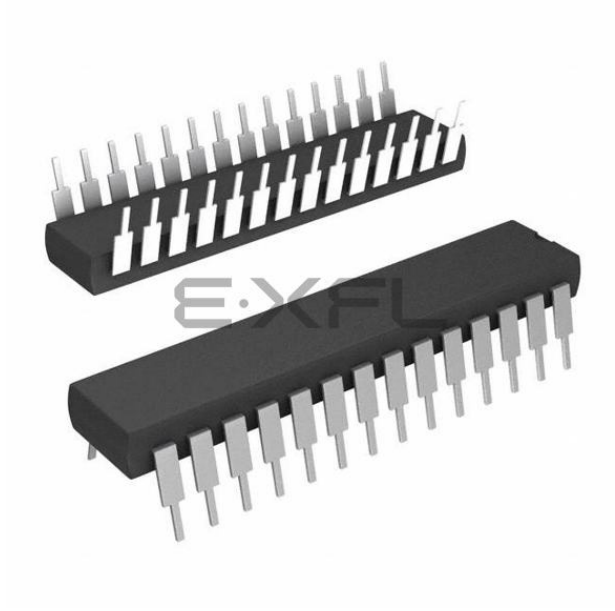

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Applications of "Embedded - Microcontrollers"

Details	
Product Status	Obsolete
Core Processor	PIC
Core Size	8-Bit
Speed	40MHz
Connectivity	I²C, SPI, UART/USART
Peripherals	Brown-out Detect/Reset, LVD, POR, PWM, WDT
Number of I/O	21
Program Memory Size	12KB (6K x 16)
Program Memory Type	FLASH
EEPROM Size	256 x 8
RAM Size	640 x 8
Voltage - Supply (Vcc/Vdd)	2V ~ 5.5V
Data Converters	A/D 5x10b
Oscillator Type	Internal
Operating Temperature	-40°C ~ 85°C (TA)
Mounting Type	Through Hole
Package / Case	28-DIP (0.300", 7.62mm)
Supplier Device Package	28-SPDIP
Purchase URL	https://www.e-xfl.com/product-detail/microchip-technology/pic18lf2439-i-sp

3.0 RESET

The PIC18FXX39 differentiates between various kinds of RESET:

a) Power-on Reset (POR)
b) $\overline{\text{MCLR}}$ Reset during normal operation
c) $\overline{\text{MCLR}}$ Reset during SLEEP
d) Watchdog Timer (WDT) Reset (during normal operation)
e) Programmable Brown-out Reset (BOR)
f) `RESET` Instruction
g) Stack Full Reset
h) Stack Underflow Reset

Most registers are unaffected by a RESET. Their status is unknown on POR and unchanged by all other RESETS. The other registers are forced to a "RESET state" on Power-on Reset, $\overline{\text{MCLR}}$, WDT Reset, Brown-out Reset, $\overline{\text{MCLR}}$ Reset during SLEEP and by the `RESET` instruction.

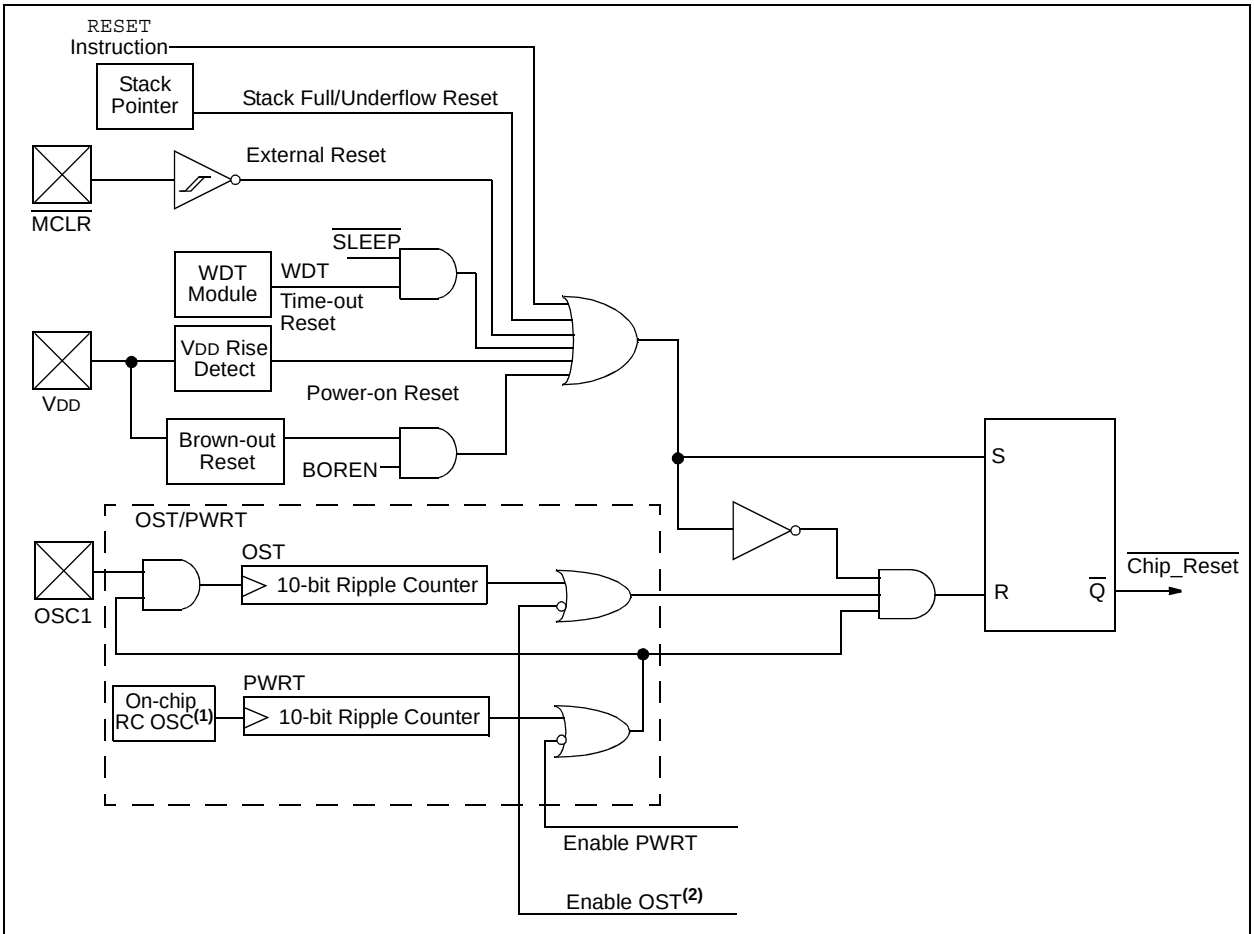
Most registers are not affected by a WDT wake-up, since this is viewed as the resumption of normal operation. Status bits from the RCON register, $\overline{\text{RI}}$, $\overline{\text{TO}}$, $\overline{\text{PD}}$, $\overline{\text{POR}}$ and $\overline{\text{BOR}}$, are set or cleared differently in different RESET situations, as indicated in Table 3-2. These bits are used in software to determine the nature of the RESET. See Table 3-3 for a full description of the RESET states of all registers.

A simplified block diagram of the On-Chip Reset Circuit is shown in Figure 3-1.

The Enhanced MCU devices have a $\overline{\text{MCLR}}$ noise filter in the $\overline{\text{MCLR}}$ Reset path. The filter will detect and ignore small pulses.

The $\overline{\text{MCLR}}$ pin is not driven low by any internal RESETS, including the WDT.

