

Oct. 1999

Ver 1.0

8-BIT SINGLE-CHIP MICROCONTROLLERS

GMS87C1404

GMS87C1408

User's Manual

 **HYUNDAI MicroElectronics**

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GMS87C1404 / GMS87C1408

CMOS SINGLE-CHIP 8-BIT MICROCONTROLLER

1. OVERVIEW

1.1 Description

The GMS87C1404 and GMS87C1408 are an advanced CMOS 8-bit microcontroller with 4K/8K bytes of EPROM. The HYUNDAI MicroElectronics GMS87C1404 and GMS87C1408 are a powerful microcontroller which provides a highly flexible and cost effective solution to many small applications such as controller for battery charger. The GMS87C1404 and GMS87C1408 provide the following standard features: 4K/8K bytes of EPROM, 192 bytes of RAM, 8-bit timer/counter, 8-bit A/D converter, 10-bit high speed PWM output, programmable buzzer driving port, 8-bit serial communication port, on-chip oscillator and clock circuitry. In addition, the GMS87C1404 and GMS87C1408 supports power saving modes to reduce power consumption.

| Device name | ROM Size | RAM Size | Package |
|-------------|----------|----------|-----------------|
| GMS87C1404 | 4K bytes | 192bytes | 28 SKDIP or SOP |
| GMS87C1408 | 8K bytes | 192bytes | 28 SKDIP or SOP |

1.2 Features

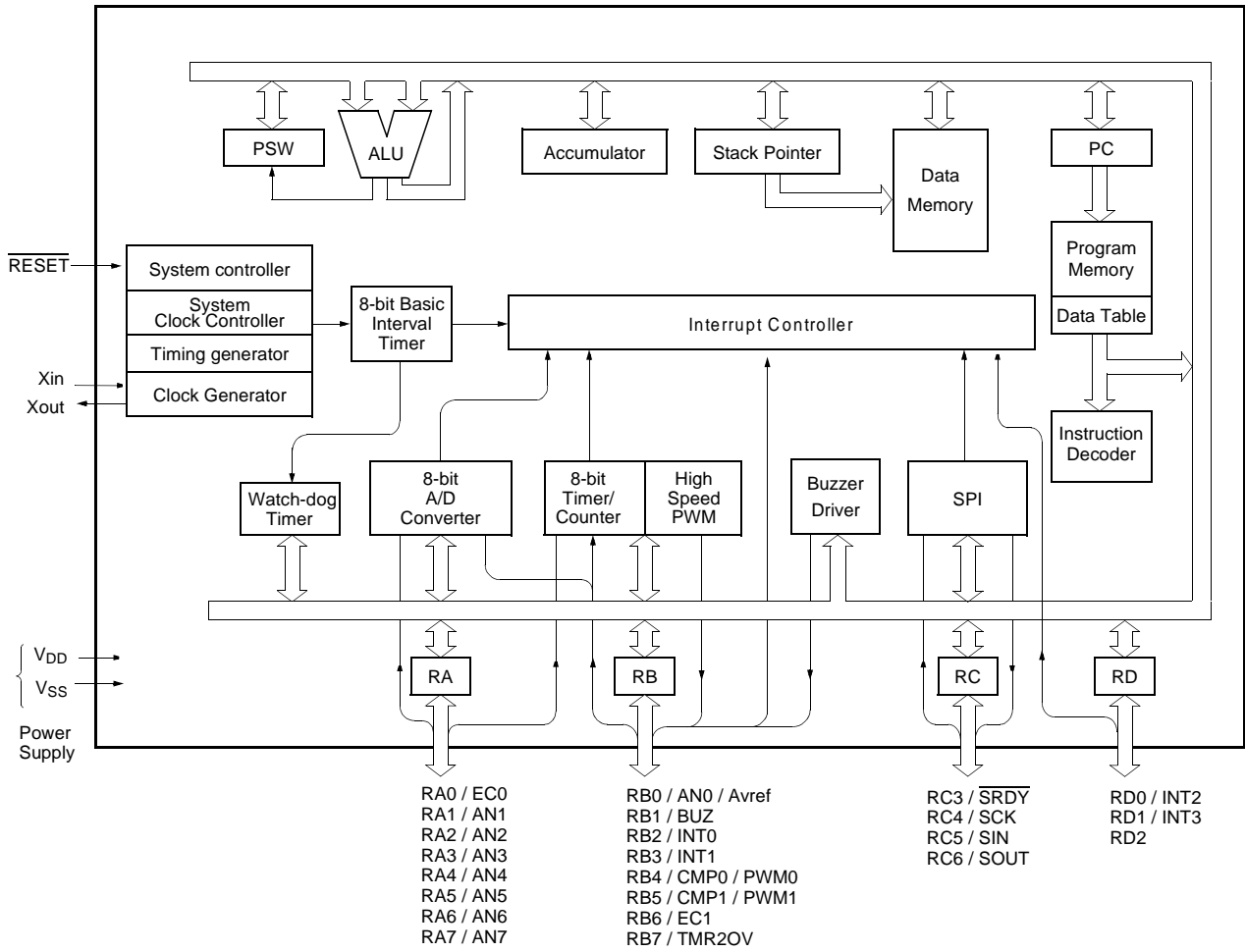
- **4K/8K Bytes On-chip Program Memory (OTP)**
- **192 Bytes of On-chip Data RAM (Included stack memory)**
- **Instruction Cycle Time:**
- 250nS at 8MHz
- **23 Programmable I/O pins (LED direct driving can be source and sink)**
- **2.5V to 5.5V Wide Operating Range**
- **One 8-bit A/D Converter**
- **One 8-bit Basic Interval Timer**
- **Four 8-bit Timer / Counters**
- **Two 10-bit High Speed PWM Outputs**
- **Watchdog timer (can be operate with internal RC-oscillation)**
- **One 8-bit Serial Peripheral Interface**
- **Twelve Interrupt sources**
- External input: 4
- A/D Conversion: 1
- Serial Peripheral Interface: 1
- Timer: 6
- **One Programmable Buzzer Driving port**
- 500Hz ~ 130kHz
- **Oscillator Type**
- Crystal
- Ceramic Resonator
- **Noise Immunity Circuit**
- Power Fail Processor
- **Power Down Mode**
- STOP mode
- Wake-up Timer mode

1.3 Development Tools

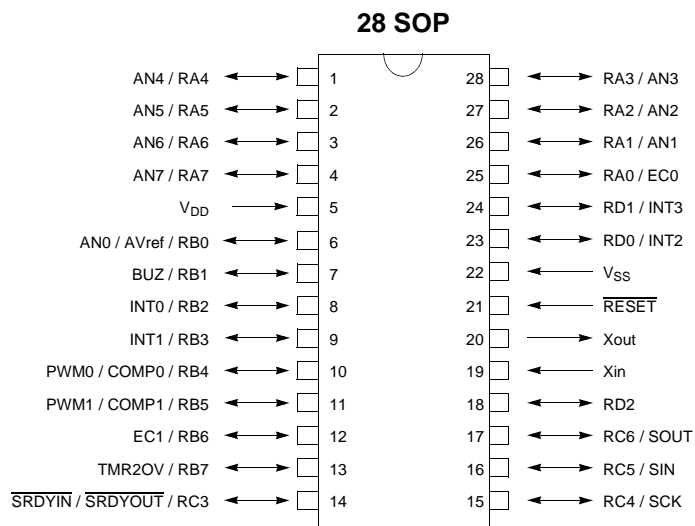
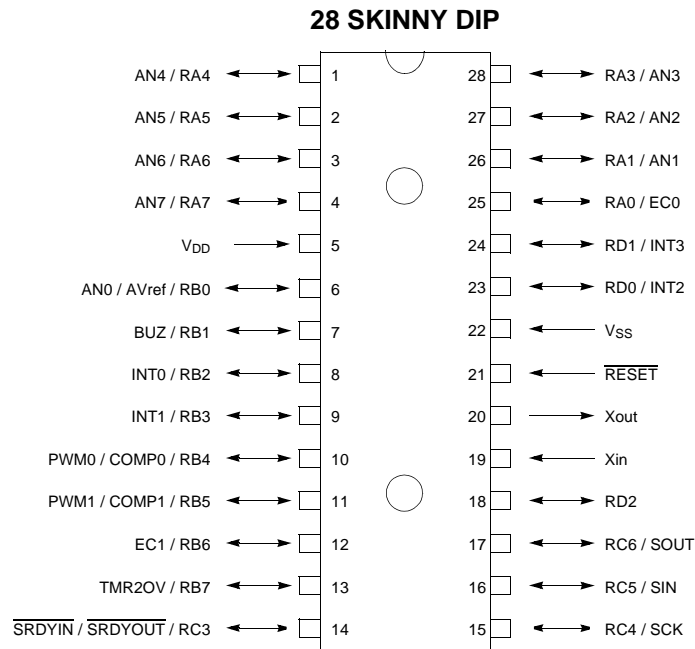
The GMS87C1404 and GMS87C1408 are supported by a full-featured macro assembler, an in-circuit emulator CHOICE-Dr™.

| | |
|-----------------------------|---------------------|
| In Circuit Emulators | CHOICE-Dr. |
| Assembler | HME Macro Assembler |
| OTP Writer | Dr. Writer |

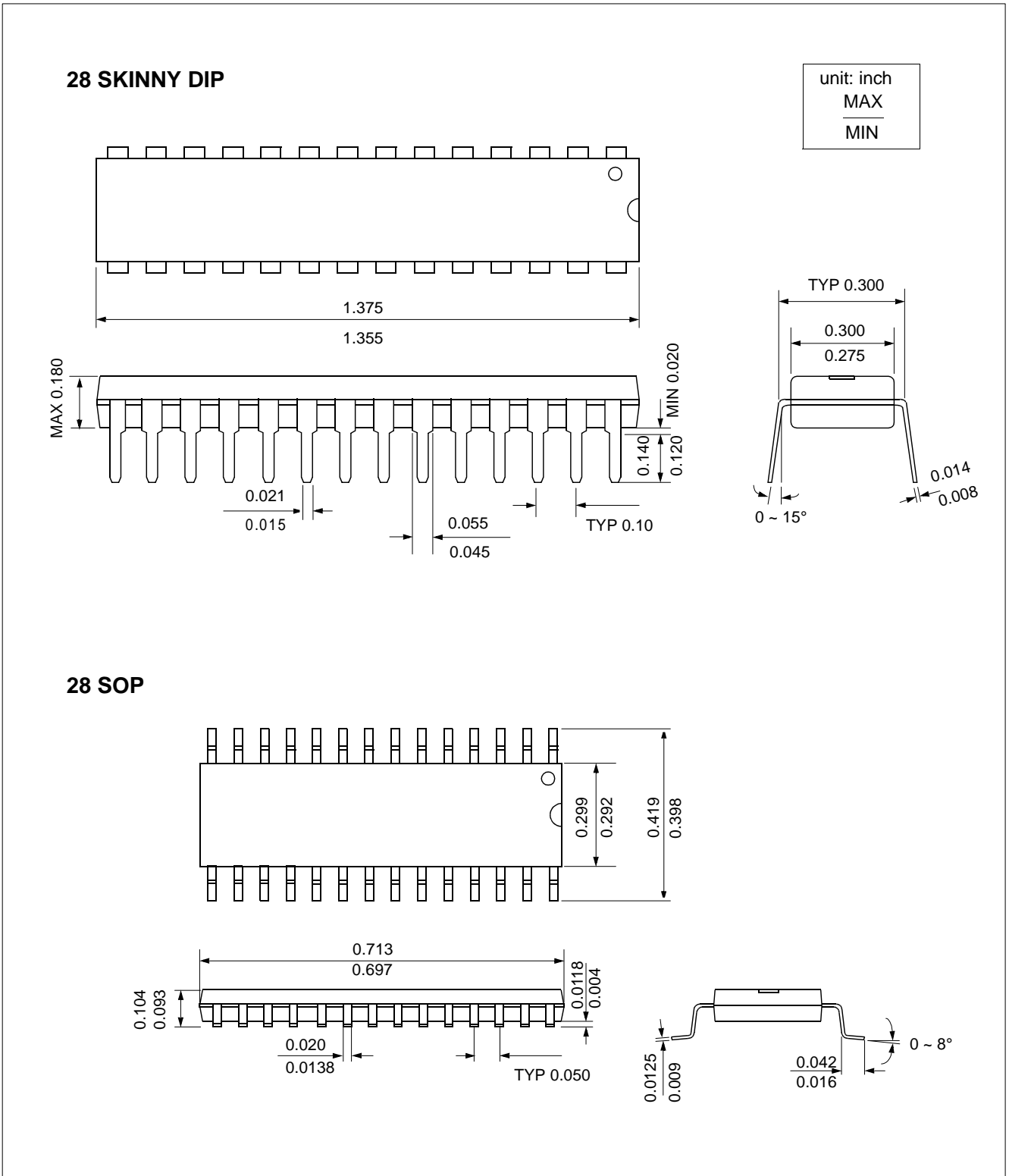
2. BLOCK DIAGRAM



3. PIN ASSIGNMENT



4. PACKAGE DIAGRAM



5. PIN FUNCTION

V_{DD}: Supply voltage.

V_{SS}: Circuit ground.

RESET: Reset the MCU.

X_{IN}: Input to the inverting oscillator amplifier and input to the internal main clock operating circuit.

X_{OUT}: Output from the inverting oscillator amplifier.

RA0~RA7: RA is an 8-bit, CMOS, bidirectional I/O port. RA pins can be used as outputs or inputs according to “1” or “0” written the their Port Direction Register(RAIO).

| Port pin | Alternate function |
|----------|------------------------------------|
| RA0 | EC0 (Event Counter Input Source) |
| RA1 | AN1 (Analog Input Port 1) |
| RA2 | AN2 (Analog Input Port 2) |
| RA3 | AN3 (Analog Input Port 3) |
| RA4 | AN4 (Analog Input Port 4) |
| RA5 | AN5 (Analog Input Port 5) |
| RA6 | AN6 (Analog Input Port 6) |
| RA7 | AN7 (Analog Input Port 7) |

Table 5-1 RA Port

In addition, RA serves the functions of the various special features in Table 5-1 .

RB0~RB7: RB is a 8-bit, CMOS, bidirectional I/O port. RB pins can be used as outputs or inputs according to “1” or “0” written the their Port Direction Register(RBIO).

RB serves the functions of the various following special features in Table 5-2

| Port pin | Alternate function |
|----------|--|
| RB0 | AN0 (Analog Input Port 0) AVref (External Analog Reference Pin) |
| RB1 | BUZ (Buzzer Driving Output Port) |
| RB2 | INT0 (External Interrupt Input Port 0) |
| RB3 | INT1 (External Interrupt Input Port 1) |
| RB4 | PWM0 (PWM0 Output) COMP0 (Timer1 Compare Output) |
| RB5 | PWM1 (PWM1 Output) COMP1 (Timer3 Compare Output) |
| RB6 | EC1 (Event Counter Input Source) |
| RB7 | TMR2OV (Timer2 Overflow Output) |

Table 5-2 RB Port

RC3~RC6: RC is a 4-bit, CMOS, bidirectional I/O port. RC pins can be used as outputs or inputs according to “1” or “0” written the their Port Direction Register(RCIO).

RC serves the functions of the serial interface following special features in Table 5-3 .

| Port pin | Alternate function |
|----------|--|
| RC3 | SRDYIN (SPI Ready Input) SRDYOUT (SPI Ready Output) |
| RC4 | SCKI (SPI CLK Input) SCKO (SPI CLK Output) |
| RC5 | SIN (SPI Serial Data Input) |
| RC6 | SOUT (SPI Serial Data Output) |

Table 5-3 RC Port

RD0~RD2: RD is a 3-bit, CMOS, bidirectional I/O port. RC pins can be used as outputs or inputs according to “1” or “0” written the their Port Direction Register(RDIO).

RD serves the functions of the external interrupt following special features in Table 5-4

| Port pin | Alternate function |
|----------|--|
| RD0 | INT2 (External Interrupt Input Port 2) |
| RD1 | INT3 (External Interrupt Input Port 3) |
| RD2 | |

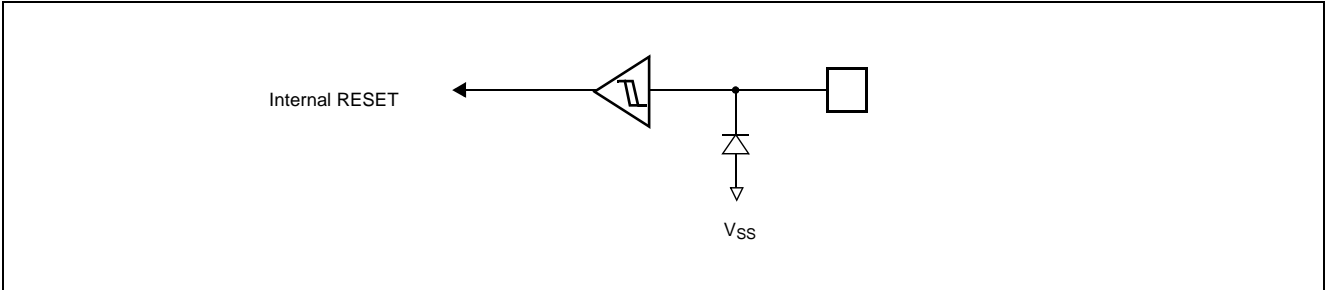
Table 5-4 RD Port

| PIN NAME | Pin No. | In/Out | Function | |
|--|---------|---------------------|-------------------------|--|
| V _{DD} | 5 | - | Supply voltage | |
| V _{SS} | 22 | - | Circuit ground | |
| $\overline{\text{RESET}}$ | 21 | I | Reset signal input | |
| X _{IN} | 19 | I | | |
| X _{OUT} | 20 | O | | |
| RA0 (EC0) | 25 | I/O (Input) | 8-bit general I/O ports | External Event Counter input 0 |
| RA1 (AN1) | 26 | I/O (Input) | | Analog Input Port 1 |
| RA2 (AN2) | 27 | I/O (Input) | | Analog Input Port 2 |
| RA3 (AN3) | 28 | I/O (Input) | | Analog Input Port 3 |
| RA4 (AN4) | 1 | I/O (Input) | | Analog Input Port 4 |
| RA5 (AN5) | 2 | I/O (Input) | | Analog Input Port 5 |
| RA6 (AN6) | 3 | I/O (Input) | | Analog Input Port 6 |
| RA7 (AN7) | 4 | I/O (Input) | | Analog Input Port 7 |
| RB0 (AVref/AN0) | 6 | I/O (Input) | 8-bit general I/O ports | Analog Input Port 0 / Analog Reference |
| RB1 (INT0) | 7 | I/O (Input) | | External Interrupt Input 0 |
| RB2 (INT1) | 8 | I/O (Input) | | External Interrupt Input 1 |
| RB3 (BUZ) | 9 | I/O (Output) | | Buzzer Driving Output |
| RB4 (PWM0/COMP0) | 10 | I/O (Output/Output) | | PWM0 Output or Timer1 Compare Output |
| RB5 (PWM1/COMP1) | 11 | I/O (Output/Output) | | PWM1 Output or Timer3 Compare Output |
| RB6 (EC1) | 12 | I/O (Output/Output) | | External Event Counter input 1 |
| RB7 (TMR2OV) | 13 | I/O (Output/Output) | | Timer2 Overflow Output |
| RC3 ($\overline{\text{SRDYIN/SRDYOUT}}$) | 14 | I/O (Input/Output) | 4-bit general I/O ports | SPI READY Input/Output |
| RC4 (SCK) | 15 | I/O (Input/Output) | | SPI CLK Input/Output |
| RC5 (SIN) | 16 | I/O (Input) | | SPI DATA Input |
| RC6 (SOUT) | 17 | I/O (Output) | | SPI DATA Output |
| RD0 (INT2) | 23 | I/O (Input) | 3-bit general I/O ports | External Interrupt Input 2 |
| RD1 (INT3) | 24 | I/O (Input) | | External Interrupt Input 3 |
| RD2 | 18 | I/O | | |

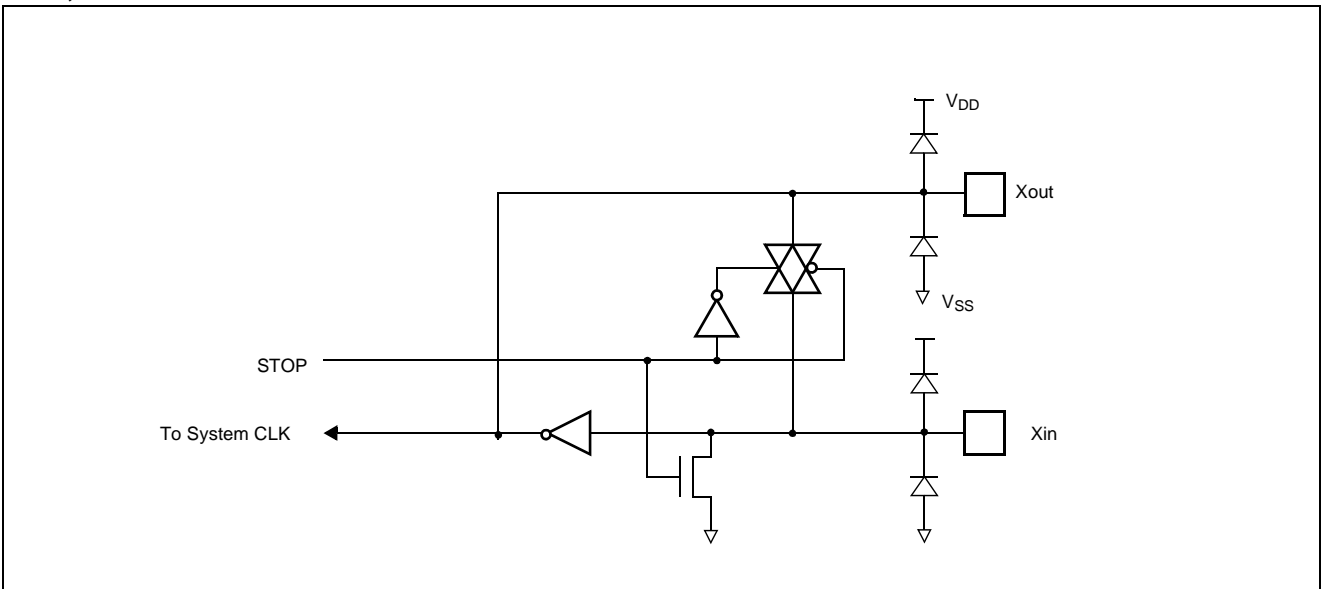
Table 5-5 Pin Description

6. PORT STRUCTURES

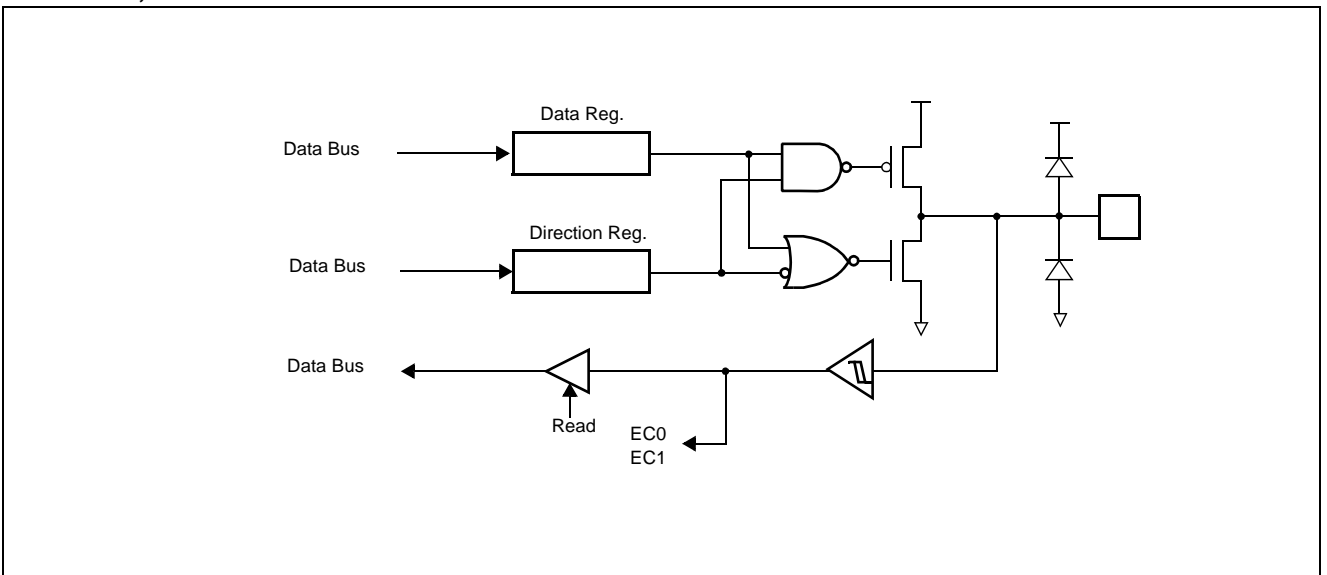
• RESET



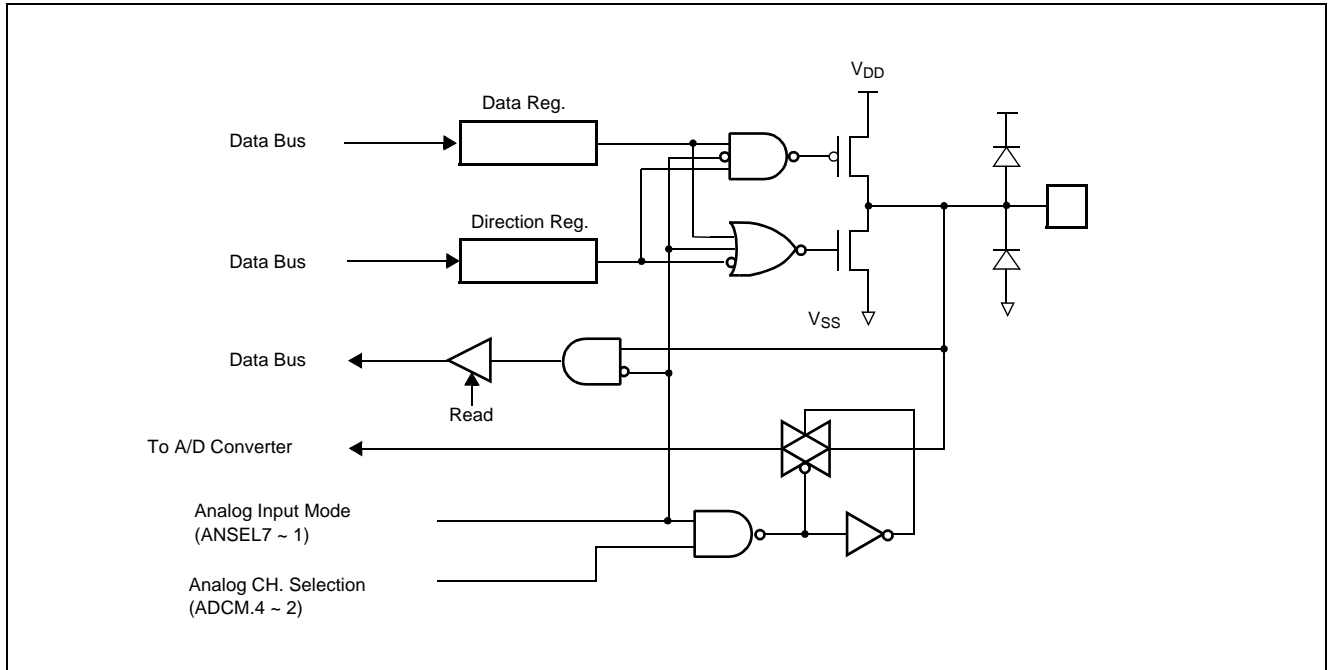
• Xin, Xout



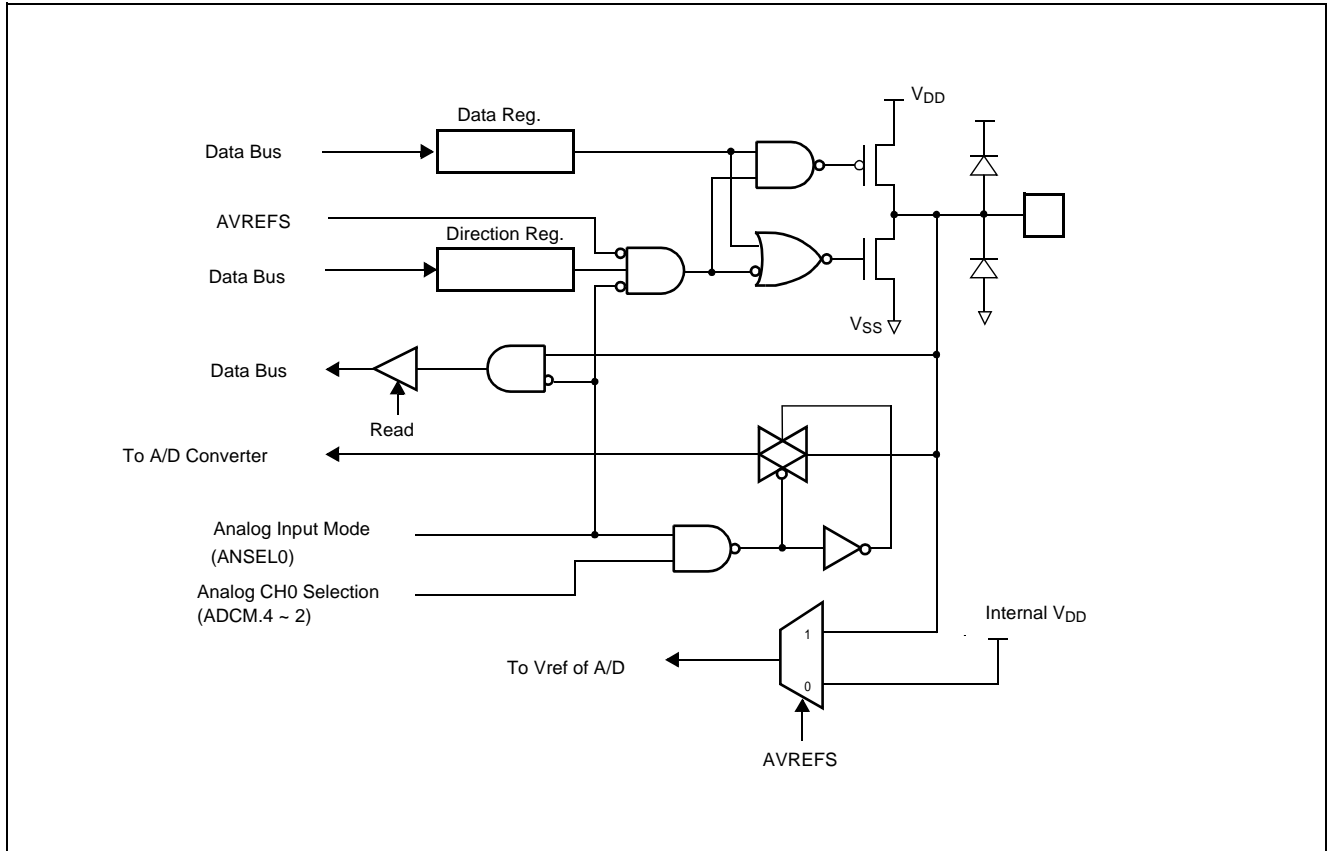
• RA0/EC0, RB6/EC1



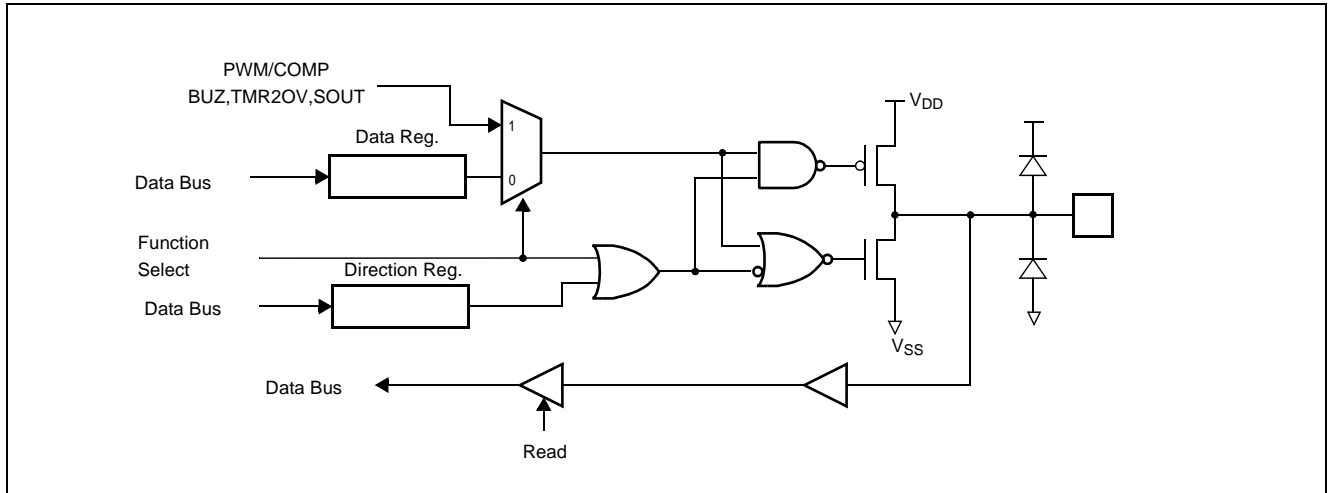
• RA1/AN1 ~ RA7/AN7



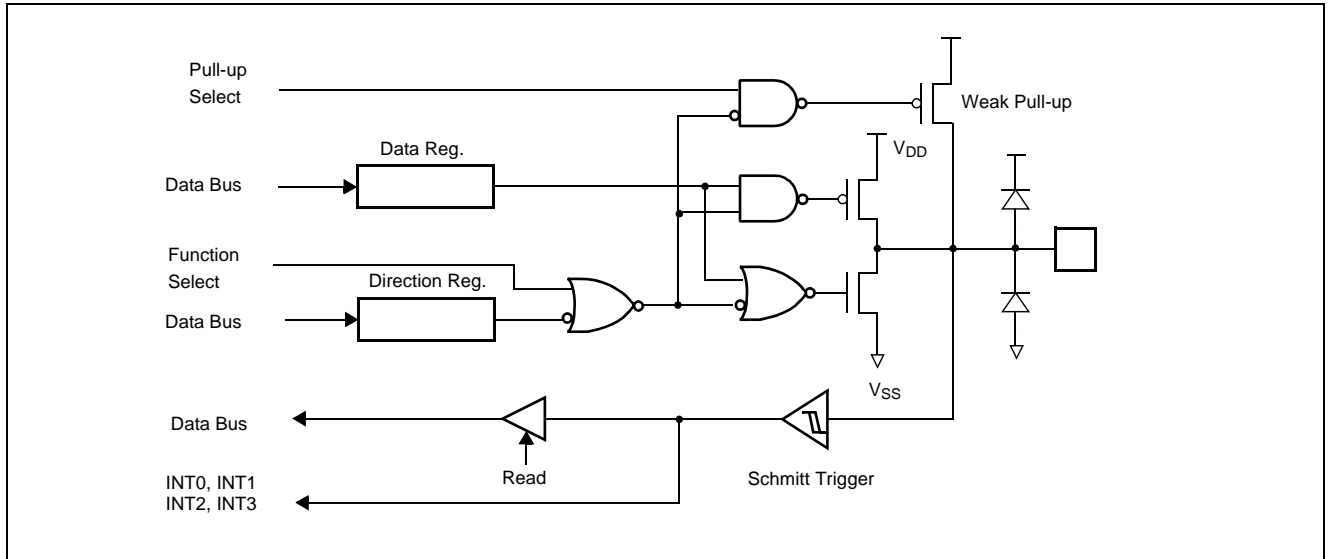
• RB0 / AN0 / AVref



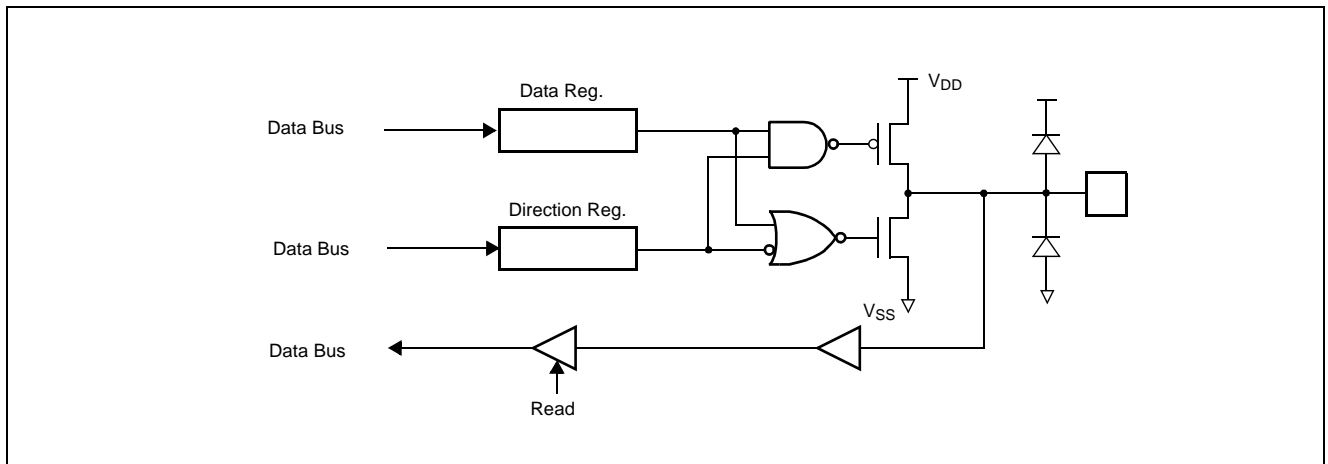
• RB1/BUZ, RB4/PWM0/COMP0, RB5/PWM1/COMP1, RB7/TMR2OV, RC6/SOUT



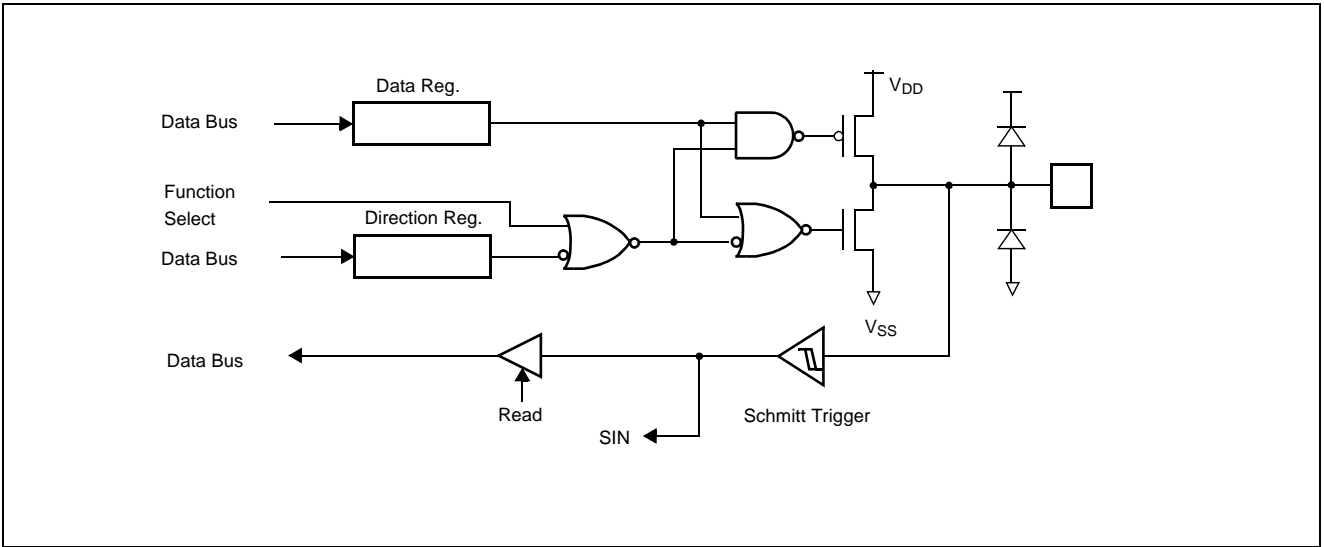
• RB2/INT0, RB3/INT1, RD0/INT2, RD1/INT3



