

ABOV SEMICONDUCTOR Co., Ltd.
8-BIT MICROCONTROLLERS

MC96FR116C

Data Sheet (Rev.1.0.1)



REVISION HISTORY

REVISION 0.0 (February 19, 2013)

- Initial preliminary version

REVISION 0.1 (May 3, 2013)

- The default interrupt definition of P1[2:0] is removed

REVISION 0.2 (November 15, 2013)

- 20 TSSOP package type is added.
- 7. ELECTRICAL CHARACTERISTICS
- 12.5 BOD mode
- The initial value of BODR register is changed from 81_H to C9_H.

REVISION 1.0 (January 23, 2014)

- Initial version

REVISION 1.0.1 (July 8, 2014)

- FUSE_CONF register description is changed for more accurate explanation.

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MC96FR116C

CMOS 8-bit Flash Microcontroller : UR

1. OVERVIEW

1.1 Description

The MC96FR116C is an advanced 8-bit microcontroller based on CMOS process with 16K Bytes of Flash. This is a powerful device which provides a highly flexible and cost effective solution to many embedded control applications.

The MC96FR116C provides the following features : 16K Bytes of embedded FLASH ROM^{NOTE1}, 2048 Bytes of XRAM, 256 Bytes of IRAM, 8/16-bit Timer/Counter, WDT, WT, 10-bit PWM, USART(w/ SPI function), I2C, Carrier Generator, 8-bit Basic Interval Timer, Watch Timer and Clock control circuit. It also provides one dedicated output pin which has large current drivability specialized for remote control application. Additionally, the MC96FR116C supports power saving modes to reduce power consumption.

^{NOTE1} In this document, the ROM means non-volatile memory which is read-writable.

Device Name	FLASH size	IRAM	XRAM	I/O PORT	Package
MC96FR116C	16KB	256B	2048B	12	16 QFN
				12	16 WLCSP
				16	20 TSSOP

1.2 Features

- **CPU**
8-bit CISC Core (8051 Compatible, 2 clocks per cycle)
- **16K Bytes On-chip FLASH**
Endurance : 10,000 times
Retention : 10 years
- **XRAM**
2048 Bytes
- **IRAM**
256 Bytes
- **General Purpose I/O**
12 Ports (P0[5:0],P1[5:0])
: 16 QFN, 16 WLCSP
16 Ports (P0[7:0],P1[7:0])
: 20 TSSOP
- **One Basic Interval Timer**
- **Timer / Counter**
8-bitx2ch(16-bitx1ch) + 16-bitx2ch
- **10-bit PWM (Using Timer0,1)**
- **16-bit PWM (using Timer3)**
- **One Watch Dog Timer**
- **One Watch Timer**
- **One USART(with SPI feature)**
- **One I2C**
- **One Carrier Generator**
- **Interrupt Sources**
External : 6
USART: 1
I2C : 1
Carrier Generator : 1

- | | |
|--|---|
| WDT : 1
WT : 1
BIT : 1
Timer0,1,2,3 : 4
FLASH : 1
Key scan: 1
Pin change(P0[7:0]):1
• Flash secure protection
• Analog Comparator for IR learning
• Power On Reset
• Programmable Brown-Out Detector
Reset: 1.55V
Interrupt or flag: 1.65, 1.8, 2.0, 2.2, 2.4V
• Minimum Instruction Execution Time
200ns (@10MHz, 1 Cycle NOP Instruction)
• Power down mode
SLEEP, STOP mode | • On-Chip IR Transistor

• On-Chip RC-Oscillator
12MHz \pm 2% after tuning @ -30 ~ +85°C
12MHz \pm 1% after tuning @ 0 ~ +50°C
• Operating Frequency
1 ~ 12MHz (Xtal oscillator)
12, 8, 6, 4MHz (Internal RC oscillator)
• Operating Voltage
1.6 ~ 3.6V (VDD)
1.6 ~ 4.0V (VDD_IR)
• Operating Temperature
• -30 ~ +85°C
• PKG Type
16 QFN, 20 TSSOP
Available Pb free package |
|--|---|

1.3 Ordering Information

Device name	ROM size	IRAM size	XRAM size	Package
MC96FR116CU	16KB FLASH	256B	2048B	16 QFN
MC96FR116C				16 WLCSP
MC96FR116CR				20 TSSOP

Table 1-1 Ordering Information

1.4 Development Tools

1.4.1 Compiler

ABOV semiconductor does not provide any compiler for MC96FR116C. As the CPU core of MC96FR116C is Mentor 8051, you can use all kinds of third party's standard 8051 compiler.

1.4.2 OCD emulator and debugger

OCD(On Chip Debugger) program is a debugging software for ABOV semiconductor's 8051 MCU series. OCD uses only two lines to download a user code, to read and modify the internal memory or SFR(Special Function Register)s. And also OCD controls MCU's internal debugging logic, which means OCD controls emulation, step run, monitoring, etc.

OCD debugger program works on Microsoft-Windows 7, NT, 2000, XP, Vista(32-bit) operating system.

If you want to see details more, please refer to OCD debugger manual. You can download debugger S/W and manual from our web-site.

The connecting pins between PC and MCU is as follows :

- DSCL (P1[0] of MC96FR116C)
- DSDA (P1[1] of MC96FR116C)



Figure 1-1 OCD Software and Connector

1.4.3 Programmer

To program or download user code into the ROM of MC96FR116C, ABOV semiconductor provides several tools. As a single programmer which can program only one chip at a time, there are PGMPlus for parallel programming and ISP/OCD for serial programming and debugging. On the other hand, you can program multi-chips at a time by using a gang programmer. Gang programmer can program up to 8 devices simultaneously.

1.4.3.1 Single programmer

1. PGMplus USB : This is a parallel programmer which is smaller and faster than our previous parallel programmer PGM Plus III.

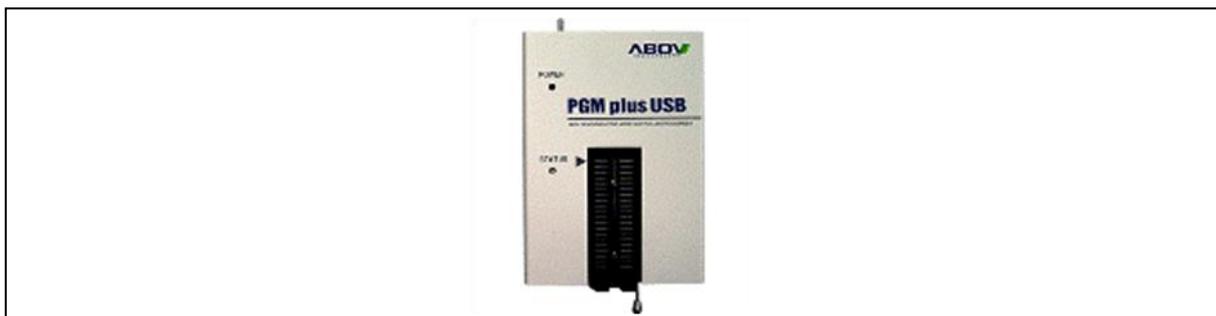


Figure 1-2 PGMplus USB

2. Ez-ISP : This is one of stand alone type ISP tool. Notable thing is that it provides power to the target MCU.



Figure 1-3 Ez-ISP

3. **OCD emulator** : You can program or debug the MCU via OCD. Because the OCD supports ISP(In System Programming), it does not require additional H/W except for developer's target system.

1.4.3.2 Gang programmer

The gang programmer can program maximum 8 MCUs at a time. So it is mainly used in mass production line. As gang programmer is standalone type, it does not require host PC.



Figure 1-4 Gang programmer

2. BLOCK DIAGRAM

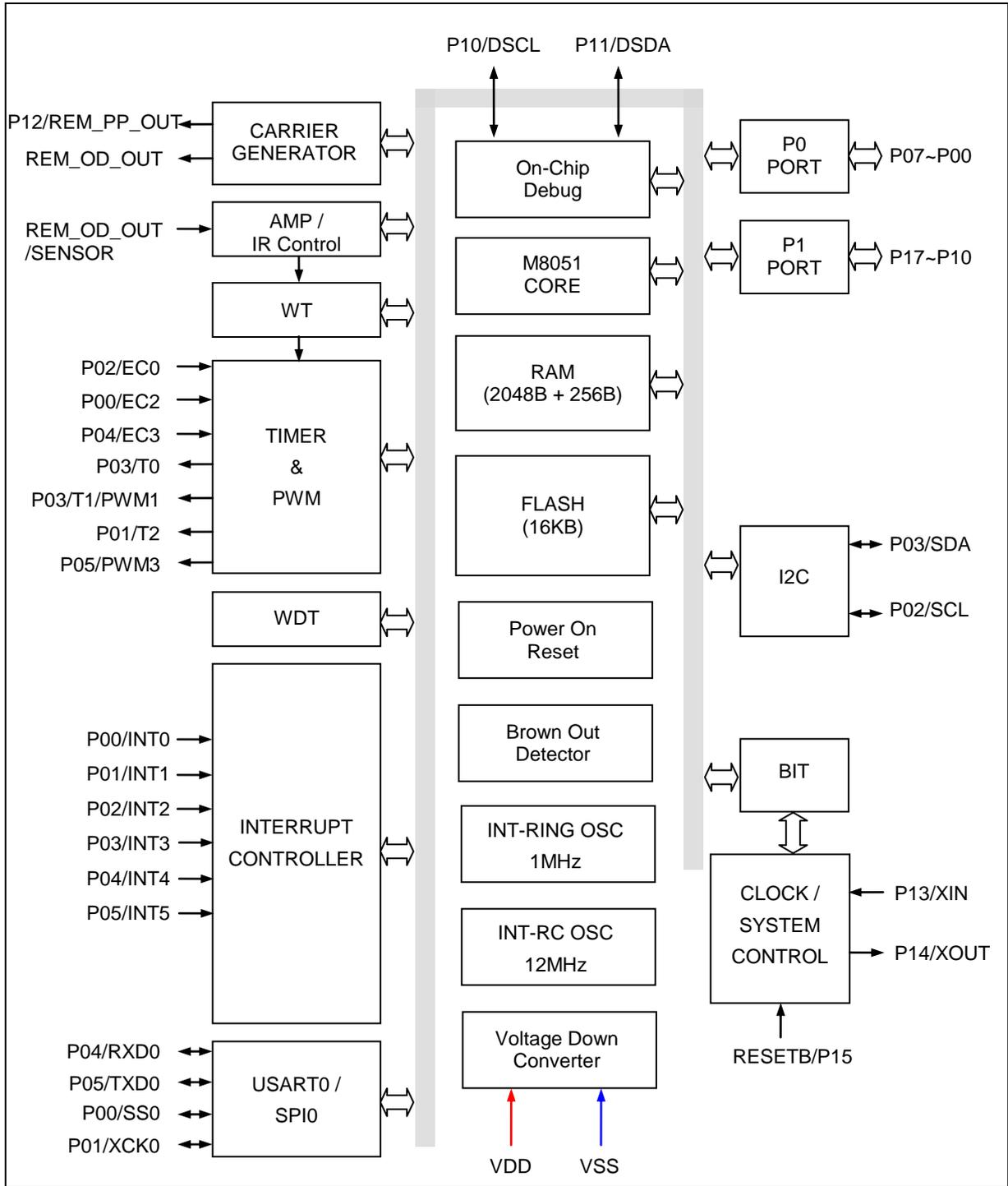


Figure 2-1 Block Diagram of MC96FR116C

PIN	Type	Option	Remarks
P15	I/O	RESETB	FUSE Control

3. PIN CONFIGURATIONS

16 QFN (MC96FR116CU)

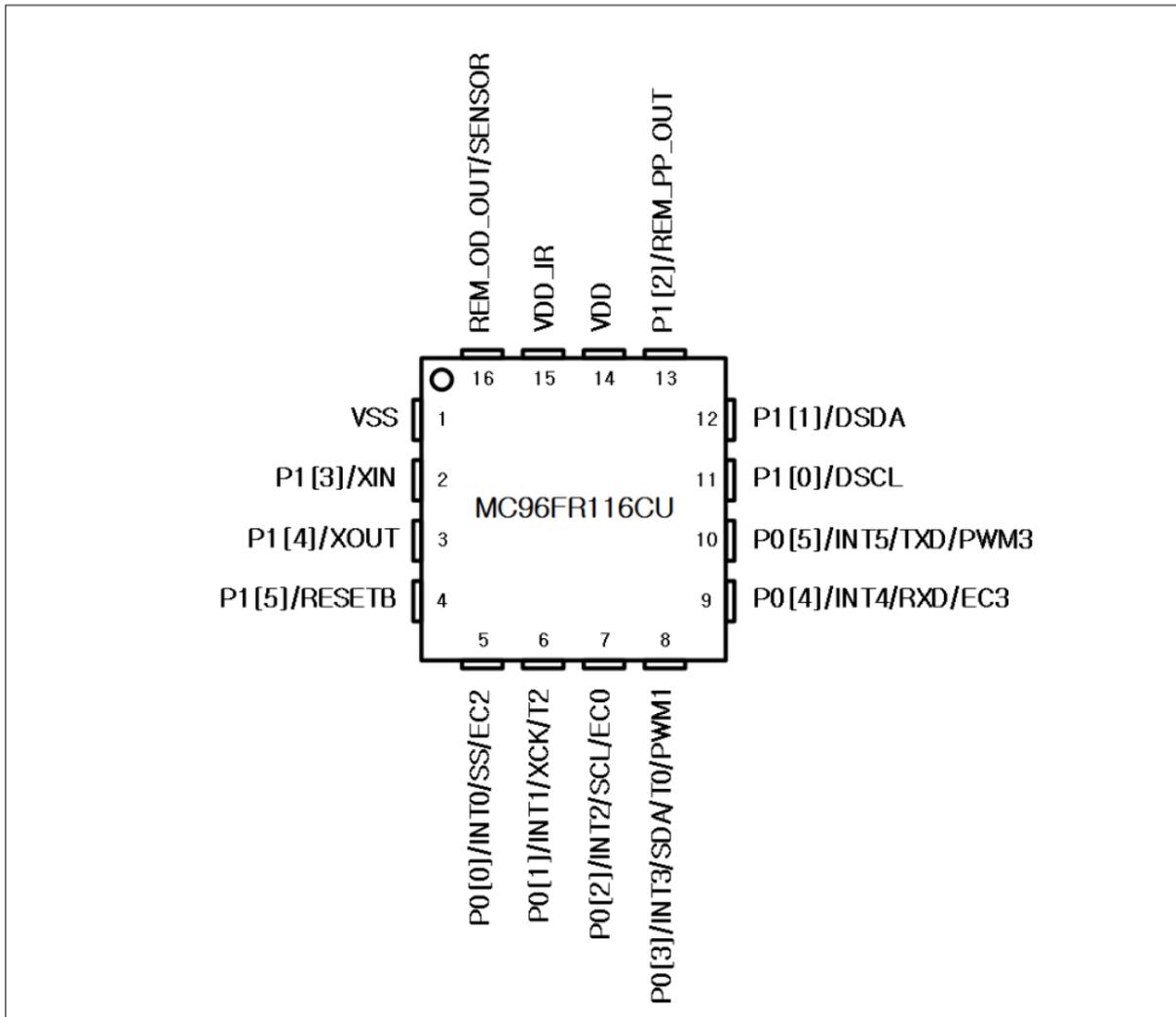


Figure 3-1 16 QFN Pinout of MC96FR116CU

16 WLCSP (MC96FR116C)

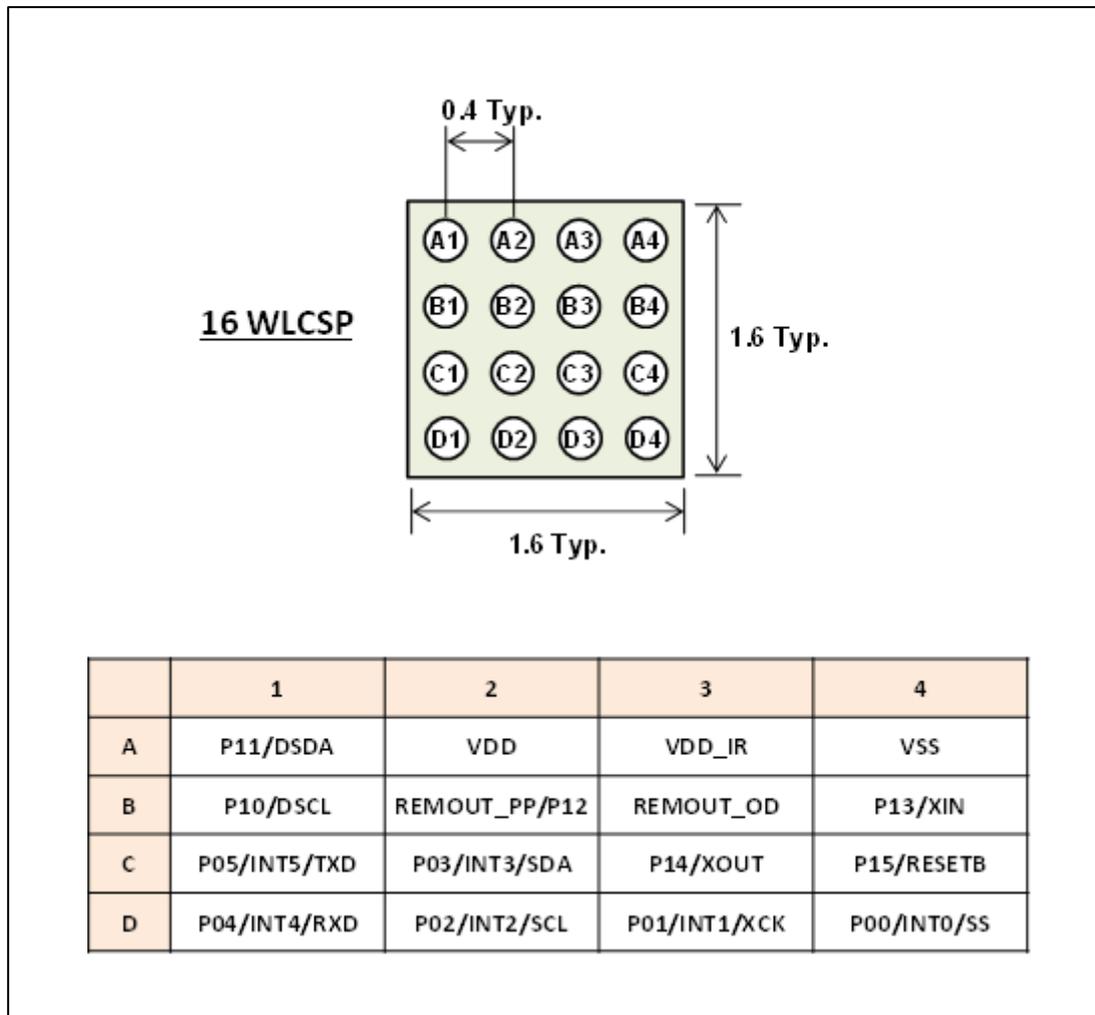


Figure 3-2 16 WLCSP Pinout of MC96FR116C

20 TSSOP (MC96FR116CR)

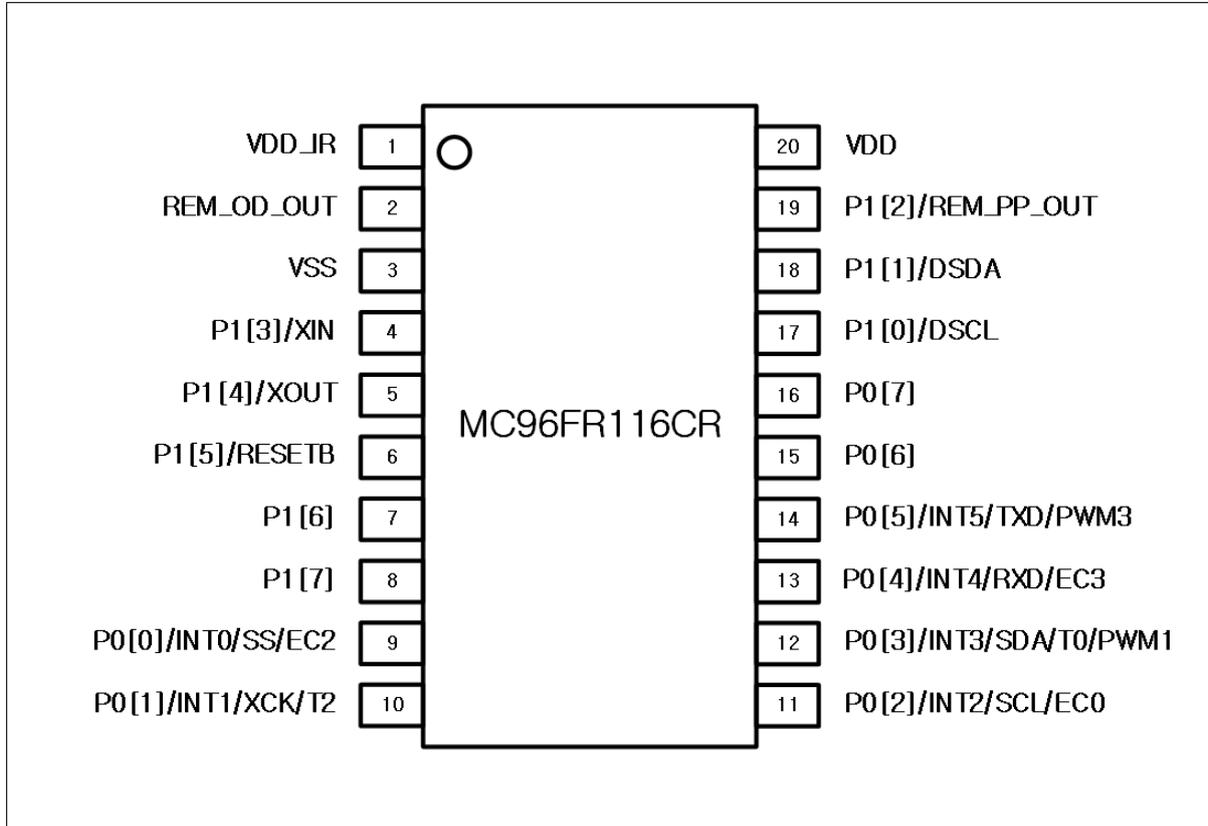


Figure 3-3 20 TSSOP Pinout of MC96FR116CR

4. PACKAGE DIMENSION

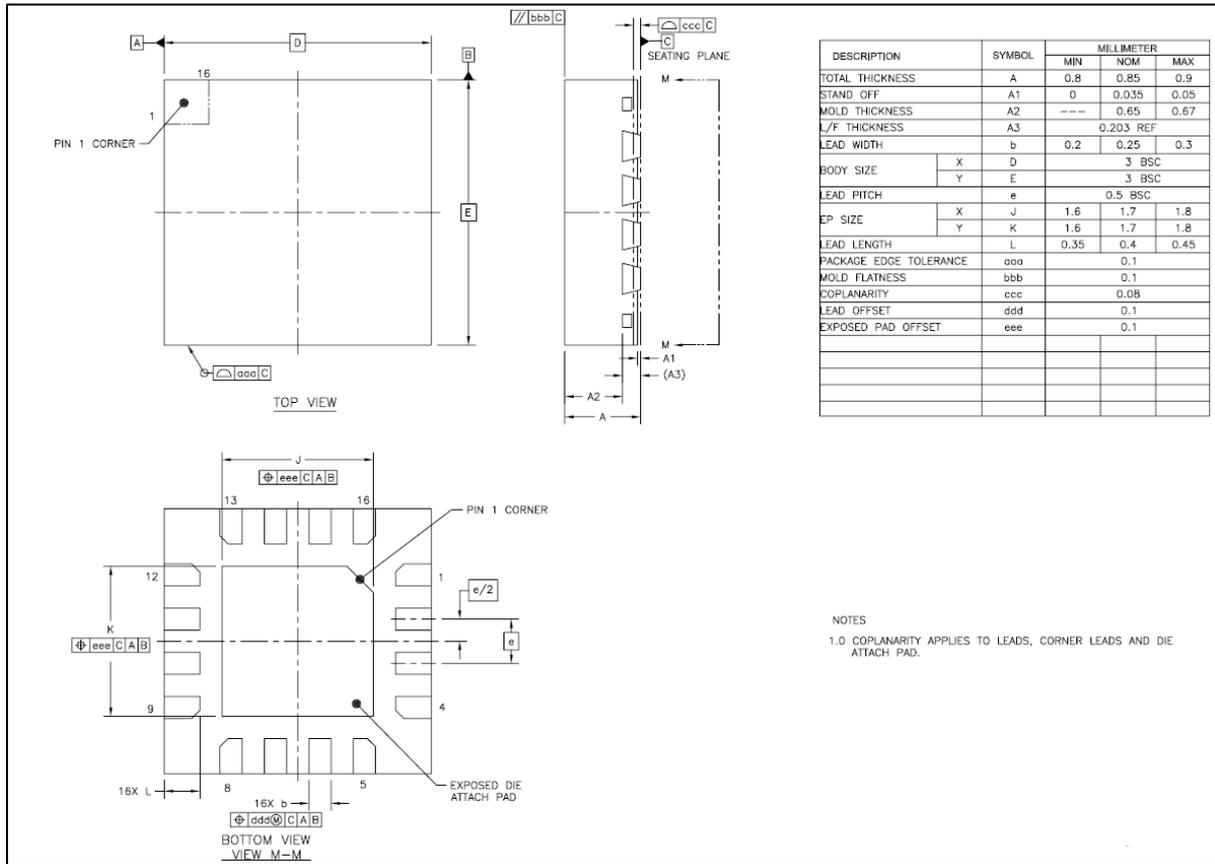


Figure 4-1 PKG DIMENSION (16 QFN)

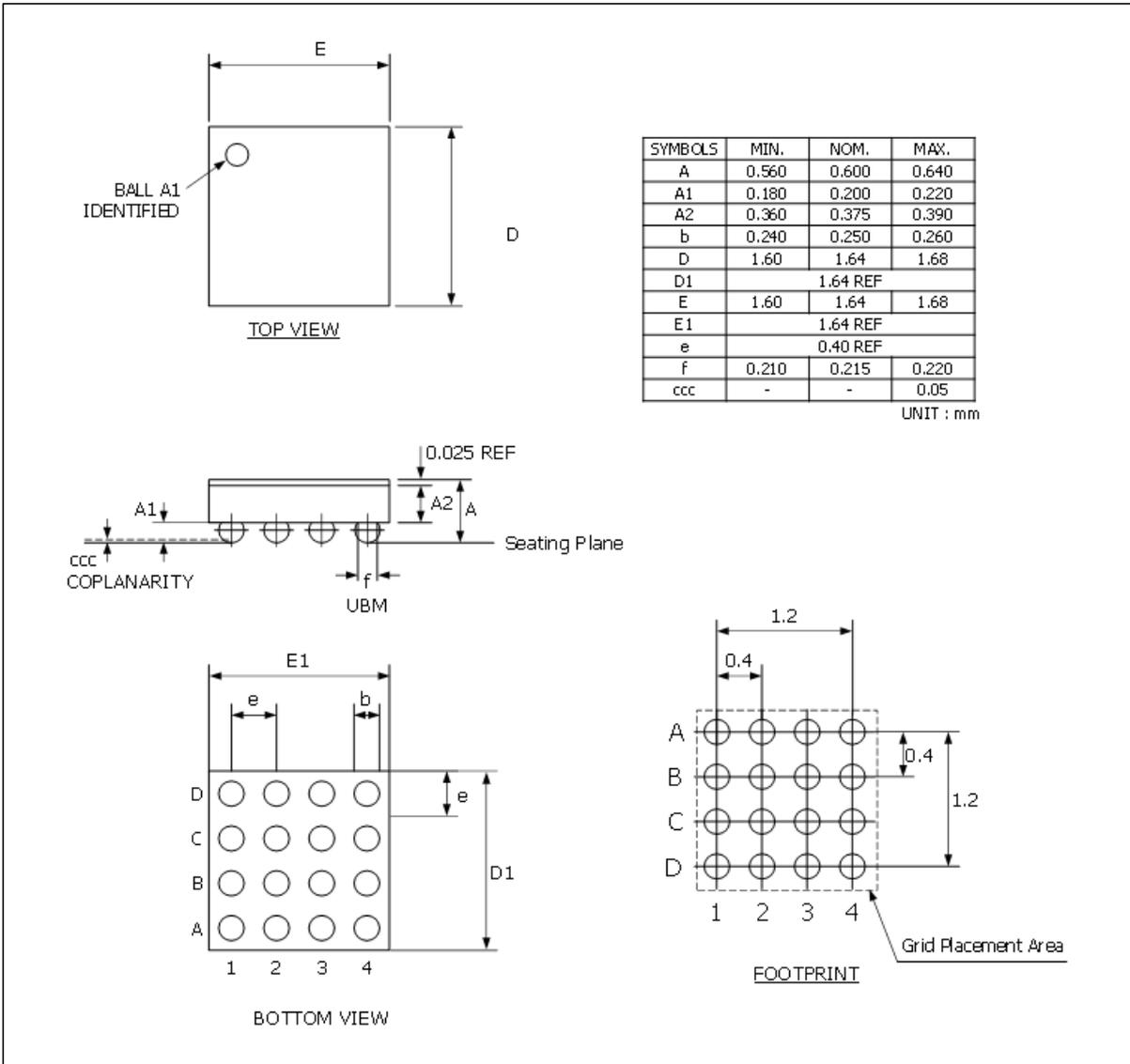


Figure 4-2 PKG DIMENSION (16 WLCSP)

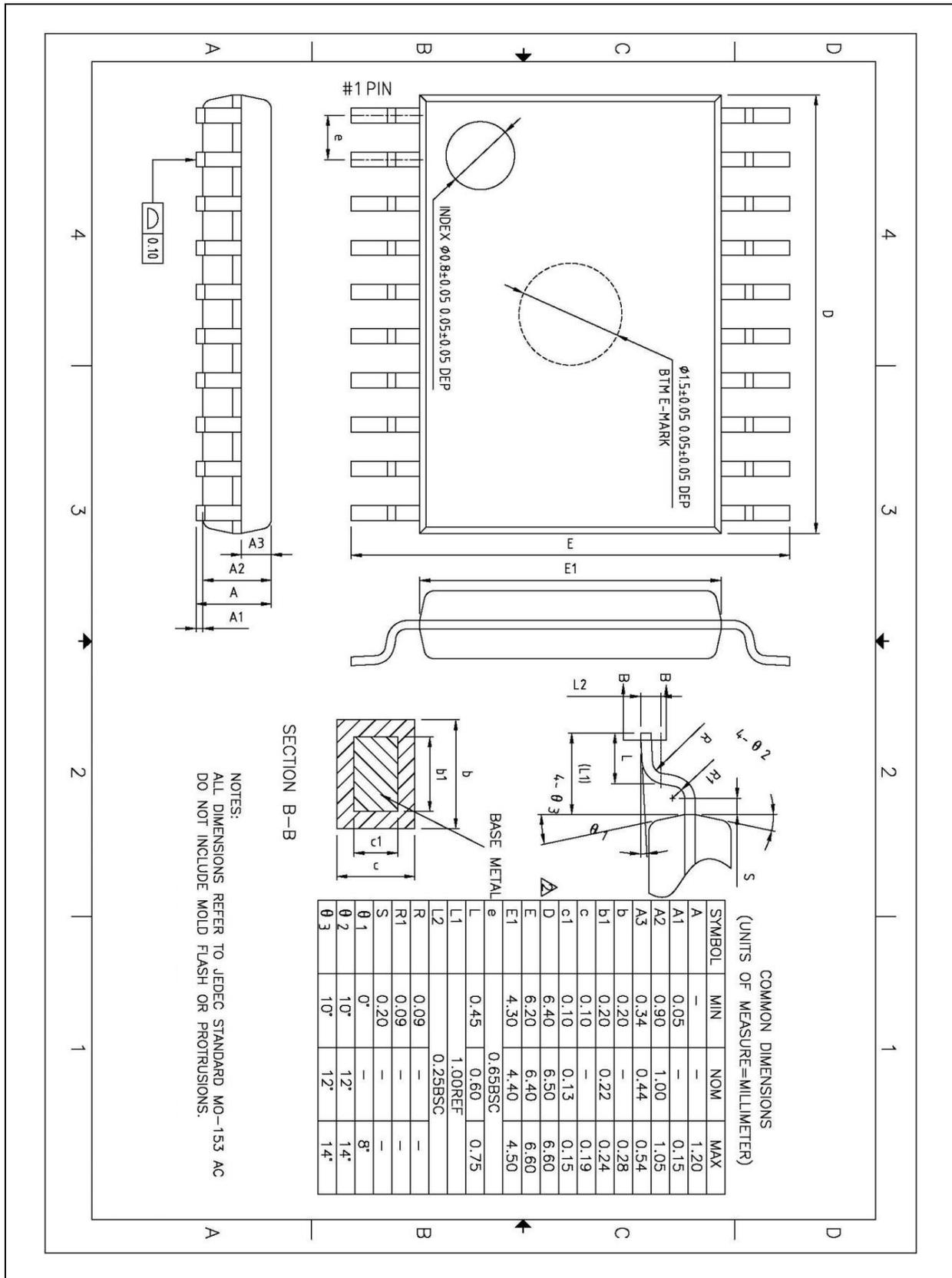


Figure 4-3 PKG DIMENSION (20 TSSOP)

5. PIN DESCRIPTION

PIN Name	I/O	Function	@RESET	Shared with
P00	I/O	- 6-bit I/O port, P0. - Can be set in input or output mode bitwise. - Internal pull-up resistor can be activated by setting PxnPU bit in PxPU register when this port is used as input port. - Can be configured as an open drain output mode by setting PxnOD bit in PxOD register.	Input	INT0 ^{NOTE1} / SS0/EC2
P01				INT1 ^{NOTE1} / XCK0/T2
P02				INT2 ^{NOTE1} / SCL/EC0
P03				INT3 ^{NOTE1} / SDA/T0/ PWM1
P04				INT4 ^{NOTE1} /RXD0/EC3
P05				INT5 ^{NOTE1} /TXD0
P06				NOTE2
P07				NOTE2
P10	I/O	3-bit I/O port, P1. - Can be set in input or output mode bitwise. - Internal pull-up resistor can be activated by setting PxnPU bit in PxPU register when this port is used as input port. - Can be configured as an open drain output mode by setting PxnOD bit in PxOD register.	Input	DSCL
P11				DSDA
P12				REM_PP_OUT
P13				XIN
P14				XOUT
P15				RESETB
P16				NOTE2
P17				NOTE2
REM_OD_OUT	I/O	1-bit I/O port. - REM open-drain output	input	SENSOR
VDD	P	Main power supply	-	
VDD_IR	P	Power supply of IR transistor and IR analog amplifier	-	
VSS	P	Ground	-	

^{NOTE1} If EIPsx is controlled, The interrupt port(INTx) is chaged to any port.

^{NOTE2} P06, P07, P16 and P17 are used at 20 TSSOP package type.

6. PORT STRUCTURES

6.1 General Purpose I/O Port

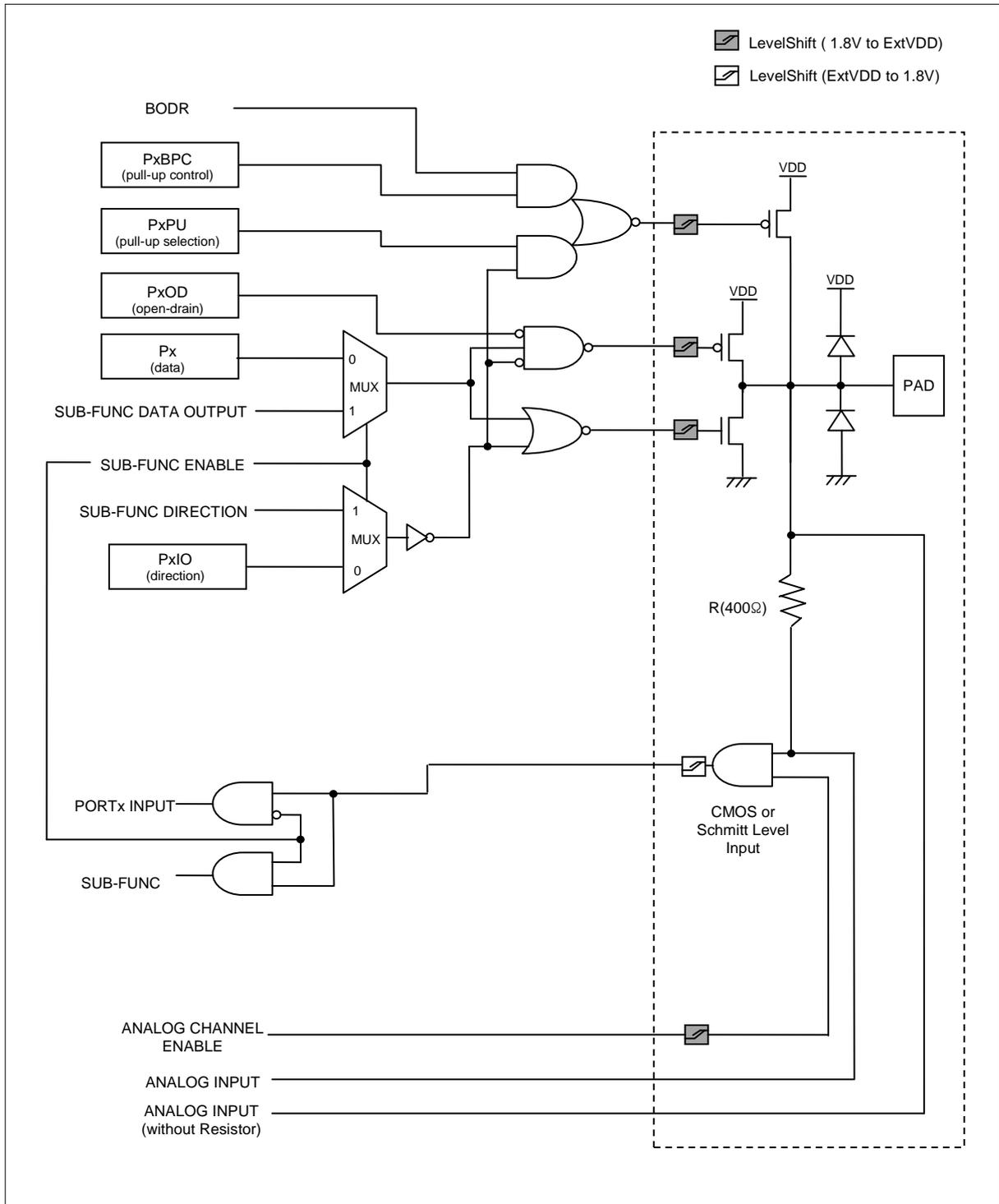
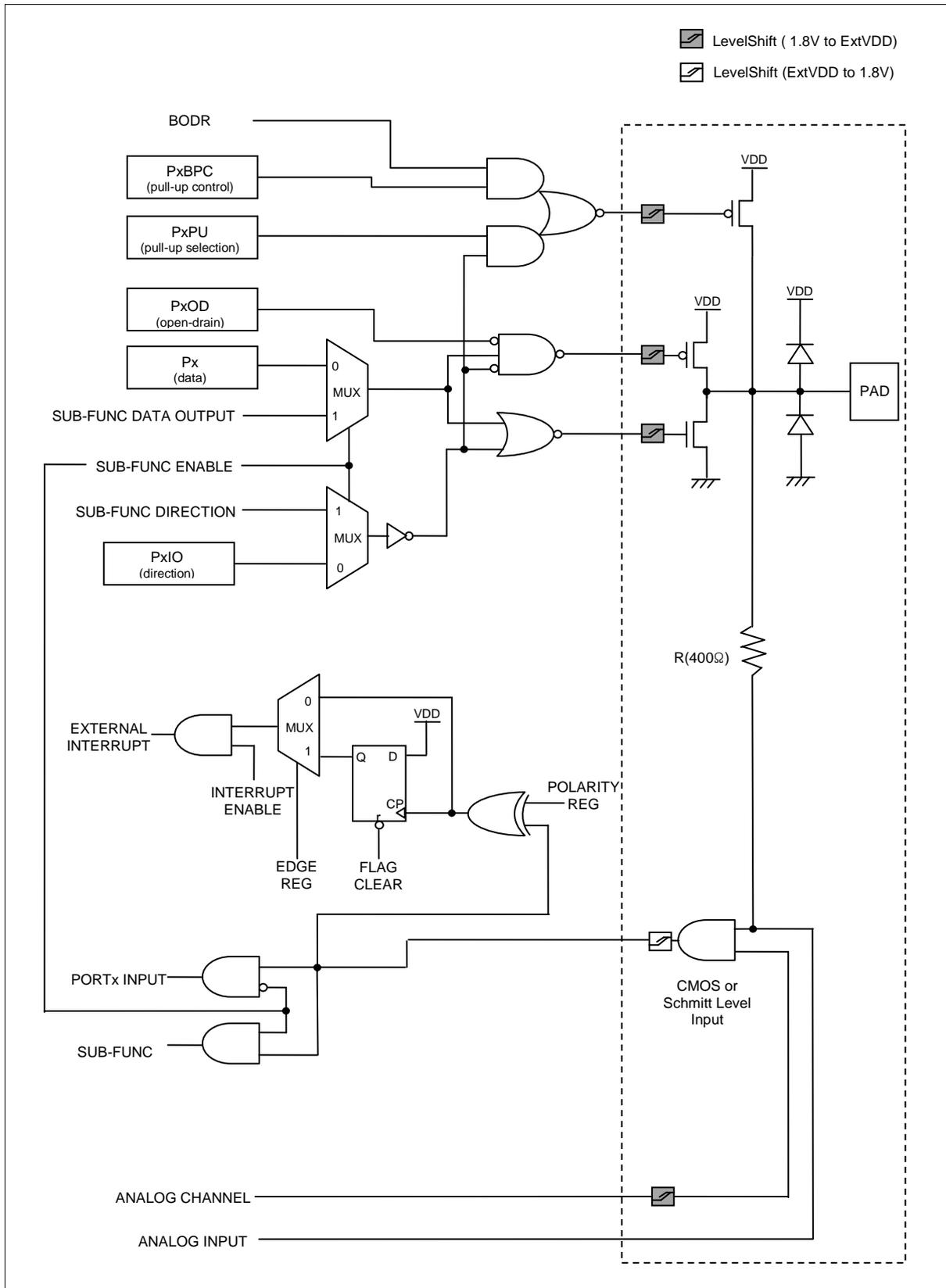


Figure 6-1 General I/O

6.2 External Interrupt I/O Port



6.3 REM_PP_OUT Port

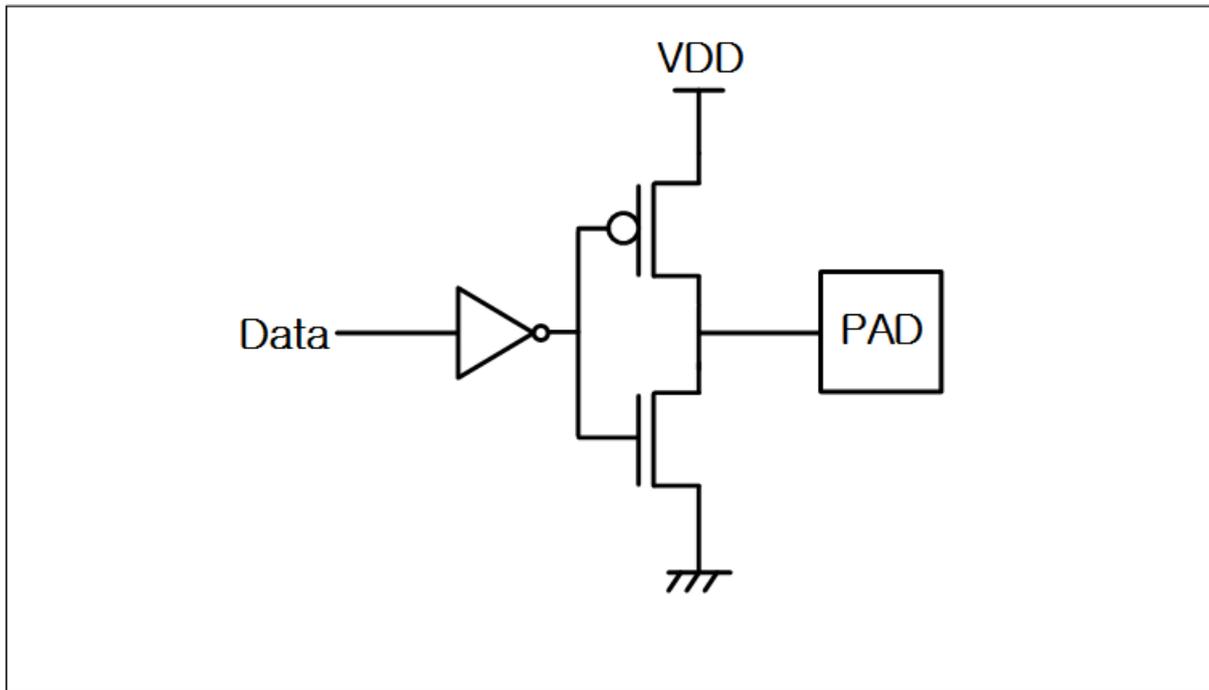


Figure 6-3 REM_PP_OUT port

6.4 REM_OD_OUT Port

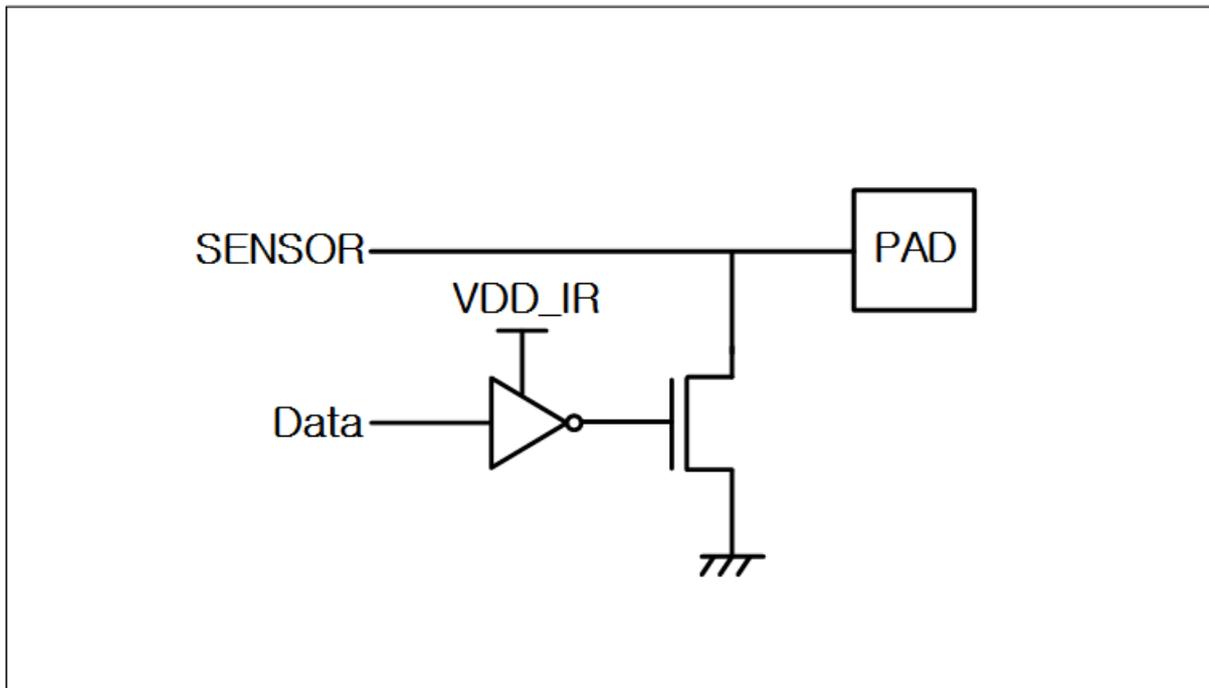


Figure 6-4 REM_OD_OUT port

7. ELECTRICAL CHARACTERISTICS

Unless otherwise noted, VDD = 1.6 ~ 3.6V, TA=-30~+85 °C.

7.1 Absolute Maximum Ratings

Parameter	Symbol	Rating	Unit
Supply Voltage	VDD	-0.3~+4.0	V
	VDD_IR	-0.3~+5.0	V
	VSS	-0.3~+0.3	V
Normal Voltage Pin	VI	-0.3~VDD+0.3	V
	VO	-0.3~VDD+0.3	V
	IOH	10	mA
	Σ IOH	80	mA
	IOL	20	mA
	Σ IOL	160	mA
Total Power Dissipation	PT	600	mW
Storage Temperature	TSTG	-65~+150	°C

Table 7-1 Absolute Maximum Ratings

^{NOTE} Stresses beyond 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 beyond 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 CONDITION

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
Supply Voltage	VDD		1.6	-	3.6	V
Operating Temperature	TOPR		-30	-	85	°C
Operating Frequency	FOPR		DC	-	12	MHz

Table 7-2 Recommended Operating Condition

7.3 VOLTAGE DROPOUT CONVERTER(1.8V Internal regulator) CHARACTERISTICS

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
Regulation Voltage		-	1.62	1.8	1.98	V

Table 7-3 Voltage Dropout Converter Characteristics

7.4 BROWN OUT DETECTOR(BOD) CHARACTERISTICS

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
Detection Level	V_{BODR}	NOTE	1.50	1.55	1.60	V
	V_{BODI0}	NOTE	1.60	1.65	1.70	V
	V_{BODI1}	NOTE	1.70	1.80	1.90	V
	V_{BODI2}	NOTE	1.90	2.00	2.10	V
	V_{BODI3}	NOTE	2.10	2.20	2.30	V
	V_{BODI4}	NOTE	2.30	2.40	2.50	V
Startup time	t_{BODS}			30		us
Detection time	t_{BODD}			2		us
Operating Current	IDD	-	-	-	40	uA

Table 7-4 Brown Out Detector Characteristics

NOTE V_{BODR} is a voltage level and BODR flag indicating it can generate internal reset due to voltage drop. When the external power drops below the V_{BODR} voltage level, the BOD detects the power condition and makes the device enter STOP-like mode called BOD mode. When the external power is restored, a BOD reset is generated according to pre-defined sequence and the device is initialized. $V_{BODI0/1/2/3/4}$ also indicate voltage levels and BODI0/1/2/3/4 are these flags. When the external power drops below the level indicated in above table, the associated flag is set to '1' and these values can be read through the BODSR register. These flags may be used to monitor the status of battery charging. **The V_{BODR} and V_{BODI0} can be revised typical level and $\pm 30mV$ tolerance.**

7.5 RAM data retention CHARACTERISTICS

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
Supply Voltage	VDD			1.0		V

Table 7-5 RAM data retention Characteristics

7.6 FLASH CHARACTERISTICS

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
Flash Read supply voltage	V_{READ}		1.48		3.6	V
Flash write supply voltage	V_{WRITE}		1.6		3.6	V
Page Erase	t_{ERS}			2.5		ms
Page Program	t_{PGM}			2.5		ms
Program/Erase Cycle				10,000		Cycles
Data Retention				10		Years

Table 7-6 FLASH Characteristics

7.7 Internal RC Oscillator CHARACTERISTICS

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
Supply Voltage	VDD		1.6	-	3.6	V
Frequency	f_{IRC}	-30~+85°C	11.76	12	12.24	MHz
		0~+50°C	11.88	12	12.12	MHz

Table 7-7 Internal RC Oscillator Characteristics

7.8 Analog Comparator CHARACTERISTICS

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
Input Offset Voltage	V_{OFFSET}	-	-	10	40	mV
Hysteresis voltage	V_{HYS}	-	-	20	-	mV
Response Time	T_{RSP}	VDD_IR=3.3V			130	ns
		VDD_IR=1.8V			4500	ns

Table 7-8 Analog Compatator Characteristics

7.9 POWER-ON RESET CHARACTERISTICS

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
RESET Release Level		-	1.3	1.4	1.5	V

Table 7-9 Power-On Reset Characteristics

7.10 DC CHARACTERISTICS

Parameter	Symbol	Condition	MIN	TYP	MAX	Unit
Input Low Voltage	VIL		0	-	0.2VDD	V
Input High Voltage	VIH		0.8VDD	-	VDD	V
Output Low Voltage	VOL	VDD=3.3V, IOL=18mA	-	0.4	0.5	V
		VDD=1.8V, IOL=7mA	-	0.4	0.5	
Output High Voltage	VOH	VDD=3.3V, IOH=12mA	VDD-0.5	-	-	V
		VDD=1.8V, IOH=2mA	VDD-0.5	-	-	
Input High Leakage Current	IIH				1	uA
Input Low Leakage Current	IIL		-1			uA
Pull-Up Resistors	RPU	VDD=3.3V	61	-	109	kΩ
		VDD=1.8V	174	-	349	kΩ
Power Supply Current	IDD1	RUN Mode, f _{XIN} =10MHz@3.6V	-	-	4.3	mA
	IDD2	SLEEP Mode, f _{XIN} =10MHz@3.6V	-	-	2.9	mA
	IDD3	STOP Mode @3.6V (Without BOD, BOD is disabled with chip at stop mode.)	-	1	15	uA

Table 7-10 DC Characteristics

7.11 AC CHARACTERISTICS

Parameter	Symbol	PIN	MIN	TYP	MAX	Unit
Operating Frequency	fMCP	XIN	0	-	12	MHz
System Clock Cycle Time	tSYS	-	83	-		ns
Oscillation Stabilization Time (8MHz)	tMST1	XIN, XOUT	-	-	10	ms
External Clock "H" or "L" Pulse Width	tCPW	XIN	40	-	-	ns
External Clock Transition Time	tRCP,tFCP	XIN	-	-	10	ns
Interrupt Input Width	tIW	INT0~INT3	2	-	-	tSYS
RESETB Input Pulse "L" Width	tRST	RESETB	-	8	-	us
External Counter Input "H" or "L" Pulse Width	tECW	EC0	2	-	-	tSYS
Event Counter Transition Time	tREC,tFEC	EC0	-	-	20	ns

Table 7-11 AC Characteristics

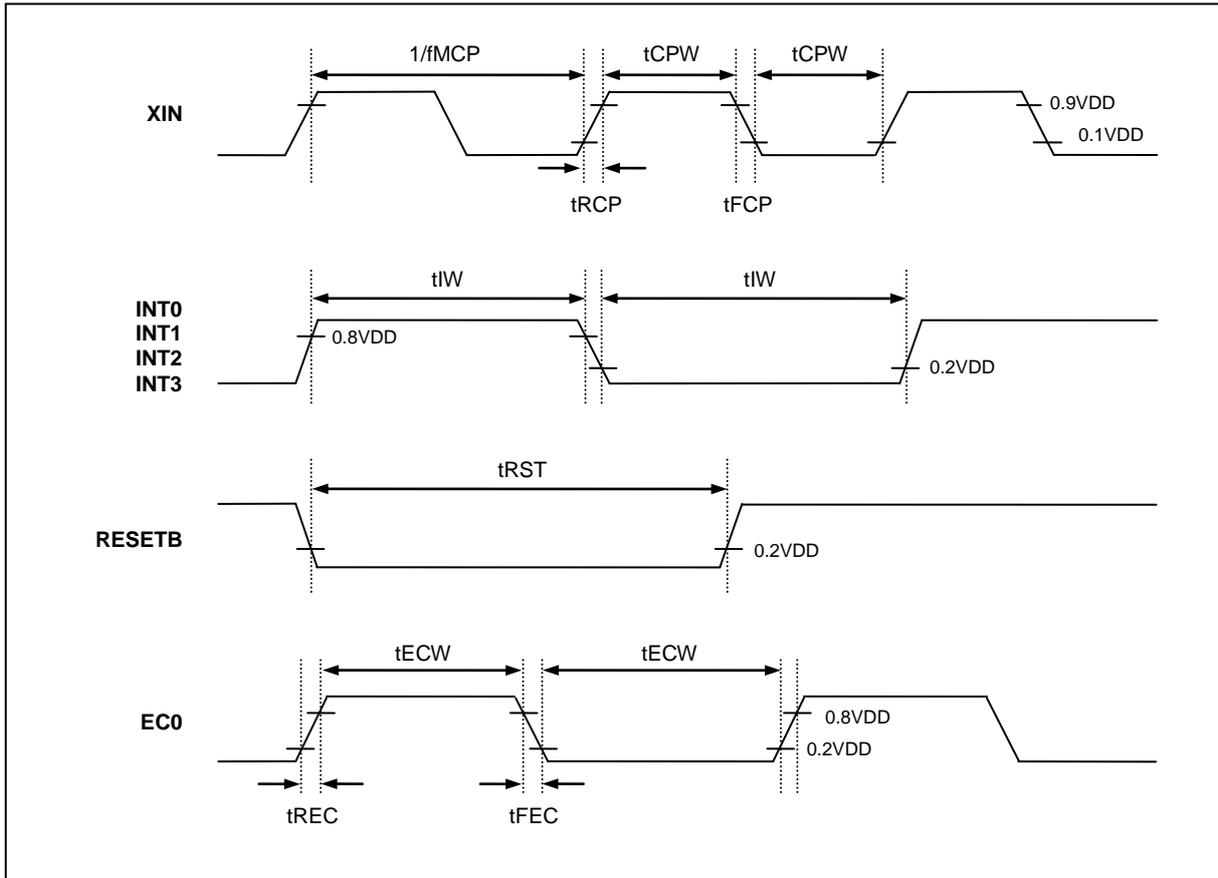


Figure 7-1 AC Timing

7.12 USART CHARACTERISTICS

The following table and figure show the timing condition of USART in SPI or Synchronous mode of operation. The USART is one of peripherals in MC96FR116C.^{NOTE1}

Parameter	Symbol ^{NOTE2}	MIN	MAX	Unit
System clock period	t_{SCLK}	83	1000	ns
Clock (XCK) period	t_{XCK}	4	1028	t_{SCLK}
Clock (XCK) high time	t_{XCKH}	2	514	t_{SCLK}
Clock (XCK) low time	t_{XCKL}	2	514	t_{SCLK}
Lead time	Master t_{LEAD}	$0.5 t_{XCK}$	$0.5 t_{XCK}$	ns
	Slave t_{LEAD}	$2 t_{SCLK}$	-	
Lag time	Master t_{LAG}	$0.5 t_{XCK}$	$0.5 t_{XCK}$	ns
	Slave t_{LAG}	$2 t_{SCLK}$	-	
Data setup time (inputs)	Master t_{SIM}	2	2	t_{SCLK}
	Slave t_{SIS}	2	2	
Data hold time (inputs)	Master t_{HIM}	10	-	ns
	Slave t_{HIS}	10	-	
Data setup time (outputs)	Master t_{SOM}	2	2	t_{SCLK}
	Slave t_{SOS}	2	2	
Data hold time (outputs)	Master t_{HOM}	-10	-	ns
	Slave t_{HOS}	-10	-	
Disable time	t_{DIS}	1	2	t_{SCLK}

Table 7-12 Timing characteristics of USART in SYNC. or SPI mode of operations

^{NOTE1} In synchronous mode, Lead and Lag time with respect to SS pin is ignored. And the case of UCPHA=0 is also applied to SPI mode only.

^{NOTE2} All timing is shown with respect to 20% VDD and 80% VDD.

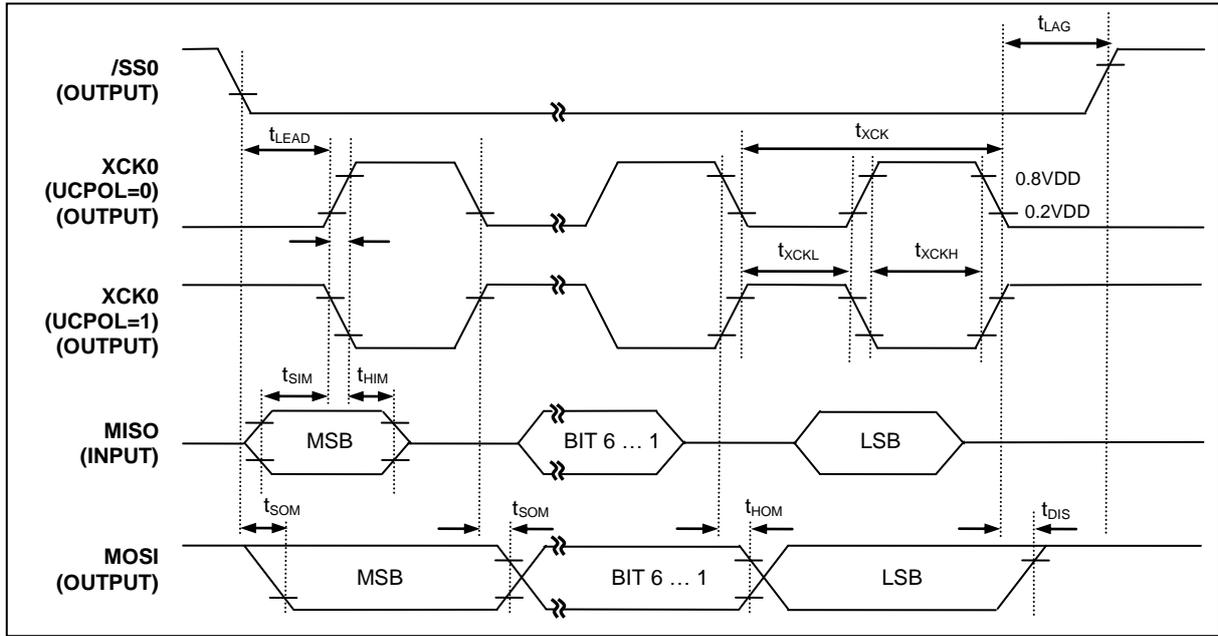


Figure 7-2 SPI master mode timing (UCPHA = 0, MSB first)

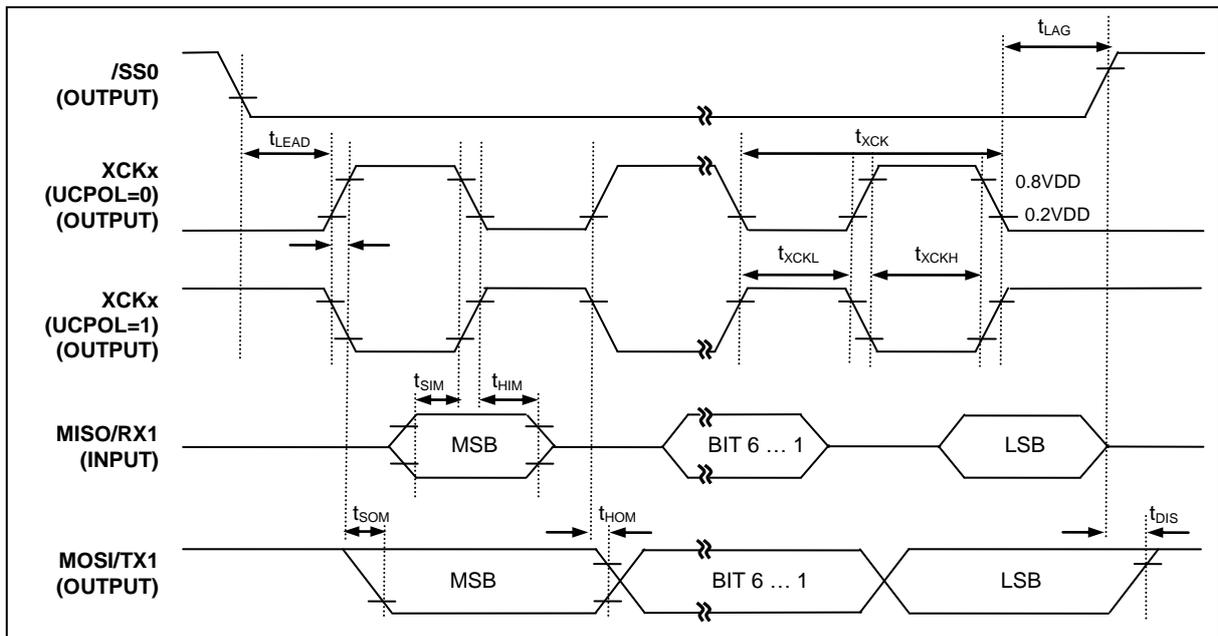


Figure 7-3 SPI / Synchronous master mode timing (UCPHA = 1, MSB first)

NOTE When in Synchronous mode, the START bit becomes MSB and the 1st or 2nd STOP bit becomes LSB.

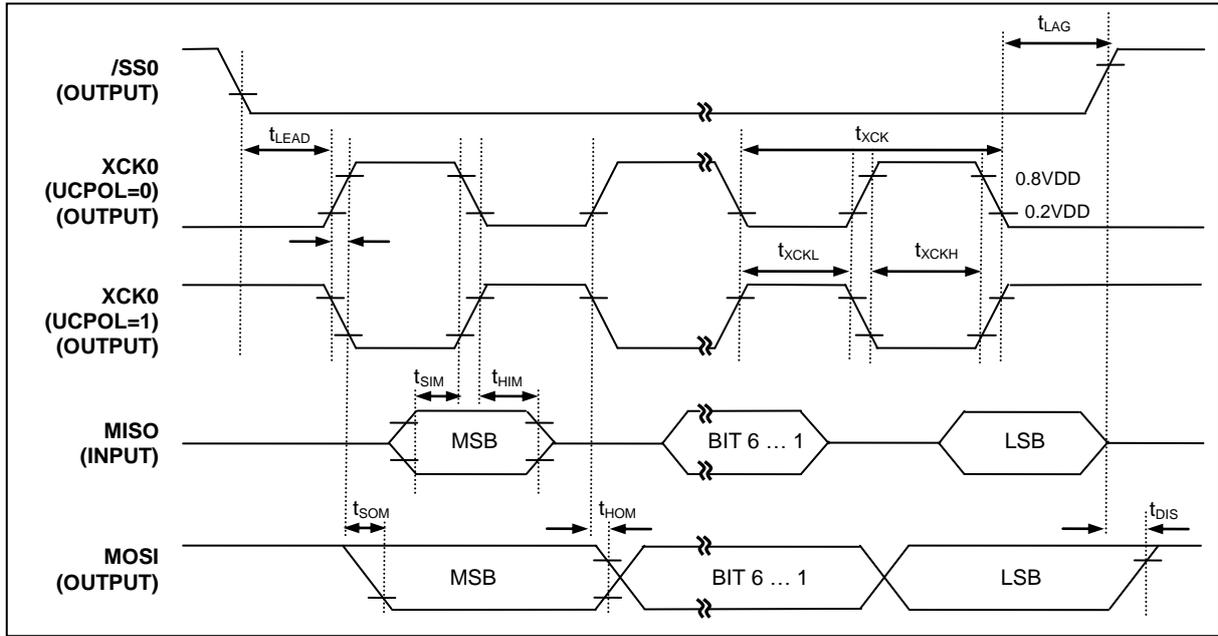


Figure 7-4 SPI slave mode timing (UCPHA = 0, MSB first)

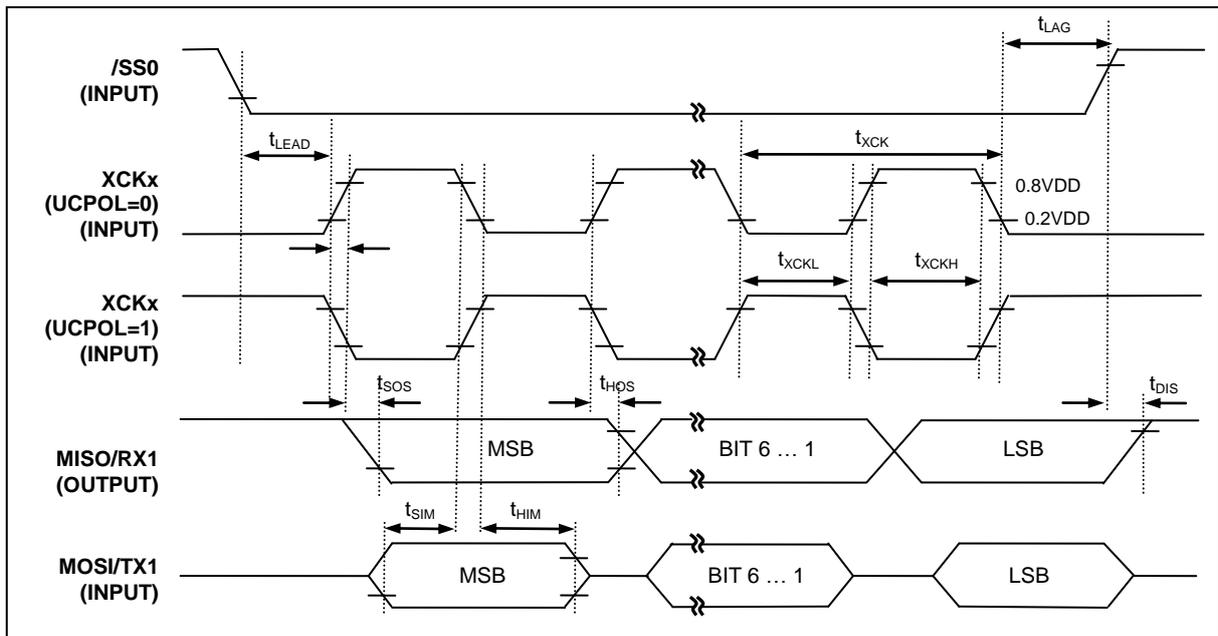


Figure 7-5 SPI / Synchronous slave mode timing (UCPHA = 1, MSB first)

NOTE¹ When in Synchronous mode, the START bit becomes MSB and the 1st or 2nd STOP bit becomes LSB.