FIGURE 3-1: SIMPLIFIED BLOCK DIAGRAM OF ON-CHIP RESET CIRCUIT



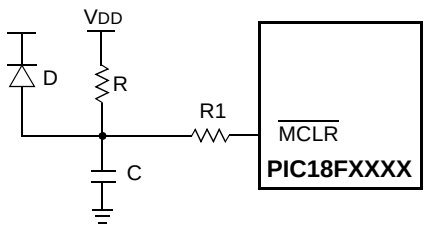
Note 1: This is a separate oscillator from the RC oscillator of the CLKI pin.
2: See Table 3-1 for time-out situations.

3.1 Power-on Reset (POR)

A Power-on Reset pulse is generated on-chip when VDD rise is detected. To take advantage of the POR circuitry, just tie the MCLR pin directly (or through a resistor) to VDD. This will eliminate external RC components usually needed to create a Power-on Reset delay. A minimum rise rate for VDD is specified (parameter D004). For a slow rise time, see Figure 3-2.

When the device starts normal operation (i.e., exits the RESET condition), device operating parameters (voltage, frequency, temperature, etc.) must be met to ensure operation. If these conditions are not met, the device must be held in RESET until the operating conditions are met.

FIGURE 3-2: EXTERNAL POWER-ON RESET CIRCUIT (FOR SLOW VDD POWER-UP)



Note 1: External Power-on Reset circuit is required only if the VDD power-up slope is too slow. The diode D helps discharge the capacitor quickly when VDD powers down.

2: R < 40 kΩ is recommended to make sure that the voltage drop across R does not violate the device's electrical specification.

3: R1 = 100Ω to 1 kΩ will limit any current flowing into MCLR from external capacitor C, in the event of MCLR/VPP pin breakdown due to Electrostatic Discharge (ESD) or Electrical Overstress (EOS).

3.2 Power-up Timer (PWRT)

The Power-up Timer provides a fixed nominal time-out (parameter 33) only on power-up from the POR. The Power-up Timer operates on an internal RC oscillator. The chip is kept in RESET as long as the PWRT is active. The PWRT's time delay allows VDD to rise to an acceptable level. A configuration bit is provided to enable/disable the PWRT.

The power-up time delay will vary from chip-to-chip due to VDD, temperature and process variation. See DC parameter D033 for details.

3.3 Oscillator Start-up Timer (OST)

The Oscillator Start-up Timer (OST) provides a 1024 oscillator cycle (from OSC1 input) delay after the PWRT delay is over (parameter 32). This ensures that the crystal oscillator or resonator has started and stabilized.

The OST time-out is invoked only for XT, LP and HS modes and only on Power-on Reset or wake-up from SLEEP.

3.4 PLL Lock Time-out

With the PLL enabled, the time-out sequence following a Power-on Reset is different from other Oscillator modes. A portion of the Power-up Timer is used to provide a fixed time-out that is sufficient for the PLL to lock to the main oscillator frequency. This PLL lock time-out (TPLL) is typically 2 ms and follows the Oscillator Start-up Time-out (OST).

3.5 Brown-out Reset (BOR)

A configuration bit, BOREN, can disable (if clear/programmed), or enable (if set) the Brown-out Reset circuitry. If VDD falls below parameter D005 for greater than parameter 35, the brown-out situation will reset the chip. A RESET may not occur if VDD falls below parameter D005 for less than parameter 35. The chip will remain in Brown-out Reset until VDD rises above BVDD. If the Power-up Timer is enabled, it will be invoked after VDD rises above BVDD; it then will keep the chip in RESET for an additional time delay (parameter 33). If VDD drops below BVDD while the Power-up Timer is running, the chip will go back into a Brown-out Reset and the Power-up Timer will be initialized. Once VDD rises above BVDD, the Power-up Timer will execute the additional time delay.

3.6 Time-out Sequence

On power-up, the time-out sequence is as follows: First, PWRT time-out is invoked after the POR time delay has expired. Then, OST is activated. The total time-out will vary based on oscillator configuration and the status of the PWRT. For example, in RC mode with the PWRT disabled, there will be no time-out at all. Figure 3-3, Figure 3-4, Figure 3-5, Figure 3-6 and Figure 3-7 depict time-out sequences on power-up.

Since the time-outs occur from the POR pulse, if MCLR is kept low long enough, the time-outs will expire. Bringing MCLR high will begin execution immediately (Figure 3-5). This is useful for testing purposes or to synchronize more than one PIC18FXXX device operating in parallel.

Table 3-2 shows the RESET conditions for some Special Function Registers, while Table 3-3 shows the RESET conditions for all the registers.

4.9 Data Memory Organization

The data memory is implemented as static RAM. Each register in the data memory has a 12-bit address, allowing up to 4096 bytes of data memory. The data memory map is divided into 16 banks that contain 256 bytes each. The lower 4 bits of the Bank Select Register (BSR<3:0>) select which bank will be accessed. The upper 4 bits for the BSR are not implemented.

The data memory contains Special Function Registers (SFRs) and General Purpose Registers (GPRs). The SFRs are used for control and status of the controller and peripheral functions, while GPRs are used for data storage and scratch pad operations in the user's application. The SFRs start at the last location of Bank 15 (FFFh) and extend downwards. Any remaining space beyond the SFRs in the Bank may be implemented as GPRs. GPRs start at the first location of Bank 0 and grow upwards. Any read of an unimplemented location will read as '0's.

The organization of the data memory space for these devices is shown in Figure 4-5 and Figure 4-6. PIC18FX439 devices have 640 bytes of data RAM, extending from Bank 0 to Bank 2 (000h through 27Fh). The block of 128 bytes above this to the top of the bank (280h to 2FFh) is used as data memory for the Motor Control kernel, and is not available to the user. Reading these locations will return random information that reflects the kernel's "scratch" data. Modifying the data in these locations may disrupt the operation of the ProMPT kernel.

PIC18FX539 devices have 1408 bytes of data RAM, extending from Bank 0 to Bank 5 (000h through 57Fh). As with the PIC18FX439 devices, the block of 128 bytes above this to the end of the bank (580h to 5FFh) is used by the Motor Control kernel.

The entire data memory may be accessed directly or indirectly. Direct addressing may require the use of the BSR register. Indirect addressing requires the use of a File Select Register (FSRn) and a corresponding Indirect File Operand (INDFn). Each FSR holds a 12-bit address value that can be used to access any location in the Data Memory map without banking.

The instruction set and architecture allow operations across all banks. This may be accomplished by indirect addressing, or by the use of the `MOVFF` instruction. The `MOVFF` instruction is a two-word/two-cycle instruction that moves a value from one register to another.

To ensure that commonly used registers (SFRs and select GPRs) can be accessed in a single cycle, regardless of the current BSR values, an Access Bank is implemented. A segment of Bank 0 and a segment of Bank 15 comprise the Access RAM. Section 4.10 provides a detailed description of the Access RAM.

4.9.1 GENERAL PURPOSE REGISTER FILE

The register file can be accessed either directly or indirectly. Indirect addressing operates using a File Select Register and corresponding Indirect File Operand. The operation of indirect addressing is shown in Section 4.12.

Enhanced MCU devices may have banked memory in the GPR area. GPRs are not initialized by a Power-on Reset and are unchanged on all other RESETS.

Data RAM is available for use as GPR registers by all instructions. The top half of Bank 15 (F80h to FFFh) contains SFRs. All other banks of data memory contain GPR registers, starting with Bank 0.

4.9.2 SPECIAL FUNCTION REGISTERS

The Special Function Registers (SFRs) are registers used by the CPU and Peripheral Modules for controlling the desired operation of the device. These registers are implemented as static RAM. A list of these registers is given in Table 4-1 and Table 4-2.