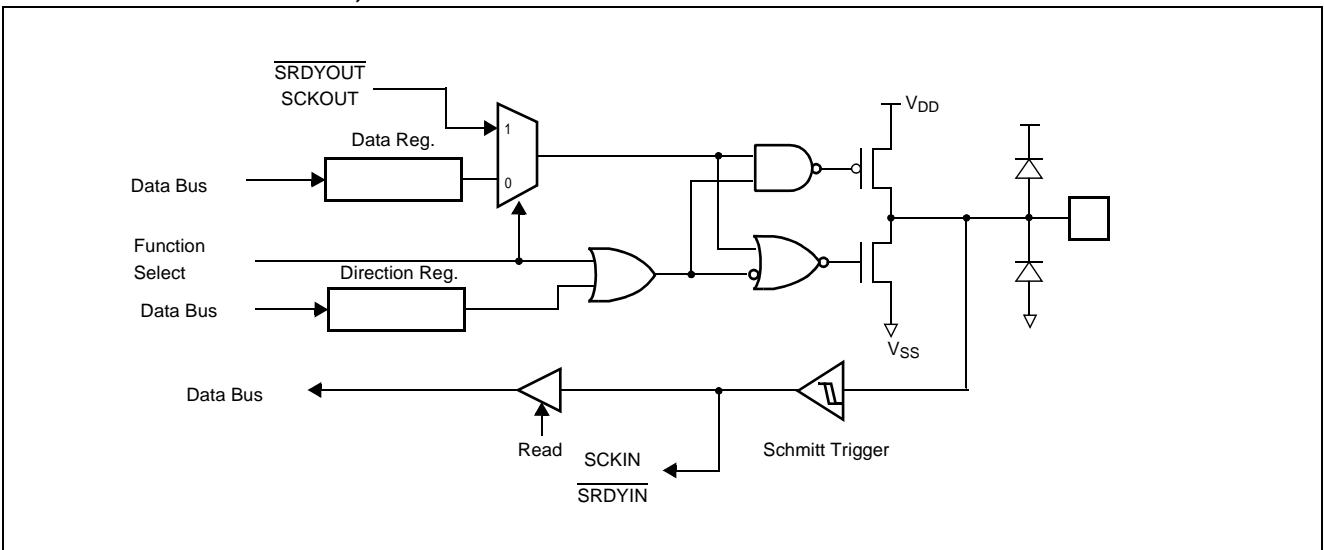
• RD2



• RC5/SIN



• RC3 / $\overline{\text{SRDYIN}}$ / $\overline{\text{SRDYOUT}}$, RC4 / SCKIN / SCKOUT



7. ELECTRICAL CHARACTERISTICS

7.1 Absolute Maximum Ratings

| | |
|--|----------------------|
| Supply voltage | -0.3 to +6.0 V |
| Storage Temperature | -40 to +125 °C |
| Voltage on any pin with respect to Ground (V_{SS}) | -0.3 to $V_{DD}+0.3$ |
| Maximum current out of V_{SS} pin | 200 mA |
| Maximum current into V_{DD} pin | 150 mA |
| Maximum current sunk by (I_{OL} per I/O Pin) | 25 mA |
| Maximum output current sourced by (I_{OH} per I/O Pin) | 15 mA |

| | |
|---|--------|
| Maximum current (ΣI_{OL}) | 150 mA |
| Maximum current (ΣI_{OH}) | 100 mA |

Note: Stresses above those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. This is a stress rating only and functional operation of the device at any other conditions above those indicated in the operational sections of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

7.2 Recommended Operating Conditions

| Parameter | Symbol | Condition | Specifications | | Unit |
|-----------------------|-----------|------------------------------|----------------|------|------|
| | | | Min. | Max. | |
| Supply Voltage | V_{DD} | $f_{XIN}=8\text{MHz}$ | 4.5 | 5.5 | V |
| | | $f_{XIN}=4.2\text{MHz}$ | 2.5 | 5.5 | V |
| Operating Frequency | f_{XIN} | $V_{DD}=4.5\sim 5.5\text{V}$ | 1 | 8 | MHz |
| | | $V_{DD}=2.5\sim 5.5\text{V}$ | 1 | 4.2 | kHz |
| Operating Temperature | T_{OPR} | | -20 | 85 | °C |

7.3 A/D Converter Characteristics

($T_A=25^\circ\text{C}$, $V_{SS}=0\text{V}$, $V_{DD}=5.12\text{V}$ @ $f_{XIN}=8\text{MHz}$, $V_{DD}=3.072\text{V}$ @ $f_{XIN}=4\text{MHz}$)

| Parameter | Symbol | Condition | Specifications | | | Unit |
|---|------------|-----------------------|----------------|------------|-----------|---------------|
| | | | Min. | Typ. | Max. | |
| Analog Input Voltage Range | V_{AIN} | AVREFS=0 | V_{SS} | - | V_{DD} | V |
| | | AVREFS=1 | V_{SS} | - | V_{REF} | |
| Analog Power Supply Input Voltage Range | V_{REF} | AVREFS=1 | 3 | - | V_{DD} | V |
| Overall Accuracy | N_{ACC} | | - | ± 1.0 | ± 1.5 | LSB |
| Non-Linearity Error | N_{NLE} | | - | ± 1.0 | ± 1.5 | LSB |
| Differential Non-Linearity Error | N_{DNLE} | | - | ± 1.0 | ± 1.5 | LSB |
| Zero Offset Error | N_{ZOE} | | - | ± 0.5 | ± 1.5 | LSB |
| Full Scale Error | N_{FSE} | | - | ± 0.25 | ± 0.5 | LSB |
| Gain Error | N_{NLE} | | - | ± 1.0 | ± 1.5 | LSB |
| Conversion Time | T_{CONV} | $f_{XIN}=8\text{MHz}$ | - | - | 10 | μS |
| | | $f_{XIN}=4\text{MHz}$ | - | - | 20 | |
| AVREF Input Current | I_{REF} | AVREFS=1 | - | 0.5 | 1.0 | mA |

7.4 DC Electrical Characteristics

($T_A = -20 \sim 85^\circ\text{C}$, $V_{DD} = 2.5 \sim 5.5\text{V}$, $V_{SS} = 0\text{V}$),

| Parameter | Symbol | Pin | Condition | Specifications | | | Unit |
|---------------------------------|-------------|-----------------------------------|--|----------------|------|--------------|---------------|
| | | | | Min. | Typ. | Max. | |
| Input High Voltage | V_{IH1} | $X_{IN}, \overline{\text{RESET}}$ | | $0.9 V_{DD}$ | - | V_{DD} | V |
| | V_{IH2} | Hysteresis Input ¹ | | $0.8 V_{DD}$ | - | V_{DD} | |
| | V_{IH3} | Normal Input | | $0.7 V_{DD}$ | - | V_{DD} | |
| Input Low Voltage | V_{IL1} | $X_{IN}, \overline{\text{RESET}}$ | | 0 | - | $0.1 V_{DD}$ | V |
| | V_{IL2} | Hysteresis Input ¹ | | 0 | - | $0.2 V_{DD}$ | |
| | V_{IL3} | Normal Input | | 0 | - | $0.3 V_{DD}$ | |
| Output High Voltage | V_{OH} | All Output Port | $V_{DD} = 5\text{V}$, $I_{OH} = -5\text{mA}$ | $V_{DD} - 1$ | - | - | V |
| Output Low Voltage | V_{OL} | All Output Port | $V_{DD} = 5\text{V}$, $I_{OL} = 10\text{mA}$ | - | - | 1 | V |
| Input Pull-up Current | I_P | RB2, RB3, RD0, RD1 | $V_{DD} = 5\text{V}$ | -550 | -420 | -200 | μA |
| Input High Leakage Current | I_{IH1} | All Pins (except X_{IN}) | $V_{DD} = 5\text{V}$ | - | - | 5 | μA |
| | I_{IH2} | X_{IN} | $V_{DD} = 5\text{V}$ | - | - | 15 | μA |
| Input Low Leakage Current | I_{IL1} | All Pins (except X_{IN}) | $V_{DD} = 5\text{V}$ | -5 | - | - | μA |
| | I_{IL2} | X_{IN} | $V_{DD} = 5\text{V}$ | -15 | - | - | μA |
| Hysteresis | $ V_T $ | Hysteresis Input ¹ | $V_{DD} = 5\text{V}$ | 0.5 | - | - | V |
| PFD Voltage | V_{PFD1} | V_{DD} | PFDM=0 | 2.5 | 3.0 | 3.5 | V |
| | V_{PFD2} | V_{DD} | PFDM=1 | 2.0 | 2.5 | 3.0 | |
| Internal RC WDT Period | T_{RCWDT} | | $V_{DD} = 5\text{V}$ | 40 | | 120 | μS |
| | | | $V_{DD} = 3\text{V}$ | 95 | | 280 | |
| Operating Current | I_{DD} | V_{DD} | $V_{DD} = 5.5\text{V}$, $f_{XIN} = 8\text{MHz}$ | - | 5 | 6 | mA |
| | | | $V_{DD} = 3.0\text{V}$, $f_{XIN} = 4\text{MHz}$ | - | 2 | 3 | |
| Wake-up Timer Mode Current | I_{WKUP} | V_{DD} | $V_{DD} = 5.5\text{V}$, $f_{XIN} = 8\text{MHz}$ | - | 1 | 2 | mA |
| | | | $V_{DD} = 3.0\text{V}$, $f_{XIN} = 4\text{MHz}$ | - | 0.5 | 1 | |
| RCWDT Mode Current at STOP Mode | I_{RCWDT} | V_{DD} | $V_{DD} = 5.5\text{V}$, $f_{XIN} = 8\text{MHz}$ | - | - | 200 | μA |
| | | | $V_{DD} = 3.0\text{V}$, $f_{XIN} = 4\text{MHz}$ | - | - | 100 | |
| Stop Mode Current | I_{STOP} | V_{DD} | $V_{DD} = 5.5\text{V}$, $f_{XIN} = 8\text{MHz}$ | - | 0.5 | 3 | μA |
| | | | $V_{DD} = 3.0\text{V}$, $f_{XIN} = 4\text{MHz}$ | - | 0.2 | 1 | |

1. Hysteresis Input: RA0, RB2, RB3, RB6, RC3, RC4, RC5, RD0, RD1

7.5 AC Characteristics

($T_A = -20 \sim +85^\circ\text{C}$, $V_{DD} = 5\text{V} \pm 10\%$, $V_{SS} = 0\text{V}$)

| Parameter | Symbol | Pins | Specifications | | | Unit |
|--------------------------------------|--------------------|------------------------------------|----------------|------|------|------|
| | | | Min. | Typ. | Max. | |
| Operating Frequency | f_{CP} | X_{IN} | 1 | - | 8 | MHz |
| External Clock Pulse Width | t_{CPW} | X_{IN} | 80 | - | - | nS |
| External Clock Transition Time | t_{RCP}, t_{FCP} | X_{IN} | - | - | 20 | nS |
| Oscillation Stabilizing Time | t_{ST} | X_{IN}, X_{OUT} | - | - | 20 | mS |
| External Input Pulse Width | t_{EPW} | INT0, INT1, INT2, INT3 EC0, EC1 | 2 | - | - | tsys |
| External Input Pulse Transition Time | t_{REP}, t_{FEP} | INT0, INT1, INT2, INT3 EC0, EC1 | - | - | 20 | nS |
| RESET Input Width | t_{RST} | RESET | 8 | - | - | tsys |

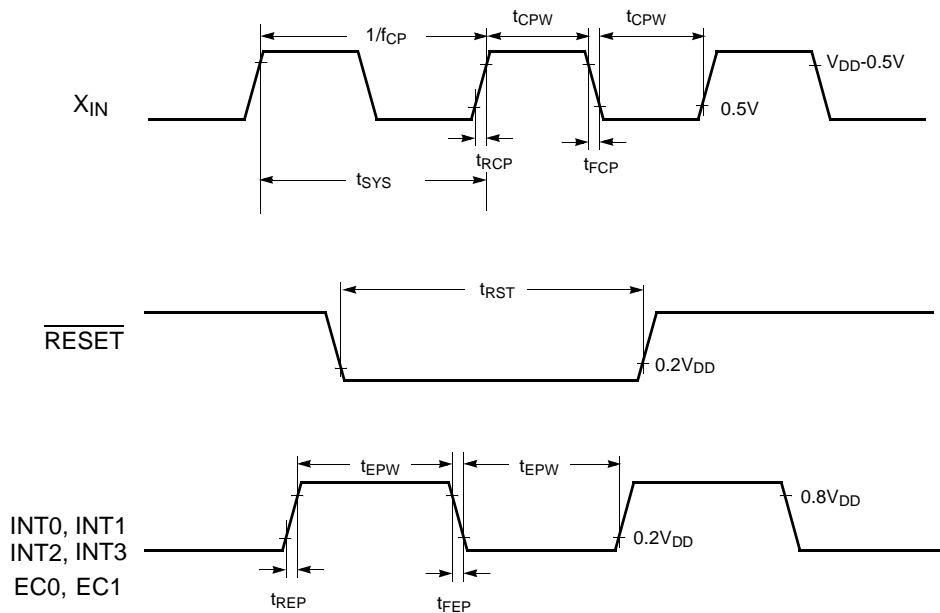


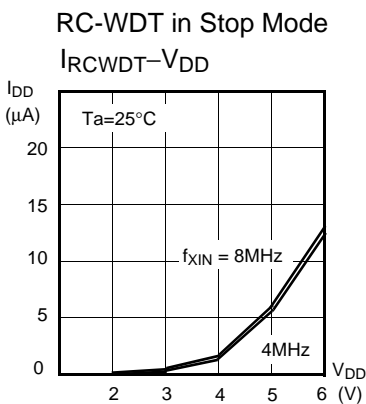
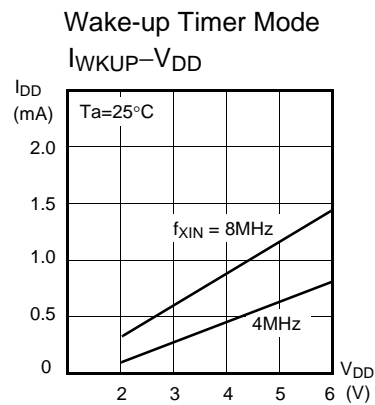
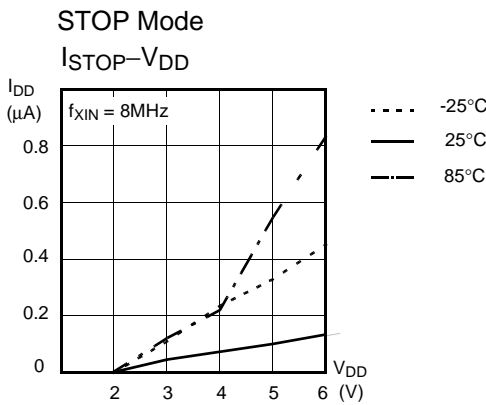
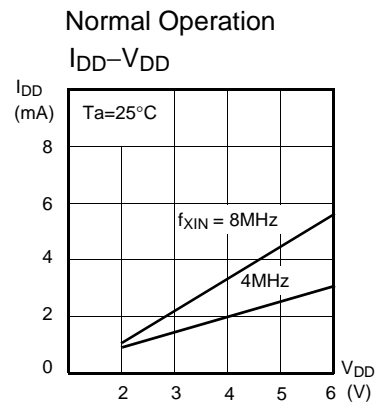
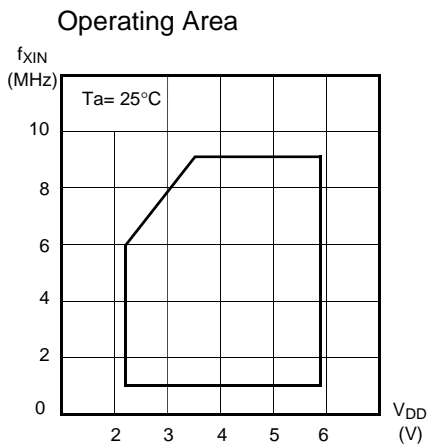
Figure 7-1 Timing Chart

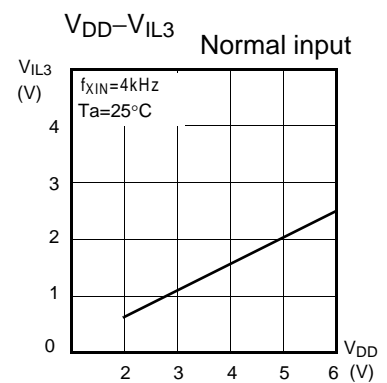
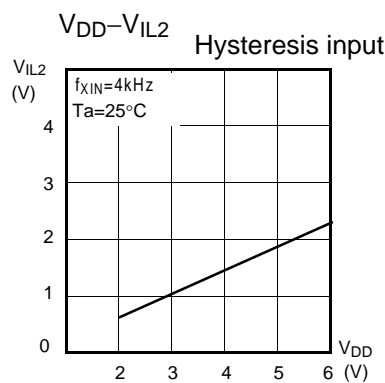
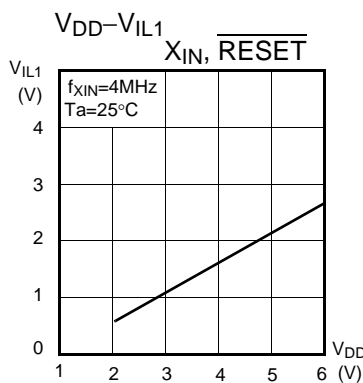
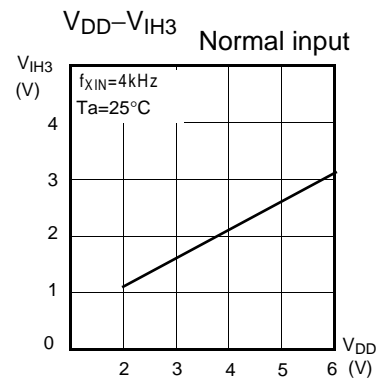
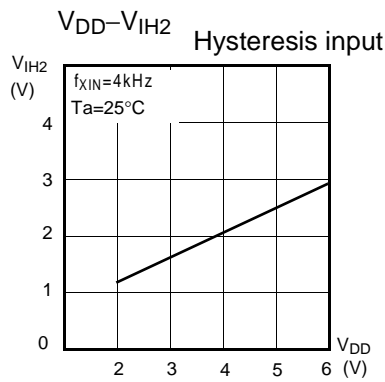
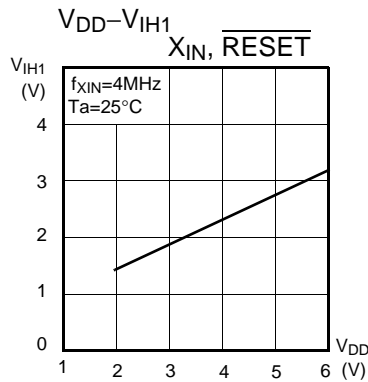
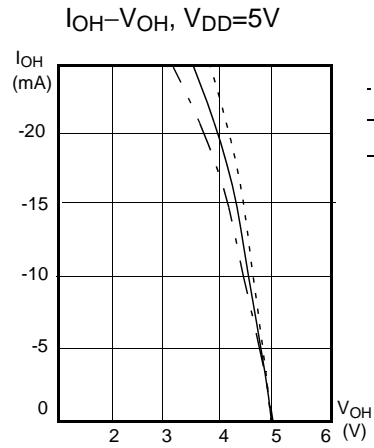
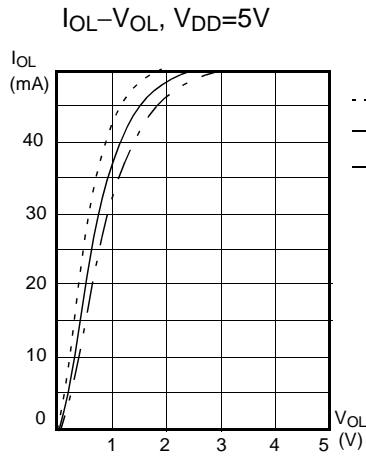
7.6 Typical Characteristics

This graphs and tables provided in this section are for design guidance only and are not tested or guaranteed.

In some graphs or tables the data presented are outside specified operating range (e.g. outside specified V_{DD} range). This is for information only and devices are guaranteed to operate properly only within the specified range.

The data presented in this section is a statistical summary of data collected on units from different lots over a period of time. “Typical” represents the mean of the distribution while “max” or “min” represents (mean + 3σ) and (mean - 3σ) respectively where σ is standard deviation





8. MEMORY ORGANIZATION

The GMS87C1404 and GMS87C1408 have separate address spaces for Program memory and Data Memory. Program memory can only be read, not written to. It can be up

to 4K /8K bytes of Program memory. Data memory can be read and written to up to 192 bytes including the stack area.

8.1 Registers

This device has six registers that are the Program Counter (PC), a Accumulator (A), two index registers (X, Y), the Stack Pointer (SP), and the Program Status Word (PSW). The Program Counter consists of 16-bit register.

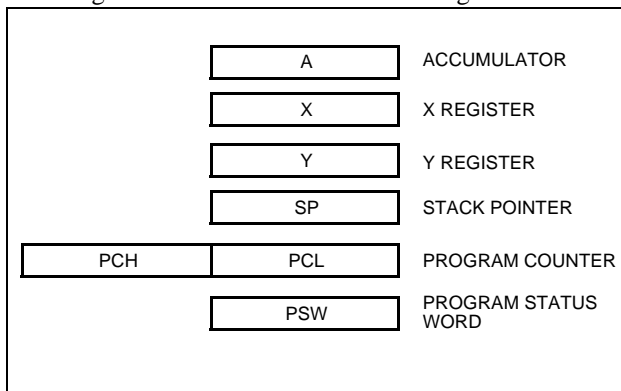


Figure 8-1 Configuration of Registers

Accumulator: The Accumulator is the 8-bit general purpose register, used for data operation such as transfer, temporary saving, and conditional judgement, etc.

The Accumulator can be used as a 16-bit register with Y Register as shown below.

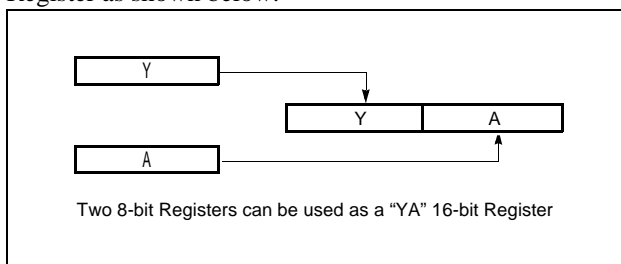


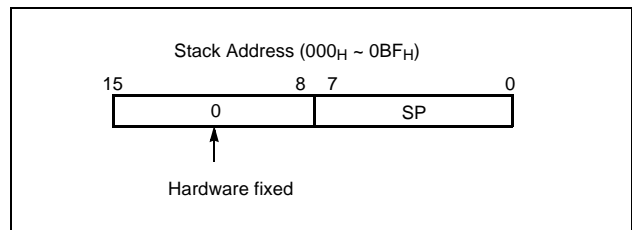
Figure 8-2 Configuration of YA 16-bit Register

X, Y Registers: In the addressing mode which uses these index registers, the register contents are added to the specified address, which becomes the actual address. These modes are extremely effective for referencing subroutine tables and memory tables. The index registers also have increment, decrement, comparison and data transfer functions, and they can be used as simple accumulators.

Stack Pointer: The Stack Pointer is an 8-bit register used for occurrence interrupts and calling out subroutines. Stack Pointer identifies the location in the stack to be accessed (save or restore).

Generally, SP is automatically updated when a subroutine call is executed or an interrupt is accepted. However, if it is used in excess of the stack area permitted by the data memory allocating configuration, the user-processed data may be lost.

The stack can be located at any position within 00H to BFH of the internal data memory. The SP is not initialized by hardware, requiring to write the initial value (the location with which the use of the stack starts) by using the initialization routine. Normally, the initial value of "BFH" is used.



Note: The Stack Pointer must be initialized by software because its value is undefined after RESET.

```
Example: To initialize the SP
LDX    #0BFH
TXSP                      ; SP ← BFH
```

Program Counter: The Program Counter is a 16-bit wide which consists of two 8-bit registers, PCH and PCL. This counter indicates the address of the next instruction to be executed. In reset state, the program counter has reset routine address (PCH:0FFH, PCL:0FEH).

Program Status Word: The Program Status Word (PSW) contains several bits that reflect the current state of the CPU. The PSW is described in Figure 8-3 . It contains the Negative flag, the Overflow flag, the Break flag the Half Carry (for BCD operation), the Interrupt enable flag, the Zero flag, and the Carry flag.

[Carry flag C]

This flag stores any carry or borrow from the ALU of CPU after an arithmetic operation and is also changed by the Shift Instruction or Rotate Instruction.

[Zero flag Z]

This flag is set when the result of an arithmetic operation or data transfer is "0" and is cleared by any other result.

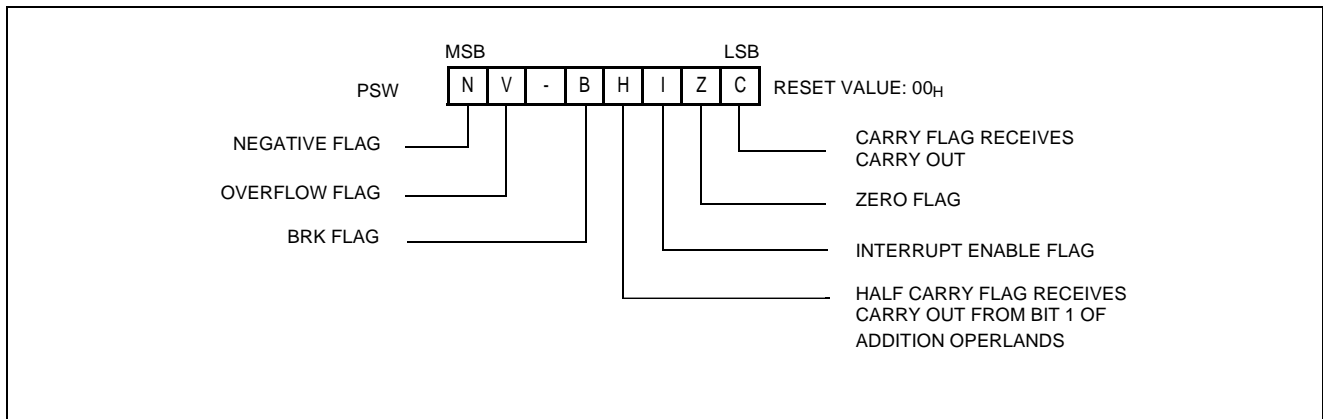


Figure 8-3 PSW (Program Status Word) Register

[Interrupt disable flag I]

This flag enables/disables all interrupts except interrupt caused by Reset or software BRK instruction. All interrupts are disabled when cleared to “0”. This flag immediately becomes “0” when an interrupt is served. It is set by the EI instruction and cleared by the DI instruction.

[Half carry flag H]

After operation, this is set when there is a carry from bit 3 of ALU or there is no borrow from bit 4 of ALU. This bit can not be set or cleared except CLRV instruction with Overflow flag (V).

[Break flag B]

This flag is set by software BRK instruction to distinguish BRK from TCALL instruction with the same vector address.

dress.

[Overflow flag V]

This flag is set to “1” when an overflow occurs as the result of an arithmetic operation involving signs. An overflow occurs when the result of an addition or subtraction exceeds +127(7FH) or -128(80H). The CLRV instruction clears the overflow flag. There is no set instruction. When the BIT instruction is executed, bit 6 of memory is copied to this flag.

[Negative flag N]

This flag is set to match the sign bit (bit 7) status of the result of a data or arithmetic operation. When the BIT instruction is executed, bit 7 of memory is copied to this flag.

8.2 Program Memory

A 16-bit program counter is capable of addressing up to 64K bytes, but these devices have 4K/8K bytes program memory space only physically implemented. Accessing a location above FFFF_H will cause a wrap-around to 0000_H.

Figure 8-4 , shows a map of Program Memory. After reset, the CPU begins execution from reset vector which is stored in address FFFE_H and FFFF_H as shown in Figure 8-5 .

As shown in Figure 8-4 , each area is assigned a fixed location in Program Memory. Program Memory area contains the user program.

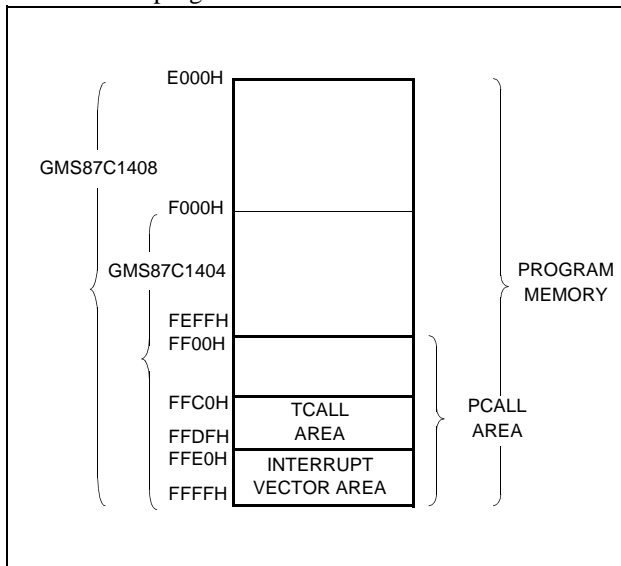


Figure 8-4 Program Memory Map

Page Call (PCALL) area contains subroutine program to reduce program byte length by using 2 bytes PCALL instead of 3 bytes CALL instruction. If it is frequently called, it is more useful to save program byte length.

Table Call (TCALL) causes the CPU to jump to each TCALL address, where it commences the execution of the service routine. The Table Call service area spaces 2-byte for every TCALL: 0FFC0_H for TCALL15, 0FFC2_H for TCALL14, etc., as shown in Figure 8-6 .

Example: Usage of TCALL

```

LDA    #5
      TCALL 0FH           ; 1BYTE INSTRUCTION
      :                ; INSTEAD OF 3 BYTES
      :                ; NORMAL CALL
;
; TABLE CALL ROUTINE
;
FUNC_A: LDA    LRG0
      RET
;
FUNC_B: LDA    LRG1
      RET
;
; TABLE CALL ADD. AREA
;
      ORG    0FFC0H
      DW    FUNC_A
      DW    FUNC_B
    
```

The interrupt causes the CPU to jump to specific location, where it commences the execution of the service routine. The External interrupt 0, for example, is assigned to location 0FFFA_H. The interrupt service locations spaces 2-byte interval: 0FFF8_H and 0FFF9_H for External Interrupt 1, 0FFFA_H and 0FFFB_H for External Interrupt 0, etc.

As for the area from 0FF00_H to 0FFFF_H, if any area of them is not going to be used, its service location is available as general purpose Program Memory.

| Address | Vector Area Memory |
|--------------------|---|
| 0FFE0 _H | - |
| E2 | - |
| E4 | Serial Peripheral Interface Interrupt Vector Area |
| E6 | Basic Interval Interrupt Vector Area |
| E8 | Watchdog Timer Interrupt Vector Area |
| EA | A/D Converter Interrupt Vector Area |
| EC | Timer/Counter 3 Interrupt Vector Area |
| EE | Timer/Counter 2 Interrupt Vector Area |
| F0 | External Interrupt 3 Vector Area |
| F2 | External Interrupt 2 Vector Area |
| F4 | Timer/Counter 1 Interrupt Vector Area |
| F6 | Timer/Counter 0 Interrupt Vector Area |
| F8 | External Interrupt 1 Vector Area |
| FA | External Interrupt 0 Vector Area |
| FC | - |
| FE | RESET Vector Area |

NOTE:
 “-” means reserved area.

Figure 8-5 Interrupt Vector Area

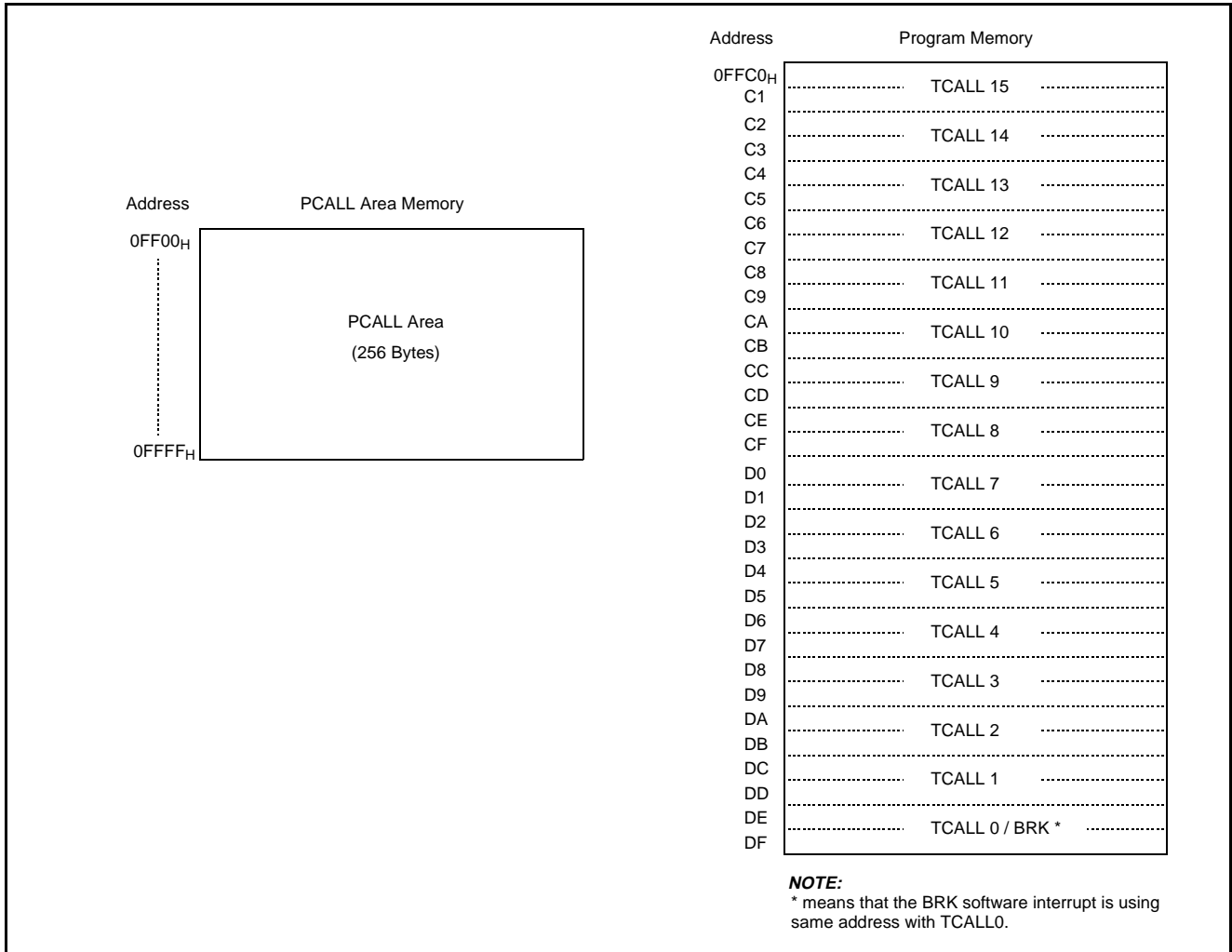
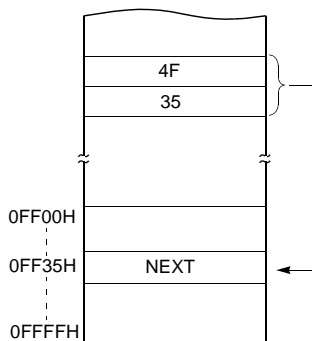


Figure 8-6 PCALL and TCALL Memory Area

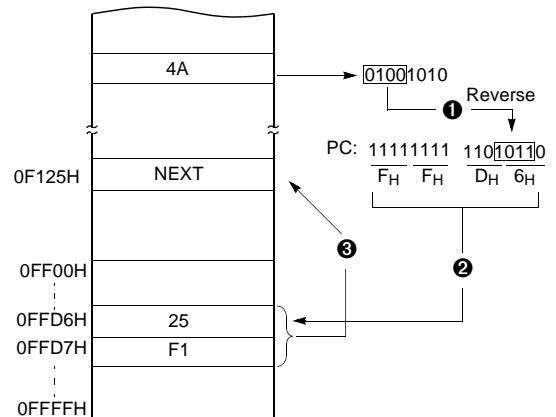
PCALL → rel

4F35 PCALL 35H



TCALL → n

4A TCALL 4



Example: The usage software example of Vector address and the initialize part.

```

ORG    0FFE0H

DW     NOT_USED           ; (0FFE0)
DW     NOT_USED           ; (0FFE2)
DW     SPI_INT            ; (0FFE4) Serial Peripheral Interface
DW     BIT_INT            ; (0FFE6) Basic Interval Timer
DW     WDT_INT            ; (0FFE8) Watchdog Timer
DW     AD_INT             ; (0FFEA) A/D
DW     TMR3_INT           ; (0FFEC) Timer-3
DW     TMR2_INT           ; (0FFEE) Timer-2
DW     INT3               ; (0FFF0) Int.3
DW     INT2               ; (0FFF2) Int.2
DW     TMR1_INT           ; (0FFF4) Timer-1
DW     TMR0_INT           ; (0FFF6) Timer-0
DW     INT1               ; (0FFF8) Int.1
DW     INT0               ; (0FFFA) Int.0
DW     NOT_USED           ; (0FFFC)
DW     RESET              ; (0FFFE) Reset

ORG    0F000H

;*****
;          MAIN          PROGRAM          *
;*****
;
RESET:   DI                ;Disable All Interrupts
        LDX #0
RAM_CLR: LDA #0            ;RAM Clear(!0000H->!00BFH)
        STA {X}+
        CMPX #0COH
        BNE RAM_CLR
;
        LDX #0BFH         ;Stack Pointer Initialize
        TXSP
;
        CALL INITIAL      ;
;
        LDM RA, #0        ;Normal Port A
        LDM RAIO,#1000_0010B ;Normal Port Direction
        LDM RB, #0        ;Normal Port B
        LDM RBIO,#1000_0010B ;Normal Port Direction
        :
        :
        LDM PFDR,#0      ;Enable Power Fail Detector
        :
        :

```

8.3 Data Memory

Figure 8-7 shows the internal Data Memory space available. Data Memory is divided into two groups, a user RAM (including Stack) and control registers.

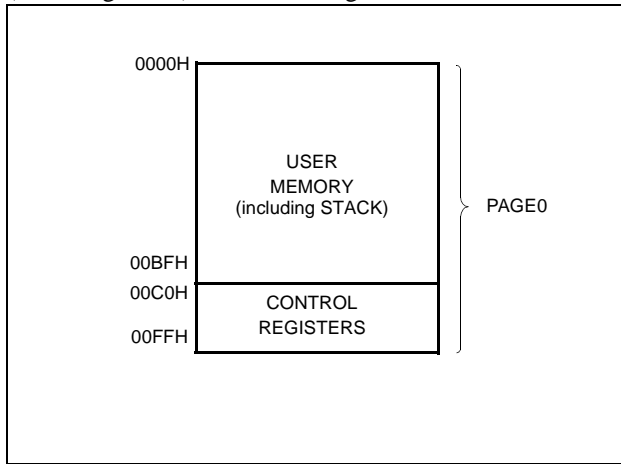


Figure 8-7 Data Memory Map

User Memory

The GMS87C1404 and GMS87C1408 has 192 × 8 bits for the user memory (RAM).

Control Registers

The control registers are used by the CPU and Peripheral function blocks for controlling the desired operation of the device. Therefore these registers contain control and status bits for the interrupt system, the timer/ counters, analog to digital converters and I/O ports. The control registers are in address range of 0C0H to 0FFH.

Note that unoccupied addresses may not be implemented on the chip. Read accesses to these addresses will in general return random data, and write accesses will have an indeterminate effect.

More detailed informations of each register are explained in each peripheral section.

Note: Write only registers can not be accessed by bit manipulation instruction. Do not use read-modify-write instruction. Use byte manipulation instruction.