7.13 REM_PP_OUT PORT CHARACTERISTICS

The characteristics of REM_PP_OUT is related with VDD, not VDD_IR.

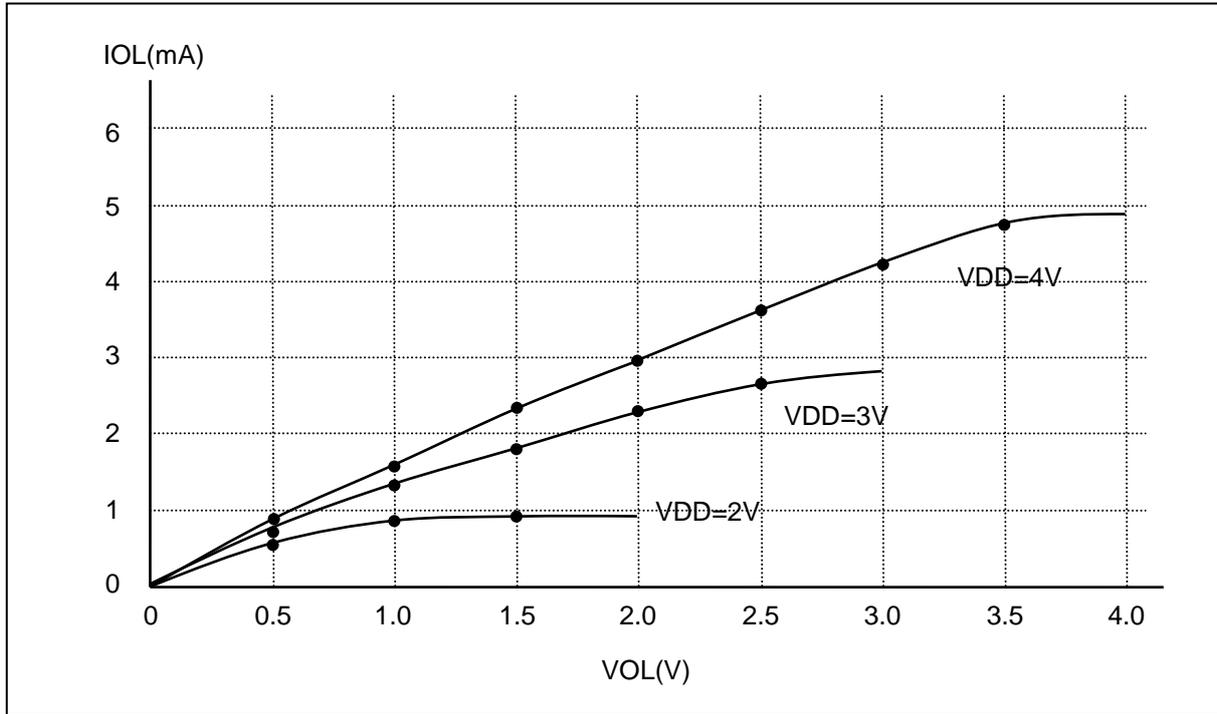


Figure 7-6 IOL vs VOL for REM_PP_OUT

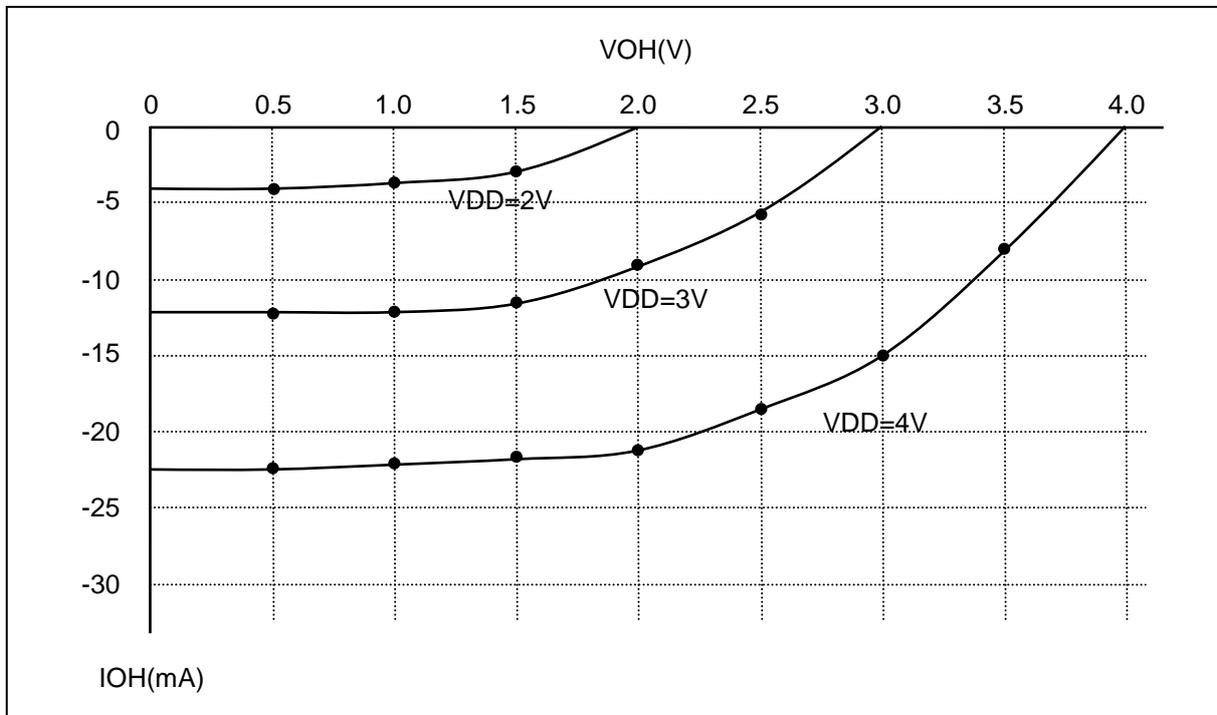


Figure 7-7 IOH vs VOH for REM_PP_OUT

7.14 REM_OD_OUT PORT CHARACTERISTICS

The characteristics of REM_OD_OUT is related with VDD_IR, not VDD.

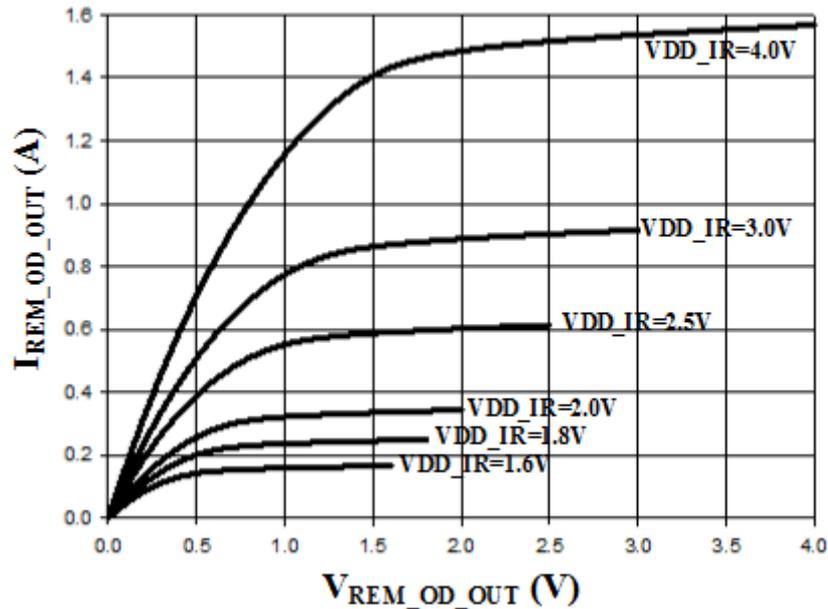


Figure 7-8 Characteristics for REM_OD_OUT

7.15 TYPICAL CHARACTERISTICS

These 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 VDD 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 + 3 σ) and (mean - 3 σ) respectively where σ is standard deviation.

8. MEMORY

The MC96FR116C has separate address spaces for Program and Data Memory. The logical separation of Program and Data Memory allows the Data Memory to be accessed by 8-bit addresses, which can be more quickly stored and manipulated by an 8-bit CPU. Nevertheless, 16-bit Data Memory addresses can also be generated through the DPTR register.

Program Memory contains user software and is read-only while the device is in normal running mode. But the Program Memory can be erased or programmed by ISP(In System Programming) method. The MC96FR116C can assign maximum 16KB to Program Memory which is divided into 2 banks.

Data Memory is composed of Internal RAM (IRAM), External RAM (XRAM). IRAM is read-writable and address space is 256B including Stack Pointer. XRAM has 2048B of memory depth and also read-writable.

^{NOTE} The terms IRAM and XRAM are used just to classify kind of memory. XRAM doesn't have to reside outside the device. In MC96FR116C, both IRAM and XRAM reside in device.

8.1 Program Memory

A 16-bit program counter is capable of addressing up to 16K bytes, but this device has 16K bytes of program memory space located in one bank 0. The following figure shows a map of program memory in MC96FR116C. After reset, the CPU begins program execution from address 0000_H. All interrupt vector is assigned to their fixed location in program memory. An interrupt causes the CPU to jump to its vector location, where the CPU commences execution of the service routine. External interrupt 0, for example, is assigned to location 000B_H. If user wants to use external interrupt 0 as an interrupt source, its service routine must begin at location 000B_H. If the interrupt is not used, its service location is available as general purpose program memory. Because all interrupt vector can use 8 bytes from each vector address ^{NOTE}, the service routine can reside entirely within that 8 bytes if an interrupt service routine is short enough (as is often the case in control applications). Normally an interrupt service routine is longer than 8 bytes, so the service routine starts with a jump instruction.

^{NOTE} Refer to Table 10-2 Interrupt Vector Address.

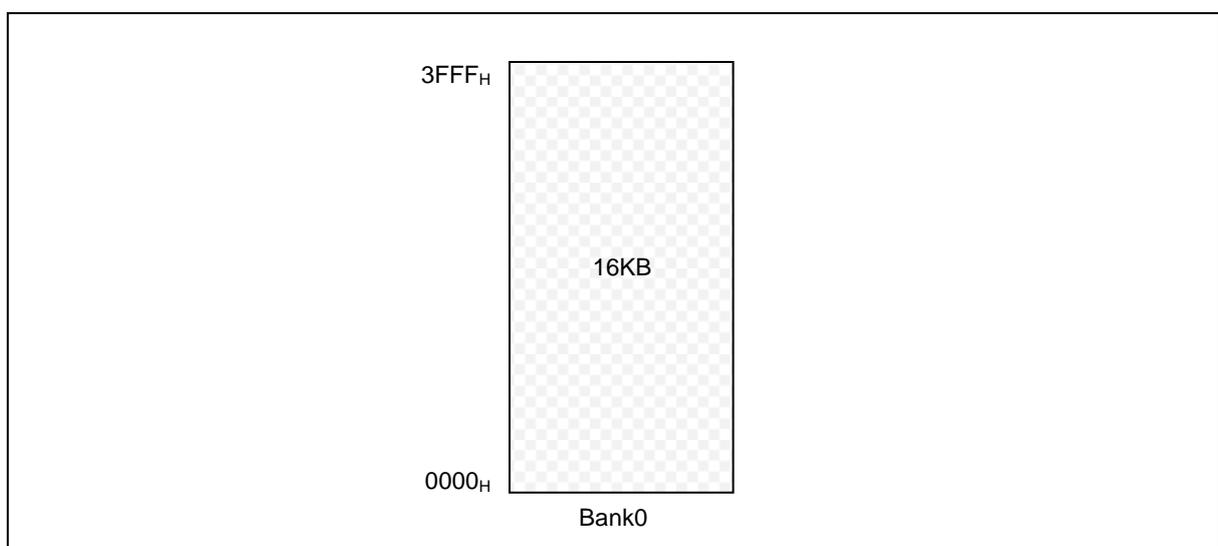


Figure 8-1 Program Memory

8.2 IRAM

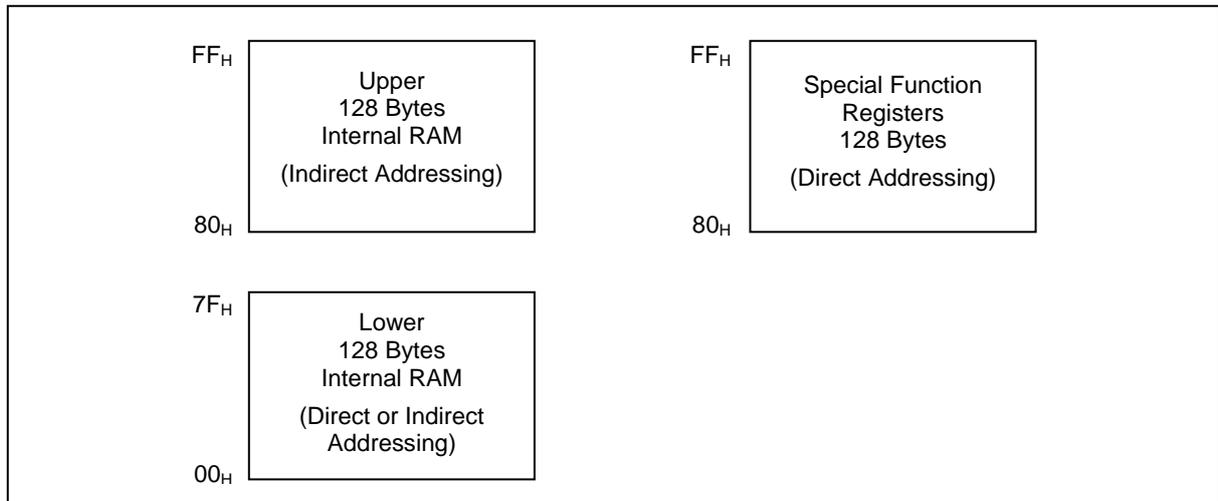


Figure 8-2 DATA MEMORY (IRAM)

Internal Data Memory is mapped in Figure 8-2. The memory space is shown divided into three blocks, which are generally referred to as the Lower 128, the Upper 128, and SFR space.

Internal Data Memory addresses are always one byte wide, which implies an address space of only 256 bytes. However, the addressing modes for internal RAM can in fact accommodate 384 bytes, using a simple trick. Direct addresses higher than 7F_{H} access one memory space, and indirect addresses higher than 7F_{H} access a different memory space. Thus Figure 8-2 shows the Upper 128 and SFR space occupying the same block of addresses, 80_{H} through FF_{H} , although they are physically separate entities.

The Lower 128 bytes of RAM are present in all devices using **MCS-51** devices as mapped in Figure 8-2. The lowest 32 bytes are grouped into 4 banks of 8 registers. Program instructions call out these registers as R0 through R7. Two bits in the Program Status Word (PSW) select which register bank is in use. This allows more efficient use of code space, since register instructions are shorter than instructions that use direct addressing.

The next 16 bytes above the register banks form a block of bit-addressable memory space. The MCS-51 instruction set includes a wide selection of single-bit instructions, and the 128 bits in this area can be directly addressed by these instructions. The bit addresses in this area are 00_{H} through 7F_{H} .

All of the bytes in the Lower 128 can be accessed by either direct or indirect addressing. The Upper 128 can only be accessed by indirect addressing. These spaces are used for user RAM and stack pointer.

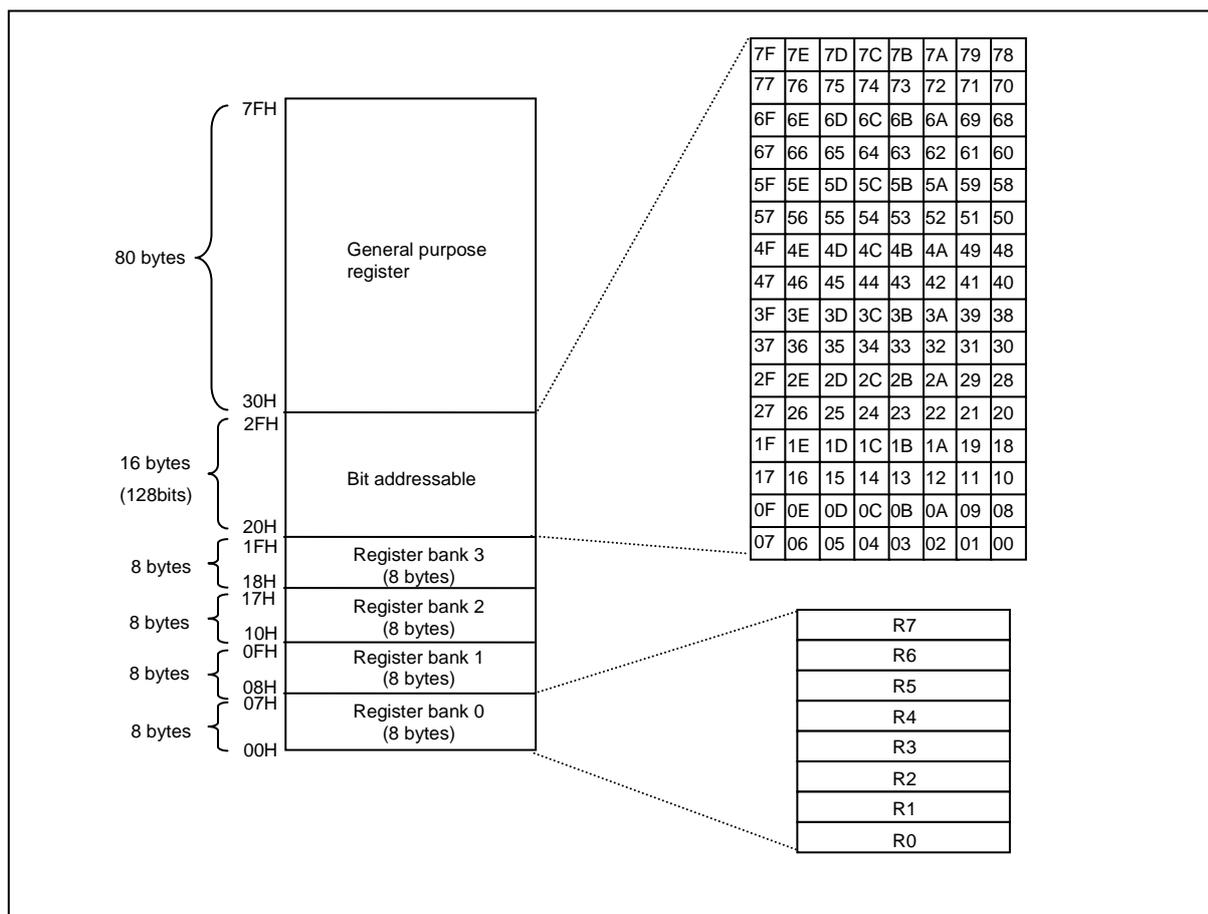


Figure 8-3 Lower 128 Byte of IRAM

8.2.1 Indirect Address Area

Note that in Figure 8.2 the SFRs and the indirect address RAM have the same addresses (80_H~FF_H). Nevertheless, they are two separate areas and accessed in two different ways.

For example the instruction

```
MOV 80H, #0AAH
```

writes 0AA_H to Port 0 which is one of the SFRs and the instruction

```
MOV R0, #80H
```

```
MOV @R0, #0BBH
```

writes 0BB_H in location 80_H of data RAM. Thus, after execution of both of the above instructions Port 0 will contain 0AA_H and location 80_H of the RAM will contain 0BB_H.

Note that stack operations are examples of indirect addressing, so the upper 128 bytes of data RAM are available as stack space in MC96FR116C.

8.2.2 Direct And Indirect Address Area

The 128 bytes of RAM which can be accessed by both direct and indirect addressing can be divided into 3 segments as listed below and shown in Figure 8.3.

Register Bank 0~3 Locations 00_H through 1F_H (32 bytes). ASM-51 and the device after reset default to register bank 0. To use the other register banks the user must select them in the software (refer to

the MCS-51 Micro Assembler User's Guide). Each register bank contains 8 one-byte registers, 0 through 7.

Reset initializes the Stack Pointer to location 07_H and it is incremented once to start from location 08_H which is the first register (R0) of the second register bank. Thus, in order to use more than one register bank, the SP should be initialized to a different location of the RAM where it is not used for data storage (ie, higher part of the RAM).

Bit Addressable Area 16 bytes have been assigned for this segment, 20_H~2F_H. Each one of the 128 bits of this segment can be directly addressed (00_H~7F_H).

The bits can be referred to in two ways both of which are acceptable by the ASM-51. One way is to refer to their addresses, ie. 00_H to 7F_H. The other way is with reference to bytes 20_H to 2F_H. Thus, bits 0_H~7_H can also be referred to as bits 20.0~20.7, and bits 8_H~F_H are the same as 21.0~21.7 and so on.

Scratch Pad Area Bytes 30_H through 7F_H are available to the user as data RAM. However, if the stack pointer has been initialized to this area, enough number of bytes should be left aside to prevent SP data destruction.

8.2.3 Special Function Registers

All I/O and peripherals operation for the MC96FR116C accessed via Special Function Registers (SFRs). These registers occupy direct Internal Data Memory space locations in the range 80_H to FF_H. Their names and addresses are given in the Table 8.9. Note these SFRs are implemented using flip-flops within the core, not as RAM.

The MC96FR116C has special registers which are provided by M8051 core. These are Program Counter(PC), Accumulator(A), B register(B), the Stack Pointer(SP), the Program Status Word(PSW), general purpose register(R0~R7) and DPTR (Data pointer register).

NOTE There's some address space in the SFRs which are not implemented. Reading these address space may return arbitrary value, and writing to these reserved SFR address may result in un-expected operation. So cautions are needed when accessing reserved address.

Accumulator (ACC) This register provides one of the operands for most ALU operations. It is denoted as 'A' in the instruction table included later in this document. On reset this register returns 00_H.

B register (B) This register provides the second operand for multiply or divide instructions. Otherwise, it may be used as a scratch pad register. On reset this register returns 00_H.

Stack Pointer (SP) The SP register contains the Stack Pointer. The Stack Pointer is used to load the program counter into Internal Data Memory during LCALL and ACALL instructions and to retrieve the program counter from memory during RET and RETI instructions. Data may also be saved on or retrieved from the stack using PUSH and POP instructions. Instructions that manipulate the stack automatically pre-increment or post-decrement the Stack Pointer so that the Stack Pointer always points to the last byte written to the stack, i.e. the top of the stack. On reset the Stack Pointer is set to 07_H.

It falls to the programmer to ensure that the location of the stack in Internal Data Memory does not interfere with other data stored therein.

Program Counter (PC) The Program Counter consists of two 8-bit registers PCH and PCL. This counter indicates the address of the next instruction to be executed. On reset, the program counter is initialized to reset routine address (PCH:00_H, PCL:00_H).

Data Pointer Register (DPTR) The Data Pointer (DPTR) is a 16-bit register which is used to form 16-bit addresses for External Data Memory accesses (MOVX A, @DPTR and MOVX @DPTR, A), for program byte moves (MOVC A, @A+DPTR) and for indirect program jumps (JMP @A+DPTR).

Two true 16-bit operations are allowed on the Data Pointer – load immediate (MOV DPTR, #data) and increment (INC DPTR).

Program Status Word (PSW) The PSW contains several status bits that reflect the current state of the CPU. The PSW, shown in Figure 8.1, resides in SFR space. It contains the Carry bit, the Auxiliary Carry (for BCD operations), the two register bank select bits, the Overflow flag, a Parity bit, and two user-definable status flags.

CY The Carry bit, other than serving the function of a Carry bit in arithmetic operations, also serves as the “Accumulator” for a number of Boolean operations.

AC The Auxiliary Carry bit, this bit is set when there is a carry from bit 3 of ALU or there is no borrow from bit 4 of ALU after operation.

RS0, RS1 The bits RS0 and RS1 are used to select one of the four register banks shown in Figure 8.3. A number of instructions refer to these RAM locations as R0 through R7. The selection of which of the four banks is being referred to is made on the basis of the bits RS0 and RS1 at execution time.

OV Overflow flag. This bit 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(7F_H) or 128(80_H). The CLR V 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.

P The Parity bit reflects the number of 1s in the Accumulator: P=1 if the Accumulator contains an odd number of 1s, and P=0 if the Accumulator contains an even number of 1s. Thus the number of 1s in the Accumulator plus P is always even.

Two bits in the PSW are uncommitted and may be used as general purpose status flags.

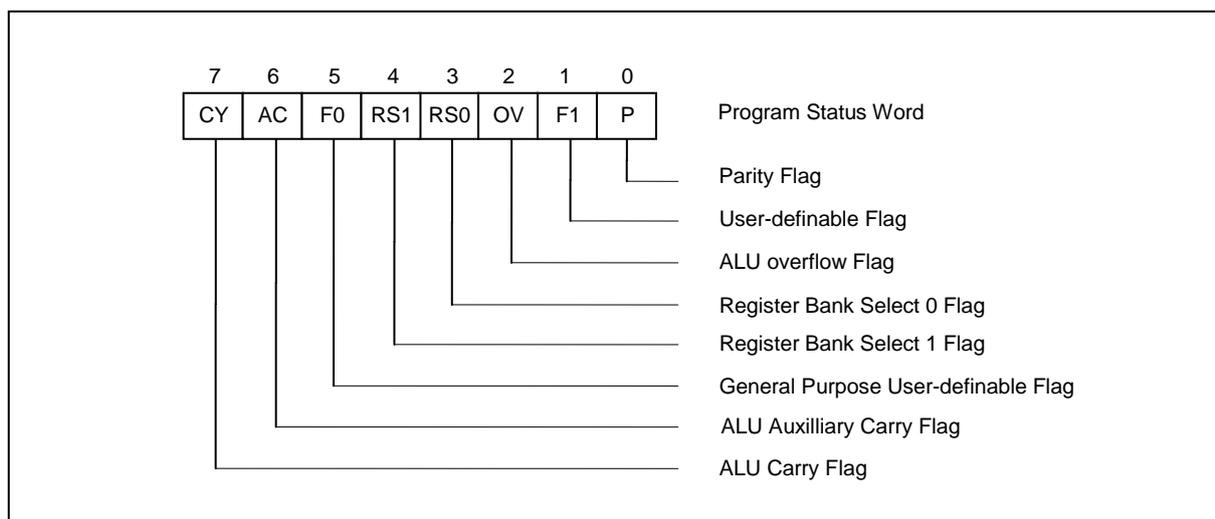


Figure 8-4 PSW Register

8.3 XRAM

There's another kind of RAM called XRAM (External RAM) in MC96FR116C and the size is 2048B, 0000_H through 07FF_H. This address space is assigned to XDATA^{NOTE} region and used for data storage.

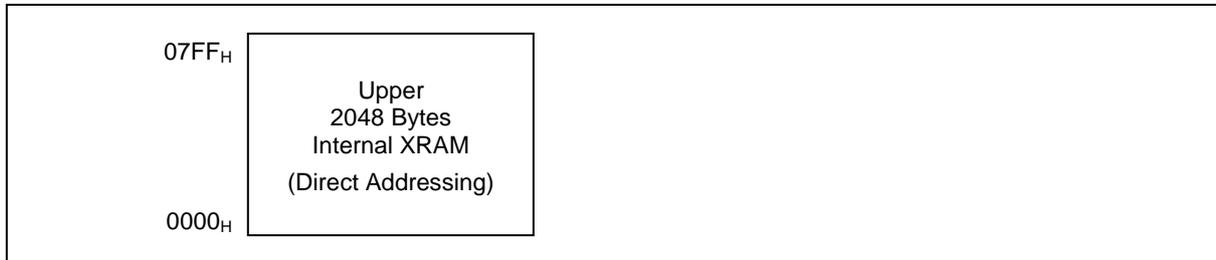


Figure 8-5 DATA MEMORY (XRAM)

^{NOTE} XRAM, 32Bytes of page buffers and some eXtended SFR(XSFR) are assigned to XDATA area in MC96FR116C. And these address space are accessed via MOVX instruction.

8.4 Registers

8.4.1 SFR Map

-	<i>Reserved</i>
	<i>M8051 Compatible</i>

	0H/8H ^{NOTE}	1H/9H	2H/AH	3H/BH	4H/CH	5H/DH	6H/EH	7H/FH
F8 _H	IP1 --00_0000	CFGCR	UCTRL11	UCTRL12	UCTRL13	USTAT1	UBAUD1	UDATA1
F0 _H	B 0000_0000	WTCR0H	WTCR0L	WTCR1H	WTCR1L	WTCR2H	WTCR2L	KITSR
E8 _H	RMR	FARH	FARM	FARL	FCR	FSR	FTCR	MCCR
E0 _H	ACC 0000_0000	FMR	UCTRL01	UCTRL02	UCTRL03	USTAT0	UBAUD0	UDATA0
D8 _H	-	-	-	-	WTDRH	IRCC0	IRCC1	IRCC2
D0 _H	PSW 0000_0000	WTMR	SMRR0	SMRR0	WTR1	WTR0	SRLC0	SRLC1
C8 _H	-	T3CR2	T3CR	T3L/CDR3L/ PWM3DRL	T3H/CDR3H/ /PWM3DRH	T3DRL/PW M3PRL	T3DRH/PW M3PRH	T2L/T2DRL/ CDR2L
C0 _H	-	P0PC 0000_0000	RDBH	RDBL	RDRH	RDRL	T2CR	T2H/T2DRH /CDR2H
B8 _H	IP --00_0000	-	RDCH	CFRH	CFRL	RDCL	RODR	ROB
B0 _H	-	EIENAB	T0CR	T0/CDR0/T0 DR	T1CR	T1DR/ PWM1PR	T1/CDR1/ PWM1DR	PWM1HR
A8 _H	IE 0000_0000	IE1	IE2	IE3	EIFLAG	EIEDGE0	EIEDGE1	EIPOLA
A0 _H	P1IO 0000_0000	-	EO 0000_0000	I2CSDHR	-	I2CDR	I2CSAR	I2CSAR1
98 _H	P0IO 0000_0000	-	-	P3IO 0000_0000	I2CMR	I2CSR	I2CSCLLR	I2CSCLHR
90 _H	-	-	-	-	-	-	-	-
88 _H	P1 0000_0000	-	SCCR	BCCR	BITR	WDTMR	WDTR	BODSR
80 _H	P0 0000_0000	SP 0000_0111	DPL 0000_0000	DPH 0000_0000	-	-	BODR 1100_1001	PCON 0000_0000

Table 8-1 SFR Map

^{NOTE} These registers are bit-addressable.

Caution : Writing to reserved registers may result in un-expected function.

8.4.2 XSFR Map

 Page Buffer (32Bytes)

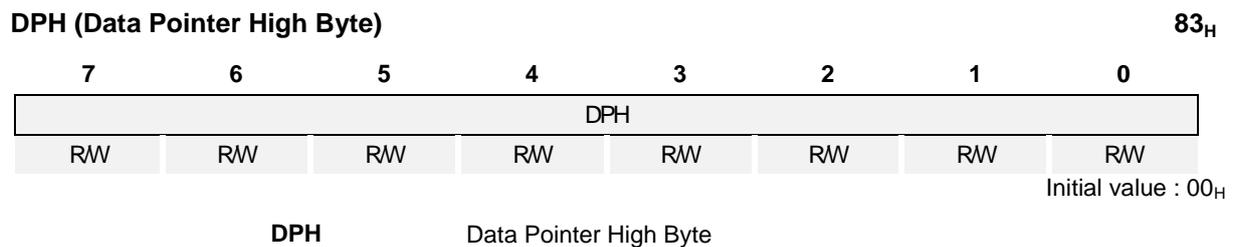
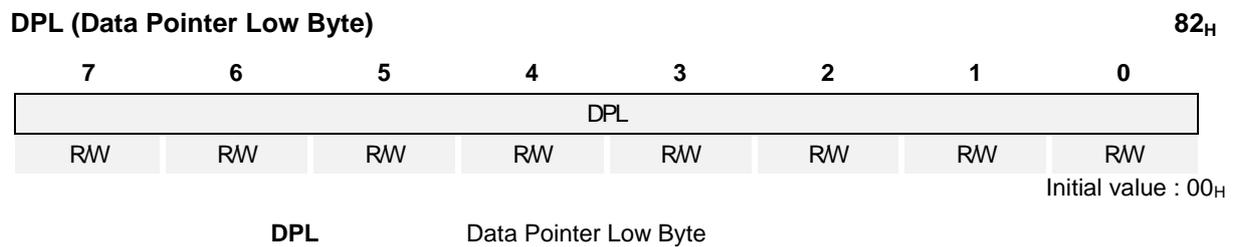
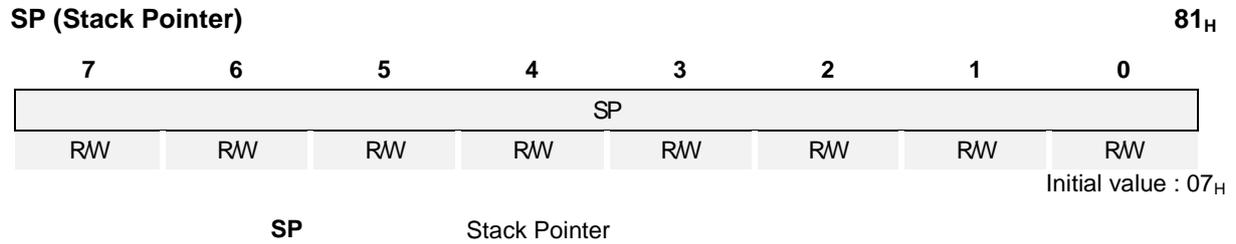
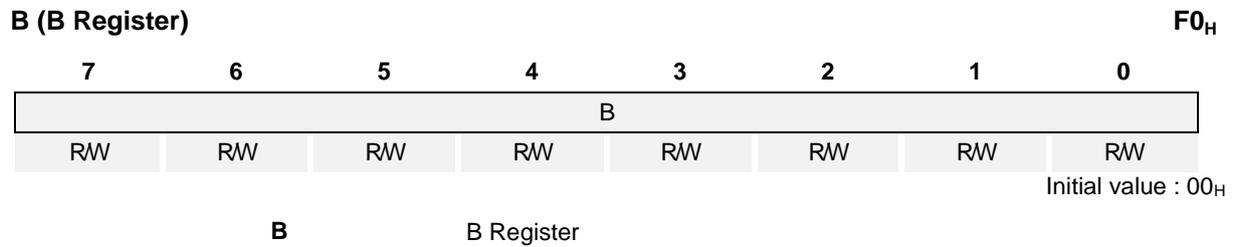
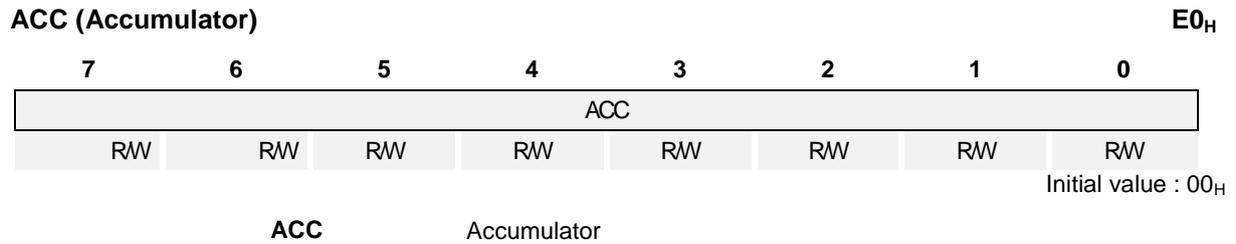
	0H/8H	1H/9H	2H/AH	3H/BH	4H/CH	5H/DH	6H/EH	7H/FH
8020 _H								
8018 _H	PBUF_18	PBUF_19	PBUF_1A	PBUF_1B	PBUF_1C	PBUF_1D	PBUF_1E	PBUF_1F
8010 _H	PBUF_10	PBUF_11	PBUF_12	PBUF_13	PBUF_14	PBUF_15	PBUF_16	PBUF_17
8008 _H	PBUF_08	PBUF_09	PBUF_0A	PBUF_0B	PBUF_0C	PBUF_0D	PBUF_0E	PBUF_0F
8000 _H	PBUF_00	PBUF_01	PBUF_02	PBUF_03	PBUF_04	PBUF_05	PBUF_06	PBUF_07
2F68 _H	FSUBA0		FSUTA1	FSUTA0	FSCtrl			
2F60 _H		FSLBA1	FSLBA0		FSLTA1	FSLTA0		FSUBA1
		-	-	-	-	-	-	-
2F50 _H	P0BPC	P1BPC	-	-	-	-	RMR2	-
2F18 _H	EIPS0	EIPS1	EIPS2	EIPS3	EIPS4	EIPS5		
2F10 _H		PMISC0	PMISC1					
2F08 _H	P0OD --00_0000	P1OD ----_000			-	-	-	CSUMH
2F00 _H	P0PU --00_0000	P1PU ----_000			-	-	CSUML	CSUMM

Table 8-2 eXtended SFR Map

Caution : Writing to reserved registers may result in un-expected function.

8.4.3 Compiler Compatible SFR

Refer to section 8.2.3 for detailed description of these registers.



PSW (Program Status Word)

D0_H

7	6	5	4	3	2	1	0
CY	AC	F0	RS1	RS0	OV	F1	P
RW	RW	RW	RW	RW	RW	RW	RW

Initial value : 00_H

CY	Carry Flag. Receives carry out from bit 1 for ALU operands.
AC	Auxiliary Carry Flag. Receives carry out from bit 1 of addition operands.
F0	General Purpose Status Flag
RS1	Register Bank Selection bit 1
RS0	Register Bank Selection bit 0
OV	Overflow Flag. Set by arithmetic operations.
F1	User-definable Flag
P	Parity of ACC. Set by hardware to 1 if it contains an odd number of 1s, otherwise it is reset to 0.

EO (Extended Operation Register)

A2_H

7	6	5	4	3	2	1	0
-	-	-	TRAP_EN	-	DPSEL2	DPSEL1	DPSEL0
R	R	R	RW	R	RW	RW	RW

Initial value : 00_H

TRAP_EN	Select the instruction between software TRAP and MOVC @(DPTR++), A.		
0	Select MOVC @(DPTR++), A instruction.		
1	Select software TRAP instruction.		
DPSEL[2:0]	Select DPT R.		
DPSEL2	DPSEL1	DPSEL0	
0	0	0	DPTR0 selected.
0	0	1	DPTR1 selected.
0	1	0	DPTR2 selected (if included).
0	1	1	DPTR3 selected (if included).
1	0	0	DPTR4 selected (if included).
1	0	1	DPTR5 selected (if included).
1	1	0	DPTR6 selected (if included).
1	1	1	DPTR7 selected (if included).

9. I/O PORTS

9.1 Introduction

The MC96FR116C has four I/O ports (P0, P1, P2, P3). Each port can be easily configured by software whether to use internal pull up resistor or not, whether to use open drain output or not, or whether the pin is input or output. Also P0 includes function that can generate interrupt when the state of P0 changes.

9.2 Register Description

9.2.1 Data Register (Px)

Data Register is a bidirectional I/O port. If ports are configured as output ports, data can be written to the corresponding bit in the Px. If ports are configured as input ports, the port value can be read from the corresponding bit in the Px.

9.2.2 Direction Register (PxIO)

The PxnIO bit in the PxIO register selects the direction of this pin. If PxnIO is written logic one, Pxn is configured as an output pin. If PxnIO is written logic zero, Pxn is configured as an input pin. All bits are cleared by a system reset.

9.2.3 Pull-up Resistor Selection Register (PxPU)

All ports P0, P1, P2, P3 have optional internal pull-ups. The PxnPU bit in the PxPU register allows the use of pull-up resistor. If PxnPU is written logic one, the pull-up resistor is activated. If PxnPU is written logic zero, the pull-up resistor is deactivated. When the port is configured as an input port, internal pull-up is deactivated regardless of the PxnPU bit. After reset, all pull-up resistors are switched off except those of P3[5:2]. According to PKG types, some of these ports are omitted, so to maintain input status, the internal pull-ups for these ports are activated.

9.2.4 Open-drain Selection Register (PxOD)

The PxnOD bit in the PxOD register controls the port type when configured as an output port. If PxnOD is written logic one, the port becomes open-drain type. If PxnOD is written logic zero, the port becomes push-pull type. After reset, open-drain function is disabled.

Caution : Port 0 has no open drain control register.

9.2.5 Pull-up Control Register (PxBPC)

When the external VDD drops below the V_{BODR} level, the ports can be selectively configured as input ports with pull-up resistors activated regardless of the PxnIO. In this case, the port direction is changed by hardware automatically. If PxnBPC is written logic one, this function is enabled. If PxnBPC is written logic zero, the port maintain its status even if the external VDD is fallen below the V_{BODR} level.

9.2.6 Pin Change Interrupt Enable Register (P0PC)

P0 port support Pin Change Interrupt (PCI) function. Pin Change Interrupt will trigger if any pin changes its status when P0nPC is set to 1. At reset, PCI function is disabled for all P0 pins.

9.2.7 Register Map

Name	Address	Dir	Default	Description
P0	80 _H	R/W	00 _H	P0 Data Register
P0IO	98 _H	R/W	00 _H	P0 Direction Register
P0PU	2F00 _H	R/W	00 _H	P0 Pull-up Resistor Selection Register
P1OD	2F08 _H	R/W	00 _H	P0 Open-drain Selection Register
P0BPC	2F50 _H	R/W	00 _H	P0 Pull-up Control Register
P0PC	C1 _H	R/W	00 _H	P0 Pin Change Interrupt Enable Register
P1	88 _H	R/W	00 _H	P1 Data Register
P1IO	A0 _H	R/W	00 _H	P1 Direction Register
P1PU	2F01 _H	R/W	00 _H	P1 Pull-up Resistor Selection Register
P1OD	2F09 _H	R/W	00 _H	P1 Open-drain Selection Register
P1BPC	2F51 _H	R/W	00 _H	P1 Pull-up Control Register
PMISC0	2F11 _H	R/W	00 _H	Port Miscellaneous 0 Register
PMISC1	2F12 _H	R/W	00 _H	Port Miscellaneous 1 Register

Table 0-1 Register Map of Port

9.2.8 PORT 0

P0 (P0 Data Register)

80_H

7	6	5	4	3	2	1	0
P07	P06	P05	P04	P03	P02	P01	P00
R/W							

Initial value : 00_H

P0[7:0] I/O Data

P0IO (P0 Direction Register)

98_H

7	6	5	4	3	2	1	0
P07IO	P06IO	P05IO	P04IO	P03IO	P02IO	P01IO	P00IO
R/W							

Initial value : 00_H

P0IO[7:0] P0 Direction
 0 Input
 1 Output

P0PU (P0 Pull-up Resistor Selection Register)

2F00_H

7	6	5	4	3	2	1	0
P07PU	P06PU	P05PU	P04PU	P03PU	P02PU	P01PU	P00PU
R/W							

Initial value : 00_H

P0PU[7:0] P0 Pull-up Control
 0 Disable pull-up
 1 Enable pull-up

P0OD (P0 Open-drain Selection Register)

2F08_H

7	6	5	4	3	2	1	0
P07OD	P06OD	P05OD	P04OD	P03OD	P02OD	P01OD	P00OD
R/W							

Initial value : 00_H

P0OD[7:0] Control P0 port type when configured as output port.
 0 Push-pull type output drive
 1 Open-drain type output drive

P0BPC (P0 Pull-up Control Register)

2F50_H

7	6	5	4	3	2	1	0
P07BPC	P06BPC	P05BPC	P04BPC	P03BPC	P02BPC	P01BPC	P00BPC
R/W							

Initial value : 00_H

P0BPC[7:0] Control port direction and use of internal pull-up resistor when external VDD drops below V_{BODR} level.
 0 Maintain its previous state (input or output)

1 Changed to input port and pull-up resistor is activated

P0PC (P0 Pin Change Interrupt Enable Register)

C1_H

7	6	5	4	3	2	1	0
P07PC	P06PC	P05PC	P04PC	P03PC	P02PC	P01PC	P00PC
RW							

Initial value : 00_H

P0PC[7:0] Control Pin Change Interrupt function
 0 Disable PCI function
 1 Enable PCI function

9.2.9 PORT 1

P1 (P1 Data Register)

88_H

7	6	5	4	3	2	1	0
P17	P16	P15	P14	P13	P12	P11	P10
RW							

Initial value : 00_H

P1[7:0] I/O Data

P1IO (P1 Direction Register)

A0_H

7	6	5	4	3	2	1	0
P17IO	P16IO	P15IO	P14IO	P13IO	P12IO	P11IO	P10IO
RW							

Initial value : 00_H

P1IO[7:0] P1 Direction
 0 Input
 1 Output

P1PU (P1 Pull-up Resistor Selection Register)

2F01_H

7	6	5	4	3	2	1	0
P17PU	P16PU	P15PU	P14PU	P13PU	P12PU	P11PU	P10PU
RW							

Initial value : 00_H

P1PU[7:0] P1 Pull-up Control
 0 Disable pull-up
 1 Enable pull-up

P1OD (P1 Open-drain Selection Register)

2F09_H

7	6	5	4	3	2	1	0
P17OD	P16OD	P15OD	P14OD	P13OD	P12OD	P11OD	P10OD
RW							

Initial value : 00_H

P1OD[7:0] Control P1 port type when configured as output port.
 0 Push-pull type output drive
 1 Open-drain type output drive

P1BPC (P1 Pull-up Control Register)

2F51_H

7	6	5	4	3	2	1	0
P17BPC	P16BPC	P15BPC	P14BPC	P13BPC	P12BPC	P11BPC	P10BPC
RW							

Initial value : 00_H

P1BPC[7:0] Control port direction and use of internal pull-up resistor when external VDD drops below V_{BODR} level.
 0 Maintain its previous state (input or output)
 1 Changed to input port and pull-up resistor is activated

9.2.10 PORT Miscellaneous

PMISC0 (Port Miscellaneous 0 Register)

2F11_H

7	6	5	4	3	2	1	0
-	-	-	-	-	-	TRODEN	TRPPEN
R	R	R	R	R	R	RW	RW

Initial value : 00_H

TRPPEN REMOUT push-pull transistor control
 0 REMOUT push-pull transistor is disabled
 1 REMOUT push-pull transistor is enabled

TRODEN REMOUT open-drain transistor control
 0 REMOUT open-drain transistor is disabled
 1 REMOUT open-drain transistor is enabled

PMISC1 (Port Miscellaneous 0 Register)

2F12_H

7	6	5	4	3	2	1	0
-	-	-	TRST1	TRST0	IRPUST2	IRPUST2	IRPUST2
R	R	R	RW	RW	RW	RW	RW

Initial value : 00_H

IRPUST IR learning pull-up strength control
 000 Disable
 001 30 K Ω
 010 35 K Ω
 011 40 K Ω
 100 45 K Ω
 101 50 K Ω
 110 55 K Ω
 111 60 K Ω

TRODST	REMOUT open-drain transistor strength selection	
00	X4	
01	X3	
10	X2	
11	X1	

10. Interrupt Controller

10.1 Overview

The interrupt controller has the following features to handle interrupt request from internal peripherals or external pins.

- support up to 21 interrupt sources ^{NOTE}
- 6 group of 4 priority level
- multiple interrupts handling
- global enable by EA bit and selective control by IEx bit
- Interrupt latency : 3~9 machine cycles in single interrupt system

^{NOTE} Interrupt controller can accept up to 24 interrupt sources, but there are only 19 interrupt sources in MC96FR116C.

Interrupt controller has 4 Interrupt Enable Registers (IE, IE1, IE2, IE3) and 2 Interrupt Priority Registers (IP, IP1). There are 16 interrupt sources in MC96FR116C and overall control is done by EA bit in IE register. When EA is set to 0, all interrupt requests are ignored. When EA is set to 1, each interrupt request is accepted or not by INTnE bit in IEx registers. 16 interrupt sources are assigned to 6 groups and each group can have different priority according to IP and IP1 registers.

By default all interrupt sources are level-triggered, but external interrupts can be set to operate in edge-trigger mode. If more than 2 interrupts of different group priority are requested almost at the same time, the request of higher priority is serviced first. And among the requests of same priority, an internal polling sequence determines which request is serviced, ie, the interrupt having lower priority number in Table 10-2 is serviced first. Even in interrupt service routine, another interrupt of higher priority can interrupt the execution of service routine for the lower priority by software configuration.

Interrupt Group	Highest Lowest			
	→			
0 (Bit0)	Interrupt0	Interrupt6	Interrupt12	Interrupt18
1 (Bit1)	Interrupt1	Interrupt7	Interrupt13	Interrupt19
2 (Bit2)	Interrupt2	Interrupt8	Interrupt14	Interrupt20
3 (Bit3)	Interrupt3	Interrupt9	Interrupt15	Interrupt21
4 (Bit4)	Interrupt4	Interrupt10	Interrupt16	Interrupt22
5 (Bit5)	Interrupt5	Interrupt11	Interrupt17	Interrupt23

Highest

↓

Lowest

Table 10-1 Interrupt Group and Default Priority

10.2 External Interrupt

The External Interrupts are triggered by the INT0, INT1, INT2, INT3, INT4 and INT5 pins. The External Interrupts can be triggered by a falling or rising edge or a low or high level. The trigger mode and trigger level is controlled by External Interrupt Edge Register (EIEDGEx) and External Interrupt Polarity Register (EIPOLA). When the external interrupt is enabled and is configured as level triggered, the interrupt will trigger as long as the pin is held low or high. External interrupts are detected asynchronously. This implies that these interrupts can be used for wake-up sources from stop mode. The interrupt requests from INT0, INT1, INT2, INT3, INT4 and INT5 pins can be monitored through the External Interrupt Flag Register (EIFLAG).

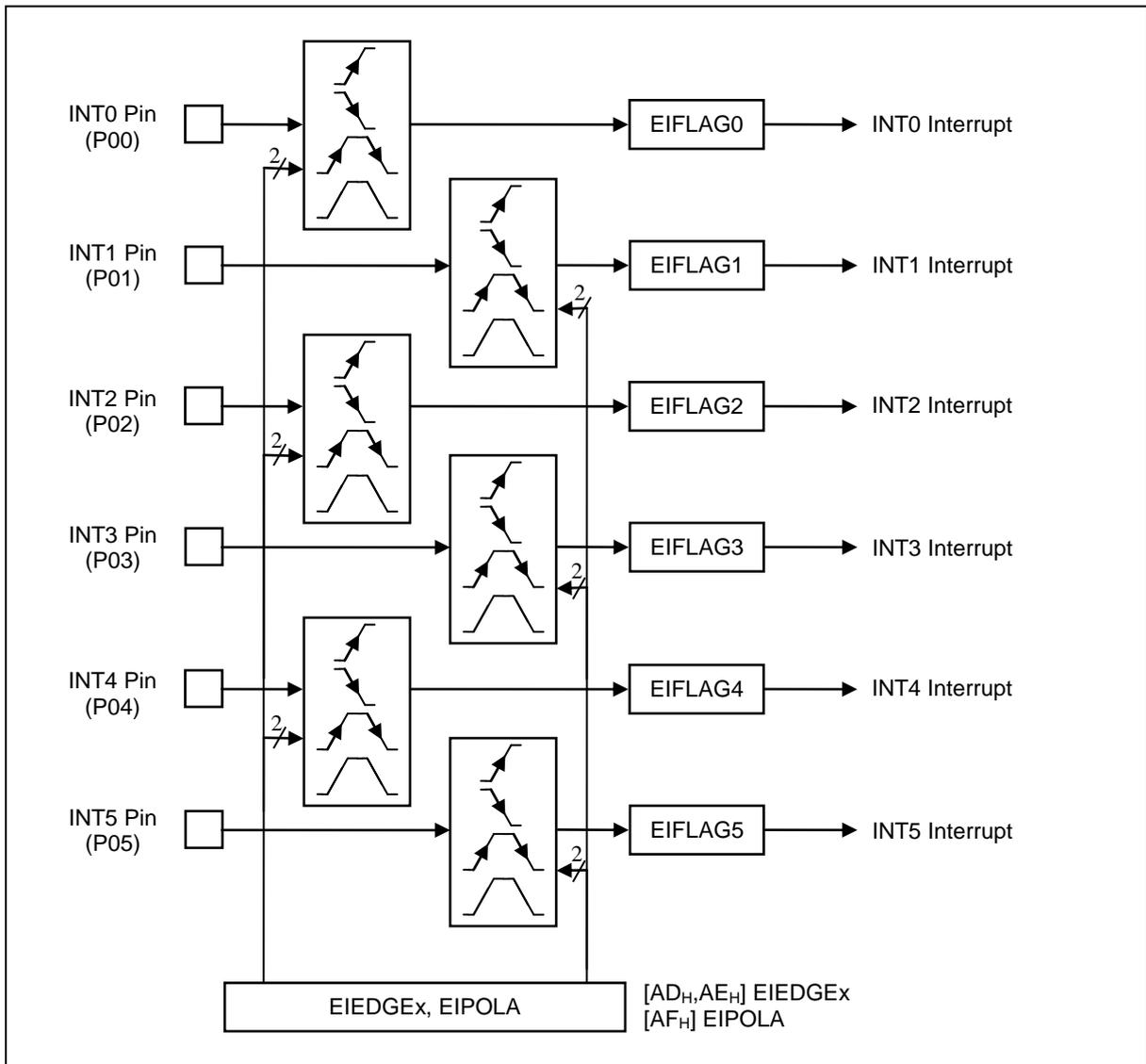


Figure 10-1 External Interrupt trigger condition

10.3 Block Diagram

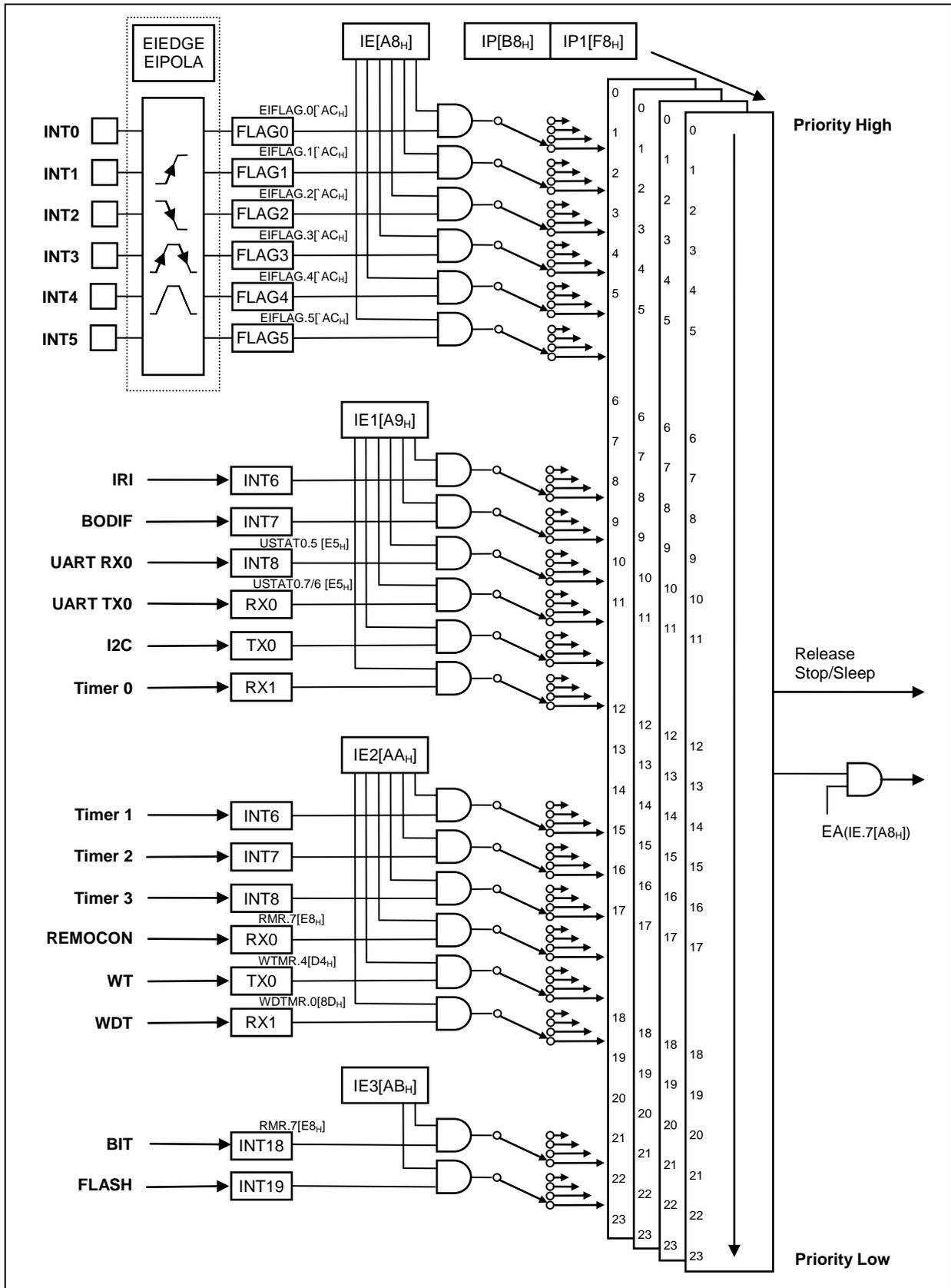


Figure 10-2 Block Diagram of Interrupt Controller

10.4 Interrupt Vectors

There are 16 interrupt sources which are from internal peripherals or from external pin inputs. When a interrupt is requested while EA bit in IE register and its individual enable bit INTnE in IEx register is set, the CPU executes a long call instruction (LCALL) to the vector address listed in Table 10-2. As can be seen in the table, all interrupt vector has 8 bytes address space except for reset vector. If priority level is not set by user software, the interrupt sources have default priority as in the following table, and the lower number has the higher priority.

Interrupt Source	Symbol	Interrupt Enable Bit	Priority	Mask	Vector Address
Hardware Reset	RESETB	Always	0	Non-Maskable	0000 _H
External Interrupt 0	INT0	IE0.0	1	Maskable	0003 _H
External Interrupt 1	INT1	IE0.1	2	Maskable	000B _H
External Interrupt 2	INT2	IE0.2	3	Maskable	0013 _H
External Interrupt 3	INT3	IE0.3	4	Maskable	001B _H
External Interrupt 4	INT4	IE0.4	5	Maskable	0023 _H
External Interrupt 5	INT5	IE0.5	6	Maskable	002B _H
IRI	INT6	IE1.0	7	Maskable	0033 _H
BOD Flag	INT7	IE1.1	8	Maskable	003B _H
USART RX0	INT8	IE1.2	9	Maskable	0043 _H
USART TX0	INT9	IE1.3	10	Maskable	004B _H
I2C	INT10	IE1.4	11	Maskable	0053 _H
T0	INT11	IE1.5	12	Maskable	005B _H
T1	INT12	IE2.0	13	Maskable	0063 _H
T2	INT13	IE2.1	14	Maskable	006B _H
T3	INT14	IE2.2	15	Maskable	0073 _H
REMOCON	INT15	IE2.3	16	Maskable	007B _H
WT	INT16	IE2.4	17	Maskable	0083 _H
WDT	INT17	IE2.5	18	Maskable	008B _H
BIT	INT18	IE3.0	19	Maskable	0093 _H
FLASH	INT19	IE3.1	20	Maskable	009B _H
KEYSCAN	INT20	IE3.2	21	Maskable	00A3 _H
Pin Change Interrupt (P0)	INT21	IE3.3	22	Maskable	00AB _H

Table 10-2 Reset and Interrupt Vectors Placement

To activate a interrupt request, both EA bit in IE register and INTnE bit in IEx register are enabled. When a interrupt is generated, the interrupt flag can be read through each status register. And almost interrupt flags are automatically cleared when their interrupt is executed. These kinds of interrupts are BIT, WDT, TIMER0/1/2/3, I2C, Watch Timer, USART RX/TX, REMOCON, KEYSCAN, Pin Change, and External Interrupt 0/1/2/3/4/5. FLASH Interrupts have no flag bit, so these interrupts cannot be used in polling mode.

10.5 Interrupt Sequence

When a interrupt occurs, the flag is stored to the status register which belongs to the interrupt source. An interrupt request is preserved until the request is accepted by CPU or cleared to '0' by a reset or an instruction.^{NOTE} The CPU accepts a interrupt request at the last cycle of current instruction. So instead of executing the instruction being fetched, the CPU executes internally a LCALL instruction and saves the PC to the stack region. At the same time the interrupt controller hands over the address of LJMP instruction to the service routine, which is used by the CPU. It takes 3 to 9 cycles to finish current instruction and jump to the interrupt service routine. After executing the service routine,

the program address is retrieved from the stack by executing RETI instruction to restart from the position where the interrupt is accepted. The following figure shows the sequence.

^{NOTE} Interrupt flags due to USART TX and FLASH are not auto-cleared when the CPU accepts the request.

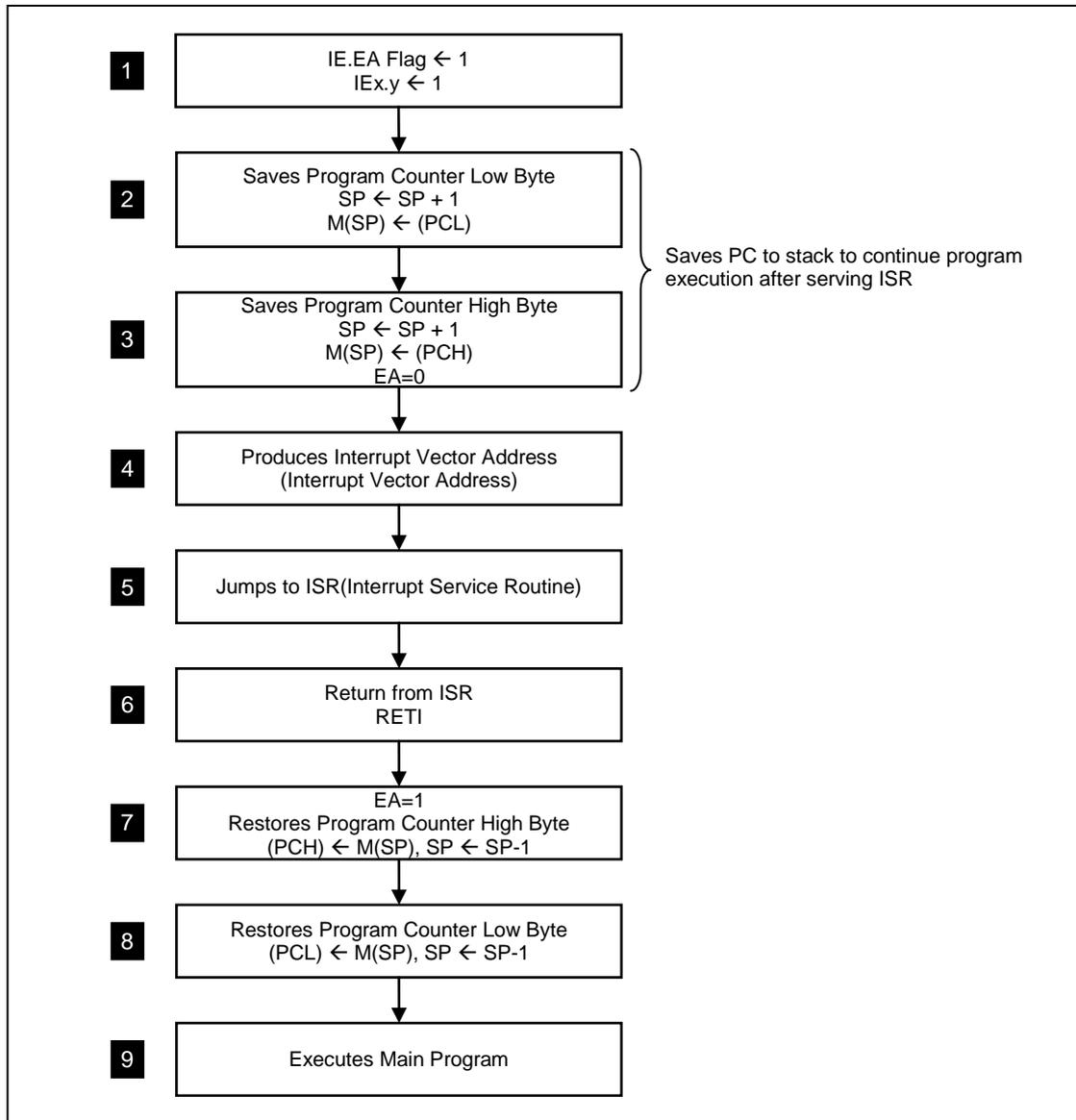


Figure 10-3 Sequence of Interrupt handling

10.6 Effective time of Interrupt Request

To activate interrupt request from interrupt sources, both EA bit in IE register and individual enable bit INTnE in IEx register must be enabled. At this time, the effective time of interrupt request after setting control registers is as follows.

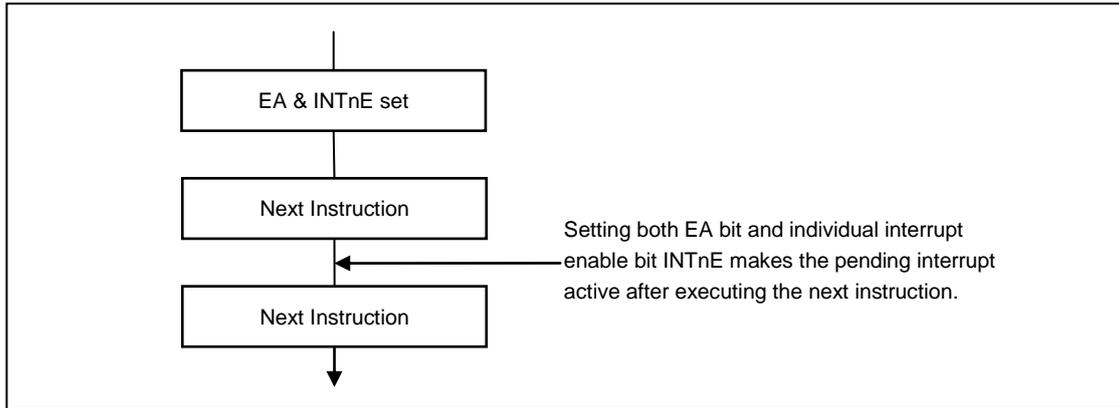


Figure 10-4 Effective time of interrupt request after setting IEx registers

10.7 Multiple Interrupts

If more than two interrupts are requested simultaneously, one of higher priority level is serviced first and others remain pending. Among pending interrupts, the interrupt of second highest priority is serviced next after executing current interrupt service.

In addition, as shown in Figure 10-6, another interrupt request can be serviced while servicing previously requested interrupt. In this case, interrupt requested later must have higher priority level and the interrupt handler should allow another interrupt request.