The SFRs can be classified into two sets; those associated with the "core" function and those related to the peripheral functions. Those registers related to the "core" are described in this section, while those related to the operation of the peripheral features are described in the section of that peripheral feature.

The SFRs are typically distributed among the peripherals whose functions they control. The unused SFR locations will be unimplemented and read as '0's. See Table 4-1 for addresses for the SFRs.

Note:	In this chapter and throughout this document, certain SFR names and individual bits are marked with an asterisk (*). This denotes registers that are not implemented in PIC18FXX39 devices, but whose names are retained to maintain compatibility with PIC18FXX2 devices. The designated bits within these registers are reserved and may be used by certain modules or the Motor Control kernel. Users should not write to these registers or alter these bit values. Failure to do this may result in erratic microcontroller operation.

4.14 RCON Register

The Reset Control (RCON) register contains flag bits that allow differentiation between the sources of a device RESET. These flags include the $\overline{TO}$, $\overline{PD}$, $\overline{POR}$, $\overline{BOR}$ and $\overline{RI}$ bits. This register is readable and writable.

For PIC18FXX39 devices, the IPEN bit must always be set (= 1) for the ProMPT kernel to function correctly. Refer to Section 8.0 (page 69) for a more detailed discussion.

Note 1: If the BOREN configuration bit is set (Brown-out Reset enabled), the $\overline{BOR}$ bit is '1' on a Power-on Reset. After a Brown-out Reset has occurred, the BOR bit will be cleared, and must be set by firmware to indicate the occurrence of the next Brown-out Reset.

2: It is recommended that the $\overline{POR}$ bit be set after a Power-on Reset has been detected, so that subsequent Power-on Resets may be detected.

REGISTER 4-3: RCON REGISTER

R/W-0	U-0	U-0	R/W-1	R-1	R-1	R/W-0	R/W-0
IPEN	—	—	$\overline{RI}$	$\overline{TO}$	$\overline{PD}$	$\overline{POR}$	$\overline{BOR}$
bit 7							bit 0

bit 7 **IPEN:** Interrupt Priority Enable bit
Always maintain this bit set for proper operation of ProMPT kernel.

bit 6-5 **Unimplemented:** Read as '0'

bit 4 **$\overline{RI}$:** RESET Instruction Flag bit
1 = The RESET instruction was not executed
0 = The RESET instruction was executed causing a device RESET (must be set in software after a Brown-out Reset occurs)

bit 3 **$\overline{TO}$:** Watchdog Time-out Flag bit
1 = After power-up, CLRWDT instruction, or SLEEP instruction
0 = A WDT time-out occurred

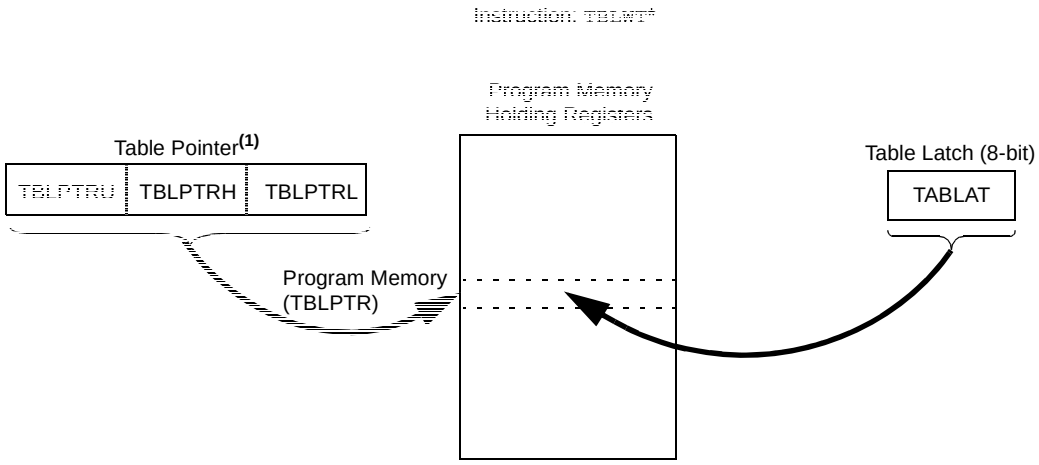
bit 2 **$\overline{PD}$:** Power-down Detection Flag bit
1 = After power-up or by the CLRWDT instruction
0 = By execution of the SLEEP instruction

bit 1 **$\overline{POR}$:** Power-on Reset Status bit
1 = A Power-on Reset has not occurred
0 = A Power-on Reset occurred (must be set in software after a Power-on Reset occurs)

bit 0 **$\overline{BOR}$:** Brown-out Reset Status bit
1 = A Brown-out Reset has not occurred
0 = A Brown-out Reset occurred (must be set in software after a Brown-out Reset occurs)

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
- n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

FIGURE 5-2: TABLE WRITE OPERATION



Note 1: Table Pointer actually points to one of eight holding registers, the address of which is determined by TBLPTRL<2:0>. The process for physically writing data to the Program Memory Array is discussed in Section 5.5.

5.2 Control Registers

Several control registers are used in conjunction with the TBLRD and TBLWT instructions. These include the:

- EECON1 register
- EECON2 register
- TABLAT register
- TBLPTR registers

5.2.1 EECON1 AND EECON2 REGISTERS

EECON1 is the control register for memory accesses.

EECON2 is not a physical register. Reading EECON2 will read all '0's. The EECON2 register is used exclusively in the memory write and erase sequences.

Control bit EEPGD determines if the access will be a program or data EEPROM memory access. When clear, any subsequent operations will operate on the data EEPROM memory. When set, any subsequent operations will operate on the program memory.

Control bit CFGS determines if the access will be to the configuration registers or to program memory/data EEPROM memory. When set, subsequent operations will operate on configuration registers, regardless of EEPGD (see Section 20.0, “Special Features of the CPU”). When clear, memory selection access is determined by EEPGD.

The FREE bit, when set, will allow a program memory erase operation. When the FREE bit is set, the erase operation is initiated on the next WR command. When FREE is clear, only writes are enabled.

The WREN bit, when set, will allow a write operation. On power-up, the WREN bit is clear. The WRERR bit is set when a write operation is interrupted by a MCLR Reset, or a WDT Time-out Reset, during normal operation. In these situations, the user can check the WRERR bit and rewrite the location. It is necessary to reload the data and address registers (EEDATA and EEADR), due to RESET values of zero.

Control bit WR initiates write operations. This bit cannot be cleared, only set, in software. It is cleared in hardware at the completion of the write operation. The inability to clear the WR bit in software prevents the accidental or premature termination of a write operation.

Note:	Interrupt flag bit, EEIF in the PIR2 register, is set when the write is complete. It must be cleared in software.

5.4 Erasing FLASH Program memory

The minimum erase block is 32 words or 64 bytes. Only through the use of an external programmer, or through ICSP control can larger blocks of program memory be bulk erased. Word erase in the FLASH array is not supported.

When initiating an erase sequence from the microcontroller itself, a block of 64 bytes of program memory is erased. The Most Significant 16 bits of the TBLPTR<21:6> point to the block being erased; TBLPTR<5:0> are ignored.

The EECON1 register commands the erase operation. The EEPGD bit must be set to point to the FLASH program memory. The WREN bit must be set to enable write operations. The FREE bit is set to select an erase operation.

For protection, the write initiate sequence for EECON2 must be used.

A long write is necessary for erasing the internal FLASH. Instruction execution is halted while in a long write cycle. The long write will be terminated by the internal programming timer.

