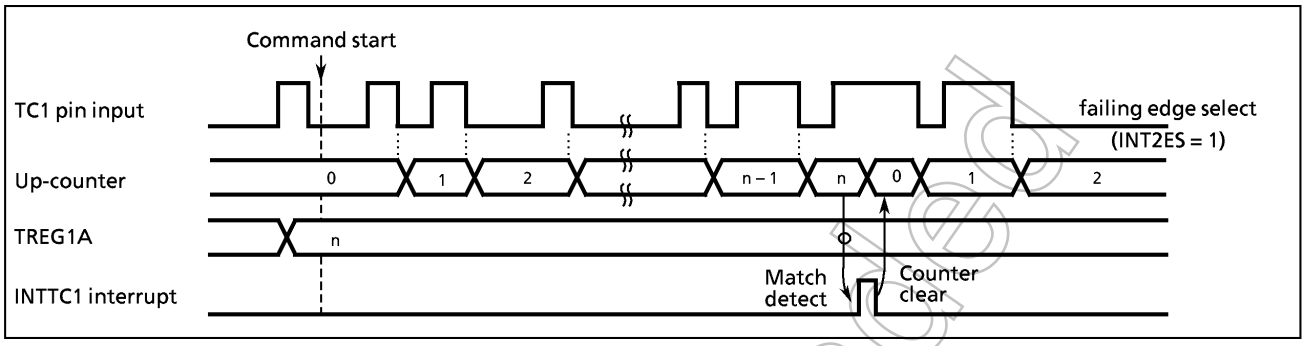


Figure 2-21. Event Counter Mode Timing Chart (INT2ES = 1)

(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" transferes 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.

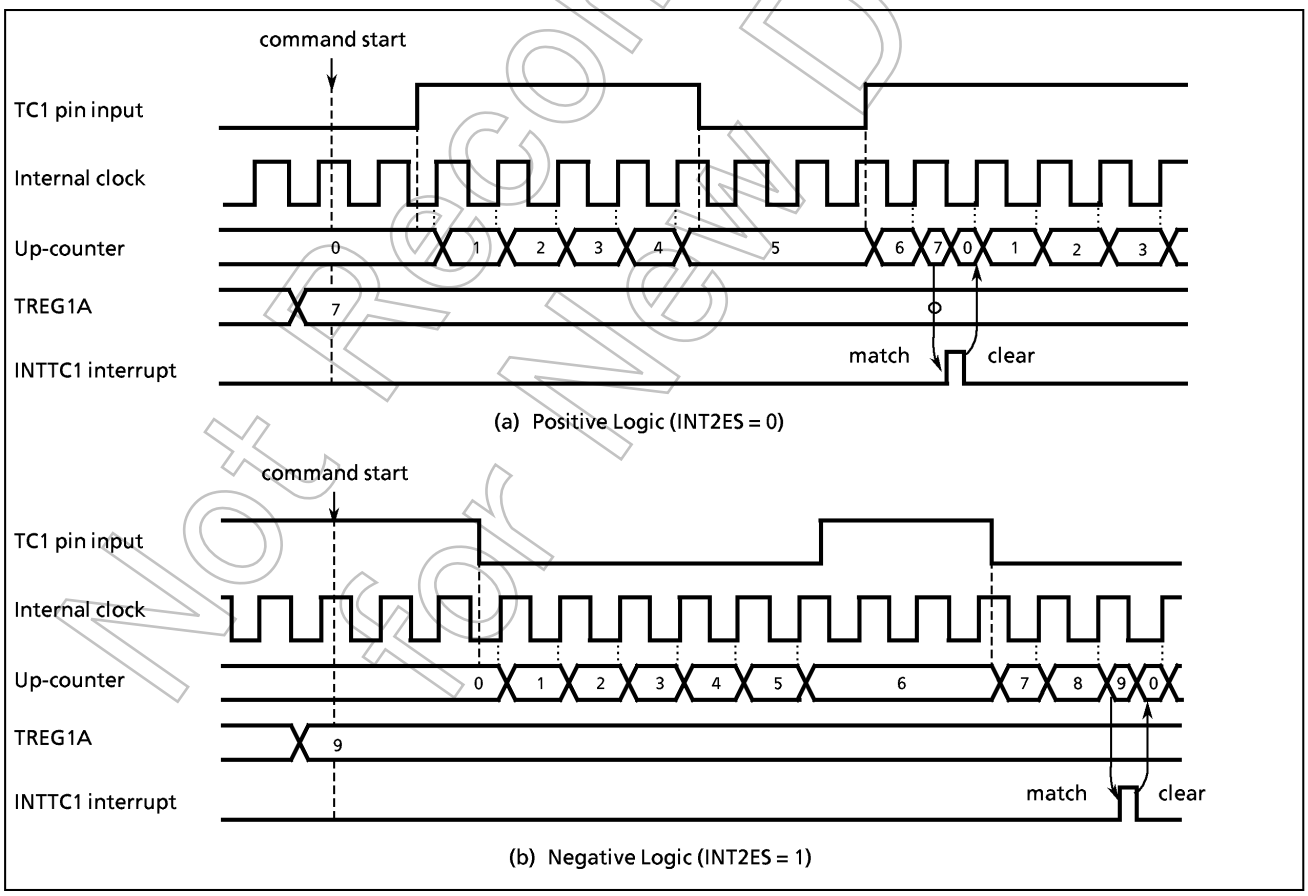


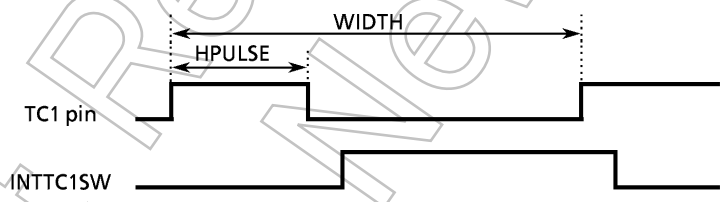
Figure 2-22. Window Mode Timing Chart

(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), 00000000B      ;  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
```



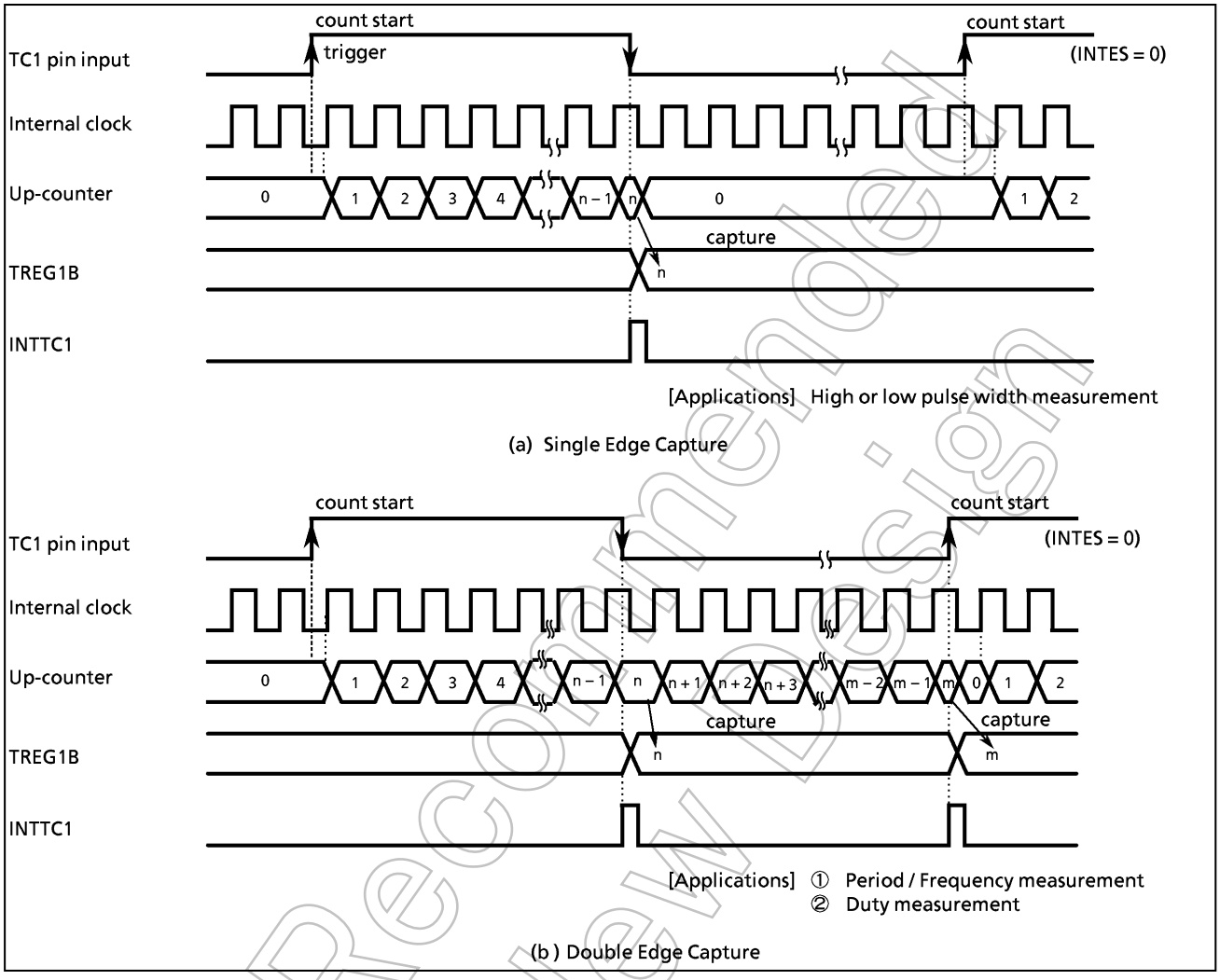


Figure 2-23. Pulse Width Measurement Mode Timing Chart

(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) 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 connected to the P14 ($\overline{PPG}$) pin. In the case of $\overline{PPG}$ output, beforehand the P14 should be set to the output mode, and the P14 output latch should be set to "1". 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 μs, "L"" level 200 μs pulse output (at fc = 8 MHz, DVCK in CGCR = "010")

```
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), 01F4H     ;  Sets a period (1 ms ÷ 2 μs = 01F4H)
LDW    (TREG1B), 0064H     ;  Sets "L" level pulse width (200 μs ÷ 2 μs = 0064H)
LD     (TC1CR), 10010011B  ;  Start
```

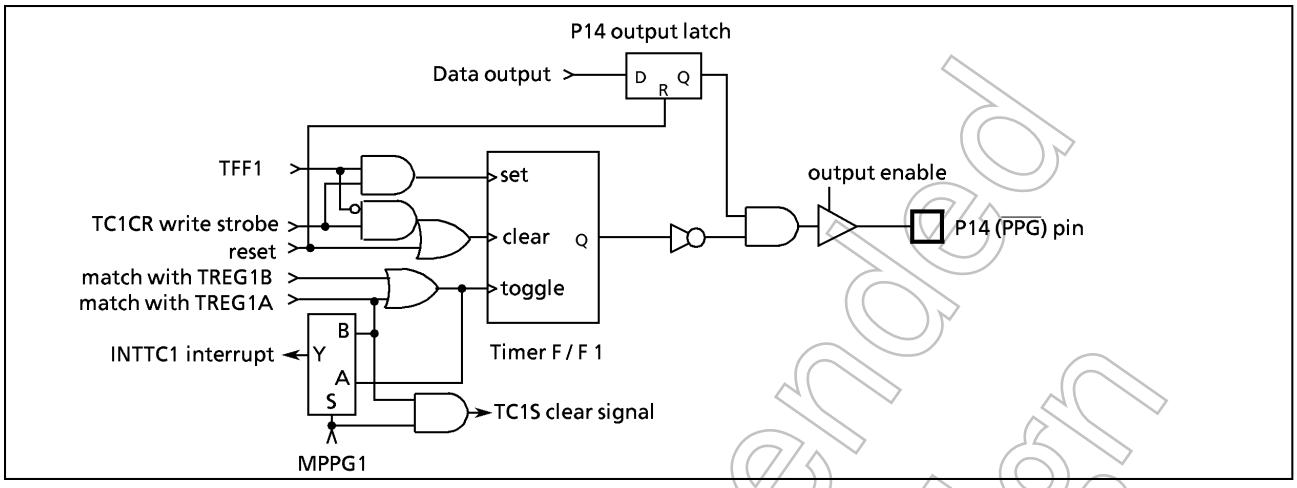


Figure 2-24. PPG Output

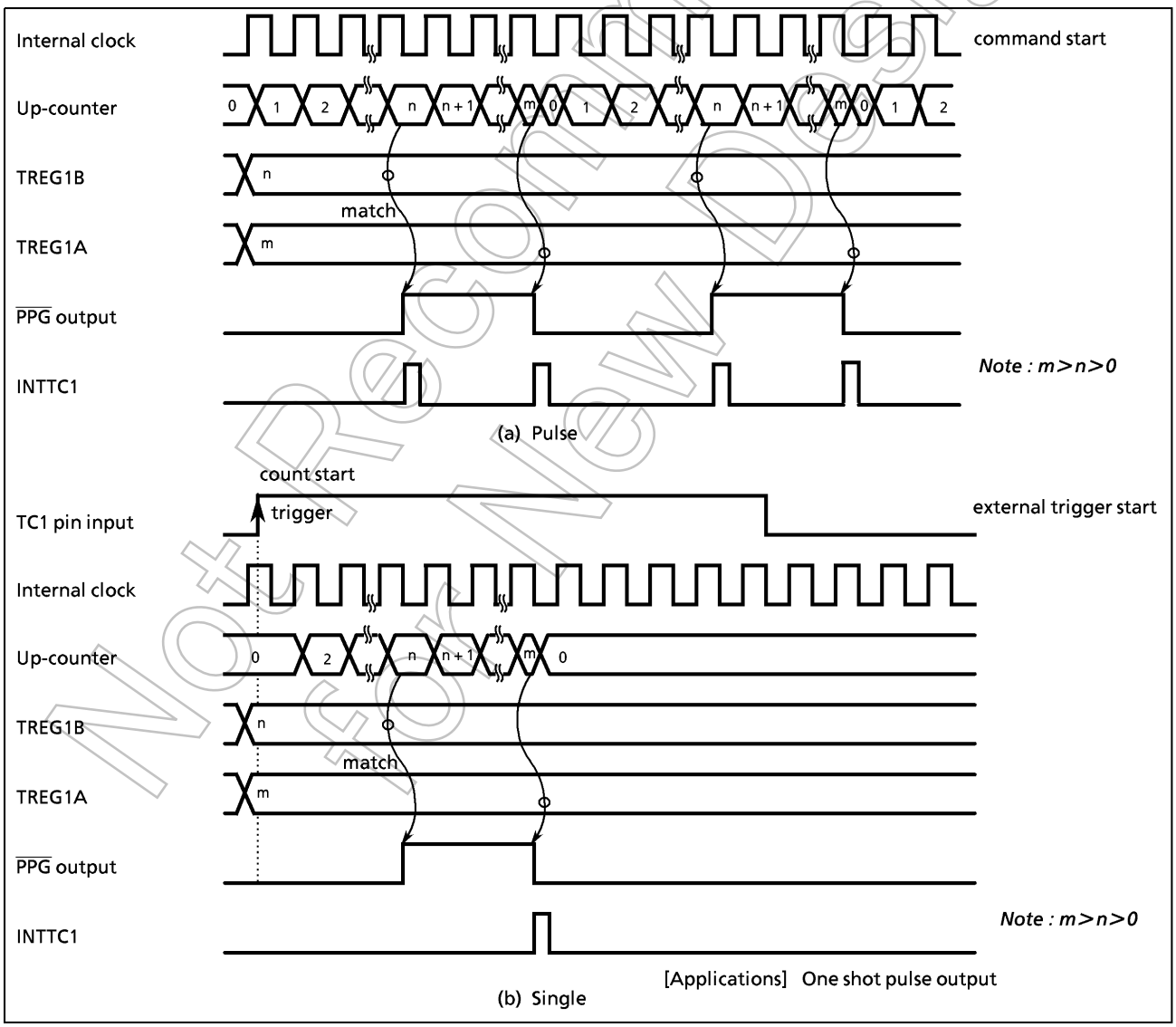


Figure 2-25. PPG Output Mode Timing Chart

2.6 16-bit Timer/Counter 2 (TC2)

2.6.1 Configuration

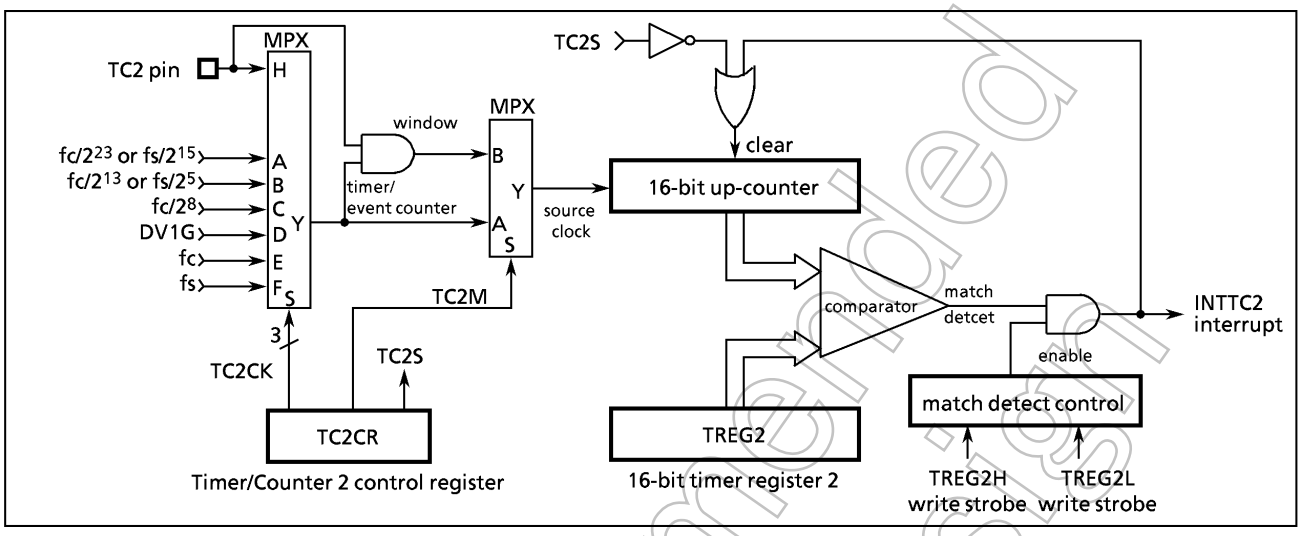


Figure 2-26. Timer/Counter 2 (TC2)

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)

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
$TREG2_H$ (0017_H)								$TREG2_L$ (0016_H)							

(Initial value : **** **** **** ****) write only

TC2CR (0015_H)

7	6	5	4	3	2	1	0
		TC2S	TC2CK				TC2M

(Initial value : **00 00*0)

TC2M	Timer/counter 2 operating mode select	0 : Timer/Event counter mode 1 : Window mode	write only
TC2CK	Timer/counter 2 source clock select	000 : Internal clock fc / 2^{23} or fs / 2^{15} [Hz] 001 : 〃 fc / 2^{13} or fs / 2^5 010 : 〃 fc / 2^8 011 : 〃 DV1G (fc / 2^4, fc / 2^5, fc / 2^6) 100 : 〃 fc (Note 5) 101 : 〃 fs 110 : Reserved 111 : External clock (TC2 pin input)	
TC2S	Timer/counter 2 start control	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.
$TREG2 > 0$ ($TREG2_{15\sim11} > 0$ 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.

Note 7 : The DV1G can be set to either fc/2^4, fc/2^5 or fc/2^6 by DVCR of the clock gear control register (CGCR). When DV1G is used, it must be set to fc/2^4, fc/2^5 or fc/2^6 at the gear ratio = 1/1, to fc/2^5 or fc/2^6 at gear ratio = 1/2, and to fc/2^6 at gear ratio = 1/4. When it is set to other values or the gear ratio is set to 1/8, DV1G (TC2CK = 011) can not operate correctly.

Figure 2-27. 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				
DV7CK = 0	DV7CK = 1			At fc = 8 MHz	At fs = 32.768 kHz	At fc = 8 MHz	At fs = 32.768 kHz
$fc / 2^{23}$[Hz]	$fs / 2^{15}$[Hz]	$fs / 2^{15}$ [Hz]	$fs / 2^{15}$ [Hz]	1.05 s	1 s	19.1 hour	18.2 hour
$fc / 2^{13}$	$fs / 2^{5}$	$fs / 2^{5}$	$fs / 2^{5}$	1.02 ms	1 ms	1.1 min	1 min
$fc / 2^{8}$	$fc / 2^{8}$	–	–	32 μs	–	2.1 s	–
$fc / 2^{6}$	$fc / 2^{6}$	–	–	8 μs	–	524.2 ms	–
$fc / 2^{5}$	$fc / 2^{5}$	–	–	4 μs	–	262.1 ms	–
$fc / 2^{4}$	$fc / 2^{4}$	–	–	2 μs	–	131.1 ms	–
–	–	fc (Note)	–	125 ns	–	7.936 ms	–
fs	fs	–	–	–	30.5 μs	–	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 $fc/2^4$ [Hz] and generates an interrupt every 25 ms (at fc = 8 MHz, DVCK in CGCR = "010").