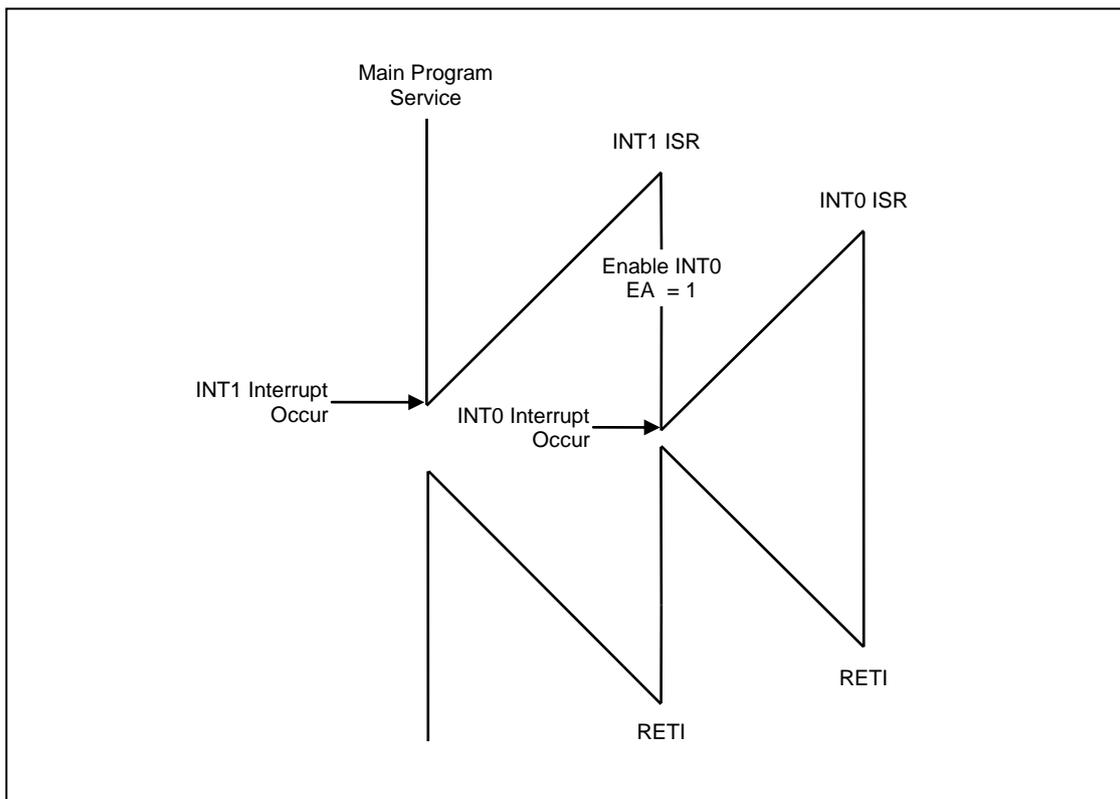


Figure 10-5 Accept of another interrupt request in interrupt service routine

The following example shows how to allow INT0 interrupt request while executing INT1 interrupt service routine. In this example, INT0 has higher group priority than INT1 interrupt according to IPO,

IP1 registers. Other interrupts having lower group priority than INT0 cannot be serviced until INT0 service routine is finished even if the INT0 interrupt handler allows those interrupt requests.

Example) Software Multi Interrupt

```

INT1 :   MOV    IE, #01H    ;Enable INT0 only
        MOV    IE1, #00H   ;Disable other interrupts
        SETB   EA
        :
        MOV    IE, #0FFH   ;Enable all Interrupts
        MOV    IE1, #0FFH
        RETI

```

In short, an interrupt service routine may only be interrupted by an interrupt of higher priority than being serviced. And when more than two interrupts are requested at the same time, the one of highest priority is serviced first.

10.8 Interrupt Service Procedure

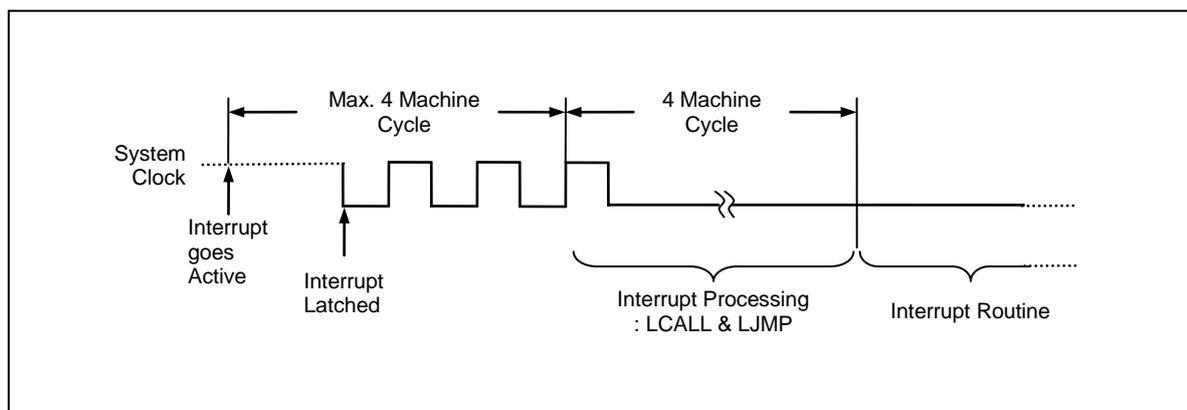


Figure 10-6 Interrupt Request and Service Procedure

10.9 Generation of Branch Address to Interrupt Service Routine(ISR)

The following figure shows the relationship between the vector address of BIT interrupt and the branch address to service routine.

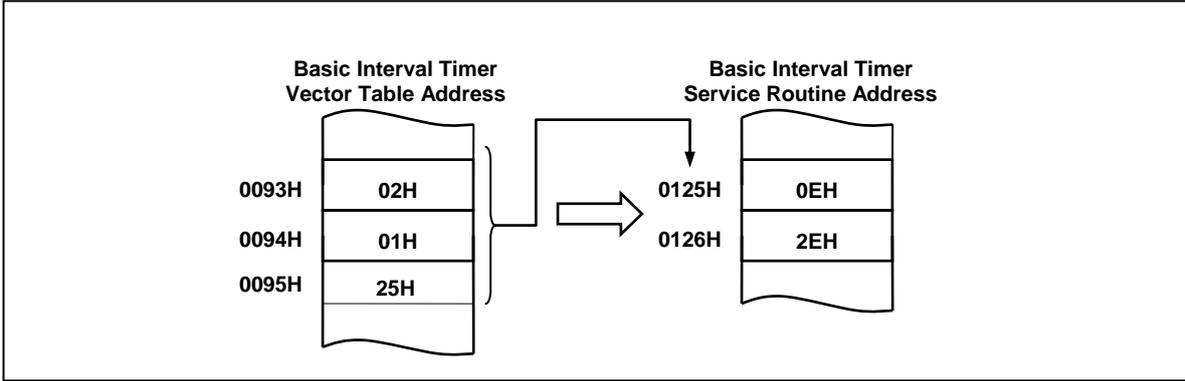


Figure 10-7 Generating branch address to BIT interrupt service routine from vector table

10.10 Saving and Restoring General Purpose Registers

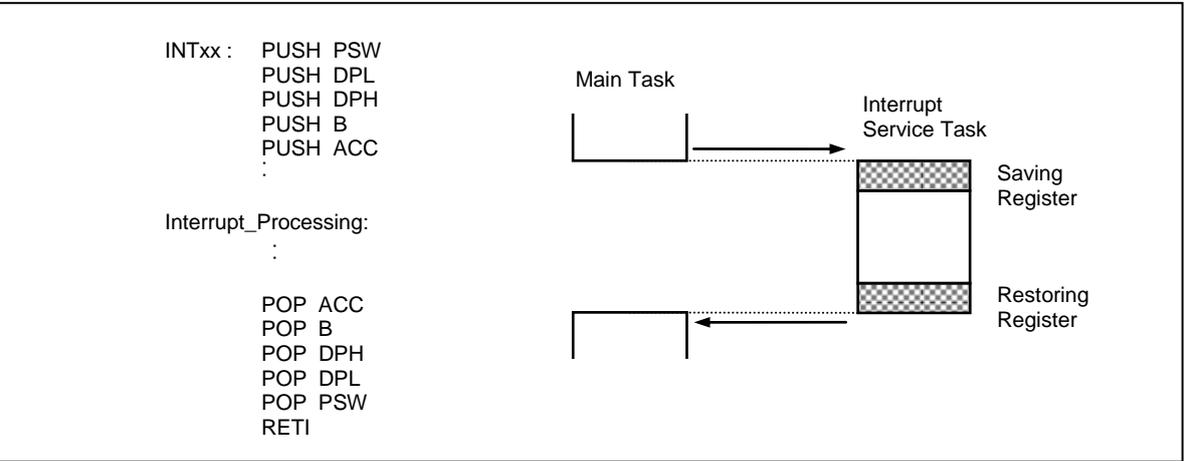


Figure 10-8 Processing General registers while an interrupt is serviced

10.11 Interrupt Timing

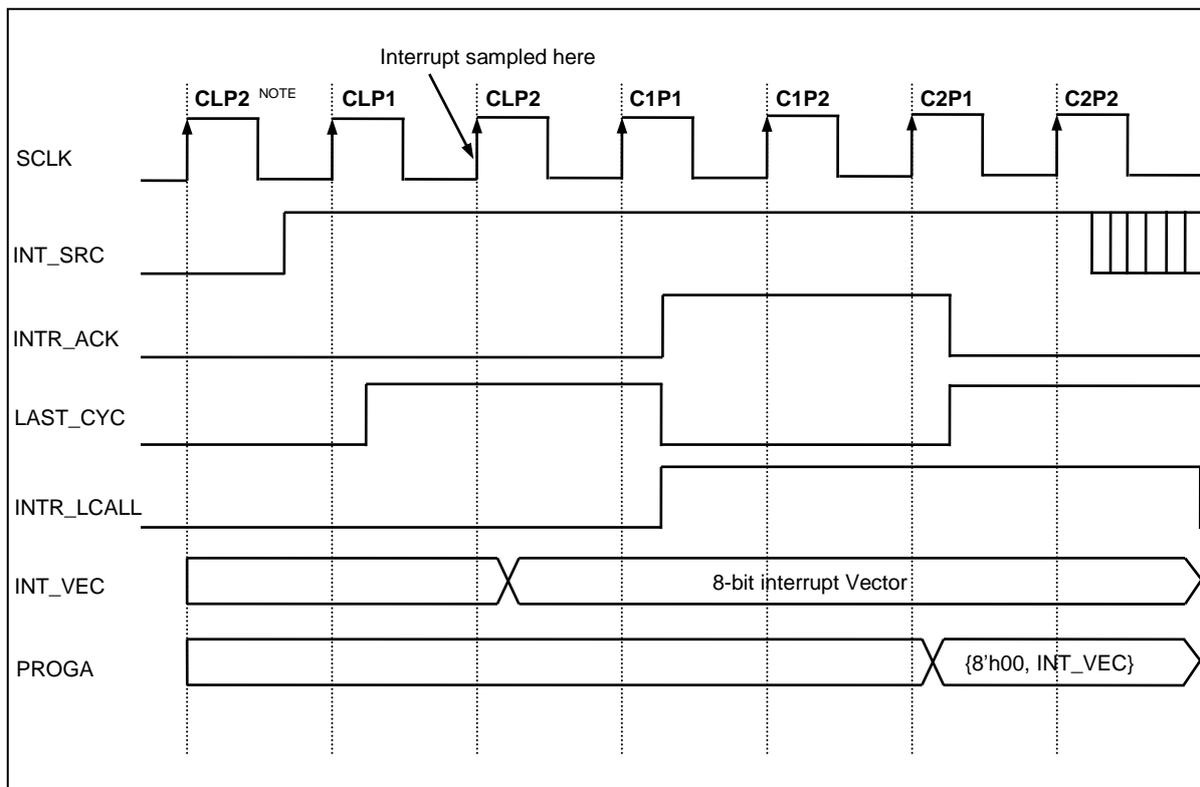


Figure 10-9 Timing chart for Interrupt Accept and Branch Address Generation

The interrupt request is sampled at the last cycle of the command currently being executed. On recognition of interrupt request, the interrupt controller hands over the corresponding lower 8-bit vector address to the CPU, M8051W and the CPU acknowledges the request at the first cycle of the next command to jump to the interrupt vector address.

NOTE command cycle C?P? : L=Last cycle, 1=1st cycle or 1st phase, 2=2nd cycle or 2nd phase

10.12 Interrupt Registers

10.12.1 Register Map

Name	Address	Dir	Default	Description
IE	A8 _H	R/W	00 _H	Interrupt Enable Register
IE1	A9 _H	R/W	00 _H	Interrupt Enable Register 1
IE2	AA _H	R/W	00 _H	Interrupt Enable Register 2
IE3	AB _H	R/W	00 _H	Interrupt Enable Register 3
IP	B8 _H	R/W	00 _H	Interrupt Priority Register
IP1	F8 _H	R/W	00 _H	Interrupt Priority Register 1
EIFLAG	AC _H	R/W	00 _H	External Interrupt Flag Register
EIEDGE0	AD _H	R/W	00 _H	External Interrupt Edge0 Register
EIEDGE1	AE _H	R/W	00 _H	External Interrupt Edge1 Register
EIPOLA	AF _H	R/W	00 _H	External Interrupt Polarity Register
EIENAB	B1 _H	R/W	00 _H	External Interrupt Enable Register
EIPSO	2F18 _H	R/W	00 _H	External Interrupt Port Select 0 Register

EIPS1	2F19 _H	R/W	01 _H	External Interrupt Port Select 1 Register
EIPS2	2F1A _H	R/W	02 _H	External Interrupt Port Select 2 Register
EIPS3	2F1B _H	R/W	03 _H	External Interrupt Port Select 3 Register
EIPS4	2F1C _H	R/W	04 _H	External Interrupt Port Select 4 Register
EIPS5	2F1D _H	R/W	05 _H	External Interrupt Port Select 5 Register

Table 10-3 Register Map of Interrupt Controller

10.12.2 Interrupt Enable Register (IE, IE1, IE2, IE3)

There're 4 interrupt enable registers which are IE, IE1, IE2 and IE3. In IE register, there's two kinds of interrupt enable bits called the global interrupt enable bit, EA, and 6 individual interrupt enable bits, INTnE. Each IE1, IE2 and IE3 register only has 6 individual interrupt enable bits. Totally 16 peripheral and external interrupts are controlled by these registers.

10.12.3 Interrupt Priority Register (IP, IP1)

As described above, each interrupt enable register has 6 individual interrupt enable bits. So, interrupt controller itself can deal up to 24 interrupt sources. These 24 sources are classified into 6 groups by 4 sources. Each group can have 4 level of priority through IP and IP1 registers. The level 3 group interrupt is of the highest priority, and the level 0 group interrupt is of the lowest priority. The initial values of IP and IP1 registers are 00_H. By default, the lower numbered interrupt has the higher priority if group priority is the same. When the group priority is decided by configuring IP and IP1 registers, among 4 interrupt sources within the group, the lower numbered interrupt has the higher priority.

10.12.4 External Interrupt Flag Register (EIFLAG)

External Interrupt Flag Register shows the status of external interrupts. Each flag is set to '1' when a port is configured as a external interrupt source, and the port state changes to equal to the interrupt generating condition according to EIEDGEx and EIPOLA register. To clear each flag, write '0' to corresponding bit position of this register.

10.12.5 External Interrupt Edge Register (EIEDGEx)

External Interrupt Edge Register decides the trigger mode of external interrupt, edge or level mode. To make a external interrupt triggered by a falling or rising edge, write '00_B' to the corresponding bit position. And to make a external interrupt triggered by a low or high level, write '01_B', '10_B' or '11_B' to the corresponding bit position. Initially, all external interrupts are triggered by high level. Note there are 2 bits for each external interrupt pin.

10.12.6 External Interrupt Polarity Register (EIPOLA)

This register has different meaning according to the value set in EIEDGEx register. When a external interrupt is configured to be triggered by a level, the high or low trigger level is selected through this register. When a external interrupt is configured to be triggered by a edge, the value in this register has nothing to do with the triggering edge.

10.12.7 External Interrupt Enable Register (EIENAB)

External Interrupt Enable Register selects each port pin, which has sub function for external interrupt, whether to use as external interrupt pin or normal port pin. When a bit in this register is written '0', the corresponding pin is used as general purpose I/O pin.

10.12.8 External Interrupt Port Selection x Register (EIPSx)

External Interrupt Port Selection x Register selects each port pin with external interrupt source.

.0<= EIPSx <= 7 : external interrupt x port is P0[EIPSx]

.8<= EIPSx <= 15: external interrupt x port is P1[EIPSx-8]

10.12.9 Register Description

IE (Interrupt Enable Register)

A8_H

7	6	5	4	3	2	1	0
EA	-	INT5E	INT4E	INT3E	INT2E	INT1E	INT0E
RW	R	RW	RW	RW	RW	RW	RW

Initial value : 00_H

EA	Global Interrupt Enable Bit
0	Ignore interrupt request from any interrupt source.
1	Accept interrupt request
INT5E	Enable or disable External Interrupt 5
0	Disable
1	Enable
INT4E	Enable or disable External Interrupt 4
0	Disable
1	Enable
INT3E	Enable or disable External Interrupt 3
0	Disable
1	Enable
INT2E	Enable or disable External Interrupt 2
0	Disable
1	Enable
INT1E	Enable or disable External Interrupt 1
0	Disable
1	enable
INT0E	Enable or disable External Interrupt 0
0	Disable
1	enable

IE1 (Interrupt Enable Register 1)**A9_H**

7	6	5	4	3	2	1	0
-	-	INT11E	INT10E-	INT9E	INT8E	INT7E	INT6E
R	R	RW-	RW	RW	RW	RW	RW

Initial value : 00_H

INT11E	Enable or disable Timer 0 Interrupt
0	Disable
1	Enable
INT10E	Enable or disable I2C interrupt
0	Disable
1	Enable
INT9E	Enable or disable USART TX0 Interrupt
0	Disable
1	Enable
INT8E	Enable or disable USART RX0 Interrupt
0	Disable
1	Enable
INT7E	Enable or disable BOD Flag Interrupt
0	Disable
1	Enable
INT6E	Enable or disable IRI Input Interrupt
0	Disable
1	enable

IE2 (Interrupt Enable Register 2)**AA_H**

7	6	5	4	3	2	1	0
-	-	INT17E	INT16E-	INT15E	INT14E	INT13E	INT12E
R	R	RW-	RW	RW	RW	RW	RW

Initial value : 00_H

INT17E	Enable or disable WDT Interrupt
0	Disable
1	Enable
INT16E	Enable or disable Watch Timer Interrupt
0	Disable
1	Enable
INT15E	REMOCON (Carrier generator) Interrupt
0	Disable
1	Enable
INT14E	Enable or disable Timer 3 Interrupt
0	Disable
1	Enable
INT13E	Enable or disable Timer 2 Interrupt
0	Disable
1	enable
INT12E	Enable or disable Timer 1 Interrupt
0	Disable
1	enable

IE3 (Interrupt Enable Register 3)**AB_H**

7	6	5	4	3	2	1	0
-	-	INT23E	INT22E-	INT21E	INT20E	INT19E	INT18E
R	R	RW-	RW	RW	RW	RW	RW

Initial value : 00_H

INT23E	Reserved
0	Disable
1	Enable
INT22E	Reserved
0	Disable
1	Enable
INT21E	Enable or disable Pin Change Interrupt
0	Disable
1	Enable
INT20E	Enable or disable KEYSKAN Interrupt
0	Disable
1	Enable
INT19E	Enable or disable FLASH Interrupt
0	Disable
1	Enable
INT18E	Enable or disable BIT Interrupt
0	Diabile
1	Enable

IP (Interrupt Priority Register)**B8_H**

7	6	5	4	3	2	1	0
-	-	IP5	IP4	IP3	IP2	IP1	IP0
R	R	RW-	RW	RW	RW	RW	RW

Initial value : 00_H**IP1 (Interrupt Priority Register 1)****F8_H**

7	6	5	4	3	2	1	0
-	-	IP15	IP14	IP13	IP12	IP11	IP10
R	R	RW-	RW	RW	RW	RW	RW

Initial value : 00_H

IP[5:0], IP1[5:0]	Select Interrupt Group Priority	
IP1 _x	IP _x	Description
0	0	Group x is of level 0 priority (lowest)
0	1	Group x is of level 1 priority
1	0	Group x is of level 2 priority
1	1	Group x is of level 3 priority (highest)

EIFLAG (External Interrupt Flag Register)**AC_H**

7	6	5	4	3	2	1	0
-	-	FLAG5	FLAG4	FLAG3	FLAG2	FLAG1	FLAG0
R	R	RW	RW	RW	RW	RW	RW

Initial value : 00_H

FLAG[5:0] External interrupt flag bit. To clear a flag, write '0' to each bit position.

0 External Interrupt not occurred
1 External Interrupt occurred

EIEDGE0 (External Interrupt Edge Register)

AD_H

7	6	5	4	3	2	1	0
EDGE3R	EDGE3F	EDGE2R	EDGE2F	EDGE1R	EDGE1F	EDGE0R	EDGE0F
RW-	RW-	RW-	RW	RW	RW	RW	RW

Initial value : 00_H

EDGE_nR Selects the trigger mode of each external interrupt pin. Trigger mode is also affected by the EDGE_nF bit.

0 External interrupt is triggered by level (default)
1 External interrupt is triggered by a rising edge

EDGE_nF Selects the trigger mode of each external interrupt pin. Trigger mode is also affected by the EDGE_nR bit.

0 External interrupt is triggered by level (default)
1 External interrupt is triggered by a falling edge

When EDGE_nR and EDGE_nF bits are set at the same time, an external interrupt is triggered by both rising and falling edge.

AE_H

EIEDGE1 (External Interrupt Edge Register)

7	6	5	4	3	2	1	0
-	-	-	-	EDGE5R	EDGE5F	EDGE4R	EDGE4F
R	R	R	R	RW	RW	RW	RW

Initial value : 00_H

EDGE_nR Selects the trigger mode of each external interrupt pin. Trigger mode is also affected by the EDGE_nF bit.

0 External interrupt is triggered by level (default)
1 External interrupt is triggered by a rising edge

EDGE_nF Selects the trigger mode of each external interrupt pin. Trigger mode is also affected by the EDGE_nR bit.

0 External interrupt is triggered by level (default)
1 External interrupt is triggered by a falling edge

When EDGE_nR and EDGE_nF bits are set at the same time, an external interrupt is triggered by both rising and falling edge.

EIPOLA (External Interrupt Polarity Register)

AF_H

7	6	5	4	3	2	1	0
-	-	POLA5	POLA4	POLA3	POLA2	POLA1	POLA0
R	R	RW-	RW	RW	RW	RW	RW

Initial value : 00_H

POLA[5:0] Selects the trigger level of external interrupt, high or low level.

- When configured as level trigger mode
- 0 External interrupt is triggered by a high level (default)
 - 1 External interrupt is triggered by a low level

EIENAB (External Interrupt Enable Register)

B1_H

7	6	5	4	3	2	1	0
-	-	ENAB3	ENAB3	ENAB3	ENAB2	ENAB1	ENAB0
R	R	RW-	RW	RW	RW	RW	RW

Initial value : 00_H

ENAB[5:0]

Configure each port pin as external interrupt pin input

- 0 The port is not used for external interrupt (default)
- 1 The port is used for external interrupt

EIPS0 (External Interrupt Port Selection 0 Register)

2F18_H

7	6	5	4	3	2	1	0
EIPS07	EIPS06	EIPS05	EIPS04	EIPS03	EIPS02	EIPS01	EIPS00
RW							

Initial value : 00_H

EIPS0[3:0]

Configure external interrupt 0 port pin as some pin

EIPS1 (External Interrupt Port Selection 1 Register)

2F19_H

7	6	5	4	3	2	1	0
EIPS17	EIPS16	EIPS15	EIPS14	EIPS13	EIPS12	EIPS11	EIPS10
RW							

Initial value : 01_H

EIPS1[3:0]

Configure external interrupt 1 port pin as some pin

EIPS2 (External Interrupt Port Selection 2 Register)

2F1A_H

7	6	5	4	3	2	1	0
EIPS27	EIPS26	EIPS25	EIPS24	EIPS23	EIPS22	EIPS21	EIPS20
RW							

Initial value : 02_H

EIPS2[3:0]

Configure external interrupt 2 port pin as some pin

EIPS3 (External Interrupt Port Selection 3 Register)

2F1B_H

7	6	5	4	3	2	1	0
EIPS37	EIPS36	EIPS35	EIPS34	EIPS33	EIPS32	EIPS31	EIPS30
RW							

Initial value : 03_H

EIPS3[3:0]

Configure external interrupt 3 port pin as some pin

2F1C_H

EIPS4 (External Interrupt Port Selection 4 Register)

7	6	5	4	3	2	1	0
EIPS47	EIPS46	EIPS45	EIPS44	EIPS43	EIPS42	EIPS41	EIPS40
R/W							

Initial value : 04_H**EIPS4[3:0]** Configure external interrupt 4 port pin as some pin**EIPS5 (External Interrupt Port Selection 5 Register)****2F1D_H**

7	6	5	4	3	2	1	0
EIPS57	EIPS56	EIPS55	EIPS54	EIPS53	EIPS52	EIPS51	EIPS50
R/W							

Initial value : 05_H**EIPS5[3:0]** Configure external interrupt 5 port pin as some pin

11. Peripheral Units

11.1 Clock Generator

11.1.1 Overview

The clock generator module plays a main role in making a stable operating clock, SCLK. There's only one clock source in MC96FR116C, which is the output of main oscillator, XINCLK, connected to the XIN and XOUT pins. The main clock input XINCLK is divided by 1.5, 2 or 3, and one of the divided clocks is used as internal operating clock, SCLK, according to the DIV[1:0] bits in SCCR register. By default, frequency of SCLK is same as that of XINCLK, ie, divided by 1.

11.1.2 Block Diagram

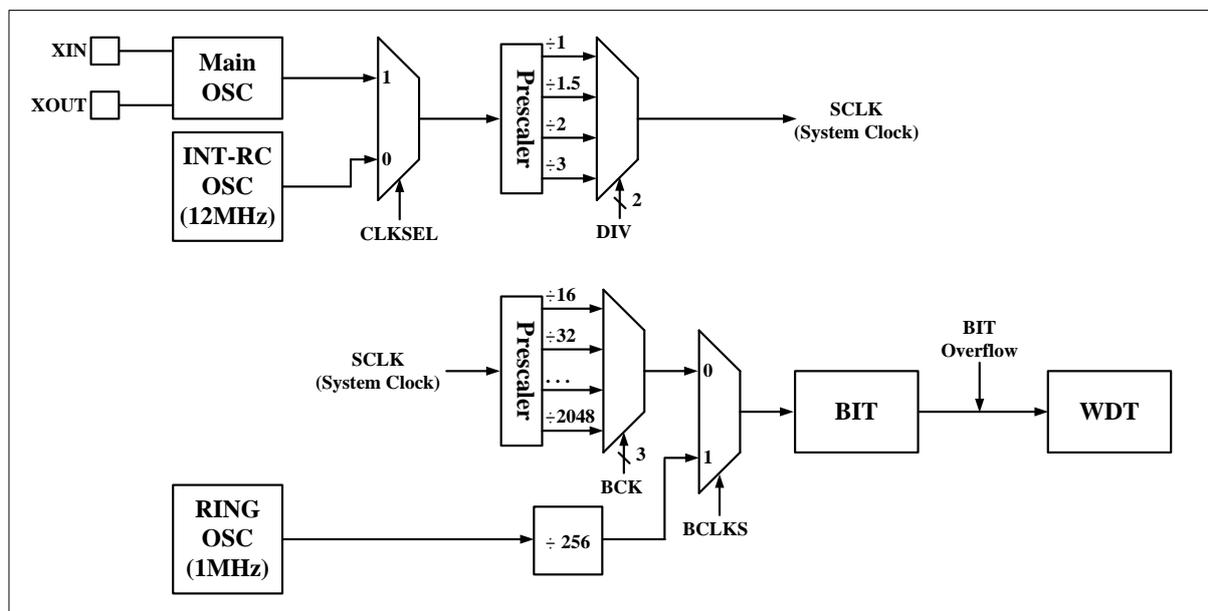


Figure 11-1 Block Diagram of Clock Generator

11.1.3 Register Map

Name	Address	Dir	Default	Description
SCCR	8A _H	R/W	00 _H	System and Clock Control Register
MCCR	EF _H	R/W	33 _H	Main Oscillator Clock Control Register

Table 11-1 Register Map of Clock Generator

11.1.4 Register Description

SCCR (System and Clock Control Register)

8A_H

7	6	5	4	3	2	1	0
ROSCEN	DIV1	DIV0	BCLKS	MOSCEN	IOSCEN	-	CLKSEL
R/W	R/W-	R/W	R/W-	R/W	R/W-	-	R/W

Initial value : 64_H

ROSCEN	The operation of RING Oscillation at stop mode. 0 Ring-Oscillator is disabled at stop mode. 1 Ring-Oscillator is enabled at stop mode.
DIV[1:0]	Selects the divide ratio of operating clock sources, XIN and INT-RC. DIV1 DIV0 Description (in case of $f_{INT-RC}=12\text{MHz}$) 0 0 $f_{XIN} / 1$ (12MHz) 0 1 $f_{XIN} / 1.5$ (8MHz) 1 0 $f_{XIN} / 2$ (6MHz) 1 1 $f_{XIN} / 3$ (4MHz)
BCLKS	BIT clock source selection 0 BIT clock source is system clock. 1 BIT clock source is internal RING oscillator.
MOSCEN	Main oscillator enable 0 Main oscialltor is disable. 1 Main oscillator is enable.
IOSCEN	Internal oscillator enable 0 Internal RC oscialltor is disable. 1 Internal RC oscillator is enable.
CLKSEL	System clock source selection 0 Internal RC oscillator is system clock source. 1 Main oscillator is system clock source.

MCCR (Main Oscillator Clock Control Register)

EF_H

7	6	5	4	3	2	1	0
-	-	ISELM1	ISELM0	-	-	ISEL1	ISEL0
-	-	R	R	-	-	RW	RW

Initial value : 33_H

ISELM[1:0] Monitors the current strength of main oscillator. ISELM is updated with ISEL at the MOSCEN of SCCR is 0 or STOP mode.

ISELM1	ISELM1	Description
0	0	X1
0	1	X2
1	0	X3
1	1	X4

ISEL[1:0] Selects the current strength of main oscillator. The applied time is not ISEL, but ISELM.

ISEL1	ISEL1	Description
0	0	X1
0	1	X2
1	0	X3
1	1	X4

11.2 Basic Interval Timer (BIT)

11.2.1 Overview

BIT module is a 8-bit counter used to guarantee oscillator stabilization time when MC96FR116C is reset or waken from STOP mode. The BIT counter is clocked by a clock divided from system clock(SCLK) and the divide ratio is selected from BCK[2:0] bits in BCCR register, from 16 to 2048. At reset, the BIT counter is clocked by a clock which is divided by 512 from SCLK. If BCLKS of SCCR is set, BIT counter is clocked by a clock which is divided by 1024 from RING oscillator, regardless of BCK[2:0].

BIT is a 8-bit binary counter and has the following features.

- Guarantees the oscillation stabilization time when a power-on or reset occurs
- Guarantees the oscillation stabilization time when this device wakes-from STOP mode
- Generates interval timer interrupt as a watch function

11.2.2 Block Diagram

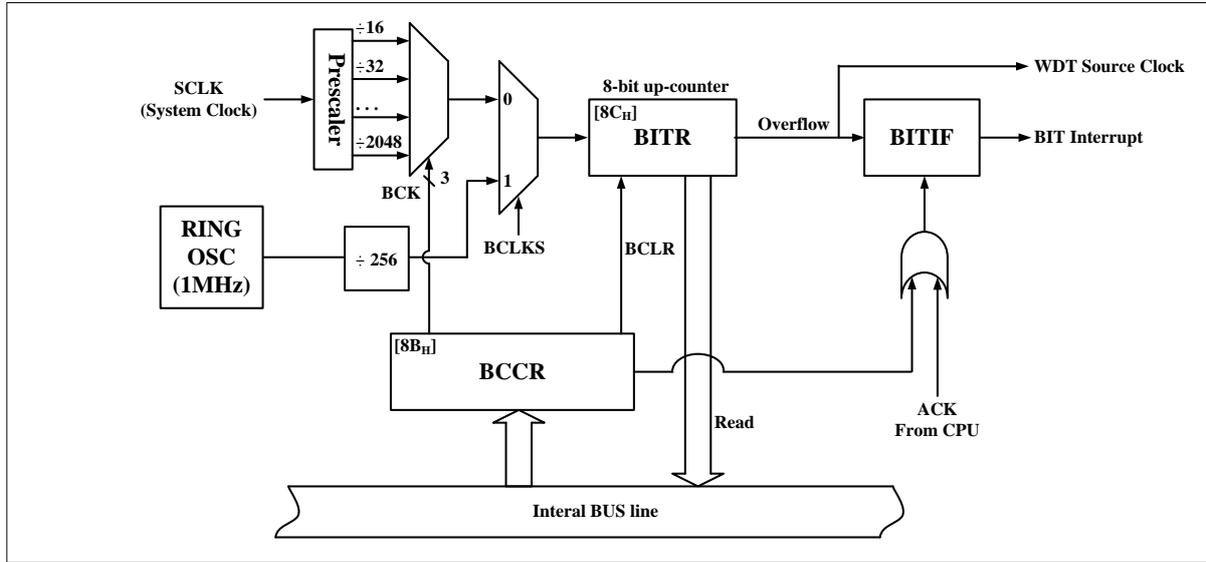


Figure 11-2 Block Diagram of BIT

11.2.3 Register Map

Name	Address	Dir	Default	Description
BCCR	8B _H	R/W	77 _H	BIT Clock Control Register
BITR	8C _H	R	00 _H	Basic Interval Timer Register

Table 11-2 Register Map of BIT

11.2.4 Register Description

BCCR (BIT Clock Control Register)

8B_H

7	6	5	4	3	2	1	0
BITF	BCK2	BCK1	BCK0	BCLR	PRD2	PRD1	PRD0
R/W							

Initial value : 57_H

BITF

Reflects the state of BIT interrupt. To clear this flag, write '0' to this bit position. The BIT interrupt occurs when BIT counter reaches to the pre-defined value. The interrupt interval is decided from BCK[2:0] and PRD[2:0] bits.

0 BIT Interrupt not occurred

1 BIT Interrupt occurred

BCK[2:0]

BCK2	BCK1	BCK0	BIT Clock	BIT Interrupt Period ^{NOTE}
0	0	0	$f_{SYS}/2^4$	1.024ms
0	0	1	$f_{SYS}/2^5$	2.048ms
0	1	0	$f_{SYS}/2^6$	4.096ms
0	1	1	$f_{SYS}/2^7$	8.192ms
1	0	0	$f_{SYS}/2^8$	16.384ms

	1	0	1	$f_{SYS} / 2^9$	32.768ms (default)
	1	1	0	$f_{SYS} / 2^{10}$	65.536ms
	1	1	1	$f_{SYS} / 2^{11}$	131.072ms
BCLR	Clears BIT Counter. Writing '1' to this bit resets BIT counter to 00 _H . BCLR bit is auto cleared.				
	0	BIT counter free runs			
	1	BIT counter is cleared and counter re-starts			
PRD[2:0]	Selects BIT interrupt interval. When BIT counter reaches to the value listed below, an interrupt may be issued. The BIT interrupt period is same as the clock period for WDT counter.				
	PRD2	PRD1	PRD0	Interrupt condition	
	0	0	0	When BITR[0] = 1	
	0	0	1	When BITR[1:0] = 11	
	0	1	0	When BITR[2:0] = 111	
	0	1	1	When BITR[3:0] = 1111	
	1	0	0	When BITR[4:0] = 11111	
	1	0	1	When BITR[5:0] = 111111	
	1	1	0	When BITR[6:0] = 1111111	
	1	1	1	When BITR[7:0] = 11111111 (default)	

^{NOTE} This is the case when the frequency of system clock, f_{SYS} , is 4MHz and the overflow period PRD[2:0] is set to 111_B. If the BCLKS of SCCR is 1, BCK is don't care. And then BIT clock source is 250uS.

The BIT interrupt period is acquired by multiplying clock period of BIT counter and the pre-defined value of BIT counter. That is, $T_{BIT_INT} = T_{BIT_CLK} \times 2^{(PRD[2:0]+1)}$, where T_{BIT_INT} is the interval of BIT interrupt and T_{BIT_CLK} is the clock period of BIT counter.

BITR (Basic Interval Timer Register)

8C_H

7	6	5	4	3	2	1	0
BIT7	BIT6	BIT5	BIT4	BIT3	BIT2	BIT1	BIT0
R	R	R	R	R	R	R	R

Initial value : 00_H

BIT[7:0] BIT counter value

11.3 Watch Dog Timer (WDT)

11.3.1 Overview

The WDT, if enabled, generates an interrupt or a system reset when the WDT counter reaches the given time-out value set in WDTR. In normal operation mode, it is required that the user software clears the WDT counter by setting WDTCL bit in WDTMR register before the time-out value is reached. If the system doesn't restart the counter, an interrupt or a system reset will be issued.

The main features are :

- 2 operating modes : Interrupt or System Reset mode
- Selectable Time-out period

In Interrupt mode, the WDT gives an interrupt when the WDT counter expires. This interrupt can be used to wake the device from SLEEP mode (not from STOP mode^{NOTE}), and also as a general system timer. One example is to limit the maximum time allowed for certain operations, giving an interrupt when the operation has run longer than expected. In System Reset mode, the WDT gives a reset when the timer expires. This is typically used to prevent system hang-up in case of runaway code.

The clock source of Watch Dog Timer is the BIT overflow. The interval of WDT interrupt is decided by BIT overflow period and WDTR value, and is calculated as follows.

$$\text{WDT Interrupt Interval} = (\text{BIT overflow period}) \times (\text{WDTR} + 1)$$

^{NOTE} MC96FR116C has only one clock source, XINCLK, and in STOP mode, the main oscillator stops. Also, the WDT/BIT module stops operation.

11.3.2 Block Diagram

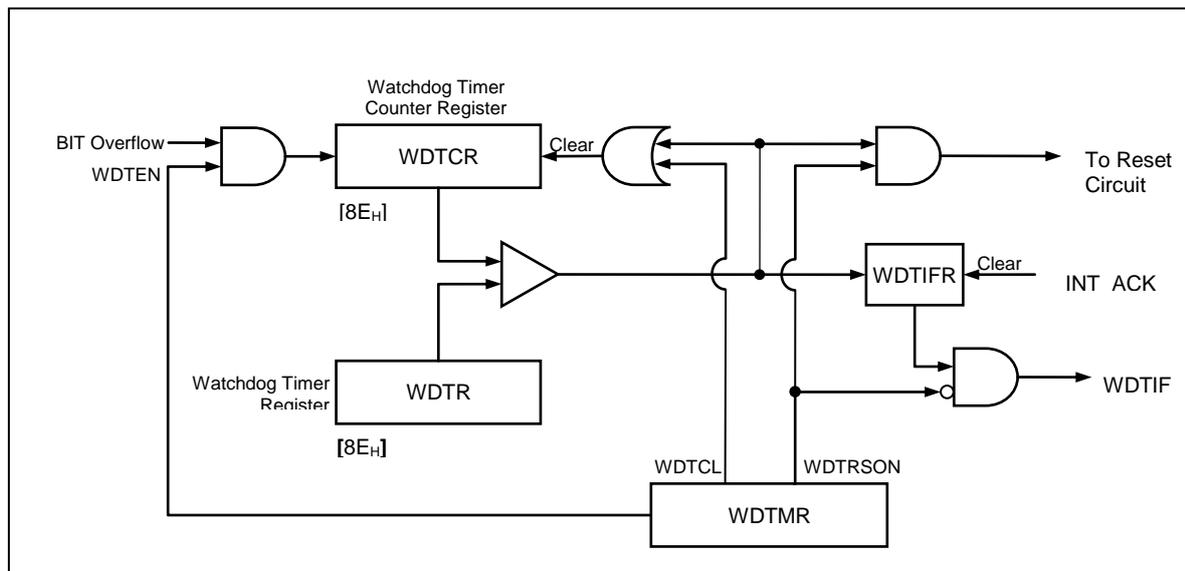


Figure 11-3 Block Diagram

11.3.3 Register Map

Name	Address	Dir	Default	Description
WDTR	8E _H	W	FF _H	Watch Dog Timer Register
WDTCR	8E _H	R	00 _H	Watch Dog Timer Counter Register
WDTMR	8D _H	R/W	00 _H	Watch Dog Timer Mode Register

Table 11-3 Register Map of WDT

11.3.4 Register Description

WDTR (Watch Dog Timer Register, Write Case) 8E_H

7	6	5	4	3	2	1	0
WDTR7	WDTR6	WDTR5	WDTR4	WDTR3	WDTR2	WDTR1	WDTR0
W	W	W	W	W	W	W	W

Initial value : FF_H

WDTR[7:0] Time-out value of WDT counter (=the period of WDT interrupt)
WDT Interrupt Interval = (BIT Interrupt Interval) x (WDTR + 1)

Precaution must be taken when writing this register. To ensure proper operation, the written value, WDTR should be greater than 01_H.

WDTCR (Watch Dog Timer Counter Register, Read Case) 8E_H

7	6	5	4	3	2	1	0
WDTCR7	WDTCR6	WDTCR5	WDTCR4	WDTCR3	WDTCR2	WDTCR1	WDTCR0
R	R	R	R	R	R	R	R

Initial value : 00_H

WDTCR[7:0] The value of WDT counter

WDTMR (Watch Dog Timer Mode Register) 8D_H

7	6	5	4	3	2	1	0
WDTEN	WDRSON	WDTCL	-	-	-	-	WDTIFR
R/W	R/W	R/W	-	-	-	-	R/W

Initial value : 00_H

WDTEN Enable or disable WDT module
0 Disable
1 Enable

WDRSON Decides whether to use WDT interrupt as a reset source or not
0 WDT operates as a free-running 8-bit timer
1 WDT reset is generated when WDT counter overflows

WDTCL Initialize WDT counter
0 Free runs
1 Reset WDT counter. This bit is auto-cleared after 1 machine cycle.

WDTIFR This flag is set when WDT interrupt is generated. This bit is cleared when the CPU services or acknowledges WDT interrupt or s/w 'write'0' to this bit position.

- 0 WDT interrupt not occurred
- 1 WDT interrupt occurred

11.3.5 WDT Interrupt Timing

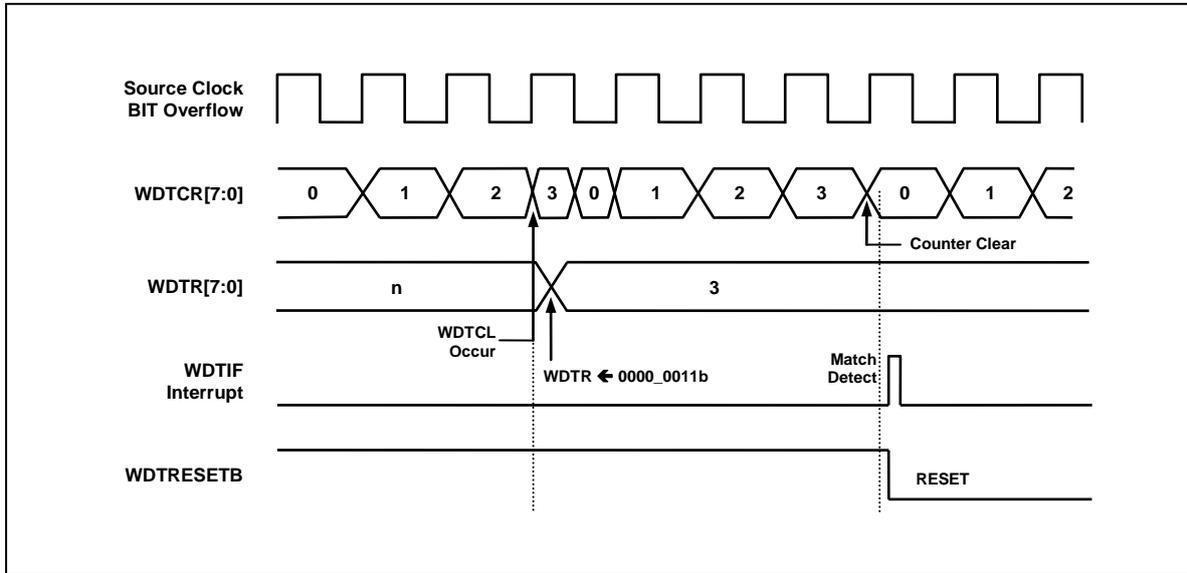


Figure 11-4 WDT Interrupt and Reset Timing

11.4 TIMER/PWM

11.4.1 8-bit Timer/Event Counter 0, 1

11.4.1.1 Overview

Timer 0 and Timer 1 can be used as either separate 8-bit Timer/Counter or one combined 16-bit Timer/Counter. Each 8-bit Timer/Event Counter module has a multiplexer, 8-bit timer data register, 8-bit counter register, mode control register, input capture register and comparator. For PWM mode of operation, Timer 1 has additional registers which are PWM1PR, PWM1DR and PWM1HR.

Timer 0 and Timer 1 have 5 operating modes as following.

- two separate 8-bit Timer/Counter Mode
- two separate 8-bit Capture Mode
- 16-bit Timer/Counter Mode
- 16-bit Capture Mode
- PWM Mode

Timer 0, 1 are clocked by an internal or external clock source (EC0). The clock source is selected by clock select logic which is controlled by the clock select bits (T0CK[2:0], T1CK[2:0]) located in the T0CR and T1CR registers. By configuring T1CK[2:0] bits, Timer 1 can be clocked by the clock source used for Timer 0 or by its own divided clock ^{NOTE}. Internal clock source is derived from the divider logic of each timer module. In Capture Mode, the counter value is captured into each Input Capture Register when an external interrupt condition is generated on INT0 or INT1 pins. In 8/16-bit Timer/Counter Mode, Timer 0 compares counter value with the value in timer data register and when counter reaches to the compare value, the timer output is toggled internally. When the T0_PE bit in T0CR register is set, the timer output overrides the normal port functionality of the I/O pin it is connected to. Timer 1 operates similar to Timer 0, and in addition can generate PWM wave form when configured as PWM mode. And the Timer 1 output or PWM output appears on T1/PWM1 pin.

^{NOTE} SCLK is internal operating clock, which is the output of clock divider logic. The input source of clock divider is XINCLK, the output of main oscillator. The divide ratio can be selected from DIV[1:0] bits in SCCR register and the default frequency is that of main oscillator output, XINCLK. For more information about clock scheme, refer to chapter 11.1.

The next table shows register setting for each timer operating mode.

16 Bit	CAP0	CAP1	PWM1E	T0CK[2:0]	T1CK[1:0]	T0/1_PE	Timer 0	Timer 1
0	0	0	0	XXX	XX	00	8-bit Timer	8-bit Timer
0	0	1	0	111	XX	00	8-bit Event Counter	8-bit Capture
0	1	0	0	XXX	XX	01	8-bit Capture	8-bit Compare Output
0	0	0	1	XXX	XX	11	8-bit Timer/Counter	10-bit PWM
1	0	0	0	XXX	11	00	16-bit Timer	
1	0	0	0	111	11	00	16-bit Event Counter	
1	1	1	0	XXX	11	00	16-bit Capture	
1	0	0	0	XXX	11	01	16-bit Compare Output	

Table 11-4 Operating modes of Timer 0, 1

11.4.1.2 8-Bit Timer/Counter Mode

8-bit Timer/Counter Mode is selected when the T0CR and T1CR registers are configured as follows.

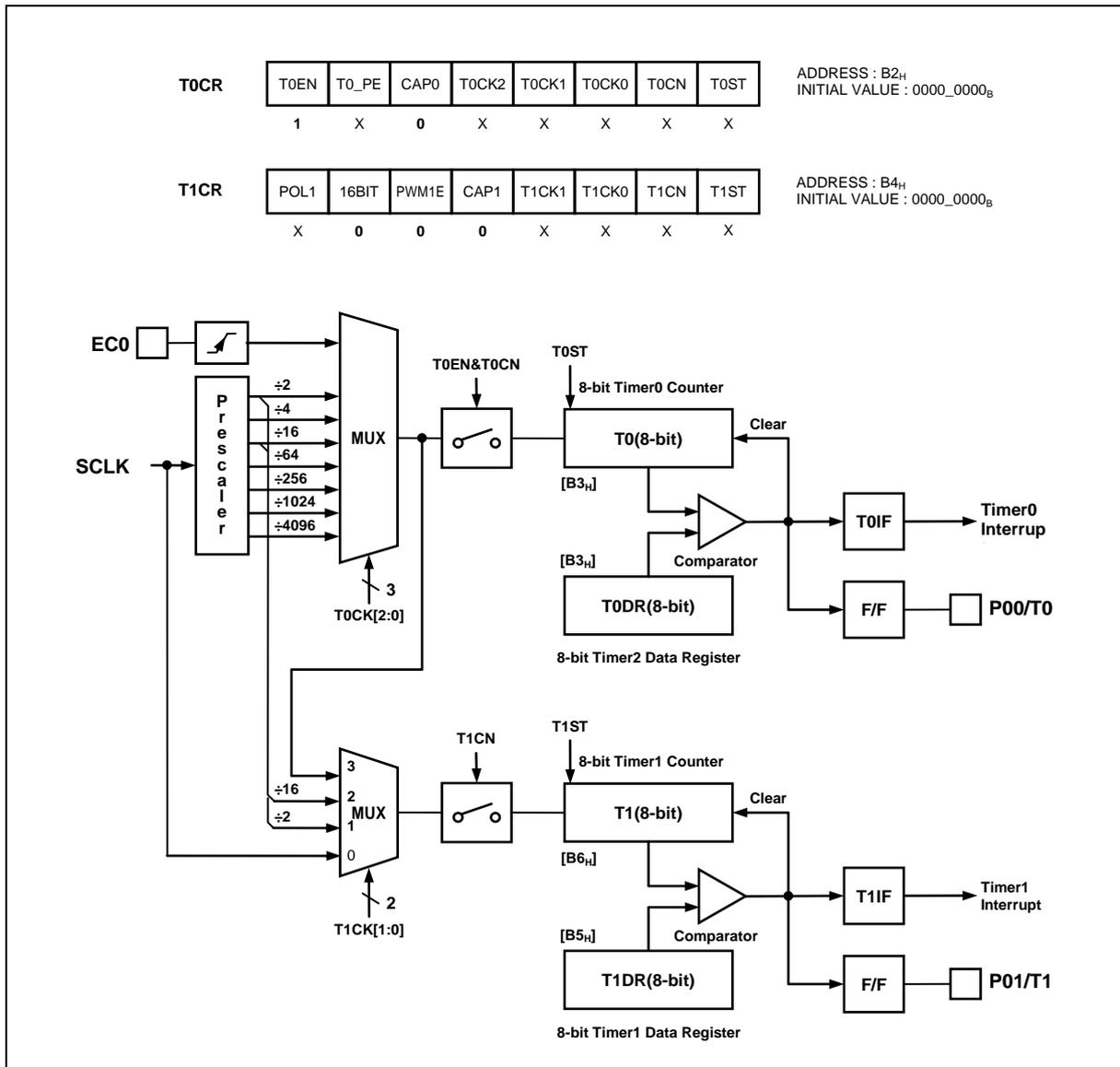


Figure 11-5 Block Diagram of Timer 0,1 in 8-bit timer/counter mode

Each Timer 0 and Timer 1 has its own counter register and data register. The counter is clocked by an internal or external clock source. Internal clock source comes from divider logic whose input clock is SCLK. For Timer 0 module, SCLK is divided by 2, 4, 16, 64, 256, 1024 and 4096. One of these divided clock is used as internal clock source of Timer 0. Divider logic of Timer 1 is much simpler. The SCLK is divided by 2 or 16. Along with these divided clock sources, the SCLK itself can be used as internal clock source of Timer 1. And Timer 1 can also be clocked by the clock source of Timer 0. Each divide ratio is decided by T0CK[2:0] and T1CK[2:0] bits. When the external clock, EC0 is selected as a clock source, the counter increases at rising edge of the clock. When the counter value of each 8-bit timer matches individual data register, an interrupt can be requested. The interrupt flags can be read through T3CR2 register.

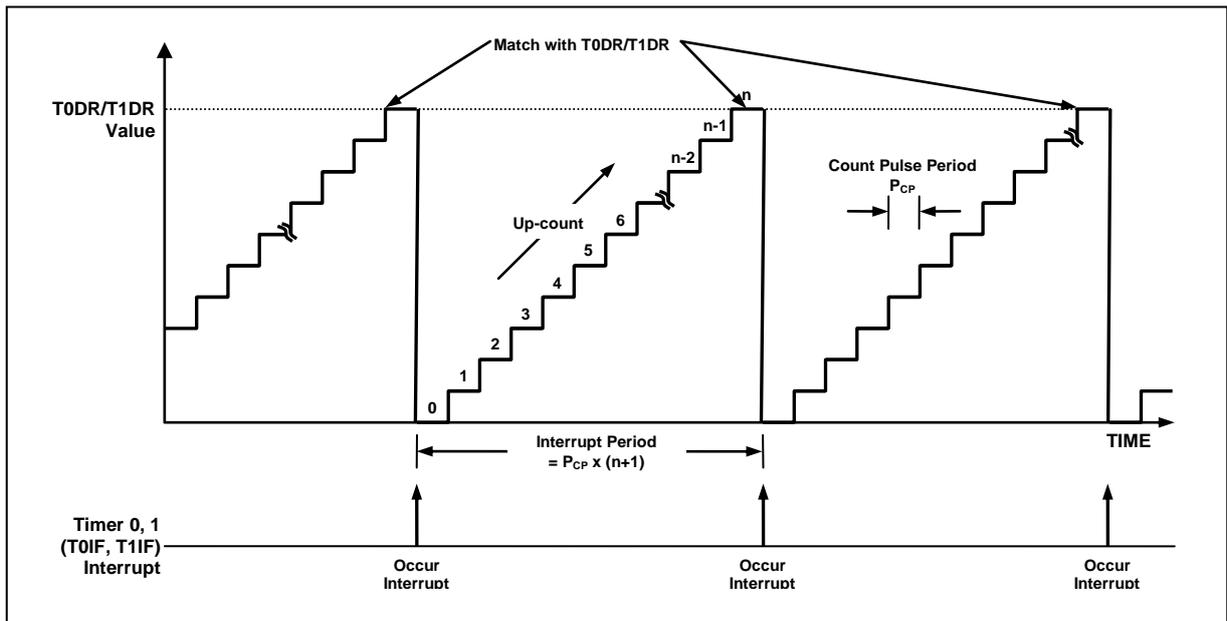


Figure 11-6 Interrupt Period of Timer 0, 1

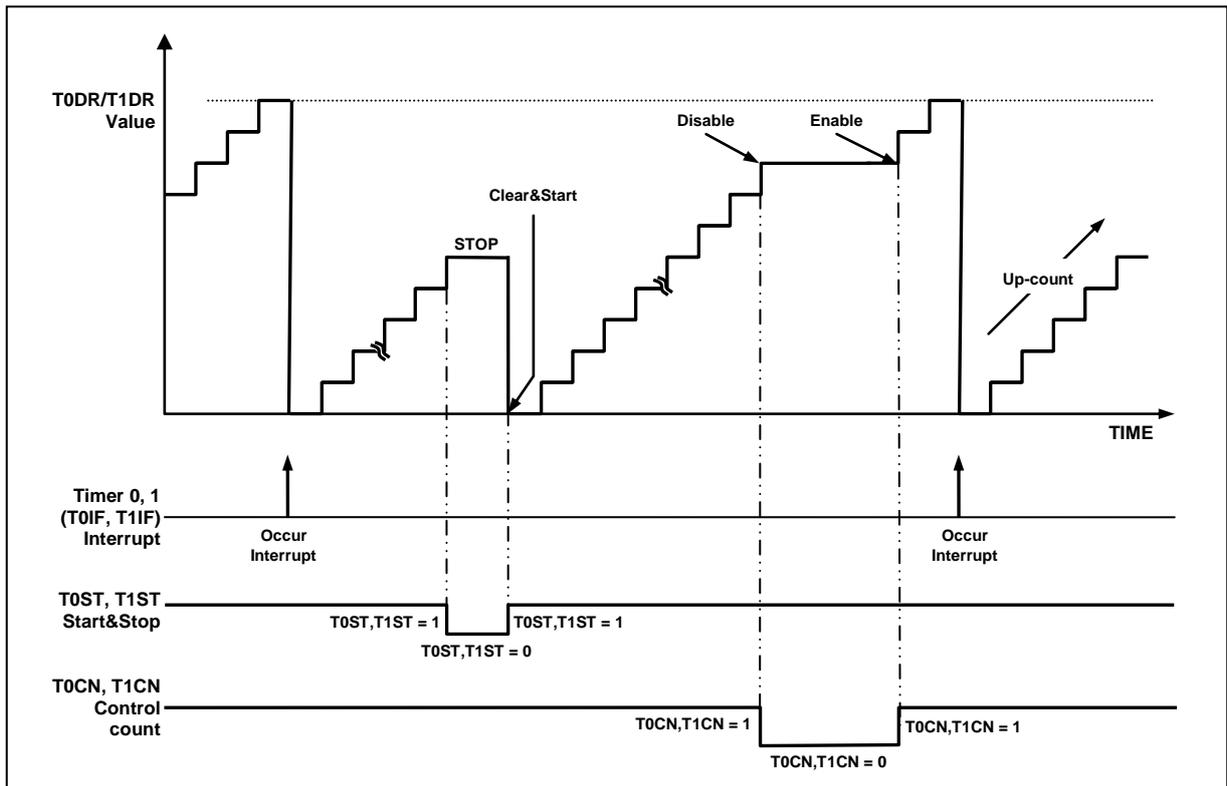


Figure 11-7 Counter Operation of Timer 0, 1

11.4.1.3 16-bit Timer/Counter Mode

When Timer 0, 1 are configured as 16-bit Timer/Counter Mode, Timer 0 becomes the lower part of the new 16-bit counter. When the lower 8-bit counter T0 matches T0DR and higher 8-bit counter T1 matches T1DR simultaneously, a 16-bit timer interrupt is issued via Timer 0 interrupt(not Timer 1). Both T0 and T1 should use the same clock source, which leads to the configuration, T1CK1=1, T1CK0=1 and 16BIT=1 in T1CR register. This means to use two separate 8-bit counters(T0, T1) as a single 16-bit counter, T1 must be clocked by the clock source of T0. This is shown in the following figure.

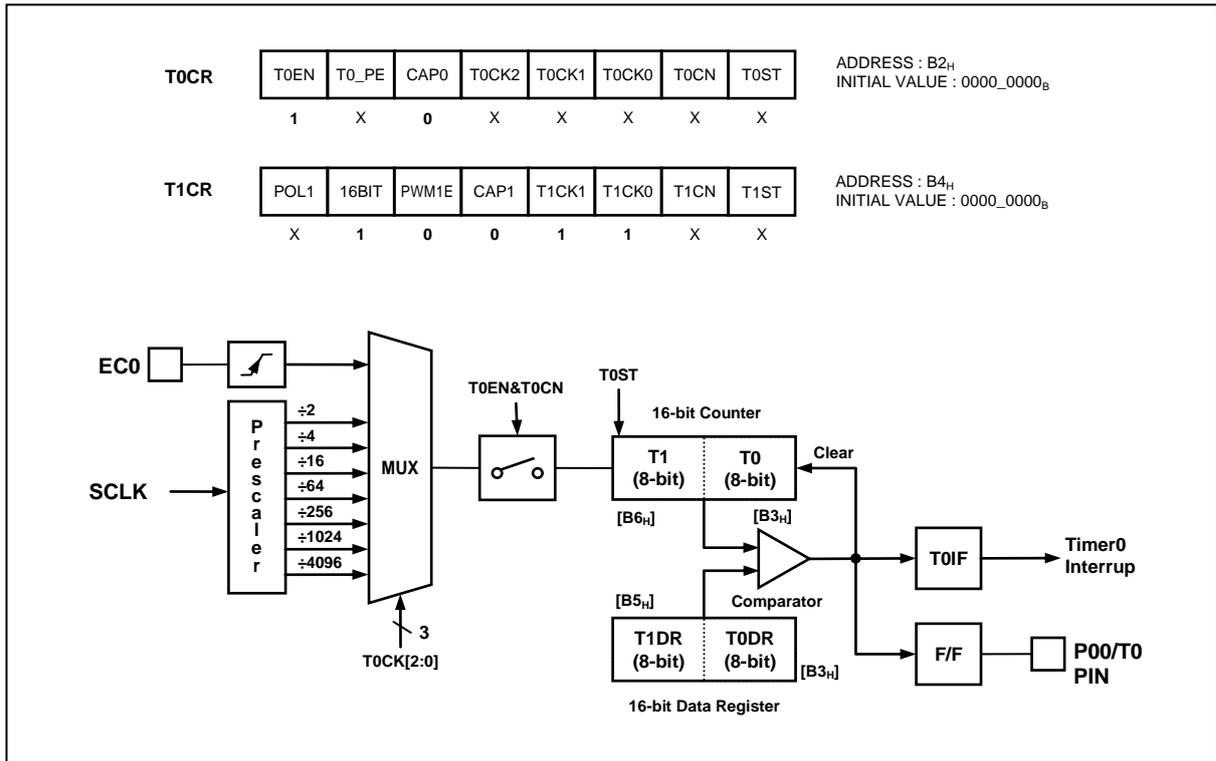


Figure 11-8 Block Diagram of Timer 0, 1 in 16-bit Timer/Counter mode

In 8-bit Timer/Counter Mode, timer output is toggled and appears on P00(P01) port whenever T0(T1) matches T0DR(T1DR). In 16-bit Timer/Counter Mode, timer output is toggled and appears on P01 port whenever T1+T0 matches T1DR+T0DR. The initial value of each timer's output is '0' and output frequency is calculated by the following equation.

$$f_{COMP} = \frac{\text{Timer Clock Frequency}}{2 \times \text{Prescaler Value} \times (TnDR + 1)}$$

where f_{COMP} is the frequency of timer output, $TnDR$ is T0DR or T1DR in 8-bit timer mode or concatenated T1DR+T0DR in 16-bit timer mode.

To observe timer output via port, T0_PE in T0CR register or T1_PE in PWM1HR register must be set.

11.4.1.4 8-bit Capture Mode

By setting CAP0(CAP1) to '1' in T0CR(T1CR) register, Timer 0(Timer 1) operates in Capture Mode. Basic timer function is still effective even in capture mode. So when the counter value reaches to the pre-defined data value in data register, an interrupt can be issued. When an external interrupt generating condition is detected on port P36(P37), the counter value is captured into capture register CDR0(CDR1). At the same time the counter T0(T1) is cleared to 00_H and counts up again.

The timer interrupt in Capture Mode is very useful when the interval of capture event on port P36(P37) is longer than the interrupt period of timer. That is, by counting number of timer interrupt, user software can figure out the time interval of external event. As you know, external interrupt is triggered by a falling edge, a rising edge or both edge according to the setting of EDEDGE register(Interrupt Edge Selection Register, AD_H).

CDR0, T0 and T0DR registers share peripheral address. Reading T0DR gives the value of CDR0 in Capture Mode, T0 in Timer/Count Mode. Writing T0DR alters the contents of T0DR in any mode. CDR1, T1 and T1DR is all the same as above.