Example; To write at CKCTRL

```
LDM CKCTRL, #09H ;Divide ratio +16
```

| Address | Symbol | R/W | RESET Value | Addressing mode |
|---------|--------|-----|-------------|------------------------|
| 0C0H | RA | R/W | Undefined | byte, bit ¹ |
| 0C1H | RAIO | R/W | 0000_0000 | byte ² |
| 0C2H | RB | R/W | Undefined | byte, bit |
| 0C3H | RBIO | R/W | 00000000 | byte |
| 0C4H | RC | R/W | Undefined | byte, bit |
| 0C5H | RCIO | R/W | -000_0--- | byte |
| 0C6H | RD | R/W | Undefined | byte, bit |
| 0C7H | RDIO | W | ----_000 | byte |
| 0CAH | RAFUNC | W | 0000_0000 | byte |
| 0CBH | RBFUNC | W | 0000_0000 | byte |
| 0CCH | PUPSEL | W | ----_0000 | byte |
| 0CDH | RDFUNC | W | ----_--00 | byte |
| 0D0H | TM0 | R/W | --00_0000 | byte, bit |
| 0D1H | T0 | R | 0000_0000 | byte |
| 0D1H | TDR0 | W | 1111_1111 | byte |
| 0D1H | CDR0 | R | 0000_0000 | byte |
| 0D2H | TM1 | R/W | 0000_0000 | byte, bit |
| 0D3H | TDR1 | W | 1111_1111 | byte |
| 0D3H | T1PPR | W | 1111_1111 | byte |
| 0D4H | T1 | R | 0000_0000 | byte |
| 0D4H | CDR1 | R | 0000_0000 | byte |
| 0D4H | T1PDR | R/W | 0000_0000 | byte, bit |
| 0D5H | PWM0HR | W | ----_0000 | byte |
| 0D6H | TM2 | R/W | --00_0000 | byte, bit |
| 0D7H | T2 | R | 0000_0000 | byte |
| 0D7H | TDR2 | W | 1111_1111 | byte |
| 0D7H | CDR2 | R | 0000_0000 | byte |
| 0D8H | TM3 | R/W | 0000_0000 | byte, bit |
| 0D9H | TDR3 | W | 1111_1111 | byte |
| 0D9H | T3PPR | W | 1111_1111 | byte |
| 0DAH | T3 | R | 0000_0000 | byte |
| 0DAH | CDR3 | R | 0000_0000 | byte |
| 0DAH | T3PDR | R/W | 0000_0000 | byte, bit |
| 0DBH | PWM1HR | W | ----_0000 | byte |
| 0DEH | BUR | W | 1111_1111 | byte |
| 0E0H | SIOM | R/W | 0000_0001 | byte, bit |
| 0E1H | SIOR | R/W | Undefined | byte, bit |
| 0E2H | IENH | R/W | 0000_0000 | byte, bit |
| 0E3H | IENL | R/W | 0000_---- | byte, bit |
| 0E4H | IRQH | R/W | 0000_0000 | byte, bit |
| 0E5H | IRQL | R/W | 0000_---- | byte, bit |
| 0E6H | IEDS | R/W | 0000_0000 | byte, bit |
| 0EAH | ADCM | R/W | --00_0001 | byte, bit |
| 0EBH | ADCR | R | Undefined | byte |
| 0ECH | BITR | R | 0000_0000 | byte |
| 0ECH | CKCTRL | W | -001_0111 | byte |
| 0EDH | WDTR | R | 0000_0000 | byte |
| 0EDH | WDTR | W | 0111_1111 | byte |
| 0EFH | PFDR | R/W | ----_100 | byte, bit |

Table 8-1 Control Registers

1. "byte, bit" means that register can be addressed by not only bit but byte manipulation instruction.
2. "byte" means that register can be addressed by only byte manipulation instruction. On the other hand, do not use any read-modify-write instruction such as bit manipulation for clearing bit.

Note: Several names are given at same address. Refer to below table.

| Addr. | When read | | | When write | |
|-------|------------|--------------|----------|------------|----------|
| | Timer Mode | Capture Mode | PWM Mode | Timer Mode | PWM Mode |
| D1H | T0 | CDR0 | - | TDR0 | - |
| D3H | - | | | TDR1 | T1PPR |
| D4H | T1 | CDR1 | T1PDR | - | T1PDR |
| D7H | T2 | CDR2 | - | TDR2 | - |
| D9H | - | | | TDR3 | T3PPR |
| DAH | T3 | CDR3 | T3PDR | - | T3PDR |
| ECH | BITR | | | CKCLR | |

Table 8-2 Various Register Name in Same Address

Stack Area

The stack provides the area where the return address is saved before a jump is performed during the processing routine at the execution of a subroutine call instruction or the acceptance of an interrupt.

When returning from the processing routine, executing the subroutine return instruction [RET] restores the contents of the program counter from the stack; executing the interrupt return instruction [RETI] restores the contents of the program counter and flags.

The save/restore locations in the stack are determined by the stack pointed (SP). The SP is automatically decreased after the saving, and increased before the restoring. This means the value of the SP indicates the stack location number for the next save.

| Address | Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|---------|-------------------|---|--------|--------|--------|---------|---------|---------|---------|
| C0H | RA | RA Port Data Register | | | | | | | |
| C1H | RAIO | RA Port Direction Register | | | | | | | |
| C2H | RB | RB Port Data Register | | | | | | | |
| C3H | RBIO | RB Port Direction Register | | | | | | | |
| C4H | RC | RC Port Data Register | | | | | | | |
| C5H | RCIO | RC Port Direction Register | | | | | | | |
| C6H | RD | RD Port Data Register | | | | | | | |
| C7H | RDIO | RD Port Direction Register | | | | | | | |
| CAH | RAFUNC | ANSEL7 | ANSEL6 | ANSEL5 | ANSEL4 | ANSEL3 | ANSEL2 | ANSEL1 | ANSEL0 |
| CBH | RBFUNC | TMR2OV | EC1I | PWM1O | PWM0O | INT1I | INT0I | BUZO | AVREFS |
| CCH | PUPSEL | - | - | - | - | PUPSEL3 | PUPSEL2 | PUPSEL1 | PUPSEL0 |
| CDH | RDFUNC | - | - | - | - | - | - | INT3I | INT2I |
| D0H | TM0 | - | - | CAP0 | T0CK2 | T0CK1 | T0CK0 | T0CN | T0ST |
| D1H | T0/TDR0/ CDR0 | Timer0 Register / Timer0 Data Register / Capture0 Data Register | | | | | | | |
| D2H | TM1 | POL | 16BIT | PWM0E | CAP1 | T1CK1 | T1CK0 | T1CN | T1ST |
| D3H | TDR1/ T1PPR | Timer1 Data Register / PWM0 Period Register | | | | | | | |
| D4H | T1/CDR1/ T1PDR | Timer1 Register / Capture1 Data Register / PWM0 Duty Register | | | | | | | |
| D5H | PWM0HR | PWM0 High Register | | | | | | | |
| D6H | TM2 | - | - | CAP2 | T2CK2 | T2CK1 | T2CK0 | T2CN | T2ST |
| D7H | T2/TDR2/ CDR2 | Timer2 Register / Timer2 Data Register / Capture2 Data Register | | | | | | | |
| D8H | TM3 | POL | 16BIT | PWM1E | CAP3 | T3CK1 | T3CK0 | T3CN | T3ST |
| D9H | TDR3/ T3PPR | Timer3 Data Register / PWM1 Period Register | | | | | | | |
| DAH | T3/CDR3/ T3PDR | Timer3 Register / Capture3 Data Register / PWM1Duty Register | | | | | | | |
| DBH | PWM1HR | PWM1 High Register | | | | | | | |
| DEH | BUR | BUCK1 | BUCK0 | BUR5 | BUR4 | BUR3 | BUR2 | BUR1 | BUR0 |
| E0H | SIOM | POL | SRDY | SM1 | SM0 | SCK1 | SCK0 | SIOST | SIOF |
| E1H | SIOR | SPI DATA REGISTER | | | | | | | |
| E2H | IENH | INT0E | INT1E | T0E | T1E | INT2E | INT3E | T2E | T3E |
| E3H | IENL | ADE | WDTE | BITE | SPIE | - | - | - | - |
| E4H | IRQH | INT0IF | INT1IF | T0IF | T1IF | INT2IF | INT3IF | T2IF | T3IF |
| E5H | IRQL | ADIF | WDTIF | BITIF | SPIF | - | - | - | - |
| E6H | IEDS | IED3H | IED3L | IED2H | IED2L | IED1H | IED1L | IED0H | IED0L |

Table 8-3 Control Registers of GMS87C1408 and GMS87C1404

These registers of shaded area can not be accessed by bit manipulation instruction as "SET1, CLR1", but should be accessed by register operation instruction as "LDM dp,#imm".

| | | | | | | | | | |
|-----|---------------------|------------------------------------|---------------------------------|-------|-------|------|-------|------|------|
| EAH | ADCM | - | - | ADEN | ADS2 | ADS1 | ADS0 | ADST | ADSF |
| EBH | ADCR | ADC Result Data Register | | | | | | | |
| ECH | BITR ¹ | Basic Interval Timer Data Register | | | | | | | |
| ECH | CKCTLR ¹ | - | WAKEUP | RCWDT | WDTON | BTCL | BTS2 | BTS1 | BTS0 |
| EDH | WDTR | WDTCL | 7-bit Watchdog Counter Register | | | | | | |
| EFH | PFDR ² | - | - | - | - | - | PFDIS | PFDM | PFDS |

Table 8-3 Control Registers of GMS87C1408 and GMS87C1404

These registers of shaded area can not be accessed by bit manipulation instruction as "SET1, CLR1", but should be accessed by register operation instruction as "LDM dp,#imm".

1. The register BITR and CKCTLR are located at same address. Address ECH is read as BITR, written to CKCTLR.
2. The register PFDR only be implemented on devices, not on In-circuit Emulator.

8.4 Addressing Mode

The GMS87C1404 and GMS87C1408 uses six addressing modes;

- Register addressing
- Immediate addressing
- Direct page addressing
- Absolute addressing
- Indexed addressing
- Register-indirect addressing

(1) Register Addressing

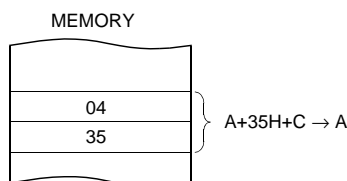
Register addressing accesses the A, X, Y, C and PSW.

(2) Immediate Addressing → #imm

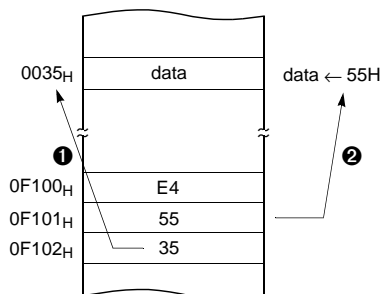
In this mode, second byte (operand) is accessed as a data immediately.

Example:

```
0435   ADC   #35H
```



```
E45535  LDM   35H, #55H
```

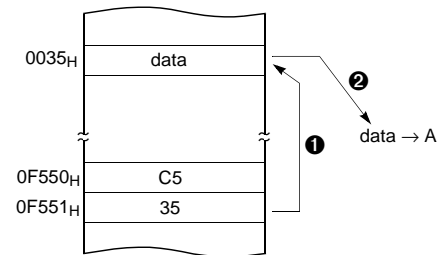


(3) Direct Page Addressing → dp

In this mode, a address is specified within direct page.

Example;

```
C535   LDA   35H           ;A ←RAM[ 35H]
```



(4) Absolute Addressing → !abs

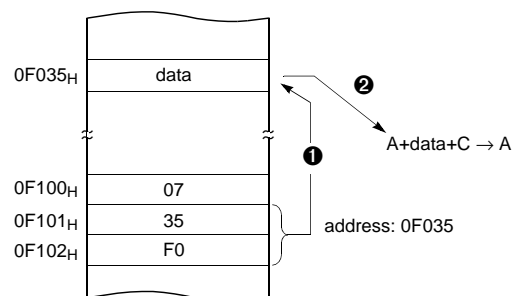
Absolute addressing sets corresponding memory data to Data, i.e. second byte(Operand I) of command becomes lower level address and third byte (Operand II) becomes upper level address.

With 3 bytes command, it is possible to access to whole memory area.

ADC, AND, CMP, CMPX, CMPY, EOR, LDA, LDX, LDY, OR, SBC, STA, STX, STY

Example;

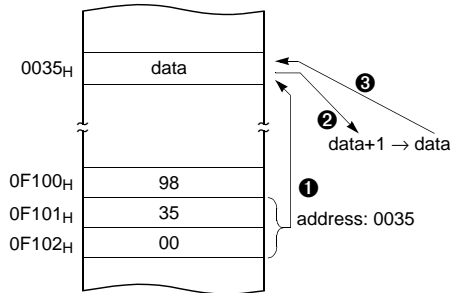
```
0735F0  ADC   !0F035H     ;A ←ROM[0F035H]
```



The operation within data memory (RAM)
ASL, BIT, DEC, INC, LSR, ROL, ROR

Example; Addressing accesses the address 0135H.

```
983500 INC !0035H ;A ←RAM[035H]
```



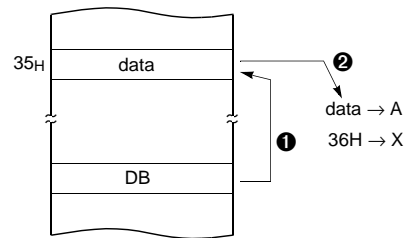
X indexed direct page, auto increment → {X}+

In this mode, a address is specified within direct page by the X register and the content of X is increased by 1.

LDA, STA

Example; X=35H

```
DB LDA {X}+
```



(5) Indexed Addressing

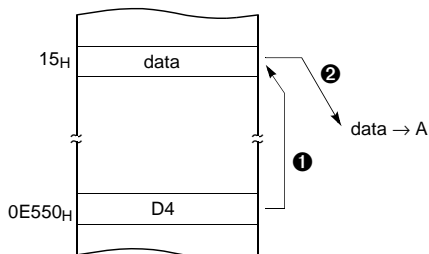
X indexed direct page (no offset) → {X}

In this mode, a address is specified by the X register.

ADC, AND, CMP, EOR, LDA, OR, SBC, STA, XMA

Example; X=15H

```
D4 LDA {X} ;ACC←RAM[X].
```



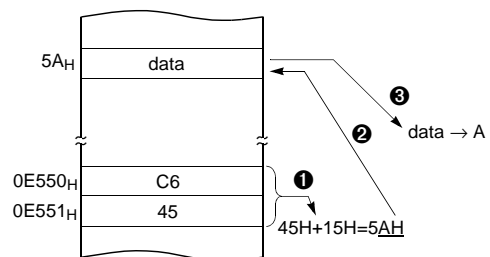
X indexed direct page (8 bit offset) → dp+X

This address value is the second byte (Operand) of command plus the data of X-register. And it assigns the memory in Direct page.

ADC, AND, CMP, EOR, LDA, LDY, OR, SBC, STA STY, XMA, ASL, DEC, INC, LSR, ROL, ROR

Example; X=015H

```
C645 LDA 45H+X
```



Y indexed direct page (8 bit offset) → dp+Y

This address value is the second byte (Operand) of command plus the data of Y-register, which assigns Memory in Direct page.

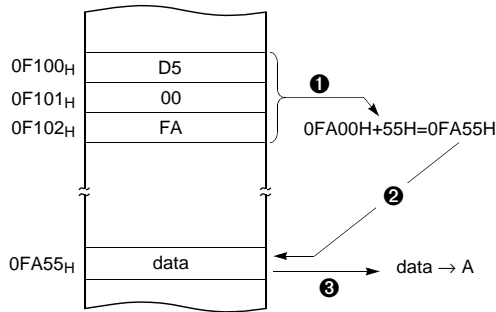
This is same with above (2). Use Y register instead of X.

Y indexed absolute →!abs+Y

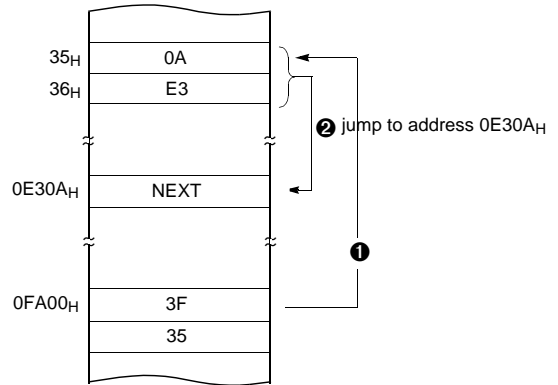
Sets the value of 16-bit absolute address plus Y-register data as Memory. This addressing mode can specify memory in whole area.

Example; Y=55H

```
D500FA LDA !0FA00H+Y
```



```
3F35 JMP [35H]
```



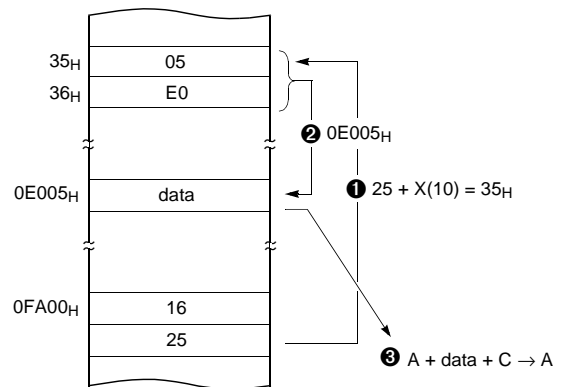
X indexed indirect → [dp+X]

Processes memory data as Data, assigned by 16-bit pair memory which is determined by pair data [dp+X+1][dp+X] Operand plus X-register data in Direct page.

ADC, AND, CMP, EOR, LDA, OR, SBC, STA

Example; X=10H

```
1625 ADC [25H+X]
```



(6) Indirect Addressing

Direct page indirect → [dp]

Assigns data address to use for accomplishing command which sets memory data(or pair memory) by Operand. Also index can be used with Index register X, Y.

JMP, CALL

Example;

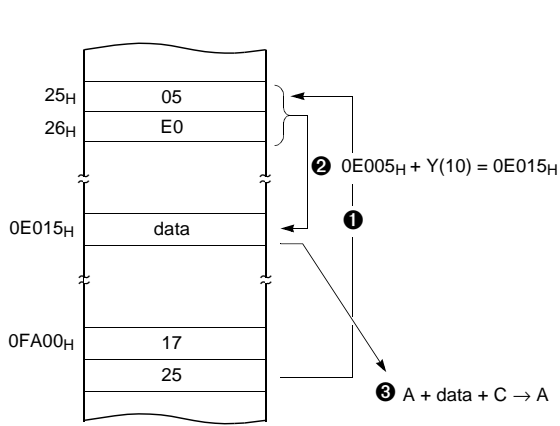
Y indexed indirect → [dp]+Y

Processes memory data as Data, assigned by the data [dp+1][dp] of 16-bit pair memory paired by Operand in Direct page plus Y-register data.

ADC, AND, CMP, EOR, LDA, OR, SBC, STA

Example; Y=10H

```
1725   ADC   [25H]+Y
```



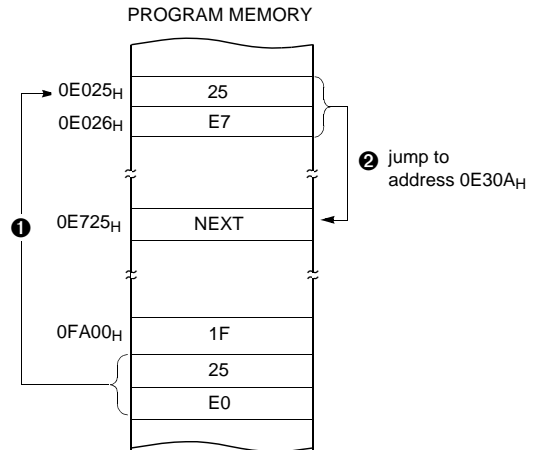
Absolute indirect → [!abs]

The program jumps to address specified by 16-bit absolute address.

JMP

Example;

```
1F25E0   JMP   [!0C025H]
```



9. I/O PORTS

The GMS87C1408 and GMS87C1404 has four ports, RA, RB, RC and RD. These ports pins may be multiplexed with an alternate function for the peripheral features on the device. In general, when a initial reset state, all ports are used as a general purpose input port.

All pins have data direction registers which can set these ports as output or input. A "1" in the port direction register defines the corresponding port pin as output. Conversely, write "0" to the corresponding bit to specify as an input pin. For example, to use the even numbered bit of RA as output ports and the odd numbered bits as input ports, write "55H" to address C1H (RA direction register) during initial setting as shown in Figure 9-1 .

Reading data register reads the status of the pins whereas writing to it will write to the port latch.

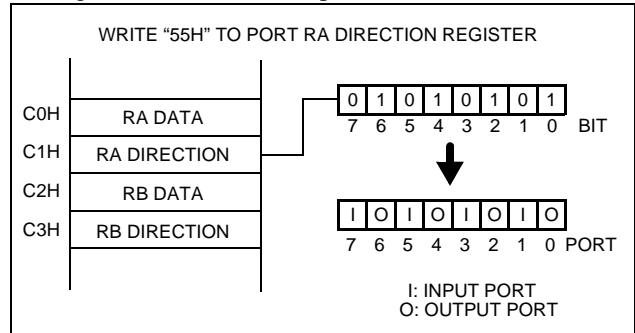


Figure 9-1 Example of port I/O assignment

9.1 RA and RAIO registers

RA is an 8-bit bidirectional I/O port (address C0H). Each port can be set individually as input and output through the RAIO register (address C1H).

RA7~RA1 ports are multiplexed with Analog Input Port (AN7~AN1) and RA0 port is multiplexed with Event Counter Input Port (ECO).

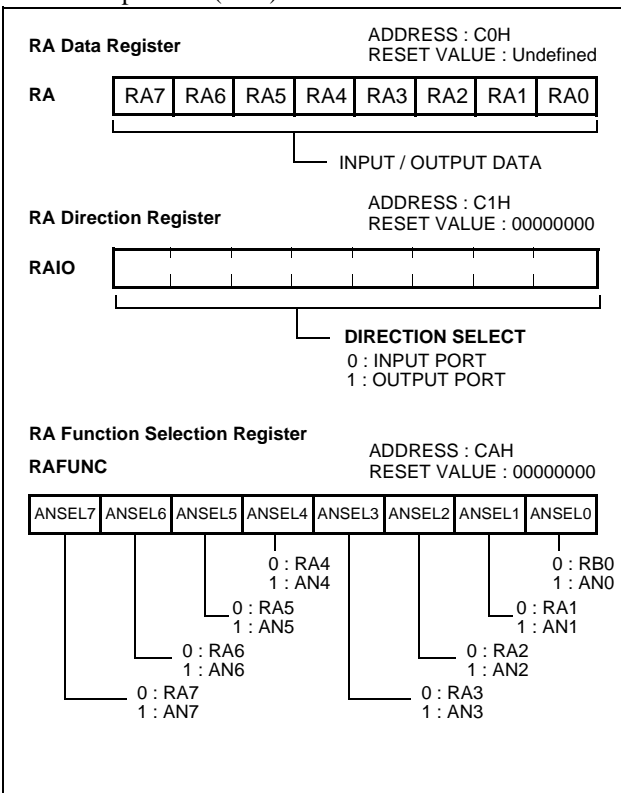


Figure 9-2 Registers of Port RA

The control register RAFUNC (address CAH) controls to

select alternate function. After reset, this value is "0", port may be used as general I/O ports. To select alternate function such as Analog Input or External Event Counter Input, write "1" to the corresponding bit of RAFUNC. Regardless of the direction register RAIO, RAFUNC is selected to use as alternate functions, port pin can be used as a corresponding alternate features (RA0/ECO is controlled by RB-FUNC)

| PORT | RAFUNC.7-0 | Description |
|----------------------|------------|-----------------------|
| RA7/AN7 | 0 | RA7 (Normal I/O Port) |
| | 1 | AN7 (ADS2-0=111) |
| RA6/AN6 | 0 | RA6 (Normal I/O Port) |
| | 1 | AN6 (ADS2-0=110) |
| RA5/AN5 | 0 | RA5 (Normal I/O Port) |
| | 1 | AN5 (ADS2-0=101) |
| RA4/AN4 | 0 | RA4 (Normal I/O Port) |
| | 1 | AN4 (ADS2-0=100) |
| RA3/AN3 | 0 | RA3 (Normal I/O Port) |
| | 1 | AN3 (ADS2-0=011) |
| RA2/AN2 | 0 | RA2 (Normal I/O Port) |
| | 1 | AN2 (ADS2-0=010) |
| RA1/AN1 | 0 | RA1 (Normal I/O Port) |
| | 1 | AN1 (ADS2-0=001) |
| RA0/ECO ¹ | | RA0 (Normal I/O Port) |
| | | ECO (TOCK2-0=111) |

1. This port is not an Analog Input port, but Event Counter clock source input port. ECO is controlled by setting TOCK2-0 = 111. The bit RAFUNC.0 (ANSEL0) controls the RB0/AN0/AVref port (Refer to Port RB).

9.2 RB and RBIO registers

RB is a 5-bit bidirectional I/O port (address C2_H). Each pin can be set individually as input and output through the RBIO register (address C3_H). In addition, Port RB is multiplexed with various special features. The control register RBFUNC (address CB_H) controls to select alternate func-

tion. After reset, this value is “0”, port may be used as general I/O ports. To select alternate function such as External interrupt or Timer compare output, write “1” to the corresponding bit of RBFUNC.

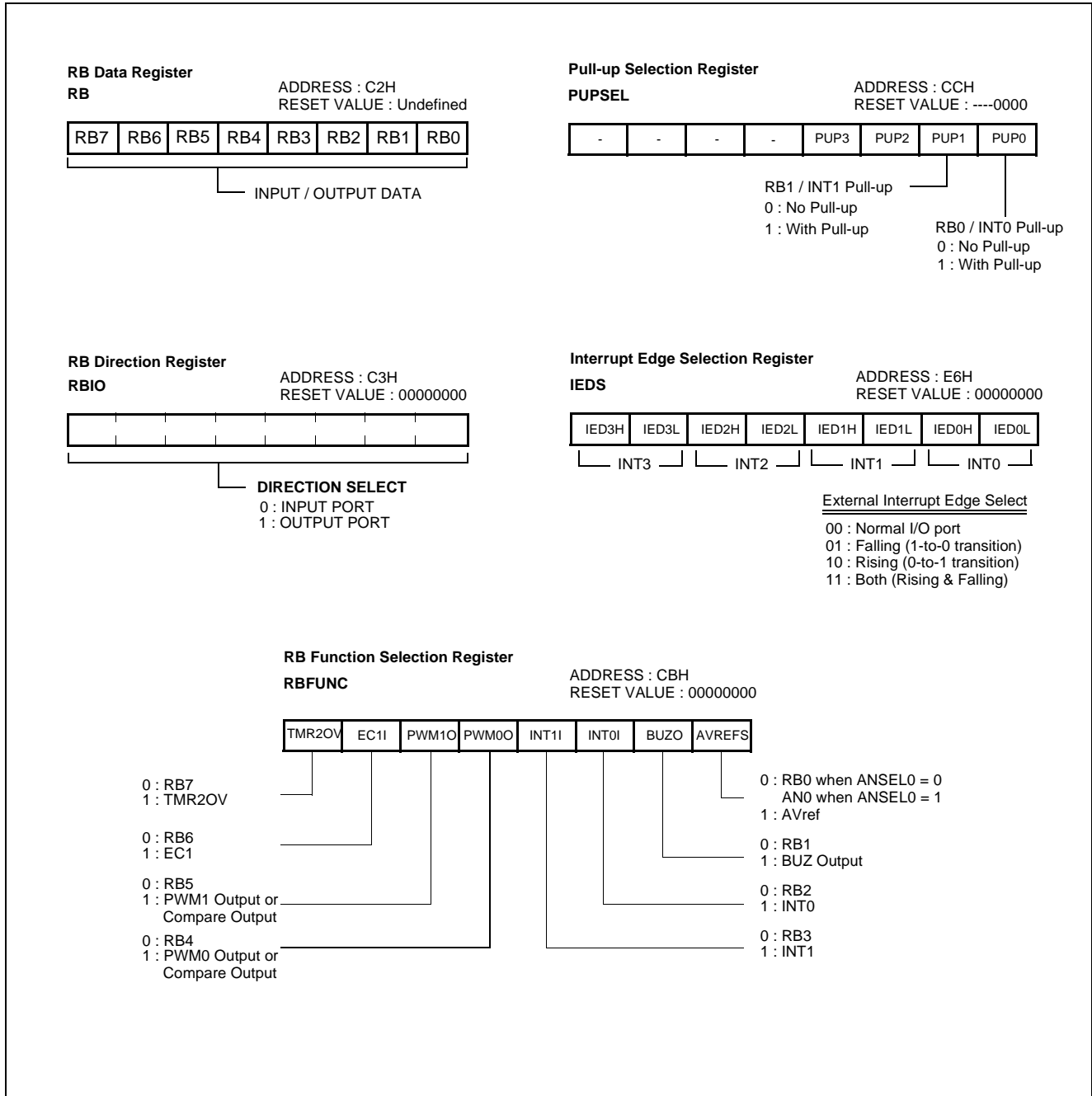


Figure 9-3 Registers of Port RB

Regardless of the direction register RBIO, RBFUNC is selected to use as alternate functions, port pin can be used as

a corresponding alternate features.

| PORT | RBFUNC.4~0 | Description |
|------------------------|----------------|--|
| RB7/ TMR2OV | 0 | RB7 (Normal I/O Port) |
| | 1 | Timer2 Overflow Output |
| RB6/EC1 | 0 | RB6 (Normal I/O Port) |
| | 1 | Event Counter 1 Input |
| RB5/ PWM1/ COMP1 | 0 | RB5 (Normal I/O Port) |
| | 1 | PWM1 Output / Timer3 Compare Output |
| RB4/ PWM0/ COMP0 | 0 | RB4 (Normal I/O Port) |
| | 1 | PWM0 Output / Timer1 Compare Output |
| RB3/INT1 | 0 | RB3 (Normal I/O Port) |
| | 1 | External Interrupt Input 1 |
| RB2/INT0 | 0 | RB2 (Normal I/O Port) |
| | 1 | External Interrupt Input 0 |
| RB1/BUZ | 0 | RB1 (Normal I/O Port) |
| | 1 | Buzzer Output |
| RB0/AN0/ AVref | 0 ¹ | RB0 (Normal I/O Port)/ AN0 (ANSEL0=1) |
| | 1 ² | External Analog Reference Voltage |

1. When ANSEL0 = "0", this port is defined for normal I/O port (RB0).

When ANSEL0 = "1" and ADS2~0 = "000", this port can be used Analog Input Port (AN0).

2. When this bit set to "1", this port defined for AVref, so it can not be used Analog Input Port AN0 and Normal I/O Port RB0.

9.3 RC and RCIO registers

RC is an 4-bit bidirectional I/O port (address C4_H). Each pin can be set individually as input and output through the RCIO register (address C5_H).

In addition, Port RC is multiplexed with Serial Peripheral Interface (SPI).

The control register SIOM (address E0_H) controls to select Serial Peripheral Interface function.

After reset, the RCIO register value is “0”, port may be used as general I/O ports. To select Serial Peripheral Interface function, write “1” to the corresponding bit of SIOM.

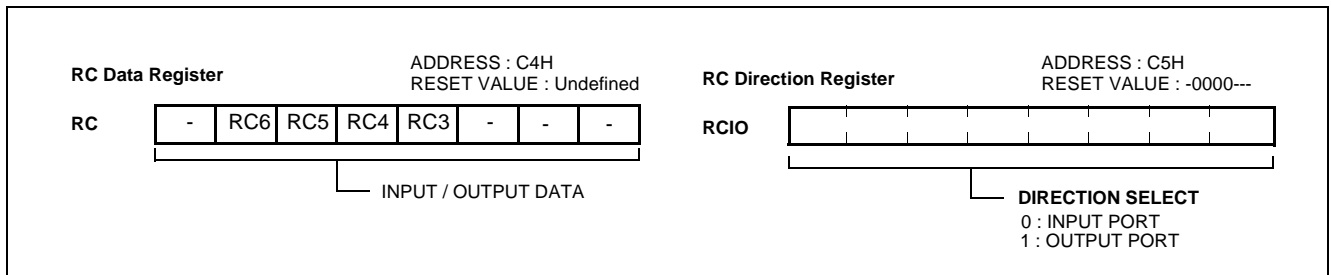


Figure 9-4 Registers of Port RC

| PORT | Function | SIOM | | | Description |
|--------------|-----------------------------|------|----------|------------|-------------------------------|
| | | SRDY | SM [1:0] | SCK [1:0] | |
| RC6/ SOUT | RC6 | X | X:0 | X:X | RC6 (Normal I/O Port) |
| | SOUT | X | X:1 | X:X | SPI Serial Data Output |
| RC5/ SIN | RC5 | X | 0:X | X:X | RC5 (Normal I/O Port) |
| | SIN | X | 1:X | X:X | SPI Serial Data Input |
| RC4/ SCK | RC4 | X | 0:0 | X:X | RC4 (Normal I/O Port) |
| | SCKO | X | 0:0 | 00, 01, 10 | SPI Synchronous Clock Output |
| | SCKI | X | 0:0 | 1:1 | SPI Synchronous Clock Input |
| RC3/ SRDY | RC3 | 0 | X:X | X:X | RC3 (Normal I/O Port) |
| | $\overline{\text{SRDYIN}}$ | 1 | X:X | 00, 01, 10 | SPI Ready Input (Master Mode) |
| | $\overline{\text{SRDYOUT}}$ | 1 | X:X | 1:1 | SPI Ready Output (Slave Mode) |

Table 9-1 Serial Communication Functions in RC Port

9.4 RD and RDIO registers

RD is a 3-bit bidirectional I/O port (address C6_H). Each pin can be set individually as input and output through the

RDIO register (address C7_H).

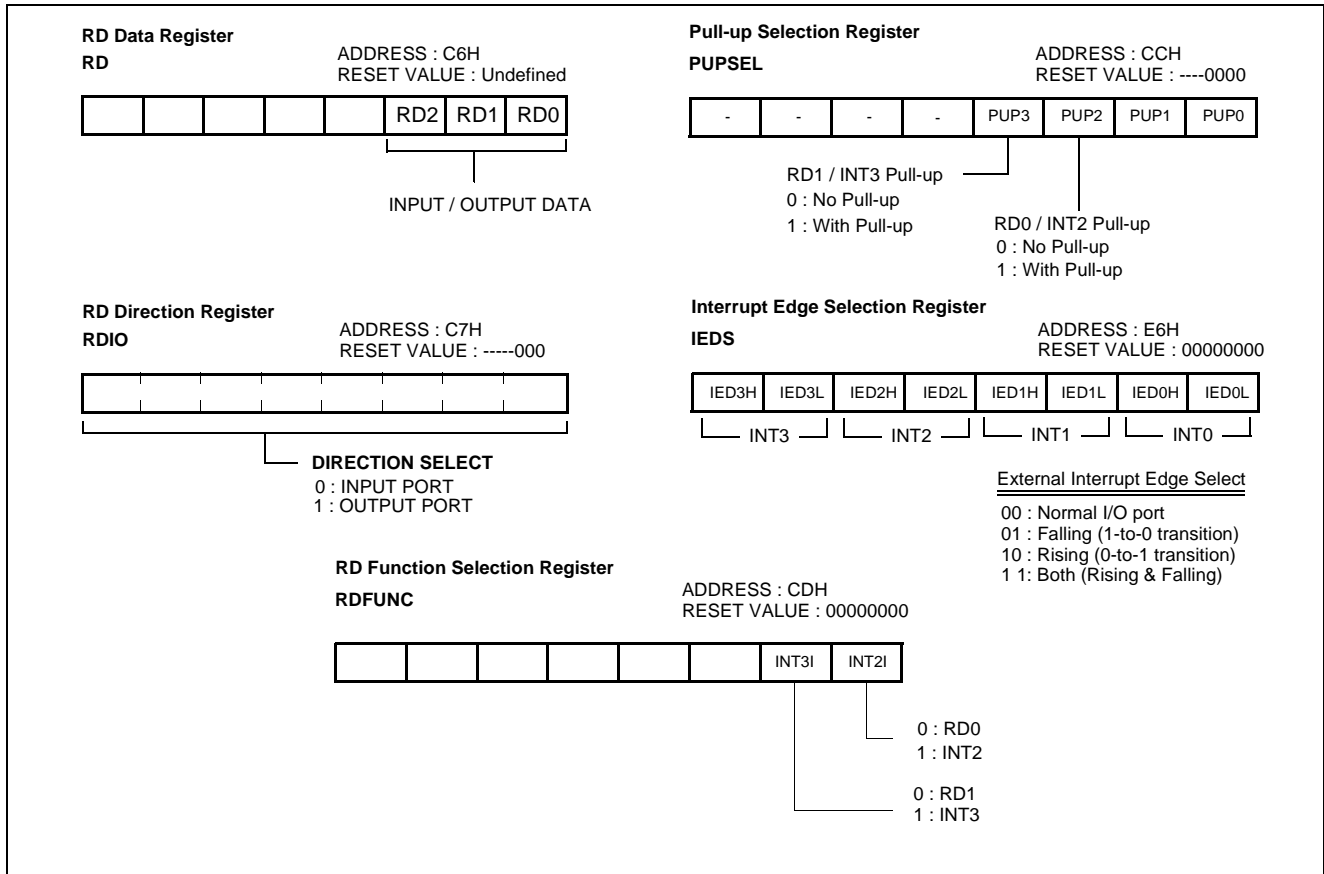


Figure 9-5 Registers of Port RD

In addition, Port RD is multiplexed with external interrupt input function. The control register RDFUNC (address CD_H) controls to select alternate function. After reset, this value is “0”, port may be used as general I/O ports. To select alternate function, write “1” to the corresponding bit of

RDFUNC. Regardless of the direction register RDIO, RDFUNC is selected to use as external interrupt input function, port pin can be used as a interrupt input feature.

10. CLOCK GENERATOR

The clock generator produces the basic clock pulses which provide the system clock to be supplied to the CPU and peripheral hardware. The main system clock oscillator oscillates with a crystal resonator or a ceramic resonator connected to the

Xin and Xout pins. External clocks can be input to the main system clock oscillator. In this case, input a clock signal to the Xin pin and open the Xout pin.

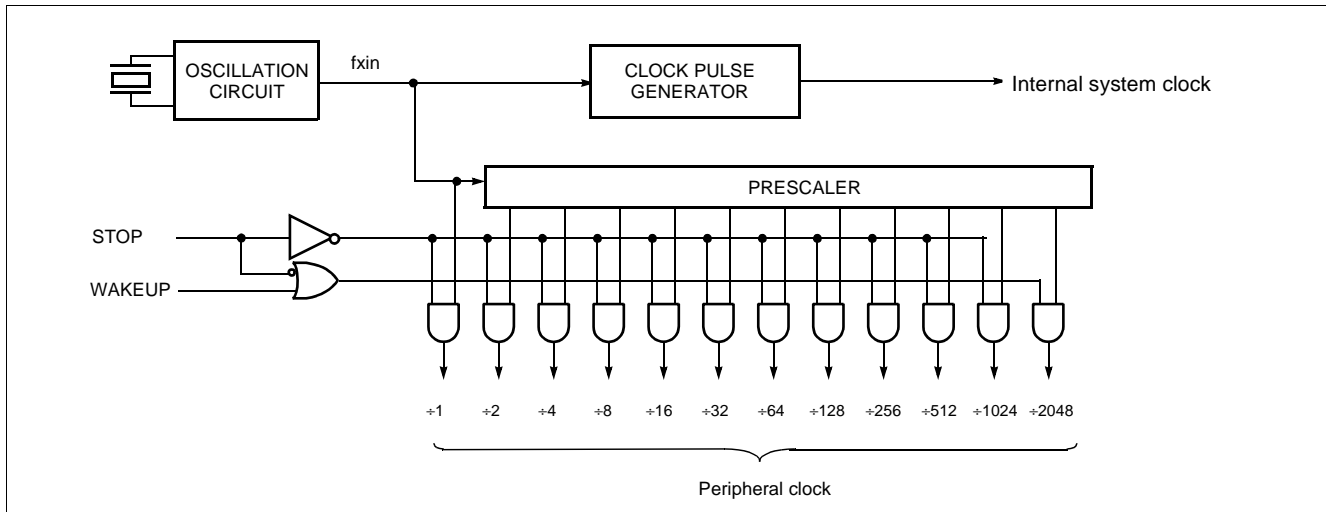


Figure 10-1 Block Diagram of Clock Pulse Generator

10.1 Oscillation Circuit

X_{IN} and X_{OUT} are the input and output, respectively, a inverting amplifier which can be set for use as an on-chip oscillator, as shown in Figure 10-2 .

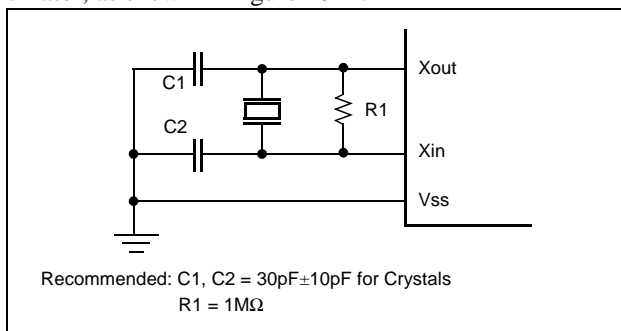


Figure 10-2 Oscillator Connections

To drive the device from an external clock source, Xout should be left unconnected while Xin is driven as shown in Figure 10-3 . There are no requirements on the duty cycle of the external clock signal, since the input to the internal clocking circuitry is through a divide-by-two flip-flop, but minimum and maximum high and low times specified on the data sheet must be observed.