```
LD      (TC2CR), 00001100B      ; Sets the TC2 mode and source clock
LDW     (TREG2), 30D4H          ; Sets TREG2 (25ms ÷ 2^4/fc = 30D4H)
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 $fcgck/2^4$ [Hz] in NORMAL1/2 or IDLE1/2 mode, and $fs/2^4$ [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 INTT2 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 fc = 8 MHz).

```
LDW     (TREG2), 0078H          ; Sets TREG2 (120 ms ÷ 2^13/fc = 0078H)
SET     (EIRH).EF14             ; Enables INTTC2 interrupt
EI
LD      (TC2CR), 00100101B      ; Starts TC2
```

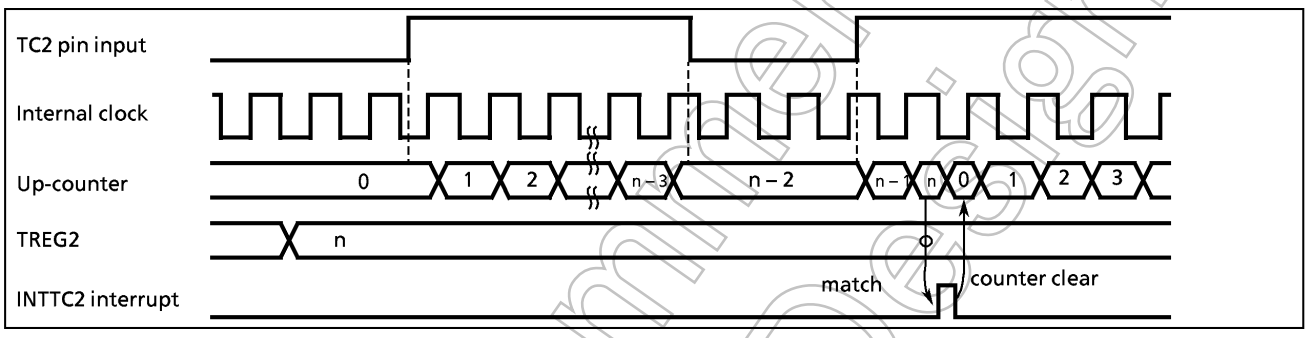


Figure 2-28. Window Mode Timing Chart

2.7 8-Bit Timer/Counter 3 (TC3)

2.7.1 Configuration

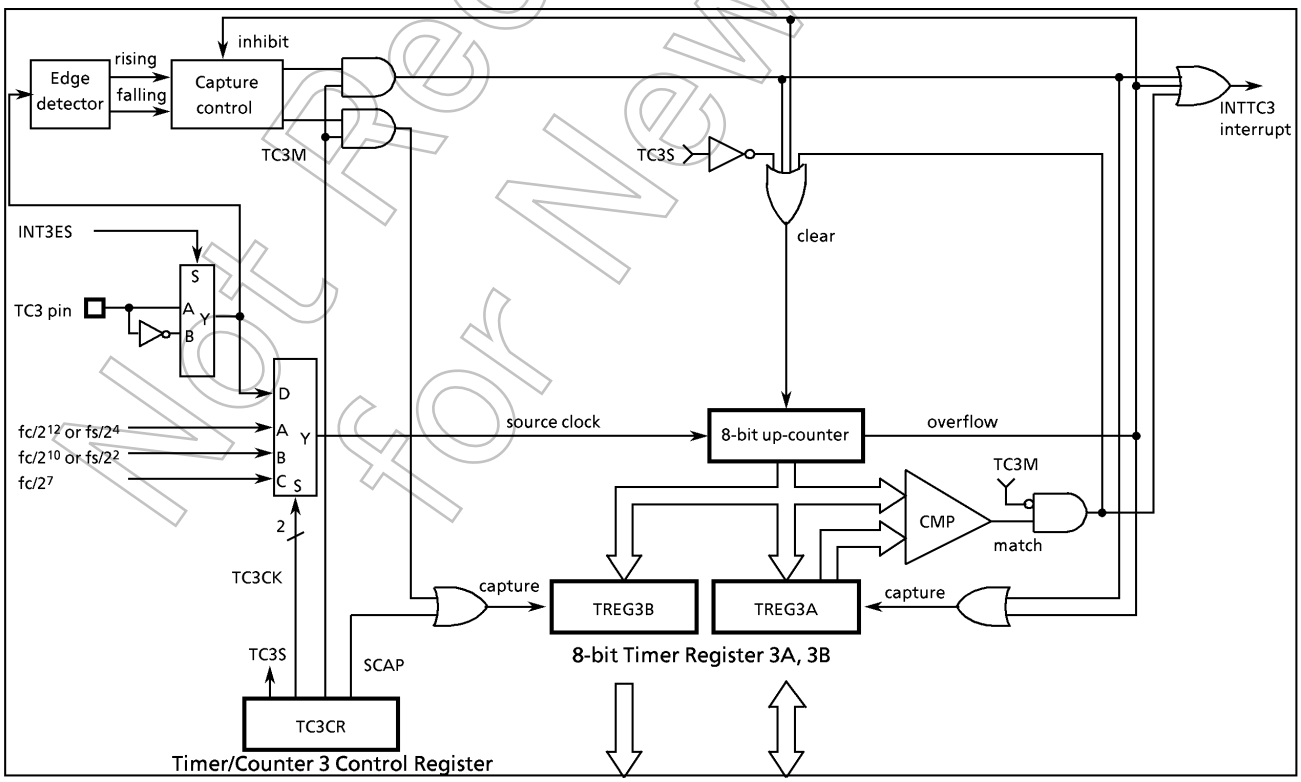


Figure 2-29. Timer/Counter 3

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 — (Initial value : *0*0 00*0)

TC3M	Timer/counter 3 operation mode set	0 : Timer/event counter 1 : Capture	Write only
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 2-30. 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				
DV7CK = 0	DV7CK = 1		At fc = 8 MHz	At fs = 32.768 kHz	At fc = 8 MHz	At fs = 32.768 kHz
$fc/2^{12}$	$fs/2^4$ [Hz]	$fs/2^4$ [Hz]	512 μs	488.28 μs	131.1 ms	124.5 ms
$fc/2^{10}$	$fs/2^2$	–	128 μs	122.07 μs	32.6 ms	31.1 ms
$fc/2^7$	$fc/2^7$	–	16 μs	–	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 fcgck/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, inputing 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.

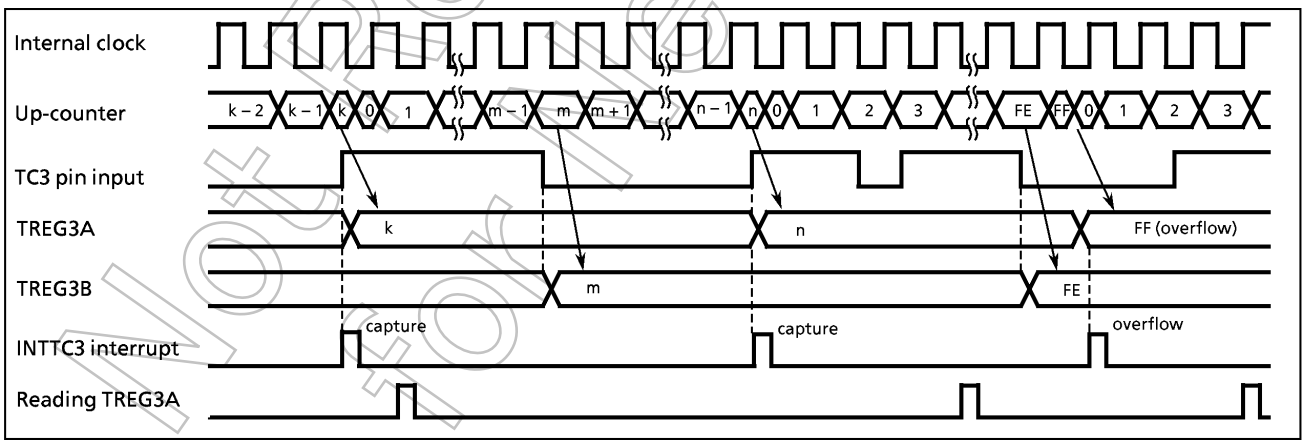


Figure 2-31. Timing Chart for Capture Mode (INT3ES = 0)

2.8 8-bit Timer/Counter 5 (TC5)

2.8.1 Configuration

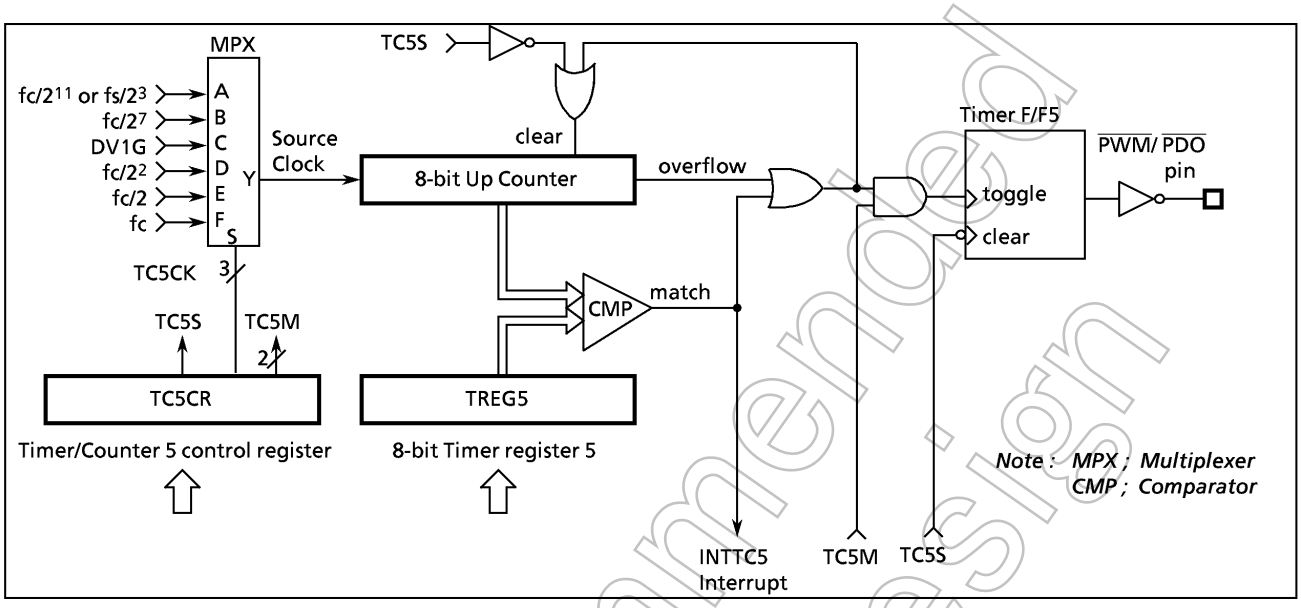


Figure 2-32. Timer/Counter 5 (TC5)

2.8.2 Control

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

TREG5 (001DH)

7	6	5	4	3	2	1	0

(Initial **** ****) Write only

TC5CR (001EH)

7	6	5	4	3	2	1	0
		TC5S	TC5CK			TC5M	

(Initial **00 0000)

TC5M	TC5 Operating mode select	00 : Timer mode 01 : Reserved 10 : Progrmmable divider output (PDO) mode 11 : Pulse width modulation (PWM) output mode	write only
TC5CK	TC5 Source clock select	000 : Reserved 001 : Internal clock fc/2^11 or fs/2^3 [Hz] 010 : Internal clock fc/2^7 011 : Internal clock DV1G (fc/2^4, fc/2^5, fc/2^6) Note 5 100 : Internal clock fc/2^2 101 : Internal clock fc/2 110 : Internal clock fc 111 : Reserved	
TC5S	TC5 Start control	0 : Stop & clear 1 : Start	

*Note 1 : fc ; High-frequency clock [Hz], fs ; Low-frequency clock [Hz], * ; don't care*

Note 2 : There are some restrictions to set a value of the timer register 5.

(a) When in PWM output mode, see an explanation of the pulse mode modification (PWM) output mode.

(b) When in any other mode than PWM output mode, 0<TREG5

Note 3 : Source clock fc/2^2, fc/2, and fc cannot be used except in PWM output mode.

Note 4 : Set the operating mode and the source clock selection when timer/counter stops (TC5S = 0).

Note 5 : The DV1G can be set to either fc/2^4, fc/2^5, fc/2^6 by DVCR of the clock gear control register (CGCR). When DV1G is used, it must be set to fc/2^4, fc/2^5 or fc/2^6 at gear ratio = 1/1, to fc/2^5 or fc/2^6 at gear ratio = 1/2, and to fc/2^6 at gear ratio = 1/4. When it is set to other values or the gear ratio is set to 1/8, DV1G (TC5CK) can not operate correctly.

Figure 2-33. 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	fc = 8 MHz	fs = 32.768 kHz
DV7CK = 0	DV7CK = 1					
$fc / 2^{11}$ [Hz]	$fs / 2^{3}$ [Hz]	$fs/2^{3}$ [Hz]	256 μs	244.14 μs	65.3 ms	62.2 ms
$fc / 2^{7}$	$fc / 2^{7}$	–	16 μs	–	4.1 ms	–
$fc / 2^{6}$	$fc / 2^{6}$	–	8 μs	–	2.0 ms	–
$fc / 2^{5}$	$fc / 2^{5}$	–	4 μs	–	1.0 ms	–
$fc / 2^{4}$	$fc / 2^{4}$	–	2 μs	–	0.5 ms	–

(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 $\overline{PDO}$ (P52) pin. In the case of $\overline{PDO}$ output, beforehand the P52 should be set to the output mode, and the P52 output latch should be set to "1". This mode can be used for 50% duty pulse output. INTTC5 interrupt is generated each time the $\overline{PDO}$ output is toggled.

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

```
SET   (P5).2              ;  P52 output latch←1
LD    (P5CR1), 00000100B
LD    (TC5CR), 00001010B  ;  Sets to TC5 modes and source clock
LD    (TREG5), 10H        ;  (1/1024 ÷ 2^7/fc) ÷ 2 = 10H
LD    (TC5CR), 00101010B  ;  Starts TC5
```

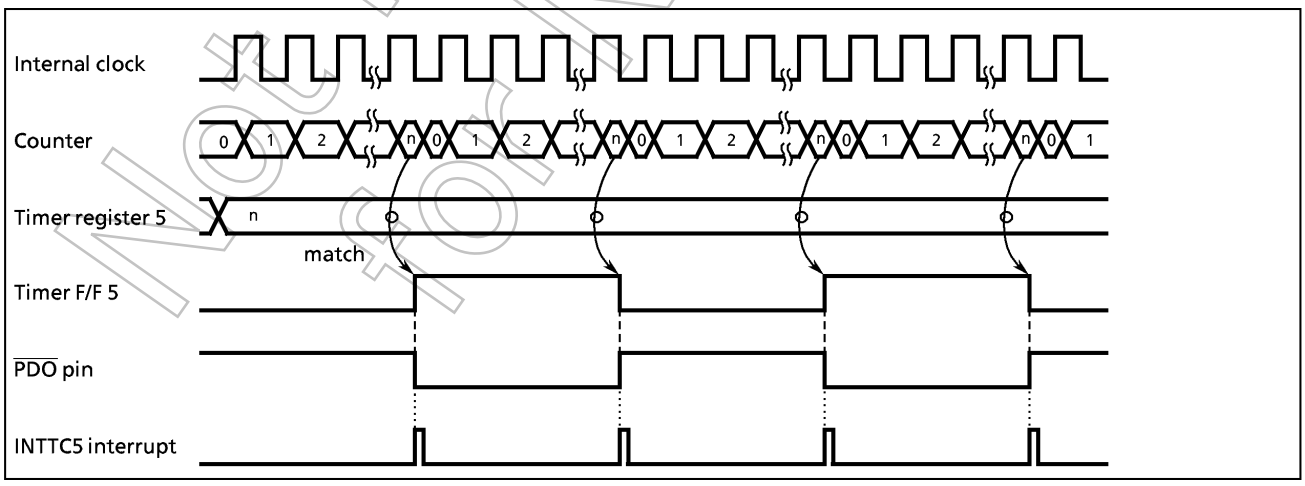


Figure 2-34. PDO Mode Timing Chart

(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 $\overline{PWM}$ (P52) pin. In the case of $\overline{PWM}$ output, beforehand the P52 should be set to the output mode, and the P52 output latch should be set to "1". 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 1 : PWM output mode can be used in only NORMAL1/2 or IDLE1/2 mode.
Note 2 : Do not overwrite TREG5 only when an INTTC5 interrupt is generated. Usually, TREG5 is overwritten in the routine of INTTC5 interrupt service.