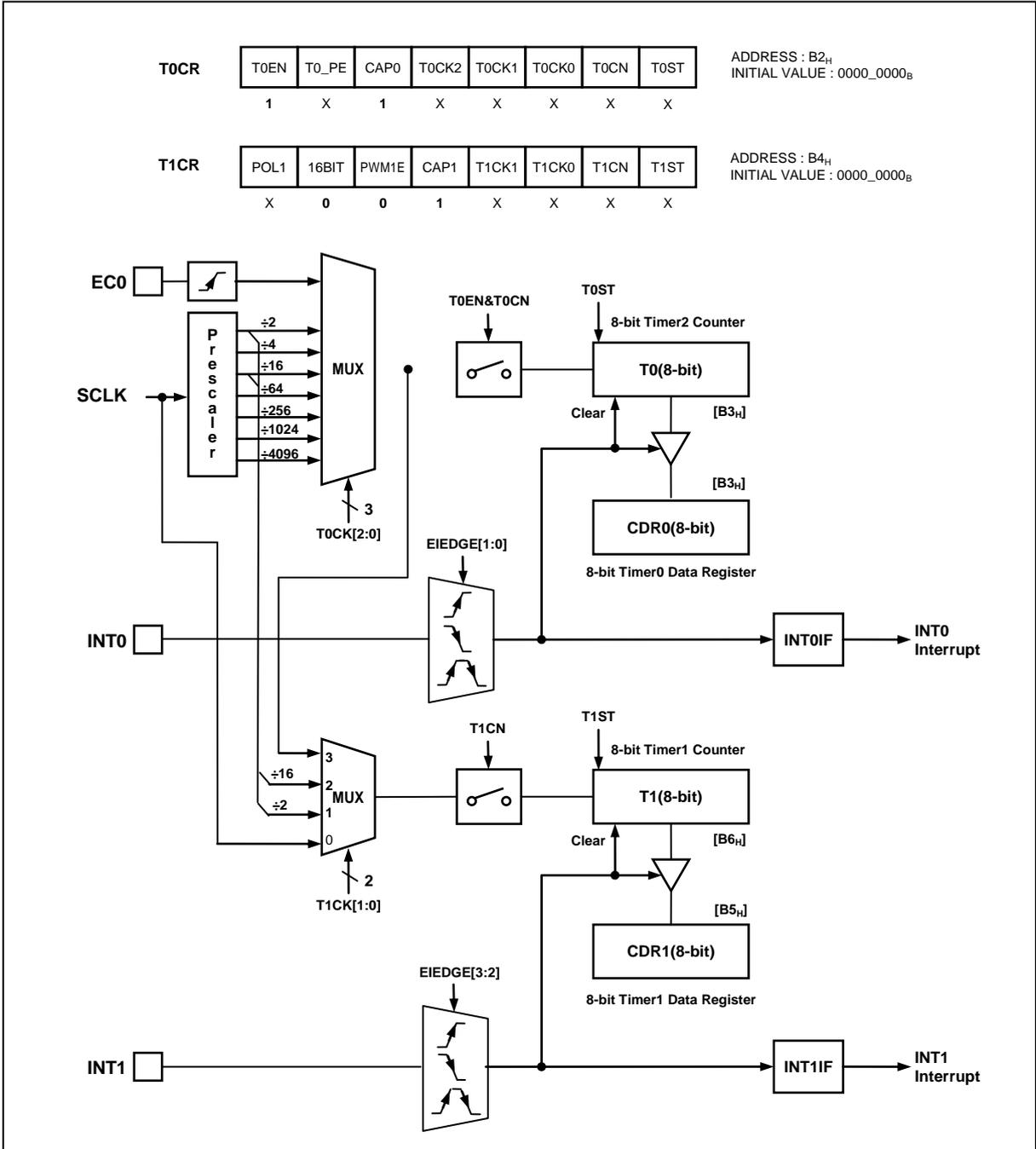


Figure 11-9 Block Diagram of Timer 0, 1 in 8-bit Capture mode

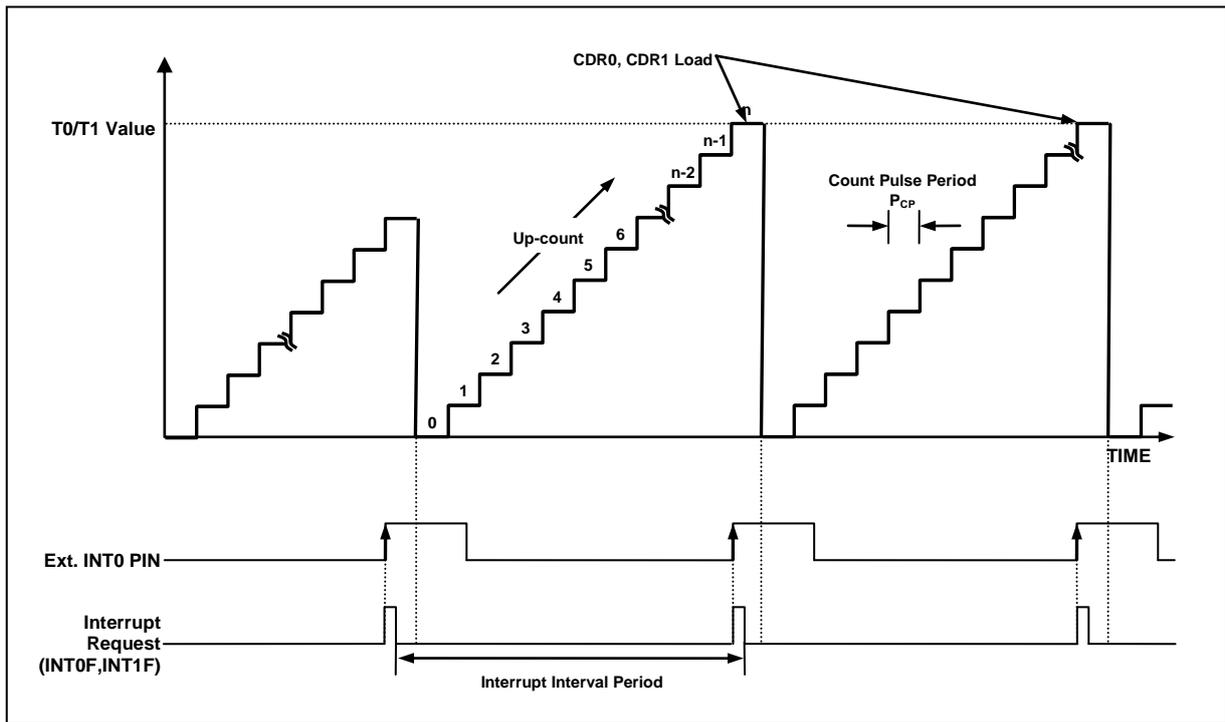


Figure 11-10 Timer 0,1 Operation in 8-bit Input Capture Mode

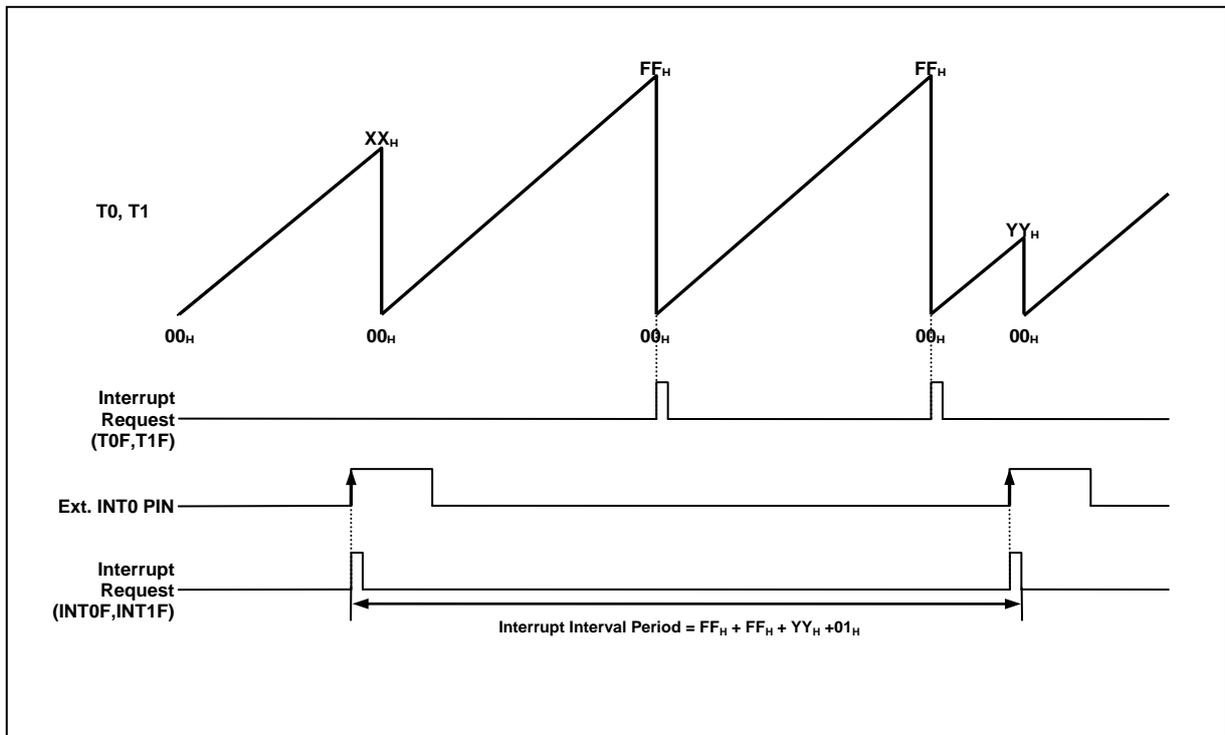


Figure 11-11 Example of Capture Interval Calculation in 8-bit Input Capture Mode

11.4.1.5 16-bit Capture Mode

If two 8-bit timers are combined to operate as a single 16-bit timer, this new timer can be in 16-bit Capture Mode. The operating mechanism is just like a 8-bit timer in capture mode except counter and capture register is 16-bit wide which are concatenated T0+T1 and CDR0+CDR1. The 16-bit counter T0+T1 is clocked by a clock source selected by T0CK[2:0] bits in T0CR register. And the T1CK1, T1CK0 and 16BIT bits in T1CR register must be set to '1' to operate correctly. The following figure shows how the Timer 0, 1 operate in 16-bit Capture Mode.

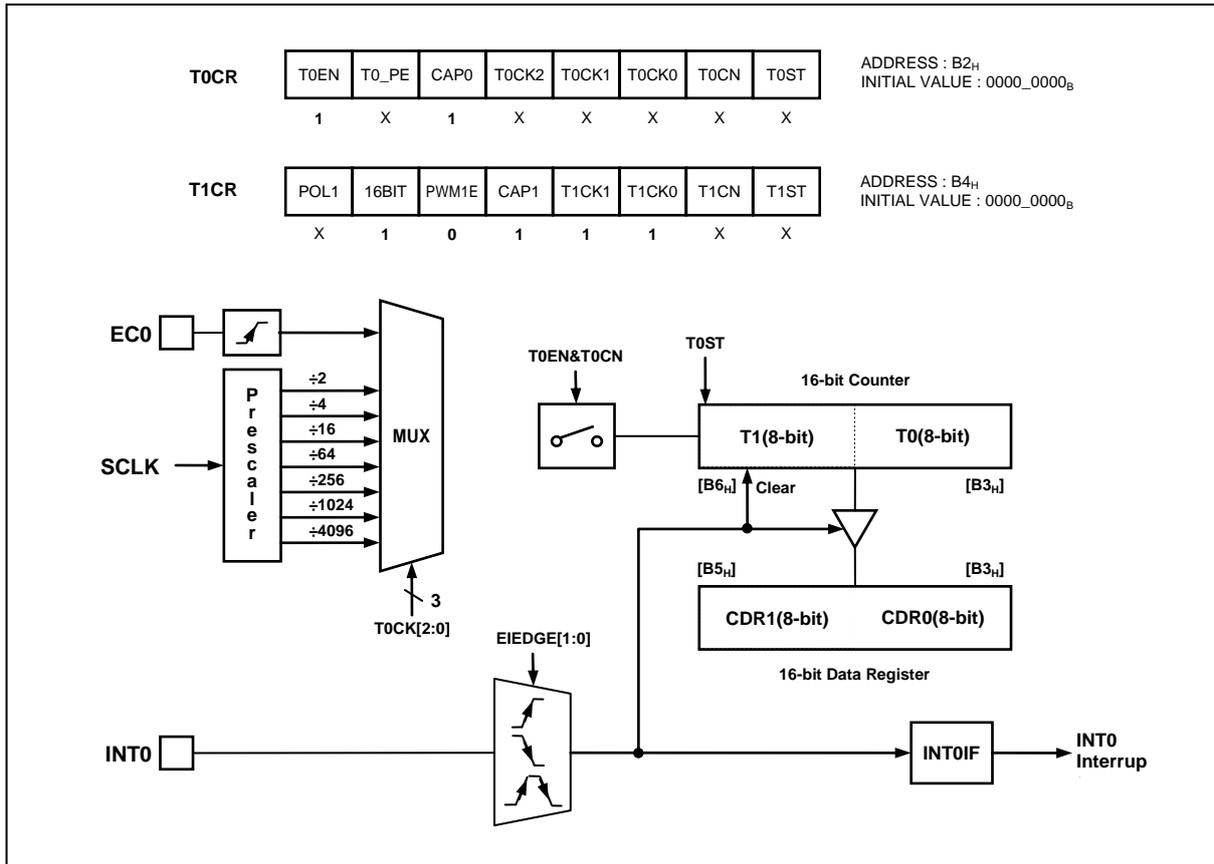


Figure 11-12 Block Diagram of Timer 0, 1 in 16-bit Capture Mode

11.4.1.6 PWM Mode (Timer 1)

Timer 1 supports simple PWM waveform generating function by setting PWM1E bit in T1CR register. To output the PWM waveform through T1/PWM1 pin, the T1_PE bit in PWM1HR register is to be set. The period and duty of PWM waveform are decided by PWM1PR(PWM Period Register), PWM1DR(PWM Duty Register) and PWM1HR registers. Note the PWM resolution is 10-bit depth, the period and duty is calculated by next equation.

$$\text{PWM Period} = [\text{PWM1HR}[3:2], \text{PWM1PR}] \times \text{Timer 1 Clock Period}$$

$$\text{PWM Duty} = [\text{PWM1HR}[1:0], \text{PWM1DR}] \times \text{Timer 1 Clock Period}$$

Resolution	Frequency		
	T1CK[1:0]=00 (125ns)	T1CK[1:0]=01 (250ns)	T1CK[1:0]=10 (2us)
10-bit	7.8KHz	3.9KHz	0.49KHz
9-bit	15.6KHz	7.8KHz	0.98KHz
8-bit	31.2KHz	15.6KHz	1.95KHz
7-bit	62.4KHz	31.2KHz	3.91KHz

Table 11-5 PWM Frequency vs. Resolution (In case frequency of SCLK(=f_{SCLK}) is 8MHz)

The POL bit in T1CR register determines the polarity of PWM waveform. Setting POL=1 makes PWM waveform high for duty value. In other case, PWM waveform is low for duty value.

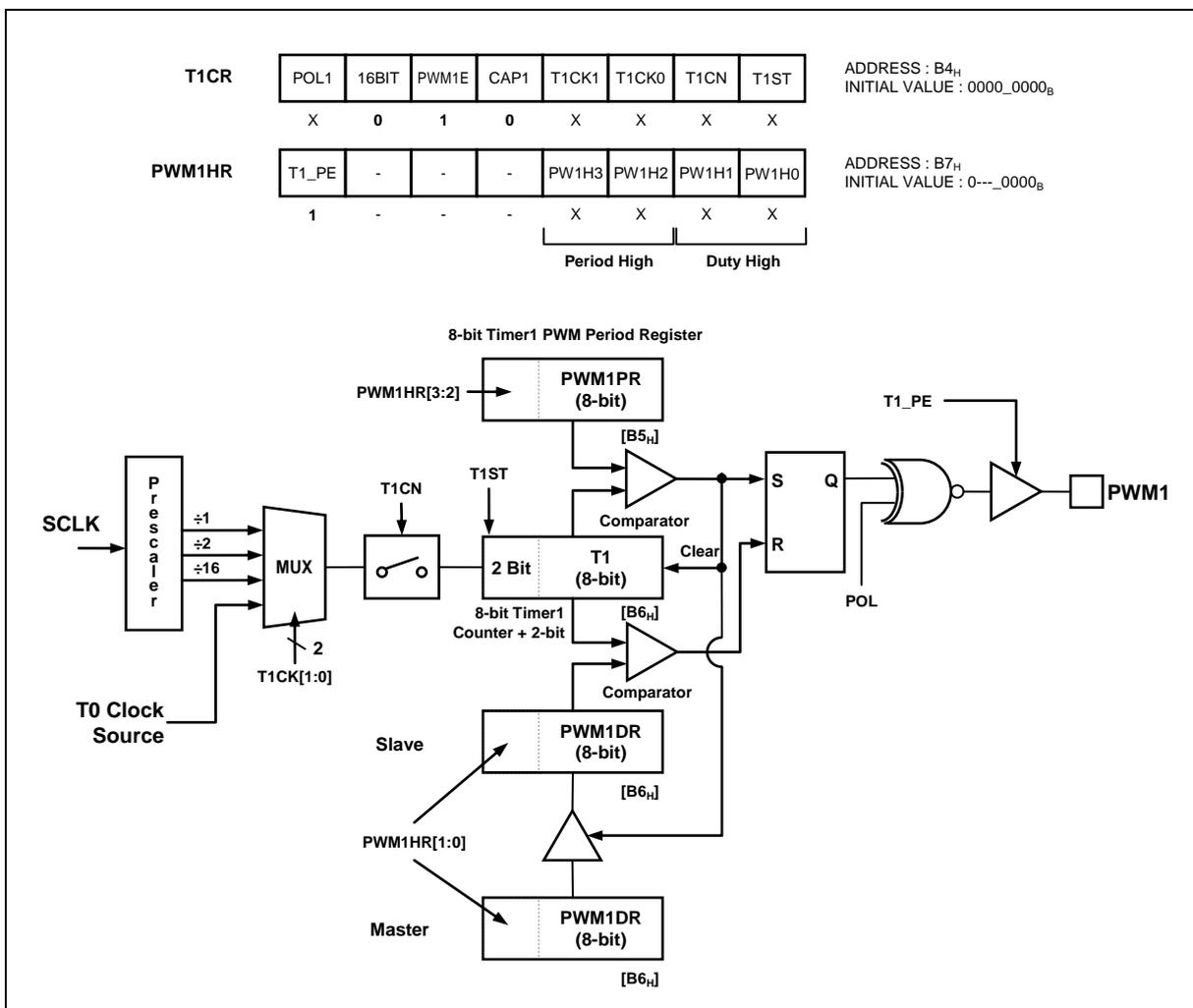


Figure 11-13 Block Diagram of Timer 1 in PWM mode

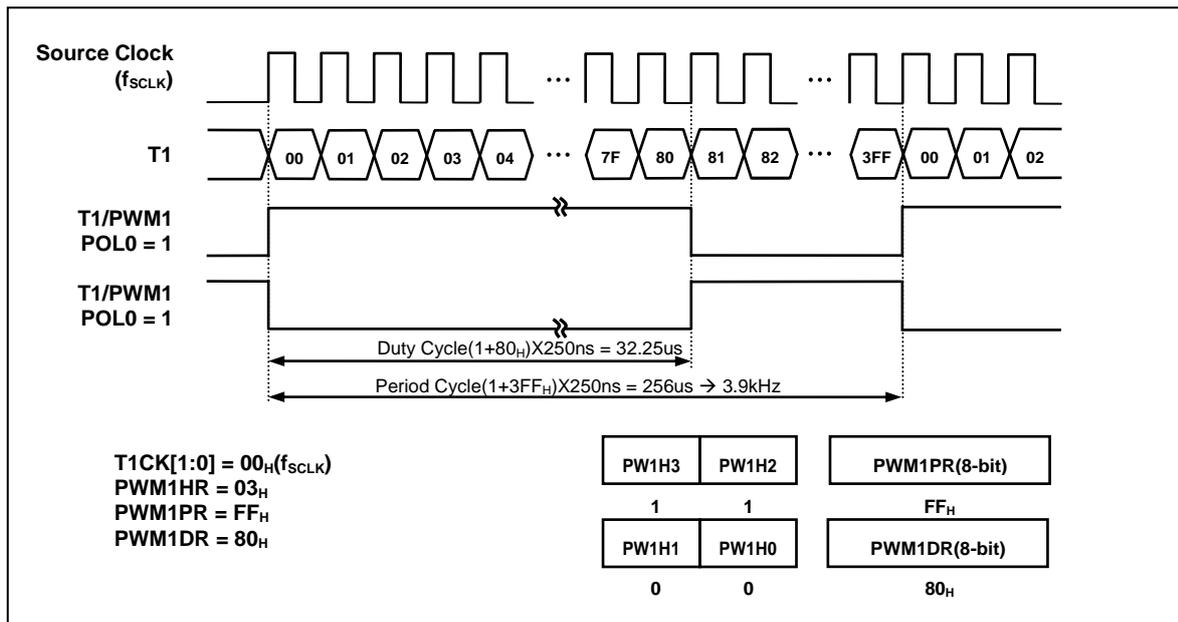


Figure 11-14 Example of PWM Waveform (In case frequency of SCLK(=f_{SCLK}) is 4MHz)

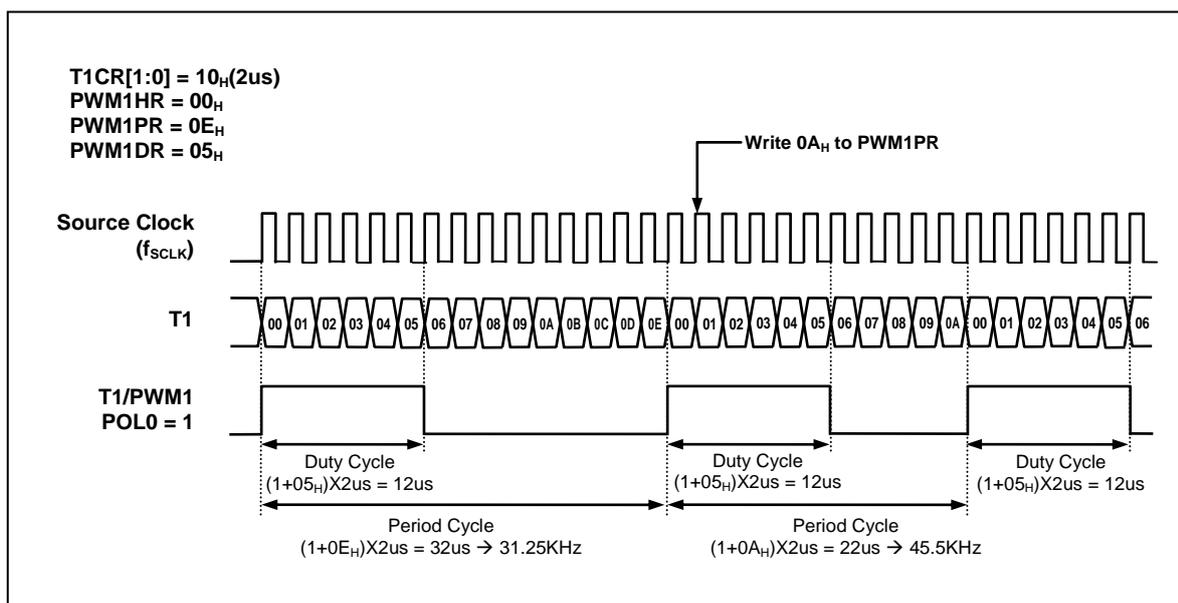


Figure 11-15 Behaviour of waveform when changing period (In case f_{SCLK} is 4MHz)

11.4.1.7 Register Map

Name	Address	Dir	Default	Description
T0CR	B2 _H	R/W	00 _H	Timer 0 Mode Control Register
T0	B3 _H	R	00 _H	Timer 0 Register
T0DR	B3 _H	W	FF _H	Timer 0 Data Register
CDR0	B3 _H	R	00 _H	Capture 0 Data Register
T1CR	B4 _H	R/W	00 _H	Timer 1 Mode Control Register

T1DR	B5 _H	W	FF _H	Timer 1 Data Register
PWM1PR	B5 _H	W	FF _H	Timer 1 PWM Period Register
T1	B6 _H	R	00 _H	Timer 1 Register
PWM1DR	B6 _H	R/W	00 _H	Timer 1 PWM Duty Register
CDR1	B6 _H	R	00 _H	Capture 1 Data Register
PWM1HR	B7 _H	W	00 _H	Timer 1 PWM High Register

Table 11-6 Register Map of Timer 0, 1

11.4.1.8 Register Description

T0CR (Timer 0 Mode Control Register)

B2_H

7	6	5	4	3	2	1	0
T0EN	T0_PE	CAP0	T0CK2	T0CK1	T0CK0	T0CN	T0ST
RW	RW	RW	RW	RW	RW	RW	RW

Initial value : 00_H

T0EN	Enables or disables Timer 0 module. 0 Disable Timer 0 1 Enable Timer 0																																				
T0_PE	Controls whether to output Timer 0 output or not through I/O pin. 0 Timer 0 output does not come out through I/O pin 1 Timer 0 output overrides the normal port functionality of I/O pin																																				
CAP0	Selects operating mode of Timer 0. 0 Timer/Counter mode 1 Capture mode																																				
T0CK[2:0]	Selects clock source of Timer 0. ^{NOTE} <table border="1"> <thead> <tr> <th>T0CK2</th> <th>T0CK1</th> <th>T0CK0</th> <th>Timer 0 clock</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>0</td> <td>f_{SCLK}/2</td> </tr> <tr> <td>0</td> <td>0</td> <td>1</td> <td>f_{SCLK}/2²</td> </tr> <tr> <td>0</td> <td>1</td> <td>0</td> <td>f_{SCLK}/2⁴</td> </tr> <tr> <td>0</td> <td>1</td> <td>1</td> <td>f_{SCLK}/2⁶</td> </tr> <tr> <td>1</td> <td>0</td> <td>0</td> <td>f_{SCLK}/2⁸</td> </tr> <tr> <td>1</td> <td>0</td> <td>1</td> <td>f_{SCLK}/2¹⁰</td> </tr> <tr> <td>1</td> <td>1</td> <td>0</td> <td>f_{SCLK}/2¹²</td> </tr> <tr> <td>1</td> <td>1</td> <td>1</td> <td>External Clock (EC0)</td> </tr> </tbody> </table>	T0CK2	T0CK1	T0CK0	Timer 0 clock	0	0	0	f _{SCLK} /2	0	0	1	f _{SCLK} /2 ²	0	1	0	f _{SCLK} /2 ⁴	0	1	1	f _{SCLK} /2 ⁶	1	0	0	f _{SCLK} /2 ⁸	1	0	1	f _{SCLK} /2 ¹⁰	1	1	0	f _{SCLK} /2 ¹²	1	1	1	External Clock (EC0)
T0CK2	T0CK1	T0CK0	Timer 0 clock																																		
0	0	0	f _{SCLK} /2																																		
0	0	1	f _{SCLK} /2 ²																																		
0	1	0	f _{SCLK} /2 ⁴																																		
0	1	1	f _{SCLK} /2 ⁶																																		
1	0	0	f _{SCLK} /2 ⁸																																		
1	0	1	f _{SCLK} /2 ¹⁰																																		
1	1	0	f _{SCLK} /2 ¹²																																		
1	1	1	External Clock (EC0)																																		
T0CN	Decides whether to pause or continue counting 0 Pause counting temporarily 1 Continue to count																																				
T0ST	Decides whether to start or stop counter 0 Stops counting 1 Clear counter and starts up-counting																																				

^{NOTE} f_{SCLK} is the frequency of internal operating clock, SCLK.

T0 (Timer 0 Register, Read Case)

B3_H

7	6	5	4	3	2	1	0
T07	T06	T05	T04	T03	T02	T01	T00

R	R	R	R	R	R	R	R
---	---	---	---	---	---	---	---

Initial value : 00_H

T0[7:0] T0 Counter value

T0DR (Timer 0 Data Register, Write Case) **B3_H**

7	6	5	4	3	2	1	0
T0D7	T0D6	T0D5	T0D4	T0D3	T0D2	T0D1	T0D0
W	W	W	W	W	W	W	W

Initial value : FF_H

T0D[7:0] T0 Compare data

CDR0 (Capture 0 Data Register, Read Case) **B3_H**

7	6	5	4	3	2	1	0
CDR07	CDR06	CDR05	CDR04	CDR03	CDR02	CDR01	CDR00
R	R	R	R	R	R	R	R

Initial value : 00_H

CDR0[7:0] T0 Capture value

T1CR (Timer 1 Mode Count Register) **B4_H**

7	6	5	4	3	2	1	0
POL	16BIT	PWM1E	CAP1	T1CK1	T1CK0	T1CN	T1ST
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 00_H

- POL** Selects polarity of PWM
 - 0 PWM waveform is low for duty value
 - 1 PWM waveform is high for duty value
- 16BIT** Selects width of Timer 0,1
 - 0 Timer 0,1 are two separate 8-bit timers
 - 1 Timer 0+1 is combined single 16-bit timer
- PWM1E** Enable PWM function of Timer 1
 - 0 Timer 1 is Normal Timer/Counter
 - 1 Timer 1 is PWM
- CAP1** Selects operating mode of Timer 1.
 - 0 Timer/Counter mode
 - 1 Capture mode
- T1CK[1:0]** Selects the clock source of Timer 1.

T1CK1	T1CK0	Timer 1 clock
0	0	f _{SCLK}
0	1	f _{SCLK} /2
1	0	f _{SCLK} /2 ⁴
1	1	Timer 0 Clock
- T1CN** Decides whether to pause or continue counting
 - 0 Pause counting temporarily
 - 1 Continue to count
- T1ST** Decides whether to start or stop counter

- 0 Stops counting
- 1 Clear counter and starts up-counting

T1DR (Timer 1 Data Register, Write Case)

B5_H

7	6	5	4	3	2	1	0
T1D7	T1D6	T1D5	T1D4	T1D3	T1D2	T1D1	T1D0
W	W	W	W	W	W	W	W

Initial value : FF_H

T1D[7:0] T1 Compare data

PWM1PR (Timer 1 PWM Period Register, Write Case)

B5_H

7	6	5	4	3	2	1	0
T1PP7	T1PP6	T1PP5	T1PP4	T1PP3	T1PP2	T1PP1	T1PP0
W	W	W	W	W	W	W	W

Initial value : FF_H

T1PP[7:0] Period of PWM waveform

T1 (Timer 1 Register, Read Case)

B6_H

7	6	5	4	3	2	1	0
T17	T16	T15	T14	T13	T12	T11	T10
R	R	R	R	R	R	R	R

Initial value : 00_H

T1[7:0] T1 Counter value

PWM1DR (Timer 1 PWM Duty Register, Write Case)

B6_H

7	6	5	4	3	2	1	0
T1PD7	T1PD6	T1PD5	T1PD4	T1PD3	T1PD2	T1PD1	T1PD0
W	W	W	W	W	W	W	W

Initial value : 00_H

T1PD[7:0] Duty of PWM waveform. NOTE) This register is meaningful only when PWM1E bit in T1CR register is '1'.

CDR1 (Capture 1 Data Register, Read Case)

B6_H

7	6	5	4	3	2	1	0
CDR17	CDR16	CDR15	CDR14	CDR13	CDR12	CDR11	CDR10
R	R	R	R	R	R	R	R

Initial value : 00_H

CDR1[7:0] T1 Capture value

PWM1HR (Timer 1 PWM High Register)

B7_H

7	6	5	4	3	2	1	0
T1_PE	-	-	-	PW1H3	PW1H2	PW1H1	PW1H0

W	-	-	-	W	W	W	W
							Initial value : 00 _H
	T1_PE	Controls whether to output Timer 1 output or not through I/O pin. Note this bit is write-only.					
		0 Timer 1 output does not come out through I/O pin					
		1 Timer 1 output overrides the normal port functionality of I/O pin					
	PW1H[3:2]	High (bit [9:8]) value of PWM period					
	PW1H[1:0]	High (bit [9:8]) value of PWM duty					

When Timer 1 operates in PWM mode, PW1H[3:2] and T1PP constitute the period of PWM, PW1H[1:0] and T1PD constitute the duty of PWM.

11.4.2 16-bit Timer 2

11.4.2.1 Overview

16-bit Timer 2 is composed of Multiplexer, Timer Data Register High/Low, Timer Register High/Low and Mode Control Register.

Timer 2 is clocked by Carrier Signal (CRF) from Carrier Generator module or by an internal clock source deriving from clock divider logic where the base clock is SCLK. This timer supports output compare(Timer/Counter) and input capture function.

When IRCEN bit in IRCC1 is set, Timer 2 operates in IR capture mode. In this mode Timer 2 can detect the envelope of IR input signal or counts the number of input carrier signal. In envelop detection mode of operation, the counter value of Timer 2 is captured into timer capture register on first rising edge of IR input(normally amplified carrier signal) and overflow of WT. When Timer 2 is used to calculate the number of carrier signal, the rising edge of input carrier becomes the clock source of Timer 2. For more information about IR capture operation, refer to WT and IRCC section.

11.4.2.2 16-bit Output Compare or Event Counter Mode

When Timer 2 is in Output Compare or Event Counter Mode, timer output is toggled and appears on P02 port whenever T2(T2H+T2L) matches T2DR(T2DRH+T2DRL). An interrupt can be requested if enabled and the interrupt flag can be read through T3CR2 register. The initial value of timer output is '0' and output frequency is calculated by the following equation.

$$f_{COMP} = \frac{\text{Timer Clock Frequency}}{2 \times \text{Prescaler Value} \times (T2DR + 1)}$$

where f_{COMP} is the frequency of timer output, T2DR is concatenated T2DRH+T2DRL. The clock source of Timer 2 is selected by T2CK[2:0] bits in T2CR register. To observe timer output via port, set T2_PE bit in T2CR register to '1'.

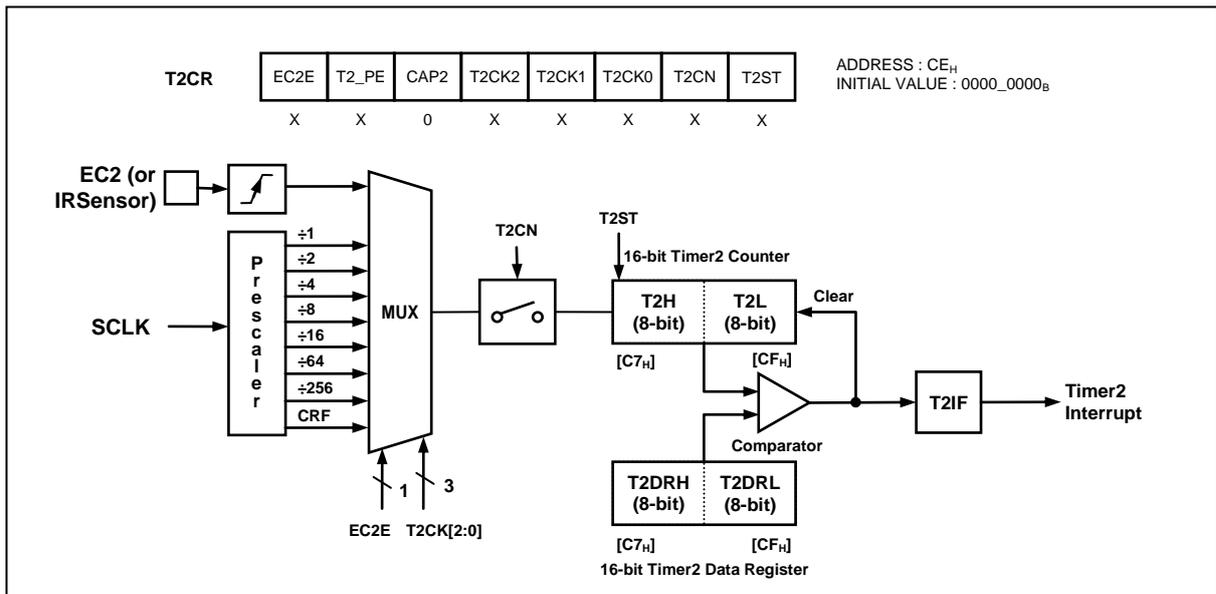


Figure 11-16 Block Diagram of 16-bit Timer 2 in Output Compare or Event Counter Mode

11.4.2.3 16-bit Capture Mode

Capture Mode is enabled by setting CAP2 bit in T2CR register. The clock source is the same as in output compare mode of operation.

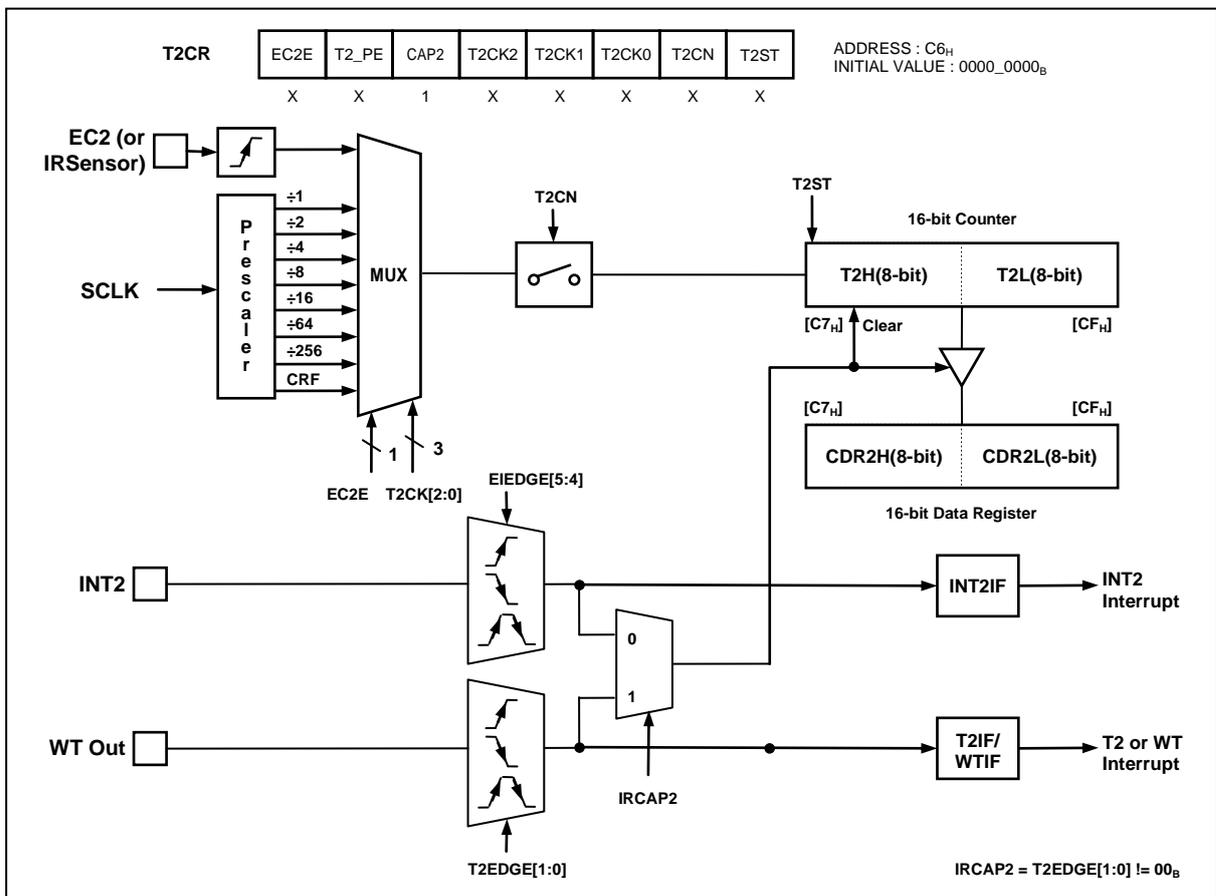


Figure 11-17 Block Diagram of Timer 2 in Capture Mode

When T2H+T2L reaches to the value of T2DRH+T2DRL, an interrupt is requested if enabled. When a compare-match occurs, the counter values T2H and T2L are captured into the capture registers CDR2H and CDR2L respectively. At the same time, the counter is cleared to 0000_H and starts up-counting.

Bit 4 and 5 in EIEDGE (External Interrupt Edge Selection Register, AD_H) register select the triggering condition of external interrupt 2(INT2), a falling edge, a rising edge or both edge.

When Timer 2 operates in IR capture mode, the capture source becomes the output of IR AMP. And the T2EDGE[1:0] bits in IRCC2 register select the triggering condition of Watch Timer output. In this mode, Timer 2 detects the envelop of input carrier signal, and the T2IR bit in IRCC2 register should be cleared to '0'

11.4.2.4 Carrier Counting Mode

Carrier Counting Mode is enabled by setting T2IR bit in IRCC2 register. This mode of operation is only available when IRCEN bit in IRCC1 register is set. The clock source is the rising edge of input carrier signal. Like output compare mode, when T2H+T2L reaches to the value of T2DRH+T2DRL, an interrupt is requested if enabled.

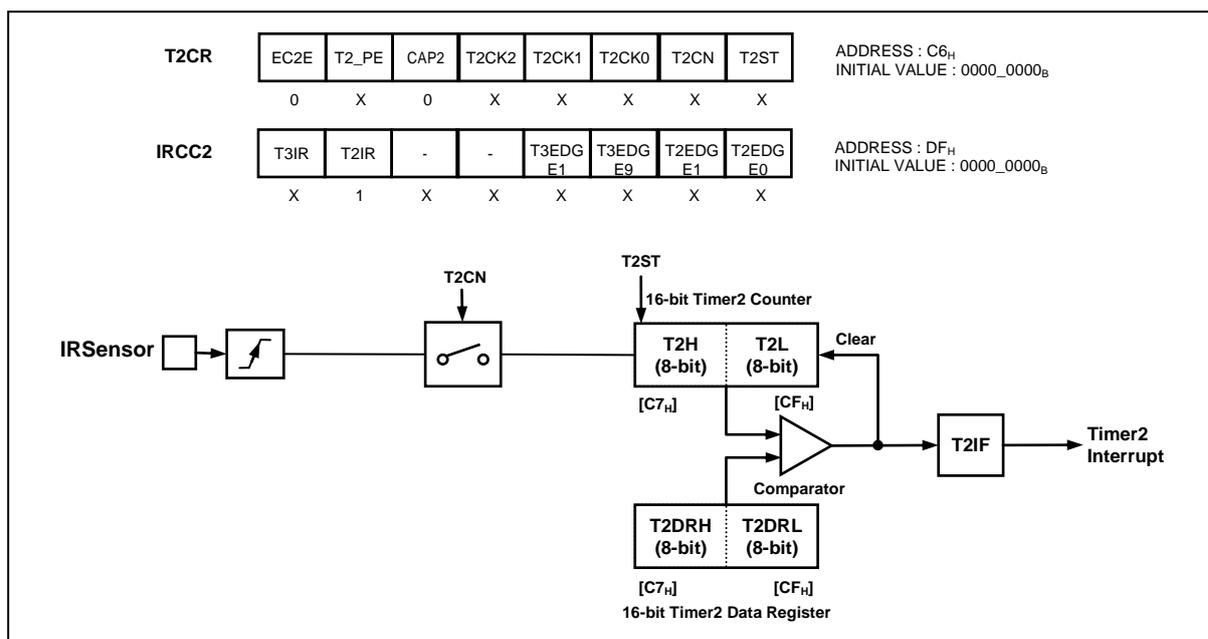


Figure 11-18 Block Diagram of Timer 2 in Carrier Counting Mode

The EC2E and CAP2 bit in T2CR register should be cleared to '0' for proper operation.

11.4.2.5 Register Map

Name	Address	Dir	Default	Description
T2CR	C6 _H	R/W	00 _H	Timer 2 Mode Control Register
T2H	C7 _H	R	00 _H	Timer 2 Counter High
T2DRH	C7 _H	W	FF _H	Timer 2 Data Register High
CDR2H	C7 _H	R	00 _H	Timer 2 Capture Data Register High

T2L	CF _H	R/W	00 _H	Timer 2 Counter Low
T2DRL	CF _H	W	FF _H	Timer 2 Data Register Low
CDR2L	CF _H	R	00 _H	Timer 2 Capture Data Register Low

Table 11-7 Register Map of Timer 2

11.4.2.6 Register Description

CDR2H, T2DRH and T2H registers share peripheral address. Reading T2DRH gives CDR0 in Capture Mode, T2H in Output Compare Mode. Writing T2DRH alters the contents of T2DRH in any mode. This applies to the case of CDR2L, T2DRL and T2L registers.

T2CR (Timer 2 Mode Control Register)

C6_H

7	6	5	4	3	2	1	0
EC2E	T2_PE	CAP2	T2CK2	T2CK1	T2CK0	T2CN	T2ST
RW	RW	RW	RW	RW	RW	RW	RW

Initial value : 00_H

- EC2E** Enable event counter mode of Timer 2.
0 Timer 2 is a normal counter.
1 Timer 2 is an event counter clocked by EC2.
- T2_PE** Controls whether to output Timer 2 output or not through I/O pin.
0 Timer 2 output does not come out through I/O pin
1 Timer 2 output overrides the normal port functionality of I/O pin
- CAP2** Selects operating mode of Timer 2.
0 Timer/Counter mode
1 Capture mode
- T2CK[2:0]** Selects clock source of Timer 2. ^{NOTE}

T2CK2	T2CK1	T2CK0	Timer 2 clock
0	0	0	f _{SCLK}
0	0	1	f _{SCLK} /2 ¹
0	1	0	f _{SCLK} /2 ²
0	1	1	f _{SCLK} /2 ³
1	0	0	f _{SCLK} /2 ⁴
1	0	1	f _{SCLK} /2 ⁶
1	1	0	f _{SCLK} /2 ⁸
1	1	1	CRF (Carrier)
- T2CN** Decides whether to pause or continue counting.
0 Pause counting temporarily
1 Continue to count
- T2ST** Decides whether to start or stop counter
0 Stops counting
1 Clears counter and starts up-counting

^{NOTE} f_{SCLK} is the frequency of internal operating clock, SCLK.

T2L (Timer 2 Counter Low, Read Case)

CF_H

7	6	5	4	3	2	1	0
---	---	---	---	---	---	---	---

T2L7	T2L6	T2L5	T2L4	T2L3	T2L2	T2L1	T2L0
R	R	R	R	R	R	R	R

Initial value : 00_H

T2L[7:0] T2 Counter Low

T2DRL (Timer 2 Data Register Low, Write Case) CF_H

7	6	5	4	3	2	1	0
T2DRL7	T2DRL6	T2DRL5	T2DRL4	T2DRL3	T2DRL2	T2DRL1	T2DRL0
W	W	W	W	W	W	W	W

Initial value : FF_H

T2DRL[7:0] T2 Compare Data Low

CDR2L (Capture Data Register 2 Low, Read Case) CF_H

7	6	5	4	3	2	1	0
CDR2L7	CDR2L6	CDR2L5	CDR2L4	CDR2L3	CDR2L2	CDR2L1	CDR2L0
R	R	R	R	R	R	R	R

Initial value : 00_H

CDR2L[7:0] T2 Capture Data Low

T2H (Timer 2 Counter High, Read Case) C7_H

7	6	5	4	3	2	1	0
T2H7	T2H6	T2H5	T2H4	T2H3	T2H2	T2H1	T2H0
R	R	R	R	R	R	R	R

Initial value : 00_H

T2H[7:0] T2 Counter High

T2DRH (Timer 2 Data Register High, Write Case) C7_H

7	6	5	4	3	2	1	0
T2DRH7	T2DRH6	T2DRH5	T2DRH4	T2DRH3	T2DRH2	T2DRH1	T2DRH0
W	W	W	W	W	W	W	W

Initial value : FF_H

T2DRH[7:0] T2 Compare Data High

CDR2H (Capture Data Register 2 High, Read Case) C7_H

7	6	5	4	3	2	1	0
CDR2H7	CDR2H6	CDR2H5	CDR2H4	CDR2H3	CDR2H2	CDR2H1	CDR2H0
R	R	R	R	R	R	R	R

Initial value : 00_H

CDR2H[7:0] T2 Capture Data High

11.4.3 16-bit Timer 3

11.4.3.1 Overview

16-bit Timer 3 is composed of Multiplexer, Timer Data Register High/Low, Timer Register High/Low, Input Capture Register High/Low, Mode Control Register, PWM Duty High/Low and PWM Period High/Low Register.

Timer 3 is can be clocked by Carrier Signal(CRF) from Carrier Generator module or by an internal clock source deriving from clock divider logic where the base clock is SCLK.

When IRCEN bit in IRCC1 is set, Timer 3 operates in IR capture mode. In this mode Timer 3 can detect the envelope of IR input signal or counts the number of input carrier signal. In envelop detection mode of operation, the counter value of Timer 3 is captured into timer capture register on first rising edge of IR input(normally amplified carrier signal) and overflow of WT. When Timer 3 is used to calculate the number of carrier signal, the rising edge of input carrier becomes the clock source of Timer 3. For more information about IR capture operation, refer to WT and IRCC section.

11.4.3.2 16-bit Output Compare or Event Counter Mode

When Timer 3 is in Output Compare or Event Counter Mode, timer output is toggled and appears on P03 port whenever T3(T3H+T3L) matches T3DR(T3DRH+T3DRL). An interrupt can be requested if enabled and the interrupt flag can be read through T3CR2 register. The initial value of timer output is '0' and output frequency is calculated by the following equation.

$$f_{COMP} = \frac{\text{Timer Clock Frequency}}{2 \times \text{Prescaler Value} \times (T3DR + 1)}$$

where f_{COMP} is the frequency of timer output. T3DR is concatenated T3DRH+T2DRL. The clock source of Timer 3 is selected by T3CK[2:0] bits in T3CR register. To observe timer output via port, set T3_PE bit in T3CR2 register to '1'.

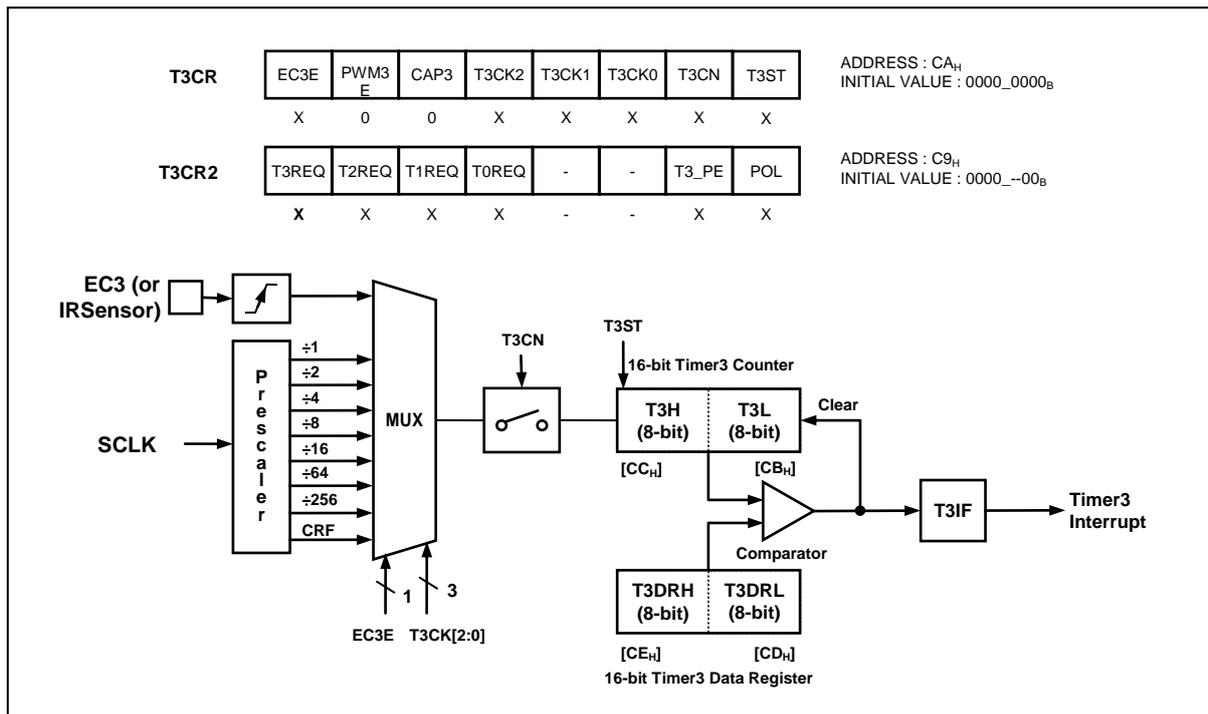


Figure 11-19 Block Diagram of Timer 3 in Output Compare or Event Counter Mode

11.4.3.3 16-bit Capture Mode

Capture Mode is enabled by setting CAP3 bit in T3CR register. The clock source is the same as in output compare mode of operation. When T3H+T3L reaches to the value of T3DRH+T3DRL, an interrupt is requested if enabled. When a compare-match occurs, the counter values T3H and T3L are captured into the capture registers CDR3H and CDR3L respectively. At the same time, the counter is cleared to 0000_H and starts up-counting.

Bit 6 and 7 in EIEDGE(External Interrupt Edge Selection Register, AD_H) register select the triggering condition of external interrupt 3(INT3), a falling edge, a rising edge or both edge.

When Timer 3 operates in IR capture mode, the capture source becomes the output of IR AMP. And the T3EDGE[1:0] bits in IRCC2 register select the triggering condition of Watch Timer output. In this mode, Timer 3 detects the envelop of input carrier signal, and the T3IR bit in IRCC2 register should be cleared to '0'

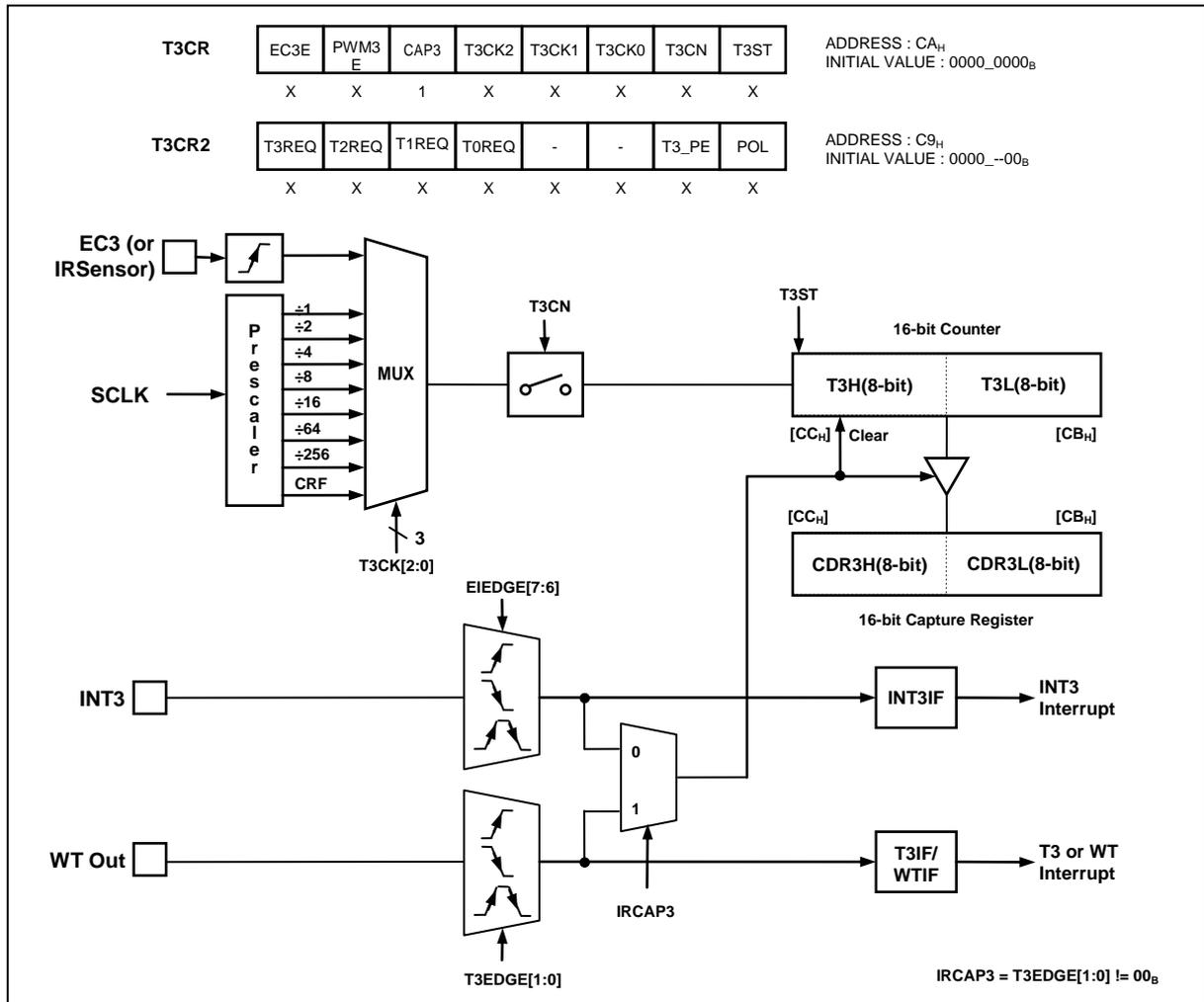


Figure 11-20 Block Diagram of Timer 3 in Capture Mode

11.4.3.4 Carrier Counting Mode

Carrier Counting Mode is enabled by setting T3IR bit in IRCC2 register. This mode of operation is only available when IRCEN bit in IRCC1 register is set. The clock source is the rising edge of input carrier signal. Like output compare mode, when T3H+T3L reaches to the value of T3DRH+T3DRL, an interrupt is requested if enabled.

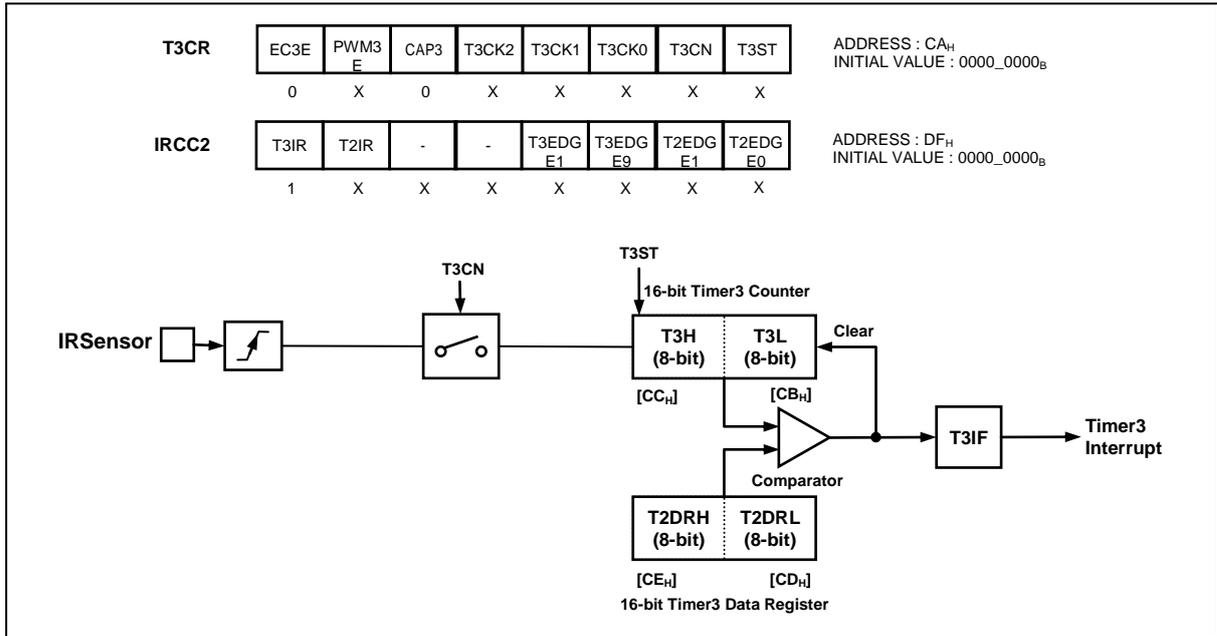


Figure 11-21 Block Diagram of Timer 3 in Carrier Counting Mode

The EC3E and CAP3 bit in T3CR register should be cleared to '0' for proper operation.

11.4.3.5 PWM Mode

Timer 3 supports simple PWM waveform generating function by setting PWM3E bit in T3CR register. As Timer 3 is 16-bit wide, the PWM resolution is also 16-bit depth. To output the PWM waveform through T3/PWM3 pin, the T3_PE bit in T3CR2 register is to be set. The period and duty of PWM waveform are decided by PWM3PRH, PWM3PRL, PWM3DRH and PWM3DRL registers. The equation to calculate period and duty is as follows.

$$\text{PWM Period} = [\text{PWM3PRH}, \text{PWM3PRL}] \times \text{Timer 3 Clock Period}$$

$$\text{PWM Duty} = [\text{PWM3DRH}, \text{PWM3DRL}] \times \text{Timer 3 Clock Period}$$

Resolution	Frequency		
	T3CK[2:0]=000 (250ns)	T3CK[2:0]=001 (500ns)	T3CK[2:0]=011 (2us)
16-bit	60.938Hz	30.469Hz	7.617Hz
15-bit	121.87Hz	60.938Hz	15.234Hz
10-bit	3.9KHz	1.95KHz	0.49KHz
9-bit	7.8KHz	3.9KHz	0.98KHz
8-bit	15.6KHz	7.8KHz	1.95KHz

Table 11-8 PWM Frequency vs. Resolution (In case of $f_{\text{SCLK}}=4\text{MHz}$)

The POL bit in T3CR register determines the polarity of PWM waveform. Setting POL=1 makes the PWM waveform high for duty value. In other case, PWM waveform is low for duty value.

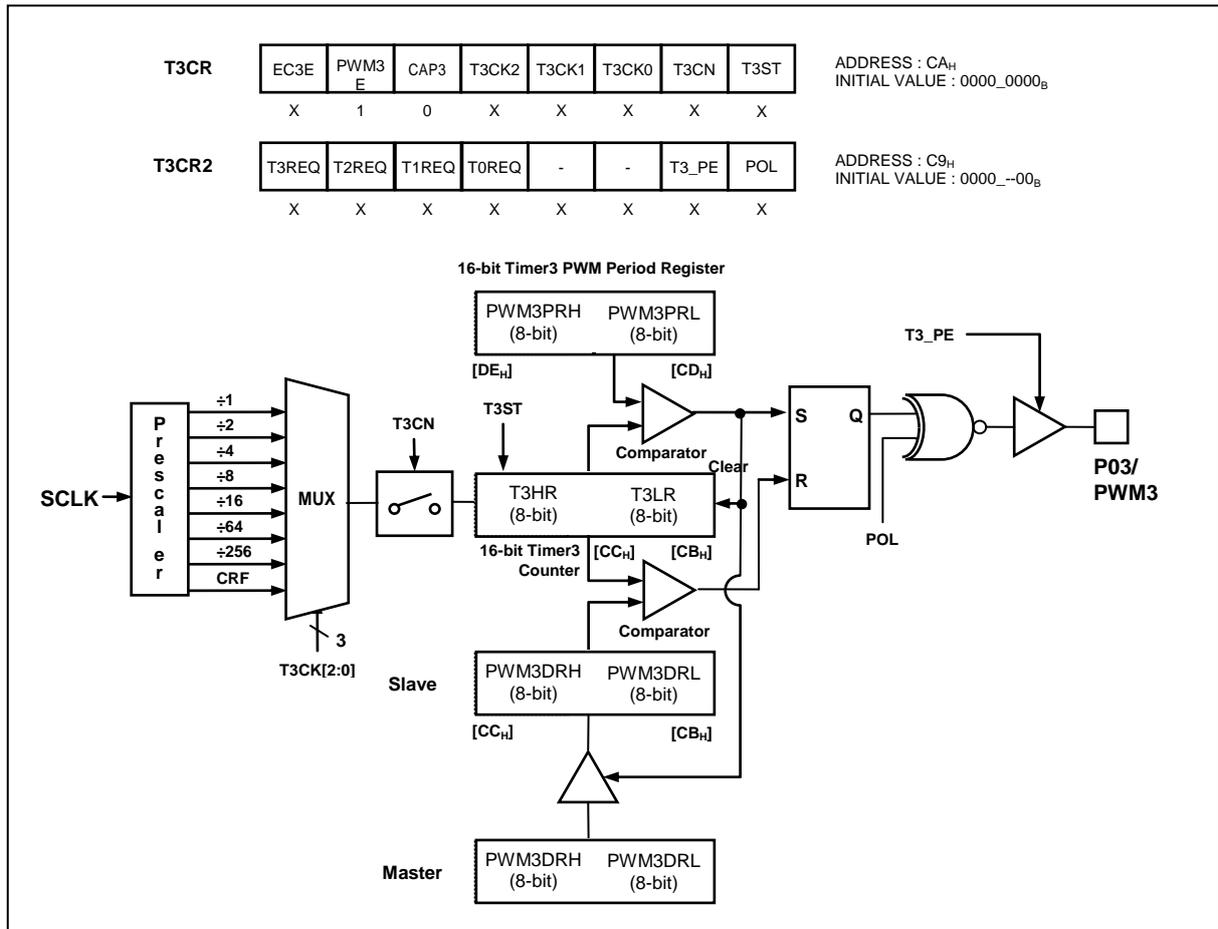


Figure 11-22 Block Diagram of Timer 3 in PWM Mode

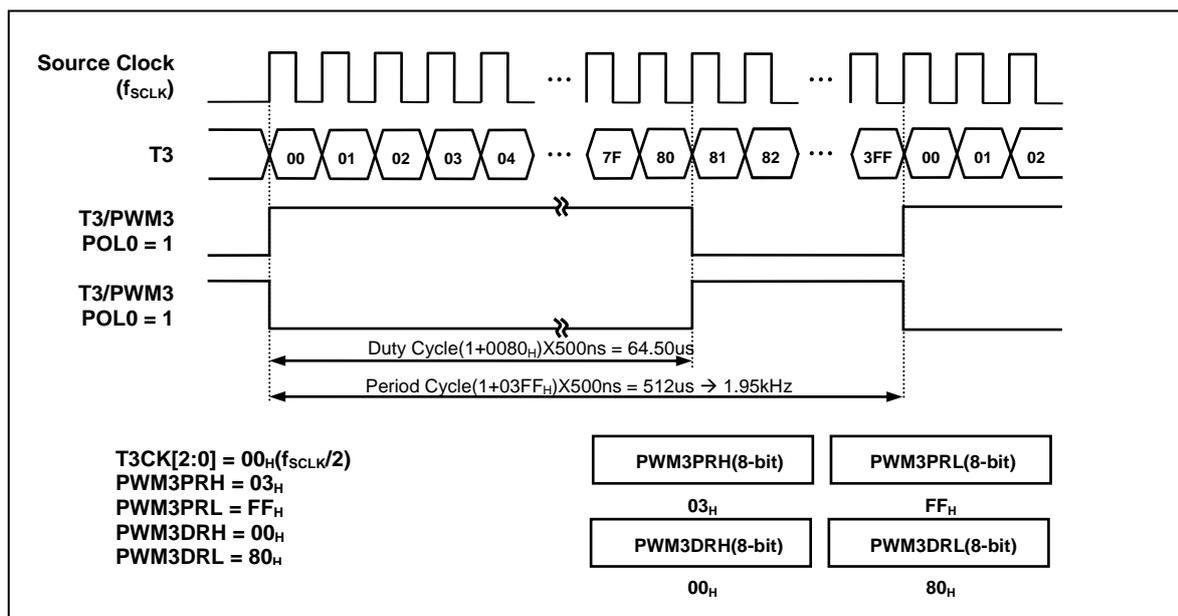


Figure 11-23 Example of PWM waveform (In case of $f_{SCLK}=4\text{MHz}$)

11.4.3.6 Register Map

Name	Address	Dir	Default	Description
T3CR2	C9 _H	R/W	00 _H	Timer 3 Mode Control Register 2
T3CR	CA _H	R/W	00 _H	Timer 3 Mode Control Register
T3L	CB _H	R	00 _H	Timer 3 Counter Low
PWM3DRL	CB _H	R/W	00 _H	PWM 3 Duty Register Low
CDR3L	CB _H	R	00 _H	Timer 3 Capture Data Register Low
T3H	CC _H	R	00 _H	Timer 3 Counter High
PWM3DRH	CC _H	R/W	00 _H	PWM 3 Duty Register High
CDR3H	CC _H	R	00 _H	Timer 3 Capture Data Register High
T3DRL	CD _H	W	FF _H	Timer 3 Data Register Low
PWM3PRL	CD _H	W	FF _H	PWM 3 Period Register Low
T3DRH	CE _H	W	FF _H	Timer 3 Data Register High
PWM3PRH	CE _H	W	FF _H	PWM 3 Peiord Register High

Table 11-9 Register Map of Timer 3

11.4.3.7 Register Description

Timer3 can generate PWM output of 16-bit resolution. The period of PWM3 is decided by PWM3PRH and PWM3PRL registers and the duty of PWM3 is decided by PWM3DRH and PWM3DRL registers. PWM3PRH and PWM3PRL registers are write-only. Note that the value of period and duty registers can be changed only when PWM3E bit in T3CR register is set.

CDR3H, PWM3DRH and T3H registers share peripheral address. When PWM mode is enabled, reading this address gives PWM3DRH. When PWM mode is disabled, reading this address gives CDR3H in Capture Mode or T3H in Output Compare Mode. Writing this address alters PWM3DRH when PWM3E bit is '1'. When PWM mode is disabled, writing this address alters T3DRH.

CDR3L, PWM3DRL and T3L registers share peripheral address. When PWM mode is enabled, reading this address gives PWM3DRL. When PWM mode is disabled, reading this address gives CDR3L in Capture Mode or T3L in Output Compare Mode. Writing this address alters PWM3DRL when PWM3E bit is '1'. When PWM mode is disabled, writing this address alters T3DRL.

T3CR (Timer 3 Mode Control Register)

CA_H

7	6	5	4	3	2	1	0
EC3E	PWM3E	CAP3	T3CK2	T3CK1	T3CK0	T3CN	T3ST
RW	RW	RW	RW	RW	RW	RW	RW

Initial value : 00_H

EC3E	Enable event counter mode of Timer 3. 0 Timer 3 is a normal counter. 1 Timer 3 is an event counter clocked by EC3.																																				
PWM3E	Enable PWM function of Timer 3 0 Timer 3 is Normal Timer/Counter 1 Timer 1 is PWM																																				
CAP3	Selects operating mode of Timer 3 0 Timer/Counter mode 1 Capture mode																																				
T3CK[2:0]	Selects the clock source of Timer 3. ^{NOTE} <table border="1"> <thead> <tr> <th>T3CK2</th> <th>T3CK1</th> <th>T3CK0</th> <th>Timer 3 clock</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>0</td> <td>f_{SCLK}</td> </tr> <tr> <td>0</td> <td>0</td> <td>1</td> <td>f_{SCLK}/2¹</td> </tr> <tr> <td>0</td> <td>1</td> <td>0</td> <td>f_{SCLK}/2²</td> </tr> <tr> <td>0</td> <td>1</td> <td>1</td> <td>f_{SCLK}/2³</td> </tr> <tr> <td>1</td> <td>0</td> <td>0</td> <td>f_{SCLK}/2⁴</td> </tr> <tr> <td>1</td> <td>0</td> <td>1</td> <td>f_{SCLK}/2⁶</td> </tr> <tr> <td>1</td> <td>1</td> <td>0</td> <td>f_{SCLK}/2⁸</td> </tr> <tr> <td>1</td> <td>1</td> <td>1</td> <td>CRF (Carrier)</td> </tr> </tbody> </table>	T3CK2	T3CK1	T3CK0	Timer 3 clock	0	0	0	f _{SCLK}	0	0	1	f _{SCLK} /2 ¹	0	1	0	f _{SCLK} /2 ²	0	1	1	f _{SCLK} /2 ³	1	0	0	f _{SCLK} /2 ⁴	1	0	1	f _{SCLK} /2 ⁶	1	1	0	f _{SCLK} /2 ⁸	1	1	1	CRF (Carrier)
T3CK2	T3CK1	T3CK0	Timer 3 clock																																		
0	0	0	f _{SCLK}																																		
0	0	1	f _{SCLK} /2 ¹																																		
0	1	0	f _{SCLK} /2 ²																																		
0	1	1	f _{SCLK} /2 ³																																		
1	0	0	f _{SCLK} /2 ⁴																																		
1	0	1	f _{SCLK} /2 ⁶																																		
1	1	0	f _{SCLK} /2 ⁸																																		
1	1	1	CRF (Carrier)																																		
T3CN	Decides whether to pause or continue counting 0 Pause counting temporarily 1 Continue to count																																				
T3ST	Decides whether to start or stop counter 0 Stops counting 1 Clear counter and starts up-counting																																				

^{NOTE} f_{SCLK} is the frequency of internal operating clock, SCLK.