Oscillation circuit is designed to be used either with a ceramic resonator or crystal oscillator. Since each crystal and ceramic resonator have their own characteristics, the user

should consult the crystal manufacturer for appropriate values of external components.

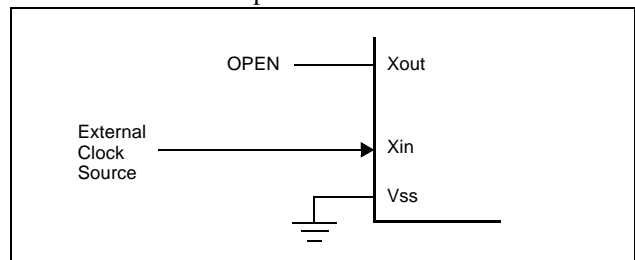


Figure 10-3 External Clock Connections

Note: When using a system clock oscillator, carry out wiring in the broken line area in Figure 10-2 to prevent any effects from wiring capacities.

- Minimize the wiring length.
- Do not allow wiring to intersect with other signal conductors.
- Do not allow wiring to come near changing high current.
- Set the potential of the grounding position of the oscillator capacitor to that of Vss. Do not ground to any ground pattern where high current is present.
- Do not fetch signals from the oscillator.

11. Basic Interval Timer

The GMS87C1408 and GMS87C1404 has one 8-bit Basic Interval Timer that is free-run, can not stop. Block diagram is shown in Figure 11-1. The 8-bit Basic interval timer register (BITR) is increased every internal count pulse which is divided by prescaler. Since prescaler has divided ratio by 8 to 1024, the count rate is 1/8 to 1/1024 of the oscillator frequency. As the count overflows from FF_H to 00_H, this overflow causes to generate the Basic interval timer interrupt. The BITF is interrupt request flag of Basic interval timer.

When write “1” to bit BTCL of CKCTLR, BITR register is cleared to “0” and restart to count-up. The bit BTCL becomes “0” after one machine cycle by hardware.

If the STOP instruction executed after writing “1” to bit WAKEUP of CKCTLR, it goes into the wake-up timer mode. In this mode, all of the block is halted except the os-

illator, prescaler (only f_{xin}÷2048) and Timer0.

If the STOP instruction executed after writing “1” to bit RCWDT of CKCTLR, it goes into the internal RC oscillated watchdog timer mode. In this mode, all of the block is halted except the internal RC oscillator, Basic Interval Timer and Watchdog Timer. More detail informations are explained in Power Saving Function. The bit WDTON decides Watchdog Timer or the normal 7-bit timer

Note: All control bits of Basic interval timer are in CKCTLR register which is located at same address of BITR (address E_{CH}). Address E_{CH} is read as BITR, written to CKCTLR. Therefore, the CKCTLR can not be accessed by bit manipulation instruction.

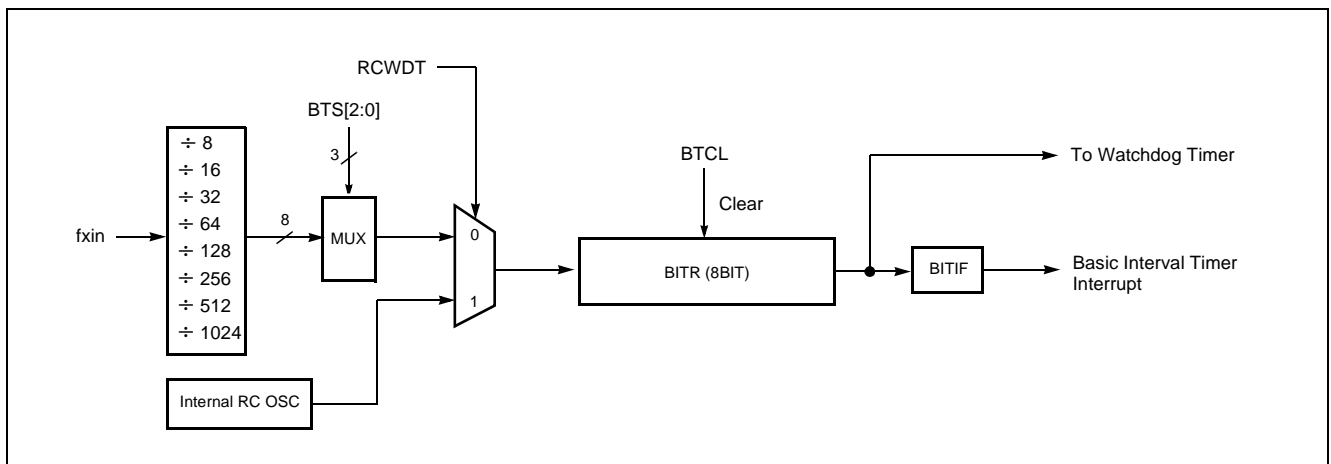


Figure 11-1 Block Diagram of Basic Interval Timer

| Clock Control Register | | | | | | | | ADDRESS : E _{CH} RESET VALUE : -0010111 Bit Manipulation Not Available |
|------------------------|---|--------|-------|-------|------|------|------|--|
| CKCTLR | - | WAKEUP | RCWDT | WDTON | BTCL | BTS2 | BTS1 | BTS0 |
| Symbol | Function Description | | | | | | | Basic Interval Timer Clock Selection |
| WAKEUP | 1 : Enables Wake-up Timer 0 : Disables Wake-up Timer | | | | | | | 000 : f _{xin} ÷ 8 001 : f _{xin} ÷ 16 010 : f _{xin} ÷ 32 011 : f _{xin} ÷ 64 100 : f _{xin} ÷ 128 101 : f _{xin} ÷ 256 110 : f _{xin} ÷ 512 111 : f _{xin} ÷ 1024 |
| RCWDT | 1 : Enables Internal RC Watchdog Timer 0 : Disables Internal RC Watchdog Time | | | | | | | |
| WDTON | 1 : Enables Watchdog Timer 0 : Operates as a 7-bit Timer | | | | | | | |
| BTCL | 1 : BITR is cleared and BTCL becomes “0” automatically after one machine cycle, and BITR continue to count-up | | | | | | | |

Figure 11-2 CKCTLR: Clock Control Register

12. TIMER / COUNTER

The GMS87C1408 and GMS87C1404 has four Timer/Counter registers. Each module can generate an interrupt to indicate that an event has occurred (i.e. timer match).

Timer 0 and Timer 1 can be used either the two 8-bit Timer/Counter or one 16-bit Timer/Counter by combining them. Also Timer 2 and Timer 3 are same. In this document, explain Timer 0 and Timer 1 because Timer2 and Timer3 same with Timer 0 and Timer 1.

In the “timer” function, the register is increased every internal clock input. Thus, one can think of it as counting internal clock input. Since a least clock consists of 2 and most clock consists of 2048 oscillator periods, the count rate is 1/2 to 1/2048 of the oscillator frequency in Timer0. And Timer1 can use the same clock source too. In addition, Timer1 has more fast clock source (1/1 to 1/8).

In the “counter” function, the register is increased in response to a 0-to-1 (rising edge) transition at its corresponding external input pin, EC0(Timer 0) or EC1(Timer 2).

In addition the “capture” function, the register is increased in response external interrupt same with timer function. When external interrupt edge input, the count register is captured into capture data register CDRx.

Timer1 and Timer 3 are shared with “PWM” function and “Compare output” function

It has seven operating modes: “8-bit timer/counter”, “16-bit timer/counter”, “8-bit capture”, “16-bit capture”, “8-bit compare output”, “16-bit compare output” and “10-bit PWM” which are selected by bit in Timer mode register TMx as shown in Figure 12-1 and Table 12-1 .

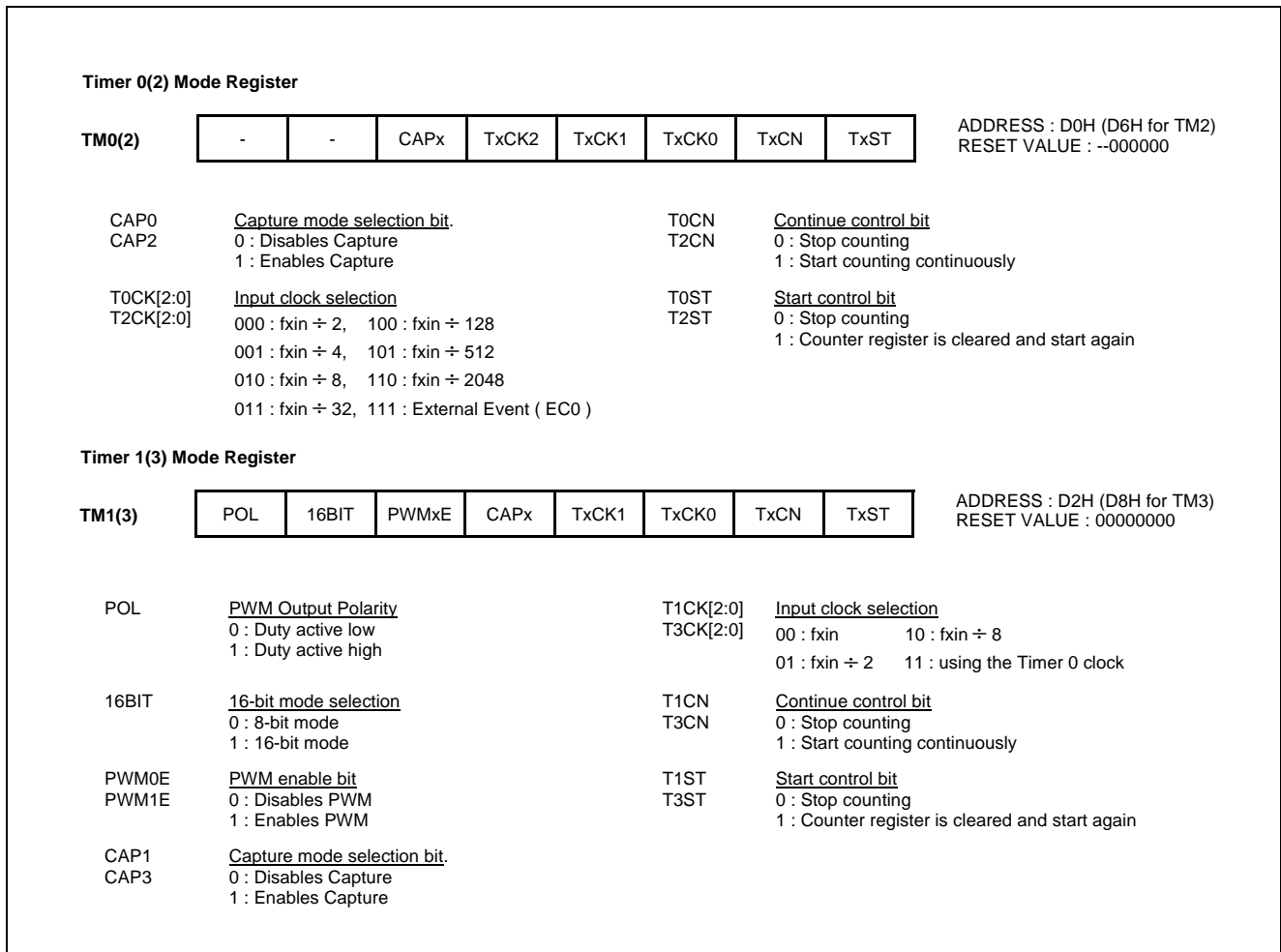


Figure 12-1 Timer Mode Register (TMx, x = 0~3)

| 16BIT | CAP0 | CAP1 | PWME | T0CK[2:0] | T1CK[1:0] | PWMO | TIMER 0 | TIMER1 |
|-------|----------------|------|------|-----------|-----------|------|-----------------------|----------------------|
| 0 | 0 | 0 | 0 | XXX | XX | 0 | 8-bit Timer | 8-bit Timer |
| 0 | 0 | 1 | 0 | 111 | XX | 0 | 8-bit Event Counter | 8-bit Capture |
| 0 | 1 | 0 | 0 | XXX | XX | 1 | 8-bit Capture | 8-bit Compare output |
| 0 | X ¹ | 0 | 1 | XXX | XX | 1 | 8-bit Timer/Counter | 10-bit PWM |
| 1 | 0 | 0 | 0 | XXX | 11 | 0 | 16-bit Timer | |
| 1 | 0 | 0 | 0 | 111 | 11 | 0 | 16-bit Event Counter | |
| 1 | 1 | X | 0 | XXX | 11 | 0 | 16-bit Capture | |
| 1 | 0 | 0 | 0 | XXX | 11 | 1 | 16-bit Compare output | |

Table 12-1 Operating Modes of Timer 0 and Timer 1

1. X: The value "0" or "1" corresponding your operation.

12.1 8-bit Timer/Counter Mode

The GMS87C1408 and GMS87C1404 has four 8-bit Timer/Counters, Timer 0, Timer 1, Timer 2 and Timer 3, as shown in Figure 12-2 .

The "timer" or "counter" function is selected by mode reg-

isters TMx as shown in Figure 12-1 and Table 12-1 . To use as an 8-bit timer/counter mode, bit CAP0 of TM0 is cleared to "0" and bits 16BIT of TM1 should be cleared to "0"(Table 12-1).

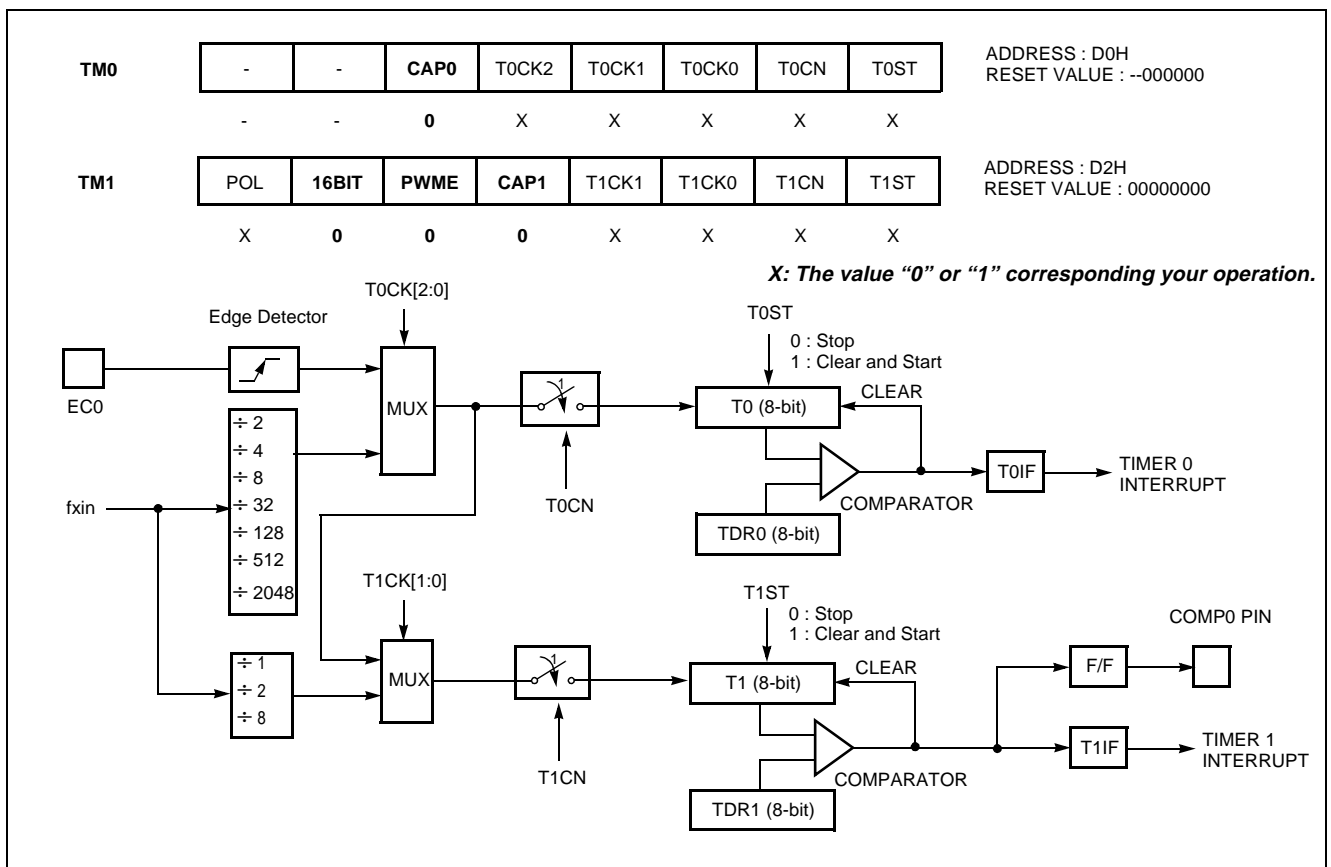


Figure 12-2 8-bit Timer / Counter Mode

These timers have each 8-bit count register and data register. The count register is increased by every internal or external clock input. The internal clock has a prescaler divide ratio option of 2, 4, 8, 32, 128, 512, 2048 (selected by control bits T0CK2, T0CK1 and T0CK0 of register TM0) and 1, 2, 8 (selected by control bits T1CK1 and T1CK0 of register TM1). In the Timer 0, timer register T0 increases from 00_H until it matches TDR0 and then reset to 00_H. The match output of Timer 0 generates Timer 0 interrupt

(latched in TOF bit). As TDRx and Tx register are in same address, when reading it as a Tx, written to TDRx.

In counter function, the counter is increased every 0-to 1 (rising edge) transition of EC0 pin. In order to use counter function, the bit RA0 of the RA Direction Register RAIO is set to "0". The Timer 0 can be used as a counter by pin EC0 input, but Timer 1 can not.

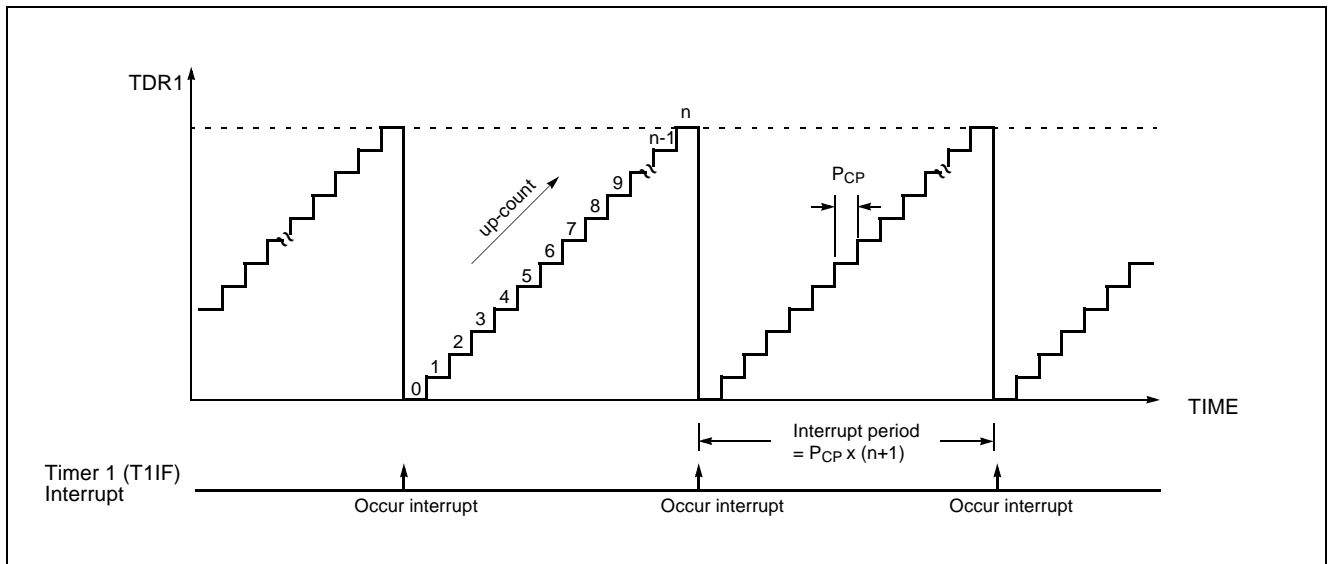


Figure 12-3 Counting Example of Timer Data Registers

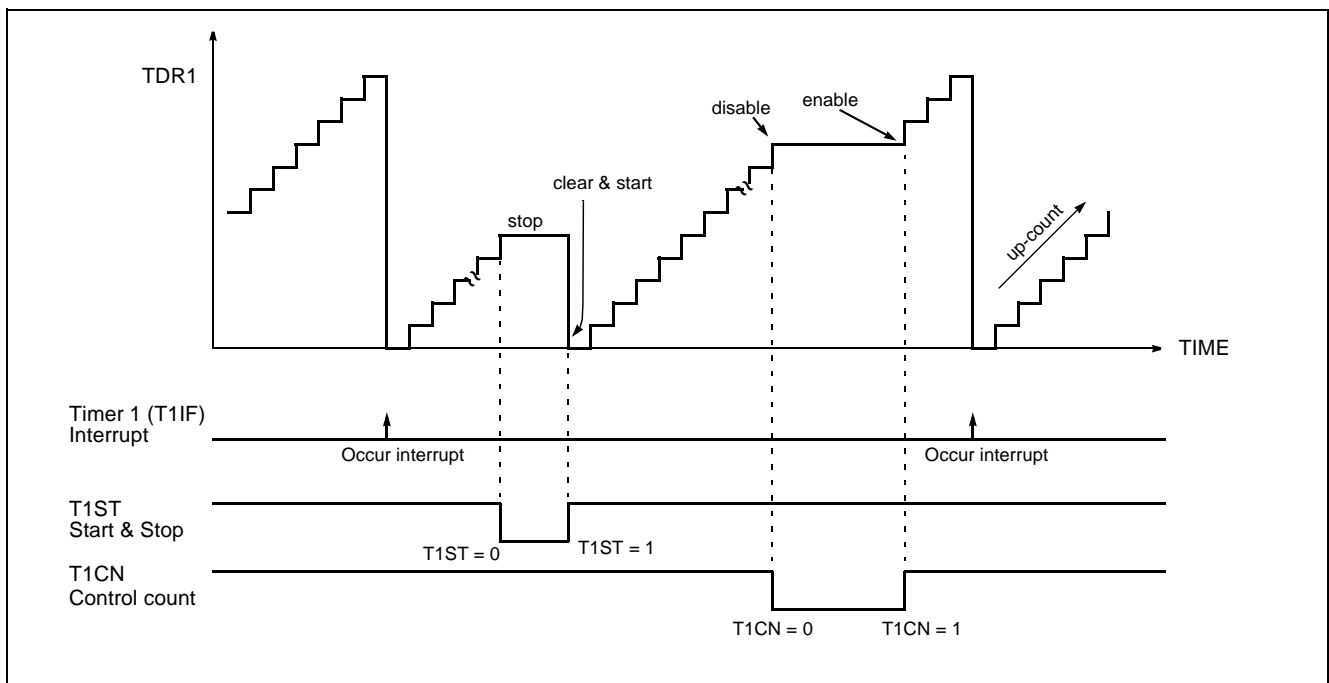


Figure 12-4 Timer Count Operation

12.2 16-bit Timer/Counter Mode

The Timer register is being run with 16 bits. A 16-bit timer/counter register T0, T1 are increased from 0000_H until it matches TDR0, TDR1 and then resets to 0000_H. The match output generates Timer 0 interrupt not Timer 1 interrupt.

The clock source of the Timer 0 is selected either internal or external clock by bit T0CK2, T0CK1 and T0SL0.

In 16-bit mode, the bits T1CK1, T1CK0 and 16BIT of TM1 should be set to "1" respectively.

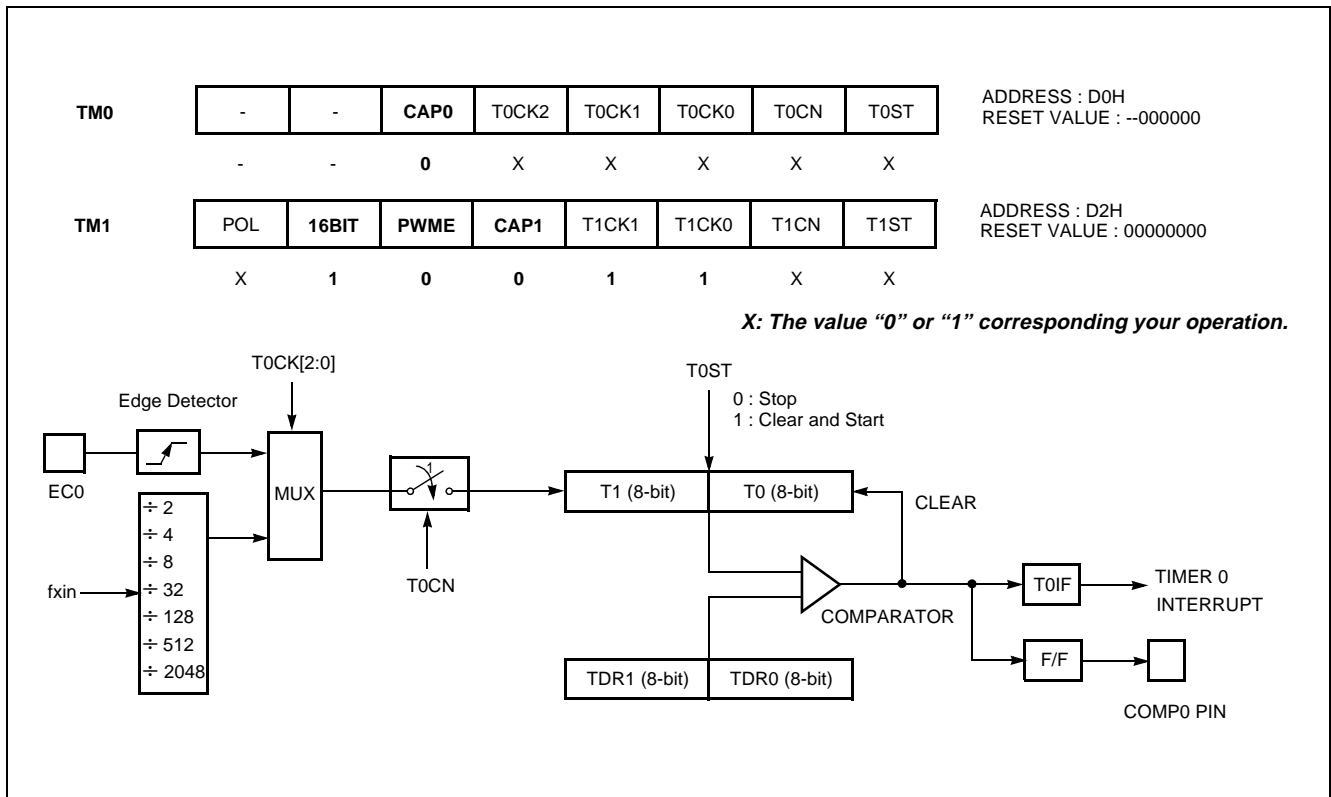


Figure 12-5 16-bit Timer / Counter Mode

12.3 8-bit Compare Output (16-bit)

The GMS87C1408 and GMS87C1404 has a function of Timer Compare Output. To pulse out, the timer match can go to port pin(COMP0) as shown in Figure 12-2 and Figure 12-5 . Thus, pulse out is generated by the timer match. These operation is implemented to pin, RB4/COMP0/ PWM.

This pin output the signal having a 50: 50 duty square

wave, and output frequency is same as below equation.

$$f_{COMP} = \frac{\text{Oscillation Frequency}}{2 \times \text{Prescaler Value} \times (TDR + 1)}$$

In this mode, the bit PWMO of RB function register (RB-FUNC) should be set to "1", and the bit PWME of timer1 mode register (TM1) should be set to "0".

In addition, 16-bit Compare output mode is available, also.

12.4 8-bit Capture Mode

The Timer 0 capture mode is set by bit CAP0 of timer mode register TM0 (bit CAP1 of timer mode register TM1 for Timer 1) as shown in Figure 12-6 .

As mentioned above, not only Timer 0 but Timer 1 can also

be used as a capture mode.

The Timer/Counter register is increased in response internal or external input. This counting function is same with normal timer mode, and Timer interrupt is generated when

timer register T0 (T1) increases and matches TDR0 (TDR1).

This timer interrupt in capture mode is very useful when the pulse width of captured signal is more wider than the maximum period of Timer.

For example, in Figure 12-8 , the pulse width of captured signal is wider than the timer data value (FF_H) over 2 times. When external interrupt is occurred, the captured value (13_H) is more little than wanted value. It can be obtained correct value by counting the number of timer overflow occurrence.

Timer/Counter still does the above, but with the added feature that a edge transition at external input INT_x pin causes the current value in the Timer x register (T0,T1), to be cap-

tured into registers CDR_x (CDR0, CDR1), respectively. After captured, Timer x register is cleared and restarts by hardware.

It has three transition modes: “falling edge”, “rising edge”, “both edge” which are selected by interrupt edge selection register IEDS (Refer to External interrupt section). In addition, the transition at INT_x pin generate an interrupt.

Note: The CDR_x, TDR_x and T_x are in same address. In the capture mode, reading operation is read the CDR_x, not T_x because path is opened to the CDR_x, and TDR_x is only for writing operation.

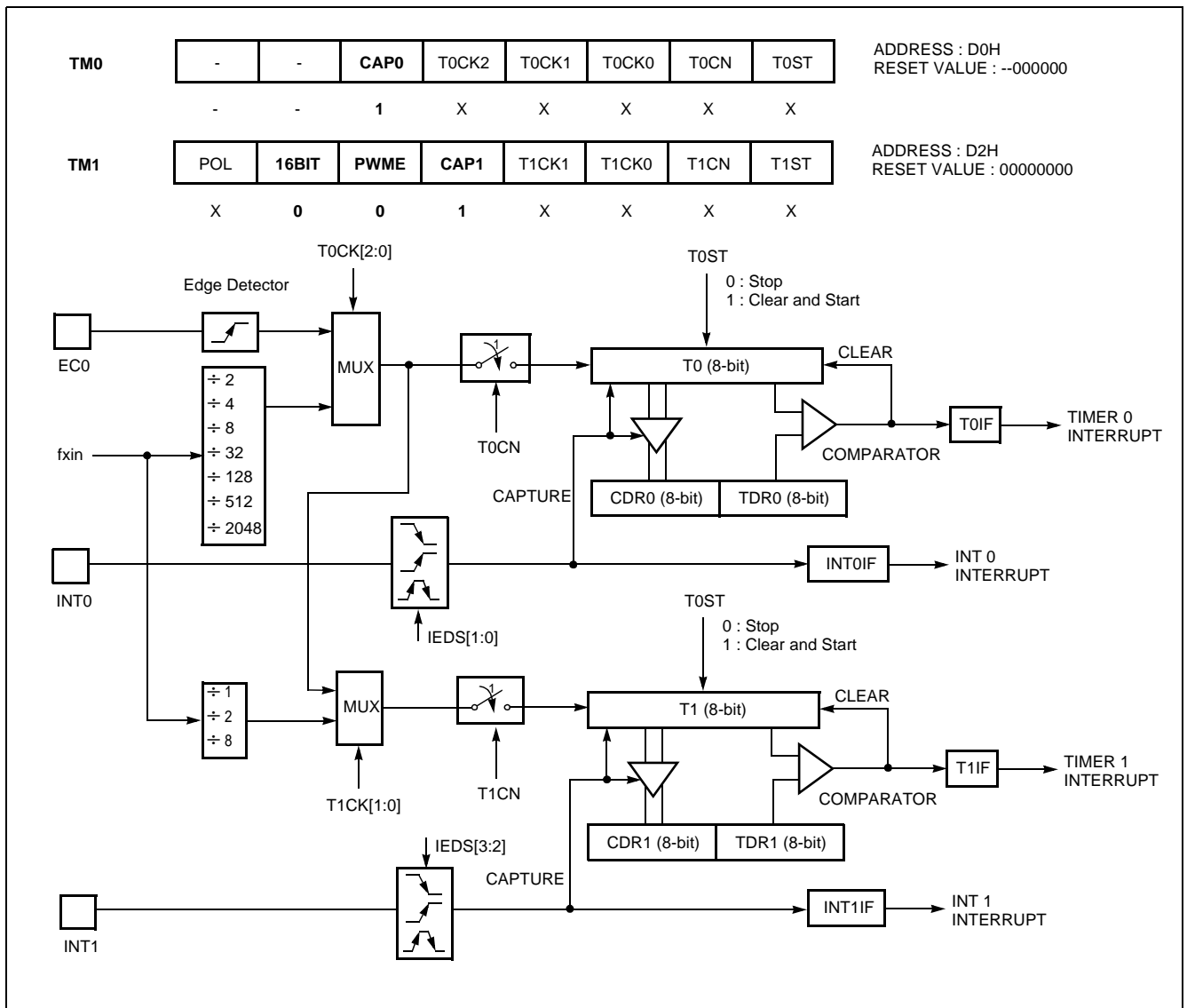


Figure 12-6 8-bit Capture Mode

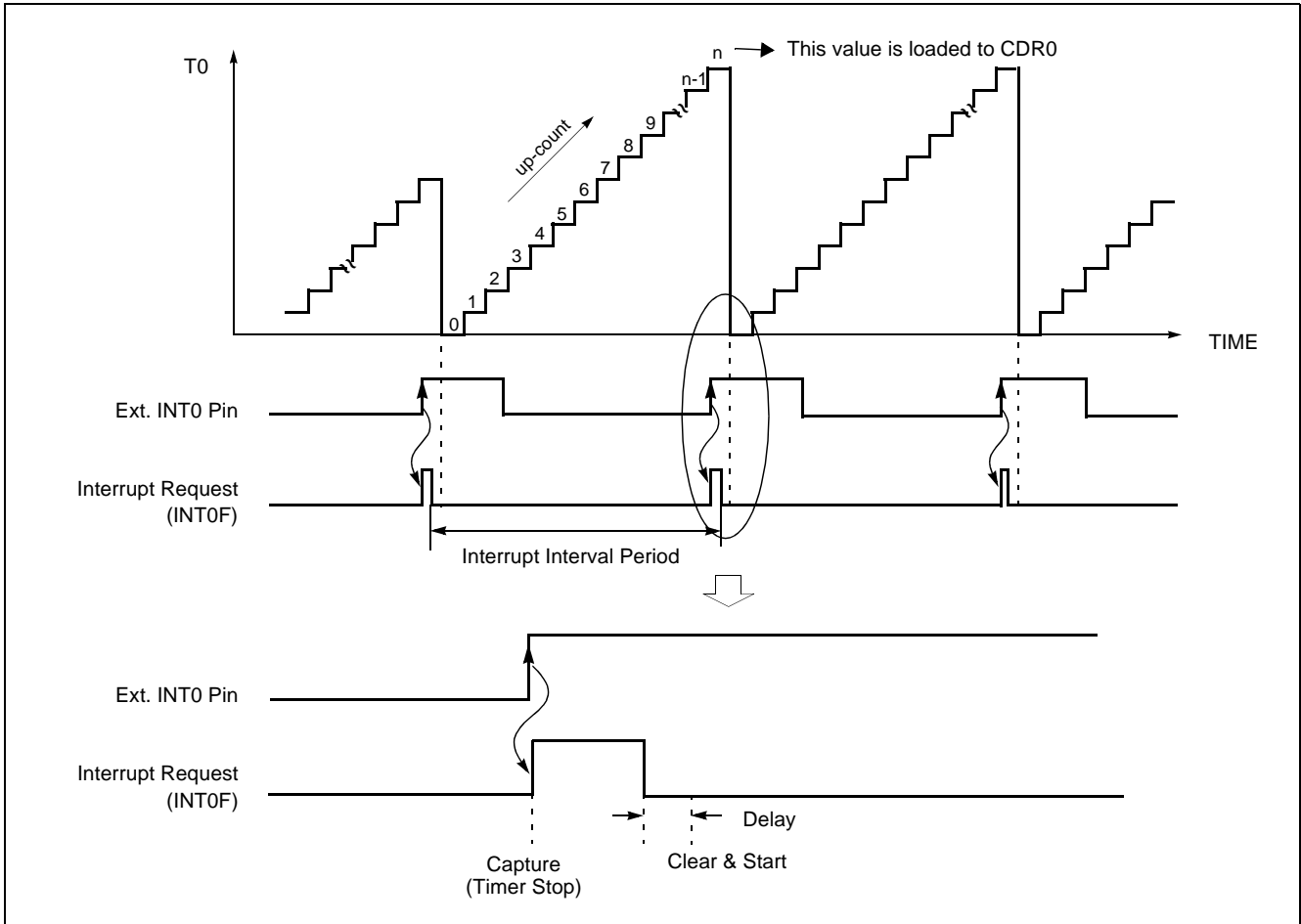


Figure 12-7 Input Capture Operation

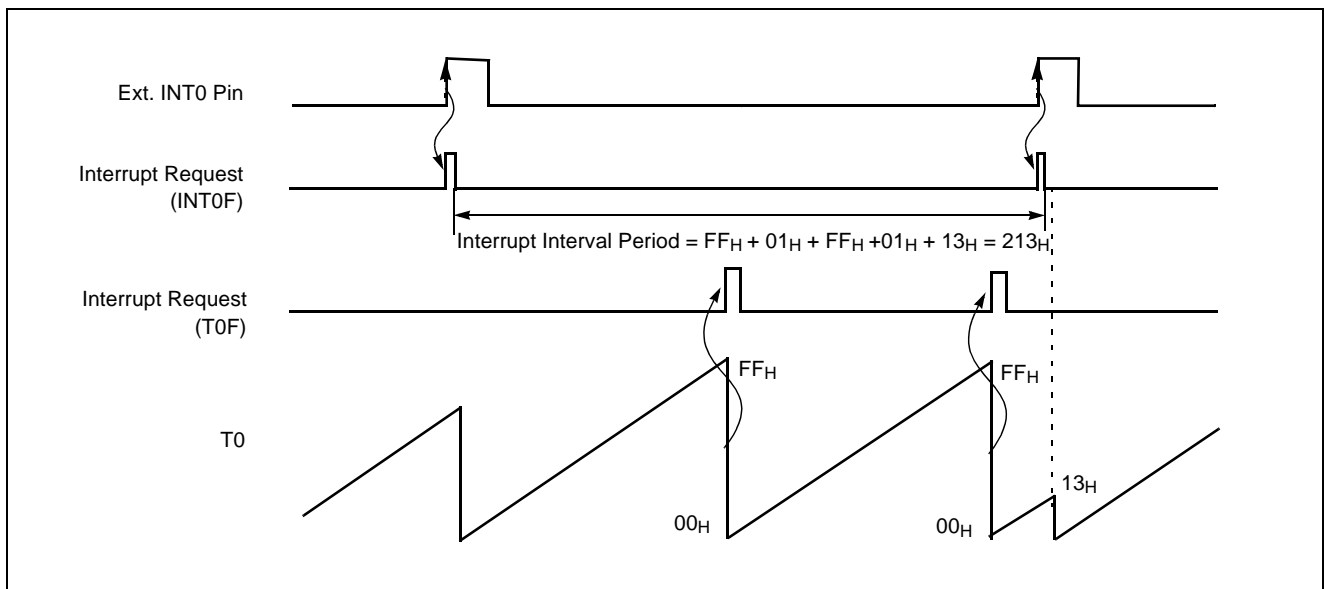


Figure 12-8 Excess Timer Overflow in Capture Mode

12.5 16-bit Capture Mode

16-bit capture mode is the same as 8-bit capture, except that the Timer register is being run will 16 bits.

In 16-bit mode, the bits T1CK1, T1CK0 and 16BIT of TM1 should be set to "1" respectively.

The clock source of the Timer 0 is selected either internal or external clock by bit T0CK2, T0CK1 and T0CK0.