5.4.1 FLASH PROGRAM MEMORY ERASE SEQUENCE

The sequence of events for erasing a block of internal program memory location is:

1. Load table pointer with address of row being erased.
2. Set EEPGD bit to point to program memory, clear CFGS bit to access program memory, set WREN bit to enable writes, and set FREE bit to enable the erase.
3. Disable interrupts.
4. Write 55h to EECON2.
5. Write AAh to EECON2.
6. Set the WR bit. This will begin the row erase cycle.
7. The CPU will stall for duration of the erase (about 2 ms using internal timer).
8. Re-enable interrupts.

EXAMPLE 5-2: ERASING A FLASH PROGRAM MEMORY ROW

```
                MOVLW   CODE_ADDR_UPPER     ; load TBLPTR with the base
                MOVWF   TBLPTRU             ; address of the memory block
                MOVLW   CODE_ADDR_HIGH
                MOVWF   TBLPTRH
                MOVLW   CODE_ADDR_LOW
                MOVWF   TBLPTRL
    ERASE_ROW
                BSF     EECON1,EEPGD        ; point to FLASH program memory
                BCF     EECON1,CFGS         ; access FLASH program memory
                BSF     EECON1,WREN         ; enable write to memory
                BSF     EECON1,FREE         ; enable Row Erase operation
                BCF     INTCON,GIE          ; disable interrupts
                MOVLW   55h
Required        MOVWF   EECON2              ; write 55h
Sequence        MOVLW   AAh
                MOVWF   EECON2              ; write AAh
                BSF     EECON1,WR           ; start erase (CPU stall)
                BSF     INTCON,GIE          ; re-enable interrupts
```


8.1 INTCON Registers

The INTCON Registers are readable and writable registers, which contain various enable, priority and flag bits.

Note: Interrupt flag bits are set when an interrupt condition occurs, regardless of the state of its corresponding enable bit or the global enable bit. User software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt. This feature allows for software polling.

REGISTER 8-1: INTCON REGISTER

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-x
GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE(1)	RBIE	TMR0IF	INT0IF	RBIF(2)
bit 7							bit 0

bit 7 **GIE/GIEH:** Global Interrupt Enable bit
1 = Enables all high priority interrupts
0 = Disables all interrupts

bit 6 **PEIE/GIEL:** Peripheral Interrupt Enable bit
1 = Enables all low priority peripheral interrupts
0 = Disables all low priority peripheral interrupts

bit 5 **TMR0IE:** TMR0 Overflow Interrupt Enable bit
1 = Enables the TMR0 overflow interrupt
0 = Disables the TMR0 overflow interrupt

bit 4 **INT0IE(1):** INT0 External Interrupt Enable bit
1 = Enables the INT0 external interrupt
0 = Disables the INT0 external interrupt

bit 3 **RBIE:** RB Port Change Interrupt Enable bit
1 = Enables the RB port change interrupt
0 = Disables the RB port change interrupt

bit 2 **TMR0IF:** TMR0 Overflow Interrupt Flag bit
1 = TMR0 register has overflowed (must be cleared in software)
0 = TMR0 register did not overflow

bit 1 **INT0IF:** INT0 External Interrupt Flag bit
1 = The INT0 external interrupt occurred (must be cleared in software)
0 = The INT0 external interrupt did not occur

bit 0 **RBIF(2):** RB Port Change Interrupt Flag bit
1 = At least one of the RB7:RB4 pins changed state (must be cleared in software)
0 = None of the RB7:RB4 pins have changed state

Note 1: Maintain this bit cleared (= 0).

2: A mismatch condition will continue to set this bit. Reading PORTB will end the mismatch condition and allow the bit to be cleared.

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
- n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

8.6 INT0 Interrupt

External interrupts on the RB0/INT0, RB1/INT1 and RB2/INT2 pins are edge triggered: either rising, if the corresponding INTEDGx bit is set in the INTCON2 register, or falling, if the INTEDGx bit is clear. When a valid edge appears on the RBx/INTx pin, the corresponding flag bit INTxF is set. This interrupt can be disabled by clearing the corresponding enable bit INTxE. Flag bit INTxF must be cleared in software in the Interrupt Service Routine before re-enabling the interrupt. All external interrupts (INT0, INT1 and INT2) can wake-up the processor from SLEEP, if bit INTxE was set prior to going into SLEEP. If the global interrupt enable bit GIE is set, the processor will branch to the interrupt vector following wake-up.

The INT0 interrupt is always configured as a high priority interrupt, and cannot be reconfigured. Interrupt priority for INT1 and INT2 is determined by the value contained in the interrupt priority bits, INT1IP (INTCON3<6>) and INT2IP (INTCON3<7>).

Because it is always configured as a high priority interrupt, INT0 cannot be used in conjunction with the ProMPT kernel; it must always be disabled (INTCON<4> = 0). Failure to do this may result in erratic operation of the motor control.

8.7 TMR0 Interrupt

In 8-bit mode (which is the default), an overflow in the TMR0 register (FFh → 00h) will set flag bit TMR0IF. In 16-bit mode, an overflow in the TMR0H:TMR0L register pair (FFFFh → 0000h) will set flag bit TMR0IF. The interrupt can be enabled or disabled by setting or clearing enable bit TMR0IE (INTCON<5>). Interrupt priority for Timer0 is determined by the value contained in the interrupt priority bit TMR0IP (INTCON2<2>). See Section 10.0 for further details on the Timer0 module.

8.8 PORTB Interrupt-on-Change

An input change on PORTB<7:4> sets flag bit RBIF (INTCON<0>). The interrupt can be enabled or disabled by setting or clearing the enable bit RBIE (INTCON<3>). Interrupt priority for PORTB interrupt-on-change is determined by the value contained in the interrupt priority bit RBIP (INTCON2<0>).

8.9 Context Saving During Interrupts

During an interrupt, the return PC value is saved on the stack. Additionally, the WREG, STATUS and BSR registers are saved on the fast return stack. If a fast return from interrupt is not used (see Section 4.3), the user may need to save the WREG, STATUS and BSR registers in software. Depending on the user's application, other registers may also need to be saved. Example 8-1 saves and restores the WREG, STATUS and BSR registers during an Interrupt Service Routine.

EXAMPLE 8-1: SAVING STATUS, WREG AND BSR REGISTERS IN RAM

```
MOVWF   W_TEMP                          ; W_TEMP is in virtual bank
MOVFF   STATUS, STATUS_TEMP             ; STATUS_TEMP located anywhere
MOVFF   BSR,    BSR_TEMP                ; BSR located anywhere
;
; USER ISR CODE
;
MOVFF   BSR_TEMP,   BSR                 ; Restore BSR
MOVF    W_TEMP,     W                   ; Restore WREG
MOVFF   STATUS_TEMP,STATUS              ; Restore STATUS
```

10.1 Timer0 Operation

Timer0 can operate as a timer or as a counter.

Timer mode is selected by clearing the T0CS bit. In Timer mode, the Timer0 module will increment every instruction cycle (without prescaler). If the TMR0L register is written, the increment is inhibited for the following two instruction cycles. The user can work around this by writing an adjusted value to the TMR0L register.

Counter mode is selected by setting the T0CS bit. In Counter mode, Timer0 will increment, either on every rising or falling edge of pin RA4/T0CKI. The incrementing edge is determined by the Timer0 Source Edge Select bit (T0SE). Clearing the T0SE bit selects the rising edge. Restrictions on the external clock input are discussed below.

When an external clock input is used for Timer0, it must meet certain requirements. The requirements ensure the external clock can be synchronized with the internal phase clock (TOSC). Also, there is a delay in the actual incrementing of Timer0 after synchronization.

10.2 Prescaler

An 8-bit counter is available as a prescaler for the Timer0 module. The prescaler is not readable or writable.

The PSA and T0PS2:T0PS0 bits determine the prescaler assignment and prescale ratio.