T3CR2 (Timer 3 Mode Control Register 2)

C9_H

7	6	5	4	3	2	1	0
T3REQ	T2REQ	T1REQ	T0REQ	-	-	T3_PE	POL3
R	R	R	R	-	-	RW	RW

Initial value : 00_H

T3REQ	Timer 3 Interrupt Flag ^{NOTE} 0 Timer 3 interrupt not occurred 1 Timer 3 interrupt occurred
T2REQ	Timer 2 Interrupt Flag ^{NOTE}

	0	Timer 2 interrupt not occurred
	1	Timer 2 interrupt occurred
T1REQ		Timer 1 Interrupt Flag ^{NOTE}
	0	Timer 1 interrupt not occurred
	1	Timer 1 interrupt occurred
T0REQ		Timer 0 Interrupt Flag ^{NOTE}
	0	Timer 0 interrupt not occurred
	1	Timer 0 interrupt occurred
POL3		Selects polarity of PWM
	0	PWM waveform is low for duty value
	1	PWM waveform is high for duty value
T3_PE		Controls whether to output Timer 3 output or not through I/O pin.
	0	Timer 3 output does not come out through I/O pin
	1	Timer 3 output overrides the normal port functionality of I/O pin

^{NOTE} Writing '0' to this bit position clears interrupt flag of each timer.

T3L (Timer 3 Counter Low, Read Case)

CB_H

7	6	5	4	3	2	1	0
T3L7	T3L6	T3L5	T3L4	T3L3	T3L2	T3L1	T3L0
R	R	R	R	R	R	R	R

Initial value : 00_H

T3L[7:0] T3 Counter Low

CDR3L (Capture Data Register 3 Low, Read Case)

CB_H

7	6	5	4	3	2	1	0
CDR3L7	CDR3L6	CDR3L5	CDR3L4	CDR3L3	CDR3L2	CDR3L1	CDR3L0
R	R	R	R	R	R	R	R

Initial value : 00_H

CDR3L[7:0] T3 Capture Data Low

PWM3DRL (PWM3 Duty Register Low, Write Case)

CB_H

7	6	5	4	3	2	1	0
T3PDL7	T3PDL6	T3PDL5	T3PDL4	T3PDL3	T3PDL2	T3PDL1	T3PDL0
W	W	W	W	W	W	W	W

Initial value : 00_H

T3PDL[7:0] PWM3 Duty Low

^{NOTE} Writing is effective only when PWM3E = 1 and T3ST = 0.

T3H (Timer 3 Counter High, Read Case)

CC_H

7	6	5	4	3	2	1	0
T3H7	T3H6	T3H5	T3H4	T3H3	T3H2	T3H1	T3H0
R	R	R	R	R	R	R	R

Initial value : 00_H

T3H[7:0] T3 Counter High

CDR3H (Capture Data Register 3 High, Read Case)**CC_H**

7	6	5	4	3	2	1	0
CDR3H7	CDR3H6	CDR3H5	CDR3H4	CDR3H3	CDR3H2	CDR3H1	CDR3H0
R	R	R	R	R	R	R	R

Initial value : 00_H**CDR3H[7:0]** T3 Capture Data High**PWM3DRH (PWM3 Duty Register High, Write Case)****CC_H**

7	6	5	4	3	2	1	0
T3PDH7	T3PDH6	T3PDH5	T3PDH4	T3PDH3	T3PDH2	T3PDH1	T3PDH0
W	W	W	W	W	W	W	W

Initial value : 00_H**T3PDH[7:0]** PWM3 Duty HighNOTE Writing is effective only when PWM3E = 1 and T3ST = 0.**T3DRL (Timer 3 Data Register Low, Write Case)****CD_H**

7	6	5	4	3	2	1	0
T3DRL7	T3DRL6	T3DRL5	T3DRL4	T3DRL3	T3DRL2	T3DRL1	T3DRL0
W	W	W	W	W	W	W	W

Initial value : FF_H**T3DRL[7:0]** T3 Compare Data LowNOTE Be sure to clear PWM3E in T3CR register before loading this register.**PWM3PRL (PWM3 Period Register Low, Write Case)****CD_H**

7	6	5	4	3	2	1	0
T3PPL7	T3PPL6	T3PPL5	T3PPL4	T3PPL3	T3PPL2	T3PPL1	T3PPL0
W	W	W	W	W	W	W	W

Initial value : FF_H**T3PPL[7:0]** PWM3 Period LowNOTE Writing is effective only when PWM3E = 1 and T3ST = 0.**T3DRH (Timer 3 Data Register High, Write Case)****CE_H**

7	6	5	4	3	2	1	0
T3DRH7	T3DRH6	T3DRH5	T3DRH4	T3DRH3	T3DRH2	T3DRH1	T3DRH0
W	W	W	W	W	W	W	W

Initial value : FF_H**T3DRH[7:0]** T3 Compare Data HighNOTE Be sure to clear PWM3E in T3CR register before loading this register.**PWM3PRH (PWM3 Period Register High, Write Case)****CE_H**

7	6	5	4	3	2	1	0
P3PPH7	P3PPH6	P3PPH5	P3PPH4	P3PPH3	P3PPH2	P3PPH1	P3PPH0
W	W	W	W	W	W	W	W

Initial value : FF_H

P3PPH[7:0]

PWM3 Period High

NOTE Writing is effective only when PWM3E = 1 and T3ST = 0.

11.5 Watch Timer with event capture function (WT)

11.5.1 Overview

The watch timer (WT) has the function for RTC (Real Time Clock) operation. This module consists of the clock source select circuit, timer counter circuit, output select circuit and control registers. To activate watch timer, determine the input clock source, output interval and then set WTEN bit in Watch Timer Mode Register (WTMR). Control bits can be set individually or at a time. To stop or reset WT, clear the WTEN bit in WTMR. To obtain high resolution, the counter of WT is composed of low 14-bit binary counter(=WTIR) and high 7-bit counter(=WT_TMR), that makes the WT counter to become 21-bit wide. The high and low counters are auto-cleared when each counter reaches to their pre-defined data values. The WT Interrupt Interval is determined by writing to WTDRH, WTDR1 and WTDR0 registers. To read each WTDRH, WTDR1 and WTDR0 returns WT_TMR, high 6-bit of WTIR, and low 8-bit of WTIR counter value.

When Watch timer operates in IR capture mode, the WT is a simple 14-bit up counter and the counter is auto-cleared by the rising edge of an incoming event source. In this mode of operation, the 7-bit counter WT_TMR stops operation and the WTIR counter value is captured into WTCR0, WTCR1, WTCR2 registers on detecting the rising or falling edge of input carrier signal. The capture sequence is decided according to the setting of SINGLE and PHASE bits in IRCC1 register.

Note that the divide ratio of input clock applies in different manner whether WT is in normal WT mode or in IR capture mode.

11.5.2 Block Diagram

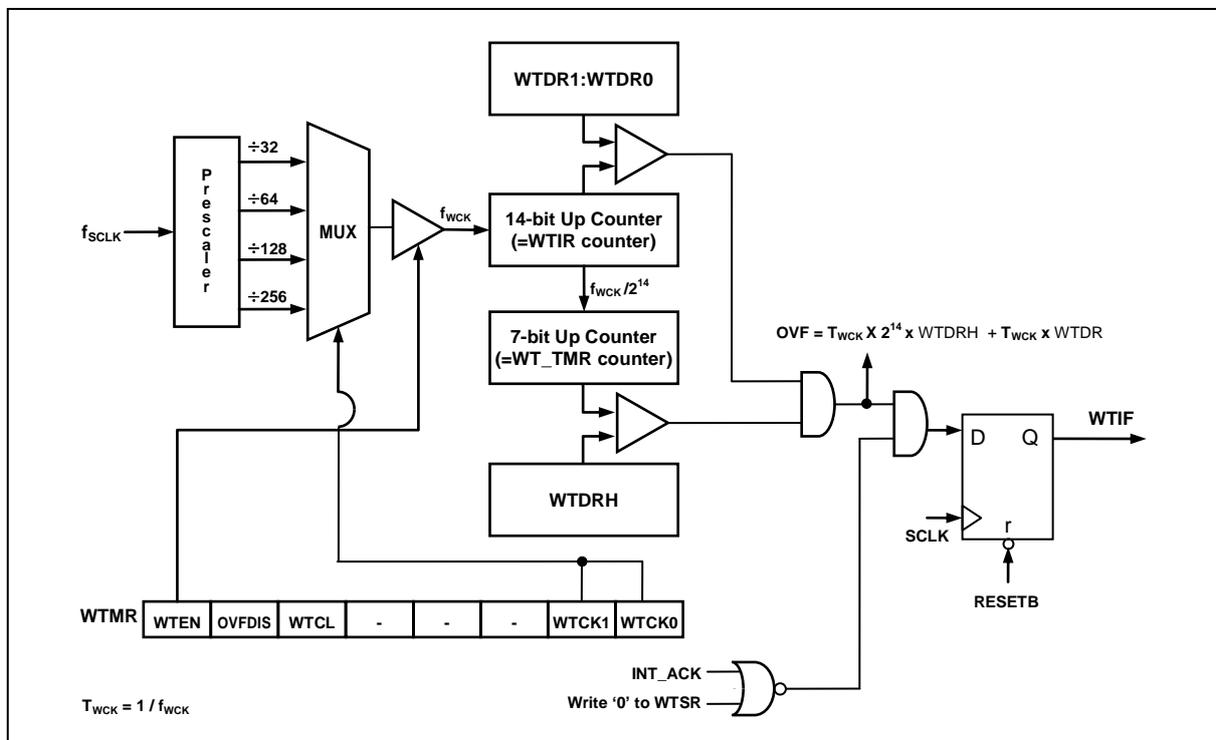


Figure 11-24 Block Diagram of Watch Timer in Normal mode

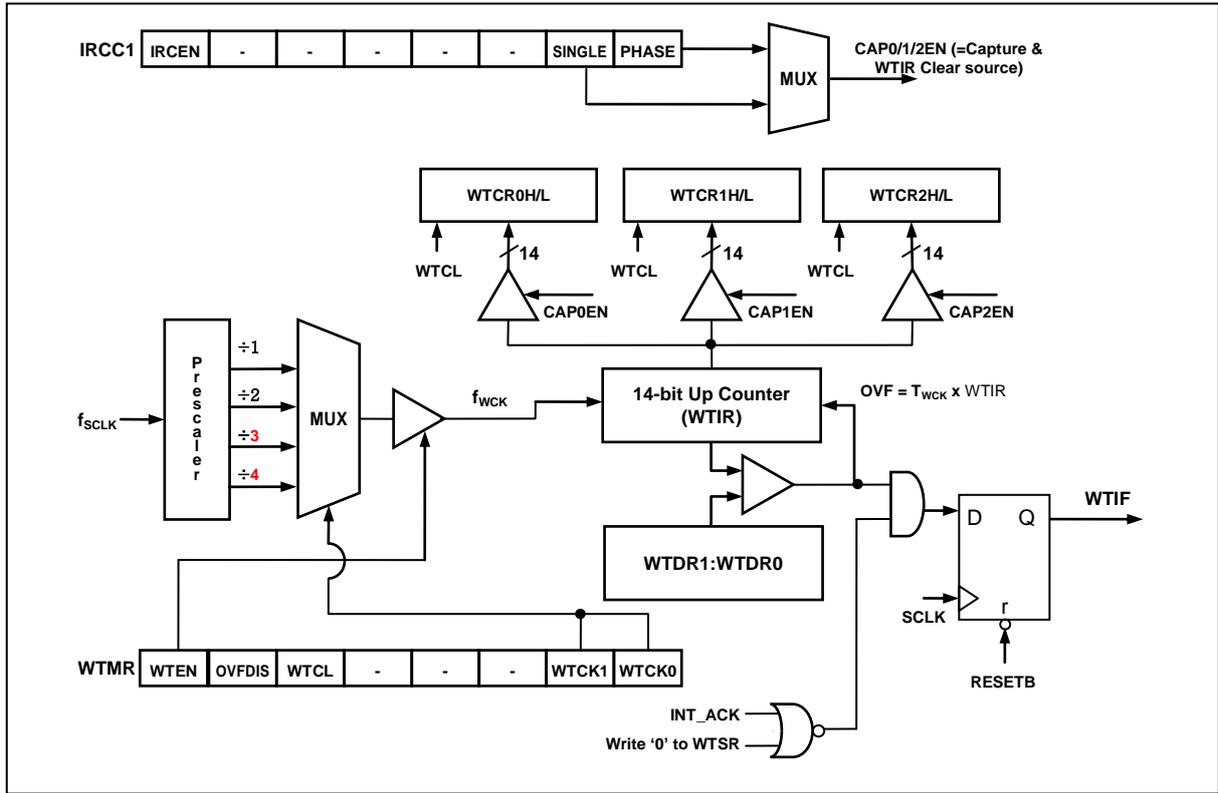


Figure 11-25 Block Diagram of Watch Timer in IR capture mode

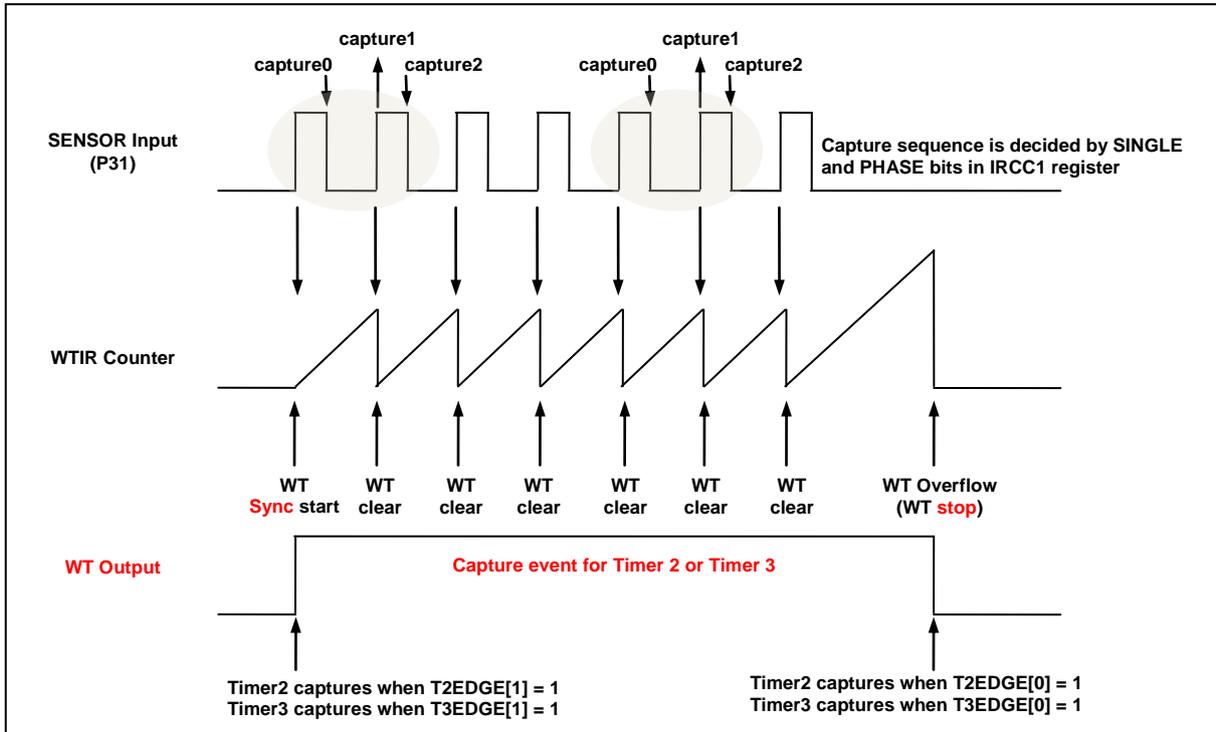


Figure 11-26 Timing Diagram of Watch Timer in IR capture mode

11.5.3 Register Map

Name	Address	Dir	Default	Description
WTMR	D1 _H	R/W	00 _H	Watch Timer Mode Register
WTDR1	D4 _H	W	3F _H	Watch Timer Data Register 1
WTDR0	D5 _H	W	FF _H	Watch Timer Data Register 0
WTSR	D9 _H	R	00 _H	Watch Timer Status Register
WTDRH	DC _H	W	7F _H	Watch Timer Data Register High
WTCR0H	F1 _H	R	3F _H	Watch Timer Capture Register0 High
WTCR0L	F2 _H	R	FF _H	Watch Timer Capture Register0 Low
WTCR1H	F3 _H	R	3F _H	Watch Timer Capture Register1 High
WTCR1L	F4 _H	R	FF _H	Watch Timer Capture Register1 Low
WTCR2H	F5 _H	R	3F _H	Watch Timer Capture Register2 High
WTCR2L	F6 _H	R	FF _H	Watch Timer Capture Register2 Low

Table 11-10 Register Map of Watch Timer

11.5.4 Register Description

WTMR (Watch Timer Mode Register)

D1_H

7	6	5	4	3	2	1	0
WTEN	OVFDIS	WTCL	-	-	-	WTCK1	WTCK0
RW	RW	RW	-	-	-	RW	RW

Initial value : 00_H

WTEN	Enable Watch Timer		
0	Disable WT		
1	Enable WT		
OVFDIS	Control auto clear function of WT when counters overflow. ^{NOTE1}		
0	Auto clear counters when overflow		
1	Overflow event is ignored		
WTCL	Clear counter of Watch Timer		
0	No operation (Free Run mode)		
1	Clear WT counter (Auto-clear after 1 cycle)		
WTCK[1:0]	Select clock source of WT ($\neq f_{WCK}$) ^{NOTE2}		
WTCK1	WTCK0	Watch Timer mode	IR Capture mode
0	0	$f_{SCLK}/32$	f_{SCLK}
0	1	$f_{SCLK}/64$	$f_{SCLK}/2$
1	0	$f_{SCLK}/128$	$f_{SCLK}/3$
1	1	$f_{SCLK}/256$	$f_{SCLK}/4$

^{NOTE1} The overflow means WT_TMR equals to WTDRH, and WTIR equals to WTCR1/0 when WT is in Watch Timer mode. In IR capture mode, the overflow condition occurs when WTIR equals to WTCR1/0.

^{NOTE2} f_{SCLK} is the frequency of system clock, SCLK.

f_{WCK} is the frequency of WTIR counter clock

WTDR1 (Watch Timer Data Register 1)

D4_H

7	6	5	4	3	2	1	0
-	-	WTDR13	WTDR12	WTDR11	WTDR10	WTDR9	WTDR8

-	-	W	W	W	W	W	W
---	---	---	---	---	---	---	---

Initial value : 3F_H

WTDR[13:8] Select WT overflow period. Reading this register returns the high 8-bit WTIR counter value.
 WT Interrupt Interval = (Twck x 2¹⁴) x (7-bit WTDRH) + (Twck x 14-bit WTDR)

WTDR0 (Watch Timer Data Register 0) D5_H

7	6	5	4	3	2	1	0
WTDR7	WTDR6	WTDR5	WTDR4	WTDR3	WTDR2	WTDR1	WTDR0
W	W	W	W	W	W	W	W

Initial value : FF_H

WTDR[7:0] Select WT overflow period. Reading this register returns the low 8-bit WTIR counter value.

WTSR (Watch Timer Status Register) D9_H

7	6	5	4	3	2	1	0
IRI	-	-	-	-	-	-	WTIFR
R	-	-	-	-	-	-	R

Initial value : 00_H

IRI IRI status (IRAMP output or Port input)
 0 IRI is '0'
 1 IRI is '1'

WTIFR Interrupt flag of WT. This flag bit is cleared when the interrupt is serviced or by writing '0' to this bit field.
 0 No WT interrupt is generated
 1 WT interrupt occurred

WTDRH (Watch Timer Data Register High) DC_H

7	6	5	4	3	2	1	0
-	WTDRH6	WTDRH5	WTDRH4	WTDRH3	WTDRH2	WTDRH1	WTDRH0
-	W	W	W	W	W	W	W

Initial value : 7F_H

WTDRH[6:0] Select WT overflow period. Reading this register returns WT_TMR counter value, the high 7-bit counter.

WTCR0H (Watch Timer Capture Register 0 High) F1_H

7	6	5	4	3	2	1	0
-	-	WTCR013	WTCR012	WTCR011	WTCR010	WTCR009	WTCR008
-	-	R	R	R	R	R	R

Initial value : 3F_H

WTCR0[13:8] When WT is in IR capture mode, the high 6-bit of WTIR counter is captured to this register at the first falling edge (when PHASE bit is '0') or first rising edge (when PHASE bit is '1') of input carrier signal. This register is initialized by setting **WTCL** bit in **WTMR**.

WTCR0L (Watch Timer Capture Register 0 Low)**F2_H**

7	6	5	4	3	2	1	0
WTCR007	WTCR006	WTCR005	WTCR004	WTCR003	WTCR002	WTCR001	WTCR000
R	R	R	R	R	R	R	R

Initial value : FF_H**WTCR0[7:0]**

When WT is in IR capture mode, the low 8-bit of WTIR counter is captured to this register at the first falling edge (when PHASE bit is '0') or first rising edge (when PHASE bit is '1') of input carrier signal. This register is initialized by setting WTCL bit in WTMR.

WTCR1H (Watch Timer Capture Register 1 High)**F3_H**

7	6	5	4	3	2	1	0
-	-	WTCR113	WTCR112	WTCR111	WTCR110	WTCR109	WTCR108
-	-	R	R	R	R	R	R

Initial value : 3F_H**WTCR1[13:8]**

When WT is in IR capture mode, the high 6-bit of WTIR counter is captured to this register at the second rising edge (when PHASE bit is '0') or first falling edge (when PHASE bit is '1') of input carrier signal. This register is initialized by setting WTCL bit in WTMR.

WTCR1L (Watch Timer Capture Register 1 Low)**F4_H**

7	6	5	4	3	2	1	0
WTCR107	WTCR106	WTCR105	WTCR104	WTCR103	WTCR102	WTCR101	WTCR100
R	R	R	R	R	R	R	R

Initial value : FF_H**WTCR1[7:0]**

When WT is in IR capture mode, the low 8-bit of WTIR counter is captured to this register at the second rising edge (when PHASE bit is '0') or first falling edge (when PHASE bit is '1') of input carrier signal. This register is initialized by setting WTCL bit in WTMR.

WTCR2H (Watch Timer Capture Register 2 High)**F5_H**

7	6	5	4	3	2	1	0
-	-	WTCR213	WTCR212	WTCR211	WTCR210	WTCR209	WTCR208
-	-	R	R	R	R	R	R

Initial value : 3F_H**WTCR2[13:8]**

When WT is in IR capture mode, the high 6-bit of WTIR counter is captured to this register at the second falling edge (when PHASE bit is '0') or second rising edge (when PHASE bit is '1') of input carrier signal. This register is initialized by setting WTCL bit in WTMR.

WTCR2L (Watch Timer Capture Register 2 Low)**F6_H**

7	6	5	4	3	2	1	0
WTCR207	WTCR206	WTCR205	WTCR204	WTCR203	WTCR202	WTCR201	WTCR200
R	R	R	R	R	R	R	R

Initial value : FF_H**WTCR2[7:0]**

When WT is in IR capture mode, the low 8-bit of WTIR counter is

captured to this register at the second falling edge (when PHASE bit is '0') or second rising edge (when PHASE bit is '1') of input carrier signal. This register is initialized by setting WTCL bit in WTMR.

The WT interrupt is requested only when overflow condition occurs. That is when WT is in IR capture mode, the interrupt is not issued even when capture event is generated.

11.6 IR Capture Control (IRCC)

11.6.1 Overview

MC96FR116C has an IR capture module which receives and captures the incoming digital IR signal to detect the IR carrier frequency and count the carrier number. With this module, the Watch Timer and Timer 2 can be configured to operate in IR capture mode by setting IRCEN bit in IRCC1 register. Also Timer 3 can support IR capture feature. Both Timer 2 and Timer 3 can detect the envelope of incoming carrier or count the number of input carrier signal according to the setting of IRCC2 register.

11.6.2 Block Diagram

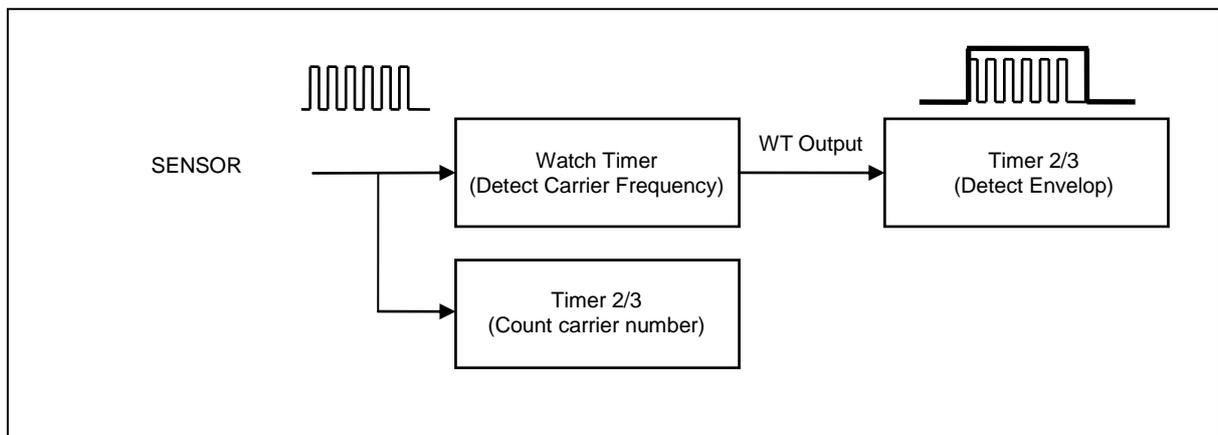


Figure 11-27 Block Diagram of IR Capture function

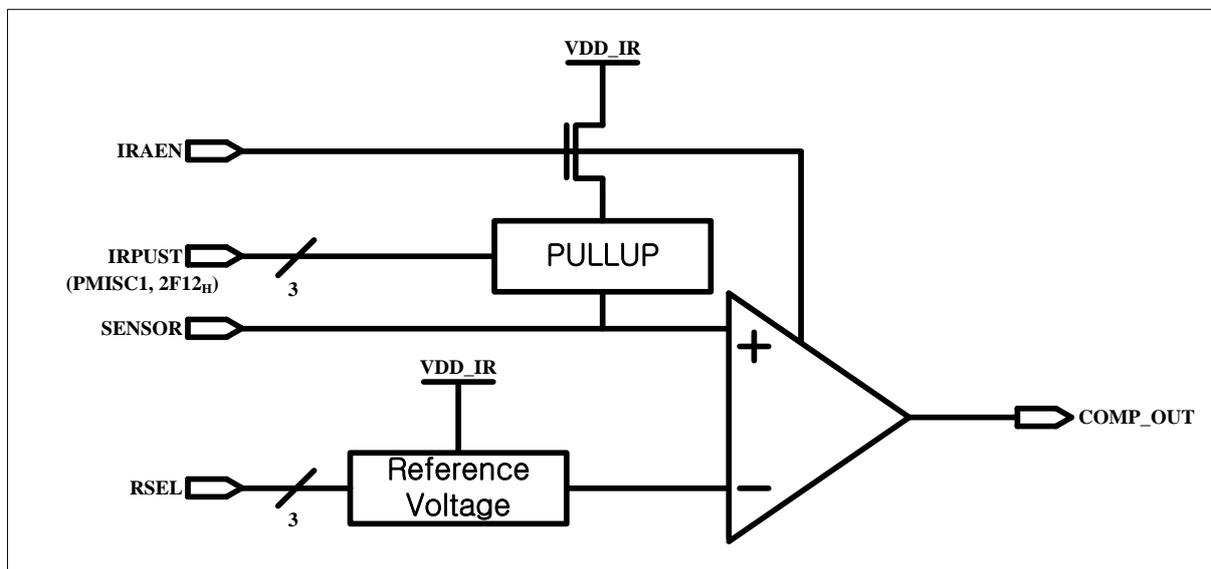


Figure 11-28 Block Diagram of IR AMP

11.6.3 Register Map

Name	Address	Dir	Default	Description
IRCC0	DD _H	R/W	00 _H	IR Capture Control Register 0
IRCC1	DE _H	R/W	00 _H	IR Capture Control Register 1
IRCC2	DF _H	R/W	00 _H	IR Capture Control Register 2

Table 11-11 Register Map of IR Capture Control module

11.6.4 Register Description

IRCC0 (IR Capture Control Register 0)

DD_H

7	6	5	4	3	2	1	0
IRAEN	-	-	-	-	RSEL2	RSEL1	RSEL0
R/W	-	-	-	-	R/W	R/W	R/W

Initial value : 00_H

- IRAEN** Enable or disable IR AMP.
 0 Disable IR AMP
 1 Enable IR AMP
- RSEL[2:0]** Select reference voltage.
 0 0 0 V0 (56/64 VDD_IR)
 0 0 1 V1 (57/64 VDD_IR)
 0 1 0 V2 (58/64 VDD_IR)
 0 1 1 V3 (59/64 VDD_IR)
 1 0 0 V4 (60/64 VDD_IR)
 1 0 1 V5 (61/64 VDD_IR)
 1 1 0 V6 (62/64 VDD_IR)
 1 1 1 V7 (63/64 VDD_IR)
 X X X IRAEN = 0; Disable (V0~V7=0V)

IRCC1 (IR Capture Register 1)

DE_H

7	6	5	4	3	2	1	0
IRCEN	IRIIF	IREEDGE1	IREEDGE0	-	IRPOL	SINGLE	PHASE
R/W	R	R/W	R/W	-	R/W	R/W	R/W

Initial value : 00_H

- IRCEN** Control operation mode of WT, T2 and T3
 0 IR capture mode is disabled, normal timer function
 1 IR capture mode is enabled (WT, T2 and T3 modules are under control of this bit)
- IRIIF** Interrupt flag of IRI input. This flag is cleared by writing '0' to this bit field or interrupt is serviced.
 0 No IRI input is generated
 1 IRI interrupt is generated on the condition by IREEDGE[1:0] bits
- IREEDGE[1:0]** Select IRI interrupt triggering condition.
 00 IRI interrupt is disabled
 01 Interrupt is triggered on falling edge of IRI input
 10 Interrupt is triggered on rising edge of IRI input

	11	Interrupt is triggered on both edge of IRI input
IRPOL	Select the polarity of WT input source.	
	0	The inverted signal from IRAMP output(=COMP_OUT) or PAD_REM_OUT input becomes the input source of WT.
	1	The multiplexed output of IRAMP output(=COMP_OUT) or PAD_REM_OUT input becomes the input source of WT.
SINGLE	Select carrier capture numbers. Used with the PHASE bit.	
	0	Capture continuously until WTIR overflows(=WTIR reaches to pre-defined value, WTDR1 and WTDR0)
	1	Capture first 3 edges of carrier signal
PHASE	Select carrier capture sequence. Used with the SINGLE bit.	
	0	Capture sequence is 1 st Falling→Rising→Falling edge
	1	Capture sequence is 1 st Rising→Falling→Rising edge

IRCC2 (IR Capture Register 2)

DF_H

7	6	5	4	3	2	1	0
T3IR	T2IR	-	-	T3EDGE1	T3EDGE0	T2EDGE1	T2EDGE0
R/W	R/W	-	-	R/W	R/W	R/W	R/W

Initial value : 00_H

T3IR	Make T3 to calculate the number of incoming carrier signal if CAP3 bit in T3CR bit is not '1'.
	0 Timer 3 is in normal operation
	1 Timer 3 calculates the number of incoming carrier signals.
T2IR	Make T2 to calculate the number of incoming carrier signal if CAP2 bit in T2CR bit is not '1'.
	0 Timer 2 is in normal operation
	1 Timer 2 calculates the number of incoming carrier signals.
T3EDGE[1:0]	Select capture edge when T3 is used for envelop detection of incoming carrier signal. These bits should be cleared to '00' when T3 operates in normal capture mode, or the WT output becomes capture source of Timer 3. The T3IR bit should be cleared to '0' also.
	00 No capture
	01 Falling edge
	10 Rising edge
	11 Both edge
T2EDGE[1:0]	Select capture edge when T2 is used for envelop detection of incoming carrier signal. These bits should be cleared to '00' when T2 operates in normal capture mode, or the WT output becomes capture source of Timer 2. The T2IR bit should be cleared to '0' also.
	00 No capture
	01 Falling edge
	10 Rising edge
	11 Both edge

The next table shows register setting for Timer 2 and 3 for IR capture features.

IRGEN	CAP2(3)	T2(3)IR	T2(3)EDGE[1:0]	Timer 2(3) Operating Mode
0	0	0	XX	Normal 16-bit Counter
0	1	X	00	Normal 16-bit Capture

1	1	X	01, 10, 11	IR Capture (Envelop detect)
1	0	1	XX	Count IR Carrier

Table 11-12 Operating modes of Timer 2(3)

11.7 Carrier Generator

11.7.1 Overview

MC96FR116C has a specific module to generate carrier signal for remote control application. The internal carrier(CRF) signal is AND-ed with register value(RODR) and outputs through REMOUT port. The frequency and duty ratio of carrier signal is controlled by two 8-bit registers, CFRH and CFRL. Carrier signal can be on/off at previous stage of REMOUT port by the CEN bit in RMR register. When CEN=1, the remote out signal is generated by AND-ing carrier signal with RODR value. When CEN=0, the 8-bit counter for carrier generation(=CRC) stops and the remote out signal comes directly from RODR value. The RODR register is updated by ROB register when the 16-bit counter for data pulse generation(=RDC) reaches to RDRH or RDRL^{NOTE}. In this case, the RDPE bit in RMR should be '1'. At each match event, an interrupt can be issued. The RODR register can also be altered by writing to this register. In this case, the RDPE bit is to be cleared to '0'. The base clock for RDC and CRC is system clock, SCLK or its divided clock. Note that the output clock of main oscillator, XINCLK, may differ from SCLK.

^{NOTE} The concatenated RDRH and RDRL composes RDR value. And the RDR register is loaded with RDB(= concatenated RDBH and RDBL) when interrupt is generated. This is like the relationship between ROB and RODR.

11.7.2 Block Diagram

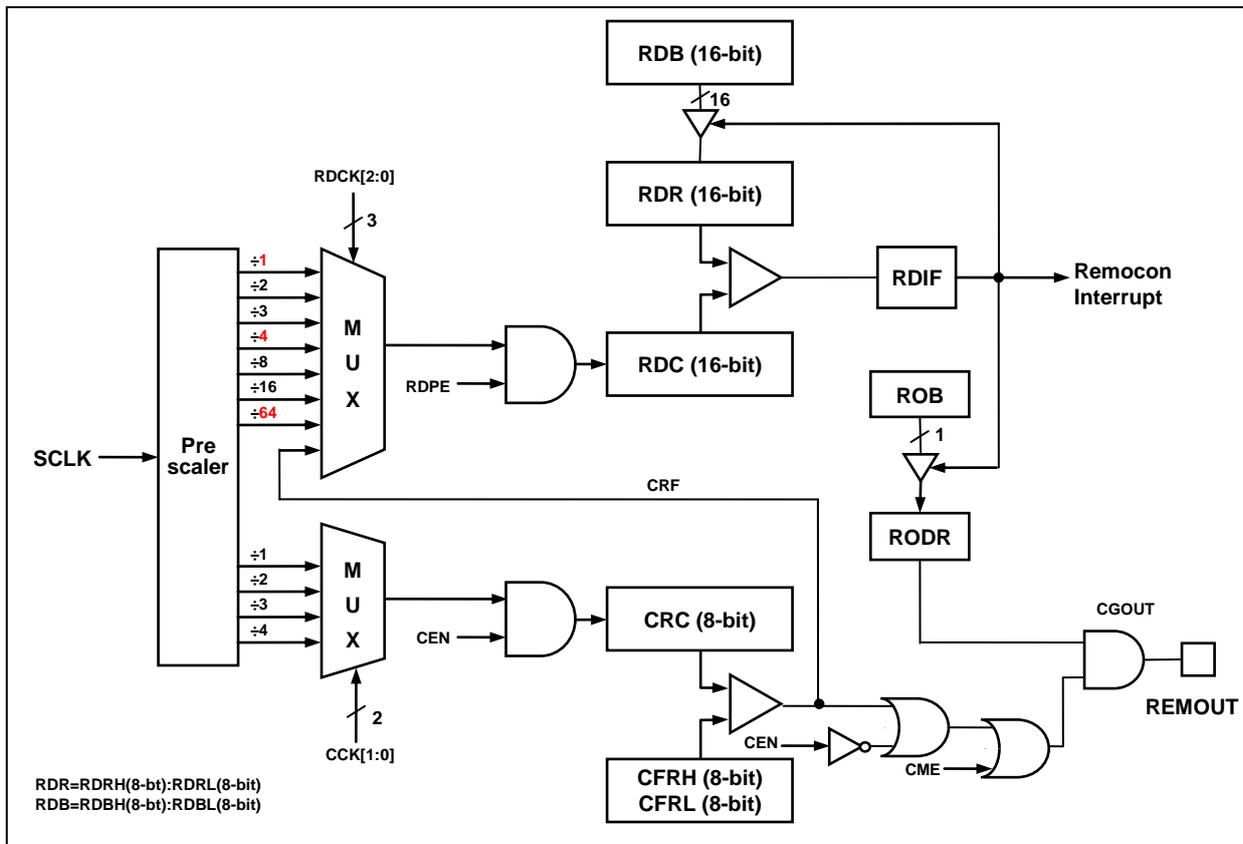


Figure 11-29 Block Diagram of Carrier Generator

11.7.3 Register Map

Name	Address	Dir	Default	Description
RMR	E8 _H	R/W	00 _H	Remocon Mode Register
RMR2	2F56 _H	R/W	00 _H	Remocon Mode Register 2
RDCH	BA _H	R	00 _H	Remocon Data Counter High
CFRH	BB _H	R/W	FF _H	Carrier Frequency Register High
CFRL	BC _H	R/W	FF _H	Carrier Frequency Register Low
RDCL	BD _H	R	00 _H	Remocon Data Counter Low
RODR	BE _H	R/W	00 _H	Remocon Output Data Register
ROB	BF _H	R/W	00 _H	Remocon Output Buffer
RDBH	C2 _H	R/W	FF _H	Remocon Data Buffer High
RDBL	C3 _H	R/W	FF _H	Remocon Data Buffer Low
RDRH	C4 _H	R/W	FF _H	Remocon Data Register High
RDRL	C5 _H	R/W	FF _H	Remocon Data Register Low

Table 11-13 Register Map of Carrier Generator

11.7.4 Register Description

RMR (Remocon Mode Register)

E8_H

7	6	5	4	3	2	1	0
RDIF	CEN	CCK1	CCK0	RDPE	RDCK2	RDCK1	RDCK0
R	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 00_H

RDIF Interrupt flag. This flag is cleared when the interrupt is serviced, RDPE bit is cleared or software writes '0' to this bit position. This flag has nothing to do with CEN bit. **Writing '1' to this bit sets the interrupt flag.**

RDCK[2:0] Selects clock source for 6-bit RDC counter. These bits are effective only when RDPE=1. ^{NOTE}

RDCK2	RDCK1	RDCK0	
0	0	0	f _{SCLK} /1
0	0	1	f _{SCLK} /2
0	1	0	f _{SCLK} /3
0	1	1	f _{SCLK} /4
1	0	0	f _{SCLK} /8
1	0	1	f _{SCLK} /16
1	1	0	f _{SCLK} /64
1	1	1	Carrier Signal(=CRF)

RDPE Remote Data Pulse Enable. Setting this bit enables RDC counter. Interrupt can only be issued when this bit is set.

0	Disable RDC counter
1	Enable RDC counter

CCK[1:0] Select clock source for 8-bit CRC counter. These bits are effective only when CEN=1. ^{NOTE}

0	0	f _{SCLK} /1
0	1	f _{SCLK} /2
1	0	f _{SCLK} /3
1	1	f _{SCLK} /4

CEN Carrier Frequency Enable. This bit enables CRC counter.
 0 Carrier Frequency is not generated.
 1 Carrier Frequency is generated and goes out through the REMOUT port with RODR value and-ed.

NOTE f_{SCLK} is the frequency of system clock, SCLK.

RMR2 (Remocon Mode Register 2) 2F56_H

7	6	5	4	3	2	1	0
-	-	-	-	-	-	-	CME
-	-	-	-	-	-	-	RW

Initial value : 00_H

CME Carrier Mask Enable
 0 Carrier is not masked.
 1 Carrier is masked.

CFRH (Carrier Frequency Register High) BB_H

7	6	5	4	3	2	1	0
CFH7	CFH6	CFH5	CFH4	CFH3	CFH2	CFH1	CFH0
RW							

Initial value : FF_H

CFH[7:0] Carrier Frequency High
 Carrier High Interval = CFH[7:0] X T_{CR_CLK}
 T_{CR_CLK} is the period of clock source for CRC counter selected by CCK[1:0].

CFRL (Carrier Frequency Register Low) BC_H

7	6	5	4	3	2	1	0
CFL7	CFL6	CFL5	CFL4	CFL3	CFL2	CFL1	CFL0
RW							

Initial value : FF_H

CFL[7:0] Carrier Frequency Low
 Carrier Low Interval = CFL[7:0] X T_{CR_CLK}
 T_{CR_CLK} is the period of clock source for CRC counter selected by CCK[1:0].

RDBH (Remocon Data Buffer High) C2_H

7	6	5	4	3	2	1	0
RDB15	RDB14	RDB13	RDB12	RDB11	RDB10	RDB9	RDB8
RW	RW	RW	RW	RW	RW	RW	RW

Initial value : FF_H

RDB[15:8] Remote Data High Buffer (Lower byte of RDB)

RDBL (Remocon Data Buffer Low) C3_H

7	6	5	4	3	2	1	0

RDB7	RDB6	RDB5	RDB4	RDB3	RDB2	RDB1	RDB0
R/W							

Initial value : FF_H

RDB[7:0] Remote Data Low Buffer (Lower byte of RDB).
The RDB is transferred to RDR when interrupt occurs.

RDRH (Remocon Data Register High)

C4_H

7	6	5	4	3	2	1	0
RDR15	RDR14	RDR13	RDR12	RDR11	RDR10	RDR9	RDR8
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : FF_H

RDR[15:8] Remote Data High (Higher byte of RDH)
Remote Data High Interval = RDR[15:0] X T_{RD_CLK}
T_{RD_CLK} is the period of clock source for RDC counter selected by RDCK[2:0].

RDRL (Remocon Data Register Low)

C5_H

7	6	5	4	3	2	1	0
RDR15	RDR14	RDR13	RDR12	RDR11	RDR10	RDR9	RDR8
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : FF_H

RDR[7:0] Remote Data Low (Lower byte of RDL)
Remote Data Low Interval = RDR[15:0] X T_{RD_CLK}
T_{RD_CLK} is the period of clock source for RDC counter selected by RDCK[2:0].

RDCH (Remocon Data Counter High)

BA_H

7	6	5	4	3	2	1	0
RDC15	RDC14	RDC13	RDC12	RDC11	RDC10	RDC9	RDC8
R	R	R	R	R	R	R	R

Initial value : 00_H

RDC[15:8] Data Counter Value High

RDCL (Remocon Data Counter Low)

BD_H

7	6	5	4	3	2	1	0
RDC7	RDC6	RDC5	RDC4	RDC3	RDC2	RDC1	RDC0
R	R	R	R	R	R	R	R

Initial value : 00_H

RDC[7:0] Data Counter Value High

RODR (Remocon Output Data Register)

BE_H

7	6	5	4	3	2	1	0
-	-	-	-	-	-	-	ROD
-	-	-	-	-	-	-	R/W

Initial value : 00_H

ROD Remote Data Output

ROB (Remocon Output Buffer)

BF_H

7	6	5	4	3	2	1	0
-	-	-	-	-	-	-	ROB
-	-	-	-	-	-	-	RW

Initial value : 00_H

ROB Remote Data Output Buffer

11.7.5 Carrier Signal and Data Pulse

The Remote Out signal(=CGOUT in Block Diagram) on REMOUT port is generated from carrier signal and RODR value. The carrier signal and RODR value are controlled independently. The CEN bit in RMR register makes the carrier signal on or off. The RODR register is updated by ROB on interrupt or by direct writing to this register. In this way, four kinds of signal muxing is supported using carrier signal and RODR value.

The period and frequency of carrier signal and remote data pulse is calculated by the following equation. The waveform is shown below.

$$t_H \text{ (Length of Carrier Signal's High Phase)} = T_{CR_CLK} \times CFRH[7:0]$$

$$t_L \text{ (Length of Carrier Signal's Low Phase)} = T_{CR_CLK} \times CFRL[7:0]$$

$$f_C \text{ (Carrier Frequency)} = 1/(t_H + t_L)$$

$$t_{DH} \text{ (Length of Data Pulse's High Phase)} = T_{RD_CLK} \times RDR[15:0]$$

$$t_{DL} \text{ (Length of Data Pulse's Low Phase)} = T_{RD_CLK} \times RDR[15:0]$$

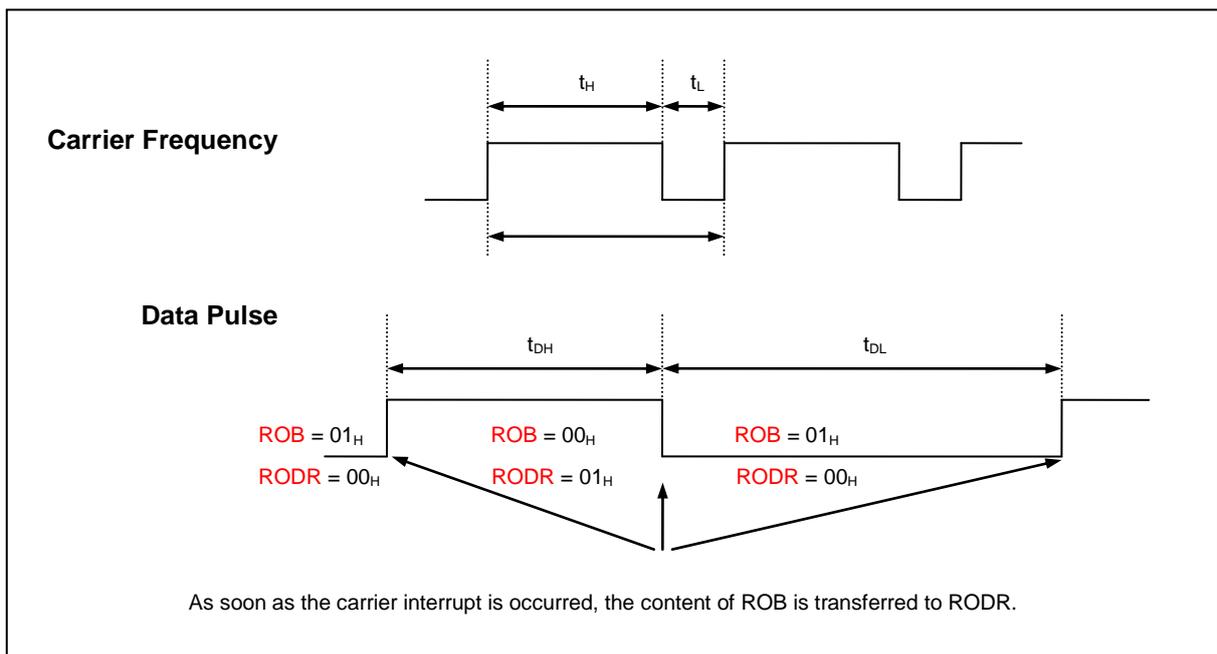


Figure 11-30 Period of Carrier signal and Remote data pulse

11.7.6 Examples of REMOUT control

Three examples of controlling REMOUT port are shown below.

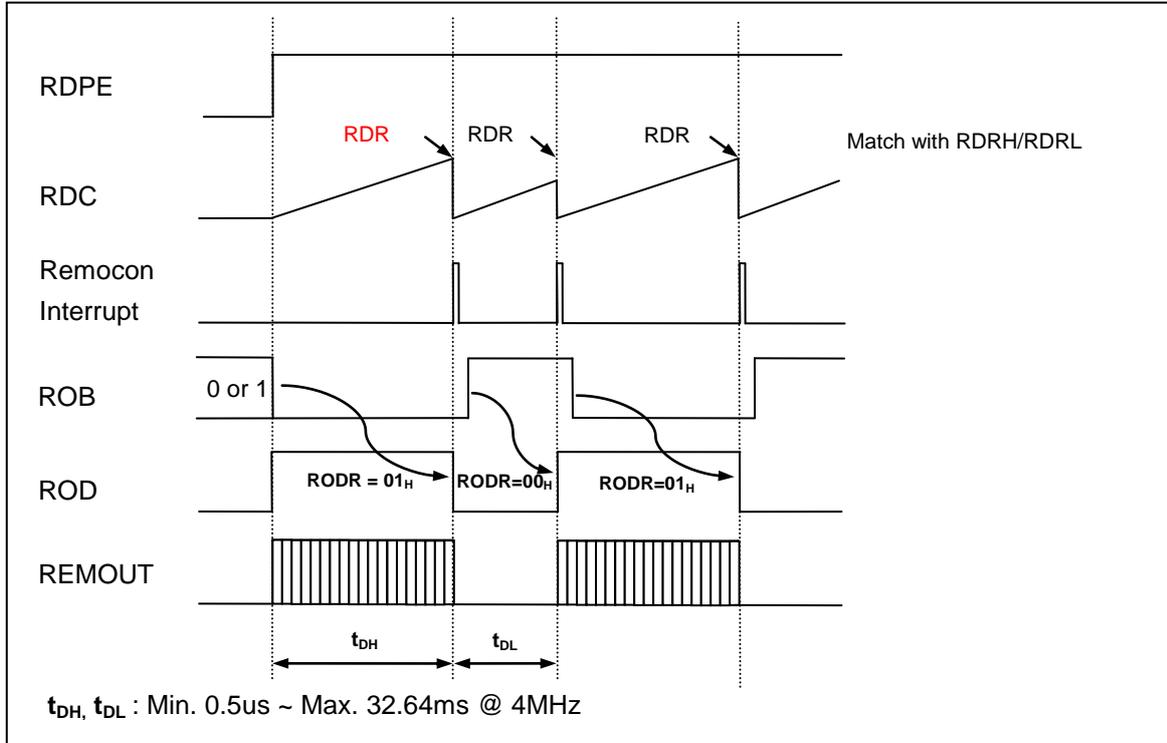


Figure 11-31 REMOUT by CRF & ROB (In case of CEN=1, RDPE=1)

The next figure shows the case carrier signal is off. As can be seen, only RODR value appears on REMOUT port. The difference between previous and below figure is apparent.

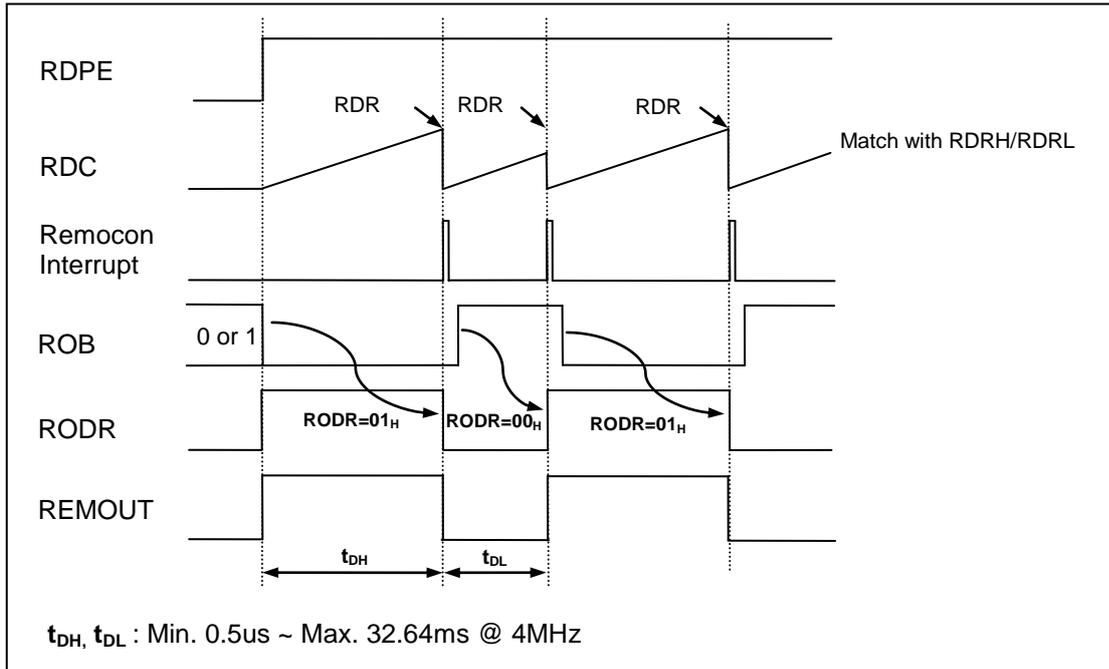


Figure 11-32 REMOUT by ROB only (In case of CEN=0, RDPE=1)

In the last figure, RODR is updated directly by writing to this register when the 16-bit Timer 2, 3 interrupts occur. As shown, the REMOUT waveforms are different according to CEN bit.

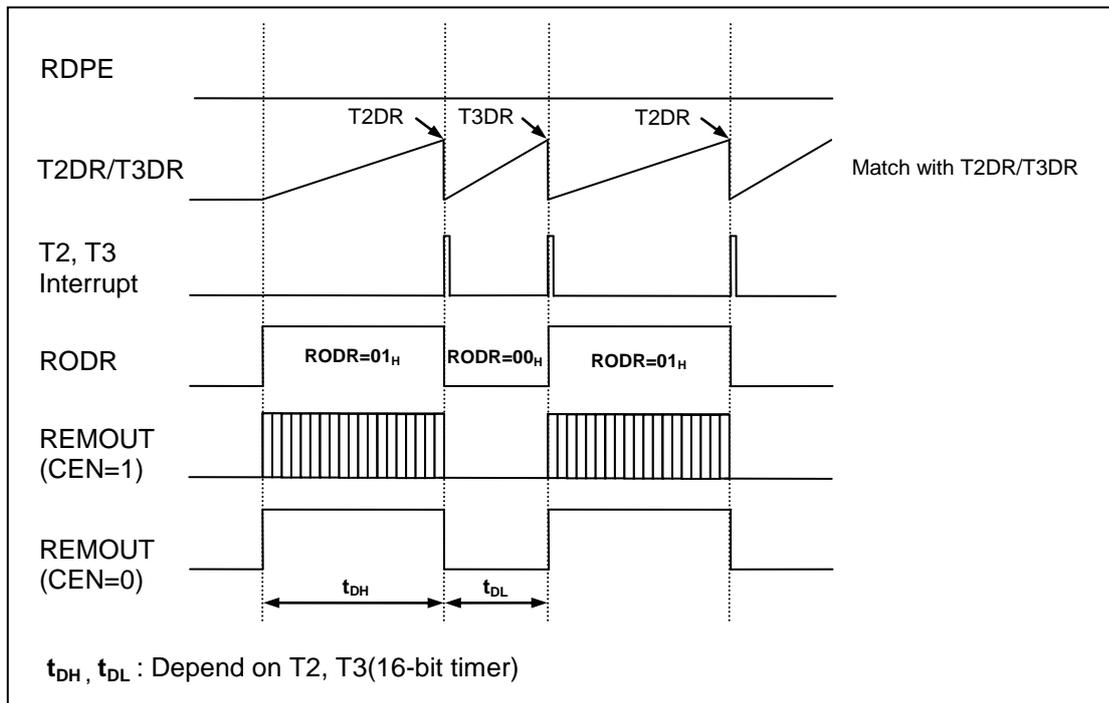


Figure 11-33 REMOUT by RODR

11.7.7 Carrier Generator Interrupt

When RDC counter reaches to RDRH or RDRL register, an interrupt can be requested. As the RDC counter functions when RDPE bit is '1', the interrupt is requested only when RDPE bit is '1'. Even if the interrupt is not required to be serviced by CPU, the flag can be read through RMR register. And

this flag is cleared when the interrupt is serviced, RDPE bit is cleared or software writes '0' to the bit position.

11.7.8 Examples of Carrier Signal Selection

The next table shows examples of selecting carrier signal according to CFRH and CFRL registers for two kinds of carrier clocks.

Registers		CR_CLK=PS1		CR_CLK=PS3		Registers		CR_CLK=PS1		CR_CLK=PS3	
CFRH	CFRL	t _H (us)	t _L (us)	t _H (us)	t _L (us)	CFRH	CFRL	t _H (us)	t _L (us)	t _H (us)	t _L (us)
00 _H	00 _H	-	-	-	-	20 _H	20 _H	8.00	8.00	32.00	32.00
01 _H	01 _H	0.25	0.25	1.00	1.00	21 _H	21 _H	8.25	8.25	33.00	33.00
02 _H	02 _H	0.50	0.50	2.00	2.00	22 _H	22 _H	8.50	8.50	34.00	34.00
03 _H	03 _H	0.75	0.75	3.00	3.00	23 _H	23 _H	8.75	8.75	35.00	35.00
04 _H	04 _H	1.00	1.00	4.00	4.00	24 _H	24 _H	9.00	9.00	36.00	36.00
05 _H	05 _H	1.25	1.25	5.00	5.00	25 _H	25 _H	9.25	9.25	37.00	37.00
06 _H	06 _H	1.50	1.50	6.00	6.00	26 _H	26 _H	9.50	9.50	38.00	38.00
07 _H	07 _H	1.75	1.75	7.00	7.00	27 _H	27 _H	9.75	9.75	39.00	39.00
08 _H	08 _H	2.00	2.00	8.00	8.00	28 _H	28 _H	10.00	10.00	40.00	40.00
09 _H	09 _H	2.25	2.25	9.00	9.00	29 _H	29 _H	10.25	10.25	41.00	41.00
0A _H	0A _H	2.50	2.50	10.00	10.00	2A _H	2A _H	10.50	10.50	42.00	42.00
0B _H	0B _H	2.75	2.75	11.00	11.00	2B _H	2B _H	10.75	10.75	43.00	43.00
0C _H	0C _H	3.00	3.00	12.00	12.00	2C _H	2C _H	11.00	11.00	44.00	44.00
0D _H	0D _H	3.25	3.25	13.00	13.00	2D _H	2D _H	11.25	11.25	45.00	45.00
0E _H	0E _H	3.50	3.50	14.00	14.00	2E _H	2E _H	11.50	11.50	46.00	46.00
0F _H	0F _H	3.75	3.75	15.00	15.00	2F _H	2F _H	11.75	11.75	47.00	47.00
10 _H	10 _H	4.00	4.00	16.00	16.00	30 _H	30 _H	12.00	12.00	48.00	48.00
11 _H	11 _H	4.25	4.25	17.00	17.00	31 _H	31 _H	12.25	12.25	49.00	49.00
12 _H	12 _H	4.50	4.50	18.00	18.00	32 _H	32 _H	12.50	12.50	50.00	50.00
13 _H	13 _H	4.75	4.75	19.00	19.00	33 _H	33 _H	12.75	12.75	51.00	51.00
14 _H	14 _H	5.00	5.00	20.00	20.00	34 _H	34 _H	13.00	13.00	52.00	52.00
15 _H	15 _H	5.25	5.25	21.00	21.00	35 _H	35 _H	13.25	13.25	53.00	53.00
16 _H	16 _H	5.50	5.50	22.00	22.00	36 _H	36 _H	13.50	13.50	54.00	54.00
17 _H	17 _H	5.75	5.75	23.00	23.00	37 _H	37 _H	13.75	13.75	55.00	55.00
18 _H	18 _H	6.00	6.00	24.00	24.00	38 _H	38 _H	14.00	14.00	56.00	56.00
19 _H	19 _H	6.25	6.25	25.00	25.00	39 _H	39 _H	14.25	14.25	57.00	57.00
1A _H	1A _H	6.50	6.50	26.00	26.00	3A _H	3A _H	14.50	14.50	58.00	58.00
1B _H	1B _H	6.75	6.75	27.00	27.00	3B _H	3B _H	14.75	14.75	59.00	59.00
1C _H	1C _H	7.00	7.00	28.00	28.00	3C _H	3C _H	15.00	15.00	60.00	60.00
1D _H	1D _H	7.25	7.25	29.00	29.00	3D _H	3D _H	15.25	15.25	61.00	61.00
1E _H	1E _H	7.50	7.50	30.00	30.00	3E _H	3E _H	15.50	15.50	62.00	62.00
1F _H	1F _H	7.75	7.75	31.00	31.00	3F _H	3F _H	15.75	15.75	63.00	63.00

Table 11-14 Period of carrier signal according to CFRH/CFRL

In above table, we assume the frequency of main oscillator, f_{XIN} is 8MHz and system clock is not divided from that clock, that is $f_{SCLK} = f_{XIN}$. PSn represents SCLK-divided clock, PS1=SCLK/2 and PS3=SCLK/8. CR_CLK is the clock source for CRC counter.

11.8 Key Scan

11.8.1 Overview

Port 0 and Port 1 can be used as key input sources. If KEY interrupt is enabled, this can be a wake-up source in STOP mode. Usually Port 0(Port 1) is used as output strobe lines, and Port 1(Port 0) is used as key input sources. The key interrupt triggering mode is selected by KITSR register.

11.8.2 Block Diagram

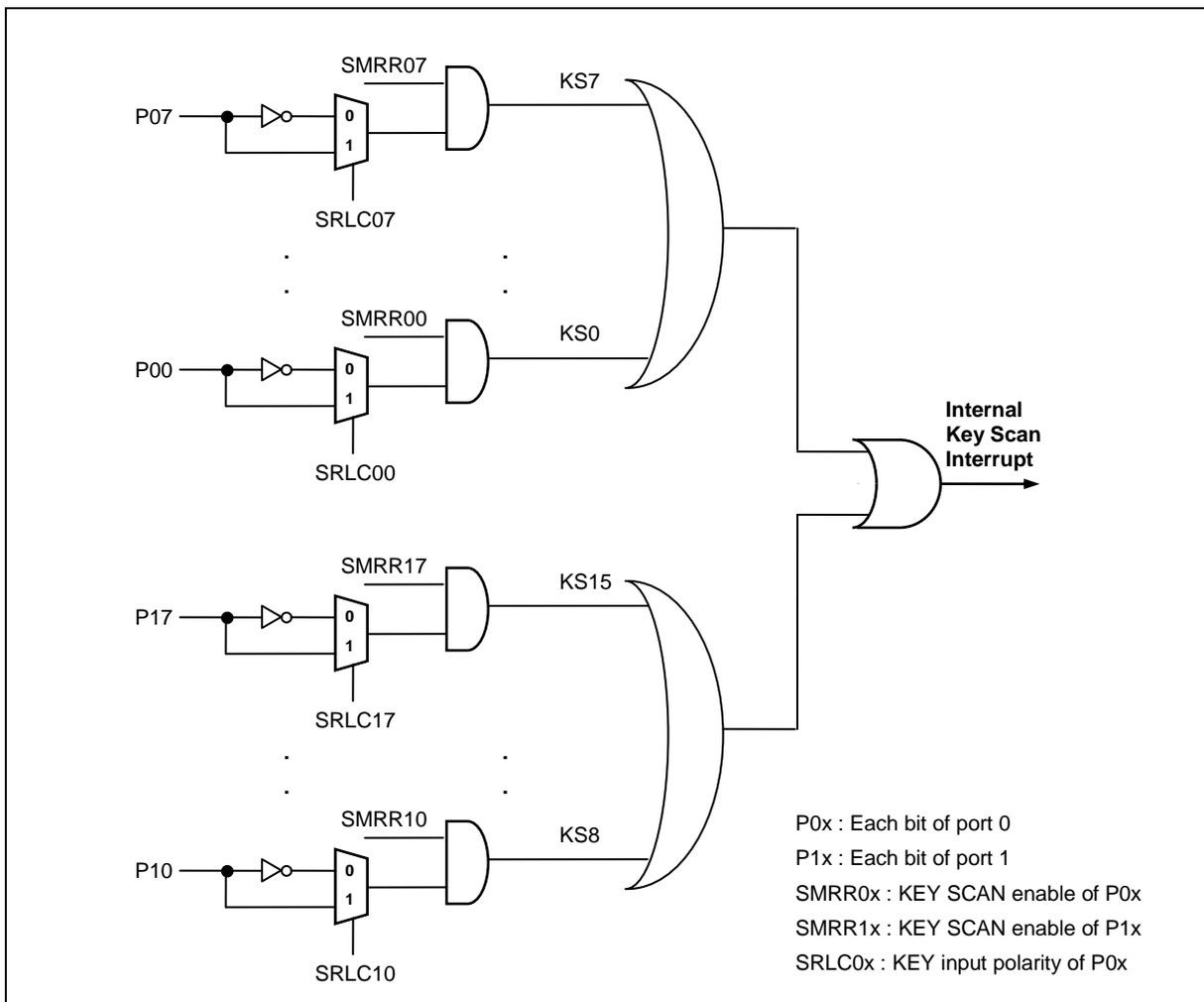


Figure 11-34 Block Diagram of KEYSKAN module

11.8.3 Register Map

Name	Address	Dir	Default	Description
SMRR0	D2 _H	R/W	00 _H	Standby Mode Release Register 0
SMRR1	D3 _H	R/W	00 _H	Standby Mode Release Register 1
SRLC0	D6 _H	R/W	00 _H	Standby Release Level Control Register 0
SRLC1	D7 _H	R/W	00 _H	Standby Release Level Control Register 1
KITSR	F7 _H	R/W	00 _H	Key Interrupt Trigger Selection Register

Table 11-15 Register Map of KEYSKAN module

11.8.4 Register Description

SMRR0 (Standby Mode Release Register 0)

D2_H

7	6	5	4	3	2	1	0
SMRR07	SMRR06	SMRR05	SMRR04	SMRR03	SMRR02	SMRR01	SMRR00
R/W							

Initial value : 00_H

SMRR0[7:0]

Enables key function of Port 0 pins.

0 Key function is not used.

1 Key function overrides the normal port functionality of I/O pin.

SMRR1 (Standby Mode Release Register 1)

D3_H

7	6	5	4	3	2	1	0
SMRR17	SMRR16	SMRR15	SMRR14	SMRR13	SMRR12	SMRR11	SMRR10
R/W							

Initial value : 00_H

SMRR1[7:0]

Enables key function of Port 1 pins.

0 Key function is not used.

1 Key function overrides the normal port functionality of I/O pin.

SRLC0 (Standby Release Level Control Register 0)

D6_H

7	6	5	4	3	2	1	0
SRLC07	SRLC06	SRLC05	SRLC04	SRLC03	SRLC02	SRLC01	SRLC00
R/W							

Initial value : 00_H

SRLC0[7:0]

Selects the trigger level of key input & interrupt when Port 0 is used as key input source.

0 Triggered by a low level

1 Triggered by a high level

SRLC1 (Standby Release Level Control Register 1)**D7_H**

7	6	5	4	3	2	1	0
SRLC17	SRLC16	SRLC15	SRLC14	SRLC13	SRLC12	SRLC11	SRLC10
RW							

Initial value : 00_H**SRLC1[7:0]** Selects the trigger level of key input & interrupt when Port 1 is used as key input source.

0 Triggered by a low level

1 Triggered by a high level

KITSR (Key Interrupt Trigger Select Register)**F7_H**

7	6	5	4	3	2	1	0
-	-	-	-	-	-	-	KITSR
-	-	-	-	-	-	-	RW

Initial value : 00_H**KITSR** Selects interrupt trigger mode.

0 Triggered by level detection

1 Triggered by edge detection

11.9 USART

11.9.1 Overview

The Universal Synchronous and Asynchronous serial Receiver and Transmitter (USART) is a highly flexible serial communication device. The main features are listed below.

- Full Duplex Operation (Independent Serial Receive and Transmit Registers)
- Asynchronous or Synchronous Operation
- Master or Slave Clocked Synchronous and SPI Operation
- Supports all four SPI Modes of Operation (Mode 0, 1, 2, 3)
- LSB First or MSB First Data Transfer @SPI mode
- High Resolution Baud Rate Generator
- Supports Serial Frames with 5,6,7,8, or 9 Data Bits and 1 or 2 Stop Bits
- Odd or Even Parity Generation and Parity Check Supported by Hardware
- Data OverRun Detection
- Framing Error Detection
- Digital Low Pass Filter
- Three Separate Interrupts on TX Complete, TX Data Register Empty and RX Complete
- Double Speed Asynchronous Communication Mode

USART has three main parts of Clock Generator, Transmitter and Receiver. The Clock Generation logic consists of synchronization logic for external clock input used by synchronous or SPI slave operation, and the baud rate generator for asynchronous or master (synchronous or SPI) operation. The Transmitter consists of a single write buffer, a serial shift register, parity generator and control logic for handling different serial frame formats. The write buffer allows a continuous transfer of data without any delay between frames. The receiver is the most complex part of the USART module due to its clock and data recovery units. The recovery unit is used for asynchronous data reception. In addition to the recovery unit, the Receiver includes a parity checker, a shift register, a two level receive FIFO (UDATAN) and control logic. The Receiver supports the same frame formats as the Transmitter and can detect Frame Error, Data OverRun and Parity Errors.