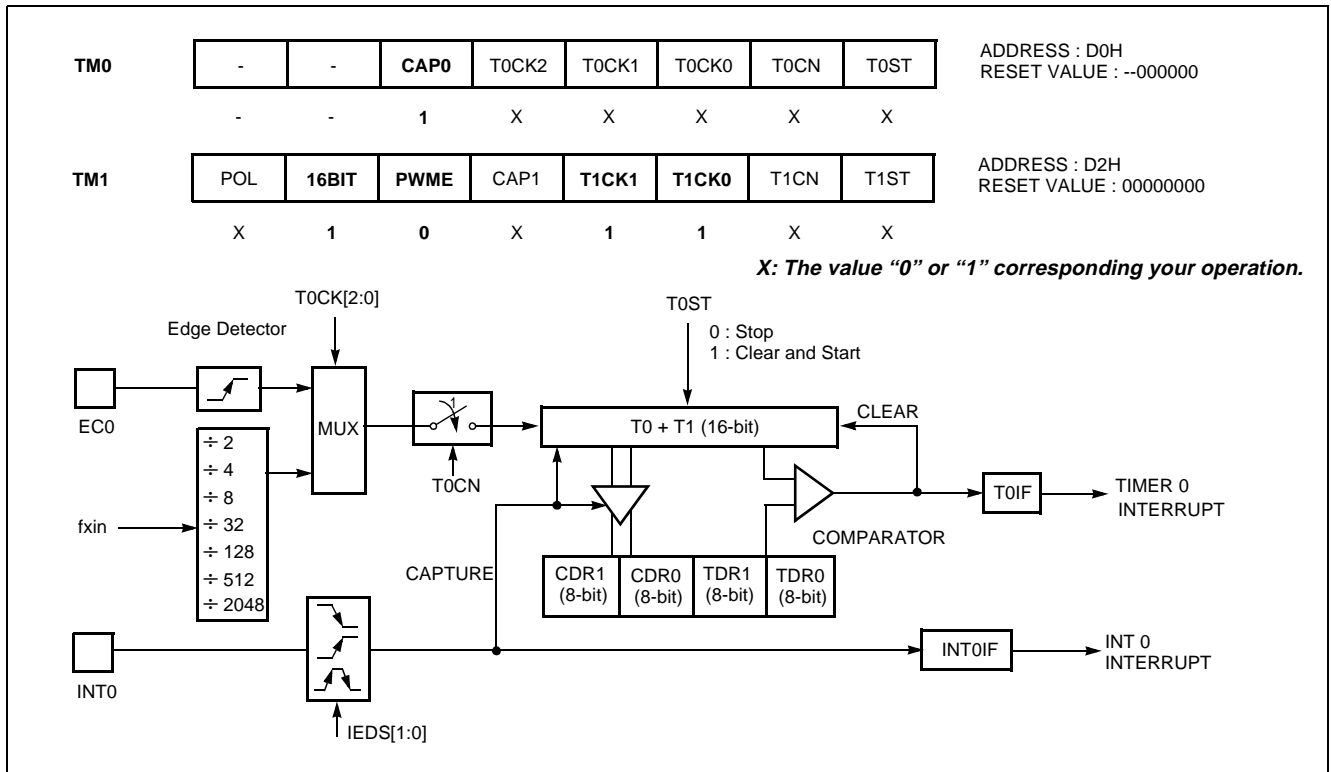


Figure 12-9 16-bit Capture Mode

12.6 PWM Mode

The GMS87C1408 and GMS87C1404 has a two high speed PWM (Pulse Width Modulation) functions which shared with Timer1 (Timer 3). In this document, it will be explained only PWM0.

In PWM mode, pin RB4/COMP0/PWM0 outputs up to a 10-bit resolution PWM output. This pin should be configure as a PWM output by setting "1" bit PWM00 in RB-FUNC register. (PWM1 output by setting "1" bit PWM10 in RBFUNC)

The period of the PWM output is determined by the T1PPR (PWM0 Period Register) and PWM0HR[3:2] (bit3,2 of PWM0 High Register) and the duty of the PWM output is determined by the T1PDR (PWM0 Duty Register) and PWM0HR[1:0] (bit1,0 of PWM0 High Register).

The user writes the lower 8-bit period value to the T1PPR and the higher 2-bit period value to the PWM0HR[3:2]. And writes duty value to the T1PDR and the PWM0HR[1:0] same way.

The T1PDR is configure as a double buffering for glitch-less PWM output. In Figure 12-10, the duty data is transferred from the master to the slave when the period data matched to the counted value. (i.e. at the beginning of next duty cycle)

$$PWM\ Period = [PWM0HR[3:2]T1PPR] \times Source\ Clock$$

$$PWM\ Duty = [PWM0HR[1:0]T1PDR] \times Source\ Clock$$

The relation of frequency and resolution is in inverse proportion. Table 12-2 shows the relation of PWM frequency vs. resolution.

If it needed more higher frequency of PWM, it should be reduced resolution.

| Resolution | Frequency | | |
|------------|---------------------|---------------------|-------------------|
| | T1CK[1:0]=00(125nS) | T1CK[1:0]=01(250nS) | T1CK[1:0]=10(1uS) |
| 10-bit | 7.8KHz | 3.9KHz | 0.98KHz |
| 9-bit | 15.6KHz | 7.8KHz | 1.95KHz |
| 8-bit | 31.2KHz | 15.6KHz | 3.90KHz |
| 7-bit | 62.5KHz | 31.2KHz | 7.81KHz |

Table 12-2 PWM Frequency vs. Resolution at 8MHz

The bit POL of TM1 decides the polarity of duty cycle.

If the duty value is set same to the period value, the PWM output is determined by the bit POL (1: High, 0: Low). And if the duty value is set to "00H", the PWM output is determined by the bit POL (1: Low, 0: High).

It can be changed duty value when the PWM output. However the changed duty value is output after the current period is over. And it can be maintained the duty value at present output when changed only period value shown as Figure 12-12 . As it were, the absolute duty time is not changed in varying frequency. But the changed period value must greater than the duty value.

Note: If changing the Timer1(3) to PWM function, it should be stop the timer clock firstly, and then set period and duty register value. If user writes register values while timer is in operation, these register could be set with certain values.

```

Ex) LDM TM1,#00H
     LDM T1PPR,#00H
     LDM T1PDR,#00H
     LDM PWM0HR,#00H
     LDM RBFUNC,#0001_1100B
     LDM TM1,#1010_1011B
    
```

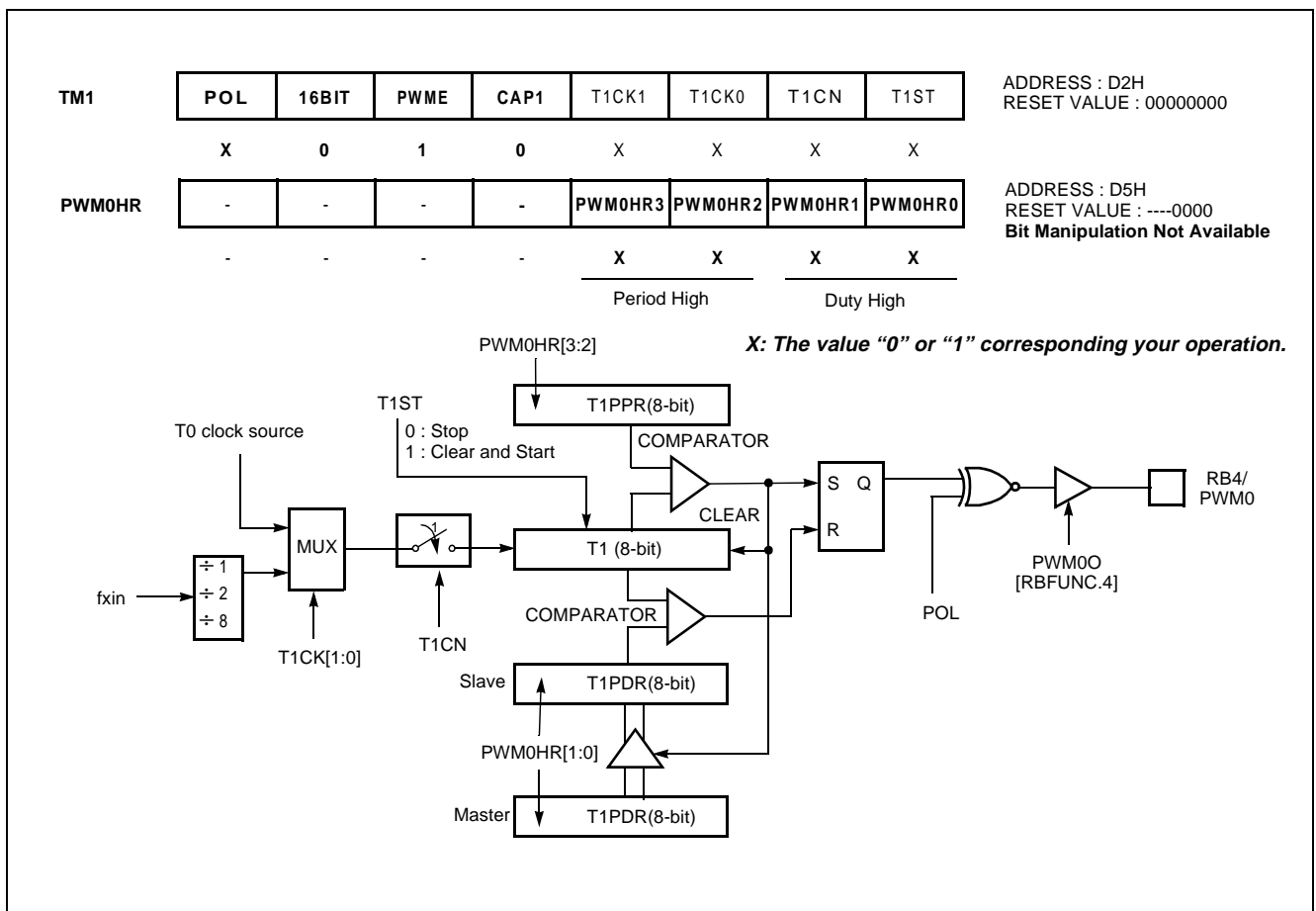


Figure 12-10 PWM Mode

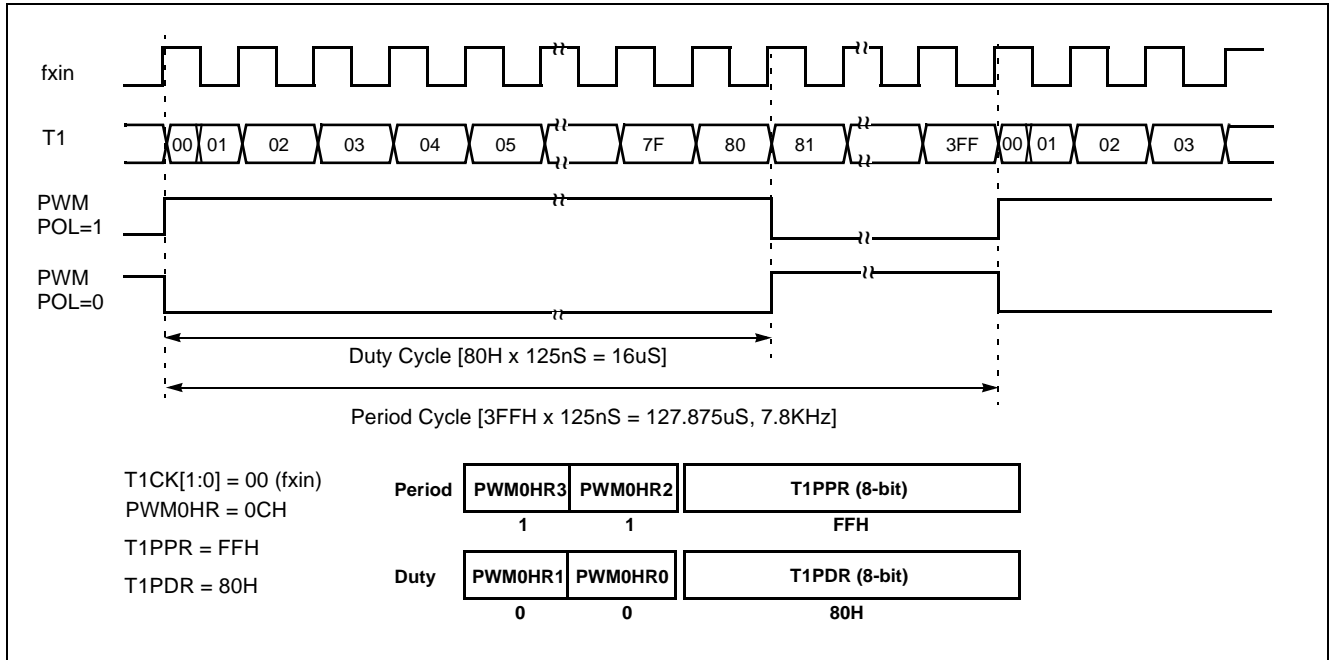


Figure 12-11 Example of PWM at 8MHz

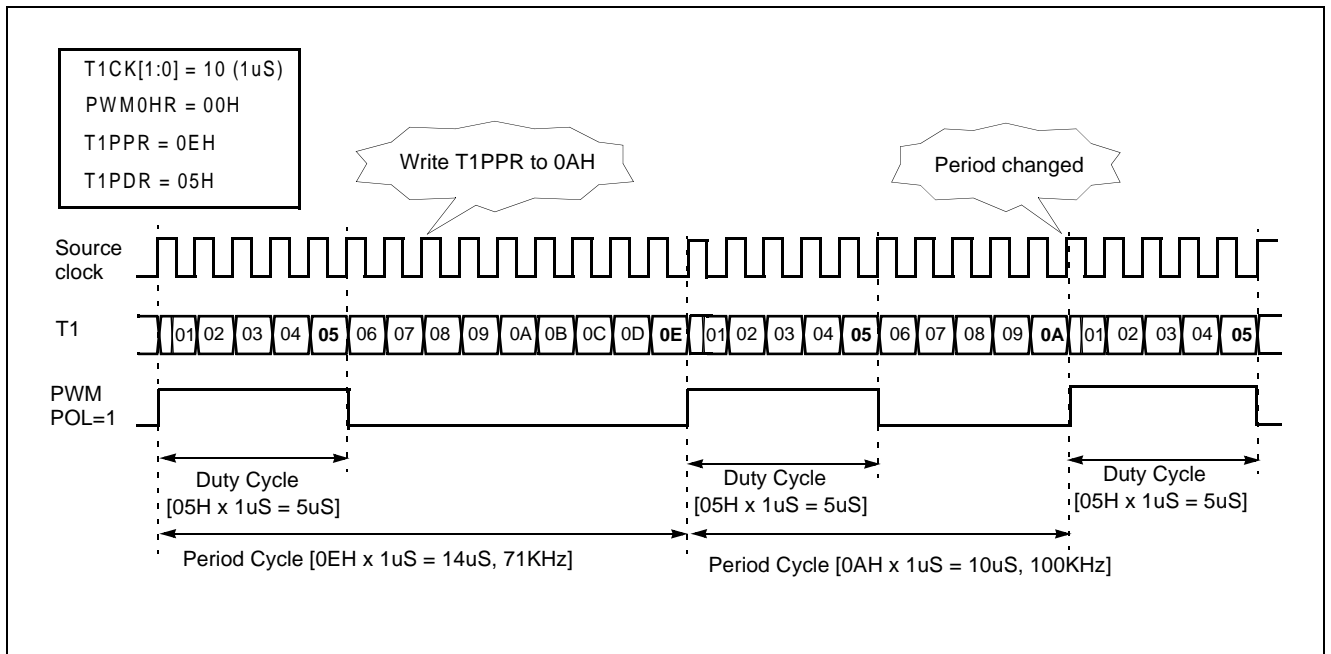
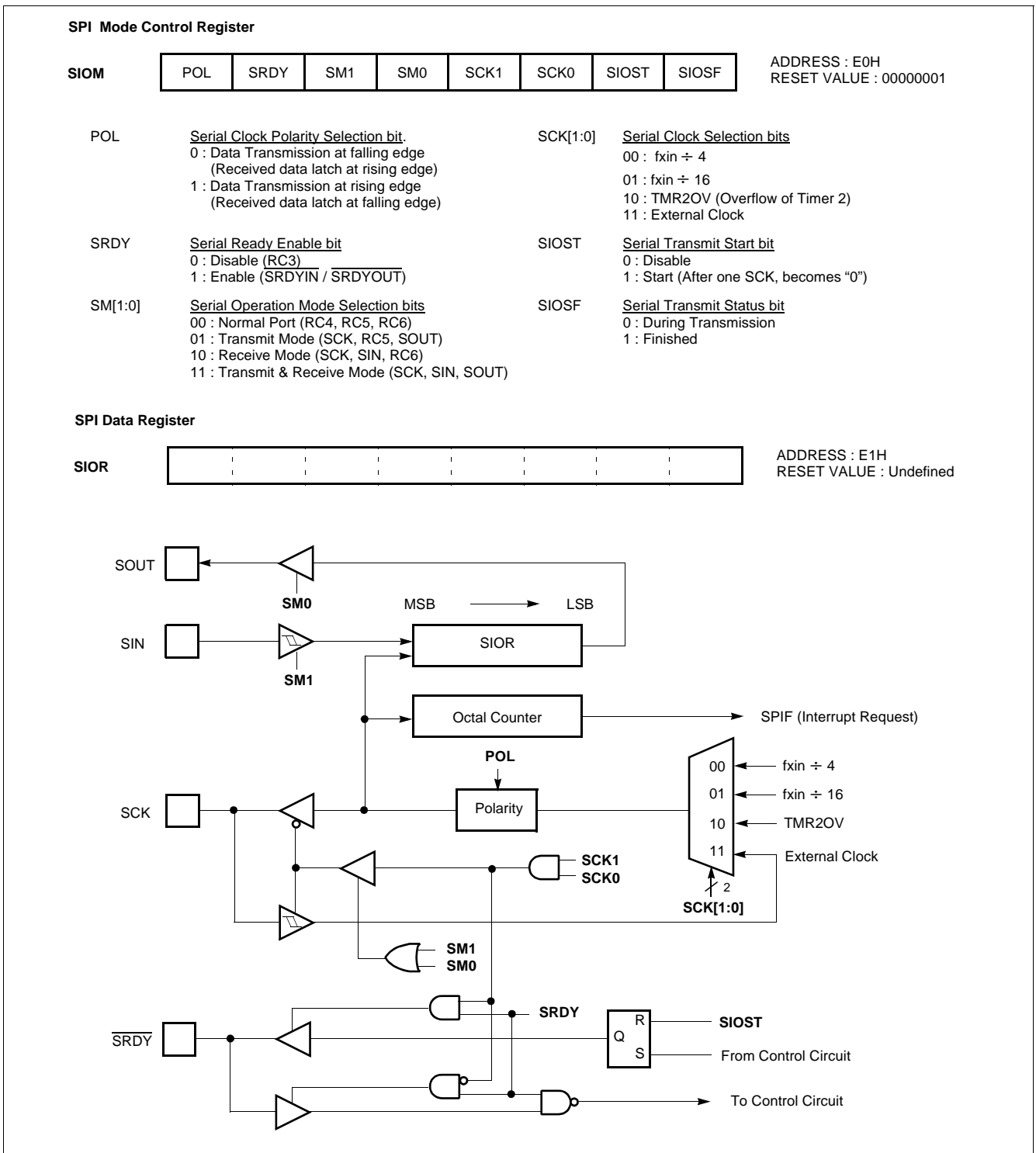


Figure 12-12 Example of Changing the Period in Absolute Duty Cycle (@8MHz)

13. Serial Peripheral Interface

The Serial Peripheral Interface (SPI) module is a serial interface useful for communicating with other peripheral of microcontroller devices. These peripheral devices may be

serial EEPROMs, shift registers, display drivers, A/D converters, etc.



The SPI allows 8-bits of data to be synchronously transmitted and received. To accomplish communication, typically three pins are used:

- Serial Data In RC5/SIN
- Serial Data Out RC6/SOUT
- Serial Clock RC4/SCK

Additionally a fourth pin may be used when in a master or a slave mode of operation:

- Serial Transfer Ready RC3/SRDYIN/SRDYOUT

The serial data transfer operation mode is decided by setting the SM1 and SM0 of SPI Mode Control Register, and the transfer clock rate is decided by setting the SCK1 and SCK0 of SPI Mode Control Register as shown in Figure 13-1 . And the polarity of transfer clock is selected by setting the POL.

The bit SRDY is used for master / slave selection. If this bit is set to "1" and SCK[1:0] is set to "11", the controller is performed to slave controller. As it were, the port RC3 is served for SRDYOUT.

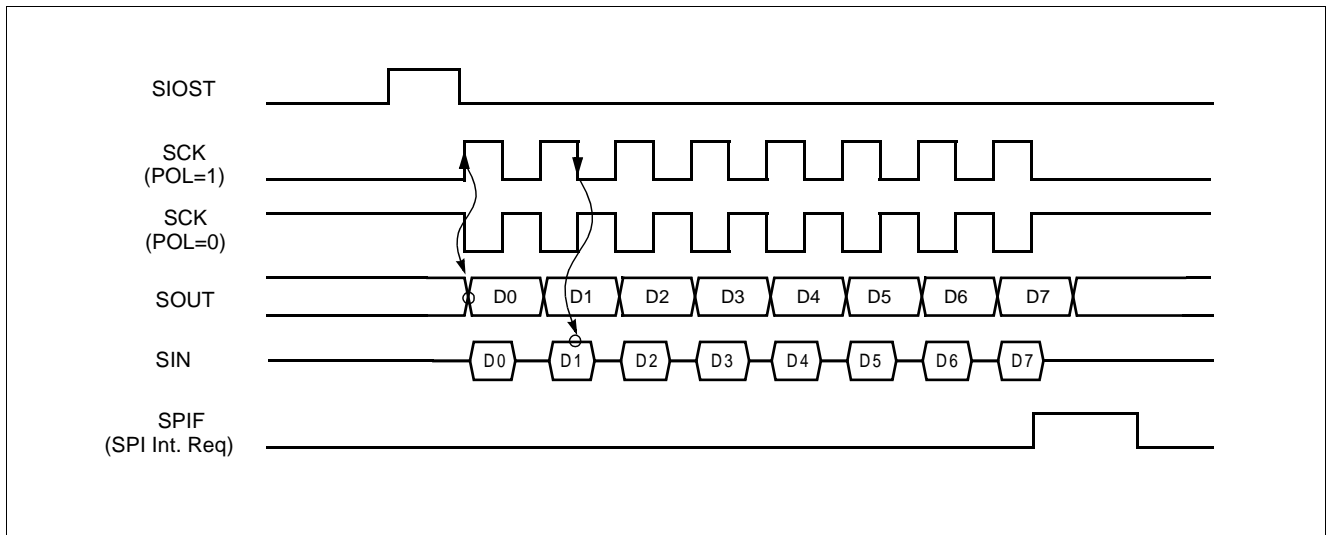


Figure 13-2 SPI Timing Diagram (without SRDY control)

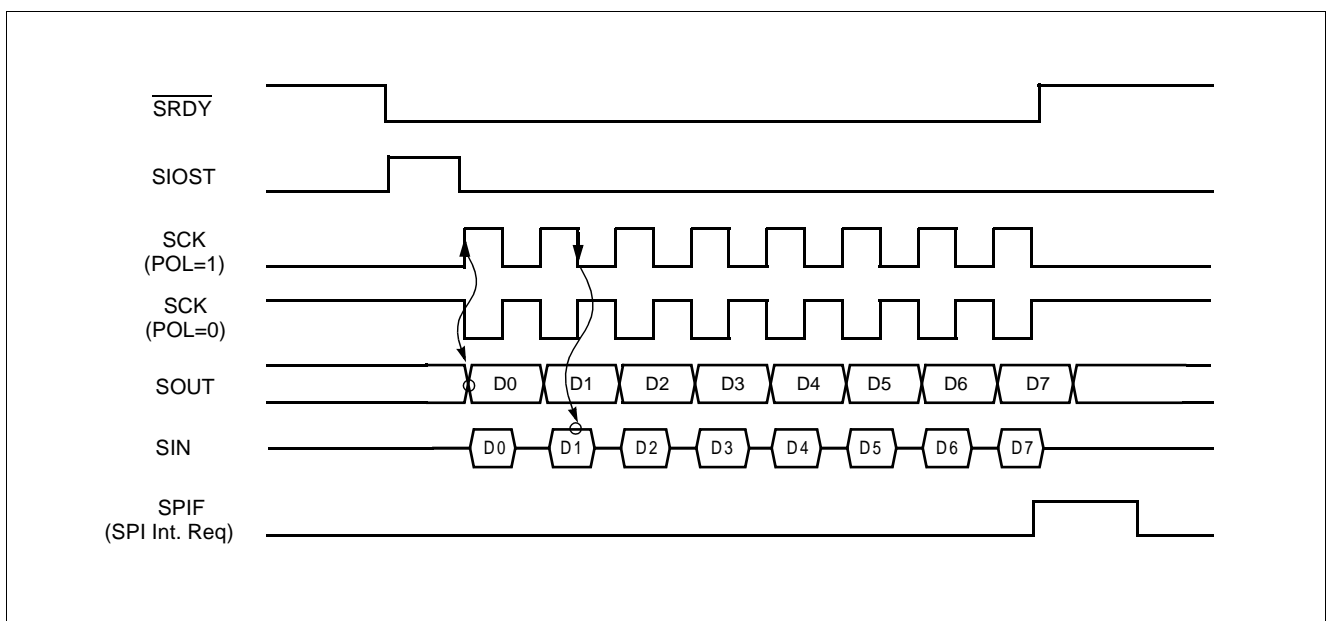


Figure 13-3 SPI Timing Diagram (with SRDY control)

14. Buzzer Output function

The buzzer driver consists of 6-bit binary counter, the buzzer register BUR and the clock selector. It generates square-wave which is very wide range frequency (480 Hz~250 KHz at $f_{xin} = 4 \text{ MHz}$) by user programmable counter.

Pin RB1 is assigned for output port of Buzzer driver by setting the bit BUZO of RBFUNC to "1".

The 6-bit buzzer counter is cleared and start the counting by writing signal to the register BUR. It is increased from 00H until it matches 6-bit register BUR.

Also, it is cleared by counter overflow and count up to output the square wave pulse of duty 50%.

The bit 0 to 5 of BUR determines output frequency for buzzer driving. Frequency calculation is following as shown below.

$$f_{BUZ}(Hz) = \frac{\text{Oscillator Frequency}}{2 \times \text{Prescaler Ratio} \times (BUR + 1)}$$

The bits BUCK1, BUCK0 of BUR selects the source clock from prescaler output.

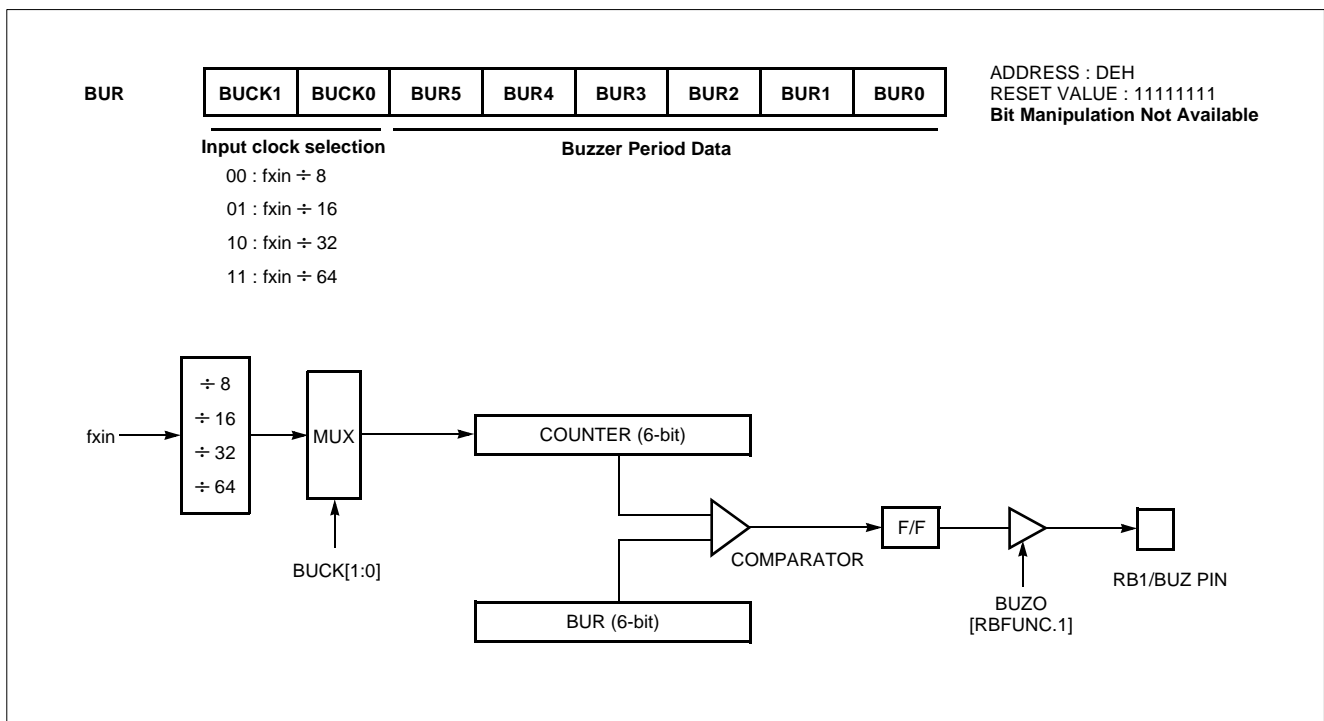


Figure 14-1 Buzzer Driver

15. ANALOG TO DIGITAL CONVERTER

The analog-to-digital converter (A/D) allows conversion of an analog input signal to a corresponding 8-bit digital value. The A/D module has eight analog inputs, which are multiplexed into one sample and hold. The output of the sample and hold is the input into the converter, which generates the result via successive approximation.

The analog reference voltage is selected to V_{DD} or AV_{ref} by setting of the bit $AVREFS$ in $RBFUNC$ register. If external analog reference AV_{ref} is selected, the bit $ANSEL0$ should not be set to "1", because this pin is used to an analog reference of A/D converter.

The A/D module has two registers which are the control register $ADCM$ and A/D result register $ADCR$. The $ADCM$ register, shown in Figure 15-2, controls the operation of the A/D converter module. The port pins can be configure as analog inputs or digital I/O.

To use analog inputs, each port is assigned analog input port by setting the bit $ANSEL[7:0]$ in $RAFUNC$ register. And selected the corresponding channel to be converted by setting $ADS[2:0]$.

The processing of conversion is start when the start bit $ADST$ is set to "1". After one cycle, it is cleared by hardware. The register $ADCR$ contains the results of the A/D conversion. When the conversion is completed, the result is loaded into the $ADCR$, the A/D conversion status bit $ADSF$ is set to "1", and the A/D interrupt flag $ADIF$ is set. The block diagram of the A/D module is shown in Figure 15-1. The A/D status bit $ADSF$ is set automatically when A/D conversion is completed, cleared when A/D conversion is in process. The conversion time takes maximum 10 μS (at $f_{xin}=8$ MHz).

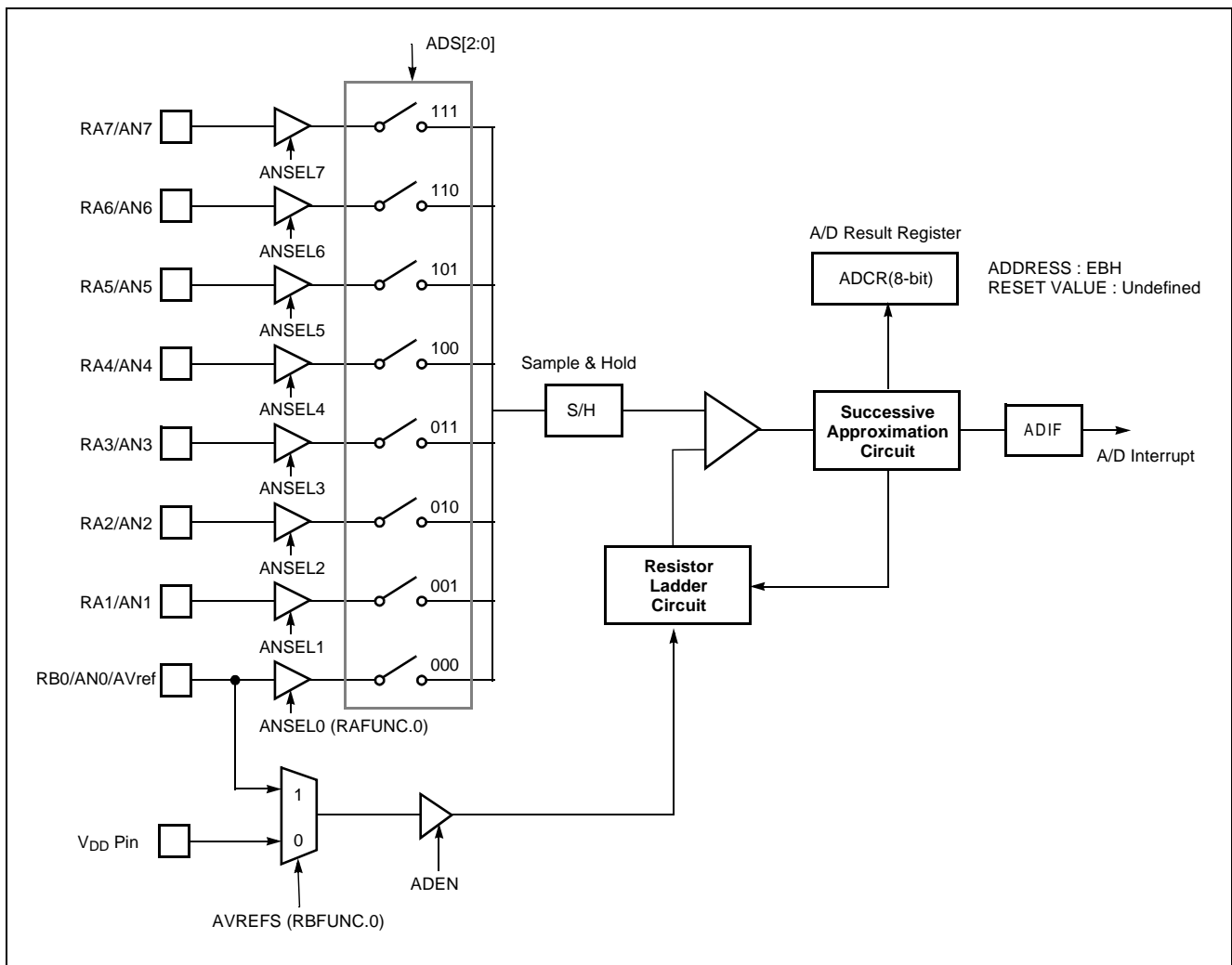


Figure 15-1 A/D Converter Block Diagram

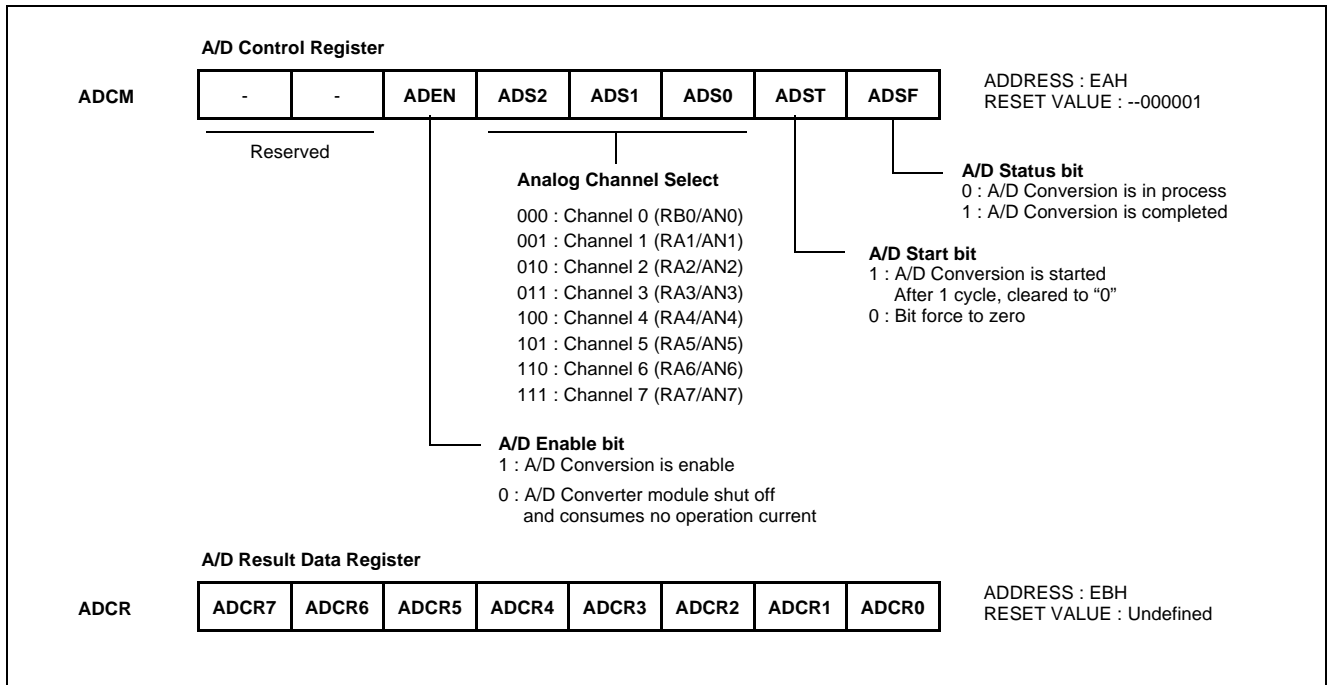


Figure 15-2 A/D Converter Registers

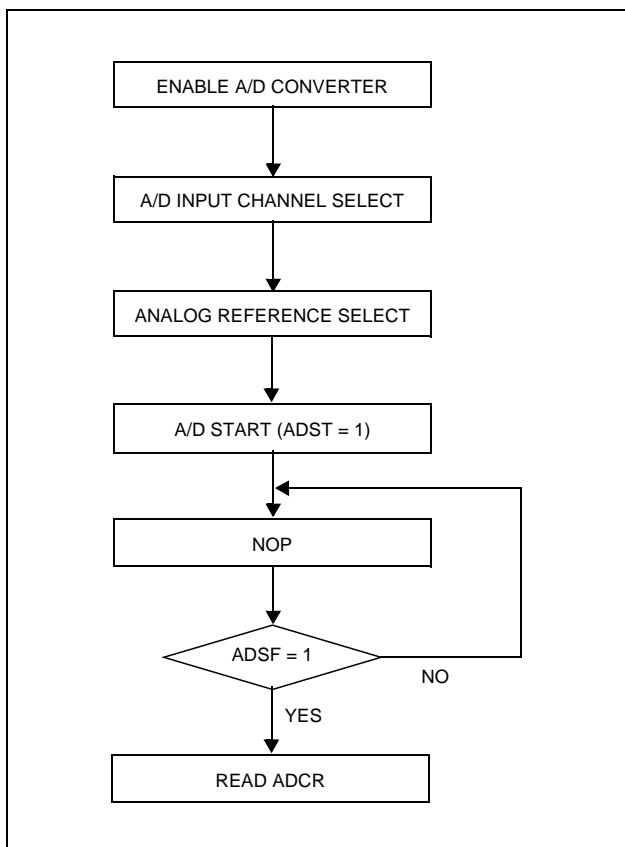


Figure 15-3 A/D Converter Operation Flow

A/D Converter Cautions

(1) Input range of AN0 to AN7

The input voltage of AN0 to AN7 should be within the specification range. In particular, if a voltage above VDD (or AVref) or below Vss is input (even if within the absolute maximum rating range), the conversion value for that channel can not be indeterminate. The conversion values of the other channels may also be affected.

(2) Noise countermeasures

In order to maintain 8-bit resolution, attention must be paid to noise on pins AVref(or VDD)and AN0 to AN7. Since the effect increases in proportion to the output impedance of the analog input source, it is recommended that a capacitor be connected externally as shown in Figure 15-4 in order to reduce noise.

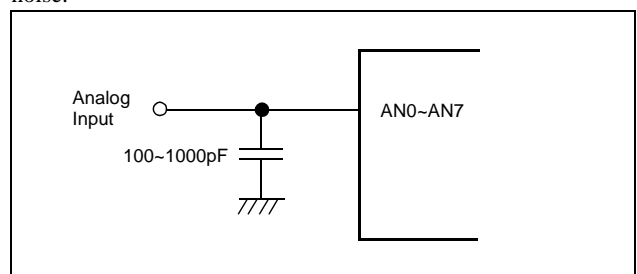


Figure 15-4 Analog Input Pin Connecting Capacitor

(3) Pins AN0/RB0 and AN1/RA1 to AN7/RA7

The analog input pins AN0 to AN7 also function as input/output port (PORT RA and RB0) pins. When A/D conversion is performed with any of pins AN0 to AN7 selected, be sure not to execute a PORT input instruction while conversion is in progress, as this may reduce the conversion resolution.

Also, if digital pulses are applied to a pin adjacent to the pin in the process of A/D conversion, the expected A/D conversion value may not be obtainable due to coupling

noise. Therefore, avoid applying pulses to pins adjacent to the pin undergoing A/D conversion.