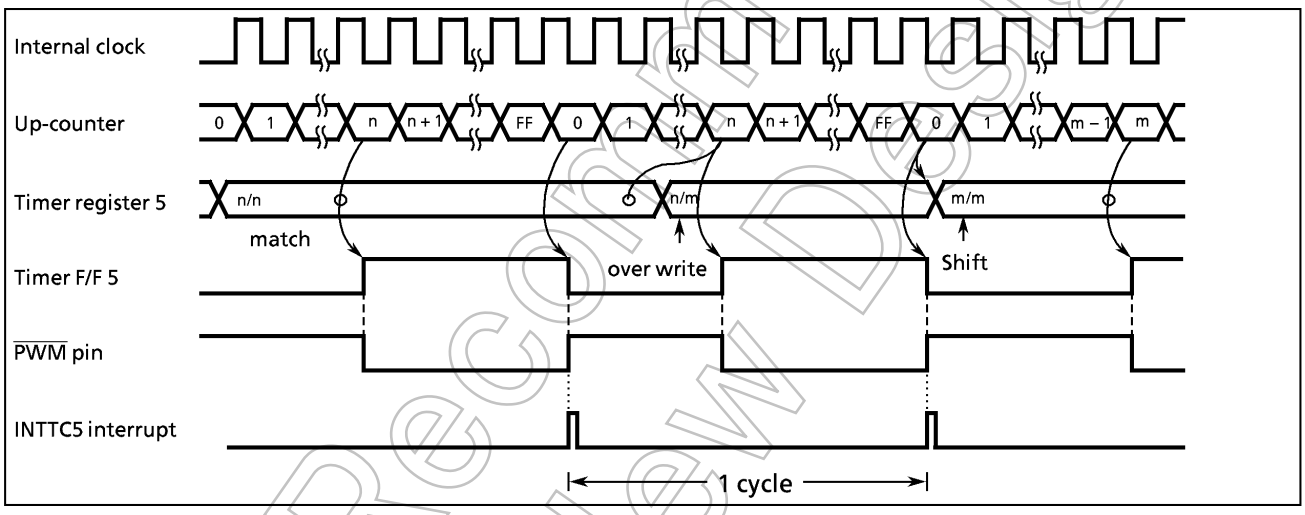


Figure 2-35. PWM Output Mode Timing Chart

Table 2-7. TREG5 minimum / maximum value setting

gear ratio	1/1		1/2		1/4		1/8	
	min	max	min	max	min	max	min	max
$fc/2^2$	3	253	4	252	6	250	10	246
fc/2	4	252	6	250	10	246	18	238
fc	6	250	10	246	18	238	34	222

PWM output

Source clock	fc = 3.58 MHz		fc = 3.84 MHz		fc = 4.00 MHz		fc = 4.19 MHz		fc = 8.00 MHz	
	Resolution	Repeat cycle	Resolution	Repeat cycle	Resolution	Repeat cycle	Resolution	Repeat cycle	Resolution	Repeat cycle
$fc/2^2$	1117.32 ns	286.03 μs	1041.67 ns	266.67 μs	1000.00 ns	256.00 μs	954.65 ns	244.39 μs	500.00 ns	128.00 μs
fc/2	558.66 ns	143.02 μs	520.83 ns	133.33 μs	500.00 ns	128.00 μs	477.33 ns	122.20 μs	250.00 ns	64.00 μs
fc	279.33 ns	71.51 μs	260.42 ns	66.67 μs	250.00 ns	64.00 μs	238.66 ns	61.10 μs	125.00 ns	32.00 μs

2.9 Serial Interface (SIO)

The 87CM53 has one clocked-synchronous 8-bit serial interface. Serial interface have 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 P45 (SO), P44 (SI), P43 ($\overline{SCK}$). The serial interface pins are also used as port P4. When used as input pins, the input pins should be set to the input mode. When used as output pins, beforehand the output pins should be set to the output mode, and output latch should be set to "1". In the transmit mode, pin P44 can be used as normal I/O port, and in the receive mode, the pin P45 can be used as normal I/O ports.

2.9.1 Configuration

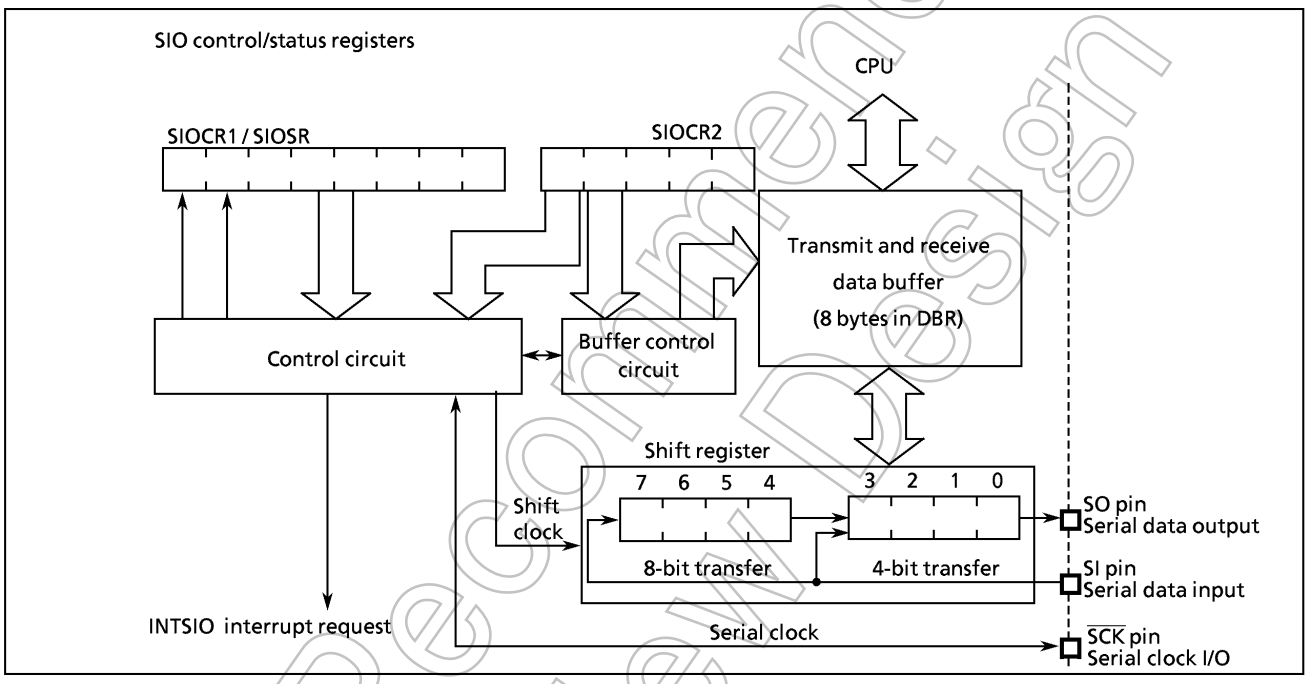


Figure 2-36. Serial Interfaces

2.9.2 Control

The serial interfaces are controlled by SIO control registers (SIOCR1/SIOCR2). The serial interface status can be determined by reading SIO status register (SIOSR).

The transmit and receive data buffer is controlled by the BUF (bits 2-0 in SIOCR2). The data buffer is assigned to address $0FF0_H$ - $0FF7_H$ for SIO 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 (INTSIO) 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 SIOCR2).

SIO Control Registers 1

SIOCR1 (0020_H)

7	6	5	4	3	2	1	0
SIOS	SIO INH	SIOM			SCK		

(Initial value : 0000 0000)

SIOS	Indicate transfer start/stop	0 : Stop 1 : Start	write only
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 101 : 8-bit receive mode 110 : 4-bit receive mode	
SCK	Serial clock select	000 : Internal clock fc / 2^{13} or fs / 2^5 [Hz] 001 : Internal clock fc / 2^8 010 : Internal clock DV3G ÷ 2 (fc/2^5 ÷ 2, fc/2^6 ÷ 2) Note 4 011 : Internal clock DV2G ÷ 2 (fc/2^4 ÷ 2, fc/2^5 ÷ 2, fc/2^6 ÷ 2) Note 4 111 : External clock (input from $\overline{SCK}$ pin) (Output on $\overline{SCK}$ 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 : SIOCR1 is write-only registers, which cannot access any of in read-modify-write instruction such as bit operate, etc.

Note 4 : The DV2G can be set to either fc/2^4, fc/2^5 or fc/2^6, and the DV3G can be set to either fc/2^5 or fc/2^6 by the DVCR of the clock gear control register (CGCR). When the DV2G and DV3G are used, they must be set to fc/2^4, fc/2^5 or fc/2^6 at the gear ratio = 1/1, to fc/2^5 or fc/2^6 at the gear ratio = 1/2, and to fc/2^6 at the gear ratio = 1/4. When they are set to other values or the gear ratio is set to 1/8, DV2G ÷ 2 and DV3G ÷ 2 (SCK = 011, 010) can not operate correctly.

SIO Status Registers

SIOSR (0020_H)

7	6	5	4	3	2	1	0
SIOF	SEF	"1"	"1"	"1"	"1"	"1"	"1"

(Initial value: 0011 1111)

SIOF	Serial transfer operating status monitor	0 : Transfer terminated 1 : Transfer in process (After SIOS is cleared to "0", SIOF is cleared to "0" at the termination of transfer or setting of SIOINH.)	read only
SEF	Shift operating status monitor	0 : Shift operation terminated 1 : Shift operation in process	

SIO Control Registers 2

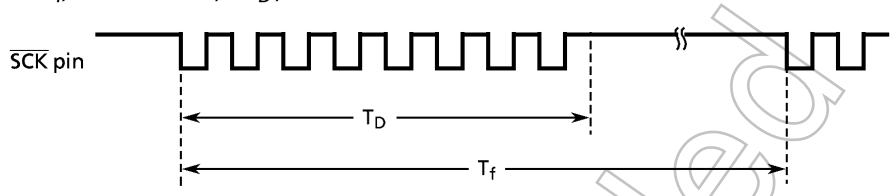
SIOCR2 (0021_H)

7	6	5	4	3	2	1	0
			WAIT		BUF		

(Initial value: ***0 0000)

WAIT	Wait control	Always sets "00" except 8-bit transmit/receive mode. 00 : $T_f = T_D$ (non-wait) 01 : $T_f = 2T_D$ 10 : $T_f = 4T_D$ 11 : $T_f = 8T_D$ (wait)	Write only
BUF	Number of transfer words	Buffer address used SIO 000 : 1 word transfer 0FF0$_H$ 001 : 2 words transfer 0FF0 - 0FF1$_H$ 010 : 3 words transfer 0FF0 - 0FF2$_H$ 011 : 4 words transfer 0FF0 - 0FF3$_H$ 100 : 5 words transfer 0FF0 - 0FF4$_H$ 101 : 6 words transfer 0FF0 - 0FF5$_H$ 110 : 7 words transfer 0FF0 - 0FF6$_H$ 111 : 8 words transfer 0FF0 - 0FF7$_H$	

Note 1 : T_f; frame time, T_D ; data transfer time



Note 2 : The lower 4 bits of each buffer are used during 4-bit transfers. Zeros (0) are stored to the upper 4bits when receiving.

Note 3 : Transmitting starts at the lowest address. Received data are also stored starting from the lowest address to the highest address. For example, in the case of SIO, the first buffer address transmitted is $0FF0_H$.

Note 4 : The value to be loaded to BUF is held after transfer is completed.

Note 5 : SIOCR2 must be set when the serial interface is stopped (SIOF = 0).

Note 6 : SIOCR2 are write-only registers, which cannot access any of in read-modify-write instruction such as bit operate, etc.

*Note 7 : *; don't care*

Figure 2-37. SIO Control Registers and Status Registers

(1) Serial Clock

a. Clock Source

SCK (bits 2 - 0 in SIOCR) 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 $\overline{SCK}$ pin. The $\overline{SCK}$ 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			Transfer rate					
NORMAL1/2, IDLE1/2 mode		SLOW, SLEEP mode						
DV7CK = 0	DV7CK = 1		fc = 8.00 MHz	fc = 4.19 MHz	fc = 4.00 MHz	fc = 3.84 MHz	fc = 358 MHz	fs = 32.768MHz
$fc/2^{13}$ [Hz]	$fs/2^5$ [Hz]	$fs/2^5$ [Hz]	0.95 Kbit/s	0.50 Kbit/s	0.48 Kbit/s	0.46 Kbit/s	0.43 Kbit/s	1 Kbit/s
$fc/2^8$	$fc/2^8$	——	30.52 Kbit/s	15.98 Kbit/s	15.26 Kbit/s	14.65 Kbit/s	13.66 Kbit/s	——
$fc/2^7$	$fc/2^7$	——	61.04 Kbit/s	31.97 Kbit/s	30.52 Kbit/s	29.30 Kbit/s	27.31 Kbit/s	——
$fc/2^6$	$fc/2^6$	——	122.07 Kbit/s	63.93 Kbit/s	61.04 Kbit/s	58.59 Kbit/s	54.63 Kbit/s	——
$fc/2^5$	$fc/2^5$	——	244.14 Kbit/s	127.87 Kbit/s	122.07 Kbit/s	117.19 Kbit/s	109.25 Kbit/s	——

Note : 1 Kbit = 1024 bit

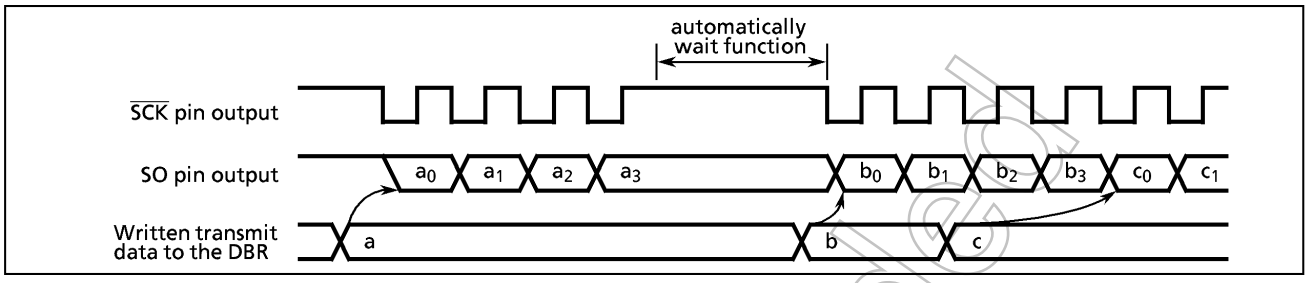
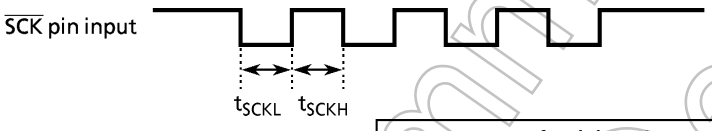


Figure 2-38. Clock Source (Internal Clock)

② External Clock

An external clock connected to the SCK pin is used as the serial clock. In this case, the P43 (SCK) must be set to the input mode. To ensure shifting, a pulse width of at least 4 machine cycles is required. This pulse is needed for the shift operation to execute certainly. Actually, there is necessary processing time for interrupting, writing, and reading. The minimum pulse is determined by setting the mode and the program.



Note : tcyc = 4/fcgck (In NORAML1/2, IDLE1/2 modes)
4/fs (In SLOW, SLEEP modes)

b. Shift edge

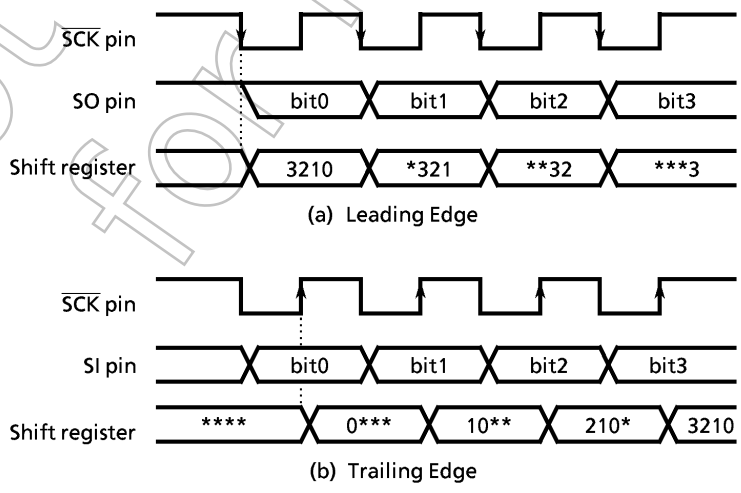
The leading edge is used to transmit, and the trailing edge is used to receive.

① Leading Edge

Transmitted data are shifted on the leading edge of the serial clock (falling edge of the SCK pin input/output).

② Trailing Edge

Received data are shifted on the trailing edge of the serial clock (rising edge of the SCK pin input/output).



*Note : * ; don't care*

Figure 2-39. 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.

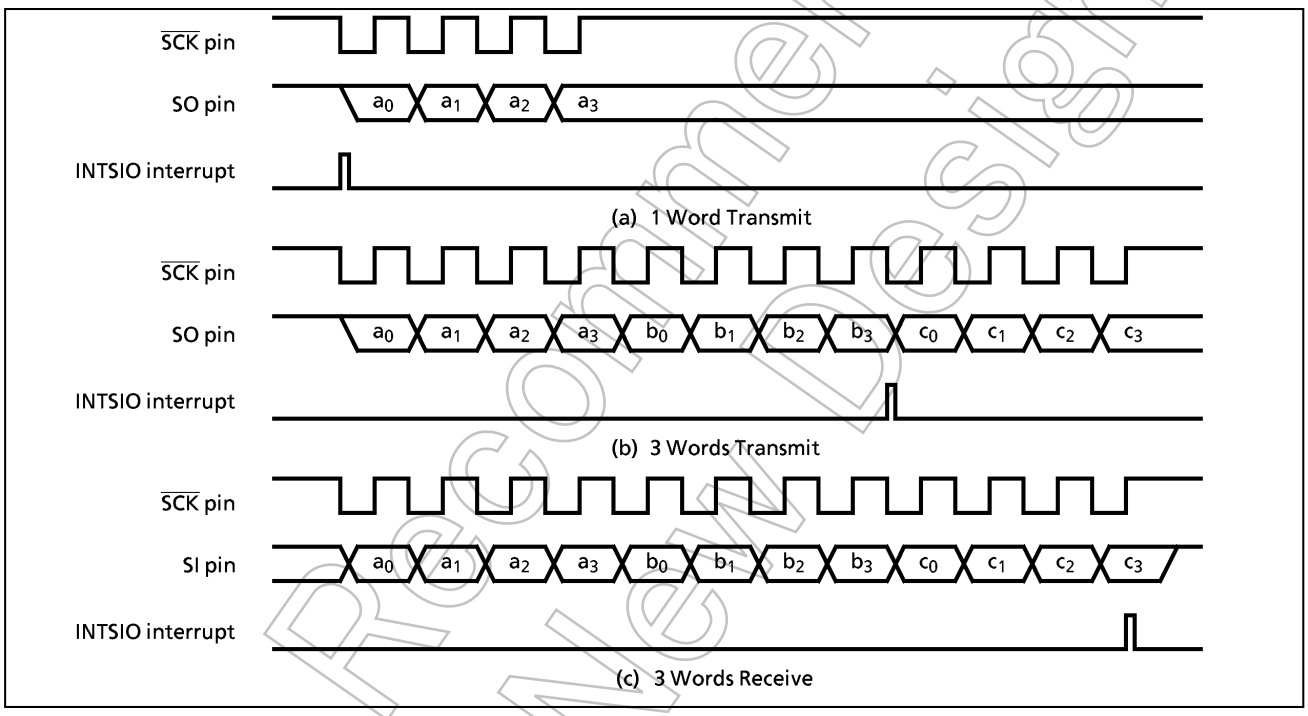


Figure 2-40. Number of Bits to Transfer (Example : 4-bit serial transfer)

2.9.3 Transfer Mode

SIOM (bits 5 - 3 in SIOCR1) is used to select the transmit, receive, or transmit/receive mode.