Clearing bit PSA will assign the prescaler to the Timer0 module. When the prescaler is assigned to the Timer0 module, prescale values in power-of-2 increments, from 1:2 through 1:256, are selectable.

When assigned to the Timer0 module, all instructions writing to the TMR0L register (e.g., `CLRF TMR0`, `MOVWF TMR0`, `BSF TMR0`, etc.) will clear the prescaler count.

Note:	Writing to TMR0L when the prescaler is assigned to Timer0 will clear the prescaler count, but will not change the prescaler assignment.

10.2.1 SWITCHING PRESCALER ASSIGNMENT

The prescaler assignment is fully under software control; it can be changed “on-the-fly” during program execution.

10.3 Timer0 Interrupt

The TMR0 interrupt is generated when the TMR0 register overflows from FFh to 00h in 8-bit mode, or FFFFh to 0000h in 16-bit mode. This overflow sets the TMR0IF bit. The interrupt can be masked by clearing the TMR0IE bit. The TMR0IE bit must be cleared in software by the Timer0 module Interrupt Service Routine before re-enabling this interrupt. The TMR0 interrupt cannot awaken the processor from SLEEP, since the timer is shut-off during SLEEP.

10.4 16-bit Mode Timer Reads and Writes

TMR0H is not the high byte of the timer/counter in 16-bit mode, but is actually a buffered version of the high byte of Timer0 (see Figure 10-2). The high byte of the Timer0 counter/timer is not directly readable nor writable. TMR0H is updated with the contents of the high byte of Timer0 during a read of TMR0L. This provides the ability to read all 16 bits of Timer0 without having to verify that the read of the high and low byte were valid, due to a rollover between successive reads of the high and low byte.

A write to the high byte of Timer0 must also take place through the TMR0H buffer register. Timer0 high byte is updated with the contents of TMR0H when a write occurs to TMR0L. This allows all 16 bits of Timer0 to be updated at once.

TABLE 10-1: REGISTERS ASSOCIATED WITH TIMER0

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on POR, BOR	Value on All Other RESETS
TMR0L	Timer0 Module Low Byte Register								xxxx xxxx	uuuu uuuu
TMR0H	Timer0 Module High Byte Register								0000 0000	0000 0000
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	0000 000x	0000 000u
T0CON	TMR0ON	T08BIT	T0CS	T0SE	PSA	T0PS2	T0PS1	T0PS0	1111 1111	1111 1111
TRISA	—	PORTA Data Direction Register							-111 1111	-111 1111

Legend: x = unknown, u = unchanged, - = unimplemented locations read as '0'. Shaded cells are not used by Timer0.

16.3.3 ENABLING SPI I/O

To enable the serial port, SSP Enable bit, SSPEN (SSPCON1<5>), must be set. To reset or reconfigure SPI mode, clear the SSPEN bit, re-initialize the SSPCON registers, and then set the SSPEN bit. This configures the SDI, SDO, SCK, and $\overline{SS}$ pins as serial port pins. For the pins to behave as the serial port function, some must have their data direction bits (in the TRIS register) appropriately programmed. That is:

- SDI is automatically controlled by the SPI module
- SDO must have TRISC<5> bit cleared
- SCK (Master mode) must have TRISC<3> bit cleared
- SCK (Slave mode) must have TRISC<3> bit set
- $\overline{SS}$ must have TRISC<4> bit set

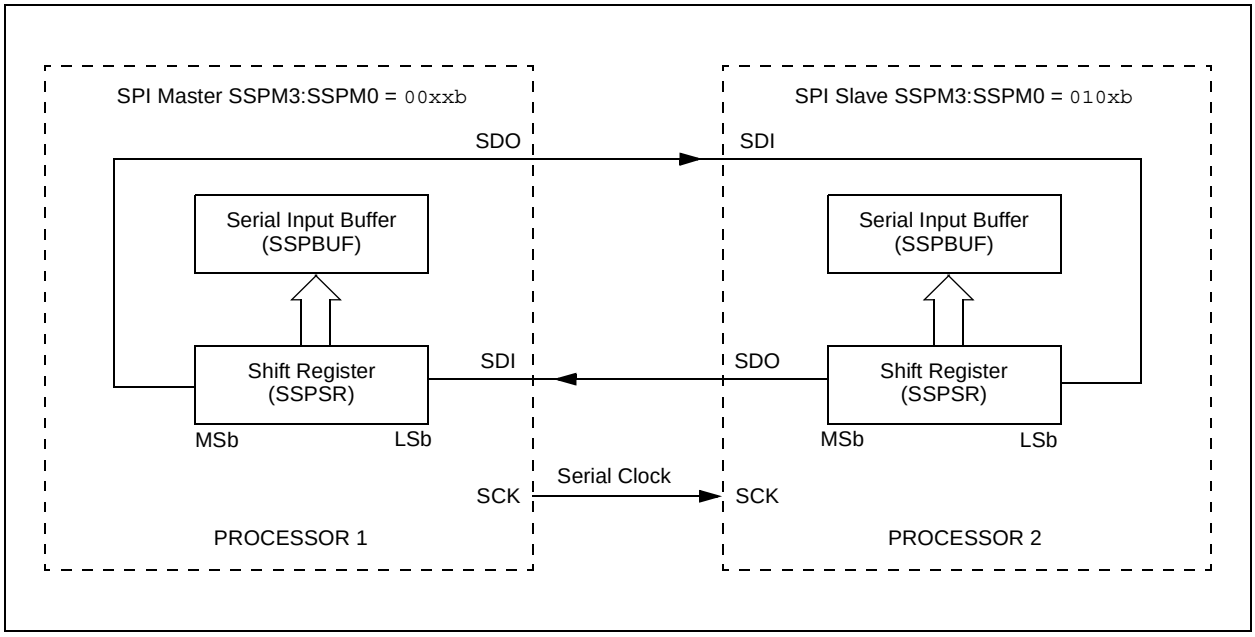
Any serial port function that is not desired may be overridden by programming the corresponding data direction (TRIS) register to the opposite value.

16.3.4 TYPICAL CONNECTION

Figure 16-2 shows a typical connection between two microcontrollers. The master controller (Processor 1) initiates the data transfer by sending the SCK signal. Data is shifted out of both shift registers on their programmed clock edge, and latched on the opposite edge of the clock. Both processors should be programmed to the same Clock Polarity (CKP), then both controllers would send and receive data at the same time. Whether the data is meaningful (or dummy data) depends on the application software. This leads to three scenarios for data transmission:

- Master sends data — Slave sends dummy data
- Master sends data — Slave sends data
- Master sends dummy data — Slave sends data

FIGURE 16-2: SPI MASTER/SLAVE CONNECTION



REGISTER 16-4: SSPCON1: MSSP CONTROL REGISTER 1 (I^2C MODE)

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
WCOL	SSPOV	SSPEN	CKP	SSPM3	SSPM2	SSPM1	SSPM0
bit 7							bit 0

bit 7 **WCOL:** Write Collision Detect bit

In Master Transmit mode:

1 = A write to the SSPBUF register was attempted while the I^2C conditions were not valid for a transmission to be started (must be cleared in software)

0 = No collision

In Slave Transmit mode:

1 = The SSPBUF register is written while it is still transmitting the previous word (must be cleared in software)

0 = No collision

In Receive mode (Master or Slave modes):

This is a “don’t care” bit

bit 6 **SSPOV:** Receive Overflow Indicator bit

In Receive mode:

1 = A byte is received while the SSPBUF register is still holding the previous byte (must be cleared in software)

0 = No overflow

In Transmit mode:

This is a “don’t care” bit in Transmit mode

bit 5 **SSPEN:** Synchronous Serial Port Enable bit

1 = Enables the serial port and configures the SDA and SCL pins as the serial port pins

0 = Disables serial port and configures these pins as I/O port pins

Note: When enabled, the SDA and SCL pins must be properly configured as input or output.

bit 4 **CKP:** SCK Release Control bit

In Slave mode:

1 = Release clock

0 = Holds clock low (clock stretch), used to ensure data setup time

In Master mode:

Unused in this mode

bit 3-0 **SSPM3:SSPM0:** Synchronous Serial Port Mode Select bits

1111 = I^2C Slave mode, 10-bit address with START and STOP bit interrupts enabled

1110 = I^2C Slave mode, 7-bit address with START and STOP bit interrupts enabled

1011 = I^2C Firmware Controlled Master mode (Slave IDLE)

1000 = I^2C Master mode, clock = FOSC / (4 * (SSPADD+1))

0111 = I^2C Slave mode, 10-bit address

0110 = I^2C Slave mode, 7-bit address

Note: Bit combinations not specifically listed here are either reserved, or implemented in SPI mode only.