11.9.2 Block Diagram

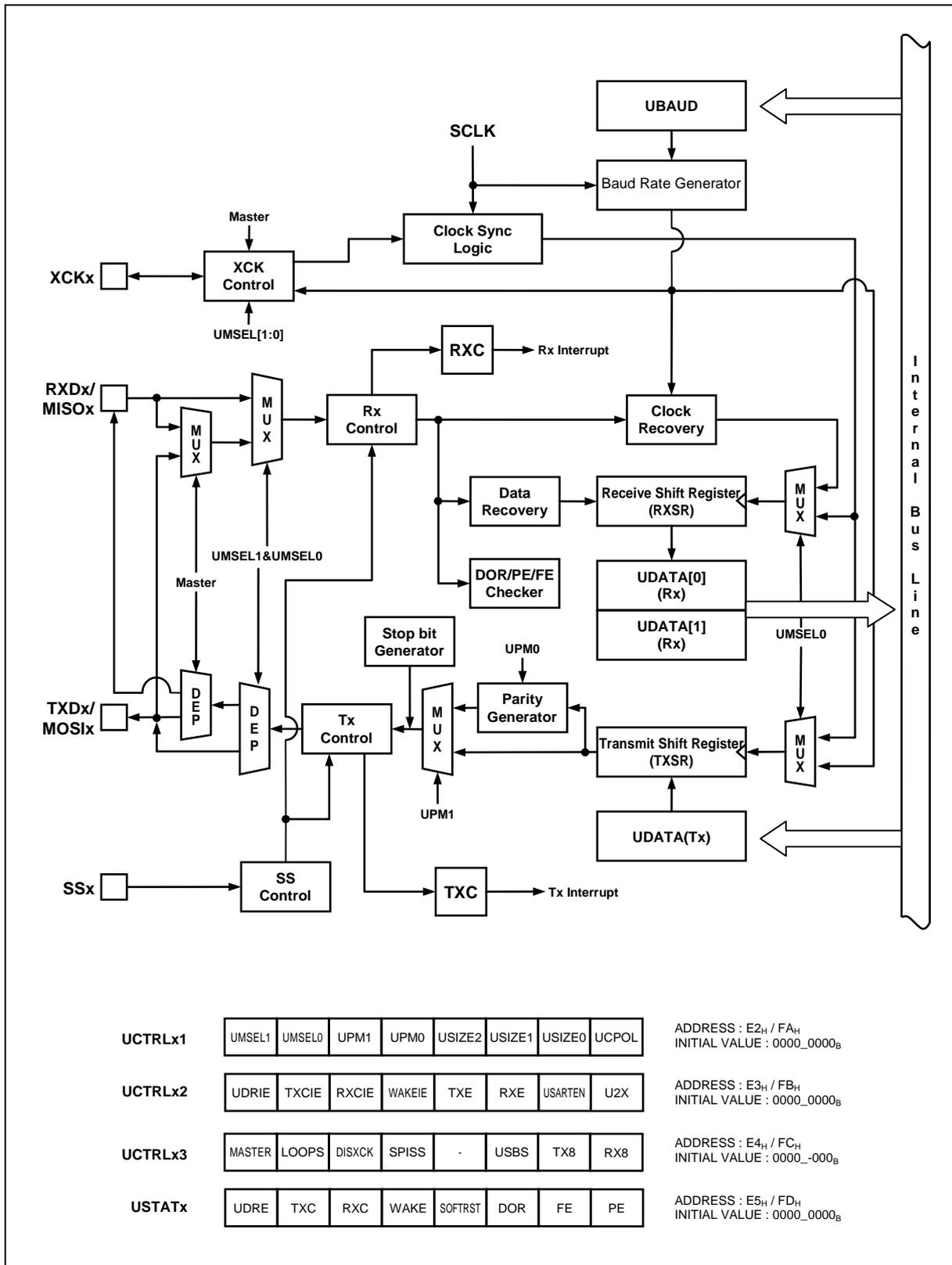


Figure 11-35 The Block Diagram of USART

11.9.3 Clock Generation

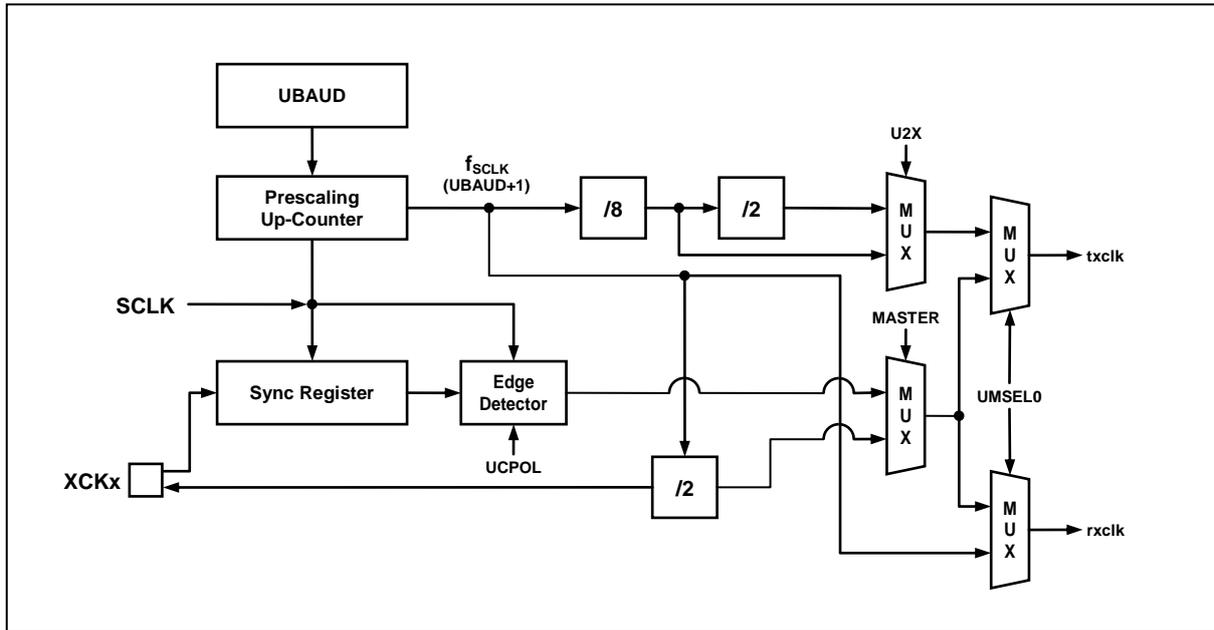


Figure 11-36 The Block Diagram of Clock Generation

The Clock generation logic generates the base clock for the Transmitter and Receiver. The USART supports four modes of clock operation and those are Normal Asynchronous, Double Speed Asynchronous, Master Synchronous and Slave Synchronous. The clock generation scheme for Master SPI and Slave SPI mode is the same as Master Synchronous and Slave Synchronous operation mode. The UMSELn bit in UCTRL1 register selects between asynchronous and synchronous operation. Asynchronous Double Speed mode is controlled by the U2X bit in the UCTRL2 register. The MASTER bit in UCTRL2 register controls whether the clock source is internal (Master mode, output port) or external (Slave mode, input port). The XCK pin is only active when the USART operates in Synchronous or SPI mode.

Table below contains equations for calculating the baud rate (in bps).

Operating Mode	Equation for Calculating Baud Rate
Asynchronous Normal Mode (U2X=0)	$\text{Baud Rate} = \frac{f_{\text{SCLK}}}{16(\text{UBAUD} + 1)}$
Asynchronous Double Speed Mode (U2X=1)	$\text{Baud Rate} = \frac{f_{\text{SCLK}}}{8(\text{UBAUD} + 1)}$
Synchronous or SPI Master Mode	$\text{Baud Rate} = \frac{f_{\text{SCLK}}}{2(\text{UBAUD} + 1)}$

Table 11-16 Equations for Calculation Baud Rate

11.9.4 External Clock (XCK)

External clocking is used by the synchronous or spi slave modes of operation.

External clock input from the XCK pin is sampled by a synchronization logic to remove meta-stability. The output from the synchronization logic must then pass through an edge detector before it can be used by the Transmitter and Receiver. This process introduces a two CPU clock period delay and therefore the maximum frequency of the external XCK pin is limited by the following equation.

$$f_{XCK} = \frac{f_{SCLK}}{4}$$

where f_{XCK} is the frequency of XCK and f_{SCLK} is the frequency of main system clock (SCLK).

11.9.5 Synchronous mode operation

When synchronous or spi mode is used, the XCK pin will be used as either clock input (slave) or clock output (master). The dependency between the clock edges and data sampling or data change is the same. The basic principle is that data input on RXD (MISO in spi mode) pin is sampled at the opposite XCK clock edge of the edge in the data output on TXD (MOSI in spi mode) pin is changed.

The UC POL bit in UCTRL1 register selects which XCK clock edge is used for data sampling and which is used for data change. As shown in the figure below, when UC POL is zero the data will be changed at rising XCK edge and sampled at falling XCK edge.

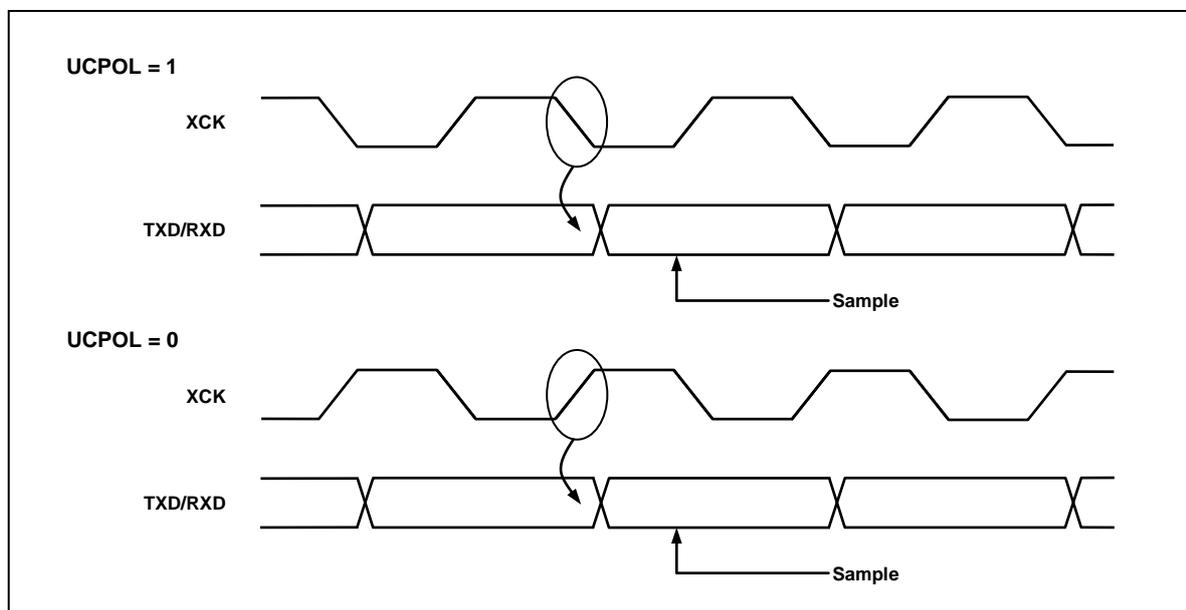


Figure 11-37 Synchronous Mode XCKn Timing.

11.9.6 Data format

A serial frame is defined to be one character of data bits with synchronization bits (start and stop bits), and optionally a parity bit for error checking.

The USART supports all 30 combinations of the following as valid frame formats.

- 1 start bit
- 5, 6, 7, 8 or 9 data bits
- no, even or odd parity bit
- 1 or 2 stop bits

A frame starts with the start bit followed by the least significant data bit (LSB). Then the next data bits, up to a total of nine, are succeeding, ending with the most significant bit (MSB). If enabled the parity bit is inserted after the data bits, before the stop bits. A high to low transition on data pin is considered as start bit. When a complete frame is transmitted, it can be directly followed by a new frame, or the communication line can be set to an idle state. The idle means high state of data pin. The next figure shows the possible combinations of the frame formats. Bits inside brackets are optional.

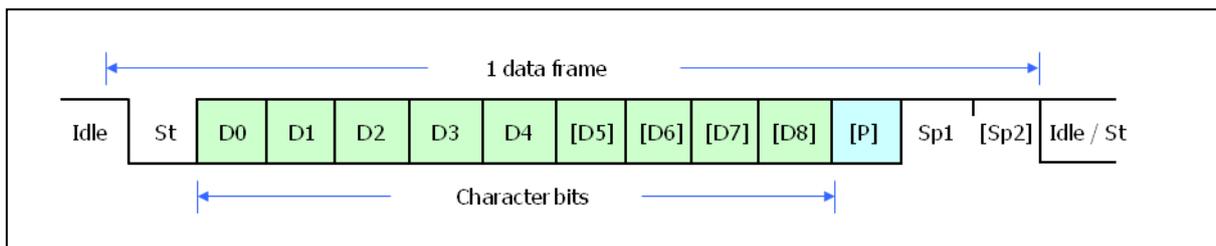


Figure 11-38 frame format

1 data frame consists of the following bits

- Idle No communication on communication line (TXD/RXD)
- St Start bit (Low)
- Dn Data bits (0~8)
- Parity bit ----- Even parity, Odd parity, No parity
- Stop bit(s) ----- 1 bit or 2 bits

The frame format used by the USART is set by the USIZE[2:0], UPM[1:0] and USBS bits in UCTRL1 register. The Transmitter and Receiver use the same setting.

11.9.7 Parity bit

The parity bit is calculated by doing an exclusive-or of all the data bits. If odd parity is used, the result of the exclusive-or is inverted. The parity bit is located between the MSB and first stop bit of a serial frame.

$$P_{\text{even}} = D_{n-1} \wedge \dots \wedge D_3 \wedge D_2 \wedge D_1 \wedge D_0 \wedge 0$$

$$P_{\text{odd}} = D_{n-1} \wedge \dots \wedge D_3 \wedge D_2 \wedge D_1 \wedge D_0 \wedge 1$$

P_{even} : Parity bit using even parity

P_{odd} : Parity bit using odd parity

D_n : Data bit n of the character

11.9.8 USART Transmitter

The USART Transmitter is enabled by setting the TXE bit in UCTRL1 register. When the Transmitter is enabled, the normal port operation of the TXD(=MOSI) pin is overridden by the serial output pin of USART. The baud-rate, operation mode and frame format must be setup once before doing any transmissions. If synchronous or spi operation is used, the clock on the XCK pin will be overridden and used as transmission clock. If USART operates in spi mode, SS pin is used as SS input pin in slave mode or can be configured as SS output pin in master mode. This can be done by setting SPISS bit in UCTRL3 register.

11.9.8.1 Sending TX data

A data transmission is initiated by loading the transmit buffer (UDATA register I/O location) with the data to be transmitted. The data written in transmit buffer is moved to the shift register when the shift register is ready to send a new frame. The shift register is loaded with the new data if it is in idle state or immediately after the last stop bit of the previous frame is transmitted. When the shift register is loaded with new data, it will transfer one complete frame at the settings of control registers. If the 9-bit characters are used in asynchronous or synchronous operation mode (USIZE[2:0]=7), the ninth bit must be written to the TX8 bit in UCTRL3 register before loading transmit buffer (UDATA register).

11.9.8.2 Transmitter flag and interrupt

The USART Transmitter has 2 flags which indicate its state. One is USART Data Register Empty (UDRE) and the other is Transmit Complete (TXC). Both flags can be interrupt sources.

UDRE flag indicates whether the transmit buffer is ready to be loaded with new data. This bit is set when the transmit buffer is empty and cleared when the transmit buffer contains data to be transmitted that has not yet been moved into the shift register. And also this flag can be cleared by writing '0' to this bit position. Writing '1' to this bit position is prevented.

When the Data Register Empty Interrupt Enable (UDRIE) bit in UCTRL2 register is set and the Global Interrupt is enabled, USART Data Register Empty Interrupt is generated while UDRE flag is set.

The Transmit Complete (TXC) flag bit is set when the entire frame in the transmit shift register has been shifted out and there are no more data in the transmit buffer. The TXC flag is automatically cleared when the Transmit Complete Interrupt service routine is executed, or it can be cleared by writing '0' to TXC bit in USTAT register.

When the Transmit Complete Interrupt Enable (TXCIE) bit in UCTRL2 register is set and the Global Interrupt is enabled, USART Transmit Complete Interrupt is generated while TXC flag is set.

11.9.8.3 Parity Generator

The Parity Generator calculates the parity bit for the sending serial frame data. When parity bit is enabled (UPM[1]=1), the transmitter control logic inserts the parity bit between the MSB and the first stop bit of the sending frame.

11.9.8.4 Disabling Transmitter

Disabling the Transmitter by clearing the TXE bit will not become effective until ongoing transmission is completed. When the Transmitter is disabled, the TXD(=MOSI) pin is used as normal General Purpose I/O (GPIO) or primary function pin.

11.9.9 USART Receiver

The USART Receiver is enabled by setting the RXE bit in the UCTRL1 register. When the Receiver is enabled, the normal pin operation of the RXD(=MISO) pin is overridden by the USART as the serial input pin of the Receiver. The baud-rate, mode of operation and frame format must be set before starting serial reception. If synchronous or spi operation is used, the clock on the XCK pin will be used as transfer clock. If USART operates in spi mode, SS pin is used as SS input pin in slave mode or can be configured as SS output pin in master mode. This can be done by setting SPISS bit in UCTRL3 register.

11.9.9.1 Receiving RX data

When USART is in synchronous or asynchronous operation mode, the Receiver starts data reception when it detects a valid start bit (LOW) on RXD(=MISO) pin. Each bit after start bit is sampled at pre-defined baud-rate (asynchronous) or sampling edge of XCK (synchronous), and shifted into the receive shift register until the first stop bit of a frame is received. Even if there's 2nd stop bit in the frame, the 2nd stop bit is ignored by the Receiver. That is, receiving the first stop bit means that a complete serial frame is present in the receiver shift register and the contents of shift register are to be moved into the receive buffer. The receive buffer is read by reading the UDATA register.

If 9-bit characters are used (USIZE[2:0] = 7) the ninth bit is stored in the RX8 bit position in the UCTRL3 register. The 9th bit must be read from the RX8 bit before reading the low 8 bits from the UDATA register. Likewise, the error flags FE, DOR, PE must be read before reading the data from UDATA register. This is because the error flags are stored in the same FIFO position of the receive buffer.

11.9.9.2 Receiver flag and interrupt

The USART Receiver has one flag that indicates the Receiver state.

The Receive Complete (RXC) flag indicates whether there are unread data present in the receive buffer. This flag is set when there are unread data in the receive buffer and cleared when the receive buffer is empty. If the Receiver is disabled (RXE=0), the receiver buffer is flushed and the RXC flag is cleared.

When the Receive Complete Interrupt Enable (RXCIE) bit in the UCTRL2 register is set and Global Interrupt is enabled, the USART Receiver Complete Interrupt is generated while RXC flag is set.

The USART Receiver has three error flags which are Frame Error (FE), Data OverRun (DOR) and Parity Error (PE). These error flags can be read from the USTAT register. As data received are stored in the 2-level receive buffer, these error flags are also stored in the same position of receive buffer. So, before reading received data from UDATA register, read the USTAT register first which contains error flags.

The Frame Error (FE) flag indicates the state of the first stop bit. The FE flag is zero when the stop bit was correctly detected as one, and the FE flag is one when the stop bit was incorrect, ie detected as zero. This flag can be used for detecting out-of-sync conditions between data frames.

The Data OverRun (DOR) flag indicates data loss due to a receive buffer full condition. A DOR occurs when the receive buffer is full, and another new data is present in the receive shift register which are to be stored into the receive buffer. After the DOR flag is set, all the incoming data are lost. To prevent data loss or clear this flag, read the receive buffer.

The Parity Error (PE) flag indicates that the frame in the receive buffer had a Parity Error when received. If Parity Check function is not enabled (UPM[1]=0), the PE bit is always read zero.

Caution : The error flags related to receive operation are not used when USART is in spi mode.

11.9.9.3 Parity Checker

If Parity Bit is enabled (UPM[1]=1), the Parity Checker calculates the parity of the data bits in incoming frame and compares the result with the parity bit from the received serial frame.

11.9.9.4 Disabling Receiver

In contrast to Transmitter, disabling the Receiver by clearing RXE bit makes the Receiver inactive immediately. When the Receiver is disabled the Receiver flushes the receive buffer and the remaining data in the buffer is all reset. The RXD(=MISO) pin is not overridden the function of USART, so RXD(=MISO) pin becomes normal GPIO or primary function pin.

11.9.9.5 Asynchronous Data Reception

To receive asynchronous data frame, the USART includes a clock and data recovery unit. The Clock Recovery logic is used for synchronizing the internally generated baud-rate clock to the incoming asynchronous serial frame on the RXD(=MISO) pin.

The Data recovery logic samples and low pass filters the incoming bits, and this removes the noise of RXD(=MISO) pin.

The next figure illustrates the sampling process of the start bit of an incoming frame. The sampling rate is 16 times the baud-rate for normal mode, and 8 times the baud rate for Double Speed mode (U2X=1). The horizontal arrows show the synchronization variation due to the asynchronous sampling process. Note that larger time variation is shown when using the Double Speed mode.

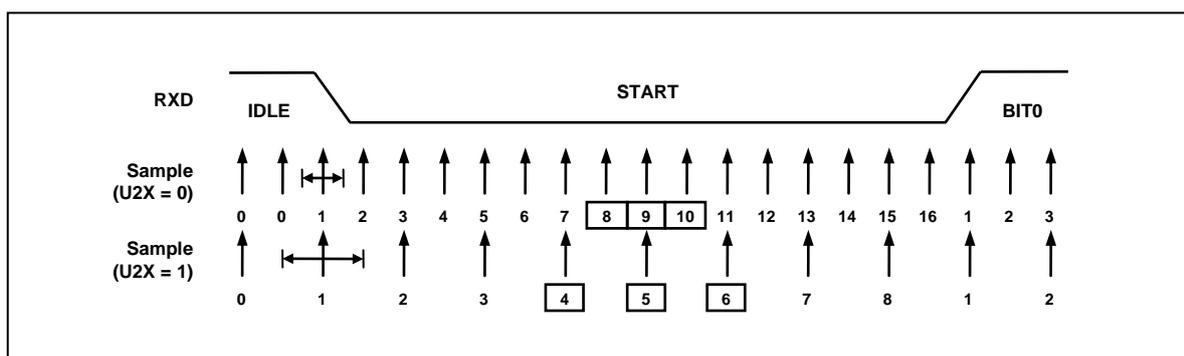


Figure 11-39 Start Bit Sampling

When the Receiver is enabled (RXE=1), the clock recovery logic tries to find a high to low transition on the RXD(=MISO) line, the start bit condition. After detecting high to low transition on RXD(=MISO) line, the clock recovery logic uses samples 8,9, and 10 for Normal mode, and samples 4, 5, and 6 for Double Speed mode to decide if a valid start bit is received. If more than 2 samples have logical low level, it is considered that a valid start bit is detected and the internally generated clock is synchronized to the incoming data frame. And the data recovery can begin. The synchronization process is repeated for each start bit.

As described above, when the Receiver clock is synchronized to the start bit, the data recovery can begin. Data recovery process is almost similar to the clock recovery process. The data recovery logic samples 16 times for each incoming bits for Normal mode and 8 times for Double Speed mode. And uses sample 8, 9, and 10 to decide data value for Normal mode, samples 4, 5, and 6 for Double Speed mode. If more than 2 samples have low levels, the received bit is considered to a logic 0 and more than 2 samples have high levels, the received bit is considered to a logic 1. The data recovery process is then repeated until a complete frame is received including the first stop bit. The decided bit value is stored in the receive shift register in order. Note that the Receiver only uses the first stop bit of a frame. Internally, after receiving the first stop bit, the Receiver is in idle state and waiting to find start bit.

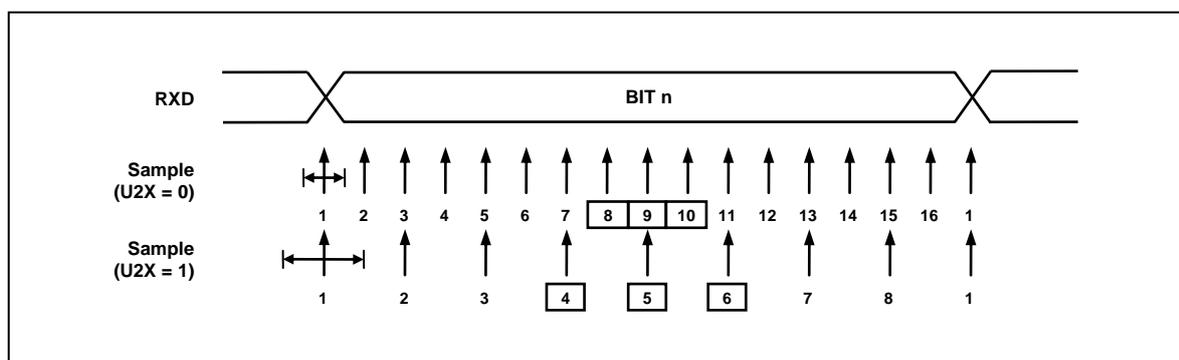


Figure 11-40 The Sampling of Data and Parity Bit

The process for detecting stop bit is like clock and data recovery process. That is, if 2 or more samples of 3 center values have high level, correct stop bit is detected, else a Frame Error flag is set. After deciding first stop bit whether a valid stop bit is received or not, the Receiver goes idle state and monitors the RXD(=MISO) line to check a valid high to low transition is detected (start bit detection).

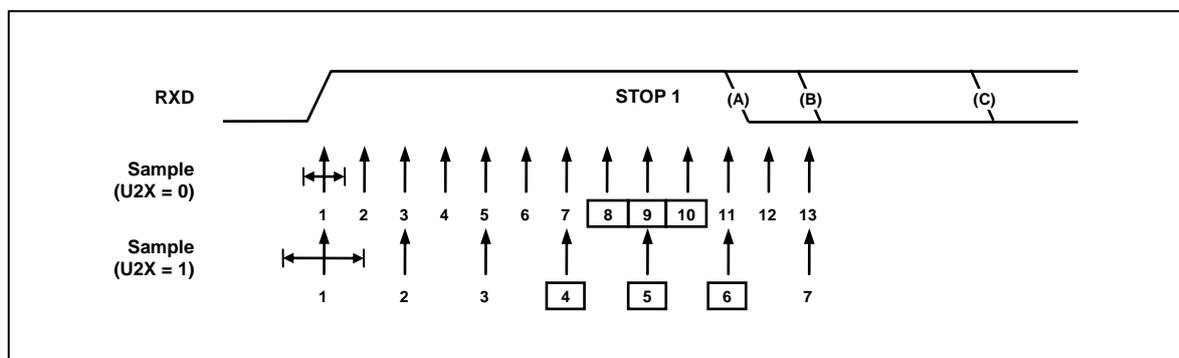


Figure 11-41 Stop Bit Sampling and Next Start Bit Sampling

11.9.10 SPI Mode

The USART can be set to operate in industrial standard SPI compliant mode. The SPI mode has the following features.

- Full duplex, three-wire synchronous data transfer
- Master or Slave operation
- Supports all four SPI modes of operation (mode0, 1, 2, and 3)
- Selectable LSB first or MSB first data transfer
- Double buffered transmit and receive
- Programmable transmit bit rate

When SPI mode is enabled (UMSEL[1:0]=11_B), the Slave Select (SS) pin becomes active low input in slave mode operation, or can be output in master mode operation if SPISS bit is set.

Note that during SPI mode of operation, the pin RXD is renamed as MISO and TXD is renamed as MOSI for compatibility to other SPI devices.

11.9.10.1 SPI Clock Formats and Timing

To accommodate a wide variety of synchronous serial peripherals from different manufacturers, the USART has a clock polarity bit (UCPOL) and a clock phase control bit (UCPHA) to select one of four clock formats for data transfers. UCPOL selectively insert an inverter in series with the clock. UCPHA chooses between two different clock phase relationships between the clock and data. Note that UCPHA and UCPOL bits in UCTRL1 register have different meaning according to the UMSEL[1:0] bits which decides the operating mode of USART.

Table below shows four combinations of UCPOL and UCPHA for SPI mode 0, 1, 2, and 3.

SPI Mode	UCPOL	UCPHA	Leading Edge	Trailing Edge
0	0	0	Sample (Rising)	Setup (Falling)
1	0	1	Setup (Rising)	Sample (Falling)
2	1	0	Sample (Falling)	Setup (Rising)
3	1	1	Setup (Falling)	Sample (Rising)

Table 11-17 SPI Mode by UCPOL & UCPHA

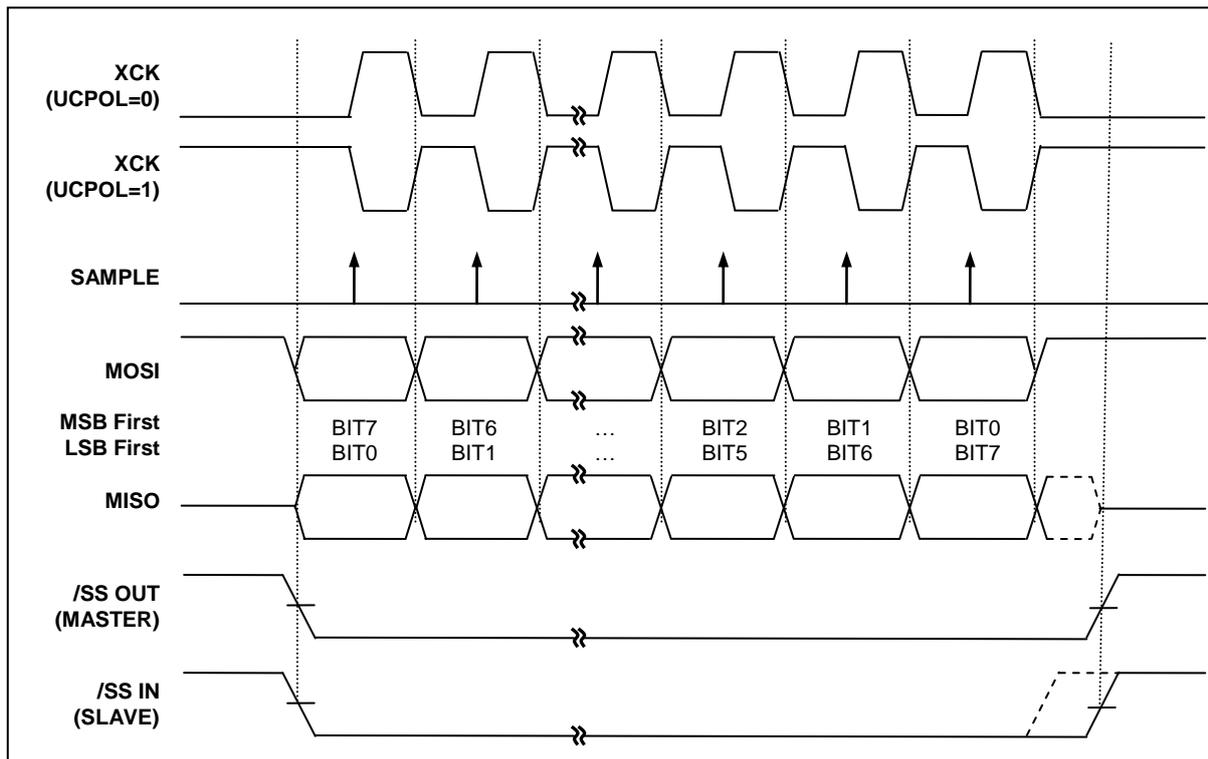


Figure 11-42 SPI Clock Formats when UCPHA=0

When UCPHA=0, the slave begins to drive its MISO output with the first data bit value when SS goes to active low. The first XCK edge causes both the master and the slave to sample the data bit value on their MISO and MOSI inputs, respectively. At the second XCK edge, the USART shifts the second data bit value out to the MOSI and MISO outputs of the master and slave, respectively. Unlike the case of UCPHA=1, when UCPHA=0, the slave's SS input must go to its inactive high level between transfers. This is because the slave can prepare the first data bit when it detects falling edge of SS input.

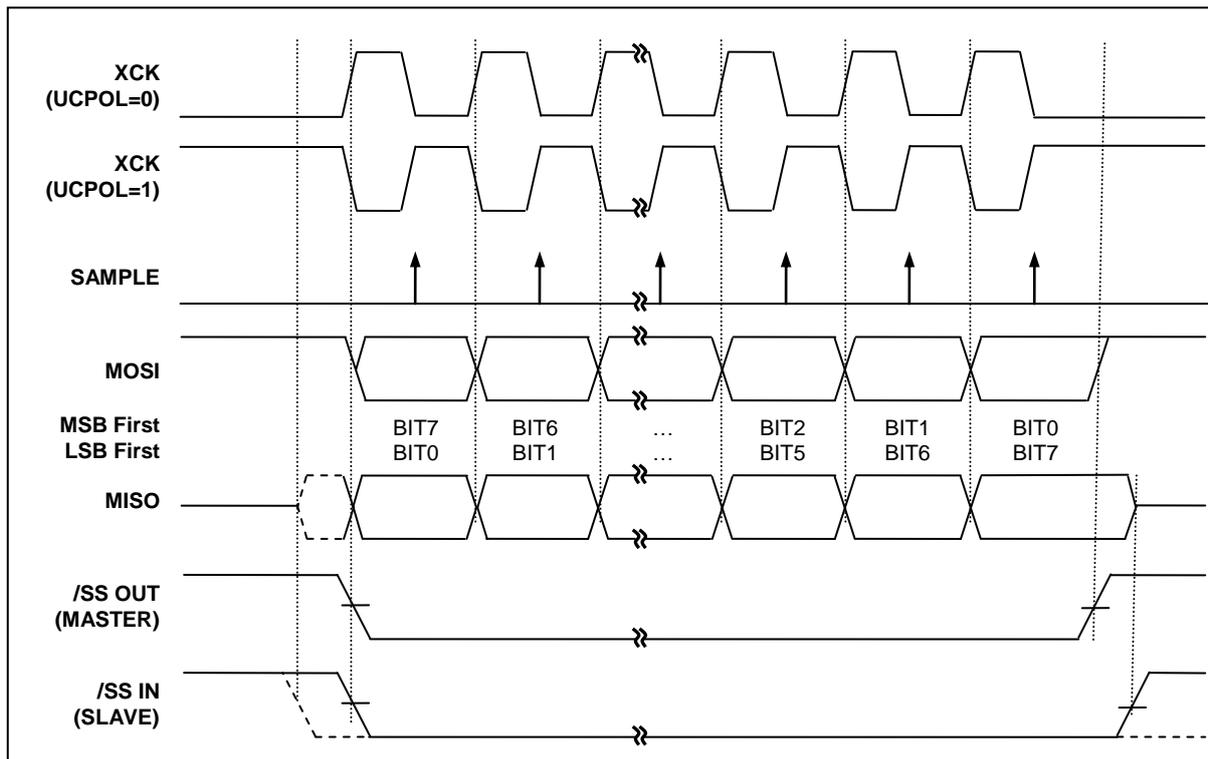


Figure 11-43 SPI Clock Formats when UCPHA=1

When UCPHA=1, the slave begins to drive its MISO output when SS goes active low, but the data is not defined until the first XCK edge. The first XCK edge shifts the first bit of data from the shifter onto the MOSI output of the master and the MISO output of the slave. The next XCK edge causes both the master and slave to sample the data bit value on their MISO and MOSI inputs, respectively. At the third XCK edge, the USART shifts the second data bit value out to the MOSI and MISO output of the master and slave respectively. When UCPHA=1, the slave's SS input is not required to go to its inactive high level between transfers.

Because the SPI logic reuses the USART resources, SPI mode of operation is similar to that of synchronous or asynchronous operation. An SPI transfer is initiated by checking for the USART Data Register Empty flag (UDRE=1) and then writing a byte of data to the UDATA Register.

Caution : In master mode of operation, even if transmission is not enabled (TXE=0), writing data to the UDATA register is necessary because the clock XCK is generated from transmitter block.

11.9.11 Register Map

Name	Address	Dir	Default	Description
UCTRL01	E2 _H	R/W	00 _H	USART0 Control 1 Register
UCTRL02	E3 _H	R/W	00 _H	USART0 Control 2 Register
UCTRL03	E4 _H	R/W	00 _H	USART0 Control 3 Register
USTAT0	E5 _H	R	80 _H	USART0 Status Register
UBAUD0	E6 _H	R/W	FF _H	USART0 Baud Rate Generation Register
UDATA0	E7 _H	R/W	FF _H	USART0 Data Register

Table 11-18 Register map of USART

11.9.12 Register Description

UCTRL01 (USART0 Control 1 Register)

E2_H

7	6	5	4	3	2	1	0
UMSEL1	UMSELO	UPM1	UPM0	USIZE2	USIZE1 UDORD	USIZE0 UCPHA	UCPOL
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 00_H

UMSEL[1:0]	Selects operation mode of USART		
UMSEL1	UMSELO	Operating Mode	
0	0	Asynchronous Mode (Normal Uart)	
0	1	Synchronous Mode (Synchronous Uart)	
1	0	Reserved	
1	1	SPI Mode	
UPM[1:0]	Selects Parity Generation and Check methods		
UPM1	UPM0	Parity mode	
0	0	No Parity	
0	1	Reserved	
1	0	Even Parity	
1	1	Odd Parity	
USIZE[2:0]	When in asynchronous or synchronous mode of operation, selects the length of data bits in frame.		
USIZE2	USIZE1	USIZE0	Data length
0	0	0	5 bit
0	0	1	6 bit
0	1	0	7 bit
0	1	1	8 bit
1	0	0	Reserved
1	0	1	Reserved
1	1	0	Reserved
1	1	1	9 bit
UDORD	This bit is in the same bit position with USIZE1. In SPI mode, when set to one the MSB of the data byte is transmitted first. When set to zero the LSB of the data byte is transmitted first.		
0	LSB First		
1	MSB First		
UCPOL	Selects polarity of XCK in synchronous or spi mode		
0	TXD(=MOSI) change @Rising Edge, RXD(=MISO) change @Falling Edge		
1	TXD(=MOSI) change @ Falling Edge, RXD(=MISO) change @ Rising Edge		
UCPHA	This bit is in the same bit position with USIZE0. In SPI mode, along with UCPOL bit, selects one of two clock formats for different kinds of synchronous serial peripherals. Leading edge means first XCK edge and trailing edge means 2 nd or last clock edge of XCK in one XCK pulse. And Sample means detecting of incoming receive bit, Setup means preparing transmit data.		
UCPOL	UCPHA	Leading Edge	Trailing Edge
0	0	Sample (Rising)	Setup (Falling)
0	1	Setup (Rising)	Sample (Falling)
1	0	Sample (Falling)	Setup (Rising)

1 1 Setup (Falling) Sample (Rising)

UCTRL02 (USART0 Control 2 Register) E3_H

7	6	5	4	3	2	1	0
UDRIE	TXCIE	RXCIE	WAKEIE	TXE	RXE	USARTEN	U2X
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 00_H

- UDRIE** Interrupt enable bit for USART Data Register Empty.
 0 Interrupt from UDRE is inhibited (use polling)
 1 When UDRE is set, request an interrupt
- TXCIE** Interrupt enable bit for Transmit Complete.
 0 Interrupt from TXC is inhibited (use polling)
 1 When TXC is set, request an interrupt
- RXCIE** Interrupt enable bit for Receive Complete
 0 Interrupt from RXC is inhibited (use polling)
 1 When RXC is set, request an interrupt
- WAKEIE** Interrupt enable bit for Asynchronous Wake in STOP mode. When device is in stop mode, if RXD(=MISO) goes to LOW level an interrupt can be requested to wake-up system.
 0 Interrupt from Wake is inhibited
 1 When WAKE is set, request an interrupt
- TXE** Enables the transmitter unit.
 0 Transmitter is disabled
 1 Transmitter is enabled
- RXE** Enables the receiver unit.
 0 Receiver is disabled
 1 Receiver is enabled
- USARTEN** Activate USART module by supplying clock.
 0 USART is disabled (clock is halted)
 1 USART is enabled
- U2X** This bit only has effect for the asynchronous operation and selects receiver sampling rate.
 0 Normal asynchronous operation
 1 Double Speed asynchronous operation

UCTRL03 (USART0 Control 3 Register) E4_H

7	6	5	4	3	2	1	0
MASTER	LOOPS	DISXCK	SPISS	-	USBS	TX8	RX8
R/W	R/W	R/W	R/W	-	R/W	R/W	R/W

Initial value : 00_H

- MASTER** Selects master or slave in SPI or Synchronous mode operation and controls the direction of XCK pin.
 0 Slave mode operation and XCK is input pin.
 1 Master mode operation and XCK is output pin
- LOOPS** Controls the Loop Back mode of USART, for test mode
 0 Normal operation
 1 Loop Back mode
- DISXCK** In Synchronous mode of operation, selects the waveform of XCK output.

	0	XCK is free-running while USART is enabled in synchronous master mode.
	1	XCK is active while any frame is on transferring.
SPISS	Controls the functionality of SS pin in master SPI mode.	
	0	SS pin is normal GPIO or other primary function
	1	SS output to other slave device
USBS	Selects the length of stop bit in Asynchronous or Synchronous mode of operation.	
	0	1 Stop Bit
	1	2 Stop Bit
TX8	The ninth bit of data frame in Asynchronous or Synchronous mode of operation. Write this bit first before loading the UDATA register.	
	0	MSB (9 th bit) to be transmitted is '0'
	1	MSB (9 th bit) to be transmitted is '1'
RX8	The ninth bit of data frame in Asynchronous or Synchronous mode of operation. Read this bit first before reading the receive buffer.	
	0	MSB (9 th bit) received is '0'
	1	MSB (9 th bit) received is '1'

USTAT0 (USART0 Status Register)

E5_H

7	6	5	4	3	2	1	0
UDRE	TXC	RXC	WAKE	SOFTTRST	DOR	FE	PE
RW	RW	RW	RW	RW	R	R	R

Initial value : 80_H

UDRE	The UDRE flag indicates if the transmit buffer (UDATA) is ready to be loaded with new data. If UDRE is '1', it means the transmit buffer is empty and can hold one or two new data. This flag can generate an UDRE interrupt. Writing '0' to this bit position will clear UDRE flag.
	0 Transmit buffer is not empty.
	1 Transmit buffer is empty.
TXC	This flag is set when the entire frame in the transmit shift register has been shifted out and there is no new data currently present in the transmit buffer. This flag is automatically cleared when the interrupt service routine of a TXC interrupt is executed. It is also cleared by writing '0' to this bit position. This flag can generate a TXC interrupt.
	0 Transmission is ongoing.
	1 Transmit buffer is empty and the data in transmit shift register are shifted out completely.
RXC	This flag is set when there are unread data in the receive buffer and cleared when all the data in the receive buffer are read. The RXC flag can be used to generate a RXC interrupt.
	0 There is no data unread in the receive buffer
	1 There are more than 1 data in the receive buffer
WAKE	This flag is set when the RXD(=MISO) pin is detected low while the CPU is in stop mode. This flag can be used to generate a WAKE interrupt. This bit is set only when in asynchronous mode of operation.
	<small>NOTE</small>
	0 No WAKE interrupt is generated.
	1 WAKE interrupt is generated.
SOFTTRST	This is an internal reset and only has effect on USART. Writing '1' to this bit initializes the internal logic of USART and is auto cleared.
	0 No operation

	1	Reset USART
DOR		This bit is set if a Data OverRun occurs. While this bit is set, the incoming data frame is ignored. This flag is valid until the receive buffer is read.
	0	No Data OverRun
	1	Data OverRun detected
FE		This bit is set if the first stop bit of next character in the receive buffer is detected as '0'. This bit is valid until the receive buffer is read.
	0	No Frame Error
	1	Frame Error detected
PE		This bit is set if the next character in the receive buffer has a Parity Error when received while Parity Checking is enabled. This bit is valid until the receive buffer is read.
	0	No Parity Error
	1	Parity Error detected

^{NOTE} When the WAKE function of USART is used as a release source from STOP mode, it is required to clear this bit in the RX interrupt service routine. Else the device will not wake-up from STOP mode again by the change of RXD(=MISO) pin.

UBAUD0 (USART0 Baud-Rate Generation Register)

E6_H

7	6	5	4	3	2	1	0
UBAUD7	UBAUD6	UBAUD5	UBAUD4	UBAUD3	UBAUD2	UBAUD1	UBAUD0
RW							

Initial value : FF_H

UBAUD [7:0] The value in this register is used to generate internal baud rate in asynchronous mode or to generate XCK clock in synchronous or spi mode. To prevent malfunction, do not write '0' in asynchronous mode, and do not write '0' or '1' in synchronous or spi mode.

UDATA0 (USART0 Data Register)

E7_H

7	6	5	4	3	2	1	0
UDATA7	UDATA6	UDATA5	UDATA4	UDATA3	UDATA2	UDATA1	UDATA0
RW							

Initial value : FF_H

UDATA [7:0] The USART Transmit Buffer and Receive Buffer share the same I/O address with this DATA register. The Transmit Data Buffer is the destination for data written to the UDATA register. Reading the UDATA register returns the contents of the Receive Buffer. Write this register only when the UDRE flag is set. In spi or synchronous master mode, write this register even if TX is not enabled to generate clock, XCK.

11.9.13 Baud Rate Setting (example)

Baud Rate	fOSC=1.00MHz				fOSC=1.8432MHz				fOSC=2.00MHz			
	U2X=0		U2X=1		U2X=0		U2X=1		U2X=0		U2X=1	
	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR
2400	25	0.2%	51	0.2%	47	0.0%	95	0.0%	51	0.2%	103	0.2%
4800	12	0.2%	25	0.2%	23	0.0%	47	0.0%	25	0.2%	51	0.2%
9600	6	-7.0%	12	0.2%	11	0.0%	23	0.0%	12	0.2%	25	0.2%
14.4K	3	8.5%	8	-3.5%	7	0.0%	15	0.0%	8	-3.5%	16	2.1%
19.2K	2	8.5%	6	-7.0%	5	0.0%	11	0.0%	6	-7.0%	12	0.2%
28.8K	1	8.5%	3	8.5%	3	0.0%	7	0.0%	3	8.5%	8	-3.5%
38.4K	1	-18.6%	2	8.5%	2	0.0%	5	0.0%	2	8.5%	6	-7.0%
57.6K	-	-	1	8.5%	1	-25.0%	3	0.0%	1	8.5%	3	8.5%
76.8K	-	-	1	-18.6%	1	0.0%	2	0.0%	1	-18.6%	2	8.5%
115.2K	-	-	-	-	-	-	1	0.0%	-	-	1	8.5%
230.4K	-	-	-	-	-	-	-	-	-	-	-	-

Baud Rate	fOSC=3.6864MHz				fOSC=4.00MHz				fOSC=7.3728MHz			
	U2X=0		U2X=1		U2X=0		U2X=1		U2X=0		U2X=1	
	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR
2400	95	0.0%	191	0.0%	103	0.2%	207	0.2%	191	0.0%	-	-
4800	47	0.0%	95	0.0%	51	0.2%	103	0.2%	95	0.0%	191	0.0%
9600	23	0.0%	47	0.0%	25	0.2%	51	0.2%	47	0.0%	95	0.0%
14.4K	15	0.0%	31	0.0%	16	2.1%	34	-0.8%	31	0.0%	63	0.0%
19.2K	11	0.0%	23	0.0%	12	0.2%	25	0.2%	23	0.0%	47	0.0%
28.8K	7	0.0%	15	0.0%	8	-3.5%	16	2.1%	15	0.0%	31	0.0%
38.4K	5	0.0%	11	0.0%	6	-7.0%	12	0.2%	11	0.0%	23	0.0%
57.6K	3	0.0%	7	0.0%	3	8.5%	8	-3.5%	7	0.0%	15	0.0%
76.8K	2	0.0%	5	0.0%	2	8.5%	6	-7.0%	5	0.0%	11	0.0%
115.2K	1	0.0%	3	0.0%	1	8.5%	3	8.5%	3	0.0%	7	0.0%
230.4K	-	-	1	0.0%	-	-	1	8.5%	1	0.0%	3	0.0%
250K	-	-	1	-7.8%	-	-	1	0.0%	1	-7.8%	3	-7.8%
0.5M	-	-	-	-	-	-	-	-	-	-	1	-7.8%

Baud Rate	fOSC=8.00MHz				fOSC=11.0592MHz				fOSC=14.7456MHz			
	U2X=0		U2X=1		U2X=0		U2X=1		U2X=0		U2X=1	
	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR	UBAUD	ERROR
2400	207	0.2%	-	-	-	-	-	-	-	-	-	-
4800	103	0.2%	207	0.2%	143	0.0%	-	-	191	0.0%	-	-
9600	51	0.2%	103	0.2%	71	0.0%	143	0.0%	95	0.0%	191	0.0%
14.4K	34	-0.8%	68	0.6%	47	0.0%	95	0.0%	63	0.0%	127	0.0%
19.2K	25	0.2%	51	0.2%	35	0.0%	71	0.0%	47	0.0%	95	0.0%
28.8K	16	2.1%	34	-0.8%	23	0.0%	47	0.0%	31	0.0%	63	0.0%
38.4K	12	0.2%	25	0.2%	17	0.0%	35	0.0%	23	0.0%	47	0.0%
57.6K	8	-3.5%	16	2.1%	11	0.0%	23	0.0%	15	0.0%	31	0.0%

76.8K	6	-7.0%	12	0.2%	8	0.0%	17	0.0%	11	0.0%	23	0.0%
115.2 K	3	8.5%	8	-3.5%	5	0.0%	11	0.0%	7	0.0%	15	0.0%
230.4 K	1	8.5%	3	8.5%	2	0.0%	5	0.0%	3	0.0%	7	0.0%
250K	1	0.0%	3	0.0%	2	-7.8%	5	-7.8%	3	-7.8%	6	5.3%
0.5M	-	-	1	0.0%	-	-	2	-7.8%	1	-7.8%	3	-7.8%
1M	-	-	-	-	-	-	-	-	-	-	1	-7.8%

11.10 I²C

11.10.1 Overview

The I²C is one of industrial standard serial communication protocols, and which uses 2 bus lines Serial Data Line (SDA) and Serial Clock Line (SCL) to exchange data. Because both SDA and SCL lines are open-drain output, each line needs pull-up resistor. The features are as shown below.

- Compatible with I²C bus standard
- Multi-master operation
- Up to 400 KHz data transfer speed
- 7 bit address
- Support two slave addresses
- Both master and slave operation
- Bus busy detection

11.10.2 Block Diagram

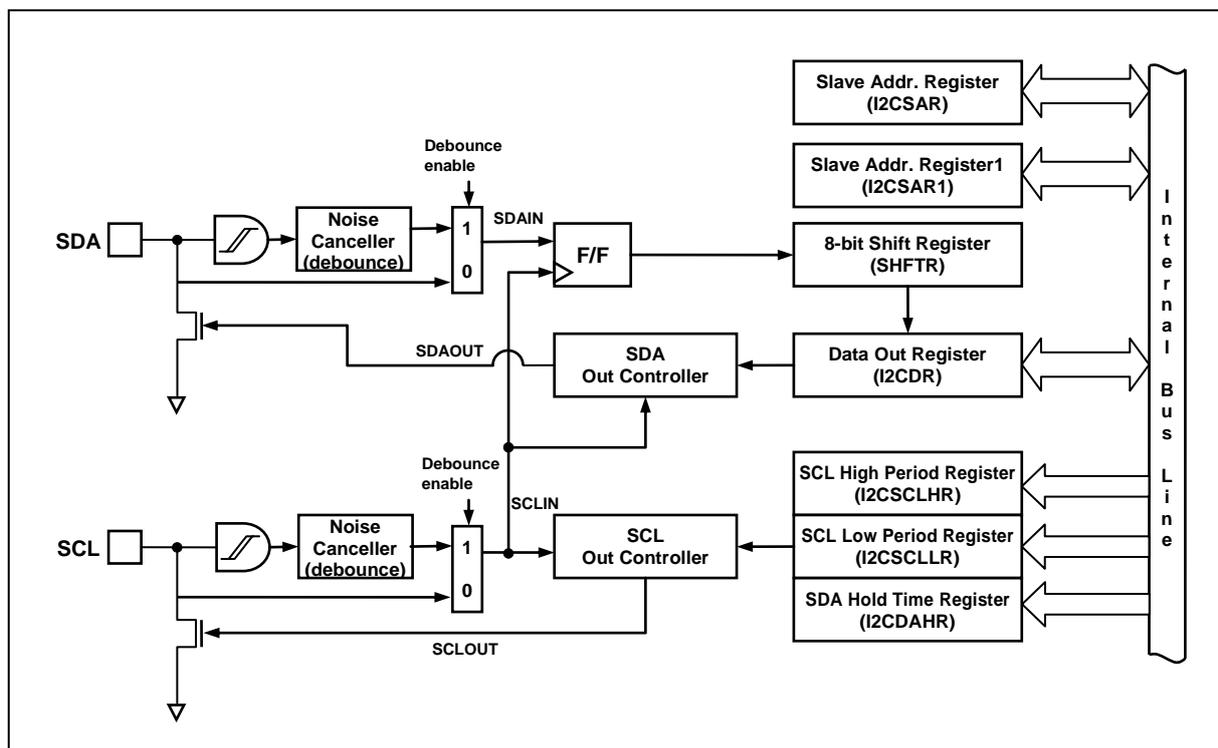


Figure 11-44 I²C Block Diagram

11.10.3 I²C Bit Transfer

The data on the SDA line must be stable during HIGH period of the clock, SCL. The HIGH or LOW state of the data line can only change when the clock signal on the SCL line is LOW. The exceptions are START(S), repeated START(Sr) and STOP(P) condition where data line changes when clock line is high.

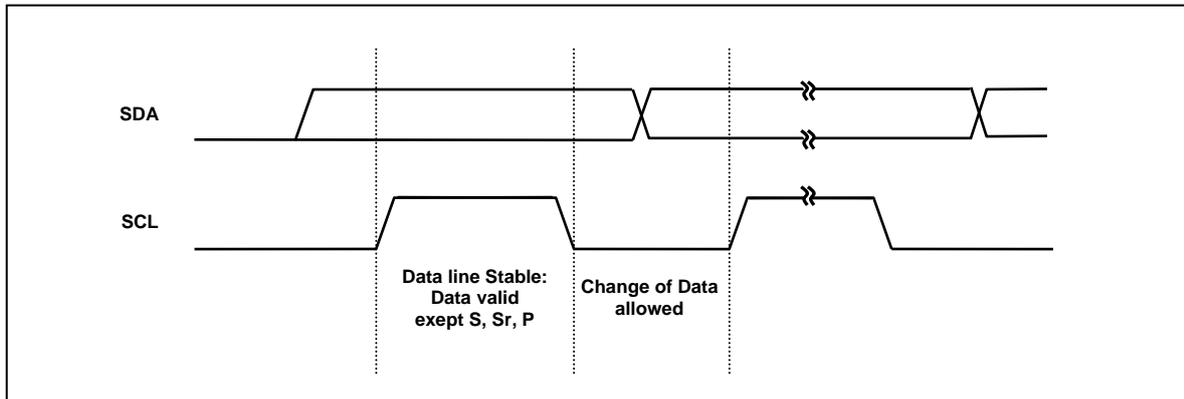


Figure 11-45 Bit Transfer on the I²C-Bus

11.10.4 Start / Repeated Start / Stop

One master can issue a START (S) condition to notice other devices connected to the SCL, SDA lines that it will use the bus. A STOP (P) condition is generated by the master to release the bus lines so that other devices can use it.

A high to low transition on the SDA line while SCL is high defines a START (S) condition.

A low to high transition on the SDA line while SCL is high defines a STOP (P) condition.

START and STOP conditions are always generated by the master. The bus is considered to be busy after START condition. The bus is considered to be free again after STOP condition, ie, the bus is busy between START and STOP condition. If a repeated START condition (Sr) is generated instead of STOP condition, the bus stays busy. So, the START and repeated START conditions are functionally identical.

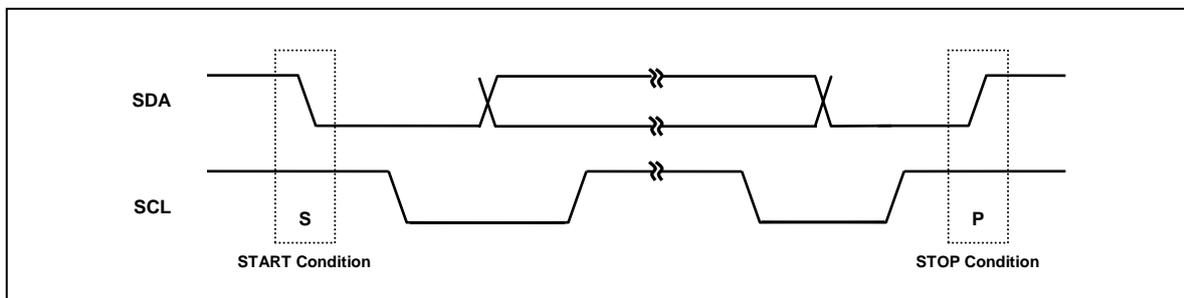


Figure 11-46 START and STOP Condition

11.10.5 Data Transfer

Every byte put on the SDA line must be 8-bits long. The number of bytes that can be transmitted per transfer is unlimited. Each byte has to be followed by an acknowledge bit. Data is transferred with

the most significant bit (MSB) first. If a slave can't receive or transmit another complete byte of data until it has performed some other function, it can hold the clock line SCL LOW to force the master into a wait state. Data transfer then continues when the slave is ready for another byte of data and releases clock line SCL.

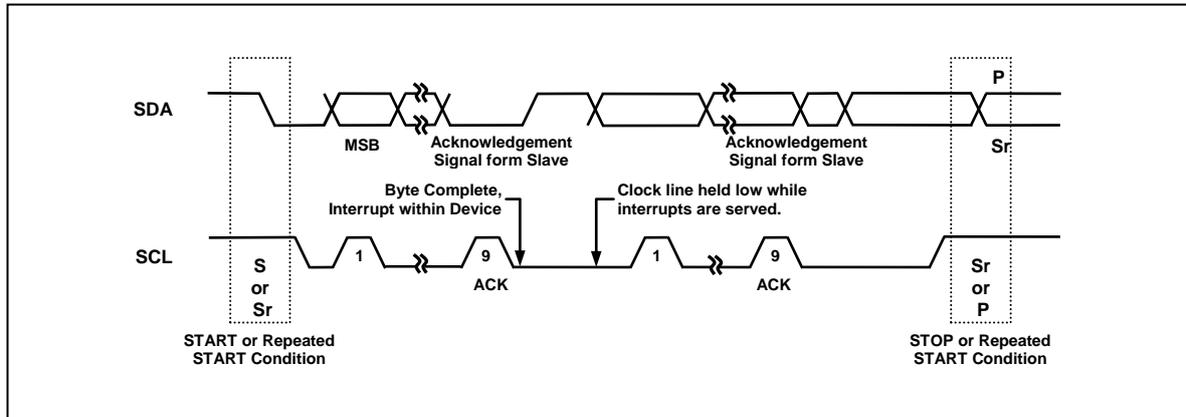


Figure 11-47 STOP or Repeated START Condition

11.10.6 Acknowledge

The acknowledge related clock pulse is generated by the master. The transmitter releases the SDA line (HIGH) during the acknowledge clock pulse. The receiver must pull down the SDA line during the acknowledge clock pulse so that it remains stable LOW during the HIGH period of this clock pulse. When a slave is addressed by a master (Address Packet), and if it is unable to receive or transmit because it's performing some real time function, the data line must be left HIGH by the slave. And also, when a slave addressed by a master is unable to receive more data bits, the slave receiver must release the SDA line (Data Packet). The master can then generate either a STOP condition to abort the transfer, or a repeated START condition to start a new transfer.

If a master receiver is involved in a transfer, it must signal the end of data to the slave transmitter by not generating an acknowledge on the last byte that was clocked out of the slave. The slave transmitter must release the data line to allow the master to generate a STOP or repeated START condition.

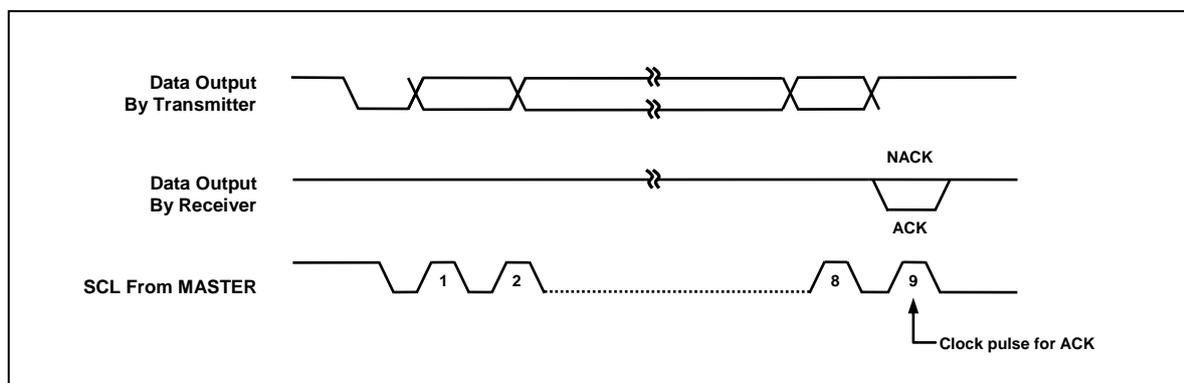


Figure 11-48 Acknowledge on the I²C-Bus

11.10.7 Synchronization / Arbitration

Clock synchronization is performed using the wired-AND connection of I²C interfaces to the SCL line. This means that a HIGH to LOW transition on the SCL line will cause the devices concerned to start counting off their LOW period and it will hold the SCL line in that state until the clock HIGH state is reached. However the LOW to HIGH transition of this clock may not change the state of the SCL line if another clock is still within its LOW period. In this way, a synchronized SCL clock is generated with its LOW period determined by the device with the longest clock LOW period, and its HIGH period determined by the one with the shortest clock HIGH period.

A master may start a transfer only if the bus is free. Two or more masters may generate a START condition. Arbitration takes place on the SDA line, while the SCL line is at the HIGH level, in such a way that the master which transmits a HIGH level, while another master is transmitting a LOW level will switch off its DATA output state because the level on the bus doesn't correspond to its own level. Arbitration continues for many bits until a winning master gets the ownership of I²C bus. Its first stage is comparison of the address bits.

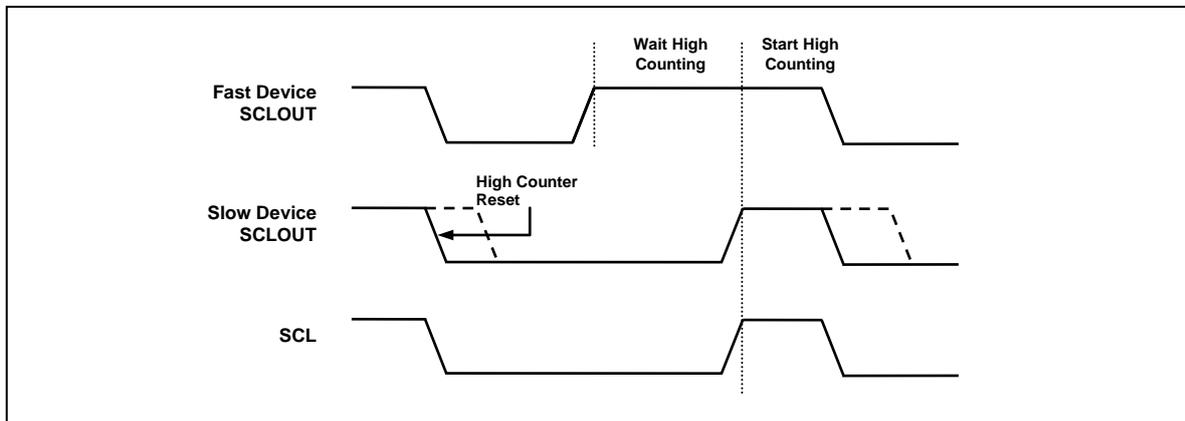


Figure 11-49 Clock Synchronization during Arbitration Procedure

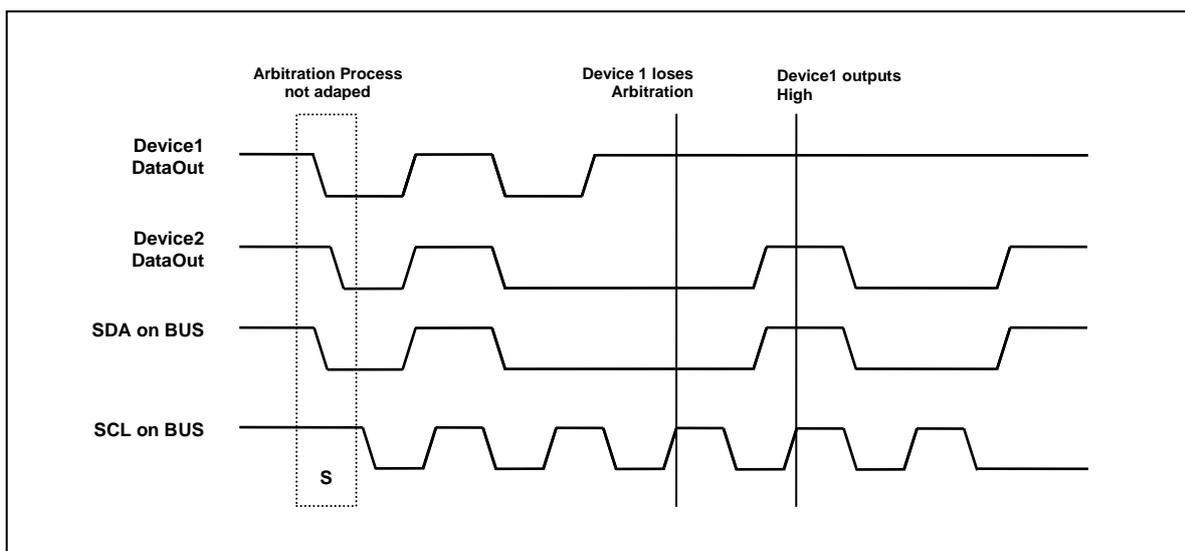


Figure 11-50 Arbitration Procedure of Two Masters

11.10.8 Operation

The I²C is byte-oriented and interrupt based. Interrupts are issued after all bus events except for a transmission of a START condition. Because the I²C is interrupt based, the application software is free to carry on other operations during a I²C byte transfer.

Note that when a I²C interrupt is generated, IIF flag in I2CMR register is set, it is cleared by writing an arbitrary value to I2CSR. When I²C interrupt occurs, the SCL line is hold LOW until writing any value to I2CSR. When the IIF flag is set, the I2CSR contains a value indicating the current state of the I²C bus. According to the value in I2CSR, software can decide what to do next.

I²C can operate in 4 modes by configuring master/slave, transmitter/receiver. The operating mode is configured by a winning master. A more detailed explanation follows below.

11.10.8.1 Master Transmitter

To operate I²C in master transmitter, follow the recommended steps below.