(4) AVref pin input impedance

A series resistor string of approximately 10K Ω is connected between the AVref pin and the Vss pin.

Therefore, if the output impedance of the reference voltage source is high, this will result in parallel connection to the series resistor string between the AVref pin and the Vss pin, and there will be a large reference voltage error.

16. INTERRUPTS

The GMS87C1408 and GMS87C1404 interrupt circuits consist of Interrupt enable register (IENH, IENL), Interrupt request flags of IRQH, IRQL, Interrupt Edge Selection Register (IEDS), priority circuit and Master enable flag("I" flag of PSW). The configuration of interrupt circuit is shown in Figure 16-1 and Interrupt priority is shown in Table 16-1 .

The External Interrupts INT0, INT1, INT2 and INT3 can each be transition-activated (1-to-0, 0-to-1 and both transition).

The flags that actually generate these interrupts are bit INT0IF, INT1IF, INT2IF and INT3IF in Register IRQH. When an external interrupt is generated, the flag that gen-

erated it is cleared by the hardware when the service routine is vectored to only if the interrupt was transition-activated.

The Timer 0, Timer 1, Timer 2 and Timer 3 Interrupts are generated by T0IF, T1IF, T2IF and T3IF, which are set by a match in their respective timer/counter register. The AD converter Interrupt is generated by ADIF which is set by finishing the analog to digital conversion. The Watch dog timer Interrupt is generated by WDTIF which set by a match in Watch dog timer register (when the bit WDTON is set to "0"). The Basic Interval Timer Interrupt is generated by BITIF which is set by a overflowing of the Basic Interval Timer Register(BITR).

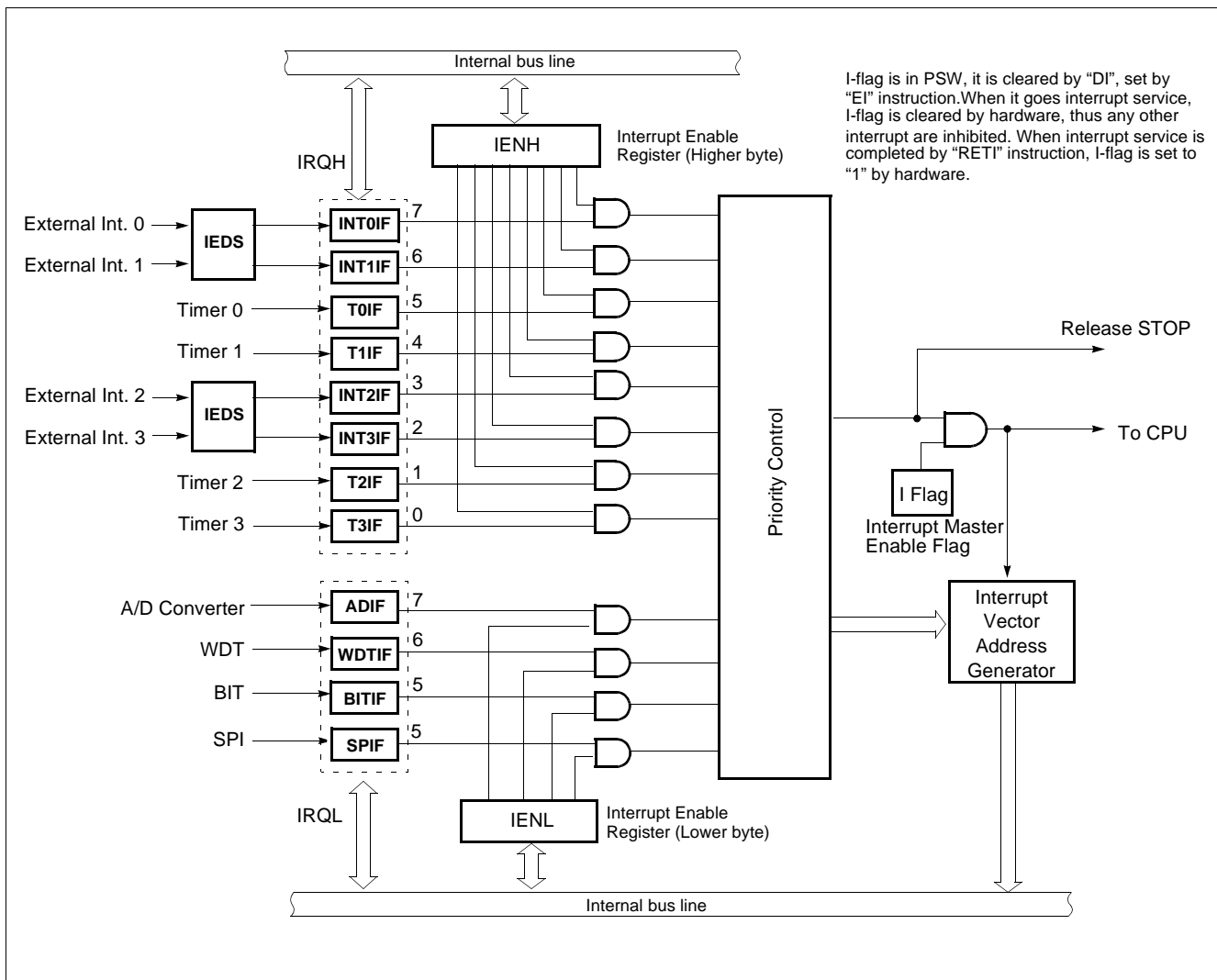


Figure 16-1 Block Diagram of Interrupt Function

The interrupts are controlled by the interrupt master enable flag I-flag (bit 2 of PSW), the interrupt enable register (IENH, IENL) and the interrupt request flags (in IRQH, IRQL) except Power-on reset and software BRK interrupt.

Interrupt enable registers are shown in Figure 16-2 . These registers are composed of interrupt enable flags of each interrupt source, these flags determines whether an interrupt will be accepted or not. When enable flag is “0”, a corresponding interrupt source is prohibited. Note that PSW contains also a master enable bit, I-flag, which disables all interrupts at once.

| Reset/Interrupt | Symbol | Priority | Vector Addr. |
|----------------------|---------|----------|-------------------|
| Hardware Reset | RESET | - | FFFE _H |
| External Interrupt 0 | INT0 | 1 | FFFA _H |
| External Interrupt 1 | INT1 | 2 | FFF8 _H |
| Timer 0 | Timer 0 | 3 | FFF6 _H |
| Timer 1 | Timer 1 | 4 | FFF4 _H |
| External Interrupt 2 | INT2 | 5 | FFF2 _H |
| External Interrupt 3 | INT3 | 6 | FFF0 _H |
| Timer 2 | Timer 2 | 7 | FFEE _H |
| Timer 3 | Timer 3 | 8 | FFEC _H |
| A/D Converter | A/D C | 9 | FFEA _H |
| Watch Dog Timer | WDT | 10 | FFE8 _H |
| Basic Interval Timer | BIT | 11 | FFE6 _H |
| Serial Interface | SPI | 12 | FFE6 _H |

Table 16-1 Interrupt Priority

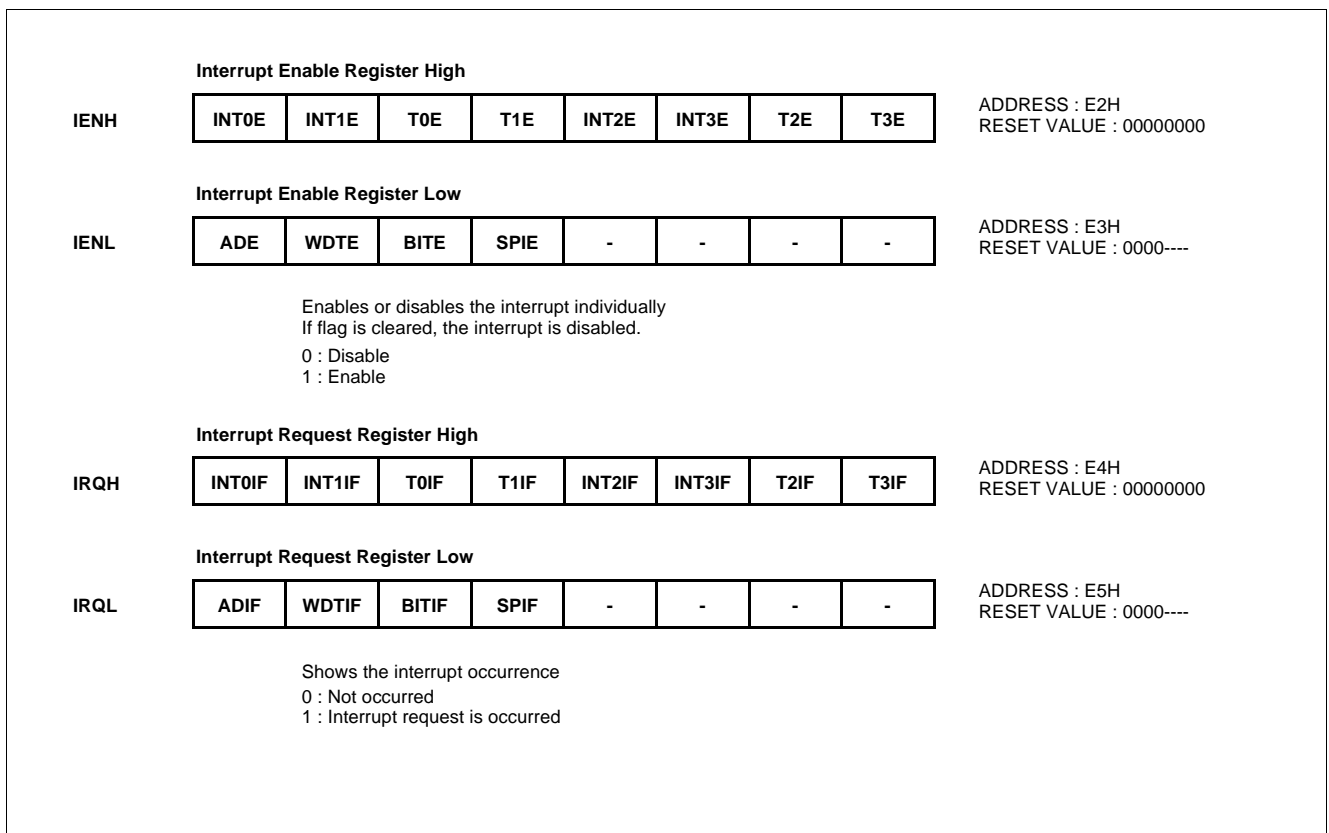


Figure 16-2 Interrupt Enable Registers and Interrupt Request Registers

When an interrupt is occurred, the I-flag is cleared and disable any further interrupt, the return address and PSW are pushed into the stack and the PC is vectored to. Once in the interrupt service routine the source(s) of the interrupt can be determined by polling the interrupt request flag bits.

The interrupt request flag bit(s) must be cleared by software before re-enabling interrupts to avoid recursive interrupts. The Interrupt Request flags are able to be read and written.

16.1 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 $8 f_{OSC}$ ($2 \mu s$ at $f_{XIN}=4MHz$) after the completion of the current instruction execution. The interrupt service task is terminated upon execution of an interrupt return instruction [RETI].

Interrupt acceptance

1. The interrupt master enable flag (I-flag) 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. Interrupt request flag for the interrupt source accepted is cleared to “0”.
3. The contents of the program counter (return address) and the program status word are saved (pushed) onto the stack area. The stack pointer decreases 3 times.
4. The entry address of the interrupt service program is read from the vector table address and the entry address is loaded to the program counter.
5. The instruction stored at the entry address of the interrupt service program is executed.

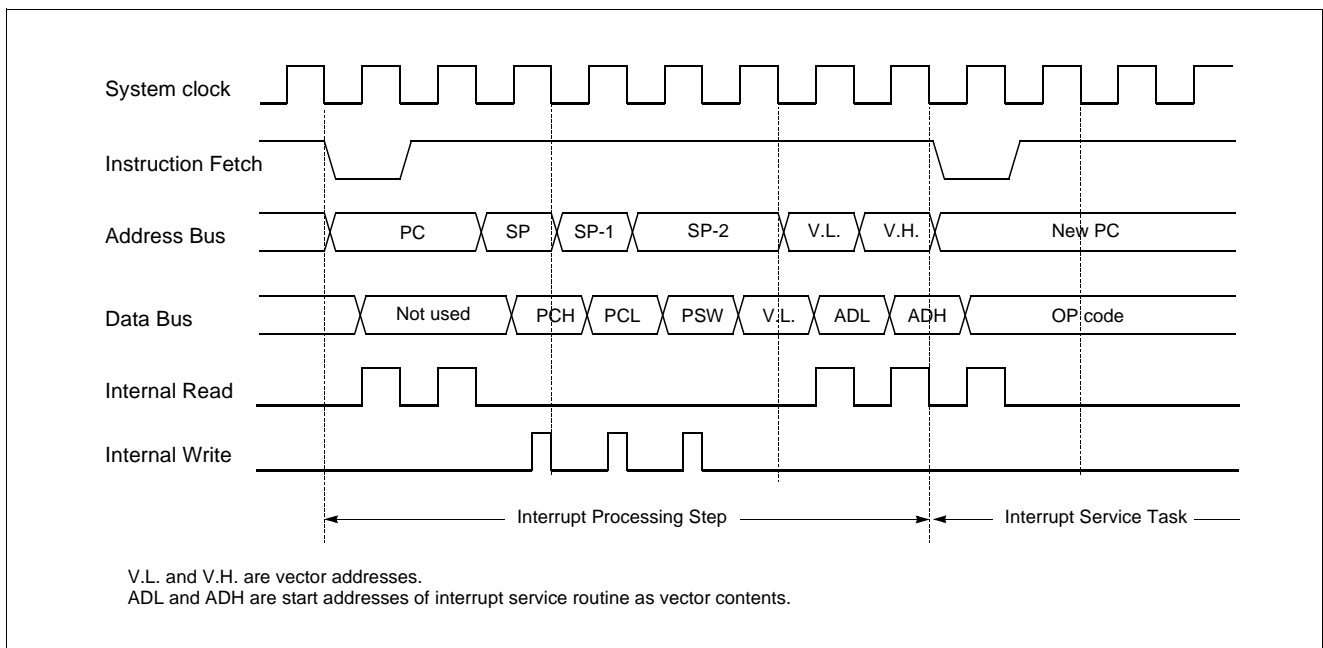
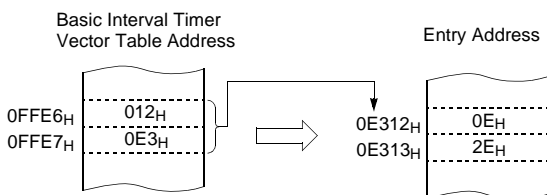


Figure 16-3 Timing chart of Interrupt Acceptance and Interrupt Return Instruction



Correspondence between vector table address for BIT interrupt and the entry address of the interrupt service program.

An interrupt request is not accepted until the I-flag is set to “1” even if a requested interrupt has higher priority than that of the current interrupt being serviced.

When nested interrupt service is required, the I-flag should be set to “1” by “EI” instruction in the interrupt service program. In this case, acceptable interrupt sources are selectively enabled by the individual interrupt enable flags.

Saving/Restoring General-purpose Register

During interrupt acceptance processing, the program counter and the program status word are automatically saved on the stack, but accumulator and other registers are not saved itself. These registers are saved by the software if necessary. Also, when multiple interrupt services are nested, 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.

Example: Register save using push and pop instructions

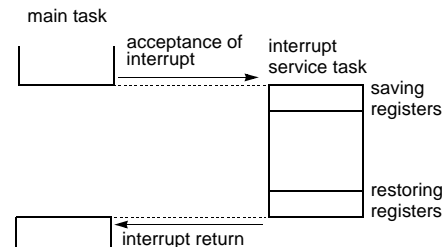
```

INTxx:  PUSH    A      ;SAVE ACC.
        PUSH    X      ;SAVE X REG.
        PUSH    Y      ;SAVE Y REG.
        

|                      |
|----------------------|
| interrupt processing |
|----------------------|


        POP     Y      ;RESTORE Y REG.
        POP     X      ;RESTORE X REG.
        POP     A      ;RESTORE ACC.
        RETI          ;RETURN
    
```

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



16.2 BRK Interrupt

Software interrupt can be invoked by BRK instruction, which has the lowest priority order.

Interrupt vector address of BRK is shared with the vector of TCALL 0 (Refer to Program Memory Section). When BRK interrupt is generated, B-flag of PSW is set to distinguish BRK from TCALL 0.

Each processing step is determined by B-flag as shown in Figure 16-4 .

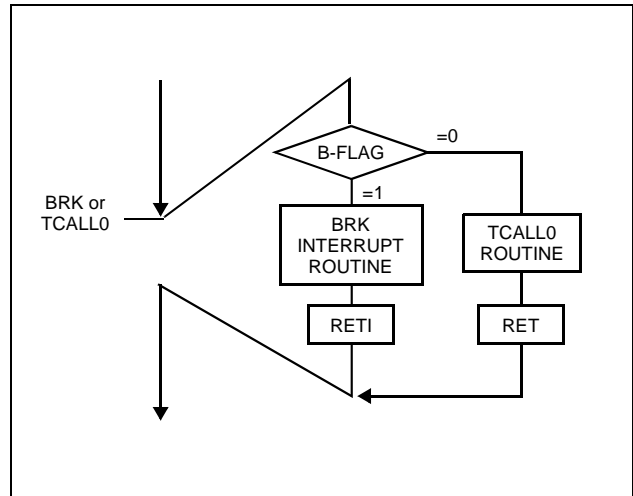


Figure 16-4 Execution of BRK/TCALL0

16.3 Multi Interrupt

If two requests of different priority levels are received simultaneously, the request of higher priority level is serviced. If requests of the interrupt are received at the same time simultaneously, an internal polling sequence determines by hardware which request is serviced.

However, multiple processing through software for special features is possible. Generally when an interrupt is accepted, the I-flag is cleared to disable any further interrupt. But as user sets I-flag in interrupt routine, some further interrupt can be serviced even if certain interrupt is in progress.

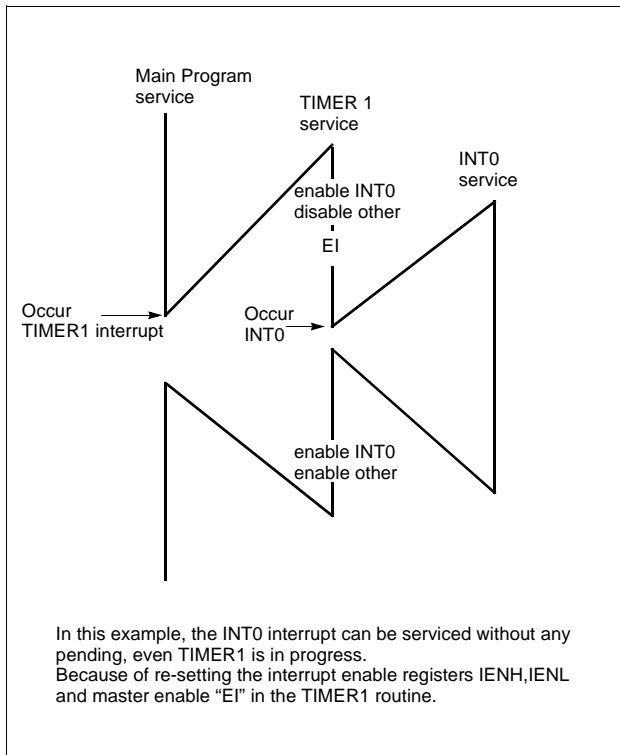


Figure 16-5 Execution of Multi Interrupt

Example: Even though Timer1 interrupt is in progress, INT0 interrupt serviced without any suspend.

```

TIMER1:  PUSH  A
         PUSH  X
         PUSH  Y
         LDM   IENH, #80H ; Enable INT0 only
         LDM   IENL, #0   ; Disable other
         EI    ; Enable Interrupt
         :
         :
         :
         :
         :
         LDM   IENH, #0FFH ; Enable all interrupts
         LDM   IENL, #0F0H
         POP   Y
         POP   X
         POP   A
         RETI
    
```

16.4 External Interrupt

The external interrupt on INT0, INT1, INT2 and INT3 pins are edge triggered depending on the edge selection register IEDS (address 0E6H) as shown in Figure 16-6 .

The edge detection of external interrupt has three transition activated mode: rising edge, falling edge, and both edge.

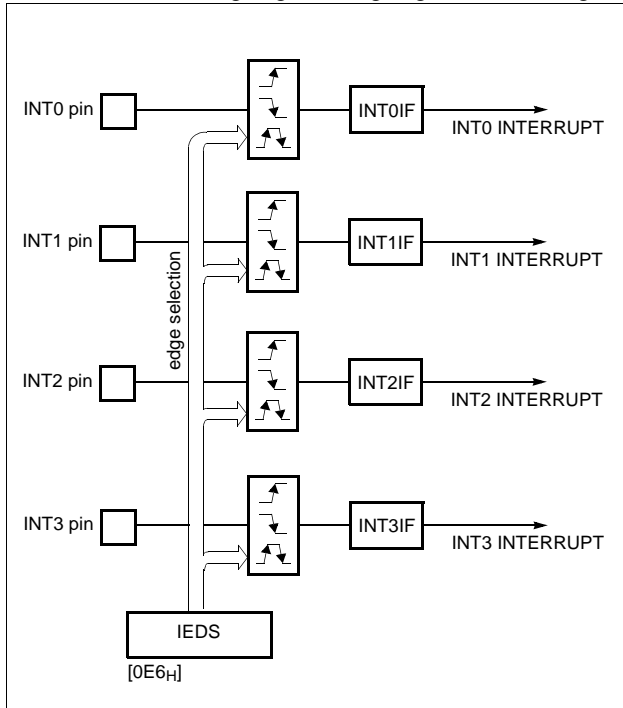


Figure 16-6 External Interrupt Block Diagram

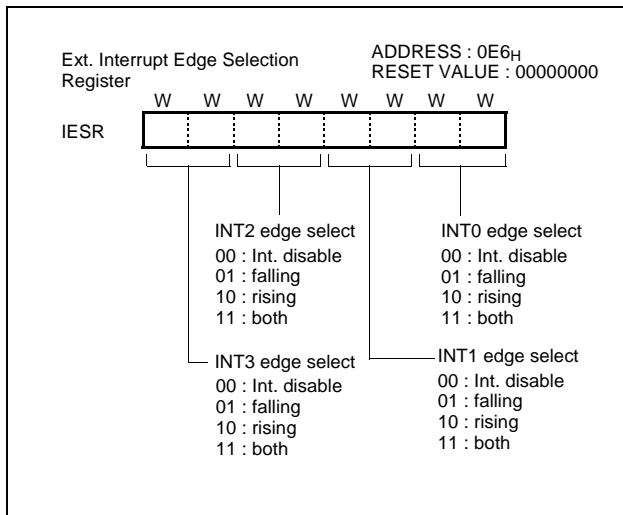
Example: To use as an INT0 and INT2

```

:
:
;**** Set port as an input port RB2,RD0
LDM    RBIO,#1111_1011B
LDM    RDIO,#1111_1110B
;
;**** Set port as an interrupt port
LDM    RBFUNC,#04H
LDM    RDFUNC,#01H
;
;**** Set Falling-edge Detection
LDM    IEDS,#0001_0001B
:
:
:
    
```

Response Time

The INT0, INT1, INT2 and INT3 edge are latched into INT0IF, INT1IF, INT2IF and INT3IF at every machine cycle. The values are not actually polled by the circuitry until the next machine cycle. If a request is active and conditions are right for it to be acknowledged, a hardware sub-routine call to the requested service routine will be the next instruction to be executed. The DIV itself takes twelve cycles. Thus, a minimum of twelve complete machine cycles elapse between activation of an external interrupt request and the beginning of execution of the first instruction of the service routine.



shows interrupt response timings.

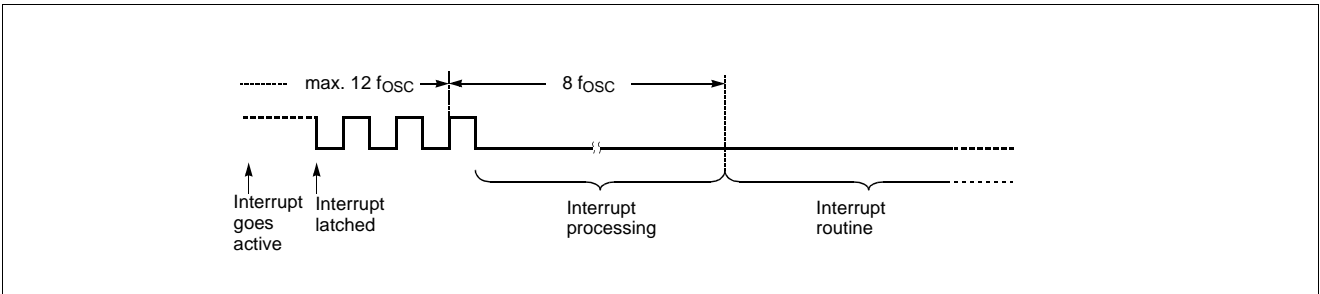


Figure 16-7 Interrupt Response Timing Diagram

17. WATCHDOG TIMER

The purpose of the watchdog timer is to detect the malfunction (runaway) of program due to external noise or other causes and return the operation to the normal condition.

The watchdog timer has two types of clock source.

The first type is an on-chip RC oscillator which does not require any external components. This RC oscillator is separate from the external oscillator of the Xin pin. It means that the watchdog timer will run, even if the clock on the Xin pin of the device has been stopped, for example, by entering the STOP mode.

The other type is a prescaled system clock.

The watchdog timer consists of 7-bit binary counter and the watchdog timer data register. When the value of 7-bit binary counter is equal to the lower 7 bits of WDTR, the interrupt request flag is generated. This can be used as WDT interrupt or reset the CPU in accordance with the bit WDTON.

Note: Because the watchdog timer counter is enabled after clearing Basic Interval Timer, after the bit WDTON set to "1", maximum error of timer is depend on prescaler ratio of Basic Interval Timer.

The 7-bit binary counter is cleared by setting WDTCL(bit7 of WDTR) and the WDTCL is cleared automatically after 1 machine cycle.

The RC oscillated watchdog timer is activated by setting the bit RCWDT as shown below.

```

:
LDM    CKCTLR, #3FH    ; enable the RC-osc WDT
LDM    WDTR, #0FFH    ; set the WDT period
STOP   ; enter the STOP mode
NOP
NOP    ; RC-osc WDT running
:
    
```

The RC oscillation period is vary with temperature, V_{DD} and process variations from part to part (approximately, 40~120uS). The following equation shows the RC oscillated watchdog timer time-out.

$$T_{RCWDT} = CLK_{RC} \times 2^8 \times [WDTR.6 \sim 0] + (CLK_{RC} \times 2^8) / 2$$

where, $CLK_{RC} = 40 \sim 120 \mu S$

In addition, this watchdog timer can be used as a simple 7-bit timer by interrupt WDTIF. The interval of watchdog timer interrupt is decided by Basic Interval Timer. Interval equation is as below.

$$T_{WDT} = [WDTR.6 \sim 0] \times \text{Interval of BIT}$$

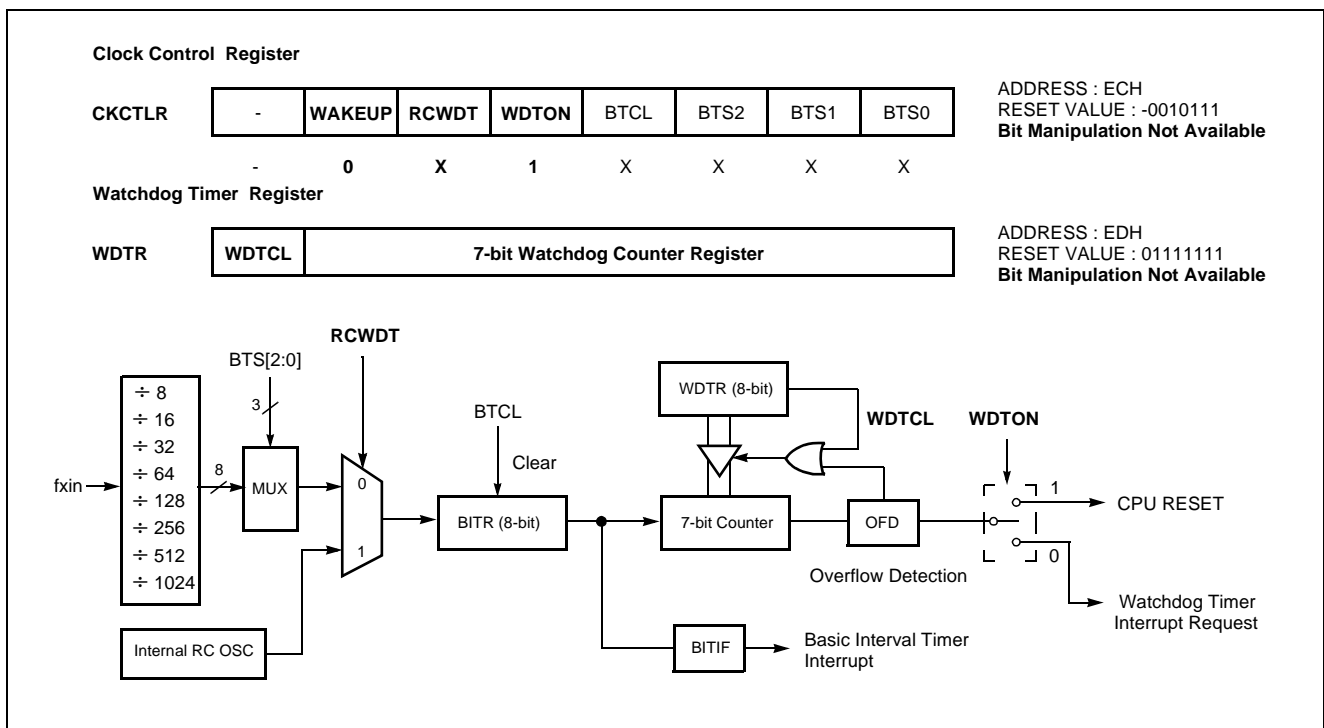


Figure 17-1 Block Diagram of Watchdog Timer

18. Power Saving Mode

For applications where power consumption is a critical factor, device provides two kinds of power saving functions, STOP mode and Wake-up Timer mode.

The power saving function is activated by execution of

STOP instruction after setting the corresponding status (WAKEUP) of CKCTLR.

Table 18-1 shows the status of each Power Saving Mode.

| Peripheral | STOP | Wake-up Timer |
|-----------------------------|----------------------------------|--|
| RAM | Retain | Retain |
| Control Registers | Retain | Retain |
| I/O Ports | Retain | Retain |
| CPU | Stop | Stop |
| Timer0, Timer2 | Stop | Operation |
| Oscillation | Stop | Oscillation |
| Prescaler | Stop | ÷ 2048 only |
| Entering Condition [WAKEUP] | 0 | 1 |
| Release Sources | RESET, RCWDT, INT0~3, EC0~1, SPI | RESET, RCWDT, INT0~3, EC0~1, SPI, TIMER0, TIMER2 |

Table 18-1 Power Saving Mode

18.1 Stop Mode

In the Stop mode, the on-chip oscillator is stopped. With the clock frozen, all functions are stopped, but the on-chip RAM and Control registers are held. The port pins out the values held by their respective port data register, port direction registers. Oscillator stops and the systems internal operations are all held up.

- The states of the RAM, registers, and latches valid immediately before the system is put in the STOP state are all held.
- The program counter stop the address of the instruction to be executed after the instruction "STOP" which starts the STOP operating mode.

The Stop mode is activated by execution of STOP instruction after clearing the bit WAKEUP of CKCTLR to "0". (This register should be written by byte operation. If this register is set by bit manipulation instruction, for example "set1" or "clr1" instruction, it may be undesired operation)

In the Stop mode of operation, V_{DD} can be reduced to minimize power consumption. Care must be taken, however, to ensure that V_{DD} is not reduced before the Stop mode is invoked, and that V_{DD} is restored to its normal operating level, before the Stop mode is terminated.

The reset should not be activated before V_{DD} is restored to its normal operating level, and must be held active long enough to allow the oscillator to restart and stabilize.

Note: After STOP instruction, at least two or more NOP instruction should be written

```
Ex)  LDM    CKCTLR,#0000_1110B
      STOP
      NOP
      NOP
```

In the STOP operation, the dissipation of the power associated with the oscillator and the internal hardware is lowered; however, the power dissipation associated with the pin interface (depending on the external circuitry and program) is not directly determined by the hardware operation of the STOP feature. This point should be little current flows when the input level is stable at the power voltage level (V_{DD}/V_{SS}); however, when the input level gets higher than the power voltage level (by approximately 0.3 to 0.5V), a current begins to flow. Therefore, if cutting off the output transistor at an I/O port puts the pin signal into the high-impedance state, a current flow across the ports input transistor, requiring to fix the level by pull-up or other means.

Release the STOP mode

The exit from STOP mode is hardware reset or external interrupt. Reset re-defines all the Control registers but does not change the on-chip RAM. External interrupts allow both on-chip RAM and Control registers to retain their values. If I-flag = 1, the normal interrupt response takes place. If I-flag = 0, the chip will resume execution starting with the instruction following the STOP instruction. It will not vector to interrupt service routine. (refer to Figure 18-1)

By reset, exit from Stop mode is shown in Figure 18-3 .When exit from Stop mode by external interrupt, enough oscillation stabilization time is required to normal operation. Figure 18-2 shows the timing diagram. When release the Stop mode, the Basic interval timer is activated on wake-up. It is increased from 00_H until FF_H . The count overflow is set to start normal operation. Therefore, before STOP instruction, user must be set its relevant prescaler divide ratio to have long enough time (more than 20msec). This guarantees that oscillator has started and stabilized..

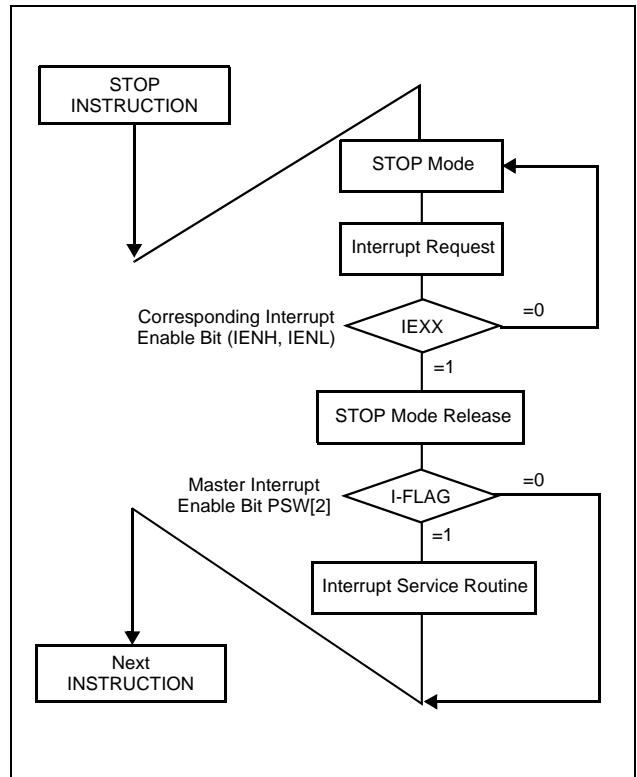


Figure 18-1 STOP Releasing Flow by Interrupts

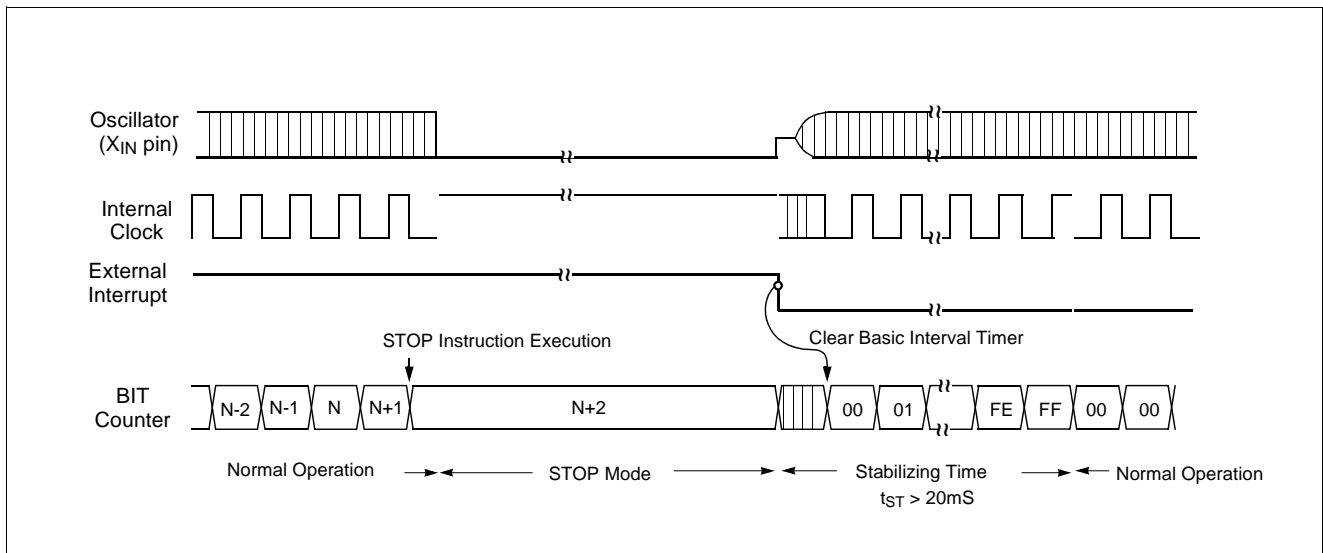


Figure 18-2 Timing of STOP Mode Release by External Interrupt

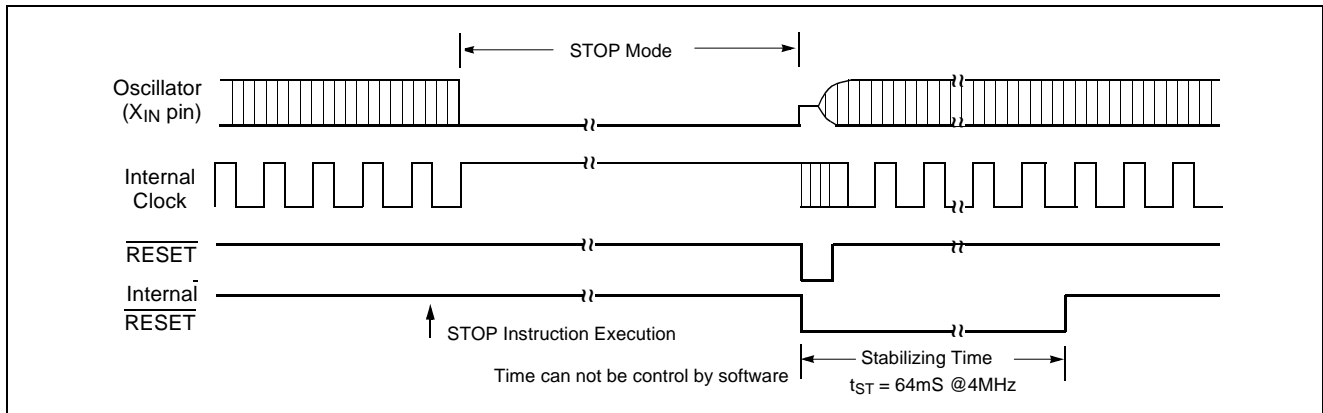


Figure 18-3 Timing of STOP Mode Release by RESET

18.2 STOP Mode using Internal RCWDT

In the STOP mode using Internal RC-Oscillated Watchdog Timer, the on-chip oscillator is stopped. But internal RC oscillation circuit is oscillated in this mode. The on-chip RAM and Control registers are held. The port pins out the values held by their respective port data register, port direction registers.

The Internal RC-Oscillated Watchdog Timer mode is activated by execution of STOP instruction after setting the bit RCWDT of CKCTLR to “1”. (This register should be written by byte operation. If this register is set by bit manipulation instruction, for example “set1” or “clr1” instruction, it may be undesired operation)

Note: After STOP instruction, at least two or more NOP instruction should be written

```
Ex)  LDM WDTR,#1111_1111B
      LDM CKCTLR,#0010_1110B
      STOP
      NOP
      NOP
```

Release the STOP mode using internal RCWDT

The exit from STOP mode using Internal RC-Oscillated Watchdog Timer is hardware reset or external interrupt. Reset re-defines all the Control registers but does not change the on-chip RAM. External interrupts allow both

on-chip RAM and Control registers to retain their values.