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as ‘0’	
- n = Value at POR	‘1’ = Bit is set	‘0’ = Bit is cleared	x = Bit is unknown

16.4.10 I²C MASTER MODE TRANSMISSION

Transmission of a data byte, a 7-bit address, or the other half of a 10-bit address is accomplished by simply writing a value to the SSPBUF register. This action will set the buffer full flag bit, BF, and allow the baud rate generator to begin counting and start the next transmission. Each bit of address/data will be shifted out onto the SDA pin after the falling edge of SCL is asserted (see data hold time specification parameter 106). SCL is held low for one baud rate generator rollover count (TBRG). Data should be valid before SCL is released high (see data setup time specification parameter 107). When the SCL pin is released high, it is held that way for TBRG. The data on the SDA pin must remain stable for that duration and some hold time after the next falling edge of SCL. After the eighth bit is shifted out (the falling edge of the eighth clock), the BF flag is cleared and the master releases SDA. This allows the slave device being addressed to respond with an $\overline{ACK}$ bit during the ninth bit time, if an address match occurred, or if data was received properly. The status of $\overline{ACK}$ is written into the ACKDT bit on the falling edge of the ninth clock. If the master receives an Acknowledge, the Acknowledge status bit, ACKSTAT, is cleared. If not, the bit is set. After the ninth clock, the SSPIF bit is set and the master clock (baud rate generator) is suspended until the next data byte is loaded into the SSPBUF, leaving SCL low and SDA unchanged (Figure 16-21).

After the write to the SSPBUF, each bit of address will be shifted out on the falling edge of SCL until all seven address bits and the $\overline{R/W}$ bit are completed. On the falling edge of the eighth clock, the master will de-assert the SDA pin, allowing the slave to respond with an Acknowledge. On the falling edge of the ninth clock, the master will sample the SDA pin to see if the address was recognized by a slave. The status of the ACK bit is loaded into the ACKSTAT status bit (SSPCON2<6>). Following the falling edge of the ninth clock transmission of the address, the SSPIF is set, the BF flag is cleared and the baud rate generator is turned off until another write to the SSPBUF takes place, holding SCL low and allowing SDA to float.

16.4.10.1 BF Status Flag

In Transmit mode, the BF bit (SSPSTAT<0>) is set when the CPU writes to SSPBUF and is cleared when all 8 bits are shifted out.

16.4.10.2 WCOL Status Flag

If the user writes the SSPBUF when a transmit is already in progress (i.e., SSPSR is still shifting out a data byte), the WCOL is set and the contents of the buffer are unchanged (the write doesn't occur).

WCOL must be cleared in software.

16.4.10.3 ACKSTAT Status Flag

In Transmit mode, the ACKSTAT bit (SSPCON2<6>) is cleared when the slave has sent an Acknowledge ($\overline{ACK}$ = 0), and is set when the slave does not Acknowledge ($\overline{ACK}$ = 1). A slave sends an Acknowledge when it has recognized its address (including a general call), or when the slave has properly received its data.

16.4.11 I²C MASTER MODE RECEPTION

Master mode reception is enabled by programming the receive enable bit, RCEN (SSPCON2<3>).

Note:	In the MSSP module, the RCEN bit must be set after the ACK sequence or the RCEN bit will be disregarded.

The baud rate generator begins counting, and on each rollover, the state of the SCL pin changes (high to low/low to high) and data is shifted into the SSPSR. After the falling edge of the eighth clock, the receive enable flag is automatically cleared, the contents of the SSPSR are loaded into the SSPBUF, the BF flag bit is set, the SSPIF flag bit is set and the baud rate generator is suspended from counting, holding SCL low. The MSSP is now in IDLE state, awaiting the next command. When the buffer is read by the CPU, the BF flag bit is automatically cleared. The user can then send an Acknowledge bit at the end of reception, by setting the Acknowledge sequence enable bit, ACKEN (SSPCON2<4>).

16.4.11.1 BF Status Flag

In receive operation, the BF bit is set when an address or data byte is loaded into SSPBUF from SSPSR. It is cleared when the SSPBUF register is read.

16.4.11.2 SSPOV Status Flag

In receive operation, the SSPOV bit is set when 8 bits are received into the SSPSR and the BF flag bit is already set from a previous reception.

16.4.11.3 WCOL Status Flag

If the user writes the SSPBUF when a receive is already in progress (i.e., SSPSR is still shifting in a data byte), the WCOL bit is set and the contents of the buffer are unchanged (the write doesn't occur).

17.0 ADDRESSABLE UNIVERSAL SYNCHRONOUS ASYNCHRONOUS RECEIVER TRANSMITTER (USART)

The Universal Synchronous Asynchronous Receiver Transmitter (USART) module is one of the two serial I/O modules. (USART is also known as a Serial Communications Interface or SCI.) The USART can be configured as a full-duplex asynchronous system that can communicate with peripheral devices, such as CRT terminals and personal computers, or it can be configured as a half-duplex synchronous system that can communicate with peripheral devices, such as A/D or D/A integrated circuits, serial EEPROMs, etc.

The USART can be configured in the following modes:

- Asynchronous (full-duplex)
- Synchronous - Master (half-duplex)
- Synchronous - Slave (half-duplex)

In order to configure pins RC6/TX/CK and RC7/RX/DT as the Universal Synchronous Asynchronous Receiver Transmitter:

- bit SPEN (RCSTA<7>) must be set (= 1),
- bit TRISC<6> must be cleared (= 0), and
- bit TRISC<7> must be set (= 1).

Register 17-1 shows the Transmit Status and Control Register (TXSTA) and Register 17-2 shows the Receive Status and Control Register (RCSTA).

REGISTER 20-11: DEVID1: DEVICE ID REGISTER 1 FOR PIC18FXX39 (BYTE ADDRESS 3FFFFEh)

R	R	R	R	R	R	R	R
DEV2	DEV1	DEV0	REV4	REV3	REV2	REV1	REV0
bit 7							bit 0

bit 7-5 **DEV2:DEV0:** Device ID bits
000 = PIC18F2539
001 = PIC18F4539
100 = PIC18F2439
101 = PIC18F4439

bit 4-0 **REV4:REV0:** Revision ID bits
These bits are used to indicate the device revision.

Legend:		
R = Readable bit	P = Programmable bit	U = Unimplemented bit, read as '0'
- n = Value when device is unprogrammed		u = Unchanged from programmed state

REGISTER 20-12: DEVID2: DEVICE ID REGISTER 2 FOR PIC18FXX39 (BYTE ADDRESS 3FFFFFh)

R	R	R	R	R	R	R	R
DEV10	DEV9	DEV8	DEV7	DEV6	DEV5	DEV4	DEV3
bit 7							bit 0

bit 7-0 **DEV10:DEV3:** Device ID bits
These bits are used with the DEV2:DEV0 bits in the Device ID Register 1 to identify the part number.