1. Enable I²C by setting IICEN bit in I2CMR. This provides main clock to the peripheral.
2. Load SLA+W into the I2CDR where SLA is address of slave device and W is transfer direction from the viewpoint of the master. For master transmitter, W is '0'. Note that I2CDR is used for both address and data.
3. Configure baud rate by writing desired value to both I2CSCLLR and I2CSCLHR for the Low and High period of SCL line.
4. Configure the I2CSDAHR to decide when SDA changes value from falling edge of SCL. If SDA should change in the middle of SCL LOW period, load half the value of I2CSCLLR to the I2CSDAHR.
5. Set the START bit in I2CMR. This transmits a START condition. And also configure how to handle interrupt and ACK signal. When the START bit is set, 8-bit data in I2CDR is transmitted out according to the baud-rate.
6. This is ACK signal processing stage for address packet transmitted by master. When 7-bit address and 1-bit transfer direction is transmitted to target slave device, the master can know whether the slave acknowledged or not in the 9th high period of SCL. If the master gains bus mastership, I²C generates GCALL interrupt regardless of the reception of ACK from the slave device. When I²C loses bus mastership during arbitration process, the MLOST bit in I2CSR is set, and I²C waits in idle state or can be operate as an addressed slave. To operate as a slave when the MLSOT bit in I2CSR is set, the ACKEN bit in I2CMR must be set and the received 7-bit address must equal to the SLA bits in I2CSAR. In this case I²C operates as a slave transmitter or a slave receiver (go to appropriate section). In this stage, I²C holds the SCL LOW. This is because to decide whether I²C continues serial transfer or stops communication. The following steps continue assuming that I²C does not lose mastership during first data transfer.

I²C (Master) can choose one of the following cases regardless of the reception of ACK signal from slave.

- 1) Master receives ACK signal from slave, so continues data transfer because slave can receive more data from master. In this case, load data to transmit to I2CDR.
- 2) Master stops data transfer even if it receives ACK signal from slave. In this case, set the STOP bit in I2CMR.
- 3) Master transmits repeated START condition with not checking ACK signal. In this case, load SLA+R/W into the I2CDR and set START bit in I2CMR.

After doing one of the actions above, write arbitrary value to I2CSR to release SCL line. In case of 1), move to step 7. In case of 2), move to step 9 to handle STOP interrupt. In case of

3), move to step 6 after transmitting the data in I2CDR and if transfer direction bit is '1' go to master receiver section.

7. 1-Byte of data is being transmitted. During data transfer, bus arbitration continues.
8. This is ACK signal processing stage for data packet transmitted by master. I²C holds the SCL LOW. When I²C loses bus mastership while transmitting data arbitrating other masters, the MLOST bit in I2CSR is set. If then, I²C waits in idle state. When the data in I2CDR is transmitted completely, I²C generates TEND interrupt.

I²C can choose one of the following cases regardless of the reception of ACK signal from slave.

- 1) Master receives ACK signal from slave, so continues data transfer because slave can receive more data from master. In this case, load data to transmit to I2CDR.
- 2) Master stops data transfer even if it receives ACK signal from slave. In this case, set the STOP bit in I2CMR.
- 3) Master transmits repeated START condition with not checking ACK signal. In this case, load SLA+R/W into the I2CDR and set the START bit in I2CMR.

After doing one of the actions above, write arbitrary value to I2CSR to release SCL line. In case of 1), move to step 7. In case of 2), move to step 9 to handle STOP interrupt. In case of 3), move to step 6 after transmitting the data in I2CDR, and if transfer direction bit is '1' go to master receiver section.

9. This is the final step for master transmitter function of I²C, handling STOP interrupt. The STOP bit indicates that data transfer between master and slave is over. To clear I2CSR, write arbitrary value to I2CSR. After this, I²C enters idle state.

The next figure depicts above process for master transmitter operation of I²C.

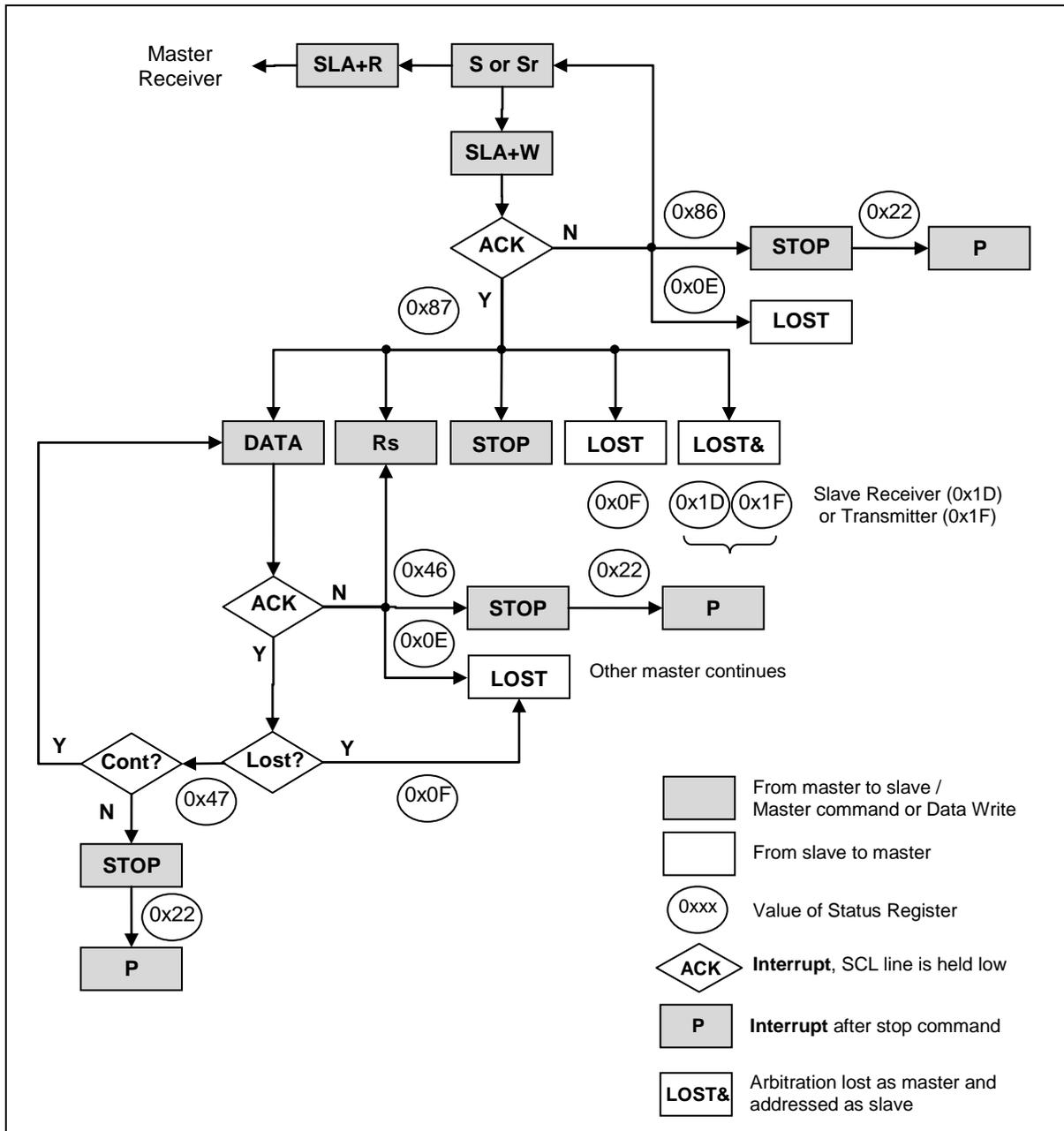


Figure 11-51 Formats and States in the Master Transmitter Mode

11.10.8.2 Master Receiver

To operate I²C in master receiver, follow the recommended steps below.

1. Enable I²C by setting IICEN bit in I2CMR. This provides main clock to the peripheral.
2. Load SLA+R into the I2CDR where SLA is address of slave device and R is transfer direction from the viewpoint of the master. For master receiver, R is '1'. Note that I2CDR is used for both address and data.
3. Configure baud rate by writing desired value to both I2CSCLLR and I2CSCLHR for the Low and High period of SCL line.
4. Configure the I2CSDAHR to decide when SDA changes value from falling edge of SCL. If SDA should change in the middle of SCL LOW period, load half the value of I2CSCLLR to the I2CSDAHR.
5. Set the START bit in I2CMR. This transmits a START condition. And also configure how to handle interrupt and ACK signal. When the START bit is set, 8-bit data in I2CDR is transmitted out according to the baud-rate.
6. This is ACK signal processing stage for address packet transmitted by master. When 7-bit address and 1-bit transfer direction is transmitted to target slave device, the master can know whether the slave acknowledged or not in the 9th high period of SCL. If the master gains bus mastership, I²C generates GCALL interrupt regardless of the reception of ACK from the slave device. When I²C loses bus mastership during arbitration process, the MLOST bit in I2CSR is set, and I²C waits in idle state or can be operate as an addressed slave. To operate as a slave when the MLSOT bit in I2CSR is set, the ACKEN bit in I2CMR must be set and the received 7-bit address must equal to the SLA bits in I2CSAR. In this case I²C operates as a slave transmitter or a slave receiver (go to appropriate section). In this stage, I²C holds the SCL LOW. This is because to decide whether I²C continues serial transfer or stops communication. The following steps continue assuming that I²C does not lose mastership during first data transfer.

I²C (Master) can choose one of the following cases according to the reception of ACK signal from slave.

- 1) Master receives ACK signal from slave, so continues data transfer because slave can prepare and transmit more data to master. Configure ACKEN bit in I2CMR to decide whether I²C ACKnowledges the next data to be received or not.
- 2) Master stops data transfer because it receives no ACK signal from slave. In this case, set the STOP bit in I2CMR.
- 3) Master transmits repeated START condition due to no ACK signal from slave. In this case, load SLA+R/W into the I2CDR and set START bit in I2CMR.

After doing one of the actions above, write arbitrary value to I2CSR to release SCL line. In case of 1), move to step 7. In case of 2), move to step 9 to handle STOP interrupt. In case of 3), move to step 6 after transmitting the data in I2CDR and if transfer direction bit is '0' go to master transmitter section.

7. 1-Byte of data is being received.
8. This is ACK signal processing stage for data packet transmitted by slave. I²C holds the SCL LOW. When 1-Byte of data is received completely, I²C generates TEND interrupt.

I²C can choose one of the following cases according to the RXACK flag in I2CSR.

- 1) Master continues receiving data from slave. To do this, set ACKEN bit in I2CMR to ACKnowledge the next data to be received.
- 2) Master wants to terminate data transfer when it receives next data by not generating ACK signal. This can be done by clearing ACKEN bit in I2CMR.
- 3) Because no ACK signal is detected, master terminates data transfer. In this case, set the STOP bit in I2CMR.
- 4) No ACK signal is detected, and master transmits repeated START condition. In this case,

11.10.8.3 Slave Transmitter

To operate I²C in slave transmitter, follow the recommended steps below.

1. If the main operating clock (SCLK) of the system is slower than that of SCL, load value 0x00 into I2CSDAHR to make SDA change within one system clock period from the falling edge of SCL. Note that the hold time of SDA is calculated by SDAH x period of SCLK where SDAH is multiple of number of SCLK coming from I2CSDAHR. When the hold time of SDA is longer than the period of SCLK, I²C (slave) cannot transmit serial data properly.
2. Enable I²C by setting IICEN bit and INTEN bit in I2CMR. This provides main clock to the peripheral.
3. When a START condition is detected, I²C receives one byte of data and compares it with SLA bits in I2CSAR. If the GCALLEN bit in I2CSAR is enabled, I²C compares the received data with value 0x00, the general call address.
4. If the received address does not equal to SLA bits in I2CSAR, I²C enters idle state ie, waits for another START condition. Else if the address equals to SLA bits and the ACKEN bit is enabled, I²C generates SSEL interrupt and the SCL line is held LOW. Note that even if the address equals to SLA bits, when the ACKEN bit is disabled, I²C enters idle state. When SSEL interrupt occurs, load transmit data to I2CDR and write arbitrary value to I2CSR to release SCL line.
5. 1-Byte of data is being transmitted.
6. In this step, I²C generates TEND interrupt and holds the SCL line LOW regardless of the reception of ACK signal from master. Slave can select one of the following cases.

1) No ACK signal is detected and I²C waits STOP or repeated START condition.

2) ACK signal from master is detected. Load data to transmit into I2CDR.

After doing one of the actions above, write arbitrary value to I2CSR to release SCL line. In case of 1) move to step 7 to terminate communication. In case of 2) move to step 5. In either case, a repeated START condition can be detected. For that case, move step 4.

7. This is the final step for slave transmitter function of I²C, handling STOP interrupt. The STOP bit indicates that data transfer between master and slave is over. To clear I2CSR, write arbitrary value to I2CSR. After this, I²C enters idle state.

The next figure shows flow chart for handling slave transmitter function of I²C.

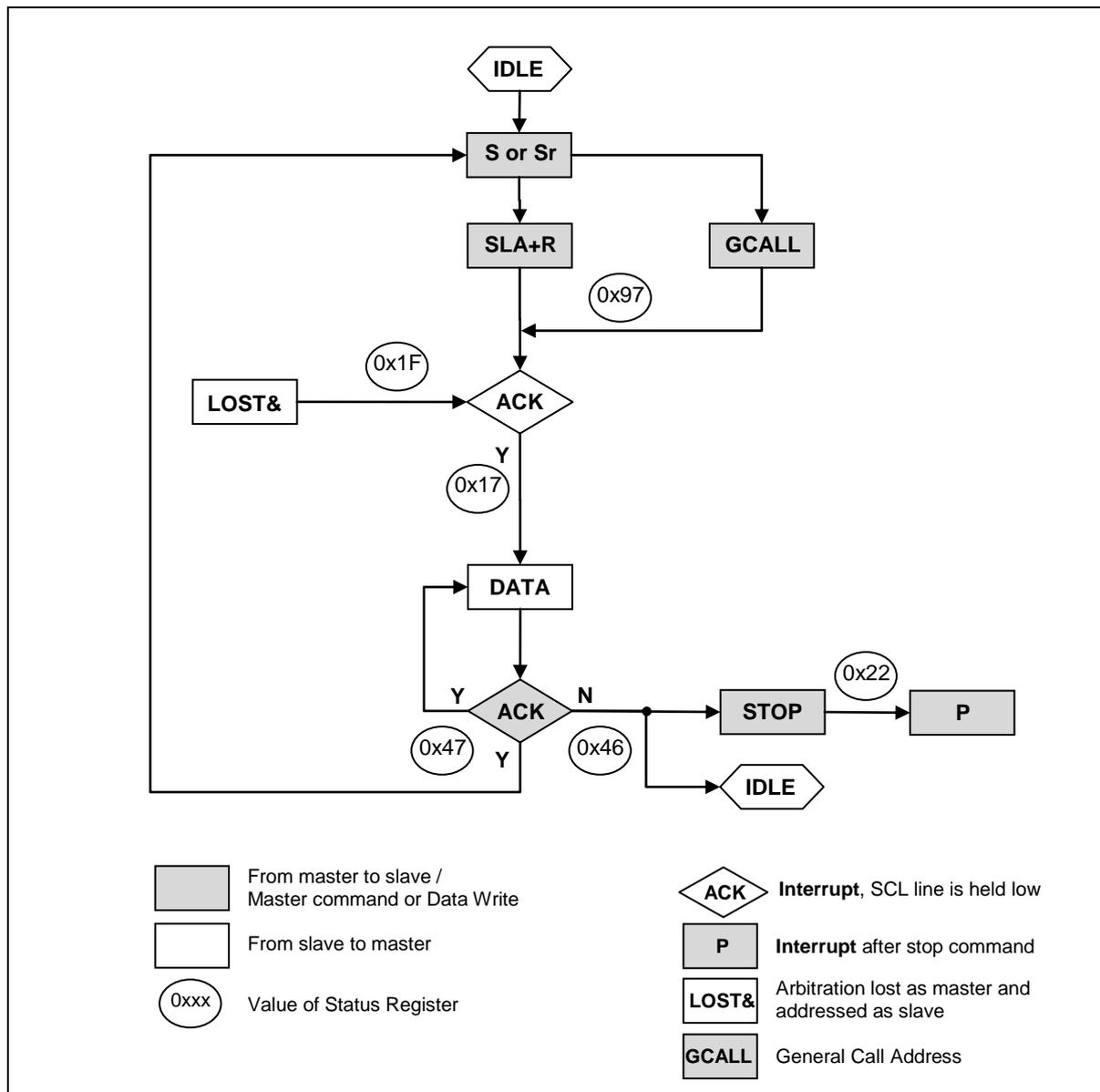


Figure 11-53 Formats and States in the Slave Transmitter Mode

11.10.8.4 Slave Receiver

To operate I²C in slave receiver, follow the recommended steps below.

1. If the main operating clock (SCLK) of the system is slower than that of SCL, load value 0x00 into I2CSDAHR to make SDA change within one system clock period from the falling edge of SCL. Note that the hold time of SDA is calculated by SDAH x period of SCLK where SDAH is multiple of number of SCLK coming from I2CSDAHR. When the hold time of SDA is longer than the period of SCLK, I²C (slave) cannot transmit serial data properly.
2. Enable I²C by setting IICEN bit and INTEN bit in I2CMR. This provides main clock to the peripheral.
3. When a START condition is detected, I²C receives one byte of data and compares it with SLA bits in I2CSAR. If the GCALLEN bit in I2CSAR is enabled, I²C compares the received data with value 0x00, the general call address.
4. If the received address does not equal to SLA bits in I2CSAR, I²C enters idle state ie, waits for another START condition. Else if the address equals to SLA bits and the ACKEN bit is enabled, I²C generates SSEL interrupt and the SCL line is held LOW. Note that even if the address equals to SLA bits, when the ACKEN bit is disabled, I²C enters idle state. When SSEL interrupt occurs and I²C is ready to receive data, write arbitrary value to I2CSR to release SCL line.
5. 1-Byte of data is being received.
6. In this step, I²C generates TEND interrupt and holds the SCL line LOW regardless of the reception of ACK signal from master. Slave can select one of the following cases.
 - 1) No ACK signal is detected (ACKEN=0) and I²C waits STOP or repeated START condition.
 - 2) ACK signal is detected (ACKEN=1) and I²C can continue to receive data from master.After doing one of the actions above, write arbitrary value to I2CSR to release SCL line. In case of 1) move to step 7 to terminate communication. In case of 2) move to step 5. In either case, a repeated START condition can be detected. For that case, move step 4.
7. This is the final step for slave receiver function of I²C, handling STOP interrupt. The STOP bit indicates that data transfer between master and slave is over. To clear I2CSR, write arbitrary value to I2CSR. After this, I²C enters idle state.

The process can be depicted as following figure when I²C operates in slave receiver mode.

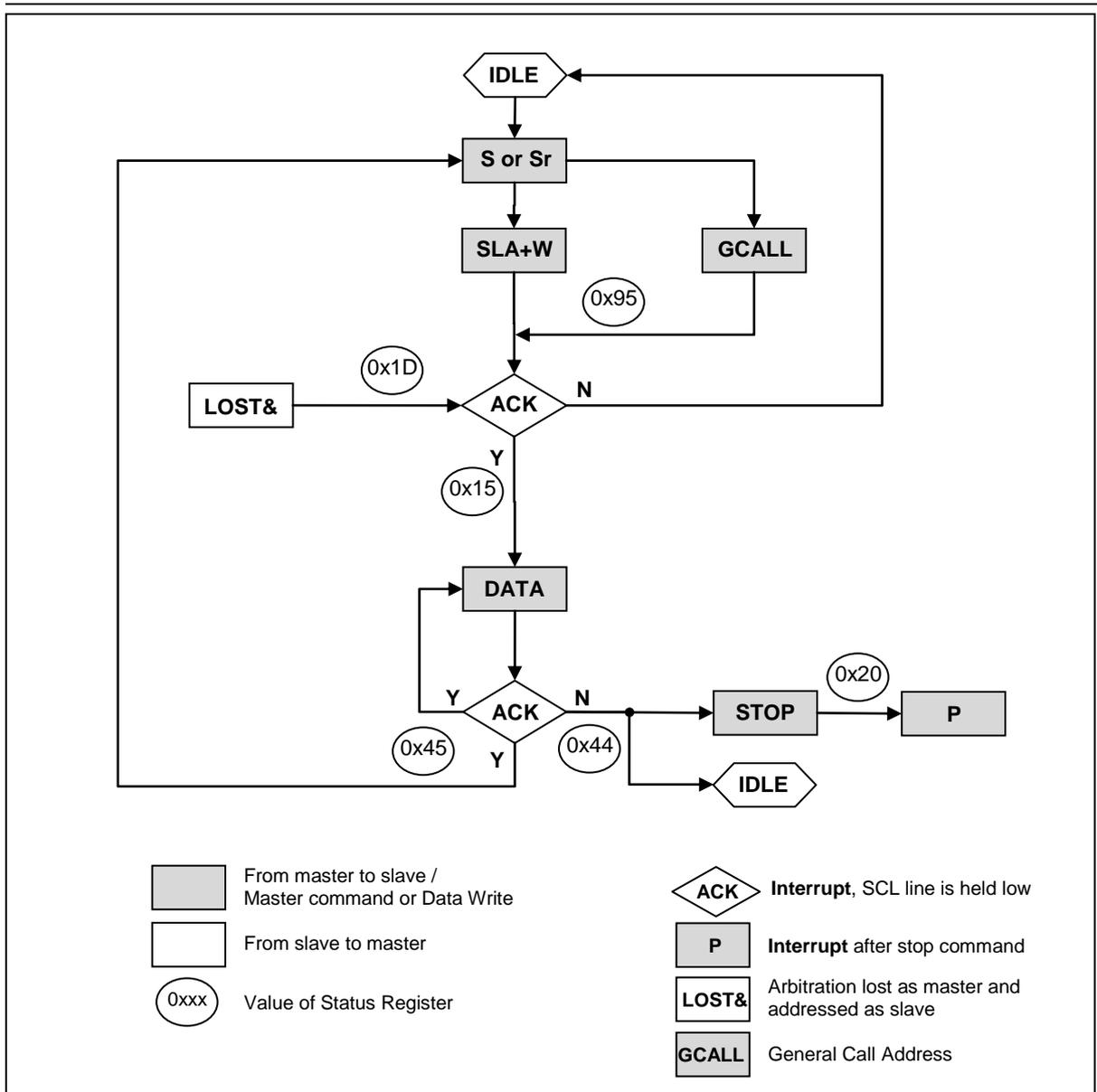


Figure 11-54 Formats and States in the Slave Receiver Mode

11.10.9 Register Map

Name	Address	Dir	Default	Description
I2CMR	9C _H	R/W	00 _H	I ² C Mode Control Register
I2CSR	9D _H	R	00 _H	I ² C Status Register
I2CSCLLR	9E _H	R/W	3F _H	SCL Low Period Register
I2CSCLHR	9F _H	R/W	3F _H	SCL High Period Register
I2CSDAHR	A3 _H	R/W	01 _H	SDA Hold Time Register
I2CDR	A5 _H	R/W	FF _H	I ² C Data Register
I2CSAR	A6 _H	R/W	00 _H	I ² C Slave Address Register
I2CSAR1	A7 _H	R/W	00 _H	I ² C Slave Address Register 1

Table 11-19 Register map of I2C

11.10.10 I²C Register description

I²C Registers are composed of I²C Mode Control Register (I2CMR), I²C Status Register (I2CSR), SCL Low Period Register (I2CSCLLR), SCL High Period Register (I2CSCLHR), SDA Hold Time Register (I2CSDAHR), I²C Data Register (I2CDR), and I²C Slave Address Register (I2CSAR).

11.10.11 Register description for I²C

I2CMR (I²C Mode Control Register)

9C_H

7	6	5	4	3	2	1	0
IIF	IICEN	RESET	INTEN	ACKEN	MASTER	STOP	START
RW	RW	RW	RW	RW	R	RW	RW

Initial value : 00_H

IIF	This is interrupt flag bit. 0 No interrupt is generated or interrupt is cleared 1 An interrupt is generated
IICEN	Enable I ² C Function Block (by providing clock) 0 I ² C is inactive 1 I ² C is active
RESET	Initialize internal registers of I ² C. 0 No operation 1 Initialize I ² C, auto cleared
INTEN	Enable interrupt generation of I ² C. 0 Disable interrupt, operates in polling mode 1 Enable interrupt
ACKEN	Controls ACK signal generation at ninth SCL period. Note) ACK signal is output (SDA=0) for the following 3 cases. When received address packet equals to SLA bits in I2CSAR When received address packet equals to value 0x00 with GCALL enabled When I ² C operates as a receiver (master or slave) 0 No ACK signal is generated (SDA=1) 1 ACK signal is generated (SDA=0)
MASTER	Represent operating mode of I ² C 0 I ² C is in slave mode 1 I ² C is in master mode
STOP	When I ² C is master, generates STOP condition. 0 No operation 1 STOP condition is to be generated
START	When I ² C is master, generates START condition. 0 No operation 1 START or repeated START condition is to be generated

I2CSR (I²C Status Register)**9D_H**

7	6	5	4	3	2	1	0
GCALL	TEND	STOP	SSEL	MLOST	BUSY	TMODE	RXACK
R	R	R	R	R	R	R	R

Initial value : 00_H

GCALL	This bit has different meaning depending on whether I ² C is master or slave. Note 1) When I ² C is a master, this bit represents whether it received AACK (Address ACK) from slave. When I ² C is a slave, this bit is used to indicate general call. 0 No AACK is received (Master mode) 1 AACK is received (Master mode) 0 Received address is not general call address (Slave mode) 1 General call address is detected (Slave mode)
TEND	This bit is set when 1-Byte of data is transferred completely. Note 1) 0 1 byte of data is not completely transferred 1 1 byte of data is completely transferred
STOP	This bit is set when STOP condition is detected. Note 1) 0 No STOP condition is detected 1 STOP condition is detected
SSEL	This bit is set when I ² C is addressed by other master. Note 1) 0 I ² C is not selected as slave 1 I ² C is addressed by other master and acts as a slave
MLOST	This bit represents the result of bus arbitration in master mode. Note 1) 0 I ² C maintains bus mastership 1 I ² C has lost bus mastership during arbitration process
BUSY	This bit reflects bus status. 0 I ² C bus is idle, so any master can issue a START condition 1 I ² C bus is busy
TMODE	This bit is used to indicate whether I ² C is transmitter or receiver. 0 I ² C is a receiver 1 I ² C is a transmitter
RXACK	This bit shows the state of ACK signal. 0 No ACK is received 1 ACK is generated at ninth SCL period

Note 1) These bits can be source of interrupt.

When an I²C interrupt occurs except for STOP interrupt, the SCL line is hold LOW. To release SCL, write arbitrary value to I2CSR. When I2CSR is written, the TEND, STOP, SSEL, LOST, RXACK bits are cleared.

I2CSCLLR (SCL Low Period Register)**9E_H**

7	6	5	4	3	2	1	0
SCLL7	SCLL6	SCLL5	SCLL4	SCLL3	SCLL2	SCLL1	SCLL0
RW							

Initial value : 3F_H**SCLL[7:0]**

This register defines the LOW period of SCL when I²C operates in master mode. The base clock is SCLK, the system clock, and the period is calculated by the formula : $t_{SCLK} \times (4 \times SCLL + 1)$ where t_{SCLK} is the period of SCLK.

I2CSCLHR (SCL High Period Register)**9F_H**

7	6	5	4	3	2	1	0
SCLH7	SCLH6	SCLH5	SCLH4	SCLH3	SCLH2	SCLH1	SCLH0
RW							

Initial value : 3F_H**SCLH[7:0]**

This register defines the HIGH period of SCL when I²C operates in master mode. The base clock is SCLK, the system clock, and the period is calculated by the formula : $t_{SCLK} \times (4 \times SCLH + 3)$ where t_{SCLK} is the period of SCLK.

So, the operating frequency of I²C in master mode (fI2C) is calculated by the following equation.

$$fI2C = \frac{1}{t_{SCLK} \times (4 (SCLL + SCLH) + 4)}$$

I2CSDAHR (SDA Hold Time Register)**A3_H**

7	6	5	4	3	2	1	0
SDAH7	SDAH6	SDAH5	SDAH4	SDAH3	SDAH2	SDAH1	SDAH0
RW							

Initial value : 01_H**SDAH[7:0]**

This register is used to control SDA output timing from the falling edge of SCL. Note that SDA is changed after $t_{SCLK} \times SDAH$. In master mode, load half the value of SCLL to this register to make SDA change in the middle of SCL. In slave mode, configure this register regarding the frequency of SCL from master. The SDA is changed after $t_{SCLK} \times (SDAH + 1)$. So, to insure normal operation in slave mode, the value $t_{SCLK} \times (SDAH + 1)$ must be smaller than the period of SCL.

I2CDR (I²C Data Register)**A5_H**

7	6	5	4	3	2	1	0
ICD7	ICD6	ICD5	ICD4	ICD3	ICD2	ICD1	ICD0
RW							

Initial value : FF_H**ICD[7:0]**

When I²C is configured as a transmitter, load this register with data to be transmitted. When I²C is a receiver, the received data is stored into this register.

I2CSAR (I²C Slave Address Register)**A6_H**

7	6	5	4	3	2	1	0
SLA07	SLA06	SLA05	SLA04	SLA03	SLA02	SLA01	SLA00
RW							

Initial value : 00_H

SLA0[7:1] These bits configure the slave address of this I²C module when I²C operates in slave mode.

GCALLEN This bit decides whether I²C allows general call address or not when I²C operates in slave mode.

0 Ignore general call address

1 Allow general call address

I2CSAR1 (I²C Slave Address Register 1)**A7_H**

7	6	5	4	3	2	1	0
SLA17	SLA16	SLA15	SLA14	SLA13	SLA12	SLA11	SLA10
RW							

Initial value : 00_H

SLA1[7:1] These bits configure the slave address of this I²C module when I²C operates in slave mode.

GCALLEN This bit decides whether I²C allows general call address or not when I²C operates in slave mode.

0 Ignore general call address

1 Allow general call address

12. POWER MANAGEMENT

12.1 Overview

MC96FR116C supports two kinds of power saving modes, SLEEP and STOP. In these modes, the program execution is stopped. There's also BOD mode caused by voltage drop, which is almost the same as STOP mode.

12.2 PERIPHERAL OPERATION IN SLEEP/STOP/BOD MODE

Peripheral	SLEEP Mode	STOP Mode	BOD mode
CPU	ALL CPU Operations are disabled	ALL CPU Operations are disabled	ALL CPU Operations are disabled
RAM	Retain	Retain	Retain
Basic Interval Timer	Operates Continuously	Stop	Stop
Watch Dog Timer	Operates Continuously	Stop	Stop
Timer0~3	Operates Continuously	Halted	Halted
Carrier Generator	Operates Continuously	Stop	Stop
USART	Operates Continuously	Stop	Stop
BOD	Enabled	Disabled	Enabled
Main OSC (1~12MHz)	Oscillation	Stop	Stop
INT-RC OSC 12MHz	Oscillation	Stop	Stop
I/O Port	Retain	Retain	Retain or Input pull-up mode
Control Register	Retain	Retain	Retain
Address / Data Bus	Retain	Retain	Retain
Release Method	By RESET, all Interrupts	By RESET, Key interrupt, External Interrupt, UART by RX, PCI	By Reset, By power rise detect

Table 12-1 CPU and peripherals state in power saving modes

12.3 SLEEP mode

To enter SLEEP mode, write 01_H to Power Control Register(PCON, 87_H). In this mode, only the CPU halts and other peripherals including main oscillator operate normally. SLEEP mode can be released by a reset or interrupt. When SLEEP mode is released by a reset, all internal logics is initialized.

The following example shows the way to enter SLEEP mode.

(ex) MOV PCON, #0000_0001b ; Enter SLEEP mode : set bits of STOP and SLEEP Control register (PCON)

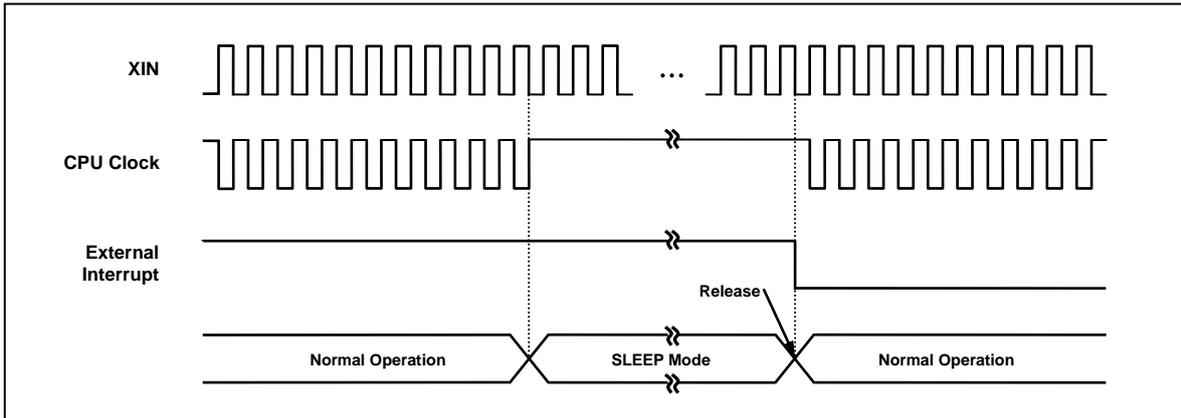


Figure 12-1 Wake-up from SLEEP mode by an interrupt

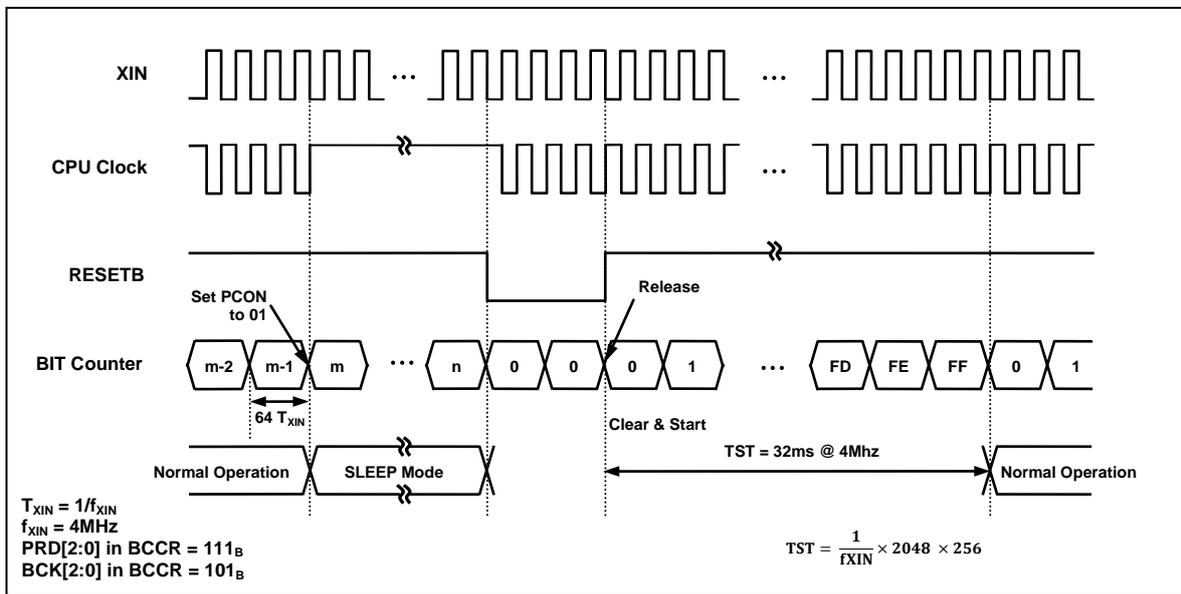


Figure 12-2 SLEEP mode release by an external reset

12.4 STOP mode

The least power consuming state called STOP mode is initiated by writing 03_H to Power Control Register (PCON, 87_H). In STOP mode, all analog and digital blocks including main oscillator stop operation. The analog block VDC also enters its own stop mode and BOD is auto-disabled, so power consumption is radically reduced. All registers value or RAM data are reserved.

STOP mode release is done by a reset or external pin interrupt request. When a reset is detected in STOP mode, the device is initialized, so all registers except for BODR register is reset to initial state. BODR register may or may not be initialized 'cause it has reset flags which are affected only by it's specific reset source. There're three kinds of reset sources which can be used to release STOP mode, power on reset(nPOR), external reset(P15) and BOD reset.

When a reset or interrupt occurs in STOP mode, the clock control logic makes system clock active when a pre-defined time is passed. The oscillation stability time can be calculated by the overflow period of BIT counter. ^{NOTE}

NOTE The oscillation stability time is up to the characteristic of an oscillator or a resonator connected to the device. So the 20ms of recommended stability time is not absolute.

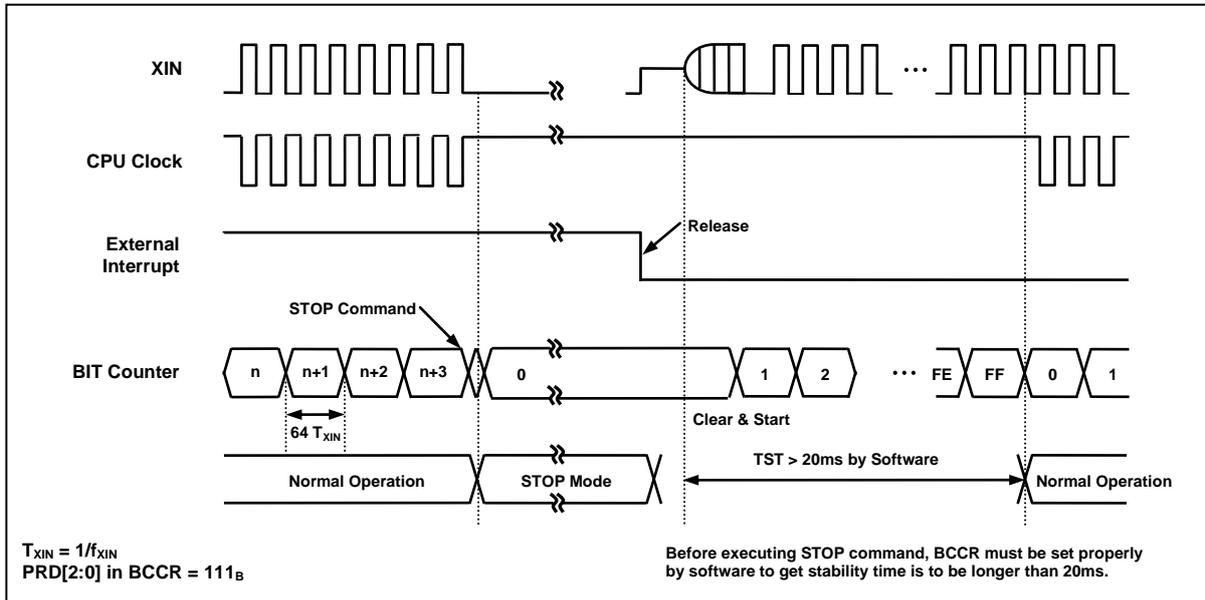


Figure 12-3 Wake-up from STOP mode by an interrupt

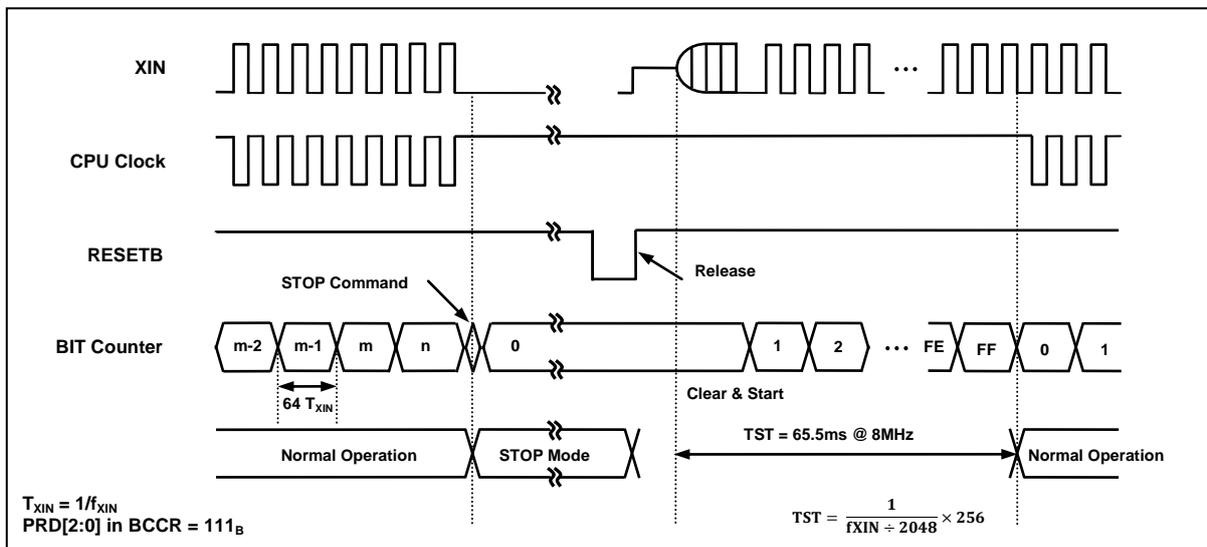


Figure 12-4 STOP mode release by an external reset

MC96FR116C acts in a little different manner after it awakes from STOP mode according to the external power condition after wake-up event.

In stop mode, the main oscillator is halted and any internal peripheral does not operate normally. So only an interrupt from external world can wake the device up from STOP mode. These kinds of interrupts are an external interrupt, key input or MISO(RXD) pin in UART mode. When an interrupt is detected, the wake-up logic enables BOD to check the external voltage level. If the voltage level is higher than the BOD stop level(= V_{BODR}), the device wakes up normally to resume program execution. Otherwise if the checked voltage level is below the V_{BODR} , it remains in STOP mode. This continues

unless the power level is recovered. Thereafter the device wakes up by another interrupt when the power level detected by BOD is sufficient. In this case, BOD reset is generated to initialize the device. To wake up by an interrupt and accept interrupt request, the EA bit in IE register and the individual interrupt enable bit INTnE in IEx registers should be set.

12.5 BOD mode

When BOD is enabled and the external voltage drops below V_{BODR} , the device enters BOD mode instantaneously. In BOD mode, all analog and digital blocks except for BOD stops operating. The internal state of the device is almost the same as in STOP mode. But there are 3 different points as follows. First, on entering BOD mode, the I/O ports can be set input ports with pull-up registers on if PxPBC registers are enabled. Second, BOD mode can only be released by voltage rise detected by BOD. And after mode exit, the device is initialized by a BOD reset event. Third, because BOD is enabled to detect voltage variation, the current consumption is larger than STOP mode of operation, typically maximum 40uA of current is consumed. Except the three different points described above, BOD mode is the same as STOP mode.

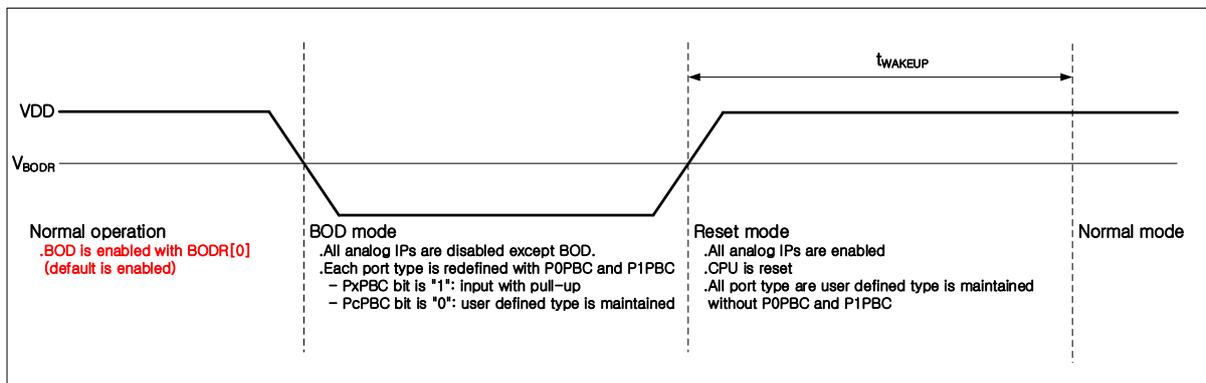


Figure 12-5 BOD mode during normal mode

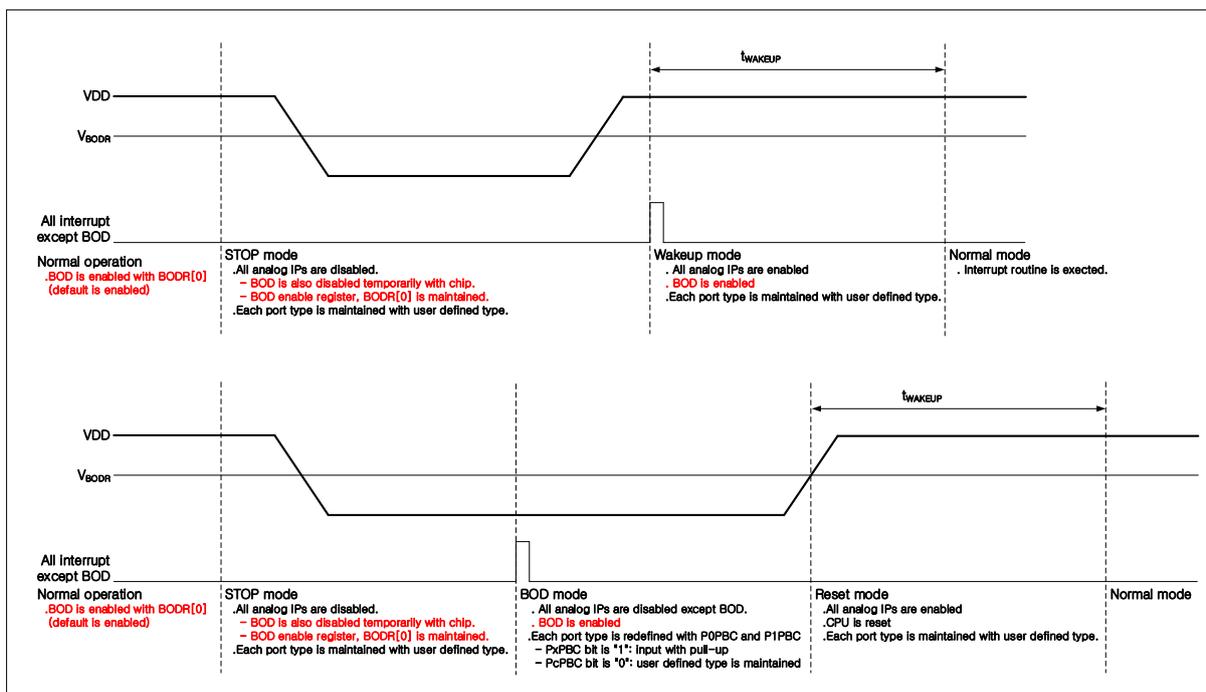


Figure 12-6 BOD mode during stop mode

12.6 Register Map

Name	Address	Dir	Default	Description
PCON	87 _H	R/W	00 _H	Power Control Register

Table 12-2 Register Map of Power Control Logic

12.7 Register Description

PCON (Power Control Register)

87_H

7	6	5	4	3	2	1	0
BIT7	BIT6	BIT5	BIT4	BIT3	BIT2	BIT1	BIT0
R/W							

Initial value : 00_H

SLEEP mode

01_H Enters SLEEP mode

STOP mode

03_H Enters STOP mode

- NOTE
1. Write PCON register 01_H or 03_H to enter SLEEP or STOP mode.
 2. When mode exit from STOP or SLEEP is done successfully, the PCON register is auto-cleared.

13. RESET

13.1 Overview

When a reset event occurs, the CPU immediately stops whatever it is doing and all internal logics except for BODR register is initialized. The external reset pin(P20) shares normal I/O pin and the functionality is defined by fuse configuration(FUSE_CONF register). The hardware configuration right after reset event is as follows.

On Chip Hardware	Initial Value
Program Counter (PC)	0000 _H
Accumulator	00 _H
Stack Pointer (SP)	07 _H
Peripheral Clocks	On
Control Registers	Refer to Peripheral Registers
Brown-Out Detector	Enabled on power-on-reset

Table 13-1 Internal status when a reset is asserted

13.2 Reset source

Reset can be caused by a power-on-reset (nPOR) event, configuration reset by software, watchdog overflow, voltage drop detection by BOD, OCD command, or by assertion of an external active-low reset pin. Five of reset sources except for power-on-reset can be configured whether to be used as a reset source or not.

- External reset pin (P20) (Share with P20 pin. Active low)
- Power-on reset (nPOR, Active low)
- WDT overflow (when WDTEN is '1' and WDTRSON is '1')
- Configuration reset by software (nSW)
- BOD reset (when BODEN is '1') ^{NOTE}
- OCD command (When debugger issues a command)

13.3 Block Diagram

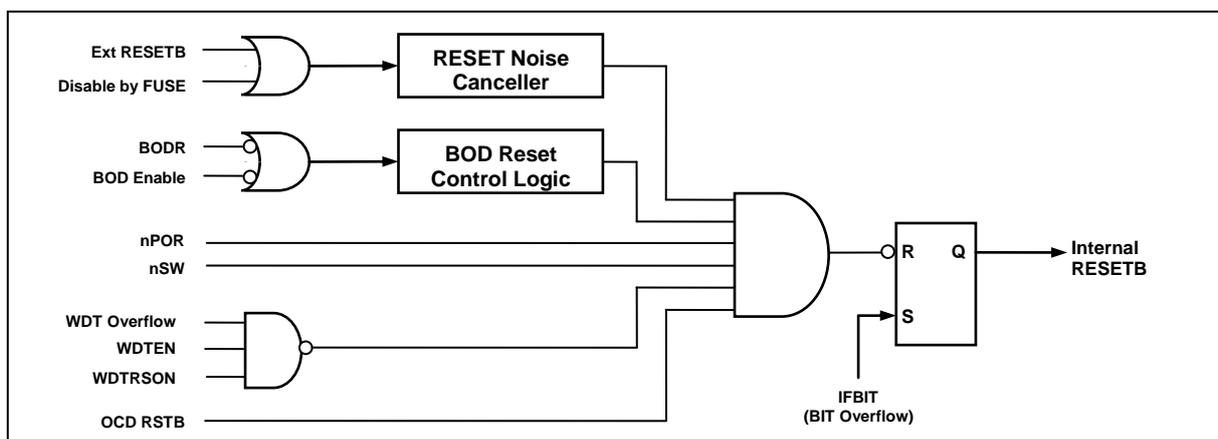


Figure 13-1 Block Diagram of Reset Circuit

NOTE Unlike other reset sources, BOD reset does not take place as soon as BODR goes HIGH(=voltage drops below BOD stop level). On detecting low voltage while the device is in normal run mode, the device enters BOD(STOP) mode first. And then by detecting voltage rise, the power control logic wakes the device up to give a reset signal.

Caution : When the device is in STOP mode by CPU command(PCON=0x03), the BOD cannot detect voltage drop because the BOD is disabled to reduce power consume. In this case, the BOD reset may be issued when a wake-up event or interrupt is generated with the external voltage below the BOD stop level.

13.4 Noise Canceller for External Reset Pin

A glitch-like or short pulse on external reset pin(P15) is ignored by the dedicated noise-canceller. To have an effect as a reset source, P15 port should be maintained low continuously at least 8us of time(T_{RNC}) in typical condition. The T_{RNC} may vary from 4.8us up to 13.8us according to the condition of manufacturing process.

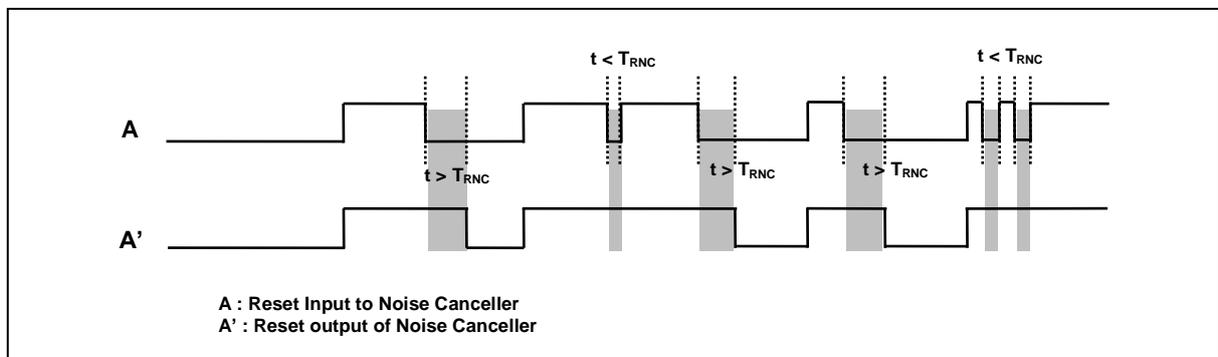


Figure 13-2 Noise Cancelling of External Reset Pin

13.5 Power-On-RESET

When power is initially applied to the MCU, or when the supply voltage drops below the V_{POR} level, the POR circuit will cause a reset condition. Owing to presence of POR, the external reset pin can be used as a normal I/O pin. Thus additional resistor and capacitor can be removed to be connected to reset pin.

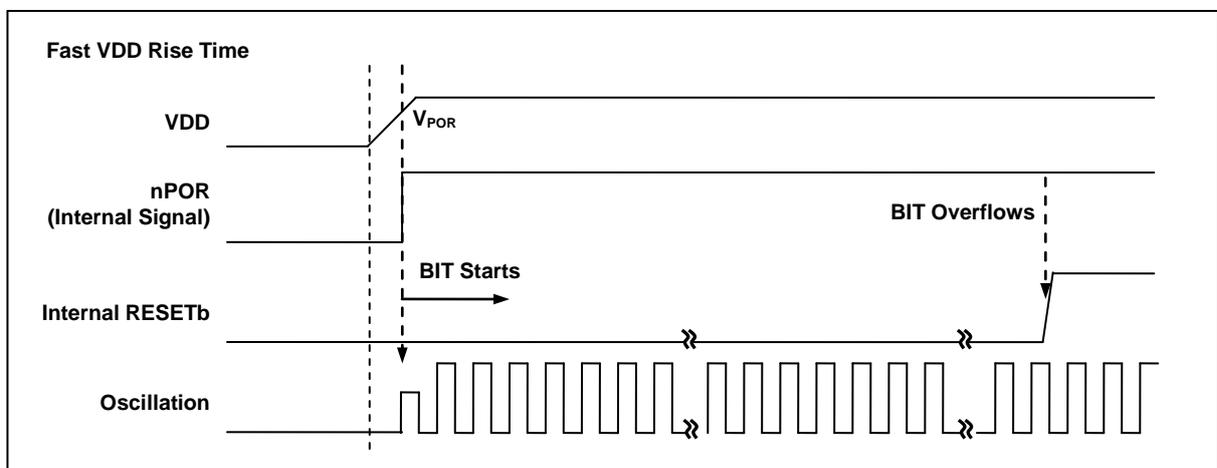


Figure 13-3 Reset Release Timing when Power is supplied (VDD Rises Rapidly)

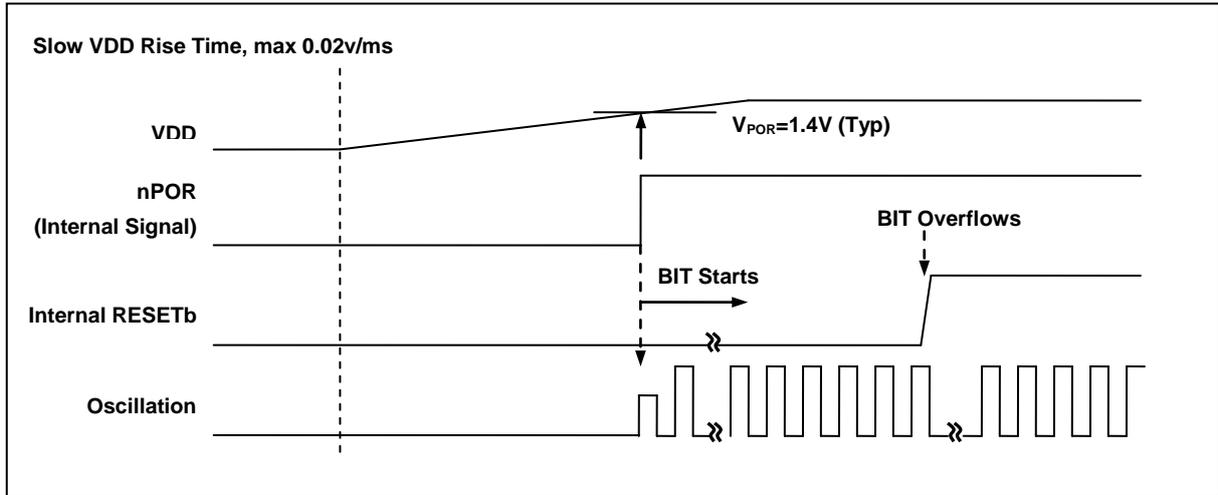


Figure 13-4 Reset Release Timing when Power is supplied (VDD Rises Slowly)

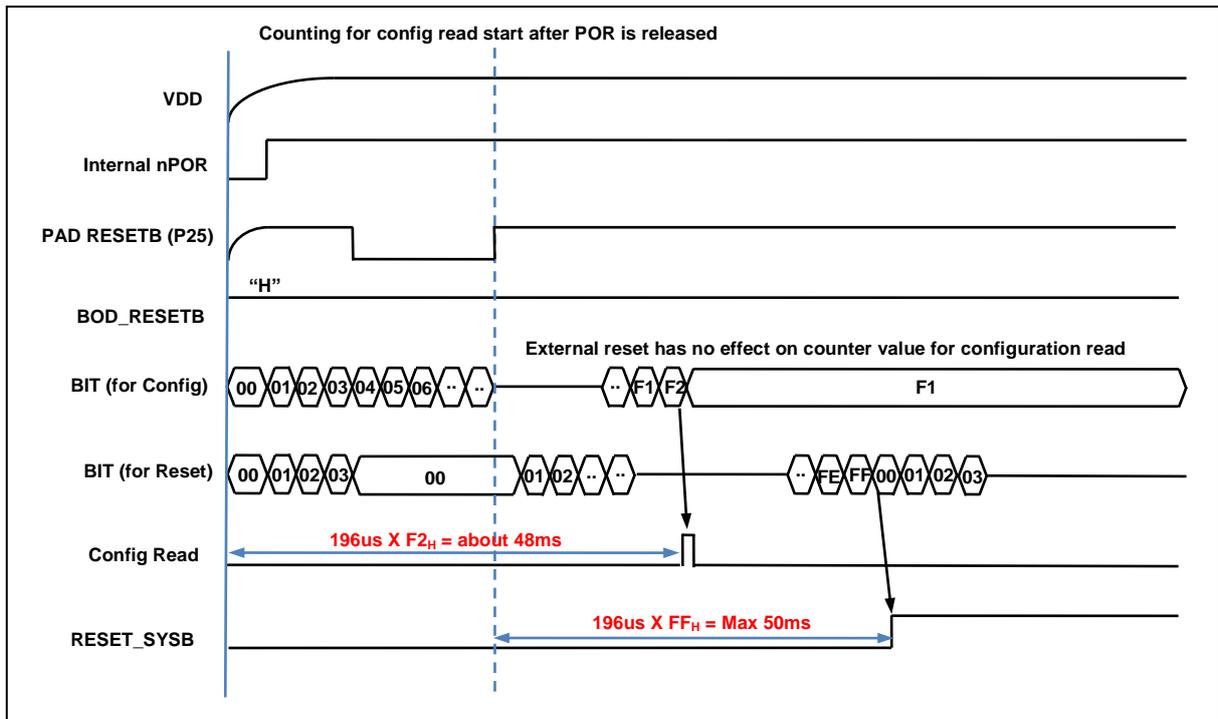


Figure 13-5 Fuse Configuration Value Read Timing after Power On

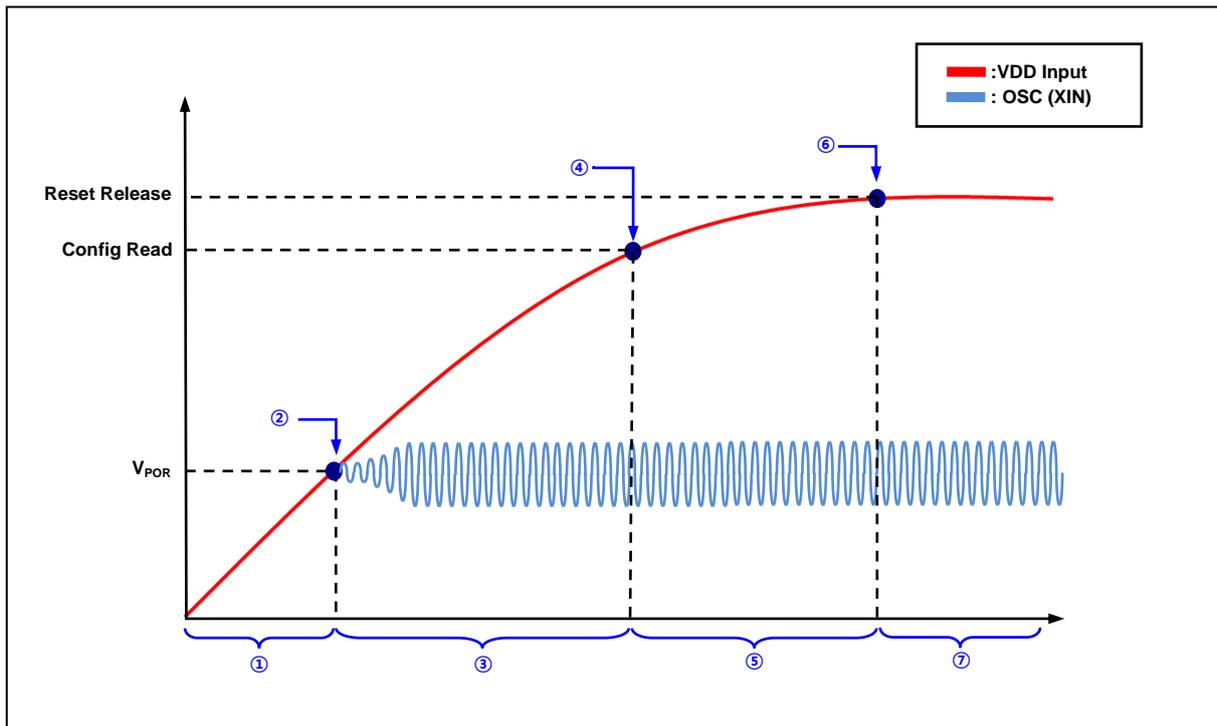


Figure 13-6 Operation according to Power Level

The above figure shows internal operation according to the voltage level and time. And the following table is short description about the figure.

Process	Description	Remarks
①	-POR	
②	-POR release point -Main OSC (Typically 8MHz) starts oscillation	-Around 1.3V ~ 1.5V
③	-(250ns X 1024) × F _{2H} (30ms) delay section -VDD must rise above flash operating voltage	-Slew Rate ≥ 0.025V/ms
④	-Configuration value read point	-Around 1.5V ~ 1.6V -Config value is determined by writing option
⑤	-Rising section to reset release level	-32ms after power-on-reset or external reset is released
⑥	-Reset release point (BIT overflow)	-BIT is used to ensure oscillation stability time
⑦	-Normal operation	

Table 13-2 Power On Sequence

13.6 External RESETB Input

External reset pin is a Schmitt Trigger type input. External reset input should be asserted low at least for 8 μ s (typically) for normal reset function when operating voltage and output of main oscillator are stable.

When the external reset input goes high, the internal reset is released after 64ms of stability time in case external clock frequency is 8MHz. For 5 clock periods from the point internal reset is released, an initialization procedure is performed. Thereafter the user program is executed from the address 0000_H.

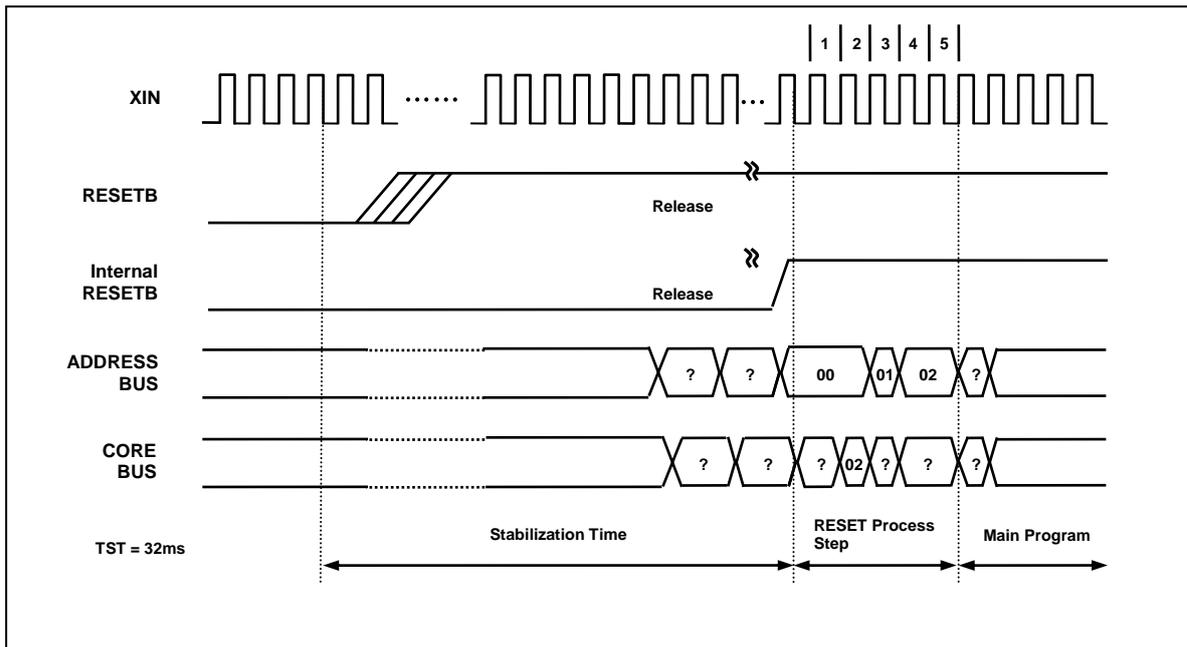


Figure 13-7 Reset procedure due to external reset input

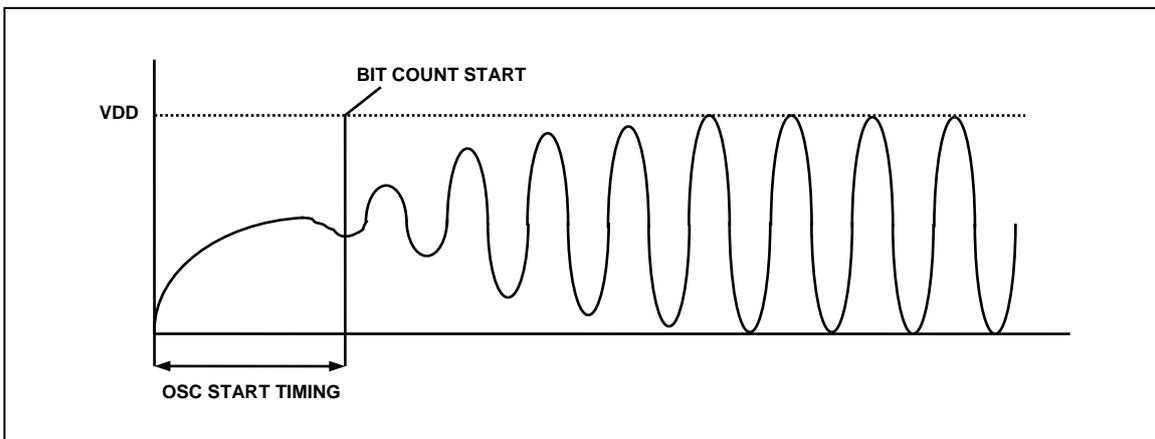


Figure 13-8 Example of oscillation

NOTE Oscillation start time does not belong to oscillation stability time.

13.7 Brown Out Detector

The MC96FR116C includes a system to protect against low voltage conditions in order to preserve memory contents and control MCU system states during supply voltage variations. The system is comprised of a power-on-reset(nPOR) and an BOD with 4 voltage level indicators. The BOD is enabled when BODEN in BODR is high. The BOD is auto-disabled upon entering STOP mode. This auto-disable function reduces operating power noticeably consumed by BOD itself.