If I-flag = 1, the normal interrupt response takes place. In this case, if the bit WDTON of CKCTLR is set to “0” and the bit WDTE of IENH is set to “1”, the device will execute the watchdog timer interrupt service routine.(Figure 18-4) However, if the bit WDTON of CKCTLR is set to “1”, the device will generate the internal RESET signal and execute the reset processing. (Figure 18-5)

If I-flag = 0, the chip will resume execution starting with the instruction following the STOP instruction. It will not vector to interrupt service routine.(refer to Figure 18-1)

When exit from STOP mode using Internal RC-Oscillated Watchdog Timer by external interrupt, the oscillation stabilization time is required to normal operation. Figure 18-4 shows the timing diagram. When release the Internal RC-Oscillated Watchdog Timer mode, the basic interval timer is activated on wake-up. It is increased from 00_H until FF_H . The count overflow is set to start normal operation. Therefore, before STOP instruction, user must be set its relevant prescaler divide ratio to have long enough time (more than 20msec). This guarantees that oscillator has started and stabilized.

By reset, exit from STOP mode using internal RC-Oscillated Watchdog Timer is shown in Figure 18-5 .

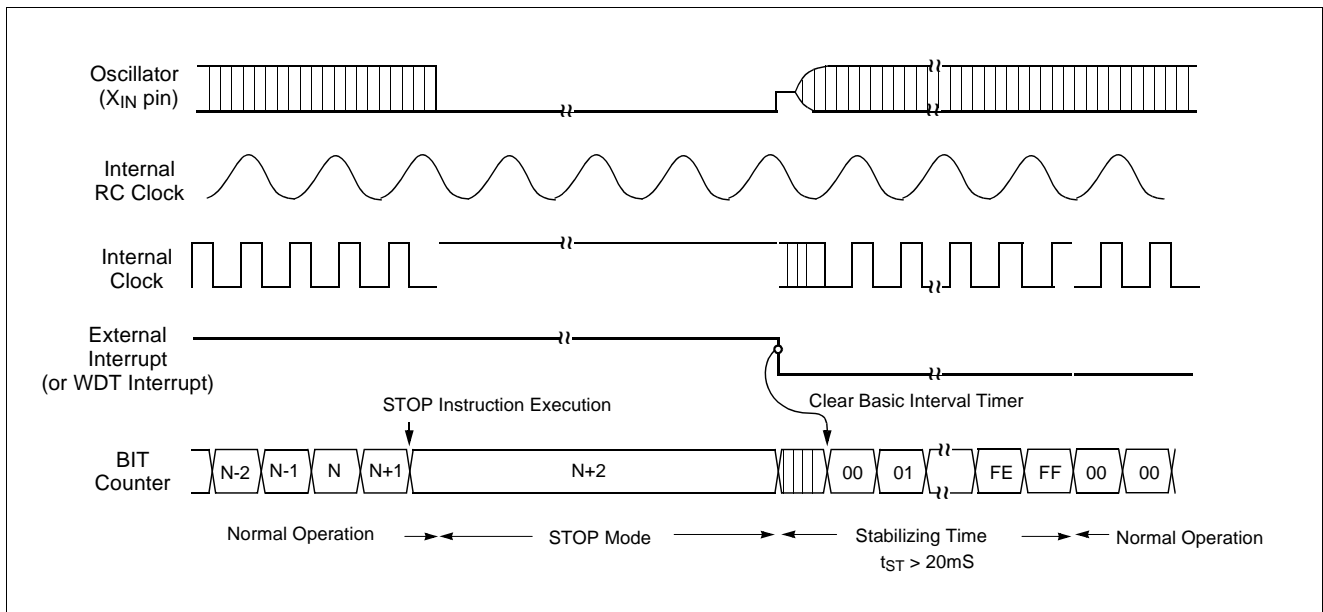


Figure 18-4 STOP Mode Releasing by External Interrupt or WDT Interrupt(using RCWDT)

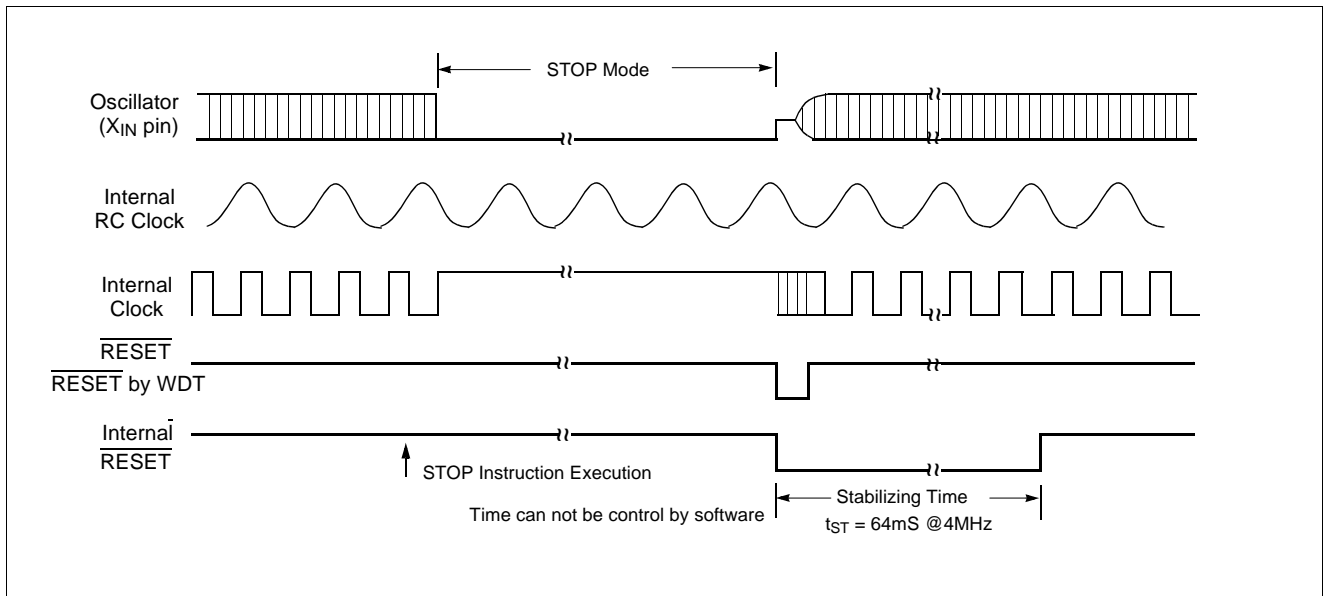


Figure 18-5 STOP Mode Releasing by RESET(using RCWDT)

18.3 Wake-up Timer Mode

In the Wake-up Timer mode, the on-chip oscillator is not stopped. Except the Prescaler(only 2048 divided ratio), Timer0 and Timer2, all functions are stopped, but the on-chip RAM and Control registers are held. The port pins out the values held by their respective port data register, port direction registers.

The Wake-up Timer mode is activated by execution of STOP instruction after setting the bit WAKEUP of CKCTLR to “1”. (This register should be written by byte operation. If this register is set by bit manipulation instruction, for example “set1” or “clr1” instruction, it may be undesired operation)

Note: After STOP instruction, at least two or more NOP instruction should be written

```
Ex) LDM TDR0,#0FFH
    LDM TMO,#0001_1011B
    LDM CKCTLR,#0100_1110B
    STOP
    NOP
    NOP
```

In addition, the clock source of timer0 and timer2 should be selected to 2048 divided ratio. Otherwise, the wake-up function can not work. And the timer0 and timer2 can be operated as 16-bit timer with timer1 and timer3(refer to timer function). The period of wake-up function is varied by setting the timer data register0, TDR0 or timer data register2, TDR2.

Release the Wake-up Timer mode

The exit from Wake-up Timer mode is hardware reset, Timer0(Timer2) overflow or external interrupt. Reset redefines all the Control registers but does not change the on-chip RAM. External interrupts and Timer0(Timer2) overflow allow both on-chip RAM and Control registers to retain their values.

If I-flag = 1, the normal interrupt response takes place. If I-flag = 0, the chip will resume execution starting with the instruction following the STOP instruction. It will not vector to interrupt service routine.(refer to Figure 18-1)

When exit from Wake-up Timer mode by external interrupt or timer0(Timer2) overflow, the oscillation stabilizing time is not required to normal operation. Because this mode do not stop the on-chip oscillator shown as Figure 18-6 .

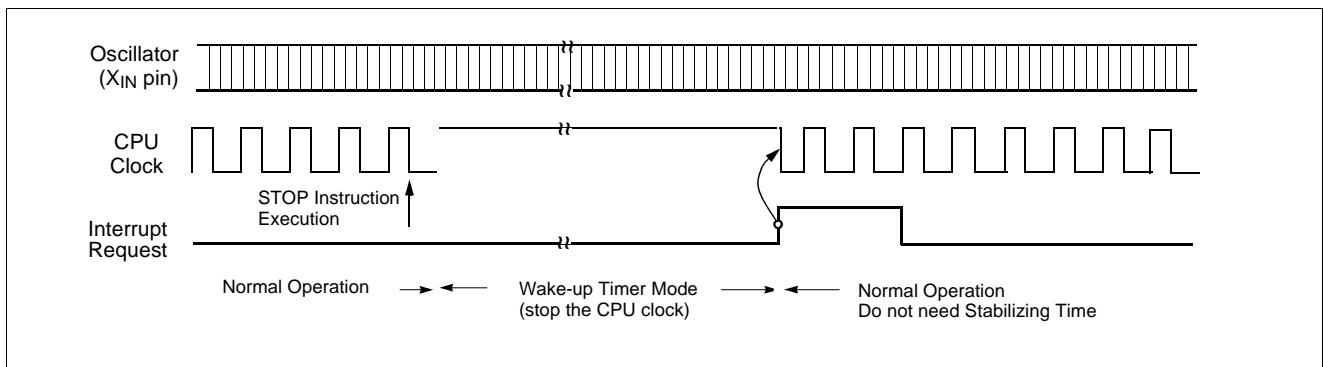


Figure 18-6 Wake-up Timer Mode Releasing by External Interrupt or Timer0(Timer2) Interrupt

18.4 Minimizing Current Consumption

The Stop mode is designed to reduce power consumption. To minimize current drawn during Stop mode, the user should turn-off output drivers that are sourcing or sinking current, if it is practical.

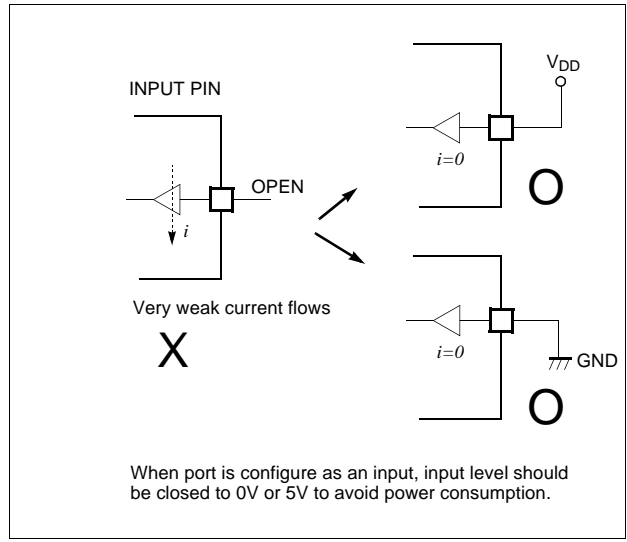
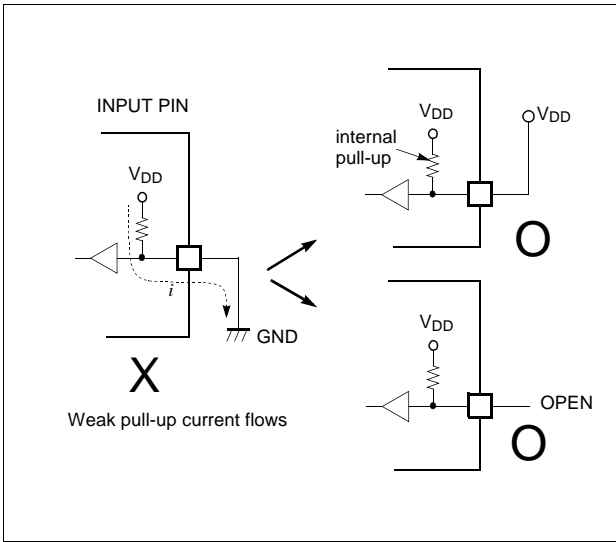
Note: In the STOP operation, the power dissipation associated with the oscillator and the internal hardware is lowered; however, the power dissipation associated with the pin interface (depending on the external circuitry and program) is not directly determined by the hardware operation of the STOP feature. This point should be little current flows when the input level is stable at the power voltage level (V_{DD}/V_{SS}); however, when the input level becomes higher than the power voltage level (by approximately 0.3V), a current begins to flow. Therefore, if cutting off the output transistor at an I/O port puts the pin signal into the high-impedance state, a current flow across the ports input transistor, requiring it to fix the level by pull-up or other means.

It should be set properly that current flow through port doesn't exist.

First consider the setting to input mode. Be sure that there is no current flow after considering its relationship with external circuit. In input mode, the pin impedance viewing from external MCU is very high that the current doesn't flow.

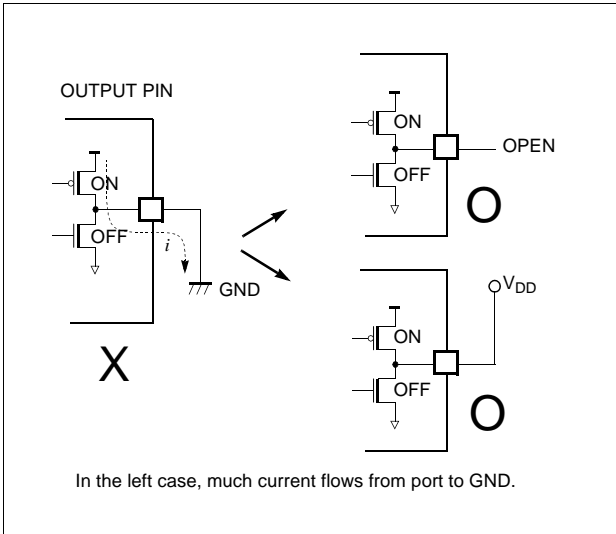
But input voltage level should be V_{SS} or V_{DD} . Be careful that if unspecified voltage, i.e. if uncertain voltage level (not V_{SS} or V_{DD}) is applied to input pin, there can be little current (max. 1mA at around 2V) flow.

If it is not appropriate to set as an input mode, then set to output mode considering there is no current flow. Setting to High or Low is decided considering its relationship with external circuit. For example, if there is external pull-up resistor then it is set to output mode, i.e. to High, and if there is external pull-down register, it is set to low.

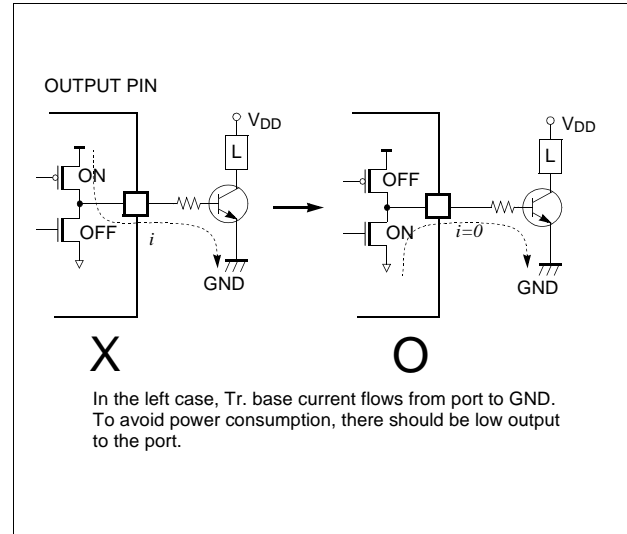


When port is configure as an input, input level should be closed to 0V or 5V to avoid power consumption.

Figure 18-7 Application Example of Unused Input Port



In the left case, much current flows from port to GND.



In the left case, Tr. base current flows from port to GND. To avoid power consumption, there should be low output to the port.

Figure 18-8 Application Example of Unused Input Port

19. RESET

The reset input is the RESET pin, which is the input to a Schmitt Trigger. A reset is accomplished by holding the RESET pin low for at least 8 oscillator periods, while the oscillator running. After reset, 64ms (at 4 MHz) add with 7 oscillator periods are required to start execution as shown in Figure 19-1 .

Internal RAM is not affected by reset. When V_{DD} is turned on, the RAM content is indeterminate. Therefore, this RAM should be initialized before reading or testing it.

Initial state of each register is shown as Table 8-1 .

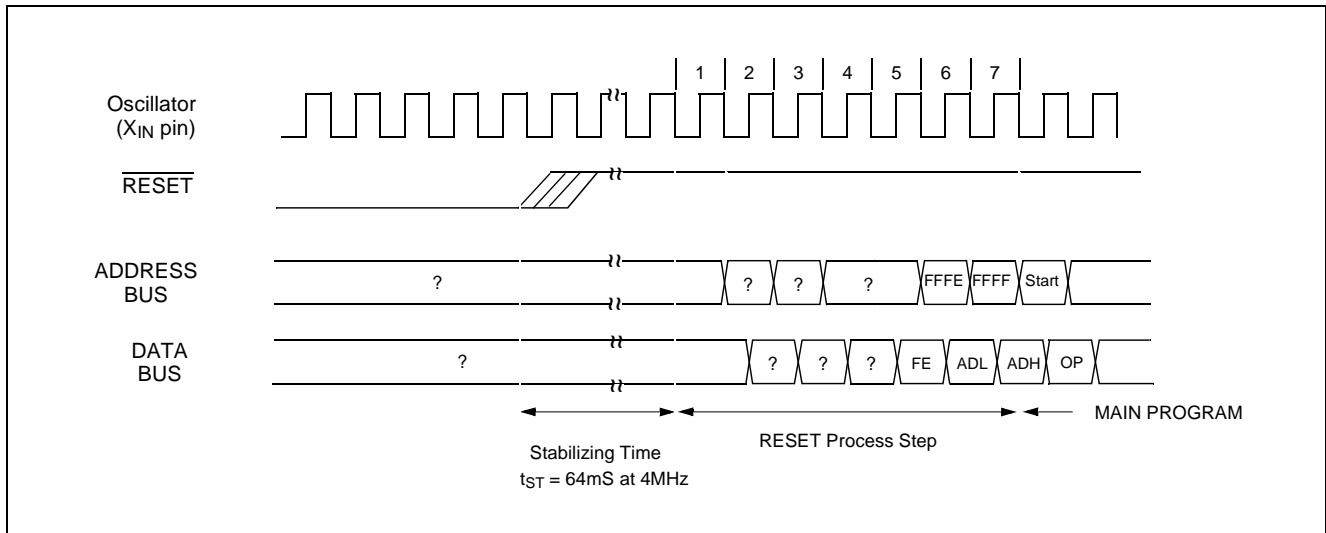


Figure 19-1 Timing Diagram after RESET

20. POWER FAIL PROCESSOR

The GMS87C1408 and GMS87C1404 has an on-chip power fail detection circuitry to immunize against power noise. A configuration register, PFDR, can enable (if clear/programmed) or disable (if set) the Power-fail Detect circuitry. If V_{DD} falls below 2.5~3.5V(2.0~3.0V) range for longer than 50 nS, the Power fail situation may reset MCU according to PFR bit of PFDR.

As below PFDR register is not implemented on the in-cir-

cuit emulator, user can not experiment with it. Therefore, after final development of user program, this function may be experimented.

Note: Power fail detect level is decided by setting the bit PFDLEVEL of CONFIG register (refer to Figure 21-1).

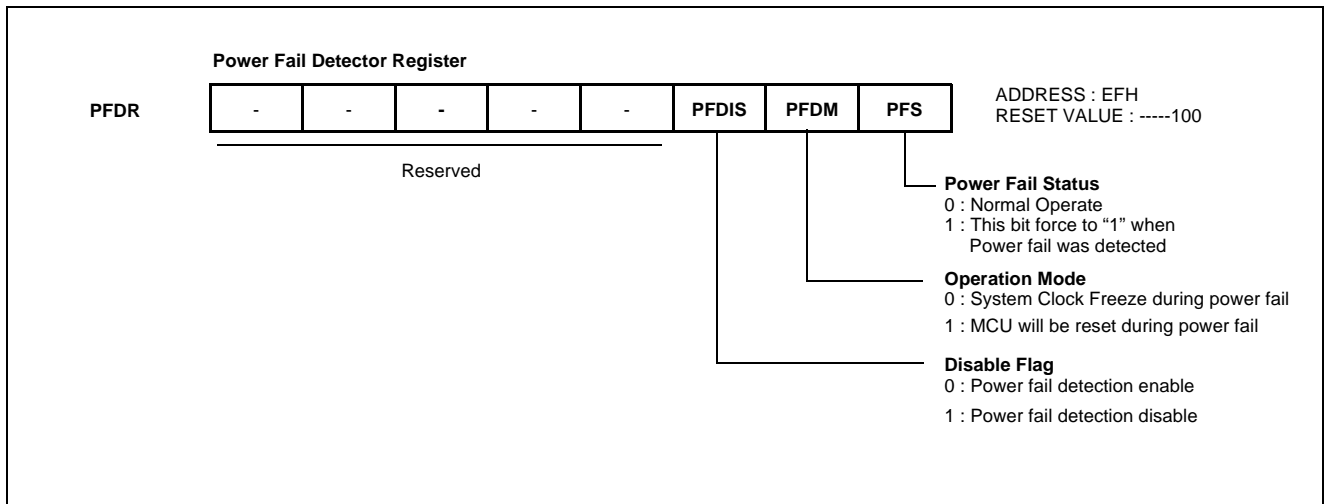


Figure 20-1 Power Fail Detector Register

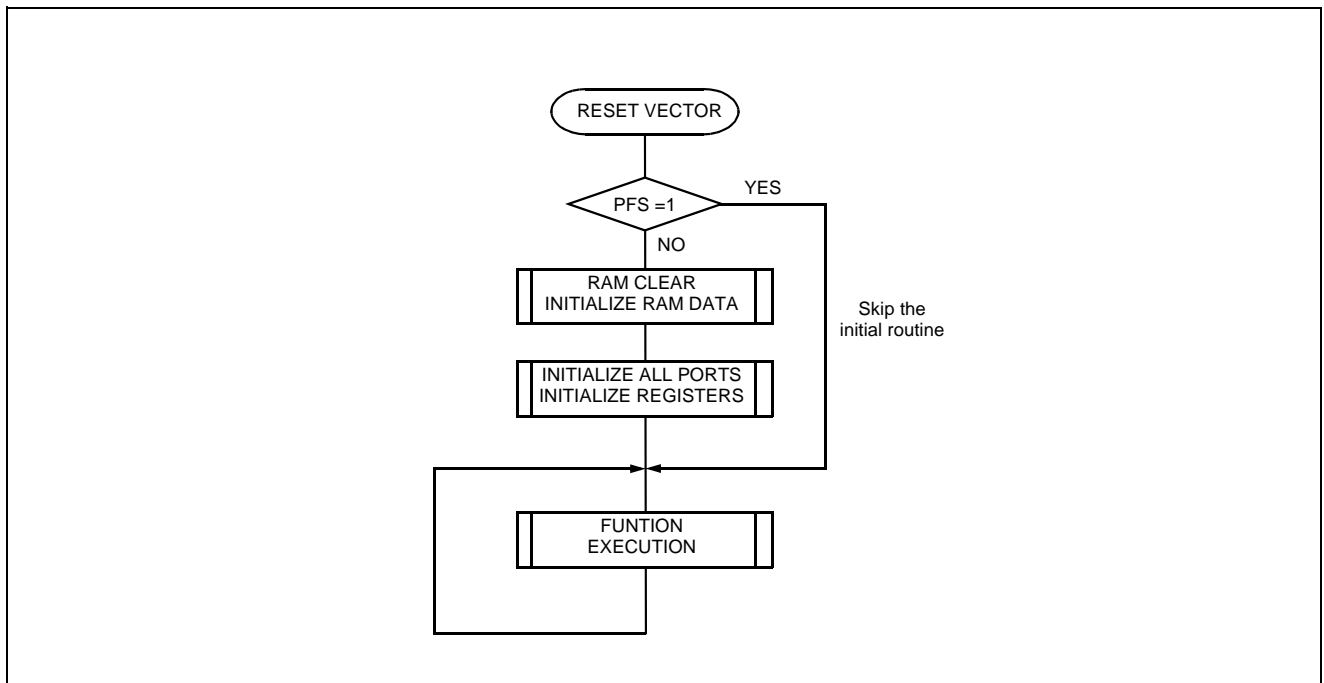


Figure 20-2 Example S/W of RESET by Power fail

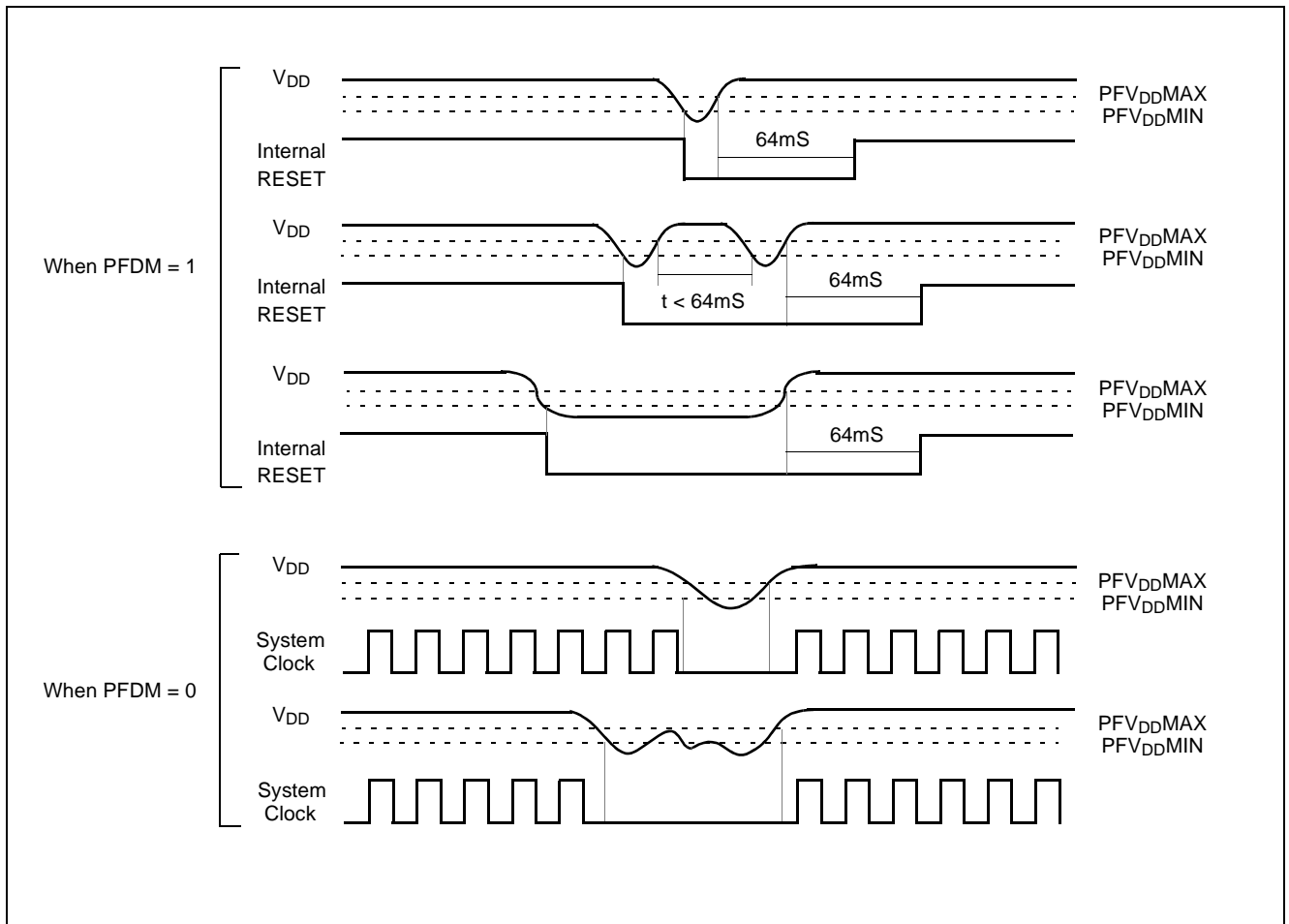


Figure 20-3 Power Fail Processor Situations

21. OTP PROGRAMMING

21.1 DEVICE CONFIGURATION AREA

The Device Configuration Area can be programmed or left unprogrammed to select device configuration such as security bit.

Ten memory locations (0F50_H ~ 0FE0_H) are designated as

Customer ID recording locations where the user can store check-sum or other customer identification numbers.

This area is not accessible during normal execution but is readable and writable during program / verify.

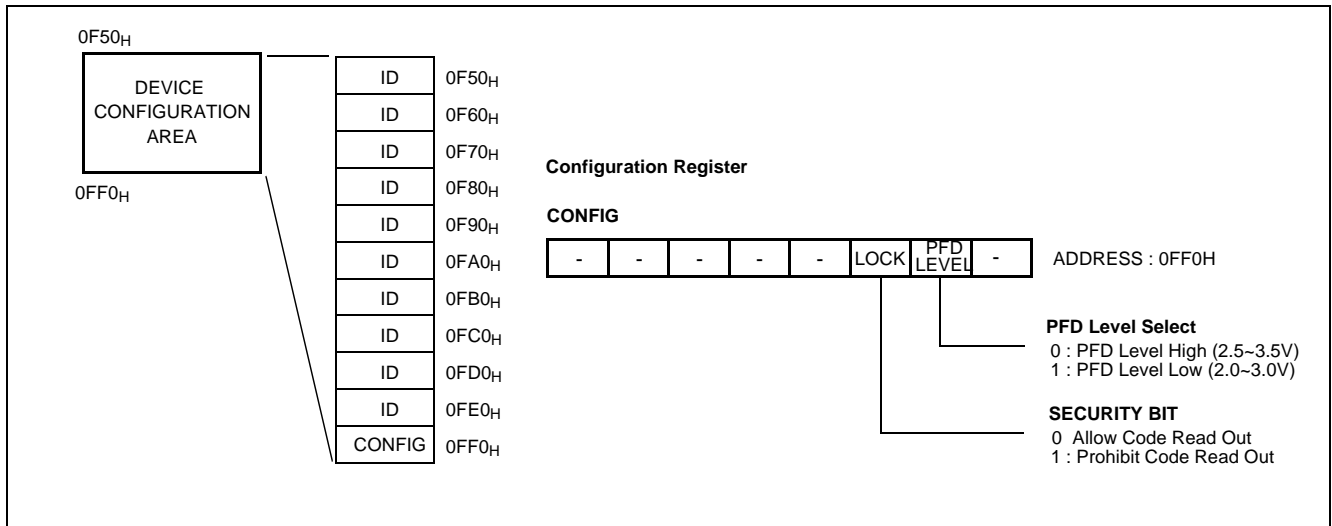


Figure 21-1 Device Configuration Area

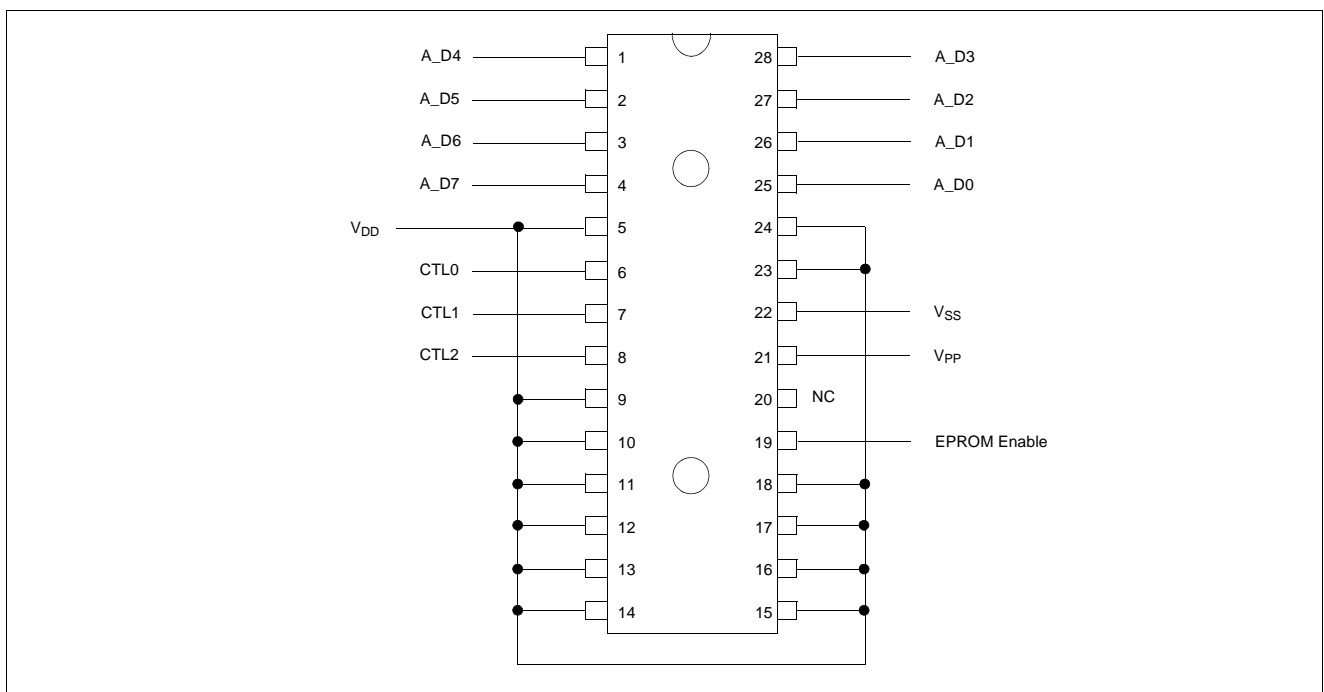


Figure 21-2 Pin Assignment

| Pin No. | User Mode | EPROM MODE | | | | |
|---------|---------------------------|-----------------|--|-----|----|----|
| | Pin Name | Pin Name | Description | | | |
| 1 | RA4 (AN4) | A_D4 | Address Input Data Input/Output | A12 | A4 | D4 |
| 2 | RA5 (AN5) | A_D5 | | A13 | A5 | D5 |
| 3 | RA6 (AN6) | A_D6 | | A14 | A6 | D6 |
| 4 | RA7 (AN7) | A_D7 | | A15 | A7 | D7 |
| 5 | V _{DD} | V _{DD} | Connect to V _{DD} (6.0V) | | | |
| 6 | RB0 (AVref/AN0) | CTL0 | Read/Write Control Address/Data Control | | | |
| 7 | RB1 (INT0) | CTL1 | | | | |
| 8 | RB2 (INT1) | CTL2 | | | | |
| 9~18 | RB3~7, RC3~6, RD2 | V _{DD} | Connect to V _{DD} (6.0V) | | | |
| 19 | X _{IN} | EPROM Enable | High Active, Latch Address in falling edge | | | |
| 20 | X _{OUT} | NC | No connection | | | |
| 21 | $\overline{\text{RESET}}$ | V _{PP} | Programming Power (0V, 12.75V) | | | |
| 22 | V _{SS} | V _{SS} | Connect to V _{SS} (0V) | | | |
| 23, 24 | RC0, 1 | V _{DD} | Connect to V _{DD} (6.0V) | | | |
| 25 | RA0 (EC0) | A_D0 | Address Input Data Input/Output | A8 | A0 | D0 |
| 26 | RA1 (AN1) | A_D1 | | A9 | A1 | D1 |
| 27 | RA2 (AN2) | A_D2 | | A10 | A2 | D2 |
| 28 | RA3 (AN3) | A_D3 | | A11 | A3 | D3 |

Table 21-1 Pin Description in EPROM Mode

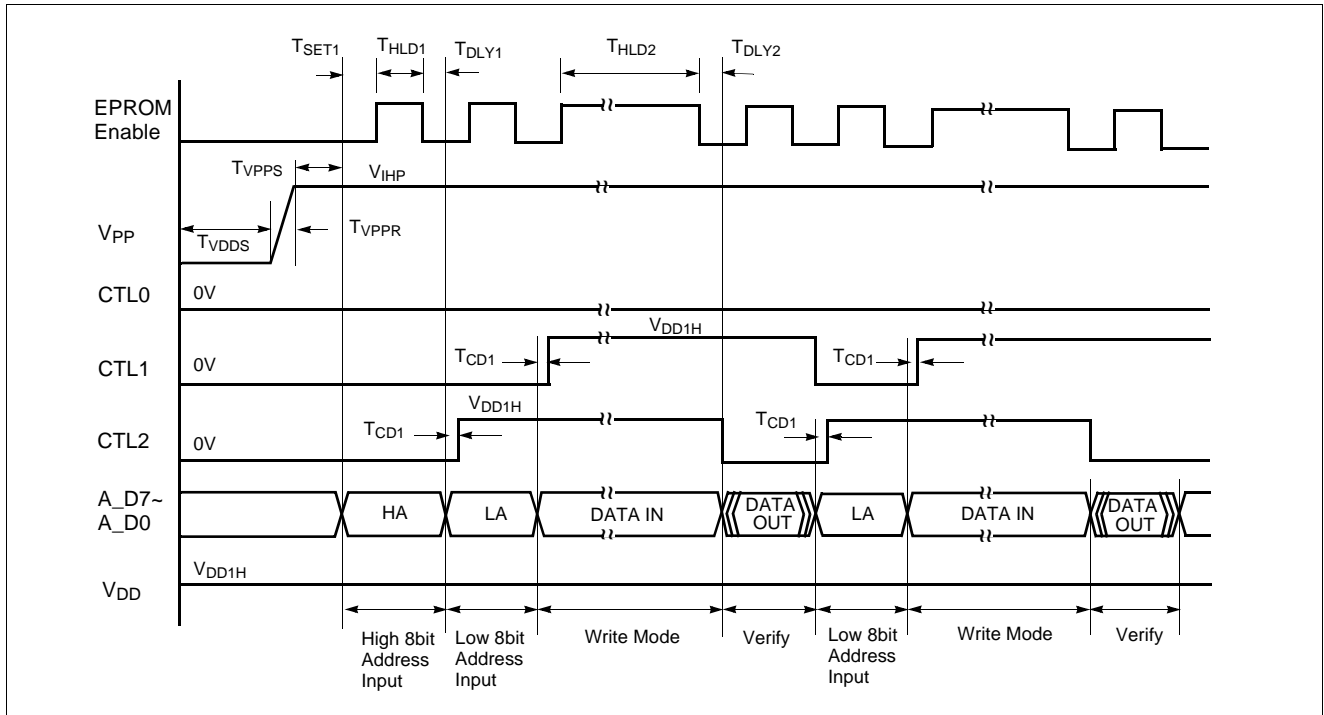


Figure 21-3 Timing Diagram in Program (Write & Verify) Mode

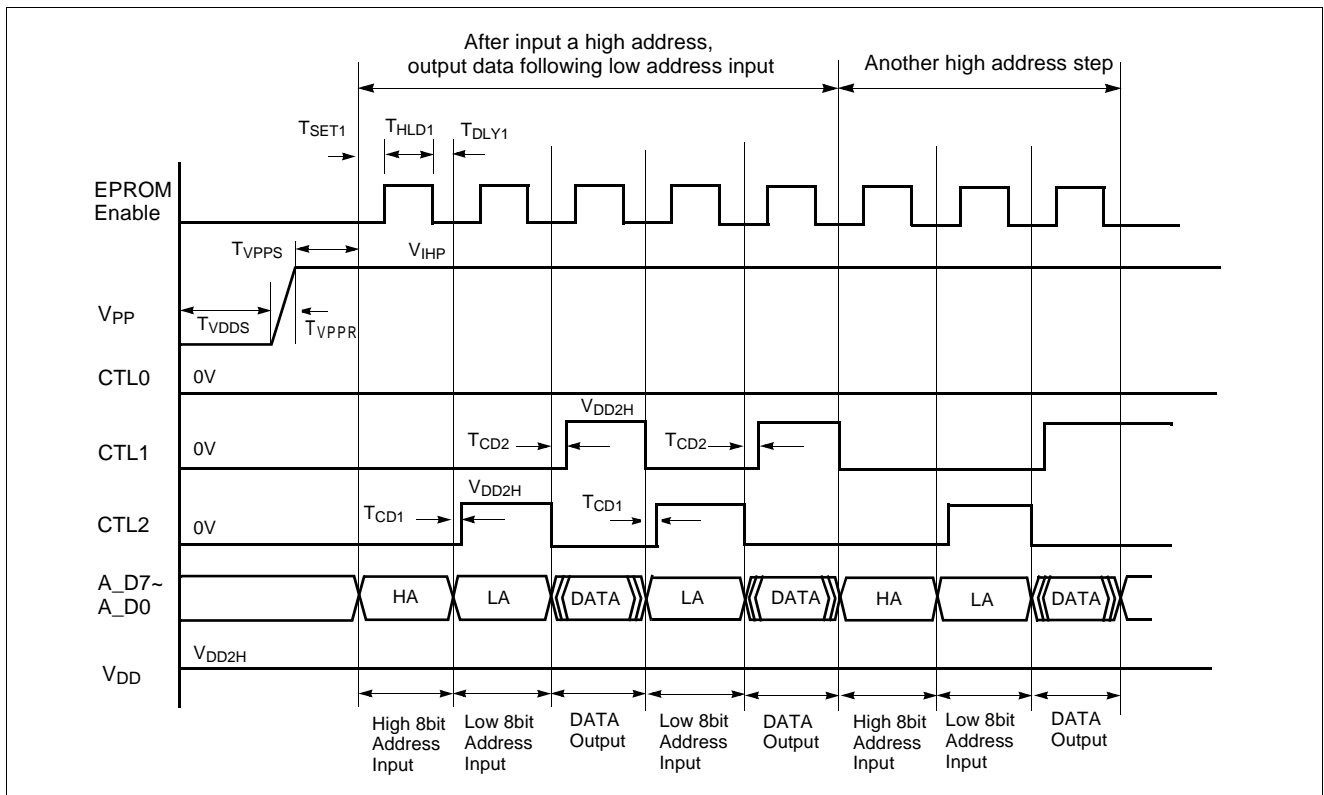


Figure 21-4 Timing Diagram in READ Mode

| Parameter | Symbol | MIN | TYP | MAX | Unit |
|--|-------------|-------------|------|-------------|------|
| Programming Supply Current | I_{VPP} | - | - | 50 | mA |
| Supply Current in EPROM Mode | I_{VDDP} | - | - | 20 | mA |
| V_{PP} Level during Programming | V_{IHP} | 11.5 | 12.0 | 12.5 | V |
| V_{DD} Level in Program Mode | V_{DD1H} | 5 | 6 | 6.5 | V |
| V_{DD} Level in Read Mode | V_{DD2H} | - | 2.7 | - | V |
| CTL2~0 High Level in EPROM Mode | V_{IHC} | $0.8V_{DD}$ | - | - | V |
| CTL2~0 Low Level in EPROM Mode | V_{ILC} | - | - | $0.2V_{DD}$ | V |
| A_D7~A_D0 High Level in EPROM Mode | V_{IHAD} | $0.9V_{DD}$ | - | - | V |
| A_D7~A_D0 Low Level in EPROM Mode | V_{ILAD} | - | - | $0.1V_{DD}$ | V |
| V_{DD} Saturation Time | T_{VDSDS} | 1 | - | - | mS |
| V_{PP} Setup Time | T_{VPPR} | - | - | 1 | mS |
| V_{PP} Saturation Time | T_{VPPS} | 1 | - | - | mS |
| EPROM Enable Setup Time after Data Input | T_{SET1} | | 200 | | nS |
| EPROM Enable Hold Time after T_{SET1} | T_{HLD1} | | 500 | | nS |
| EPROM Enable Delay Time after T_{HLD1} | T_{DLY1} | | 200 | | nS |
| EPROM Enable Hold Time in Write Mode | T_{HLD2} | | 100 | | nS |
| EPROM Enable Delay Time after T_{HLD2} | T_{DLY2} | | 200 | | nS |
| CTL2,1 Setup Time after Low Address input and Data input | T_{CD1} | | 100 | | nS |
| CTL1 Setup Time before Data output in Read and Verify Mode | T_{CD2} | | 100 | | nS |