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

In these modes, the SIOCR1 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.

When the transmit is started, after the SIOF goes "high" output from the S0 pin holds final bit of the last data until falling edge of the $\overline{SCK}$.

The transmission is ended by clearing SIOS to "0" or setting 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 SIOSR) 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".

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

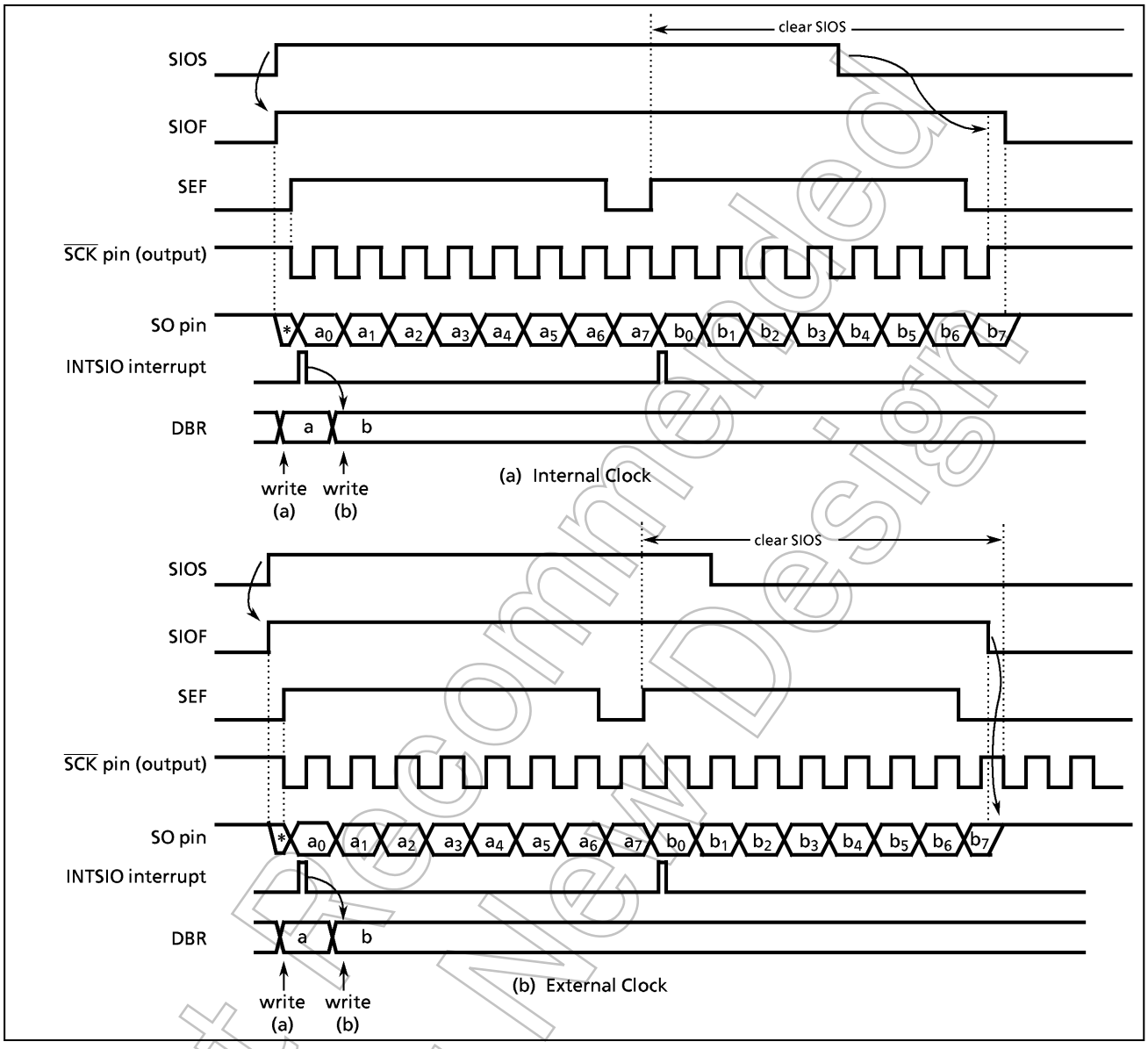


Figure 2-41. Transfer Mode (Example: 8-bit, 1 Word Transfer)

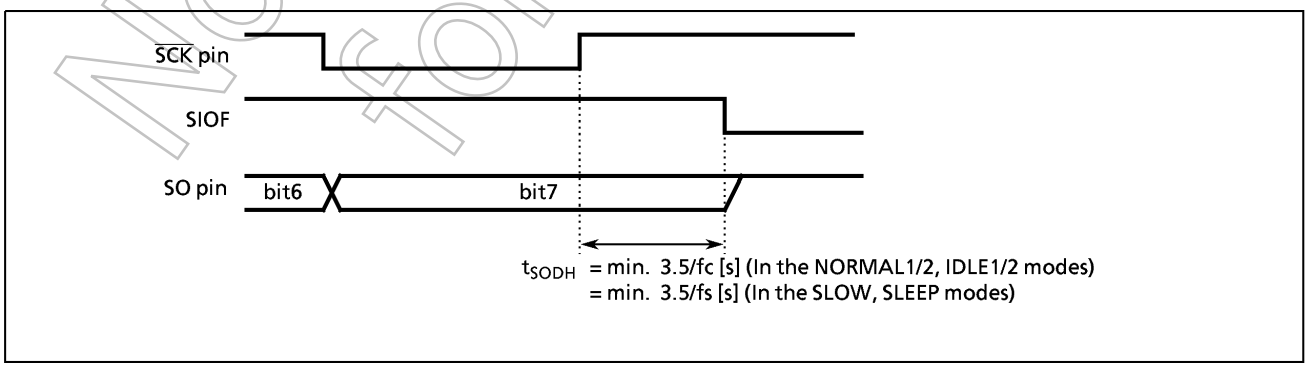


Figure 2-42. Transmitted Data Hold Time at End of Transmit

(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.

The receiving is ended by clearing SIOS to "0" or setting SIOINH to "1" in buffer full interrupt service program. When SIOINH is set, the receiving is immediately ended and SIOF is cleared to "0". When SIOS is cleared, the current data are transferred to the buffer. After SIOS cleaned, 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 SIOSR). SIOF is cleared to "0" when the transmission is ended.

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 data receive, 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.

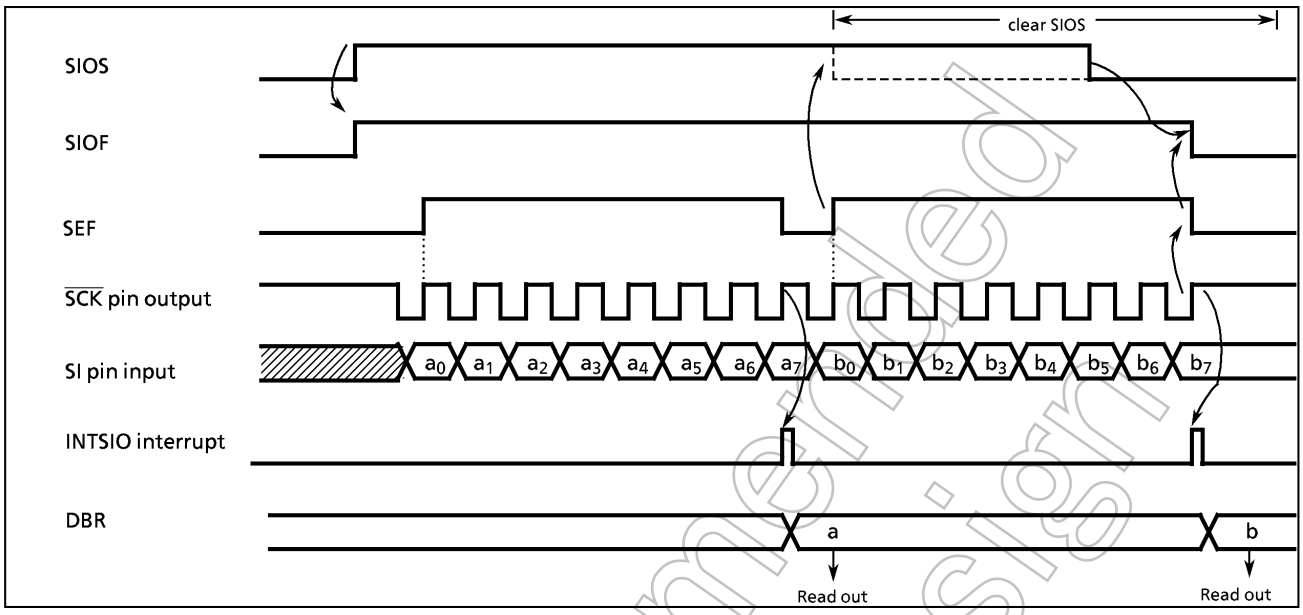


Figure 2-43. Receive Mode (Example : 8-bit, 1 word, internal clock)

(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 : The wait is also canceled by writing to a DBR not being used as a transmit data buffer registers; 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, 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.

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 $\overline{SCK}$.

Clear SIOS to "0" to SIOINH to "1" in INTSIO interrupt service program to end transmit/receive mode.

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 SIOSR). 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 confirmed that SIOF clearing to "0". The number of words can be changed during automatic-wait operation of an internal clock. In this case, BUF must be rewritten before the final transmitted/received data is read out.
When SIOINH is set, the transmit/receive operation is immediately ended and SIOF is cleared 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.*

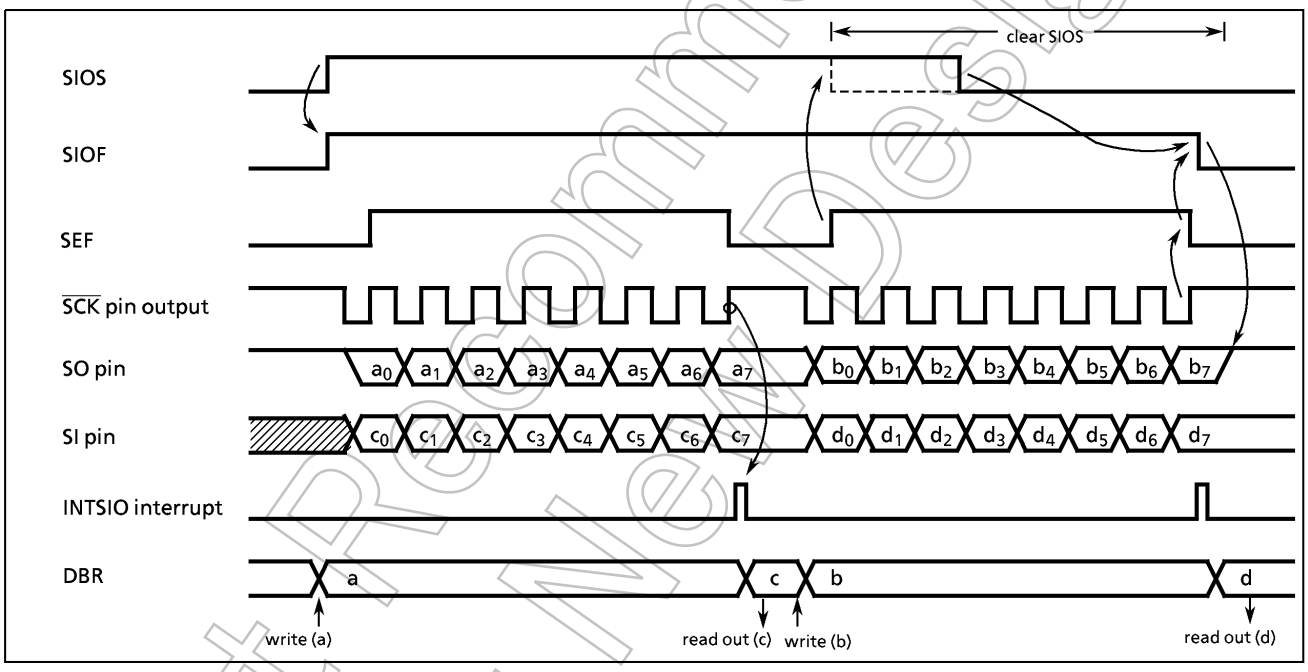


Figure 2-44. Transmit/Receive Mode (Example : 8-bit, 1word, internal clock)

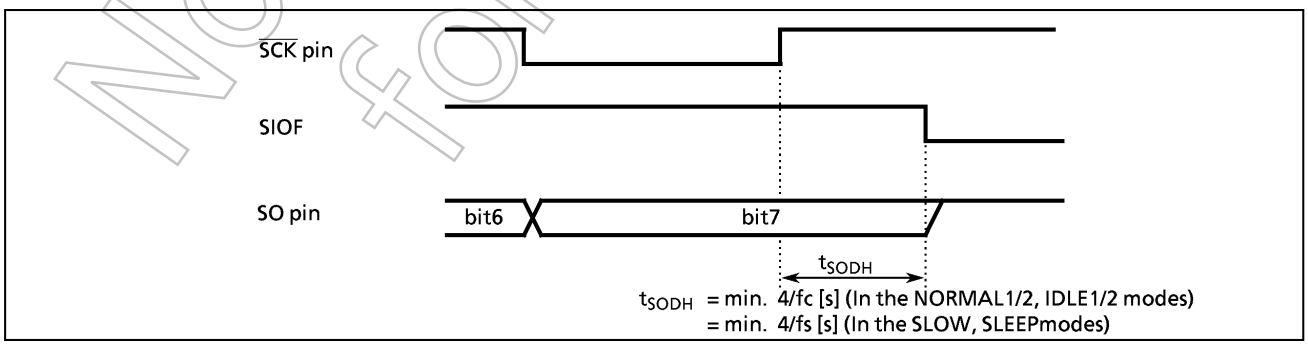


Figure 2-45. Transmitted Data Hold Time at End of Transmit/Receive

2.10 UART (Asynchronous serial interface)

The 87CM53 has 1 channel of UART (asynchronous serial interface) .

The UART is connected to external devices via RxD and TxD. RxD is also used as P40 ; TxD, as P41. When used as RxD pin, P40 should be set to the input mode. When used as TxD pin, beforehand P41 should be set to the output mode and the output latch should be set to "1".

2.10.1 Configuration

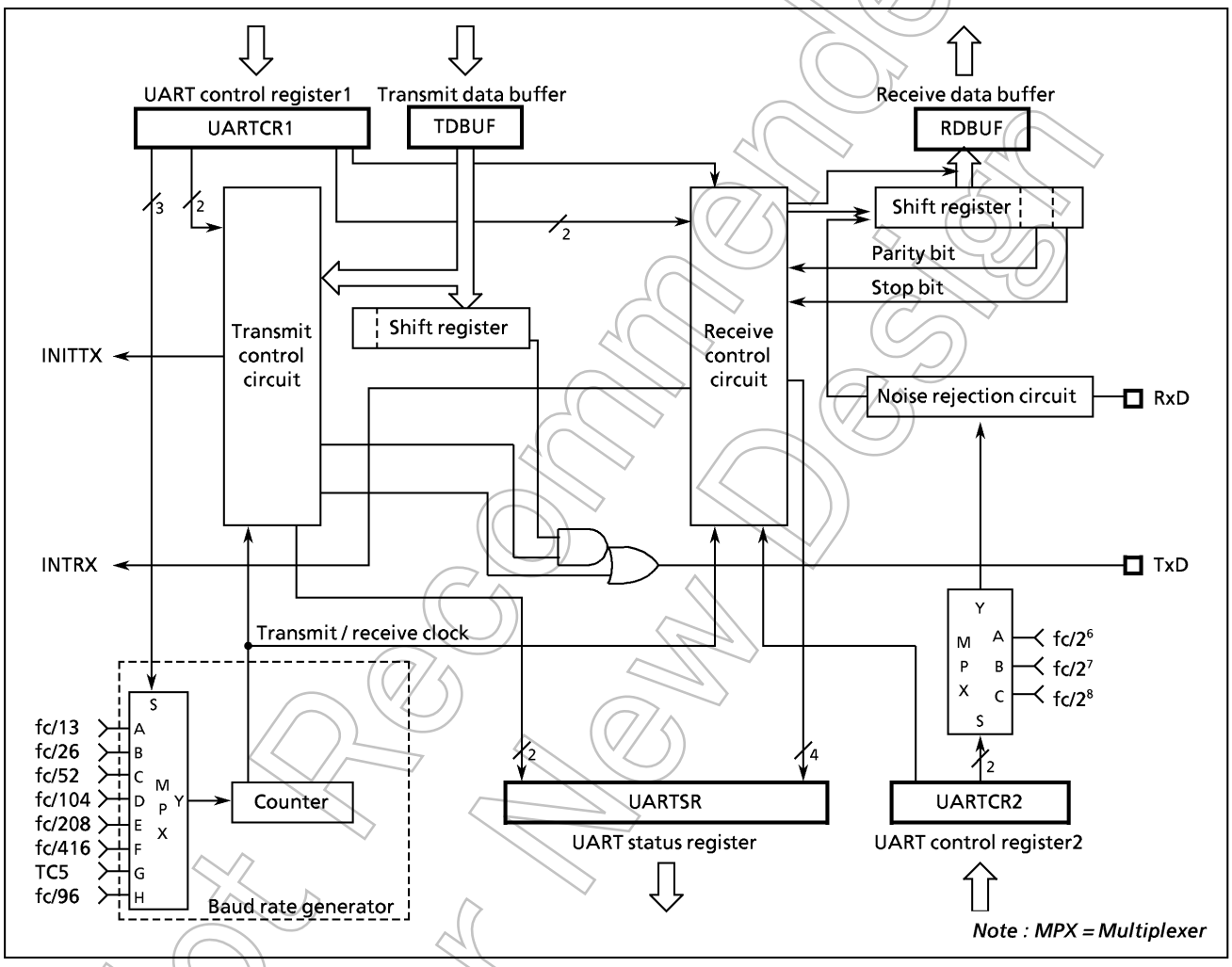


Figure 2-46. UART

2.10.2 Control

UART is controlled by the UART control registers (UARTCR1, UARTCR2). The operating status can be monitored using the UART status register (UARTSR).