The BOD has two main functions. One is to generate a BOD stop level(=BODR) and the other is to indicate voltage levels above BOD stop level denoted by BODI0,1,2,3,4 each.

Remember that BOD itself does not generate a reset signal. When operating voltage drops below a pre-defined level(V_{BODR}), the BOD does not cause the whole system to be reset, but signals main chip to enter BOD(STOP) mode instantaneously. For more information about BOD stop, refer to section 12.4 POWER MANAGEMENT.

Besides BOD stop level, the BOD gives four low voltage warning flags to indicate to the user that the supply voltage is approaching, but is still above, the BOD stop level. These flags can be read through the BODSR register, also can be an interrupt source when BODIEN bit in BODSR is set.

Like external reset, BODR is also filtered by a dedicated noise cancelling logic. A pulse shorter than about 2us(typically) is ignored by the system.

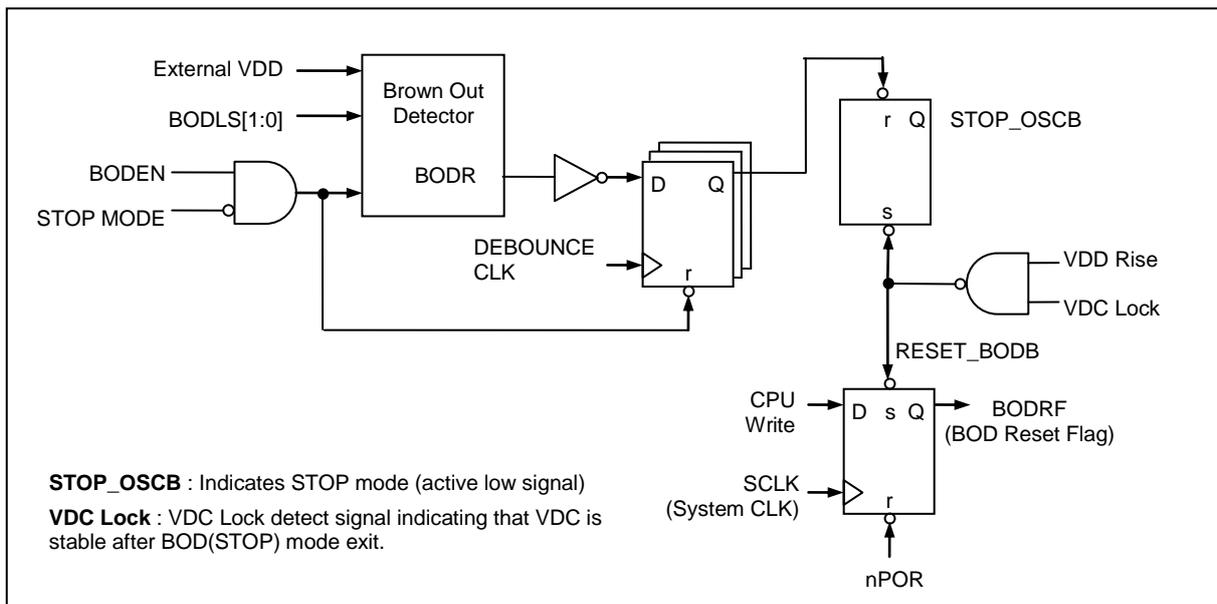


Figure 13-9 Block Diagram of BOD

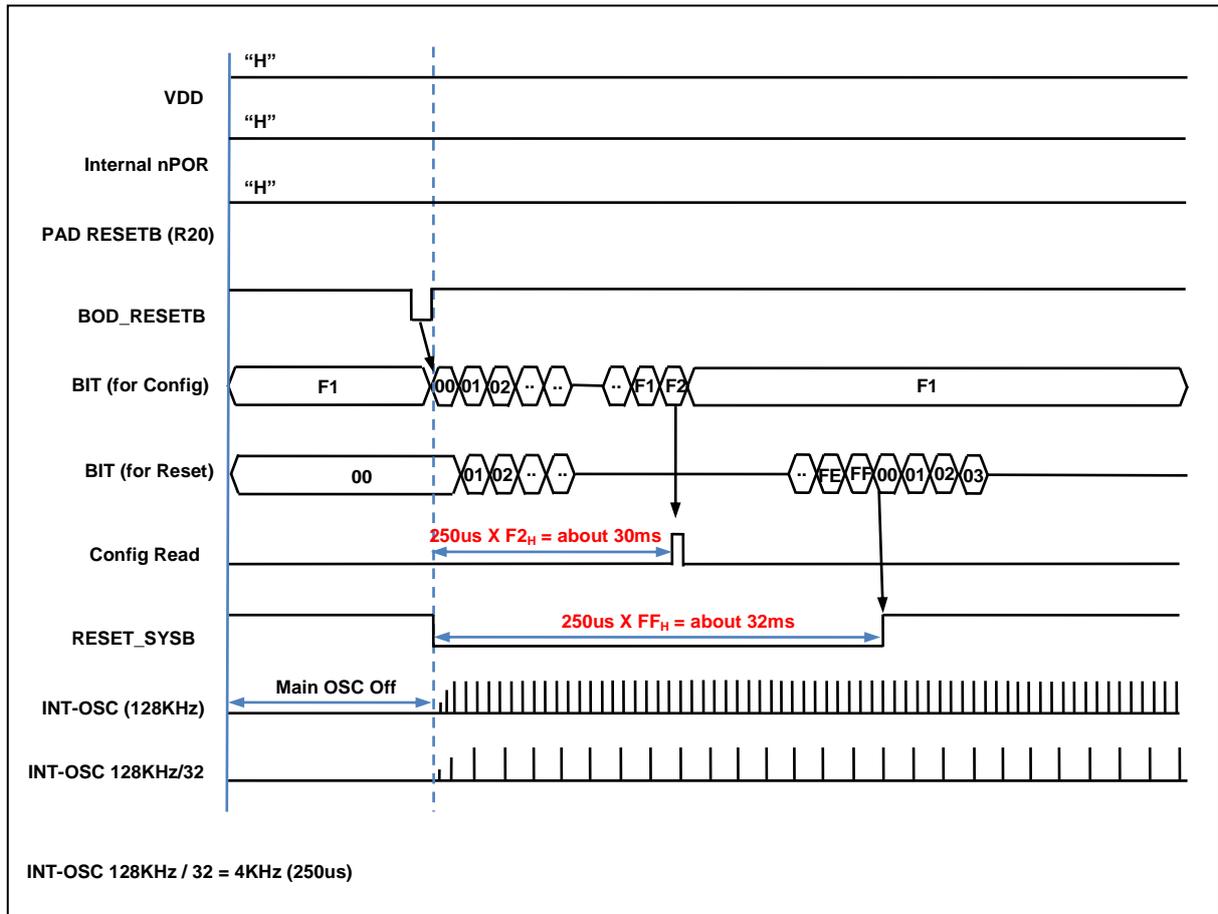


Figure 13-10 Configuration value read timing when BOD RESET is asserted

13.8 Register Map

Name	Address	Dir	Default	Description
BODR	86 _H	R/W	C9 _H	BOD Control Register
BODSR	8F _H	R/W	00 _H	BOD Status Register
CFGCR	F9 _H	R/W	01 _H	Configuration Control Register

Table 13-3 Register Map of BOD

13.9 Register Description

BODR (BOD Control Register)

86_H

7	6	5	4	3	2	1	0
PORF	EXTRF	WDTRF	OCDRF	BODRF	BODLS2	BODLS1	BODEN
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : C9_H

PORF Power-on reset or software reset event ^{NOTE}
 0 No POR event detected after clear
 1 POR occurred

EXTRF External Reset Event ^{NOTE}

	0	No external reset detected after clear		
	1	External reset occurred		
WDTRF	Watchdog reset event ^{NOTE}			
	0	No WDT reset detected after clear		
	1	WDT reset occurred		
OCDRF	On-chip debugger reset event ^{NOTE}			
	0	No OCD reset detected after clear		
	1	OCD reset occurred		
BODRF	Brown-out detector reset event ^{NOTE}			
	0	No BOD reset detected after clear		
	1	BOD reset occurred		
BODLS[2:1]	Select bod flag level bit[2:1]			
	BODLS2	BODLS1	BODLS0(BODSR[6])	
	1	1	1	BODI0(1.63V) is bod flag.
	0	0	0	BODI1(1.8V) is bod flag.
	0	0	1	BODI2(2.0V) is bod flag.
	0	1	0	BODI3(2.2V) is bod flag.
	0	1	1	BODI4(2.4V) is bod flag.
BODEN	Enables or disables BOD. If stop mode is entered, BOD is temporary disabled. And if stop mode is exited, BOD state id restored with BODEN.			
	0	Disable BOD		
	1	Enable BOD		

^{NOTE} To clear each reset flag, write '0' to associated bit position.

Initial vaule of ocd mode(debug mode) is D9_H.

BODSR (BOD Status Register)

8F_H

7	6	5	4	3	2	1	0
BODIF	BODLS0	BODIT					
R	RW	RW	-	-	-	-	-

Initial value : 00_H

BODIF	BOD interrupt flag. To clear this flag, write '0' to this bit position.
	0 BOD interrupt not requested
	1 BOD interrupt requested
BODLS[0]	Select bod flag level bit[0]. Please refer the register of BODLS[2:1], BODR.
BODIT	Select bod flag type.
	0 Level event
	1 Falling edge envet

CFGCR (Configuration Control Register)

8F_H

7	6	5	4	3	2	1	0
SWRM	-	-	STUE	-	-	SWU	SWR
RW	-	-	RW	-	-	RW	RW

Initial value : 10_H

- SWRM** The monitor of Software reset
- 0 Software reset was not asserted.
 - 1 Software reset was asserted.
- STUE** Configuration/trimming register update is enabled at stop mode.
- 0 Hardware will not update configuration register at stop mode.
 - 1 Hardware will update configuration register at stop mode.
- SWU** Configuration/trimming register update enable with at software
- 0 Configuration register will not be updated.
 - 1 Configuration register will be updated at once.
- SWR** Generate software reset signal.
- 0 Software reset is no enabled.
 - 1 Software reset is enabled.

14. On-chip Debug System

14.1 Overview

14.1.1 Description

The On-chip debug system(OCD) of MC96FR116C is used to program/erase the non-volatile memory or debug the device. The main features are shown as follows.

14.1.2 Features

- Two-wire external interface : 1-wire serial clock input, 1-wire bi-directional serial data bus
- Debugger Access to :
 - All Internal Peripheral Units
 - Internal data RAM
 - Program Counter
 - Non-volatile Memories
- Extensive On-chip Debug Support for Break Conditions, Including
 - Break Instruction
 - Single Step Break
 - Program Memory Break Points on Single Address
 - Programming of Flash, Fuses, and Lock Bits through the two-wire Interface
 - On-chip Debugging Supported by Dr.Choice[®]
- Operating frequency : Supports the maximum frequency of the target MCU

Caution : When the device operates with OCD module connected, the main oscillator of MC96FR116C does not stop even if it is in STOP mode.

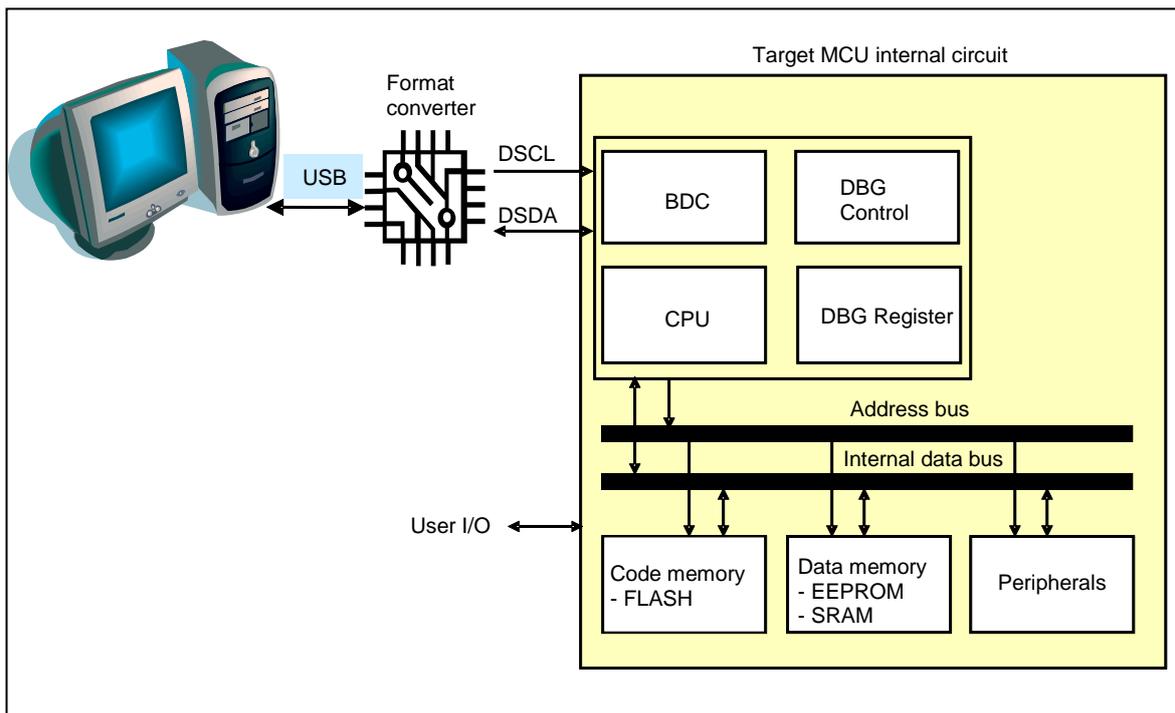


Figure 14-1 Block Diagram of On-Chip Debug System

14.2 Two-pin external interface

14.2.1 Basic transmission packet

- ✓ 10-bit packet transmission via two-wire interface.
- ✓ 1 packet consists of 8-bit data, 1-bit parity and 1-bit acknowledge.
- ✓ Even parity for 8-bit transmit data.
- ✓ Receiver gives acknowledge bit by pulling the data line low when 8-bit transmit data and parity bit has no error.
- ✓ When transmitter receives no acknowledge bit from the receiver, error process is done by transmitter.
- ✓ When acknowledge error is generated, host PC issues a stop condition and re-transmits the command.
- ✓ Background debugger command is composed of a bundle of packets.
- ✓ Each packet starts with a start condition and ends with a stop condition.

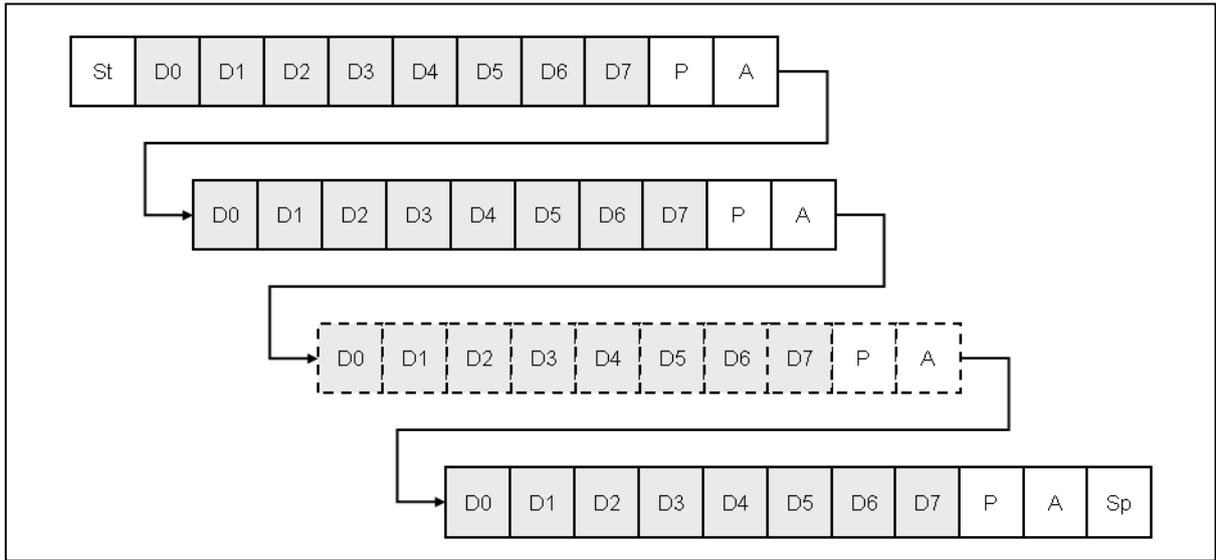


Figure 14-2 10-bit transmission packets

14.2.2 Packet transmission timing

14.2.2.1 Data transfer

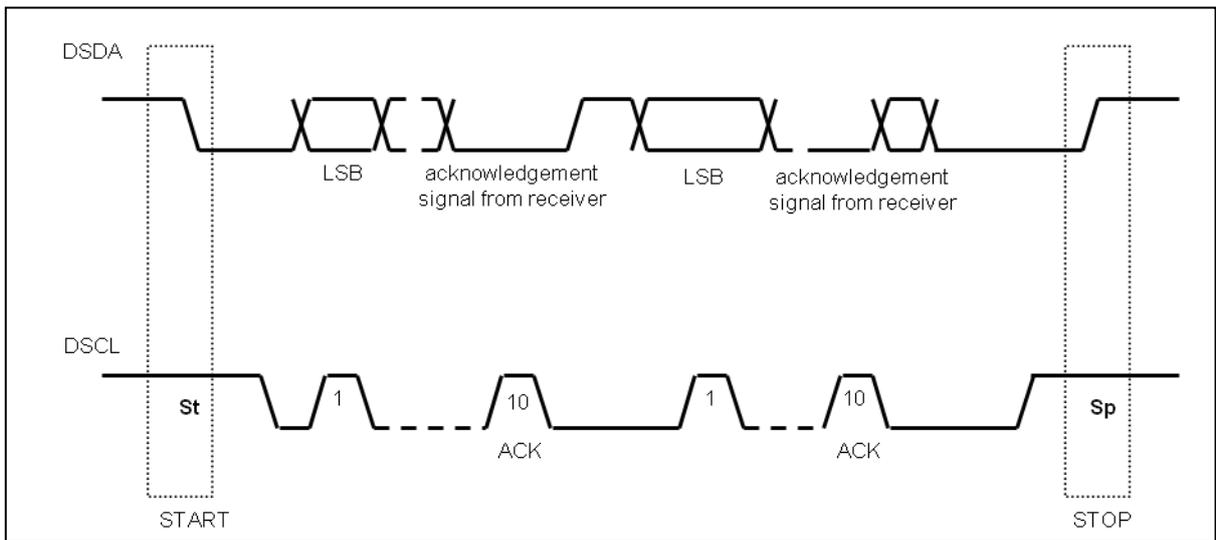


Figure 14-3 Data transfer on the twin bus

14.2.2.2 Bit transfer

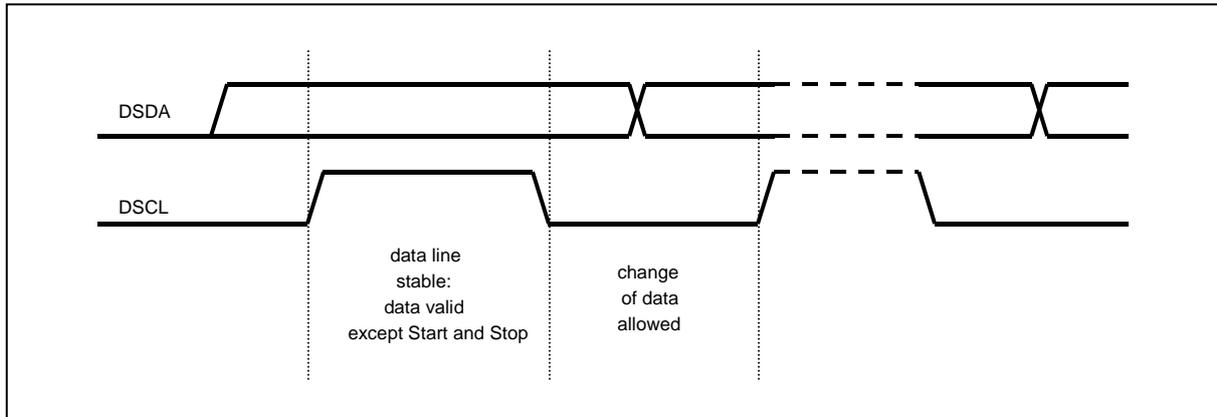


Figure 14-4 Bit transfer on the serial bus

14.2.2.3 Start and stop condition

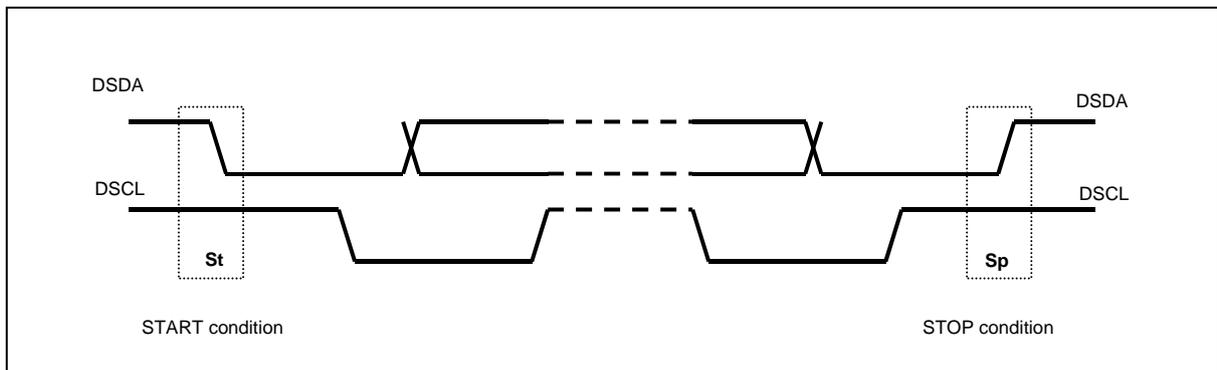


Figure 14-5 Start and stop condition

14.2.2.4 Acknowledge bit

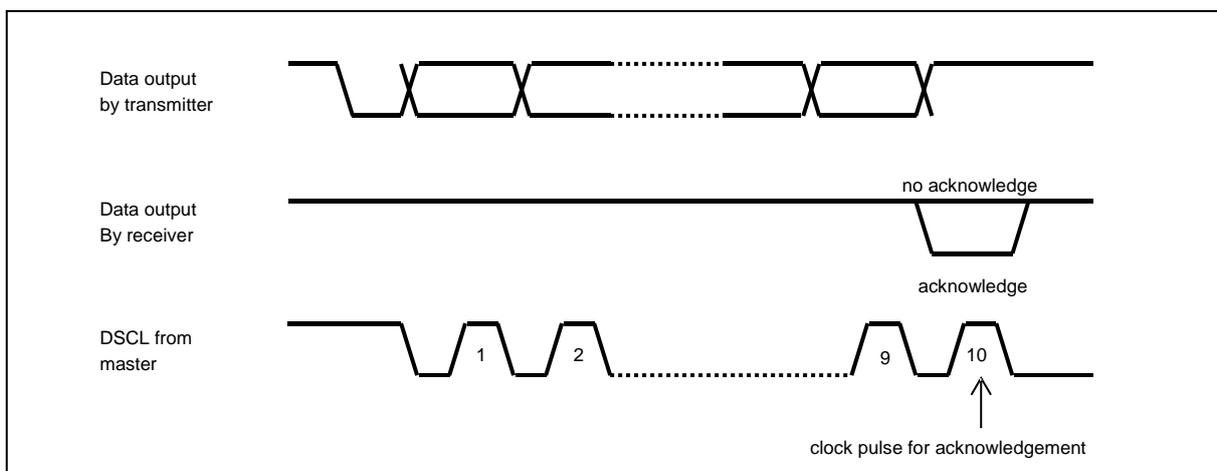


Figure 14-6 Acknowledge by receiver

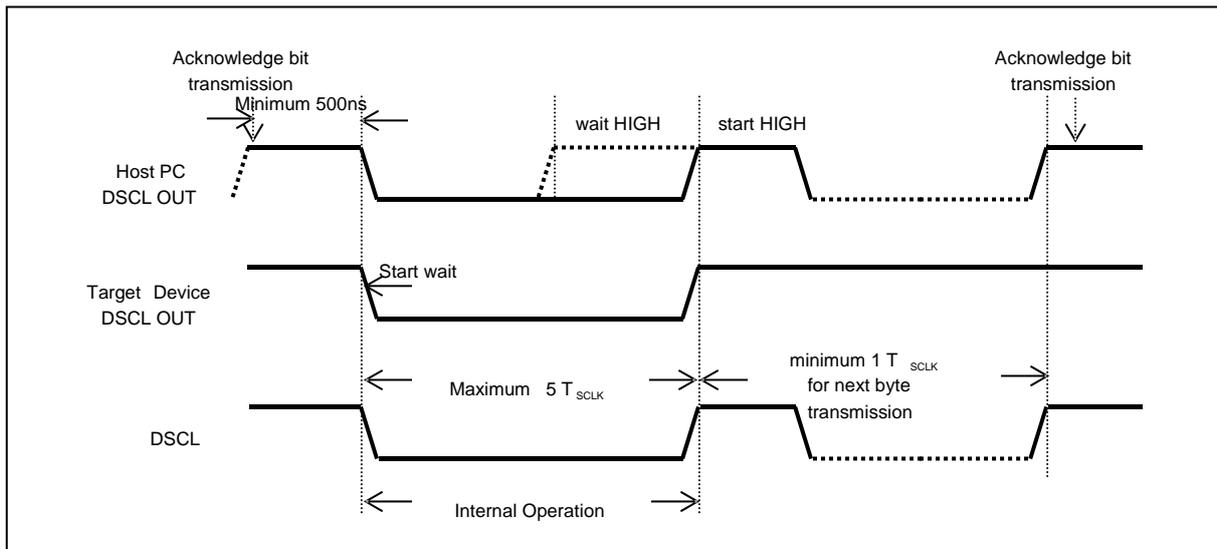


Figure 14-7 Clock synchronization during wait procedure

14.2.3 Connection of transmission

Two-pin interface connection uses open-drain (wired-AND bidirectional I/O).

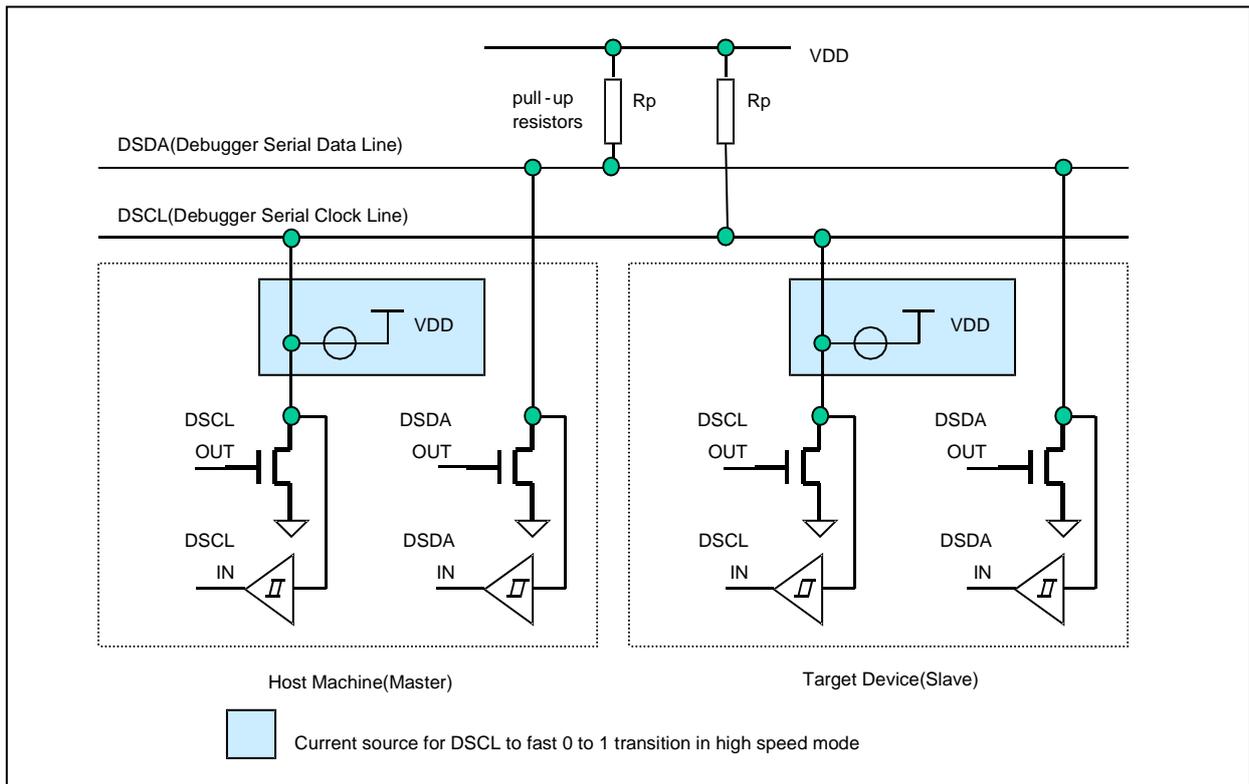


Figure 14-8 Wire connection for serial communication

15. FLASH Memory Controller

15.1 Overview

15.1.1 Description

The MC96FR116C has 16KB of embedded FLASH memory. On reset, this non-volatile memory is used as code memory. In user application program, parts of this non-volatile memory can be updated. Program and erase is performed by ISP via OCD or parallel ROM writer in byte size.

15.1.2 Features of FLASH

- Memory size : 16Kbytes
- Boot Area : Configurable boot area according to BSIZE[1:0]
- Can be updated through registers setting(ISP feature)
- PROGRAM or ERASE operation is performed with single power supply
- Command interface for fast program and erase operation
- Up to 10,000 program/erase cycles at typical voltage and temperature
- Security feature : Code and Boot Area
- Page (Buffer) Size : 64B (XDATA region, addresses 8000_H ~ 803F_H)

15.2 Boot Area

Boot Area located in program memory area can store Boot program code for upgrading application code by interfacing with I/O port pins.

The Boot Area can't be erased or programmed by unless LOCKB in FUSE_CONF is cleared for the safety of boot code.

The size of Boot Area can be varied by BSIZE bits in FUSE_CONF. See chapter 16.

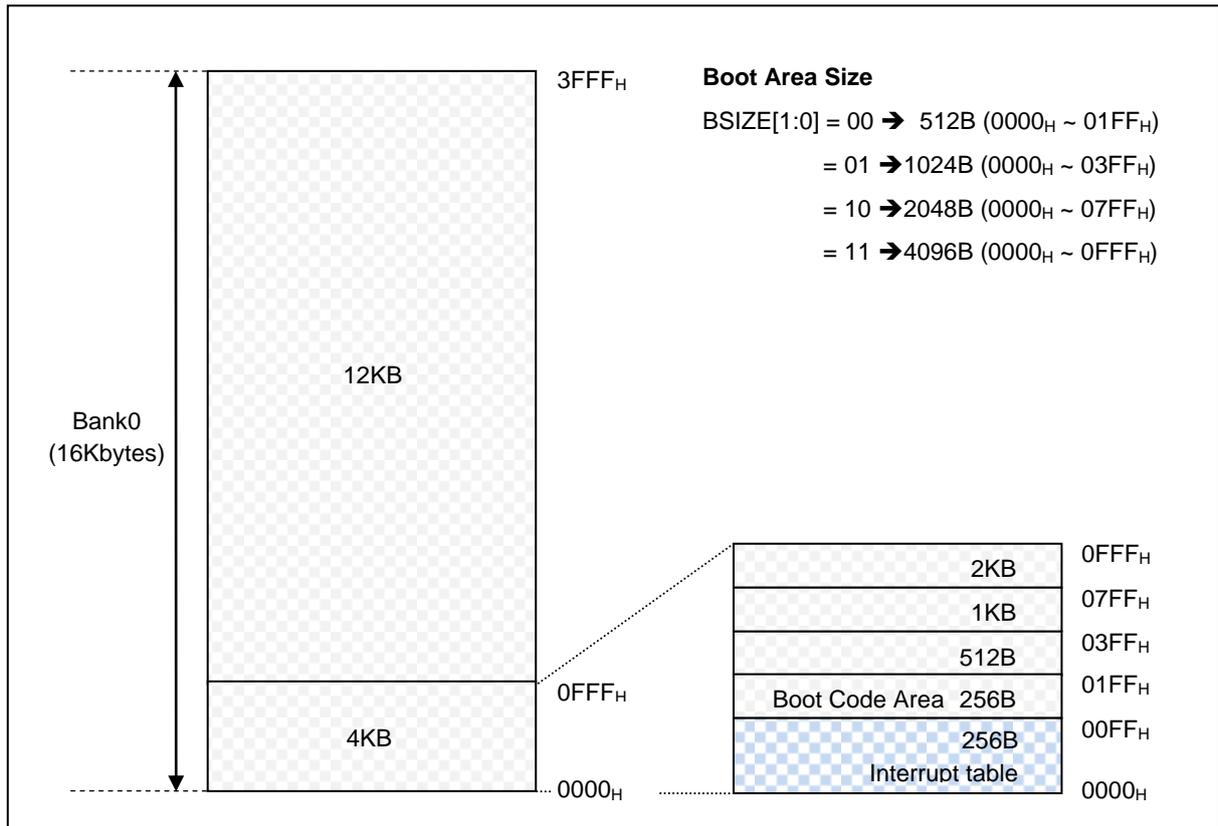


Figure 15-1 Program Memory Address Space

15.3 Register Map

Name	Address	Dir	Default	Description
FMR	E1 _H	R/W	00 _H	FLASH Mode Register
FARH	E9 _H	R/W	00 _H	FLASH Address Register High
FARM	EA _H	R/W	00 _H	FLASH Address Register Middle
FARL	EB _H	R/W	00 _H	FLASH Address Register Low
FCR	EC _H	R/W	03 _H	FLASH Control Register
FSR	ED _H	R/W	80 _H	F LASH Status Register
FTCR	EE _H	R/W	00 _H	F LASH Time Control Register
CSUMH	2F06 _H	R	00 _H	FLASH Read Checksum Register High
CSUMM	2F07 _H	R	00 _H	FLASH Read Checksum Register Middle
CSUML	2F0F _H	R	00 _H	FLASH Read Checksum Register Low
FSLBA _x	2F61 _H ~2F62 _H	R/W	00 _H	F LASH Secure Lock Base Address Register
FSLTA _x	2F64 _H ~2F65 _H	R/W	00 _H	F LASH Secure Lock Top Address Register
FSUBA _x	2F67 _H ~2F68 _H	R/W	00 _H	F LASH Secure Unlock Base Address Register
FSUTA _x	2F6A _H ~2F6B _H	R/W	00 _H	F LASH Secure Unlock Top Address Register
FSCTRL	2F6C _H	R/W	00 _H	F LASH Secure Control Register
PageBuffer	8000 _H ~803F _H	R/W		FLASH Page Buffer @XSFR

Table 15-1 Register Map of FLASH Memory Controller

15.4 Register Description

15.4.1 FLASH Control Registers Description

FMR (FLASH Mode Register)

E1_H

7	6	5	4	3	2	1	0
AEF	PBUFF	FSEL	ESEL	OTPE	VFY	READ	nFERST
RW	RW	RW	RW	RW	RW	RW	RW

Initial value : 01_H

AEF	FLASH Bulk Erase Enable. 0 FLASH Bulk Erase Disabled 1 FLASH Bulk Erase Enabled
PBUFF	Select Flash Page Buffer. 0 Main cell selected. 1 Page buffer selected.
OTPE	Select OTP area 0 No operation 1 OTP READ/WRITE is enabled
VFY	Enable verify mode with PGM or ERASE bit 0 No verify operation 1 Program Verify with PGM=1 Erase Verify with ERASE=1
READ	FLASH Read(VFY=0) or Write(program or erase) Verify(VFY=1). This bit initiates reading the entire FLASH area, and must be set in chip test mode, debugger mode or rom writing mode. Clear all FARH, FARM and FARL before setting this bit for proper operation. 0 No operation 1 Start Read or Verify operation
nFERST	Reset FLASH/EEPROM Controller. This bit is auto-set after 1 system clock period. 0 No operation 1 Reset internal registers for FLASH/EEPROM Controller

Caution : The FEMR register is not used in normal operation including self programming. Do not alter the contents of this register if possible.

FARH (FLASH Address Register High)

E9_H

7	6	5	4	3	2	1	0
-	-	-	-	FADDR19	FADDR17	FADDR17	FADDR16
-	-	-	-	RW	RW	RW	RW

Initial value : 00_H

FADDR[19:16]	Flash Address High (Write) Checksum result in auto verify mode (Read)
---------------------	--

FARM (FLASH Address Register Middle)

EA_H

7	6	5	4	3	2	1	0
---	---	---	---	---	---	---	---

FADDR15	FADDR14	FADDR13	FADDR12	FADDR11	FADDR10	FADDR9	FADDR8
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 00_H

FADDR[15:8] Flash Address Middle (Write)
Checksum result in auto verify mode (Read, PCRCRD=0)
CRC result in auto verify mode (Read, PCRCRD=1)

FARL (FLASH Address Register Low)

EB_H

7	6	5	4	3	2	1	0
FADDR7	FADDR6	FADDR5	FADDR4	FADDR3	FADDR2	FADDR1	FADDR0
R/W							

Initial value : 00_H

FADDR[7:0] Flash Address Low. As flash page buffer size is of 64 Bytes, only the **MSB** of this register is meaningful. (Write)
Checksum result in auto verify mode (Read, PCRCRD=0)
CRC result in auto verify mode (Read, PCRCRD=1)

FARH, FARM and FARL registers are used for program, erase, or auto-verify operation. In program or erase mode, these registers point to the page number to be programmed or erased.

FCR (FLASH Control Register)

EC_H

7	6	5	4	3	2	1	0
-	-	EXIT1	EXIT0	CMD3	PGM/ CMD2	ERASE/ CMD1	nPBRST/ CMD0
-	-	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 01_H

EXIT[1:0] Exit from program or erase mode. This bit is auto-cleared after 1 system clock period.

EXIT1	EXIT0	Description
0	0	No exit
0	1	No exit
1	0	No exit
1	1	Exit

CMD[3:0] FLASH Command. The CMD0 bit(=nPBRST) is auto-set after 1 system clock period.

0000	Page Buffer Reset
0011	Erase
0101	Program
1101	LOCKF Program
others	Prohibited (no operation)

FSR (FLASH Status Register)

ED_H

7	6	5	4	3	2	1	0
nPEVBSY	VFGOOD	PCRCRD	-	ROMINT	PMODE	EMODE	VMODE
R	R/W	R/W	-	R/W	R	R	R

Initial value : 80_H

nPEVBSY BUSY flag. Represents that program, erase, or verify operation is on-

	going, active low. This bit is auto-set when operation is done.
	0 Busy (Operation processing)
	1 Operation completed
VFYGOOD	Auto-verification result flag
	0 Auto-verification failed
	1 Auto-verification succeeded
PCRCRD	CRC calculation data read control. For correct operation, clear the FARH, FARM and FARL before starting CRC or setting READ bit in FEMR.
	0 Reading FARH, FARM and FARL registers return checksum value (24-bit)
	1 Reading FARM and FARL registers return CRC result (16-bit)
ROMINT	FLASH Interrupt Flag. This bit is auto-cleared when program, erase, or verify operation is started.
	0 No interrupt requested
	1 Interrupt requested
PMODE	Program mode flag
EMODE	Erase mode flag
VMODE	Verify mode flag

FTCR (FLASH Time control Register)

EE_H

7	6	5	4	3	2	1	0
TCR7	TCR6	TCR5	TCR4	TCR3	TCR2	TCR1	TCR0
RW							

Initial value : 00_H

TCR[7:0] Program or Erase Time control

Program or erase time is controlled by the value in FETCR register.

The FLASH Memory controller includes a 10-bit counter used to calculate program or erase time. The counter is clocked by a clock which is divided by 64 from XIN clock(XIN/64). It's a simple counter. When program or erase operation starts, the counter is cleared and start up-counting until it reaches the target value coming from FTCR. On matching, the counter stops and the PEVBSY flag is set.

In bulk erase mode, the TCR[7:0] becomes the most significant eight bits in counter target value, and the least significant two bits are filled with "11". In program or erase mode, the most significant two bit is filled with '01, the least significant bit is filled with '1', and the TCR[7:0] becomes the middle eight bits in counter target value. So the program or erase time is calculated by the following equation. In the following equation and description, it is assumed that the frequency of external clock source, f_{XIN} is 8MHz. In that case, the period of XIN/64 clock is about 8us.

$$T_{pe} = (TCR+1) * 2 * 8us$$

$$T_{be} = (TCR+1) * 4 * 8us$$

where T_{pe} is time to be taken when program or erase operation is performed in byte- or page-size, T_{be} is time for bulk erase operation.

Normally the maximum program or erase time can be $8us * 512 \approx 4ms$. And considering the error rate of $\pm 10\%$, about 3.6~4.4ms of program/erase time can be ensured. Similarly in bulk erase mode, the maximum time can be 8ms, so 7.2~8.8ms of bulk erase time will be applied.

The CSUMH, CSUMM and CSUML registers are test purpose only.

CSUMH (FLASH Read Check Sum Register High)

2F06_H

7	6	5	4	3	2	1	0
CSUM23	CSUM22	CSUM21	CSUM20	CSUM19	CSUM18	CSUM17	CSUM16
R	R	R	R	R	R	R	R

Initial value : 00_H

CSUM[23:16] FLASH Read Checksum in auto-verify mode

CSUMM (FLASH Read Check Sum Register Middle)

2F07_H

7	6	5	4	3	2	1	0
CSUM15	CSUM14	CSUM13	CSUM12	CSUM11	CSUM10	CSUM9	CSUM8
R	R	R	R	R	R	R	R

Initial value : 00_H

CSUM[15:8] FLASH Read Checksum in auto-verify mode

CSUML (FLASH Read Check Sum Register Low)

2F0F_H

7	6	5	4	3	2	1	0
CSUM7	CSUM6	CSUM5	CSUM4	CSUM3	CSUM2	CSUM1	CSUM0
R	R	R	R	R	R	R	R

Initial value : 00_H

CSUM[7:0] FLASH Read Checksum in auto-verify mode

In auto-verify mode, the FLASH address increases automatically by one. CSUMH, CSUMM and CSUML registers are read-only, and reading these registers returns the 24-bit checksum result.

FSLBA1 (FLASH Secure Lock Base Address 1 Register)

2F61_H

7	6	5	4	3	2	1	0
FSLBA15	FSLBA14	FSLBA13	FSLBA12	FSLBA11	FSLBA10	FSLBA9	FSLBA8
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 00_H

FSLBA[15:8] Flash Secure Lock Base Address

FSLBA0 (FLASH Secure Lock Base Address 0 Register)

2F62_H

7	6	5	4	3	2	1	0
FSLBA7	FSLBA6	FSLBA5	FSLBA4	FSLBA3	FSLBA2	FSLBA1	FSLBA0
R/W							

Initial value : 00_H

FSLBA[7:0] Flash Secure Lock Base Address

FSLTA1 (FLASH Secure Lock Top Address 1 Register) 2F64_H

7	6	5	4	3	2	1	0
FSLTA15	FSLTA14	FSLTA13	FSLTA12	FSLTA11	FSLTA10	FSLTA9	FSLTA8
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 00_H

FSLTA[15:8] Flash Secure Lock Top Address

FSLTA1 (FLASH Secure Lock Top Address 0 Register) 2F65_H

7	6	5	4	3	2	1	0
FSLTA7	FSLTA6	FSLTA5	FSLTA4	FSLTA3	FSLTA2	FSLTA1	FSLTA0
R/W							

Initial value : 00_H

FSLTA[7:0] Flash Secure Lock Top Address

FSUBA1 (FLASH Secure Unlock Base Address 1 Register) 2F67_H

7	6	5	4	3	2	1	0
FSUBA15	FSUBA14	FSUBA13	FSUBA12	FSUBA11	FSUBA10	FSUBA9	FSUBA8
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 00_H

FSUBA[15:8] Flash Secure Unlock Base Address

FSUBA1 (FLASH Secure Unlock Base Address 0 Register) 2F68_H

7	6	5	4	3	2	1	0
FSUBA7	FSUBA6	FSUBA5	FSUBA4	FSUBA3	FSUBA2	FSUBA1	FSUBA0
R/W							

Initial value : 00_H

FSUBA[7:0] Flash Secure Unlock Base Address

FSUTA1 (FLASH Secure Unlock Top Address 1 Register) 2F6A_H

7	6	5	4	3	2	1	0
FSUTA15	FSUTA14	FSUTA13	FSUTA12	FSUTA11	FSUTA10	FSUTA9	FSUTA8
R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W

Initial value : 00_H

FSUTA[15:8] Flash Secure Unlock Top Address

FSUTA1 (FLASH Secure Unlock Top Address 0 Register) 2F6B_H

7	6	5	4	3	2	1	0
FSUTA7	FSUTA6	FSUTA5	FSUTA4	FSUTA3	FSUTA2	FSUTA1	FSUTA0
R/W							

Initial value : 00_H

FSUTA[7:0] Flash Secure Unlock Top Address

FSCTRL (FLASH Secure Control Register)

2F6C_H

7	6	5	4	3	2	1	0
-	-	-	-	-	-	UCTRL	LCTRL
R	R	R	R	R	R	RW	RW

Initial value : 00_H

- UCTRL** FLASH unlock control
- 0 FLASH unlock control is disabled
 - 1 FLASH unlock control is enabled
- LCTRL** FLASH lock control
- 0 FLASH lock control is disabled
 - 1 FLASH lock control is disabled

FSLB_{Ax}, FSLT_{Ax}, FSUB_{Ax}, FSUT_{Ax} and FSCTRL registers are used for code write protection. If FSLB_{Ax} is 0x0100, FSLT_{Ax} is 0x4000 and FSCTRL[0] is 1, code region from 0x0100 to 0x4000 is protected for erase and program. If FSUB_{Ax} is 0x0200, FSUT_{Ax} is 0x3000 and FSCTRL[1] is 1, code region from 0x0200 to 0x3000 is unprotected for erase and program. The priority of UCTRL is higher than that of LCTRL.

15.5 Memory map

As described previously, MC96FR116C has 16KB of Program Memory called FLASH. It is needed to write page address into FARH, FARM and FARL registers to program or erase the non-volatile memory.

15.5.1 FLASH area division

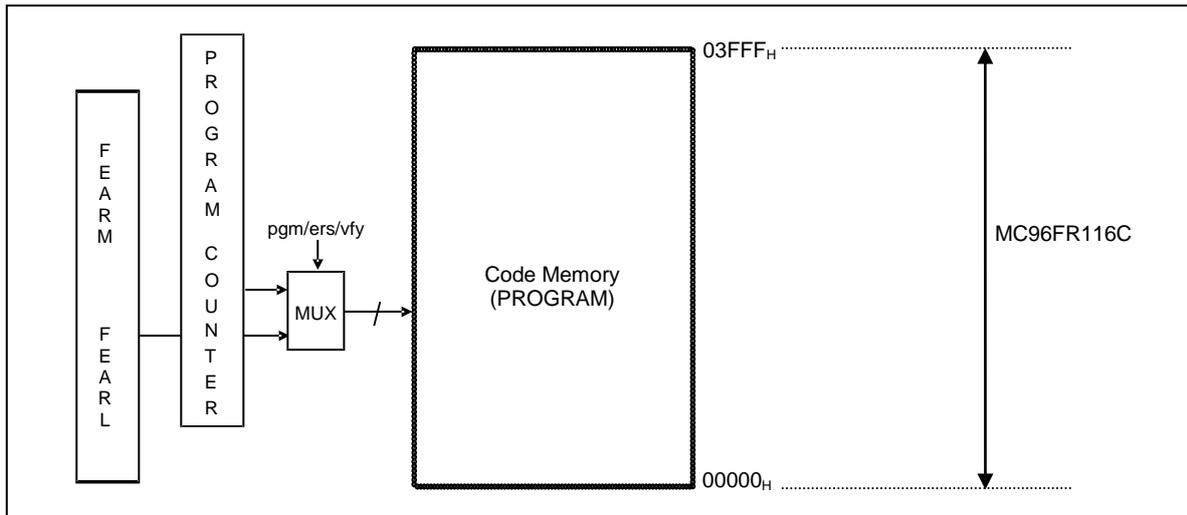


Figure 15-2 FLASH Memory Map

15.5.2 Address configuration of FLASH memory

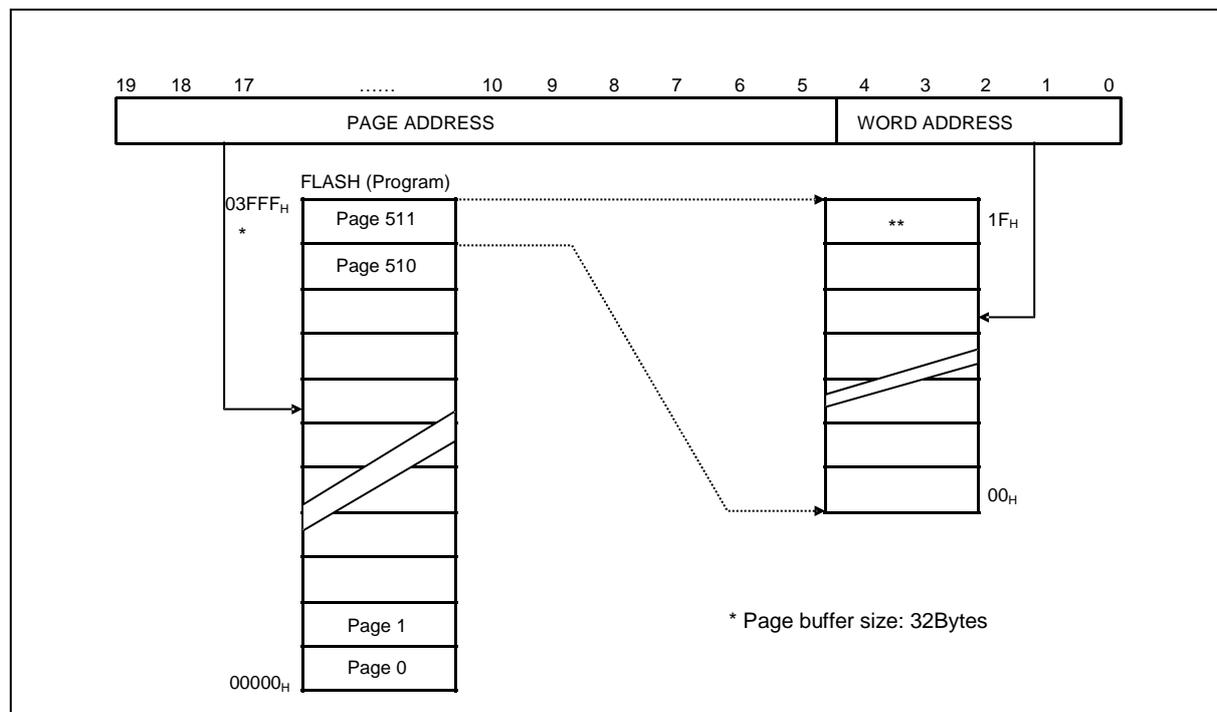


Figure 15-3 FLASH Memory Address generation

15.6 Serial In-System Program Mode

Serial In-System Program is performed via the interface of debugger which uses two wires. For more information about debugger, refer to chapter 14.

15.6.1 ISP or Self Programming Sequence

In MC96FR116C, the commands needed to update FLASH is commenced by FECR register only. PROGRAM or ERASE sequence is as follows :

1. Set Erase or Program time : FETCR(EE_H) = 0xxx ^{NOTE1}
2. Enter ISP or Self Program Mode ^{NOTE2}
3. Reset Page Buffer : FECR(EC_H) = 0x00
4. Load Page Buffer by "MOVX" instruction (up to 64Bytes).
5. Set Page Address to be programmed or erased by writing FARH(E9_H), FARM(EA_H) and FARL(EB_H)
- 6-1. Set AEF and FSEL bits in FEMR. (This is used in ISP mode for Bulk Erase operation)
- 6-2. Set OTPE bit in FEMR. (OTPE bit is used to access OTP area. Set this bit if needed.)
- 6-3. Set VFY bit in FEMR. (VFY bit is used for read-verify operation. Set this bit if needed.)
7. Start Erase or Program : FECR(EC_H) = 0x03(Erase) or 0x05(Program)
8. Wait PEVBSY bit in FESR(ED_H) : for OCD mode
9. ISP or Self Program Mode Exit : FECR(EC_H) = 0x31

^{NOTE1} Program or Erase time is only to be set before real program or erase operation. Normally, the FETCR value doesn't have to be changed.

^{NOTE2} Between flash program mode entry and exit, there can be several program or erase operation. It is only need to exit flash program mode when all program or erase operations are done.

Step \ Operation	Page/Byte Program	Page/Byte Erase	Bulk Erase
Set Erase or Program Time	1) FETCR = 0xxx	1) FETCR = 0xxx	1) FETCR = 0xxx
Mode Entry	2) Mode Entry	2) Mode Entry	2) Mode Entry
Page Buffer Reset	3) FECR = 0x00	3) FECR = 0x00	3) FECR = 0x00
Load Page Buffer	4) Load bytes by MOVX instruction	4) Load bytes by MOVX instruction	4) Load page(64B) by movx instruction
Set Page Address	5) FARH = 0xxx	5) FARH = 0x00	
	FARM = 0xxx	FARM = 0xxx	
	FARL = 0xxx	FARL = 0xxx	
Set AEF/FSEL (Bulk Erase only)			6-1) FEMR = 0xA1
Set OTPE (OTP Access only)	6-2) FEMR = 0x09	6-2) FEMR = 0x09	6-2) FEMR = 0x09
Set VFY (Verify operation only)	6-3) FEMR = 0x02	6-3) FEMR = 0x02	6-3) FEMR = 0x02
Start Program or Erase	7) FECR = 0x05	7) FECR = 0x03	7) FECR = 0x03
Wait PEVBSY (OCD only)	8) Wait PEVBSY	8) Wait PEVBSY	8) Wait PEVBSY

Mode Exit	9) Mode Exit	9) Mode Exit	9) Mode Exit
-----------	--------------	--------------	--------------

Table 15-2 Program or Erase sequence in ISP or Self Program Mode

15.6.1.1 FLASH Read

- Step 1. Enter OCD(=ISP) mode.
- Step 2. Set ENBDM bit of BCR.
- Step 3. Enable debug and Request debug mode.
- Step 4. Read data from Flash.

15.6.1.2 Enable ISP or Self Programming Mode

- Step 1. Enter OCD(=ISP) mode.^{NOTE 1}
- Step 2. Set ENBDM bit of BCR.
- Step 3. Enable debug and Request debug mode.
- Step 3. Enter program/erase mode sequence.^{NOTE 2}

- (1) Write AA_H to 1555_H
- (2) Write 55_H to 1AAA_H
- (3) Write A5_H to 1555_H

^{NOTE 1}. Refer to chapter 14

^{NOTE 2}. Command sequence to activate FLASH program/erase mode. It is composed of sequential write to fixed FLASH addresses.

15.6.2 Example of FLASH control in C language

The next example code shows how to program or erase a specific page area of FLASH using C language. The program or erase sequence used in the test code complies with above rules. In this example code, the page address F000_H is erased and programmed.

Example:

```

////////////////////////////////////
// Project   : Write data to EEPROM at 0xF000
// Device    : MC96FR116C
// Oscillator : 4MHz
// Compiler  : Keil uvision C Compiler V7.20
////////////////////////////////////

```

```

#include <intrins.h>
#include "MC96FR116C.h"

```

```

#define FLASH_PBUFF_SIZE    64

```

```

// PGM or ERASE Timing, normally the same values are set.
#define PGMTIME          0x4F    // 2.5ms @4MHz
#define ERSTIME          0x4F    // 2.5ms @4MHz

void page_buffer_reset();
void flash_page_write(unsigned int addr, unsigned char *wdata);
void flash_page_erase(unsigned int addr);
void flash_program_enter();
void flash_program_exit();

xdata unsigned char pagerom[FLASH_PBUFF_SIZE] _at_ 0x8000; // page buffer
data  unsigned char page_data[FLASH_PBUFF_SIZE];          // write data buffer

void main()
{
    unsigned p_index;

    // Step 2
    flash_program_entry();

    eeprom_page_erase(0xF000);

    // Tmp data for page write operation. Try other data!!!
    for (p_index=0; p_index < FLASH_PBUFF_SIZE; p_index++) {
        page_data[p_index] = p_index;
    }

    eeprom_page_write(0xF000, page_data);

    // Step 10
    flash_program_exit();
    while(1);
}

void flash_page_erase(unsigned int addr)
{
    int i;
    unsigned char temp;
    int addr_index;

    // Step 1
    FETCR = ERSTIME;

    // Step 3
    page_buffer_reset();

    // Step 4

```

```

        for (i=0; i < FLASH_PBUFF_SIZE; i++) {
            pagerom[i] = 0x00;
        }

// Step 5
    FARL = (unsigned char) addr;
    FARM = (unsigned char) (addr>>8);

// Step 8
    FECR = 0x0B;

// Step 9 : It is optional because the CPU clock halts while in program or erase operation.
    while(FESR>>7 == 0x00);
}

void flash_page_write(unsigned int addr, unsigned char *wdata)
{
    int i;
    unsigned char temp;
    int addr_index;

// Step 1
    FETCR = PGMTIME;

// Step 3
    page_buffer_reset();

// Step 4
    for (i=0; i < FLASH_PBUFF_SIZE; i++) {
        pagerom[i] = wdata[i];
    }

// Step 5
    FARL = (unsigned char) addr;
    FARM = (unsigned char) (addr>>8);

// Step 8
    FECR = 0x0D;

// Step 9 : It is optional because the CPU clock halts while in program or erase operation.
    while(FESR>>7 == 0x00);
}

void page_buffer_reset()
{
    FECR = 0x00;
}

```

```

void flash_program_exit()
{
    FECR = 0x31;
}

```

15.6.3 Summary of FLASH Program/Erase Mode

Flash Operation	Description
FLASH read	Read cell by byte.
FLASH write	Write cell by bytes or page.
FLASH page erase	Erase cell by page.
FLASH bulk erase	Erase the whole cells.
FLASH program verify	Read cell in verify mode after programming.
FLASH erase verify	Read cell in verify mode after erase.
FLASH page buffer load	Load data to page buffer.

Table 15-3 FLASH operating mode

15.7 Security

The MC96FR116C provides one LOCKF bit to protect memory contents from illegal attempt to read. The LOCKF bit can be erased only by bulk erase operation.

LOCKF	USER MODE								OCD(ISP) / PMODE							
	FLASH				OTP				FLASH				OTP			
	R	W	PE	BE	R	W	PE	BE	R	W	PE	BE	R	W	PE	BE
0	O	O	O	X	X	X	X	X	O	O	O	O	O	O	O	O
1	O	O	O	X	X	X	X	X	X	X	X	O	O	X	X	O

Table 15-4 Memory protection by lock bit

- LOCKF : Lock bit of FLASH memory
- R : Read
- W : Write
- PE : Page Erase
- BE : Bulk Erase
- O : Operation is possible.
- X : Operation is impossible.

16. FUSE

16.1 FUSE Control Register

FUSE_CONF (Pseudo-Configure Data)

2FF0_H

7	6	5	4	3	2	1	0
BSIZE1	BSIZE0	-	-	RSTDIS	-	LOCKB	LOCKF
R	R	R	R	R	R	R	R

Initial value : 00_H

BSIZE[1:0] Select Specific Area for Write Protection (Boot Area)

Note) When LOCKB='1', it is applied.

00 512B (0000h~01FFh)

01 1024B (0000h~03FFh)

10 2048B (0000h~07FFh)

11 4096B (0000h~0FFFh)

RSTDIS Select external reset function

0 RESETB pin enable

1 RESETB pin disable

LOCKB Enable Specific Area Write Protection

0 Disable

1 Enable

LOCKF Code Read Protection

0 Disable

1 Enable

17. APPENDIX

A. Instruction Table

The instruction length of M8051W can be 1, 2, or 3 bytes as listed in the following table. It takes 1, 2, or 4 cycles for the CPU to execute an instruction. The cycle is composed of two internal clock periods.

ARITHMETIC				
Mnemonic	Description	Bytes	Cycles	Hex code
ADD A,Rn	Add register to A	1	1	28-2F
ADD A,dir	Add direct byte to A	2	1	25
ADD A,@Ri	Add indirect memory to A	1	1	26-27
ADD A,#data	Add immediate to A	2	1	24
ADDC A,Rn	Add register to A with carry	1	1	38-3F
ADDC A,dir	Add direct byte to A with carry	2	1	35
ADDC A,@Ri	Add indirect memory to A with carry	1	1	36-37
ADDC A,#data	Add immediate to A with carry	2	1	34
SUBB A,Rn	Subtract register from A with borrow	1	1	98-9F
SUBB A,dir	Subtract direct byte from A with borrow	2	1	95
SUBB A,@Ri	Subtract indirect memory from A with borrow	1	1	96-97
SUBB A,#data	Subtract immediate from A with borrow	2	1	94
INC A	Increment A	1	1	04
INC Rn	Increment register	1	1	08-0F
INC dir	Increment direct byte	2	1	05
INC @Ri	Increment indirect memory	1	1	06-07
DEC A	Decrement A	1	1	14
DEC Rn	Decrement register	1	1	18-1F
DEC dir	Decrement direct byte	2	1	15
DEC @Ri	Decrement indirect memory	1	1	16-17
INC DPTR	Increment data pointer	1	2	A3
MUL AB	Multiply A by B	1	4	A4
DIV AB	Divide A by B	1	4	84
DA A	Decimal Adjust A	1	1	D4

LOGICAL				
Mnemonic	Description	Bytes	Cycles	Hex code
ANL A,Rn	AND register to A	1	1	58-5F
ANL A,dir	AND direct byte to A	2	1	55
ANL A,@Ri	AND indirect memory to A	1	1	56-57
ANL A,#data	AND immediate to A	2	1	54
ANL dir,A	AND A to direct byte	2	1	52
ANL dir,#data	AND immediate to direct byte	3	2	53
ORL A,Rn	OR register to A	1	1	48-4F
ORL A,dir	OR direct byte to A	2	1	45
ORL A,@Ri	OR indirect memory to A	1	1	46-47
ORL A,#data	OR immediate to A	2	1	44
ORL dir,A	OR A to direct byte	2	1	42
ORL dir,#data	OR immediate to direct byte	3	2	43
XRL A,Rn	Exclusive-OR register to A	1	1	68-6F
XRL A,dir	Exclusive-OR direct byte to A	2	1	65

XRL A, @Ri	Exclusive-OR indirect memory to A	1	1	66-67
XRL A,#data	Exclusive-OR immediate to A	2	1	64
XRL dir,A	Exclusive-OR A to direct byte	2	1	62
XRL dir,#data	Exclusive-OR immediate to direct byte	3	2	63
CLR A	Clear A	1	1	E4
CPL A	Complement A	1	1	F4
SWAP A	Swap Nibbles of A	1	1	C4
RL A	Rotate A left	1	1	23
RLC A	Rotate A left through carry	1	1	33
RR A	Rotate A right	1	1	03
RRC A	Rotate A right through carry	1	1	13

DATA TRANSFER				
Mnemonic	Description	Bytes	Cycles	Hex code
MOV A,Rn	Move register to A	1	1	E8-EF
MOV A,dir	Move direct byte to A	2	1	E5
MOV A,@Ri	Move indirect memory to A	1	1	E6-E7
MOV A,#data	Move immediate to A	2	1	74
MOV Rn,A	Move A to register	1	1	F8-FF
MOV Rn,dir	Move direct byte to register	2	2	A8-AF
MOV Rn,#data	Move immediate to register	2	1	78-7F
MOV dir,A	Move A to direct byte	2	1	F5
MOV dir,Rn	Move register to direct byte	2	2	88-8F
MOV dir,dir	Move direct byte to direct byte	3	2	85
MOV dir,@Ri	Move indirect memory to direct byte	2	2	86-87
MOV dir,#data	Move immediate to direct byte	3	2	75
MOV @Ri,A	Move A to indirect memory	1	1	F6-F7
MOV @Ri,dir	Move direct byte to indirect memory	2	2	A6-A7
MOV @Ri,#data	Move immediate to indirect memory	2	1	76-77
MOV DPTR,#data	Move immediate to data pointer	3	2	90
MOVC A,@A+DPTR	Move code byte relative DPTR to A	1	2	93
MOVC A,@A+PC	Move code byte relative PC to A	1	2	83
MOVX A,@Ri	Move external data(A8) to A	1	2	E2-E3
MOVX A,@DPTR	Move external data(A16) to A	1	2	E0
MOVX @Ri,A	Move A to external data(A8)	1	2	F2-F3
MOVX @DPTR,A	Move A to external data(A16)	1	2	F0
PUSH dir	Push direct byte onto stack	2	2	C0
POP dir	Pop direct byte from stack	2	2	D0
XCH A,Rn	Exchange A and register	1	1	C8-CF
XCH A,dir	Exchange A and direct byte	2	1	C5
XCH A,@Ri	Exchange A and indirect memory	1	1	C6-C7
XCHD A,@Ri	Exchange A and indirect memory nibble	1	1	D6-D7

BOOLEAN				
Mnemonic	Description	Bytes	Cycles	Hex code
CLR C	Clear carry	1	1	C3
CLR bit	Clear direct bit	2	1	C2
SETB C	Set carry	1	1	D3
SETB bit	Set direct bit	2	1	D2
CPL C	Complement carry	1	1	B3
CPL bit	Complement direct bit	2	1	B2

ANL C,bit	AND direct bit to carry	2	2	82
ANL C,/bit	AND direct bit inverse to carry	2	2	B0
ORL C,bit	OR direct bit to carry	2	2	72
ORL C,/bit	OR direct bit inverse to carry	2	2	A0
MOV C,bit	Move direct bit to carry	2	1	A2
MOV bit,C	Move carry to direct bit	2	2	92

BRANCHING				
Mnemonic	Description	Bytes	Cycles	Hex code
ACALL addr 11	Absolute jump to subroutine	2	2	11→F1
LCALL addr 16	Long jump to subroutine	3	2	12
RET	Return from subroutine	1	2	22
RETI	Return from interrupt	1	2	32
AJMP addr 11	Absolute jump unconditional	2	2	01→E1
LJMP addr 16	Long jump unconditional	3	2	02
SJMP rel	Short jump (relative address)	2	2	80
JC rel	Jump on carry = 1	2	2	40
JNC rel	Jump on carry = 0	2	2	50
JB bit,rel	Jump on direct bit = 1	3	2	20
JNB bit,rel	Jump on direct bit = 0	3	2	30
JBC bit,rel	Jump on direct bit = 1 and clear	3	2	10
JMP @A+DPTR	Jump indirect relative DPTR	1	2	73
JZ rel	Jump on accumulator = 0	2	2	60
JNZ rel	Jump on accumulator ≠ 0	2	2	70
CJNE A,dir,rel	Compare A,direct jne relative	3	2	B5
CJNE A,#d,rel	Compare A,immediate jne relative	3	2	B4
CJNE Rn,#d,rel	Compare register, immediate jne relative	3	2	B8-BF
CJNE @Ri,#d,rel	Compare indirect, immediate jne relative	3	2	B6-B7
DJNZ Rn,rel	Decrement register, jnz relative	2	2	D8-DF
DJNZ dir,rel	Decrement direct byte, jnz relative	3	2	D5

MISCELLANEOUS				
Mnemonic	Description	Bytes	Cycles	Hex code
NOP	No operation	1	1	00

ADDITIONAL INSTRUCTIONS (selected through EO[7:4])				
Mnemonic	Description	Bytes	Cycles	Hex code
MOVC @(DPTR++),A	M8051W/M8051EW-specific instruction supporting software download into program memory	1	2	A5
TRAP	Software break command	1	1	A5

In the above table, an entry such as E8-EF indicates a continuous block of hex opcodes used for 8 different registers, the register numbers of which are defined by the lowest three bits of the corresponding code. Non-continuous blocks of codes, shown as 11→F1 (for example), are used for absolute jumps and calls, with the top 3 bits of the code being used to store the top three bits of the destination address.

The CJNE instructions use the abbreviation #d for immediate data; other instructions use #data.