Table 21-2 AC/DC Requirements for Program/Read Mode

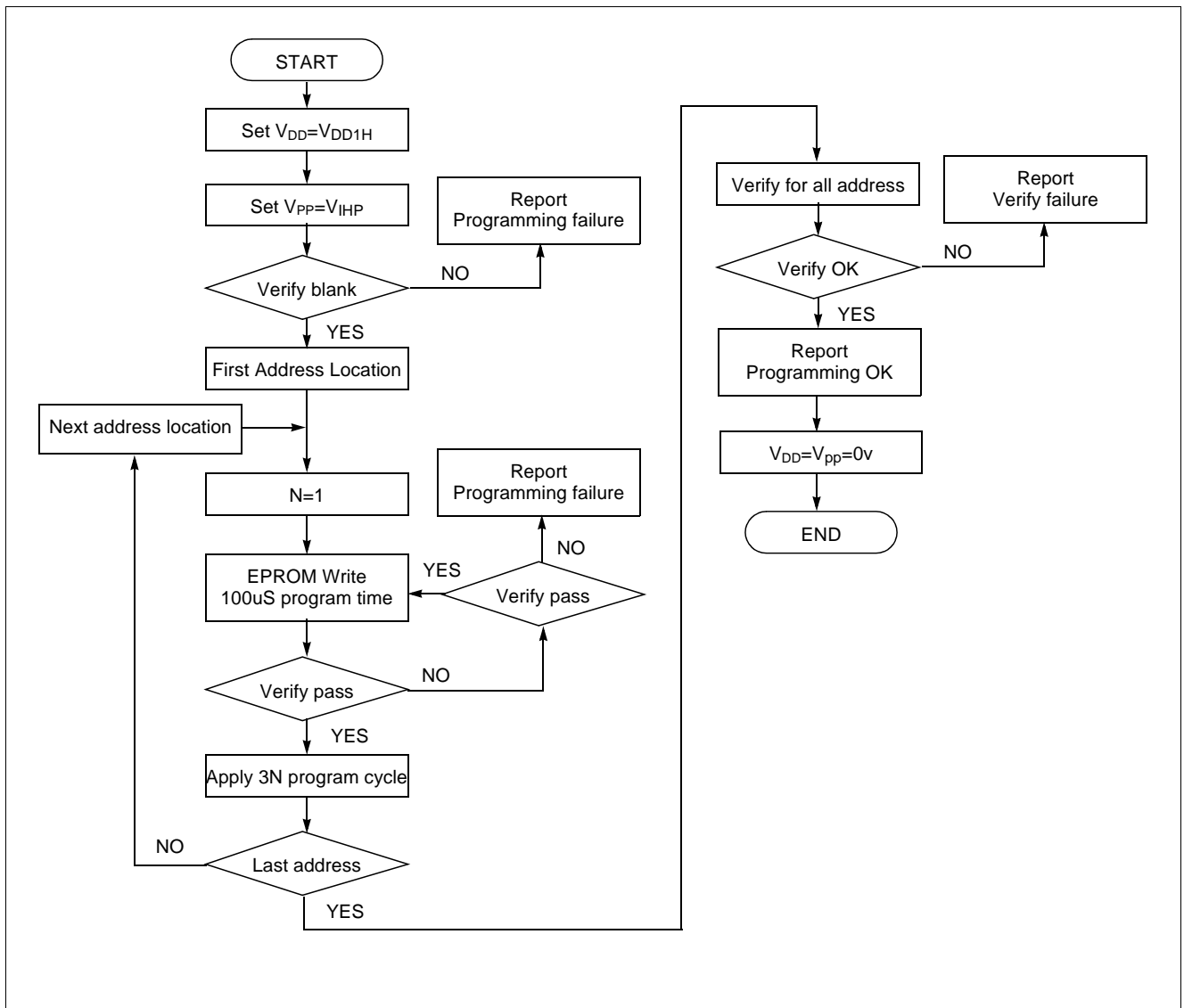


Figure 21-5 Programming Flow Chart

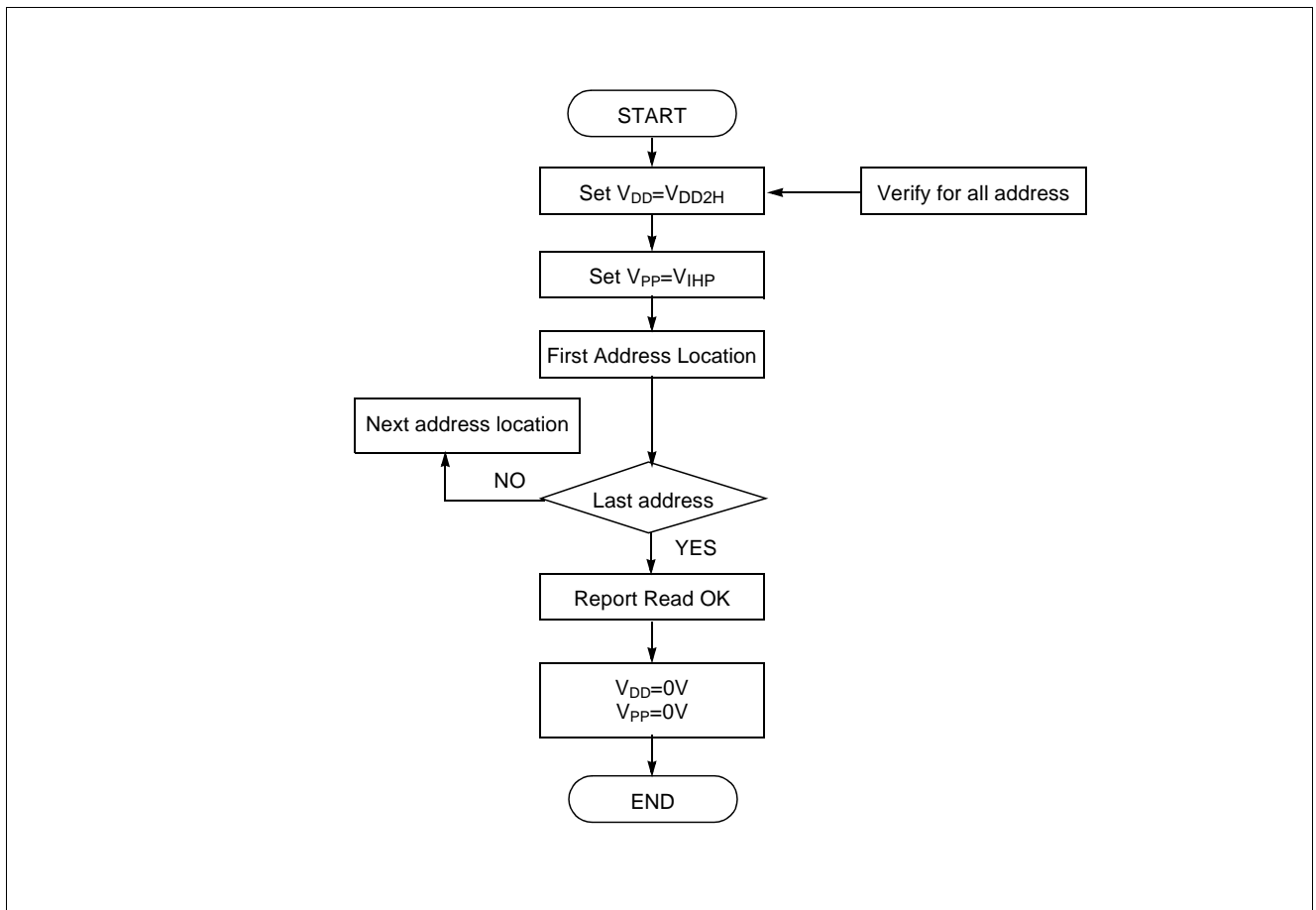


Figure 21-6 Reading Flow Chart

APPENDIX

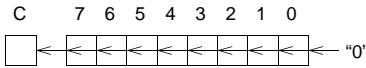
A. INSTRUCTION MAP

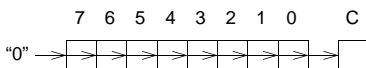
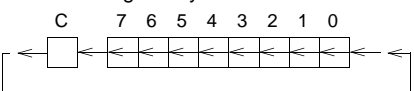
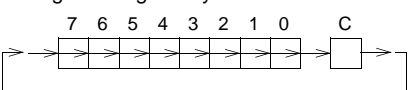
| LOW HIGH | 0000 00 | 00001 01 | 00010 02 | 00011 03 | 00100 04 | 00101 05 | 00110 06 | 00111 07 | 01000 08 | 01001 09 | 01010 0A | 01011 0B | 01100 0C | 01101 0D | 01110 0E | 01111 0F |
|-------------|------------|----------------|------------------|-------------------|----------------|-------------|-------------|-------------|-------------|-------------|-------------|---------------|-------------|--------------|-------------|----------------|
| 000 | - | SET1 dp.bit | BBS A.bit,rel | BBS dp.bit,rel | ADC #imm | ADC dp | ADC dp+X | ADC !abs | ASL A | ASL dp | TCALL 0 | SETA1 .bit | BIT dp | POP A | PUSH A | BRK |
| 001 | CLRC | | | | SBC #imm | SBC dp | SBC dp+X | SBC !abs | ROL A | ROL dp | TCALL 2 | CLRA1 .bit | COM dp | POP X | PUSH X | BRA rel |
| 010 | CLRG | | | | CMP #imm | CMP dp | CMP dp+X | CMP !abs | LSR A | LSR dp | TCALL 4 | NOT1 M.bit | TST dp | POP Y | PUSH Y | PCALL Upage |
| 011 | DI | | | | OR #imm | OR dp | OR dp+X | OR !abs | ROR A | ROR dp | TCALL 6 | OR1 OR1B | CMPX dp | POP PSW | PUSH PSW | RET |
| 100 | CLRV | | | | AND #imm | AND dp | AND dp+X | AND !abs | INC A | INC dp | TCALL 8 | AND1 AND1B | CMPY dp | CBNE dp+X | TXSP | INC X |
| 101 | SETC | | | | EOR #imm | EOR dp | EOR dp+X | EOR !abs | DEC A | DEC dp | TCALL 10 | EOR1 EOR1B | DBNE dp | XMA dp+X | TSPX | DEC X |
| 110 | SETG | | | | LDA #imm | LDA dp | LDA dp+X | LDA !abs | TXA | LDY dp | TCALL 12 | LDC LDCB | LDX dp | LDX dp+Y | XCN | DAS |
| 111 | EI | | | | LDM dp,#imm | STA dp | STA dp+X | STA !abs | TAX | STY dp | TCALL 14 | STC M.bit | STX dp | STX dp+Y | XAX | STOP |

| LOW HIGH | 10000 10 | 10001 11 | 10010 12 | 10011 13 | 10100 14 | 10101 15 | 10110 16 | 10111 17 | 11000 18 | 11001 19 | 11010 1A | 11011 1B | 11100 1C | 11101 1D | 11110 1E | 11111 1F |
|-------------|-------------|----------------|------------------|-------------------|-------------|---------------|---------------|---------------|-------------|-------------|-------------|--------------|---------------|-------------|--------------|---------------|
| 000 | BPL rel | CLR1 dp.bit | BBC A.bit,rel | BBC dp.bit,rel | ADC {X} | ADC !abs+Y | ADC [dp+X] | ADC [dp]+Y | ASL !abs | ASL dp+X | TCALL 1 | JMP !abs | BIT !abs | ADDW dp | LDX #imm | JMP [labs] |
| 001 | BVC rel | | | | SBC {X} | SBC !abs+Y | SBC [dp+X] | SBC [dp]+Y | ROL !abs | ROL dp+X | TCALL 3 | CALL !abs | TEST !abs | SUBW dp | LDY #imm | JMP [dp] |
| 010 | BCC rel | | | | CMP {X} | CMP !abs+Y | CMP [dp+X] | CMP [dp]+Y | LSR !abs | LSR dp+X | TCALL 5 | MUL | TCLR1 !abs | CMPW dp | CMPX #imm | CALL [dp] |
| 011 | BNE rel | | | | OR {X} | OR !abs+Y | OR [dp+X] | OR [dp]+Y | ROR !abs | ROR dp+X | TCALL 7 | DBNE Y | CMPX !abs | LDYA dp | CMPY #imm | RETI |
| 100 | BMI rel | | | | AND {X} | AND !abs+Y | AND [dp+X] | AND [dp]+Y | INC !abs | INC dp+X | TCALL 9 | DIV | CMPY !abs | INCW dp | INC Y | TAY |
| 101 | BVS rel | | | | EOR {X} | EOR !abs+Y | EOR [dp+X] | EOR [dp]+Y | DEC !abs | DEC dp+X | TCALL 11 | XMA {X} | XMA dp | DECW dp | DEC Y | TYA |
| 110 | BCS rel | | | | LDA {X} | LDA !abs+Y | LDA [dp+X] | LDA [dp]+Y | LDY !abs | LDY dp+X | TCALL 13 | LDA {X}+ | LDX !abs | STYA dp | XAY | DAA |
| 111 | BEQ rel | | | | STA {X} | STA !abs+Y | STA [dp+X] | STA [dp]+Y | STY !abs | STY dp+X | TCALL 15 | STA {X}+ | STX !abs | CBNE dp | XYX | NOP |

B. INSTRUCTION SET

1. ARITHMETIC/ LOGIC OPERATION

| NO. | MNEMONIC | OP CODE | BYTE NO | CYCLE NO | OPERATION | FLAG NVGBHIZC |
|-----|----------------|---------|---------|----------|---|---------------|
| 1 | ADC #imm | 04 | 2 | 2 | Add with carry. $A \leftarrow (A) + (M) + C$ | NV--H-ZC |
| 2 | ADC dp | 05 | 2 | 3 | | |
| 3 | ADC dp + X | 06 | 2 | 4 | | |
| 4 | ADC !abs | 07 | 3 | 4 | | |
| 5 | ADC !abs + Y | 15 | 3 | 5 | | |
| 6 | ADC [dp + X] | 16 | 2 | 6 | | |
| 7 | ADC [dp] + Y | 17 | 2 | 6 | | |
| 8 | ADC { X } | 14 | 1 | 3 | | |
| 9 | AND #imm | 84 | 2 | 2 | Logical AND $A \leftarrow (A) \wedge (M)$ | N-----Z- |
| 10 | AND dp | 85 | 2 | 3 | | |
| 11 | AND dp + X | 86 | 2 | 4 | | |
| 12 | AND !abs | 87 | 3 | 4 | | |
| 13 | AND !abs + Y | 95 | 3 | 5 | | |
| 14 | AND [dp + X] | 96 | 2 | 6 | | |
| 15 | AND [dp] + Y | 97 | 2 | 6 | | |
| 16 | AND { X } | 94 | 1 | 3 | | |
| 17 | ASL A | 08 | 1 | 2 | Arithmetic shift left  | N-----ZC |
| 18 | ASL dp | 09 | 2 | 4 | | |
| 19 | ASL dp + X | 19 | 2 | 5 | | |
| 20 | ASL !abs | 18 | 3 | 5 | | |
| 21 | CMP #imm | 44 | 2 | 2 | Compare accumulator contents with memory contents $(A) - (M)$ | N-----ZC |
| 22 | CMP dp | 45 | 2 | 3 | | |
| 23 | CMP dp + X | 46 | 2 | 4 | | |
| 24 | CMP !abs | 47 | 3 | 4 | | |
| 25 | CMP !abs + Y | 55 | 3 | 5 | | |
| 26 | CMP [dp + X] | 56 | 2 | 6 | | |
| 27 | CMP [dp] + Y | 57 | 2 | 6 | | |
| 28 | CMP { X } | 54 | 1 | 3 | | |
| 29 | CMPX #imm | 5E | 2 | 2 | Compare X contents with memory contents $(X) - (M)$ | N-----ZC |
| 30 | CMPX dp | 6C | 2 | 3 | | |
| 31 | CMPX !abs | 7C | 3 | 4 | | |
| 32 | CMPY #imm | 7E | 2 | 2 | Compare Y contents with memory contents $(Y) - (M)$ | N-----ZC |
| 33 | CMPY dp | 8C | 2 | 3 | | |
| 34 | CMPY !abs | 9C | 3 | 4 | | |
| 35 | COM dp | 2C | 2 | 4 | 1'S Complement : $(dp) \leftarrow \sim(dp)$ | N-----Z- |
| 36 | DAA | DF | 1 | 3 | Decimal adjust for addition | N-----ZC |
| 37 | DAS | CF | 1 | 3 | Decimal adjust for subtraction | N-----ZC |
| 38 | DEC A | A8 | 1 | 2 | Decrement $M \leftarrow (M) - 1$ | N-----Z- |
| 39 | DEC dp | A9 | 2 | 4 | | |
| 40 | DEC dp + X | B9 | 2 | 5 | | |
| 41 | DEC !abs | B8 | 3 | 5 | | |
| 42 | DEC X | AF | 1 | 2 | | |
| 43 | DEC Y | BE | 1 | 2 | | |
| 44 | DIV | 9B | 1 | 12 | | |

| NO. | MNEMONIC | OP CODE | BYTE NO | CYCLE NO | OPERATION | FLAG NVGBHIZC |
|-----|----------------|---------|---------|----------|--|---------------|
| 45 | EOR #imm | A4 | 2 | 2 | Exclusive OR $A \leftarrow (A) \oplus (M)$ | N-----Z- |
| 46 | EOR dp | A5 | 2 | 3 | | |
| 47 | EOR dp + X | A6 | 2 | 4 | | |
| 48 | EOR !abs | A7 | 3 | 4 | | |
| 49 | EOR !abs + Y | B5 | 3 | 5 | | |
| 50 | EOR [dp + X] | B6 | 2 | 6 | | |
| 51 | EOR [dp] + Y | B7 | 2 | 6 | | |
| 52 | EOR { X } | B4 | 1 | 3 | | |
| 53 | INC A | 88 | 1 | 2 | Increment $M \leftarrow (M) + 1$ | N-----Z- |
| 54 | INC dp | 89 | 2 | 4 | | |
| 55 | INC dp + X | 99 | 2 | 5 | | |
| 56 | INC !abs | 98 | 3 | 5 | | |
| 57 | INC X | 8F | 1 | 2 | | |
| 58 | INC Y | 9E | 1 | 2 | | |
| 59 | LSR A | 48 | 1 | 2 | Logical shift right  | N-----ZC |
| 60 | LSR dp | 49 | 2 | 4 | | |
| 61 | LSR dp + X | 59 | 2 | 5 | | |
| 62 | LSR !abs | 58 | 3 | 5 | | |
| 63 | MUL | 5B | 1 | 9 | Multiply : $YA \leftarrow Y \times A$ | N-----Z- |
| 64 | OR #imm | 64 | 2 | 2 | Logical OR $A \leftarrow (A) \vee (M)$ | N-----Z- |
| 65 | OR dp | 65 | 2 | 3 | | |
| 66 | OR dp + X | 66 | 2 | 4 | | |
| 67 | OR !abs | 67 | 3 | 4 | | |
| 68 | OR !abs + Y | 75 | 3 | 5 | | |
| 69 | OR [dp + X] | 76 | 2 | 6 | | |
| 70 | OR [dp] + Y | 77 | 2 | 6 | | |
| 71 | OR { X } | 74 | 1 | 3 | | |
| 72 | ROL A | 28 | 1 | 2 | Rotate left through carry  | N-----ZC |
| 73 | ROL dp | 29 | 2 | 4 | | |
| 74 | ROL dp + X | 39 | 2 | 5 | | |
| 75 | ROL !abs | 38 | 3 | 5 | | |
| 76 | ROR A | 68 | 1 | 2 | Rotate right through carry  | N-----ZC |
| 77 | ROR dp | 69 | 2 | 4 | | |
| 78 | ROR dp + X | 79 | 2 | 5 | | |
| 79 | ROR !abs | 78 | 3 | 5 | | |
| 80 | SBC #imm | 24 | 2 | 2 | Subtract with carry $A \leftarrow (A) - (M) - \sim(C)$ | NV--HZC |
| 81 | SBC dp | 25 | 2 | 3 | | |
| 82 | SBC dp + X | 26 | 2 | 4 | | |
| 83 | SBC !abs | 27 | 3 | 4 | | |
| 84 | SBC !abs + Y | 35 | 3 | 5 | | |
| 85 | SBC [dp + X] | 36 | 2 | 6 | | |
| 86 | SBC [dp] + Y | 37 | 2 | 6 | | |
| 87 | SBC { X } | 34 | 1 | 3 | | |
| 88 | TST dp | 4C | 2 | 3 | Test memory contents for negative or zero (dp) - 00 _H | N-----Z- |
| 89 | XCN | CE | 1 | 5 | Exchange nibbles within the accumulator $A_7 \sim A_4 \leftrightarrow A_3 \sim A_0$ | N-----Z- |

2. REGISTER / MEMORY OPERATION

| NO. | MNEMONIC | OP CODE | BYTE NO | CYCLE NO | OPERATION | FLAG NVGBHIZC |
|-----|----------------|---------|---------|----------|--|---------------|
| 1 | LDA #imm | C4 | 2 | 2 | Load accumulator $A \leftarrow (M)$ | N-----Z- |
| 2 | LDA dp | C5 | 2 | 3 | | |
| 3 | LDA dp + X | C6 | 2 | 4 | | |
| 4 | LDA !abs | C7 | 3 | 4 | | |
| 5 | LDA !abs + Y | D5 | 3 | 5 | | |
| 6 | LDA [dp + X] | D6 | 2 | 6 | | |
| 7 | LDA [dp] + Y | D7 | 2 | 6 | | |
| 8 | LDA { X } | D4 | 1 | 3 | | |
| 9 | LDA { X }+ | DB | 1 | 4 | X- register auto-increment : $A \leftarrow (M), X \leftarrow X + 1$ | |
| 10 | LDM dp,#imm | E4 | 3 | 5 | Load memory with immediate data : $(M) \leftarrow \text{imm}$ | ----- |
| 11 | LDX #imm | 1E | 2 | 2 | Load X-register $X \leftarrow (M)$ | N-----Z- |
| 12 | LDX dp | CC | 2 | 3 | | |
| 13 | LDX dp + Y | CD | 2 | 4 | | |
| 14 | LDX !abs | DC | 3 | 4 | | |
| 15 | LDY #imm | 3E | 2 | 2 | Load Y-register $Y \leftarrow (M)$ | N-----Z- |
| 16 | LDY dp | C9 | 2 | 3 | | |
| 17 | LDY dp + X | D9 | 2 | 4 | | |
| 18 | LDY !abs | D8 | 3 | 4 | | |
| 19 | STA dp | E5 | 2 | 4 | Store accumulator contents in memory $(M) \leftarrow A$ | ----- |
| 20 | STA dp + X | E6 | 2 | 5 | | |
| 21 | STA !abs | E7 | 3 | 5 | | |
| 22 | STA !abs + Y | F5 | 3 | 6 | | |
| 23 | STA [dp + X] | F6 | 2 | 7 | | |
| 24 | STA [dp] + Y | F7 | 2 | 7 | | |
| 25 | STA { X } | F4 | 1 | 4 | | |
| 26 | STA { X }+ | FB | 1 | 4 | X- register auto-increment : $(M) \leftarrow A, X \leftarrow X + 1$ | |
| 27 | STX dp | EC | 2 | 4 | Store X-register contents in memory $(M) \leftarrow X$ | ----- |
| 28 | STX dp + Y | ED | 2 | 5 | | |
| 29 | STX !abs | FC | 3 | 5 | | |
| 30 | STY dp | E9 | 2 | 4 | Store Y-register contents in memory $(M) \leftarrow Y$ | ----- |
| 31 | STY dp + X | F9 | 2 | 5 | | |
| 32 | STY !abs | F8 | 3 | 5 | | |
| 33 | TAX | E8 | 1 | 2 | Transfer accumulator contents to X-register : $X \leftarrow A$ | N-----Z- |
| 34 | TAY | 9F | 1 | 2 | Transfer accumulator contents to Y-register : $Y \leftarrow A$ | N-----Z- |
| 35 | TSPX | AE | 1 | 2 | Transfer stack-pointer contents to X-register : $X \leftarrow \text{sp}$ | N-----Z- |
| 36 | TXA | C8 | 1 | 2 | Transfer X-register contents to accumulator : $A \leftarrow X$ | N-----Z- |
| 37 | TXSP | 8E | 1 | 2 | Transfer X-register contents to stack-pointer : $\text{sp} \leftarrow X$ | N-----Z- |
| 38 | TYA | BF | 1 | 2 | Transfer Y-register contents to accumulator : $A \leftarrow Y$ | N-----Z- |
| 39 | XAX | EE | 1 | 4 | Exchange X-register contents with accumulator : $X \leftrightarrow A$ | ----- |
| 40 | XAY | DE | 1 | 4 | Exchange Y-register contents with accumulator : $Y \leftrightarrow A$ | ----- |
| 41 | XMA dp | BC | 2 | 5 | Exchange memory contents with accumulator $(M) \leftrightarrow A$ | N-----Z- |
| 42 | XMA dp+X | AD | 2 | 6 | | |
| 43 | XMA {X} | BB | 1 | 5 | | |
| 44 | XYX | FE | 1 | 4 | Exchange X-register contents with Y-register : $X \leftrightarrow Y$ | ----- |

3. 16-BIT OPERATION

| NO. | MNEMONIC | OP CODE | BYTE NO | CYCLE NO | OPERATION | FLAG NVGBHIZC |
|-----|----------|---------|---------|----------|--|---------------|
| 1 | ADDW dp | 1D | 2 | 5 | 16-Bits add without carry $YA \leftarrow (YA) + (dp + 1)(dp)$ | NV--H-ZC |
| 2 | CMPW dp | 5D | 2 | 4 | Compare YA contents with memory pair contents : $(YA) - (dp+1)(dp)$ | N-----ZC |
| 3 | DECW dp | BD | 2 | 6 | Decrement memory pair $(dp+1)(dp) \leftarrow (dp+1)(dp) - 1$ | N-----Z- |
| 4 | INCW dp | 9D | 2 | 6 | Increment memory pair $(dp+1)(dp) \leftarrow (dp+1)(dp) + 1$ | N-----Z- |
| 5 | LDYA dp | 7D | 2 | 5 | Load YA $YA \leftarrow (dp + 1)(dp)$ | N-----Z- |
| 6 | STYA dp | DD | 2 | 5 | Store YA $(dp + 1)(dp) \leftarrow YA$ | ----- |
| 7 | SUBW dp | 3D | 2 | 5 | 16-Bits subtract without carry $YA \leftarrow (YA) - (dp + 1)(dp)$ | NV--H-ZC |

4. BIT MANIPULATION

| NO. | MNEMONIC | OP CODE | BYTE NO | CYCLE NO | OPERATION | FLAG NVGBHIZC |
|-----|-------------|---------|---------|----------|--|---------------|
| 1 | AND1 M.bit | 8B | 3 | 4 | Bit AND C-flag : $C \leftarrow (C) \wedge (M.bit)$ | -----C |
| 2 | AND1B M.bit | 8B | 3 | 4 | Bit AND C-flag and NOT : $C \leftarrow (C) \wedge \sim(M.bit)$ | -----C |
| 3 | BIT dp | 0C | 2 | 4 | Bit test A with memory : | MM----Z- |
| 4 | BIT !abs | 1C | 3 | 5 | $Z \leftarrow (A) \wedge (M), N \leftarrow (M_7), V \leftarrow (M_6)$ | |
| 5 | CLR1 dp.bit | y1 | 2 | 4 | Clear bit : $(M.bit) \leftarrow "0"$ | ----- |
| 6 | CLRA1 A.bit | 2B | 2 | 2 | Clear A bit : $(A.bit) \leftarrow "0"$ | ----- |
| 7 | CLRC | 20 | 1 | 2 | Clear C-flag : $C \leftarrow "0"$ | -----0 |
| 8 | CLRG | 40 | 1 | 2 | Clear G-flag : $G \leftarrow "0"$ | --0----- |
| 9 | CLRv | 80 | 1 | 2 | Clear V-flag : $V \leftarrow "0"$ | -0--0--- |
| 10 | EOR1 M.bit | AB | 3 | 5 | Bit exclusive-OR C-flag : $C \leftarrow (C) \oplus (M.bit)$ | -----C |
| 11 | EOR1B M.bit | AB | 3 | 5 | Bit exclusive-OR C-flag and NOT : $C \leftarrow (C) \oplus \sim(M.bit)$ | -----C |
| 12 | LDC M.bit | CB | 3 | 4 | Load C-flag : $C \leftarrow (M.bit)$ | -----C |
| 13 | LDCB M.bit | CB | 3 | 4 | Load C-flag with NOT : $C \leftarrow \sim(M.bit)$ | -----C |
| 14 | NOT1 M.bit | 4B | 3 | 5 | Bit complement : $(M.bit) \leftarrow \sim(M.bit)$ | ----- |
| 15 | OR1 M.bit | 6B | 3 | 5 | Bit OR C-flag : $C \leftarrow (C) \vee (M.bit)$ | -----C |
| 16 | OR1B M.bit | 6B | 3 | 5 | Bit OR C-flag and NOT : $C \leftarrow (C) \vee \sim(M.bit)$ | -----C |
| 17 | SET1 dp.bit | x1 | 2 | 4 | Set bit : $(M.bit) \leftarrow "1"$ | ----- |
| 18 | SETA1 A.bit | 0B | 2 | 2 | Set A bit : $(A.bit) \leftarrow "1"$ | ----- |
| 19 | SETC | A0 | 1 | 2 | Set C-flag : $C \leftarrow "1"$ | -----1 |
| 20 | SETG | C0 | 1 | 2 | Set G-flag : $G \leftarrow "1"$ | --1----- |
| 21 | STC M.bit | EB | 3 | 6 | Store C-flag : $(M.bit) \leftarrow C$ | ----- |
| 22 | TCLR1 !abs | 5C | 3 | 6 | Test and clear bits with A : $A - (M), (M) \leftarrow (M) \wedge \sim(A)$ | N-----Z- |
| 23 | TSET1 !abs | 3C | 3 | 6 | Test and set bits with A : $A - (M), (M) \leftarrow (M) \vee (A)$ | N-----Z- |

5. BRANCH / JUMP OPERATION

| NO. | MNEMONIC | OP CODE | BYTE NO | CYCLE NO | OPERATION | FLAG NVGBHIZC |
|-----|----------------|---------|---------|----------|---|---------------|
| 1 | BBC A.bit,rel | y2 | 2 | 4/6 | Branch if bit clear : | ----- |
| 2 | BBC dp.bit,rel | y3 | 3 | 5/7 | if (bit) = 0 , then $pc \leftarrow (pc) + rel$ | ----- |
| 3 | BBS A.bit,rel | x2 | 2 | 4/6 | Branch if bit set : | ----- |
| 4 | BBS dp.bit,rel | x3 | 3 | 5/7 | if (bit) = 1 , then $pc \leftarrow (pc) + rel$ | ----- |
| 5 | BCC rel | 50 | 2 | 2/4 | Branch if carry bit clear if (C) = 0 , then $pc \leftarrow (pc) + rel$ | ----- |
| 6 | BCS rel | D0 | 2 | 2/4 | Branch if carry bit set if (C) = 1 , then $pc \leftarrow (pc) + rel$ | ----- |
| 7 | BEQ rel | F0 | 2 | 2/4 | Branch if equal if (Z) = 1 , then $pc \leftarrow (pc) + rel$ | ----- |
| 8 | BMI rel | 90 | 2 | 2/4 | Branch if minus if (N) = 1 , then $pc \leftarrow (pc) + rel$ | ----- |
| 9 | BNE rel | 70 | 2 | 2/4 | Branch if not equal if (Z) = 0 , then $pc \leftarrow (pc) + rel$ | ----- |
| 10 | BPL rel | 10 | 2 | 2/4 | Branch if minus if (N) = 0 , then $pc \leftarrow (pc) + rel$ | ----- |
| 11 | BRA rel | 2F | 2 | 4 | Branch always $pc \leftarrow (pc) + rel$ | ----- |
| 12 | BVC rel | 30 | 2 | 2/4 | Branch if overflow bit clear if (V) = 0 , then $pc \leftarrow (pc) + rel$ | ----- |
| 13 | BVS rel | B0 | 2 | 2/4 | Branch if overflow bit set if (V) = 1 , then $pc \leftarrow (pc) + rel$ | ----- |
| 14 | CALL !abs | 3B | 3 | 8 | Subroutine call | ----- |
| 15 | CALL [dp] | 5F | 2 | 8 | $M(sp) \leftarrow (pc_H)$, $sp \leftarrow sp - 1$, $M(sp) \leftarrow (pc_L)$, $sp \leftarrow sp - 1$, if !abs, $pc \leftarrow abs$; if [dp], $pc_L \leftarrow (dp)$, $pc_H \leftarrow (dp+1)$. | ----- |
| 16 | CBNE dp,rel | FD | 3 | 5/7 | Compare and branch if not equal : | ----- |
| 17 | CBNE dp+X,rel | 8D | 3 | 6/8 | if (A) \neq (M) , then $pc \leftarrow (pc) + rel$. | ----- |
| 18 | DBNE dp,rel | AC | 3 | 5/7 | Decrement and branch if not equal : | ----- |
| 19 | DBNE Y,rel | 7B | 2 | 4/6 | if (M) \neq 0 , then $pc \leftarrow (pc) + rel$. | ----- |
| 20 | JMP !abs | 1B | 3 | 3 | Unconditional jump | ----- |
| 21 | JMP [!abs] | 1F | 3 | 5 | $pc \leftarrow$ jump address | ----- |
| 22 | JMP [dp] | 3F | 2 | 4 | | ----- |
| 23 | PCALL upage | 4F | 2 | 6 | U-page call $M(sp) \leftarrow (pc_H)$, $sp \leftarrow sp - 1$, $M(sp) \leftarrow (pc_L)$, $sp \leftarrow sp - 1$, $pc_L \leftarrow (upage)$, $pc_H \leftarrow "OFFH"$. | ----- |
| 24 | TCALL n | nA | 1 | 8 | Table call : $(sp) \leftarrow (pc_H)$, $sp \leftarrow sp - 1$, $M(sp) \leftarrow (pc_L)$, $sp \leftarrow sp - 1$, $pc_L \leftarrow (Table \text{ vector } L)$, $pc_H \leftarrow (Table \text{ vector } H)$ | ----- |

6. CONTROL OPERATION & etc.

| NO. | MNEMONIC | OP CODE | BYTE NO | CYCLE NO | OPERATION | FLAG NVGBHIZC |
|-----|----------|---------|---------|----------|--|---------------|
| 1 | BRK | 0F | 1 | 8 | Software interrupt : $B \leftarrow "1"$, $M(sp) \leftarrow (pc_H)$, $sp \leftarrow sp-1$, $M(s) \leftarrow (pc_L)$, $sp \leftarrow sp - 1$, $M(sp) \leftarrow (PSW)$, $sp \leftarrow sp - 1$, $pc_L \leftarrow (0FFDE_H)$, $pc_H \leftarrow (0FFDF_H)$. | ---1-0-- |
| 2 | DI | 60 | 1 | 3 | Disable interrupts : $I \leftarrow "0"$ | -----0-- |
| 3 | EI | E0 | 1 | 3 | Enable interrupts : $I \leftarrow "1"$ | -----1-- |
| 4 | NOP | FF | 1 | 2 | No operation | ----- |
| 5 | POP A | 0D | 1 | 4 | $sp \leftarrow sp + 1$, $A \leftarrow M(sp)$ | |
| 6 | POP X | 2D | 1 | 4 | $sp \leftarrow sp + 1$, $X \leftarrow M(sp)$ | ----- |
| 7 | POP Y | 4D | 1 | 4 | $sp \leftarrow sp + 1$, $Y \leftarrow M(sp)$ | |
| 8 | POP PSW | 6D | 1 | 4 | $sp \leftarrow sp + 1$, $PSW \leftarrow M(sp)$ | restored |
| 9 | PUSH A | 0E | 1 | 4 | $M(sp) \leftarrow A$, $sp \leftarrow sp - 1$ | |
| 10 | PUSH X | 2E | 1 | 4 | $M(sp) \leftarrow X$, $sp \leftarrow sp - 1$ | ----- |
| 11 | PUSH Y | 4E | 1 | 4 | $M(sp) \leftarrow Y$, $sp \leftarrow sp - 1$ | |
| 12 | PUSH PSW | 6E | 1 | 4 | $M(sp) \leftarrow PSW$, $sp \leftarrow sp - 1$ | |
| 13 | RET | 6F | 1 | 5 | Return from subroutine $sp \leftarrow sp + 1$, $pc_L \leftarrow M(sp)$, $sp \leftarrow sp + 1$, $pc_H \leftarrow M(sp)$ | ----- |
| 14 | RETI | 7F | 1 | 6 | Return from interrupt $sp \leftarrow sp + 1$, $PSW \leftarrow M(sp)$, $sp \leftarrow sp + 1$, $pc_L \leftarrow M(sp)$, $sp \leftarrow sp + 1$, $pc_H \leftarrow M(sp)$ | restored |
| 15 | STOP | EF | 1 | 3 | Stop mode (halt CPU, stop oscillator) | ----- |