UART control register

UARTCR1 (0022_H)

7	6	5	4	3	2	1	0
TXE	RXE	STBT	EVEN	PE	BRG		

(Initial value 0000 0000)

BRG	Transmit clock select	000 : fc / 13 [Hz] 001 : fc / 26 010 : fc / 52 011 : fc / 104 100 : fc / 208 101 : fc / 416 110 : INTTC5 (INT5 interrupt request) 111 : f c / 96	write only
PE	Parity addition	0 : No parity 1 : Parity	
EVEN	Even-numbered parity	0 : Odd-numbered parity 1 : Even-numbered parity	
STBT	Transmit stop bit length	0 : 1 bit 1 : 2 bit	
RXE	Receive operation	0 : Disable 1 : Enable	
TXE	Transfer operation	0 : Disable 1 : Enable	

Note 1 : When operations are disabled by setting TXE and RXE bit to "0", the setting becomes valid when data transmit or receive complete. When the transmit data is stored in the transmit data buffer, the data are not transmitted. Even if data transmit is enabled, until new data are written to the transmit data buffer, the current data are not transmitted.

Note 2 : The transmit clock and the parity are common to transmit and receive.

Note 3 : UARTCR1 is a write-only register; therefore, it cannot be operated with read modify commands (SET, CLR and other bit operation commands; AND, OR and other multiplication commands).

UARTCR2 (0023_H)

7	6	5	4	3	2	1	0
					RXDNC		STOPBR

(Initial value **** *000)

STOPBR	Receive stop bit length	0 : 1 bit 1 : 2 bit	write only
RxDNC	Selection of RxD input noise rejection time	00 : No noise rejection (hysteresis input) 01 : Rejects pulses shorter than 31 / fcgck [s] as noise 10 : Rejects pulses shorter than 63 / fcgck [s] as noise 11 : Rejects pulses shorter than 127 / fcgck [s] as noise	

Note 4 : When RxDNC = 01, pulses longer than 96/fcgck [s] are always regarded as signals ; when RxDNC = 10, longer than 192/fcgck [s] ; and when RxDNC = 11, longer than 384/fcgck [s]

Note 5 : UARTCR1 is a write-only register; therefore, it cannot be operated with read modify commands (SET, CLR and other bit operation commands; AND, OR and other multiplication commands).

Figure 2-47. UART control register

UARTSR (0022_H)

7	6	5	4	3	2	1	0
PERR	FERR	OERR	RBFL	TEND	TBEP	"1"	"1"

(Initial value 0000 1111)

TBEP	Transmit data buffer empty flag	0 : – 1 : Transmit data buffer empty	read only
TEND	Transmit end flag	0 : Transmitting 1 : Transmit end	
RBFL	Receive data buffer full flag	0 : – 1 : Receive data buffer full	
OERR	Overrun error flag	0 : No overrun error 1 : Overrun error	
FERR	Framing error flag	0 : No framing error 1 : Framing error	
PERR	Parity error flag	0 : No parity error 1 : Parity error	

UART receive data buffer (Initial value 0000 0000) read only

RDBUF (0024_H)

7	6	5	4	3	2	1	0

UART transmit data buffer (Initial value 0000 0000) write only

TDBUF (0024_H)

7	6	5	4	3	2	1	0

Note : TDBUF is a write-only resistor; therefore, it cannot be operated with read modify commands (SET, CLR and other bit operation commands; AND, OR and other multiplication commands).

Figure 2-48. UART Status Register and Data Buffer Registers

2.10.3 Transfer Data Format

In UART, a one-bit start bit (low level) , stop bit (bit length selectable at high level, by STBT), and parity (select parity in PE ; even-or odd-numbered parity by EVEN) are added to the transfer data. The transfer data formats are shown as follow.

Table 2-9.

PE	STBT	Frame length: 1 2 3 ------- 8 9 10 11 12
0	0	Start bit0 bit1 ----- bit6 bit7 Stop1
0	1	Start bit0 bit1 ----- bit6 bit7 Stop1 Stop2
1	0	Start bit0 bit1 ----- bit6 bit7 Parity Stop1
1	1	Start bit0 bit1 ----- bit6 bit7 Parity Stop1 Stop2

2.10.4 Transfer Rate

The baud rate of UART is set of BRG (bit 0, 1, and 2 in UARTCR1) . The example of the baud rate shown as follows.

Table 2-10.

BRG	Sourse clock	
	8 MHz	4 MHz
000	38400 [baud]	19200 [baud]
001	19200	9600
010	9600	4800
011	4800	2400
100	2400	1200
101	1200	600

$$\text{Transfer rate} = \frac{\text{Transfer clock}}{16}$$

When TC5 is used as the UART transfer rate (when BRG = 110), the transfer clock and transfer rate are detarmined as follows :

$$\text{Transfer rate} = \frac{\text{Transfer clock}}{16} \qquad \text{Transfer clock} = \text{interrupt cycle} = \frac{\text{TC5 source clock}}{\text{TREG5 set value}}$$

Note : When INTTC5 interrupt of the TC5 is used as the transfer clock, use it on the conditions that the INTTC5 operates correctly.
It is recommended to use the TC5 in the timer mode.

2.10.5 Data Sampling

The UART receiver keeps sampling input using the clock selected by BRG (bit 0, 1, and 2 in UARTCR1) until a start bit is detected in RxD pin input. RT clock starts at the falling edge of the RxD pin. Once a start bit is detected, the start bit, data bits, stop bit(s), and parity bit are sampled at three times of RT7, RT8, and RT9 during one receiver clock interval (RT clock). (RT0 is the position where the bit supposedly starts) . Bit is determined according to majority rule (the data are the same twice or more out of three samplings) .

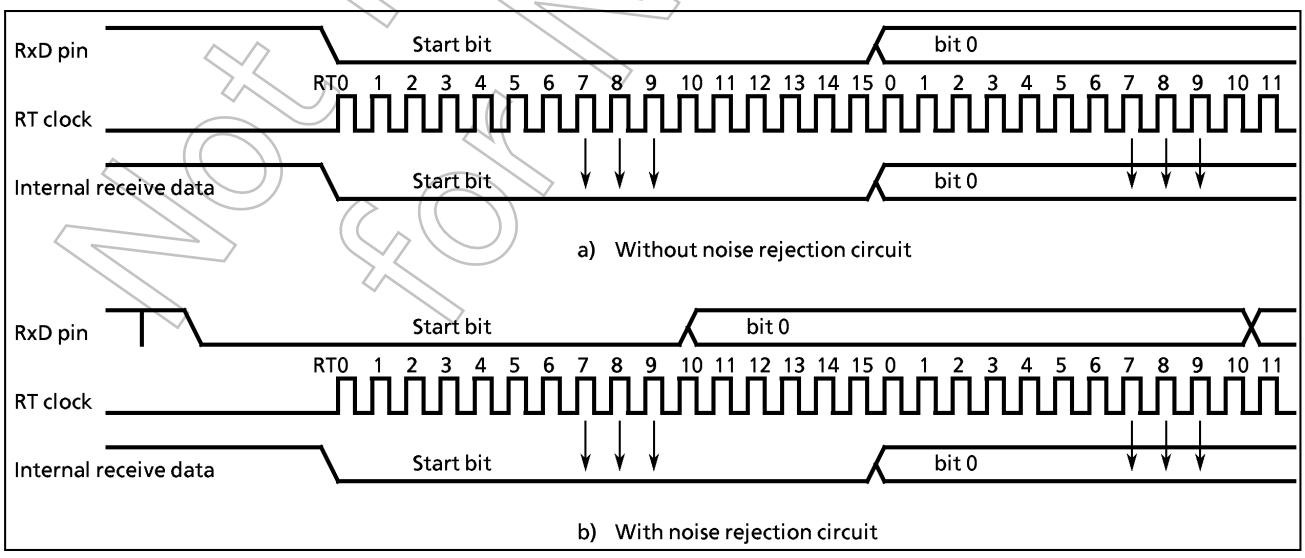


Figure 2-49. Data Samping

2.10.6 STOP Bit Length

Select a transmit stop bit length (1 or 2 bits) by STBT (bit5 in UARTCR1)

2.10.7 Parity

Set parity/no parity by PE ; set parity type (odd-or even-numbered) by EVEN (bit 4 in UARTCR1).

2.10.8 Transmit / Receive

(1) Data transmit

Set TXE (bit 7 in UARTCR1) to 1. Read UARTSR to check TBEP = 1, then write data in TDBUF (transmit data buffer). Writing data in TDBUF zero-clears TBEP, transfers the data to the transmit shift register and the data are sequentially output from the TxD pin. The data output include a one-bit start bit, stop bits whose number is specified in STBT (bit 5 in UARTCR1) and a parity bit if parity addition is specified. Select the data transfer baud rate using bits 0 to 2 in UARTCR1. When data transmit starts, transmit buffer empty flag TBEP is zero-cleared and an INTTX interrupt is generated.

When transmitting data, first read UARTSR, then write data in TDBUF. Otherwise, TBEP is not zero-cleared and transmit does not start.

(2) Data receive

Set RXE (bit 6 in UARTCR1) to 1. When data are received via the RxD pin, the receive data are transferred to RDBUF (receive data buffer). At this time, the data transmitted include a start bit and stop bit(s) and a parity bit if parity addition is specified. When stop bit(s) are received, data only are extracted and transferred to RDBUF (receive data buffer). Then the receive buffer full flag RBFL is set and an INTRX interrupt is generated. Select the data transfer baud rate using bits 0 to 2 in UARTCR1.

If an overrun error (OERR) occurs when data are received, the data are not transferred to RDBUF (receive data buffer) but discarded; data in the RDBUF are not affected.

2.10.9 Status Flag / Interrupt Signal

(1) Parity error

When parity determined using the receive data bits differs from the received parity bit, the parity error flag PERR is set in UARTSR. Reading UARTSR then RDBUF clears PERR.

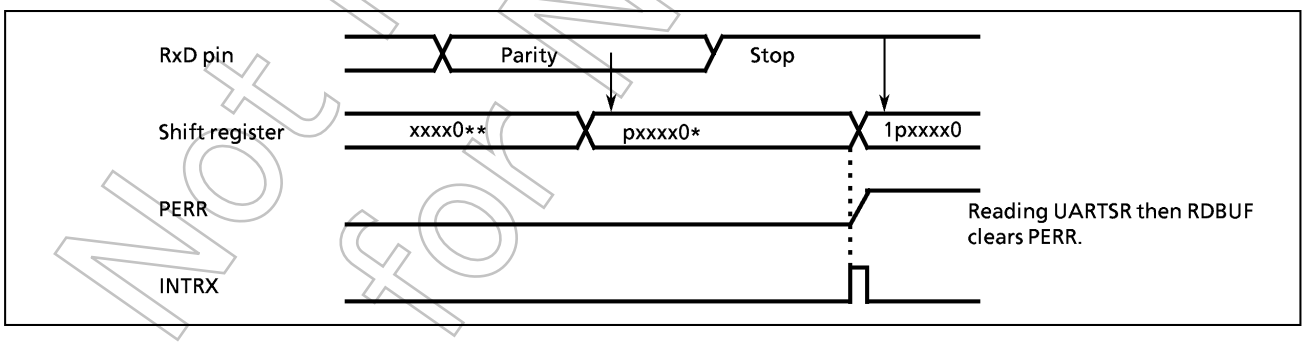


Figure 2-50. Generation of Parity Error

(2) Framing error

When 0 is sampled as the stop bit in the receive data, framing error flag FERR is set. Reading UARTSR then RDBUF clears FERR.

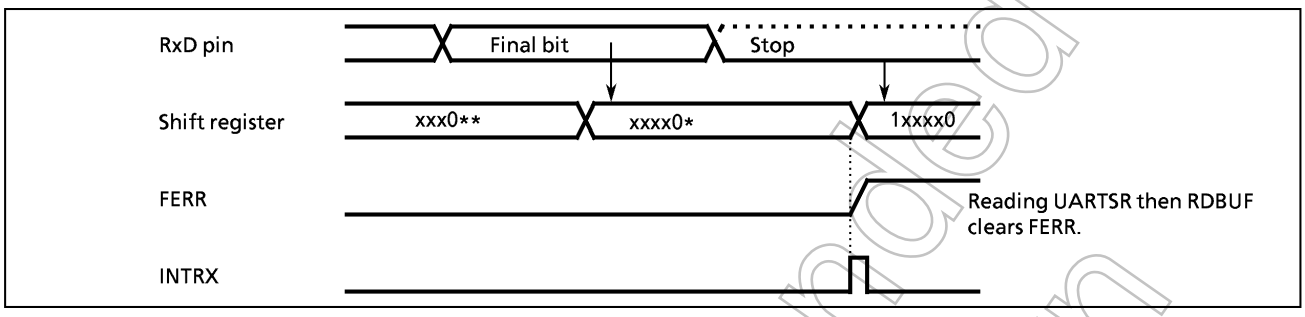


Figure 2-51. Generation of Framing Error

(3) Overrun error

When all bits in the next data are received while unread data are still in RDBUF, overrun error flag OERR is set. In this case, the receive data is discarded ; data in RDBUF are not affected. Reading UARTSR then RDBUF clears OERR.

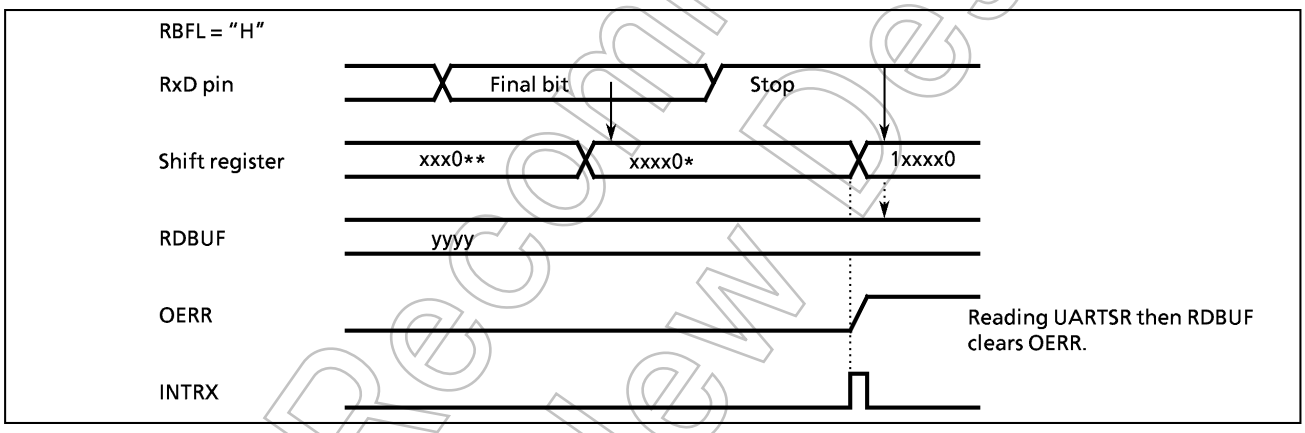


Figure 2-52. Generation of Overrun Error

(4) Receive data buffer full

Loading the received data in RDBUF sets receive data buffer full flag RBFL. Reading UARTSR then RDBUF clears the RBFL.

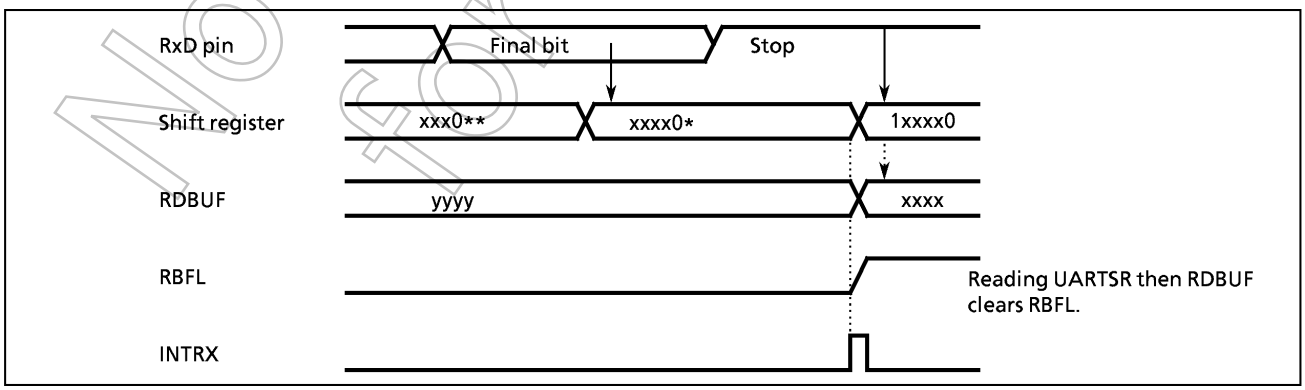


Figure 2-53. Generation of Receive Buffer Full

(5) Transmit data buffer empty

When no data is in the transmit buffer TDBUF, TBEP is set, that is, when data in TDBUF are transferred to the transmit shift register and data transmit starts, transmit data buffer empty flag TBEP is set. Reading UARTSR then writing the data to TDBUF clears TBEP.

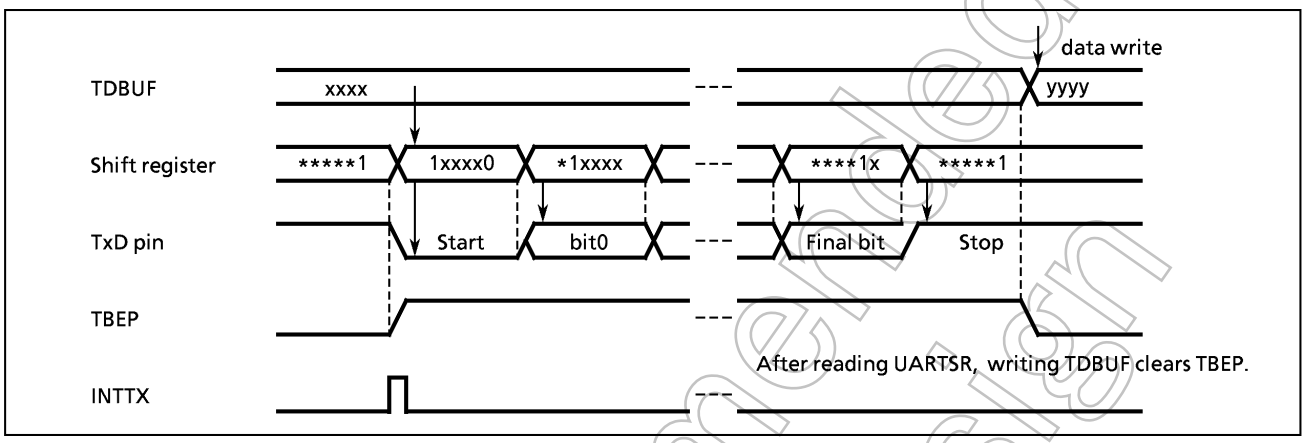


Figure 2-54. Generation of Transmit Buffer Empty

(6) Transmit end flag

When data are transmitted and no data is in TDBUF (TBEP = 1), transmit end flag TEND is set. Writing data to TDBUF then staring data transmit clears TEND.