Legend:		
R = Readable bit	P = Programmable bit	U = Unimplemented bit, read as '0'
- n = Value when device is unprogrammed		u = Unchanged from programmed state

TABLE 21-2: PIC18FXXX INSTRUCTION SET (CONTINUED)

Mnemonic, Operands		Description	Cycles	16-Bit Instruction Word MSb LSb	Status Affected	Notes
LITERAL OPERATIONS						
ADDLW	k	Add literal and WREG	1	0000 1111 kkkk kkkk	C, DC, Z, OV, N	
ANDLW	k	AND literal with WREG	1	0000 1011 kkkk kkkk	Z, N	
IORLW	k	Inclusive OR literal with WREG	1	0000 1001 kkkk kkkk	Z, N	
LFSR	f, k	Move literal (12-bit) 2nd word to FSRx 1st word	2	1110 1110 00ff kkkk 1111 0000 kkkk kkkk	None	
MOVLB	k	Move literal to BSR<3:0>	1	0000 0001 0000 kkkk	None	
MOVLW	k	Move literal to WREG	1	0000 1110 kkkk kkkk	None	
MULLW	k	Multiply literal with WREG	1	0000 1101 kkkk kkkk	None	
RETLW	k	Return with literal in WREG	2	0000 1100 kkkk kkkk	None	
SUBLW	k	Subtract WREG from literal	1	0000 1000 kkkk kkkk	C, DC, Z, OV, N	
XORLW	k	Exclusive OR literal with WREG	1	0000 1010 kkkk kkkk	Z, N	
DATA MEMORY ↔ PROGRAM MEMORY OPERATIONS						
TBLRD*		Table Read	2	0000 0000 0000 1000	None	
TBLRD*+		Table Read with post-increment		0000 0000 0000 1001	None	
TBLRD*-		Table Read with post-decrement		0000 0000 0000 1010	None	
TBLRD+*		Table Read with pre-increment		0000 0000 0000 1011	None	
TBLWT*		Table Write	2 (5)	0000 0000 0000 1100	None	
TBLWT*+		Table Write with post-increment		0000 0000 0000 1101	None	
TBLWT*-		Table Write with post-decrement		0000 0000 0000 1110	None	
TBLWT+*		Table Write with pre-increment		0000 0000 0000 1111	None	

Note 1: When a PORT register is modified as a function of itself (e.g., `MOVF PORTB, 1, 0`), the value used will be that value present on the pins themselves. For example, if the data latch is '1' for a pin configured as input and is driven low by an external device, the data will be written back with a '0'.

2: If this instruction is executed on the TMR0 register (and, where applicable, d = 1), the prescaler will be cleared if assigned.

3: If Program Counter (PC) is modified or a conditional test is true, the instruction requires two cycles. The second cycle is executed as a `NOP`.

4: Some instructions are 2-word instructions. The second word of these instructions will be executed as a `NOP`, unless the first word of the instruction retrieves the information embedded in these 16-bits. This ensures that all program memory locations have a valid instruction.

5: If the Table Write starts the write cycle to internal memory, the write will continue until terminated.

GOTO **Unconditional Branch**

Syntax: [*label*] GOTO k

Operands: $0 \le k \le 1048575$

Operation: $k \rightarrow PC<20:1>$

Status Affected: None

Encoding:

1st word (k<7:0>)	1110	1111	k_7kkk	$kkkk_0$
2nd word(k<19:8>)	1111	$k_{19}kkk$	kkkk	$kkkk_8$

Description: GOTO allows an unconditional branch anywhere within entire 2 Mbyte memory range. The 20-bit value 'k' is loaded into PC<20:1>. GOTO is always a two-cycle instruction.

Words: 2

Cycles: 2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'<7:0>,	No operation	Read literal 'k'<19:8>, Write to PC
No operation	No operation	No operation	No operation

Example: GOTO THERE

After Instruction
PC = Address (THERE)

INCF **Increment f**

Syntax: [*label*] INCF f [,d [,a]

Operands: $0 \le f \le 255$
$d \in [0,1]$
$a \in [0,1]$

Operation: (f) + 1 → dest

Status Affected: C, DC, N, OV, Z

Encoding:

0010	10da	ffff	ffff

Description: The contents of register 'f' are incremented. If 'd' is 0, the result is placed in W. If 'd' is 1, the result is placed back in register 'f' (default). If 'a' is 0, the Access Bank will be selected, overriding the BSR value. If 'a' = 1, then the bank will be selected as per the BSR value (default).

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	Write to destination

Example: INCF CNT, 1, 0

Before Instruction
CNT = 0xFF
Z = 0
C = ?
DC = ?

After Instruction
CNT = 0x00
Z = 1
C = 1
DC = 1

SUBWFB **Subtract W from f with Borrow**

Syntax: [*label*] SUBWFB f [,d [,a]

Operands: $0 \le f \le 255$
$d \in [0,1]$
$a \in [0,1]$

Operation: (f) – (W) – ($\overline{C}$) → dest

Status Affected: N, OV, C, DC, Z

Encoding:

0101	10da	ffff	ffff

Description: Subtract W and the carry flag (borrow) from register 'f' (2's complement method). If 'd' is 0, the result is stored in W. If 'd' is 1, the result is stored back in register 'f' (default). If 'a' is 0, the Access Bank will be selected, overriding the BSR value. If 'a' is 1, then the bank will be selected as per the BSR value (default).

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	Write to destination

Example 1: `SUBWFB REG, 1, 0`

Before Instruction
REG = 0x19 (0001 1001)
W = 0x0D (0000 1101)
C = 1
After Instruction
REG = 0x0C (0000 1011)
W = 0x0D (0000 1101)
C = 1
Z = 0
N = 0 ; result is positive

Example 2: `SUBWFB REG, 0, 0`

Before Instruction
REG = 0x1B (0001 1011)
W = 0x1A (0001 1010)
C = 0
After Instruction
REG = 0x1B (0001 1011)
W = 0x00
C = 1
Z = 1 ; result is zero
N = 0

Example 3: `SUBWFB REG, 1, 0`

Before Instruction
REG = 0x03 (0000 0011)
W = 0x0E (0000 1101)
C = 1
After Instruction
REG = 0xF5 (1111 0100)
; [2's comp]
W = 0x0E (0000 1101)
C = 0
Z = 0
N = 1 ; result is negative

SWAPF **Swap f**

Syntax: [*label*] SWAPF f [,d [,a]

Operands: $0 \le f \le 255$
$d \in [0,1]$
$a \in [0,1]$

Operation: (f<3:0>) → dest<7:4>,
(f<7:4>) → dest<3:0>

Status Affected: None

Encoding:

0011	10da	ffff	ffff

Description: The upper and lower nibbles of register 'f' are exchanged. If 'd' is 0, the result is placed in W. If 'd' is 1, the result is placed in register 'f' (default). If 'a' is 0, the Access Bank will be selected, overriding the BSR value. If 'a' is 1, then the bank will be selected as per the BSR value (default).