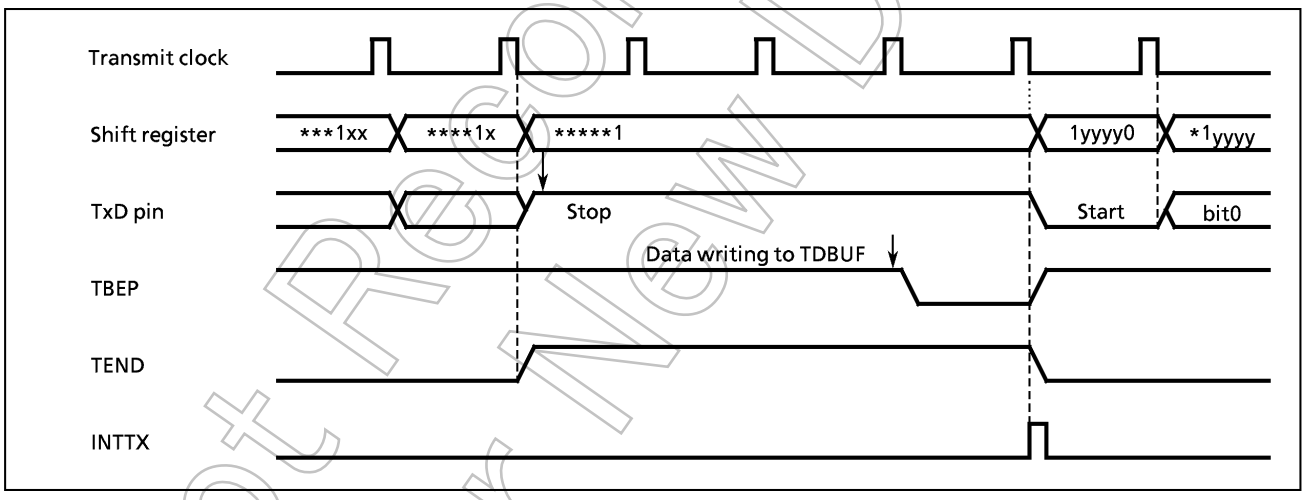


Figure 2-55. Generation of Transmit Buffer Empty

2.11 Tone Generator

TMP87CM53 incorporates a Dual Tone Multi Frequency (DTMF) generator, which generates dial tone signals for the tone dialing system, and a melody generator, which generates melody frequencies. The tone dial signal is one of 16 types of DTMF synthetic waves obtained by overlapping selected sine waves, one from the low-frequency group consisting of four frequencies, and one from the high-frequency group consisting of four frequencies.

(DTMF ; Dual Tone Multi Frequency)

2.11.1 Configuration of Tone Generator

Figure 2-56 shows the configuration of the DTMF generator and melody generator. The tone generator consists of a frequency/deviation frequency divider which generates the DTMF/melody basic clock (dtgck) from fc, programmable dividers (ROW/COLUMN) which generate tone ROW/COLUMN frequency from dtgck, sine wave synthesizers, an adder (TONE) which adds and outputs ROW/COLUMN sine waves, a programmable divider which generates melody frequencies from dtgck, a sine wave synthesizer (compatible with COLUMN), an amp (MELODY1) which outputs melody sine waves, and a melody square wave output device (MELODY2).

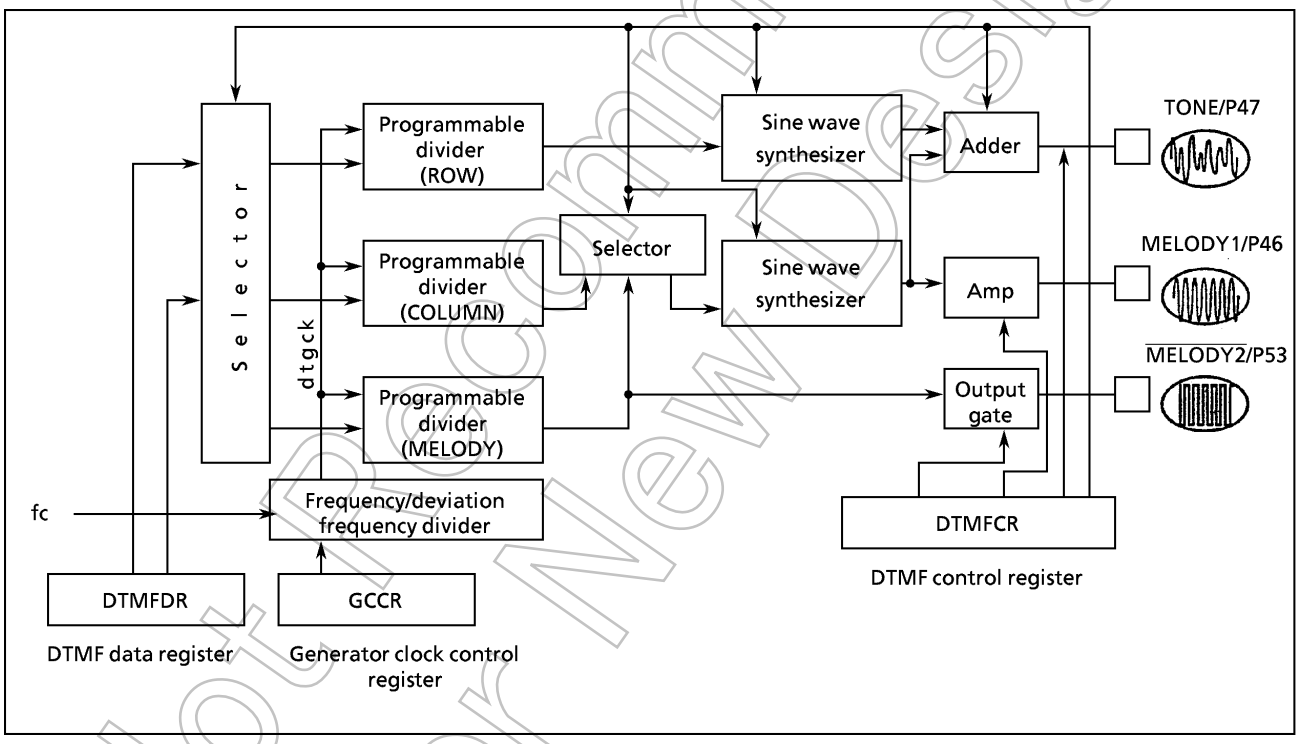


Figure 2-56. Configuration of Tone Generator

2.11.2 Tone Control

(1) DTMF Basic clock control

DTMF is based on a 480kHz basic tone clock (dtgck) ; therefore, GCSEL needs to be set with the generator clock register (GCCR) so that dtgck is at 480kHz. The melody is based on 960kHz; therefore, when MOLODY mode is selected, dtgck is automatically set to 960kHz. Do not change the setting values once they are programmed.

Note 1 : GCCR is a write-only register; therefore, it cannot be operated with read modify commands (SET, CLR and other bit operation commands; AND, OR and other multiplication commands).
Note 2 : When executing read commands with GCCR, bits 3 to 7 are read as "1".

GCCR ($002C_H$)

7	6	5	4	3	2	1	0
					GCSEL		

(Initial value **** *100)

GCSEL	fc→dtgck frequency/deviation frequency select (values in parentheses for melody)	00* : reserved 010 : 3.58 MHz → 480.2 (960.5) kHz 011 : 3.84 MHz → 480.0 (960.0) kHz 100 : 4.00 MHz → 480.0 (960.0) kHz 101 : 4.19 MHz → 479.3 (957.7) kHz 110 : 8.00 MHz → 480.0 (960.0) kHz 111 : reserved * ; don't care	write only

Figure 2-57. Basic Clock Select Register

(2) DTMF and melody control register

The tone is controlled by generator mode select (DTMFCR) and generator data select (DTMFDR).

DTMFCR ($002D_H$)

7	6	5	4	3	2	1	0
			CSEL	MELS	MEL1S	MEL2S	DTMFS

(Initial value ***0 0000)

CSEL	Operation select	0 : Disable 1 : Enable	R/W
MSEL	Mode select	0 : DTMF mode 1 : MELODY mode	
MEL1S	Pin function select 1	0 : P46 input/output 1 : MELODY 1 output (sine wave)	
MEL2S	Pin function select 2	0 : P53 input/output 1 : $\overline{\text{MELODY2}}$ output (square wave)	
DTMFS	Pin function select 3	0 : P47 input/output 1 : TONE output	

DTMFDR ($002E_H$)

7	6	5	4	3	2	1	0
ROW/NOTE				COLUMN/OCTAVE			

(Initial value 0000 0000)

ROW / NOTE	ROW tone output frequency select/see Table 2-13 for tone selection.	0001 : Outputs a single tone of 697.7Hz 0010 : Outputs a single tone of 769.2Hz 0100 : Outputs a single tone of 857.1Hz 1000 : Outputs a single tone of 937.5Hz	R/W
COLUMN / OCTAVE	COLUMN tone output frequency select/ see Table 2-13 for octave selection	0001 : Outputs a single tone of 1212.1Hz 0010 : Outputs a single tone of 133.3Hz 0100 : Outputs a single tone of 1481.5Hz 1000 : Outputs a single tone of 1621.6Hz	

Figure 2-58. Mode Select Register/Data Register

2.11.3 Function

(1) DTMF function

When using tone output (DTMFCR bits 4, 3 and 0) with CSEL and DTMFS set to "1" and MSEL set to "0", set P47 to output mode. When DTMFS is set to "1", tone output will be enabled. When both ROW and COLUMN codes are disabled, the intermediate level of the sine wave will be output. When MLSEL is set to "1", the intermediate level will be output but will differ from the previous intermediate level.

When DTMFS is set to "0", DTMFS becomes a port regardless of DTMF status. When P47 is set to the output mode, the output changes to the output latch value. If P47 is set to open drain with input/output control register 2 (P4CR2) and the output latch is set to "1", the output becomes "Hi-Z".

Note : To maintain precision during tone output, do not output through ports P4 to P7.

Table 2-11 Tone Output Frequencies and Deviations from Standard Frequency

	Frequency	Standard frequency	fc = 3.84 MHz fc = 4.00 MHz fc = 8.00 MHz		fc = 3.58 MHz		fc = 4.19 MHz	
	code	(Hz)	output	deviation (%)	output	deviation (%)	output	deviation(%)
ROW	0001	697	697.674	0.10 %	698.029	0.15 %	696.013	– 0.14 %
	0010	770	769.230	– 0.10 %	769.621	– 0.05 %	767.399	– 0.34 %
	0100	852	857.143	0.60 %	857.579	0.66 %	855.102	0.36 %
	1000	941	937.500	– 0.37 %	937.976	– 0.32 %	935.268	– 0.61 %
COLUMN	0001	1209	1212.121	0.26 %	1212.737	0.31 %	1209.235	0.02 %
	0010	1336	1333.333	– 0.20 %	1334.011	– 0.15 %	1330.158	– 0.44 %
	0100	1477	1481.481	0.30 %	1482.234	0.35 %	1477.954	0.07 %
	1000	1633	1621.622	– 0.70 %	1622.446	– 0.65 %	1617.761	– 0.93 %

Note : Except error of are frequency

Table 2-12 Correspondence between Dial Keys and Frequency Select Codes Set as ROW and COLUMN Data in DTMFDR

		COLUMN data		
	Frequency select code	0001 (1209)	0010 (1336)	0100 (1477)
ROW data	0001 (697)	1	2	3
	0010 (770)	4	5	6
	0100 (852)	7	8	9
	1000 (941)	*	0	#
		Typical dial key pads		

( ) : Standard frequency in Hz

(2) MELODY function

When using MELODY1 output (DTMFCR bits 4, 3 and 2/1) with CSEL, MSEL and MEL1S/MEL2S set to "1". When using MELODY1 set P46 to the output mode. When using MELODY2 output, set P53 to the output mode.

When MEL1S is set to "1", MELODY1 will be output. When NOTE or OCTAVE codes are disabled, the intermediate level of the sine wave will be output. When MSEL are set to "0", the intermediate level will be output but will differ from the previous intermediate level.

When MEL1S is set to "0", MEL1S becomes a port regardless of MELODY status. When P46 is set to the output mode, the output changes to the output latch value. If P46 is set to open drain with input/output control register 2 (P4CR2) and the output latch is set to "1", the output becomes "Hi-Z".

MEL2S and P53 perform the same function. When output latch is set to "1" and set to open drain without pull-up resistor, the output becomes "Hi-Z".

Note : To maintain precision during MELODY1 output, do not output through ports P4 to P7.

Example : Output signal corresponding to 5A code.

```
LD      (GCCR), 04H       ;  Selects source frequency of 4M.
LD      (P4CR1), 40H      ;  Set P46 to output mode.
        ⎩
LD      (DTMFCR), 1EH     ;  Controls port (selects MELODY1 or MELODY2).
LD      (DTMFCR), 00H     ;  Sets invalid NOTE data.
LD      (DTMFCR), 01H     ;  Sets valid OCTAVE data.
LD      (DTMFCR), 61H     ;  Sets valid NOTE data.
```

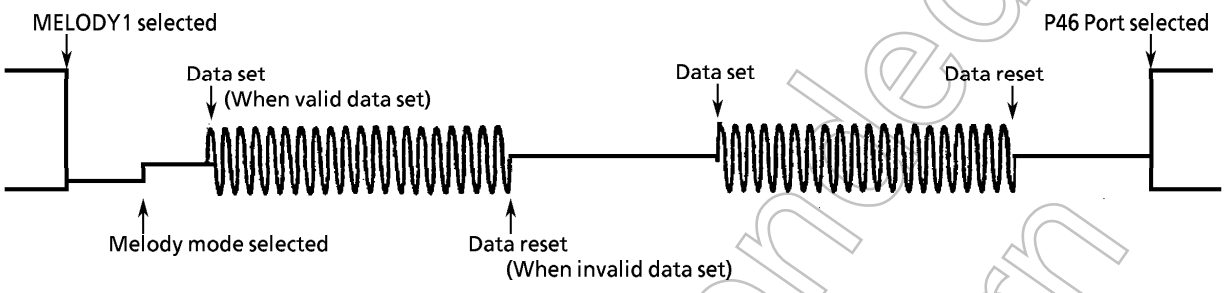
Melody Output Frequency Deviation

Table 2-13.

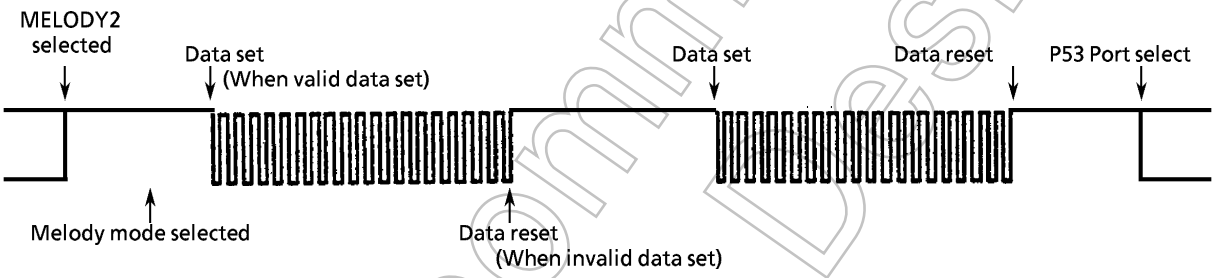
Octave select code (OCTABE)	Note select code (NOTE)	Code	Target frequency (Hz)	3.84 MHz 4.00 MHz 8.00 MHz		3.58 MHz		4.19 MHz	
				output (Hz)	deviation (%)	output (Hz)	deviation (%)	output (Hz)	deviation (%)
**00	0000	–	–	–	–	–	–	–	–
**00	0001	4E	329.628	329.670	0.01 %	329.838	0.06 %	328.89	– 0.23 %
**00	0010	4F	349.228	348.837	– 0.11 %	349.015	– 0.06 %	348.01	– 0.35 %
**00	0011	4F#	369.994	370.370	0.10 %	370.558	0.15 %	369.49	– 0.14 %
**00	0100	4G	391.995	389.611	– 0.61 %	389.808	– 0.56 %	388.68	– 0.84 %
**00	0101	4G#	415.305	416.667	0.33 %	416.878	0.38 %	415.67	0.09 %
**00	0110	4A	440.000	441.177	0.27 %	441.401	0.32 %	440.13	0.03 %
**00	0111	4A#	466.164	468.750	0.55 %	468.988	0.61 %	467.63	0.32 %
**00	1000	4B	493.883	491.803	– 0.42 %	492.053	– 0.37 %	490.63	– 0.66 %
**00	1001	5C	523.251	526.316	0.59 %	526.583	0.64 %	525.06	0.35 %
**00	1010	5C#	554.365	555.556	0.21 %	555.838	0.27 %	554.23	– 0.02 %
**00	1011	5D	587.330	588.235	0.15 %	588.534	0.21 %	586.83	– 0.08 %
**00	1100	5D#	622.254	625.000	0.44 %	625.318	0.49 %	623.51	0.20 %
**00	1101	–	–	200.000	–	200.102	–	199.52	–
**00	1110	–	–	267.857	–	267.993	–	267.22	–
**00	1111	–	–	333.333	–	333.503	–	332.54	–
**01	0000	–	–	–	–	–	–	–	–
**01	0001	5E	659.255	659.341	0.01 %	659.676	0.06 %	657.77	– 0.23 %
**01	0010	5F	698.456	697.675	– 0.11 %	698.029	– 0.06 %	696.01	– 0.35 %
**01	0011	5F#	739.989	740.741	0.10 %	741.117	0.15 %	738.98	– 0.14 %
**01	0100	5G	783.991	779.221	– 0.61 %	779.617	– 0.56 %	777.37	– 0.85 %
**01	0101	5G#	830.609	833.334	0.33 %	833.757	0.38 %	831.35	0.09 %
**01	0110	5A	880.000	882.353	0.27 %	882.801	0.32 %	880.25	0.03 %
**01	0111	5A#	932.328	937.500	0.55 %	937.976	0.61 %	935.27	0.32 %
**01	1000	5B	987.767	983.607	– 0.42 %	984.106	– 0.37 %	981.26	– 0.66 %
**01	1001	6C	1046.502	1052.632	0.59 %	1053.166	0.64 %	1050.13	0.35 %
**01	1010	6C#	1108.731	1111.111	0.21 %	1111.676	0.27 %	1108.47	– 0.02 %
**01	1011	6D	1174.659	1176.471	0.15 %	1177.068	0.21 %	1173.67	– 0.08 %
**01	1100	6D#	1244.508	1250.000	0.44 %	1250.635	0.49 %	1247.02	0.20 %
**01	1101	–	–	400.000	–	400.203	–	399.05	–
**01	1110	–	–	535.714	–	535.986	–	534.44	–
**01	1111	–	–	666.667	–	667.005	–	665.08	–
**10	0000	–	–	–	–	–	–	–	–
**10	0001	6E	1318.510	1318.681	0.01 %	1319.351	0.06 %	1315.54	– 0.23 %
**10	0010	6F	1396.913	1395.349	– 0.11 %	1396.058	– 0.06 %	1392.03	– 0.35 %
**10	0011	6F#	1479.978	1481.481	0.10 %	1482.234	0.15 %	1477.95	– 0.14 %
**10	0100	6G	1567.982	1558.442	– 0.61 %	1559.234	– 0.56 %	1554.73	– 0.85 %
**10	0101	6G#	1661.219	1666.667	0.33 %	1667.514	0.38 %	1662.70	0.09 %
**10	0110	6A	1760.000	1764.706	0.27 %	1765.603	0.32 %	1760.50	0.03 %
**10	0111	6A#	1864.655	1875.000	0.55 %	1875.953	0.61 %	1870.54	0.32 %
**10	1000	6B	1975.533	1967.213	– 0.42 %	1968.213	– 0.37 %	1962.53	– 0.66 %
**10	1001	7C	2093.005	2105.263	0.59 %	2106.333	0.64 %	2100.25	0.35 %
**10	1010	7C#	2217.461	2222.222	0.21 %	2223.351	0.27 %	2216.93	– 0.02 %
**10	1011	7D	2349.318	2352.941	0.15 %	2354.137	0.21 %	2347.34	– 0.08 %
**10	1100	7D#	2489.016	2500.000	0.44 %	2501.270	0.49 %	2494.05	0.20 %
**10	1101	–	800.000	800.000	–	800.407	–	798.10	–
**10	1110	–	1067.000	1071.428	–	1071.972	–	1068.88	–
**10	11110	–	1333.000	1333.333	–	1334.011	–	1330.16	–
**11	****	–	–	–	–	–	–	–	–