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	Write to destination

Example: `SWAPF REG, 1, 0`

Before Instruction
REG = 0x53
After Instruction
REG = 0x35

23.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings (†)

Ambient temperature under bias ..... -55°C to +125°C

Storage temperature ..... -65°C to +150°C

Voltage on any pin with respect to V_{SS} (except V_{DD}, $\overline{MCLR}$, and RA4) ..... -0.3V to (V_{DD} + 0.3V)

Voltage on V_{DD} with respect to V_{SS} ..... -0.3V to +7.5V

Voltage on $\overline{MCLR}$ with respect to V_{SS} **(Note 2)** ..... 0V to +13.25V

Voltage on RA4 with respect to Vss ..... 0V to +8.5V

Total power dissipation **(Note 1)** 1.0W

Maximum current out of V_{SS} pin ..... 300 mA

Maximum current into V_{DD} pin ..... 250 mA

Input clamp current, I_{IK} (V_I < 0 or V_I > V_{DD}) ..... ±20 mA

Output clamp current, I_{OK} (V_O < 0 or V_O > V_{DD}) ..... ±20 mA

Maximum output current sunk by any I/O pin ..... 25 mA

Maximum output current sourced by any I/O pin ..... 25 mA

Maximum current sunk by PORTA, PORTB, and PORTE **(Note 3)** (combined) ..... 200 mA

Maximum current sourced by PORTA, PORTB, and PORTE **(Note 3)** (combined) ..... 200 mA

Maximum current sunk by PORTC and PORTD **(Note 3)** (combined) ..... 200 mA

Maximum current sourced by PORTC and PORTD **(Note 3)** (combined) ..... 200 mA

Note 1: Power dissipation is calculated as follows:
$P_{dis} = V_{DD} \times \{I_{DD} - \sum I_{OH}\} + \sum \{(V_{DD}-V_{OH}) \times I_{OH}\} + \sum(V_{ol} \times I_{OL})$

2: Voltage spikes below V_{SS} at the $\overline{MCLR}/V_{PP}$ pin, inducing currents greater than 80 mA, may cause latchup. Thus, a series resistor of 50-100Ω should be used when applying a "low" level to the $\overline{MCLR}/V_{PP}$ pin, rather than pulling this pin directly to V_{SS}.

3: PORTD and PORTE not available on the PIC18F2X39 devices.

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

FIGURE 23-6: CLKO AND I/O TIMING

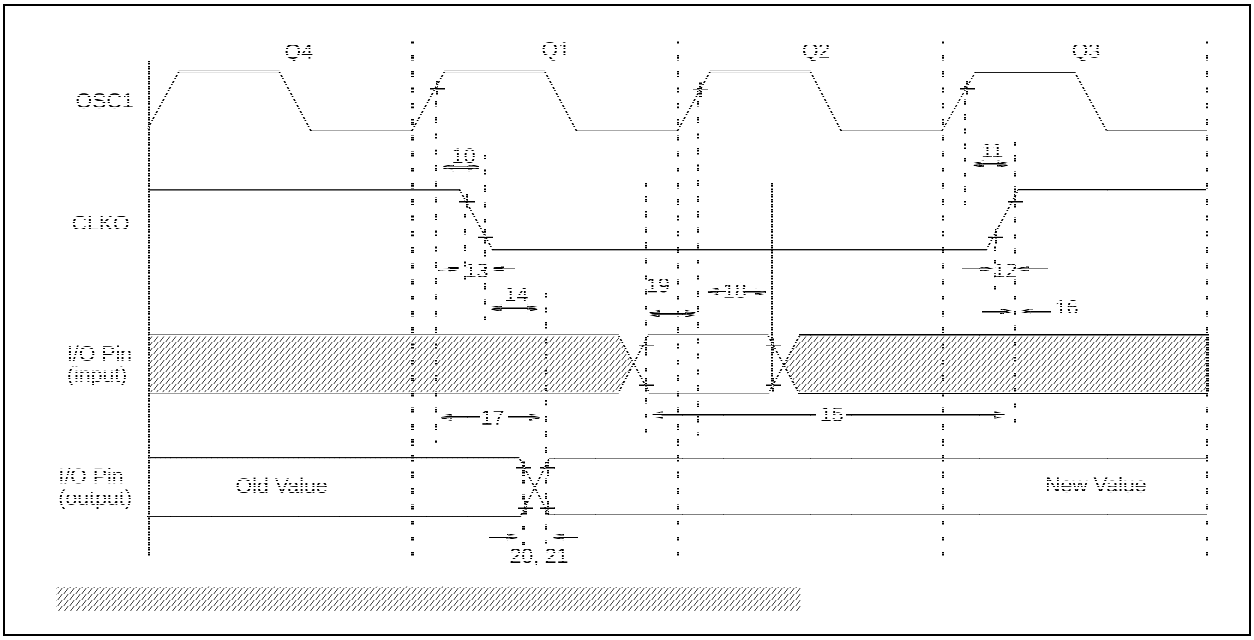


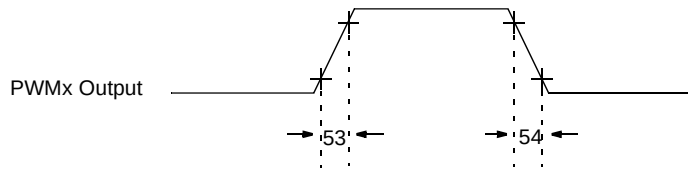
TABLE 23-6: CLKO AND I/O TIMING REQUIREMENTS

Param. No.	Symbol	Characteristic		Min	Typ	Max	Units	Conditions
10	TosH2ckL	OSC1↑ to CLKO↓		—	75	200	ns	**(Note 1)**
11	TosH2ckH	OSC1↑ to CLKO↑		—	75	200	ns	**(Note 1)**
12	TckR	CLKO rise time		—	35	100	ns	**(Note 1)**
13	TckF	CLKO fall time		—	35	100	ns	**(Note 1)**
14	TckL2ioV	CLKO↓ to Port out valid		—	—	0.5 TCY + 20	ns	**(Note 1)**
15	TioV2ckH	Port in valid before CLKO ↑		0.25 TCY + 25	—	—	ns	**(Note 1)**
16	TckH2ioI	Port in hold after CLKO ↑		0	—	—	ns	**(Note 1)**
17	TosH2ioV	OSC1↑ (Q1 cycle) to Port out valid		—	50	150	ns	
18	TosH2ioI	OSC1↑ (Q2 cycle) to Port input invalid (I/O in hold time)	PIC18**F**XXXX	100	—	—	ns	
18A			PIC18**LF**XXXX	200	—	—	ns	
19	TioV2osH	Port input valid to OSC1↑ (I/O in setup time)		0	—	—	ns	
20	TioR	Port output rise time	PIC18**F**XXXX	—	10	25	ns	
20A			PIC18**LF**XXXX	—	—	60	ns	VDD = 2V
21	TioF	Port output fall time	PIC18**F**XXXX	—	10	25	ns	
21A			PIC18**LF**XXXX	—	—	60	ns	VDD = 2V
22††	TINP	INT pin high or low time		TCY	—	—	ns	
23††	TRBP	RB7:RB4 change INT high or low time		TCY	—	—	ns	
24††	TRCP	RC7:RC4 change INT high or low time		20			ns	

†† These parameters are asynchronous events not related to any internal clock edges.

Note 1: Measurements are taken in RC mode, where CLKO output is 4 x TOSC.

FIGURE 23-10: PWM TIMINGS (PWM1 AND PWM2)



Note: Refer to Figure 23-4 for load conditions.

TABLE 23-9: PWM TIMING REQUIREMENTS (PWM1 AND PWM2)

Param. No.	Symbol	Characteristic		Min	Max	Units	Conditions
53	TccR	PWMx Output Rise Time	PIC18**F**XXXX	—	25	ns	
			PIC18**LF**XXXX	—	60	ns	V_{DD} = 2V
54	TccF	PWMx Output Fall Time	PIC18**F**XXXX	—	25	ns	
			PIC18**LF**XXXX	—	60	ns	V_{DD} = 2V