Note 1: * don't care
Note 2: Except error of osc frequency

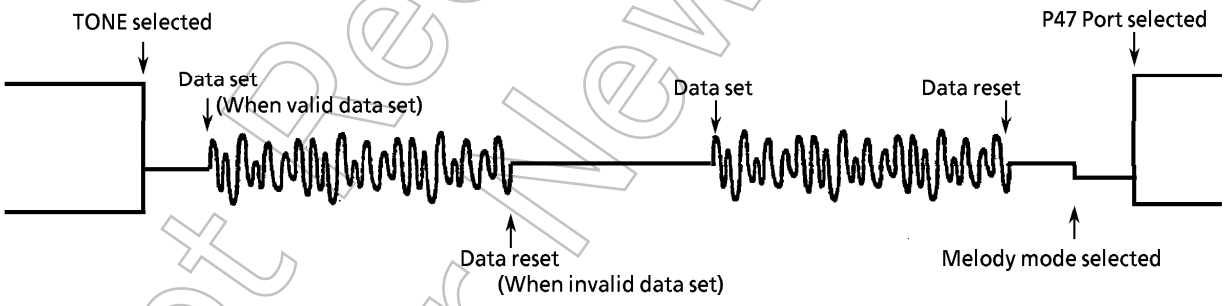
Tone Generator Output Waveform



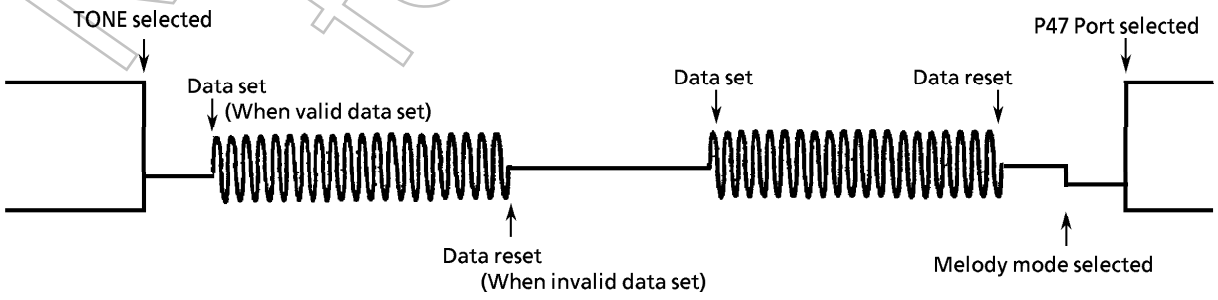
MELODY Generator (Sine Wave : **MELODY1** Output)



MELODY Generator (Square Wave : **MELODY2** Output)



DTMF Generator (Dual-tone Mode : **TONE** Output)



DTMF Generator (Single-tone Mode: **TONE** Output)

Tone Output Test

The 87CM53 has no test mode to test tone outputs.

When the waveform needs testing and adjusting, a program must be made in advance.

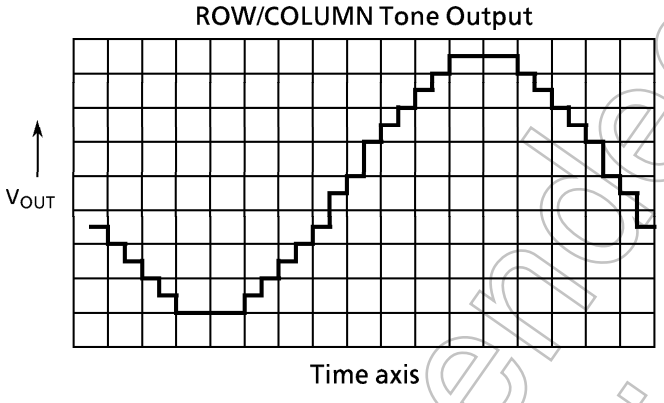


Figure 2-59. Single-Tone Waveform

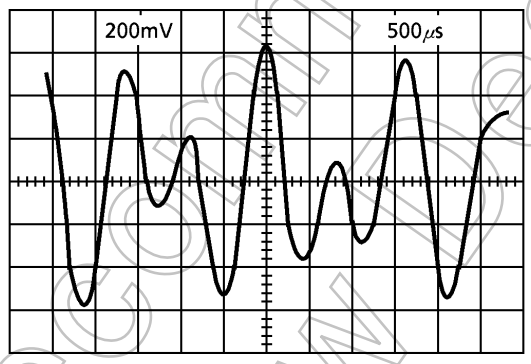


Figure 2-60. Dual-Tone Waveform

2.12 8-bit A/D Converter (ADC)

The 87CM53 has an 8-channel multiplexed-input 8-bit successive approximate type A/D converter with sample and hold.

The analog power source (VAREF) automatically cut off in stop mode and when analog input is disabled.

2.12.1 Configuration

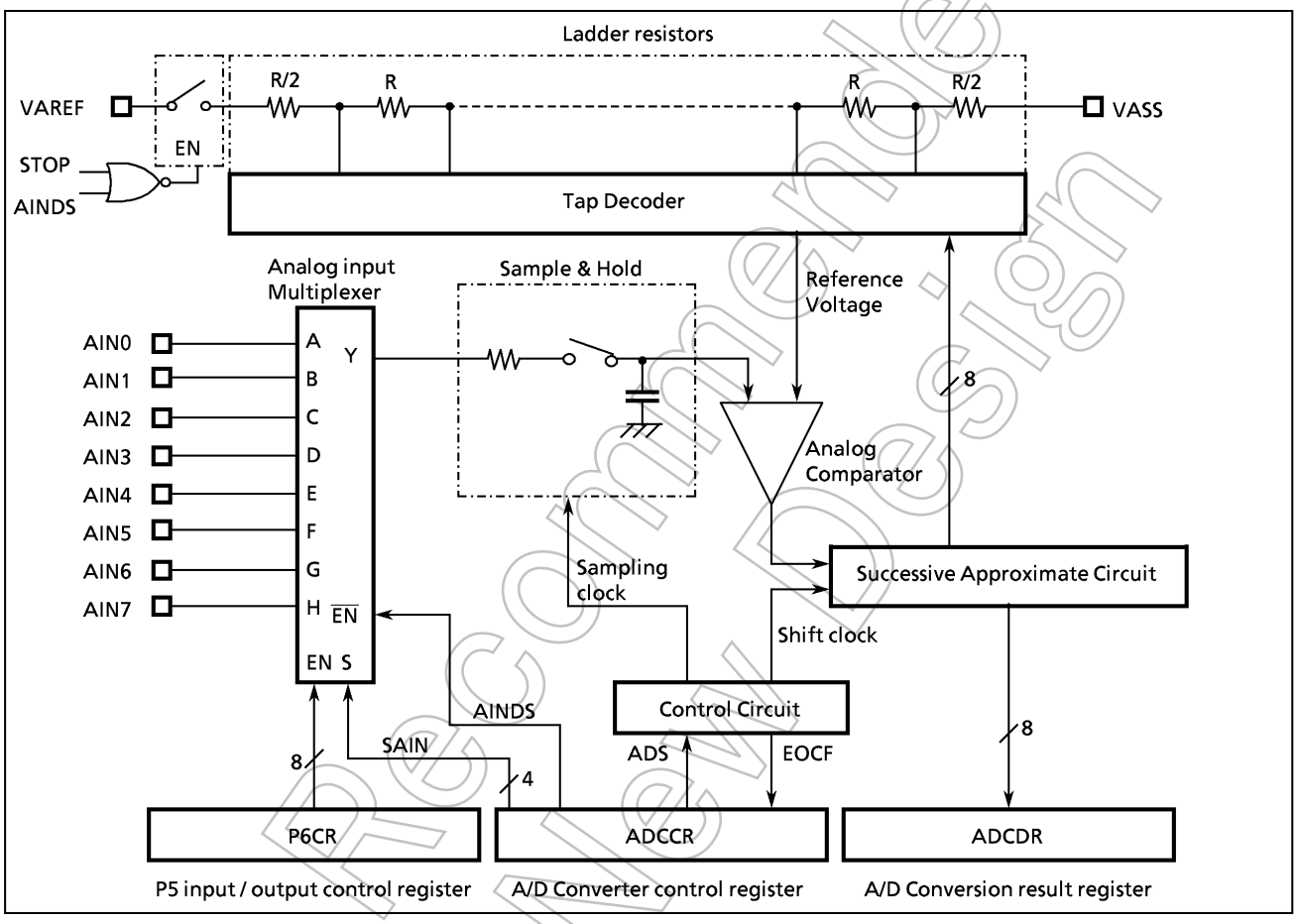


Figure 2-61. A/D Converter

2.12.2 Control

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

A/D Conversion Result Register

	7	6	5	4	3	2	1	0	
ADCDR ($000F_H$)									Read only

Figure 2-62. A/D Converter Result Register

A/D Converter Control Register

ADCCR ($000E_H$)

7	6	5	4	3	2	1	0
EOCF	ADS	ACK	AINDS	SAIN			

(Initial value : 0000 0000)

SAIN	Analog input selection	0000 : AIN0 0001 : AIN1 0010 : AIN2 0011 : AIN3 0100 : AIN4 0101 : AIN5 0110 : AIN6 0111 : AIN7 1*** : reserved	R/W
AINDS	Analog input control	0 : Enable 1 : Disable	
ACK	Conversion time selection	0 : Conversion time = 184/fcgck 1 : Conversion time = 736/fcgck	
ADS	A/D conversion start	0 : – 1 : A/D conversion start	
EOCF	End of A/D conversion flag	0 : Under conversion or Before conversion 1 : End of conversion	R

*Note 1 : * ; don't care*

Note 2 : Select analog input when A/D converter stops.

Note 3 : The ADS is automatically cleared to "0" after starting conversion.

Note 4 : The EOCF is cleared to "0" when reading the ADCDR.

Note 5 : The EOCF is read-only.

Figure 2-63. A/D Converter Control Register and A/D Conversion Result Register

2.12.3 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 ladder resistance. The reference voltage is compared with an analog input voltage and A/D conversion is performed.

Channels operating on analog input must be set to the input pin with P6 input/output control (P6CR).

(1) Start of A/D conversion

Prior to A/D conversion start, select one pin among analog input channels (AIN7 to AIN0) using the SAIN (bit 3 - 0 in ADCCR). Clear AINDS (bit 4 in ADCCR) to 0.

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 A/D conversion time using the ACK (bit 5 in ADCCR).

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

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

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

Setting the ADS to "1" during A/D conversion resumes conversion from the beginning.

The analog input voltage is sampled every 4 machine cycles after A/D conversion start.

Note : Keeping the same level of an analog input during 4 Machine Cycle Time is necessary for charging the sample hold circuit which has a resistor (typ. 5 k) and a capacitor (typ. 12pF).

(2) Reading of A/D conversion result

Read the conversion value stored in the A/D conversion register after the end of conversion is confirmed. (EOCF = 1)

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

(3) A/D conversion in STOP mode

When the MCU places in the STOP mode during the A/D conversion, the conversion is terminated and the A/D 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.

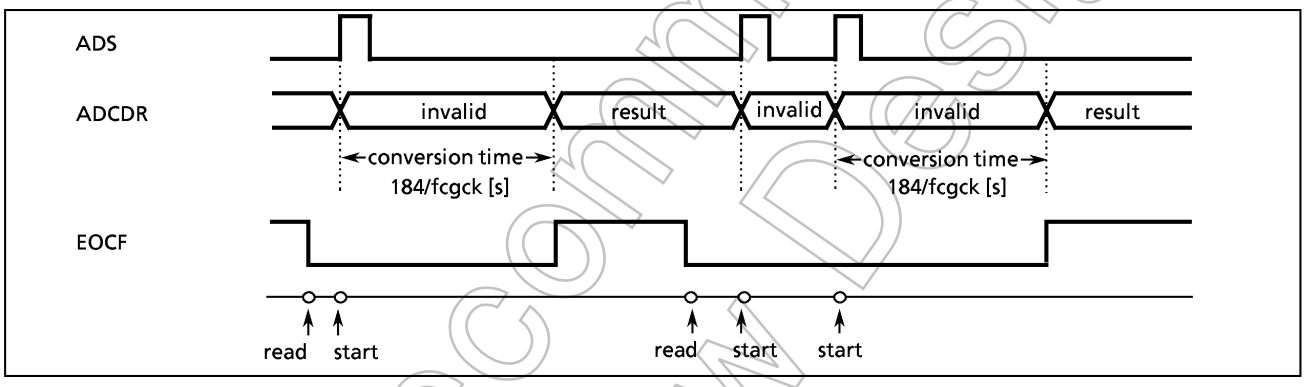


Figure 2-64. A/D conversion Timing chart

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

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

Figure 2-65 shows the relationship between An analog input voltage and A/D converted 8-bit digital value.

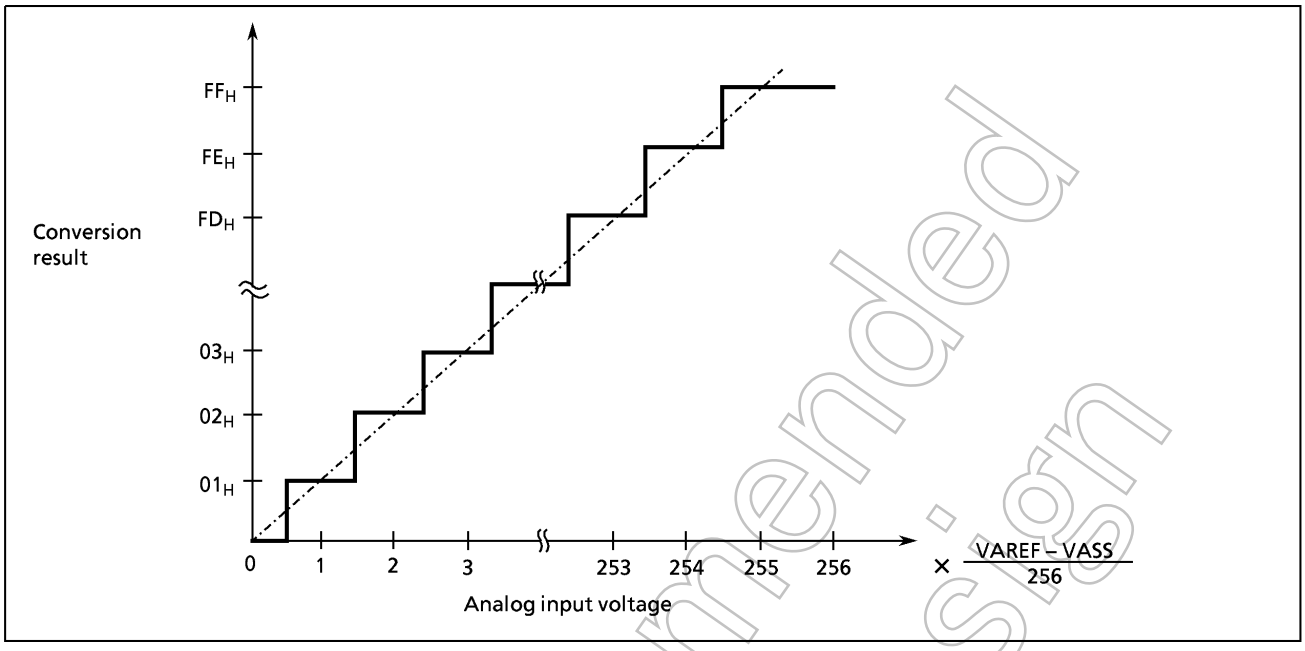


Figure2-65. Analog Input Voltage vs A/D Conversion Result (typ.)

2.13 Key on Wake-Up

With the 87CM53 stop mode can be released with $\overline{\text{STOP}}$ pin (P20) and STPR0 to STPR7 pins (P80 to P87).

2.13.1 Configuration

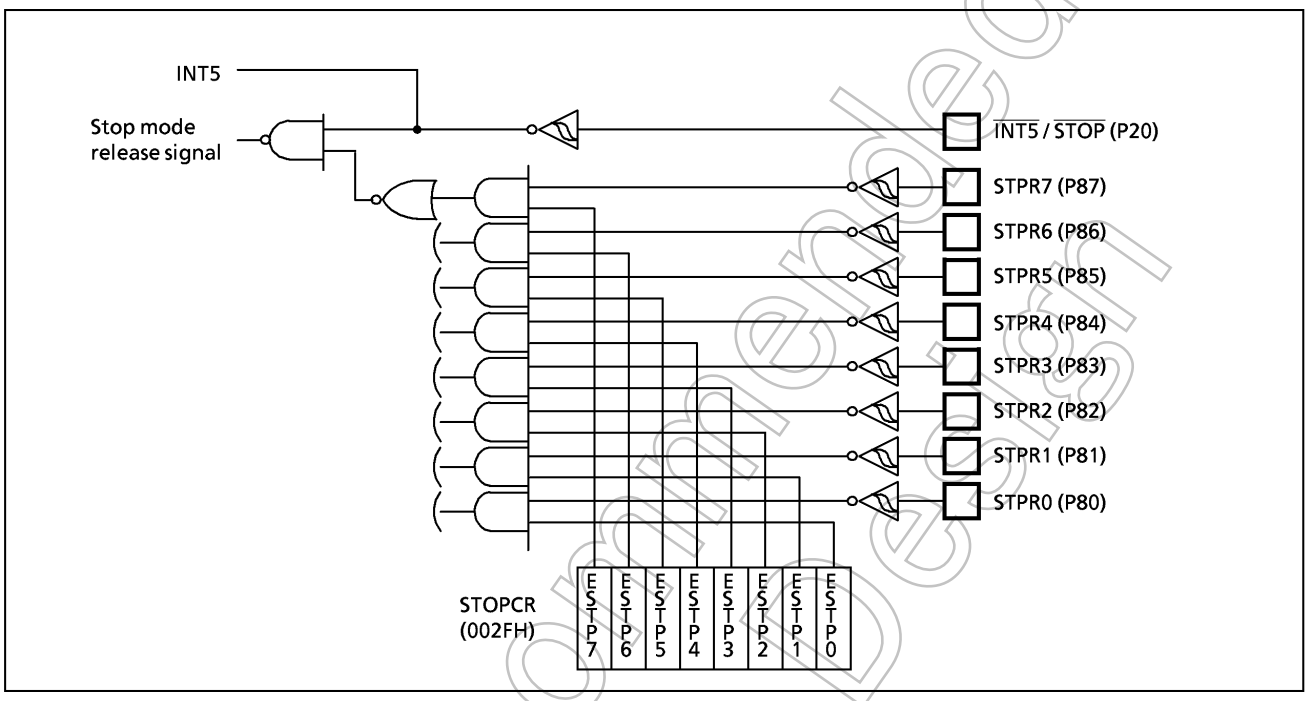


Figure 2-66. Key on Wake-Up

2.13.2 Control

The stop mode release control register (STOPCR) can be used to set stop mode release for STPR0 to STPR7 pins for each bit. The P8 pull-up control register (P8PUCR) can be used to set the pull-up resistance for each bit.

STPR0 to STPR7 pins to be used must be set to input pins with the port 8 input/output control register (P8CR). Initiate stop mode with system control register 1 (SYSCR1), and release stop mode by setting one of the STPR0 to STPR7 pins to "L" level. (see Note 1.)

When using the key wake-up function (STPR0 to STPR7), use RELM, which selects the stop mode release, to select the level mode (SYSCR1 bit 6 to "1").

Confirm the status of STPR0 to STPR7 pins by reading the P8 port, and verify that the level of each pin is set to "H" before initiating stop mode.

Stop mode release control register

STOPCR ($002F_H$)

7	6	5	4	3	2	1	0
ESTP7	ESTP6	ESTP5	ESTP4	ESTP3	ESTP2	ESTP1	ESTP0

(Initial value: 00000000)

STOPCR	Releases stop mode using P8 port. (desegnated for each bit)	0 : Disable 1 : Enable	R/W

Note 1 : In case of the Edge-sensitive release mode of STOP mode, if it is necessary to release STOP mode by $\overline{STOP}$ pin input, the level of Key Wake Up input pins which are permitted to release STOP mode should be "H".

Note 2 : In case of the Edge-sensitive release mode of STOP mode, if it is necessary to release the STOP mode by Key Wake Up pin input, the level of $\overline{STOP}$ pin should be "L" and the level of Key Wake Up pins which are permitted to release STOP mode should be "H".

Note 3 : In case of the Level-sensitive release mode of STOP Mode, if the level of Key Wake Up pins which are permitted to release STOP mode is "L", STOP mode will not start and release sequence (warming up) will start.

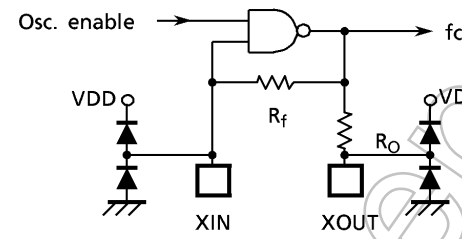
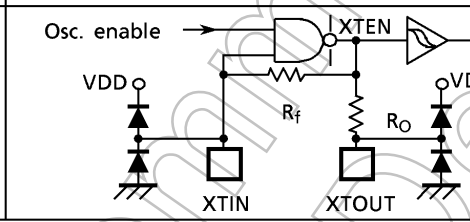
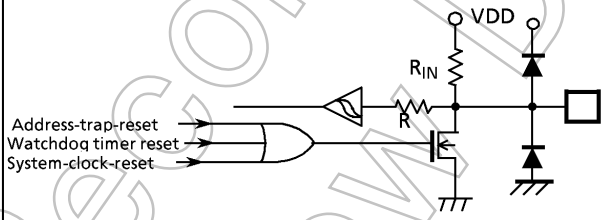
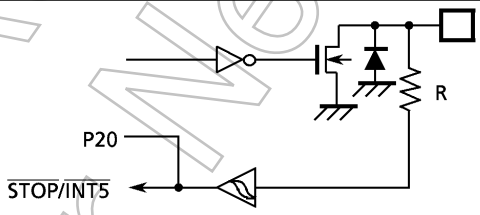
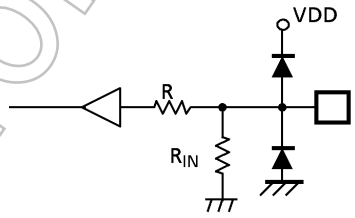
Note 4 : When using Key Wake Up function, P22 should be used as $\overline{STOP}$ pin. (When P22 is used as I/O, the change of P22 condition may release the STOP mode.)

Figure 2-67. Stop Release Control Registor

INPUT / OUTPUT CIRCUITRY

(1) Control pins

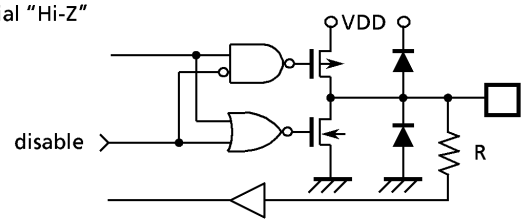
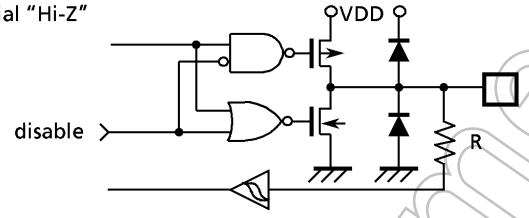
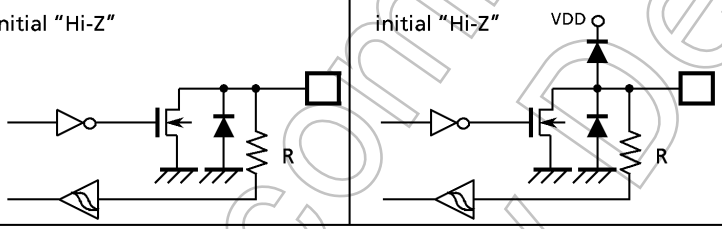
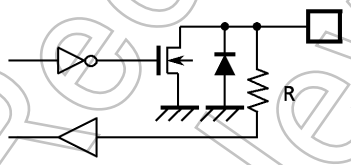
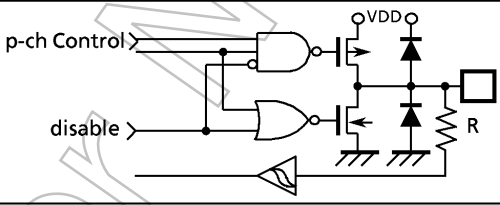
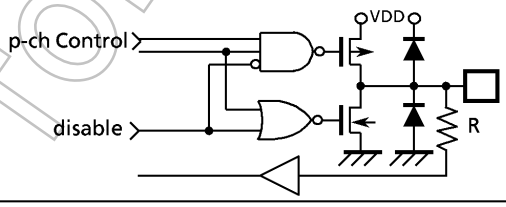
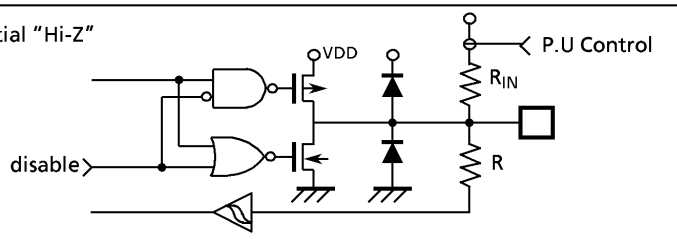
The input / output circuitries of the 87CM53 control pins are shown below.
Please specify either the single-clock mode or the dual-clock mode by a code (NM1 or NM2) as an option for an operating mode during reset.

CONTROL PIN	I/O	INPUT / OUTPUT CIRCUITRY and CODE	REMARKS
XIN XOUT	Input Output		Resonator connecting pins (high-frequency) R_f = 1.2 MΩ (typ.) R_o = 1.5 kΩ (typ.)
XTIN (P21) XTOUT (P22)	Input Output	NM1: Refer to port P2 NM2: 	Resonator connecting pins (low-frequency) R_f = 6 MΩ (typ.) R_o = 220 kΩ (typ.) In only dual-clock mode
$\overline{\text{RESET}}$	I/O		Sink open drain output Hysteresis input Pull-up resistor R_{IN} = 220 kΩ (typ.) R = 1 kΩ (typ.)
$\overline{\text{STOP}}$/$\overline{\text{INT5}}$ (P20)	Input		Hysteresis input R = 1 kΩ (typ.)
TEST	Input		Pull-down resistor R_{IN} = 70 kΩ (typ.) R = 1 kΩ (typ.)

Note1 : The TEST pin of the 87PM53 does not have a pull-down resistor. Be sure to fix the TEST pin to low in MCU mode.
Note2 : The 87PM53 is placed in the single-clock mode during reset. (NM1)

(2) Input/output ports

The input/output circuitries of the 87CM53 input/output ports are shown below.

PORT	I/O	INPUT/OUTPUT CIRCUITRY	REMARKS
P0 P6	I/O	initial "Hi-Z" 	Tri-state I/O R = 1kΩ (typ.)
P1	I/O	initial "Hi-Z" 	Tri-state I/O Hysteresis input R = 1kΩ (typ.)
P2	I/O	P20, P23 / P21, P22 initial "Hi-Z" 	Sink open drain output Hysteresis input R = 1kΩ (typ.)
P3	I/O	initial "Hi-Z" 	Sink open drain output High current output R = 1kΩ (typ.)
P4 P5	I/O	initial "Hi-Z" 	Sink open drain or Tri-state I/O (Programable port option) Hysterisis input R = 1kΩ (typ.)
P7 P9	I/O	initial "Hi-Z" 	Sink open drain or Tri-state I/O (Programable port option) R = 1kΩ (typ.)
P8	I/O	initial "Hi-Z" 	Tri-state I/O Programable Pull-up resistor R_{IN} = 70kΩ (typ.) R = 1kΩ (typ.) Hysterisis input

Electrical Characteristics

Absolute Maximum Ratings (V_{SS} = 0 V)

Parameter	Symbol	Pins	Ratings	Unit
Supply Voltage	VDD		– 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 1pin)	I_{OUT1}	Ports P0, P1, P2, P4, P5, P6, P7, P8, P9	3.2	mA
	I_{OUT2}	Port P3	30	
Output Current (Total)	Σ I_{OUT1}	Ports P0, P1, P2, P4, P5, P6, P7, P8, P9	160	mA
	Σ I_{OUT2}	Port P3	120	
Power Dissipation [Topr = 70°C]	PD		350	mW
Soldering Temperature (time)	Tsld		260 (10s)	°C
Storage Temperature	Tstg		– 55 to 125	°C
Operating Temperature	Topr		– 30 to 60	°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 60°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	2.2 Note 2		
				IDLE1, 2 mode			
			fs = 32.768 kHz	SLOW mode			
				SLEEP mode			
				STOP mode	2.0		
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		0	V_{DD} × 0.30	V
	V_{IL2}	Hysteresis input				V_{DD} × 0.25	
	V_{IL3}		V_{DD} < 4.5 V			V_{DD} × 0.10	
Clock Frequency	fc	XIN, XOUT	V_{DD} = 4.5 to 5.5 V		3.58	8.0	MHz
			V_{DD} = 2.7 to 5.5 V			4.19	
	fs	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 fc: The supply voltage range of the conditions shows the value in NORMAL1, 2 modes and·IDLE 1,2 modes.

Note 3: When the A/D converter is used, VDD must be set to ≧ 2.7 V.

D.C. Characteristics

(V_{SS} = 0 V, Topr = – 30 to 60°C)

Parameter	Symbol	Pins	Conditions		Min	Typ.	Max	Unit
Hysteresis Voltage	V_{HS}	Hysteresis input			–	0.9	–	V
Input Current	I_{IN1}	TEST	V_{DD} = 5.5 V V_{IN} = 5.5 V / 0 V		–	–	± 2	μA
	I_{IN2}	Sink open drain port and tri-state port						
	I_{IN3}	$\overline{RESET}$, $\overline{STOP}$						
Input Resistance	R_{IN2}	$\overline{RESET}$			100	220	450	kΩ
	R_{IN}	P8 pull-up resistor			30	70	150	
Output Leakage Current	I_{LO}	Sink open drain port and tri-state port	V_{DD} = 5.5 V, V_{OUT} = 5.5 V		–	–	2	μA
Output High Voltage	V_{OH2}	Tri-state port	V_{DD} = 4.5 V, I_{OH} = – 0.7 mA		4.1	–	–	V
Output Low Voltage	V_{OL}	Except XOUT and P3	V_{DD} = 4.5 V, I_{OL} = 1.6 mA		–	–	0.4	V
Output Low Current	I_{OL3}	Port P3	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	TONE no output	–	9	12	mA
				TONE output	–	10.5	13.5	
Supply Currnt in IDLE 1, 2 mode				TONE no output	–	4.5	6.5	
				TONE output	–	6.0	8.0	
Supply Currnt in NORMAL 1, 2 mode			V_{DD} = 2.2 V V_{IN} = 2.2 V / 0.2 V fc = 4.2 MHz fs = 32.768 kHz	TONE no output	–	1.5	2.5	
				TONE output	–	2.0	3.0	
Supply Currnt in IDLE 1, 2 mode				TONE no output	–	0.8	1.8	
				TONE output	–	1.3	2.3	
Supply Current in SLOW mode	I_{DD}		V_{DD} = 3.0 V V_{IN} = 2.8 V / 0.2 V fs = 32.768 kHz		–	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

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.

A/D Conversion Characteristics

(V_{SS} = 0 V, V_{DD} = 2.7 to 5.5 V, Topr = – 30 to 60°C)

Parameter	Symbol	Conditions	Min	Typ.	Max	Unit
Analog Reference Voltage	V_{AREF}	$V_{AREF} - V_{ASS} \geqq 2.5$ V	2.7	—	V_{DD}	V
	V_{ASS}		V_{SS}	—	1.5	
Analog Input Voltage	V_{AIN}	$V_{DD} = V_{AREF}$ = 5.0 V $V_{SS} = V_{ASS}$ = 0.0 V	V_{ASS}	—	V_{AREF}	V
Analog Supply Current	I_{REF}		—	0.5	1.0	V
Nonlinearity Error		V_{DD} = 2.7 to 5.5 V	—	—	± 1	mA
Zero Point Error		V_{SS} = 0.0 V	—	—	± 1	
Full Scale Error		V_{AREF} = 2.700 V, 5.000 V	—	—	± 1	LSB
Total Error		V_{ASS} = 0.000 V	—	—	± 2	

Note: Total Error = total number of each type error excluding guantization error.

Tone Output Characteristics

(V_{SS} = 0 V, V_{DD} = 2.2 to 5.5 V, Topr = – 30 to 60°C)

Parameter	Symbol	Conditions	Min	Typ.	Max	Unit
Tone Output Voltage (ROW)	V_{TONE}	RL ≧ 10 kΩ, V_{DD} = 2.2 V	126	150	178	mVrms
Pre-Emphasis High Band (COL / ROW)	PEHB	PEHB = 20 log (COL/ROW)	1	2	3	dB
Output Distortion	DIS		—	—	5	%
Frequency Stability	△f	fc = 3.84 MHz, 4.00 MHz, 8.00 MHz (Except error of osc. frequency)	—	—	0.7	%
		fc = 3.58 MHz (Except error of osc. frequency)	—	—	0.66	
		fc = 4.19 MHz (Except error of osc. frequency)	—	—	0.93	

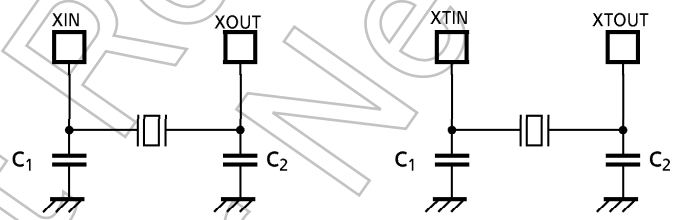
A.C. Characteristics

(V_{SS} = 0 V, Topr = – 40 to 85°C)

Parameter	Symbol	Conditions	Min	Typ.	Max	Unit
Machine Cycle Time	tcy	In NORMAL1, 2 mode (gear ratio)	0.5 (1/1)	–	8.9(1/8)	μs
		In IDLE1, 2 mode (gear ratio)				
		In SLOW mode	117.6		133.3	
		In SLEEP mode				
High Level Clock Pulse Width	t_{WCH}	For external clock operation (XIN input) fc = 8 MHz	50	–	–	ns
Low Level Clock Pulse Width	t_{WCL}					
High Level Clock Pulse Width	t_{WSH}	For external clock operation (XTIN input) fs = 32.768 kHz	14.7	–	–	μs
Low Level Clock Pulse Width	t_{WSL}					

Recommended Oscillating Condition

Parameter	Oscillator	Frequency	Recommended Oscillator		Recommended Condition C_1	Recommended Condition C_2
High-frequency	Ceramic Resonator	8 MHz	KYOCERA	KBR8.0M	30 pF	30 pF
		4 MHz	KYOCERA	KBR4.0MS		
			MURATA	CSA4.00MG		
	Crystal Oscillator	8 MHz	TOYOCOM	210B 8.0000	20 pF	20 pF
		4 MHz	TOYOCOM	204B 4.0000		
Low-frequency	Crystal Oscillator	32.768 kHz	NDK	MX-38T	15 pF	15 pF



(1) High-frequency (2) Low-frequency

Note: When it is used in high electrical field, an electrical shield of the package is recommended to retain normal operations

Note: To obtain an accurate oscillating frequency the condenser capacity must be adjusted on the set.