PIC18F2450/4450 Data Sheet

24/40/44-Pin High-Performance, 12 MIPS, Enhanced Flash, USB Microcontrollers with nanoWatt Technology

28/40/44-Pin High-Performance, 12 MIPS, Enhanced Flash, USB Microcontrollers with nanoWatt Technology

Universal Serial Bus Features:

- USB V2.0 Compliant
- Low Speed (1.5 Mb/s) and Full Speed (12 Mb/s)
- Supports Control, Interrupt, Isochronous and Bulk Transfers
- Supports Up to 32 Endpoints (16 bidirectional)
- 256-Byte Dual Access RAM for USB
- On-Chip USB Transceiver with On-Chip Voltage Regulator
- Interface for Off-Chip USB Transceiver

Power-Managed Modes:

- Run: CPU on, Peripherals on
- Idle: CPU off, Peripherals on
- Sleep: CPU off, Peripherals off
- Idle mode Currents Down to 5.8 μA Typical
- Sleep mode Currents Down to 0.1 μA Typical
- Timer1 Oscillator: 1.8 μA Typical, 32 kHz, 2V
- Watchdog Timer: 2.1 μA Typical
- Two-Speed Oscillator Start-up

Flexible Oscillator Structure:

- Four Crystal modes, including High-Precision PLL for USB
- Two External Clock modes, up to 48 MHz
- Internal 31 kHz Oscillator
- Secondary Oscillator using Timer1 @ 32 kHz
- Dual Oscillator Options allow Microcontroller and USB module to Run at Different Clock Speeds
- Fail-Safe Clock Monitor:
  - Allows for safe shutdown if any clock stops

Peripheral Highlights:

- High-Current Sink/Source: 25 mA/25 mA
- Three External Interrupts
- Three Timer modules (Timer0 to Timer2)
- Capture/Compare/PWM (CCP) module:
  - Capture is 16-bit, max. resolution 5.2 ns
  - Compare is 16-bit, max. resolution 83.3 ns
  - PWM output: PWM resolution is 1 to 10-bit
- Enhanced USART module:
  - LIN bus support
- 10-Bit, Up to 13-Channel Analog-to-Digital Converter module (A/D):
  - Up to 100 ksps sampling rate
  - Programmable acquisition time

Special Microcontroller Features:

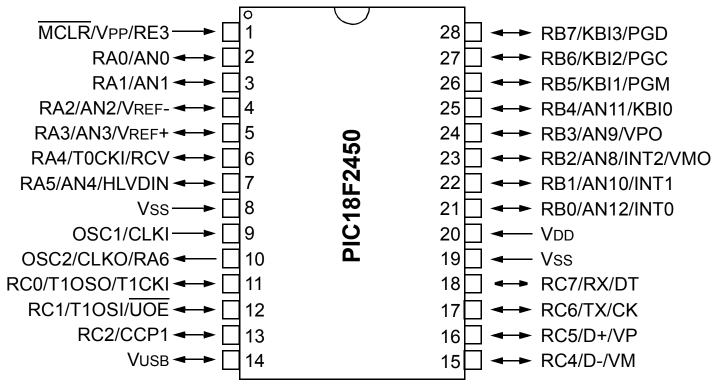
- C Compiler Optimized Architecture with Optional Extended Instruction Set
- Flash Memory Retention: > 40 Years
- Self-Programmable under Software Control
- Priority Levels for Interrupts
- 8 x 8 Single-Cycle Hardware Multiplier
- Extended Watchdog Timer (WDT):
  - Programmable period from 4 ms to 131s
- Programmable Code Protection
- Single-Supply In-Circuit Serial Programming™ (ICSP™) via Two Pins
- In-Circuit Debug (ICD) via Two Pins
- Optional Dedicated ICD/ICSP Port (44-pin TQFP devices only)
- Wide Operating Voltage Range (2.0V to 5.5V)

Device	Program Memory		Data Memory SRAM (bytes)	I/O	10-Bit A/D (ch)	CCP	EUSART	Timers 8/16-Bit
	Flash (bytes)	# Single-Word Instructions						
PIC18F2450	16K	8192	768*	23	10	1	1	1/2
PIC18F4450	16K	8192	768*	34	13	1	1	1/2

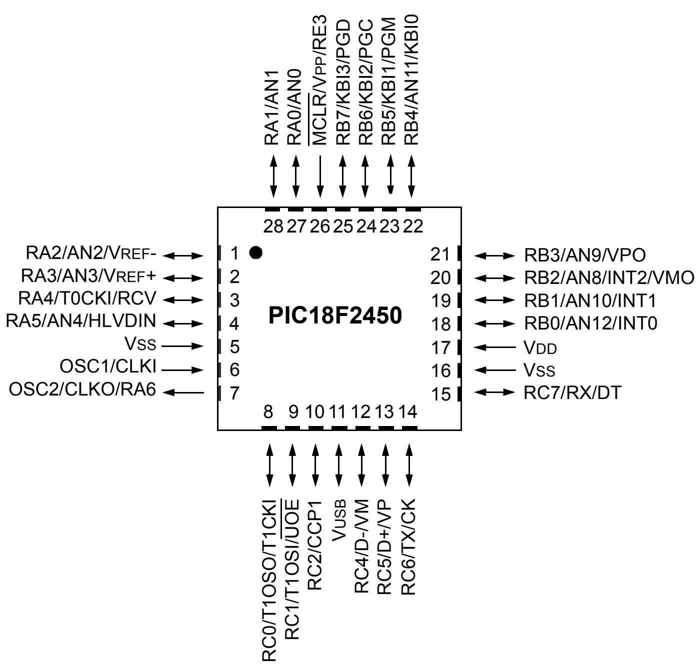
* Includes 256 bytes of dual access RAM used by USB module and shared with data memory.

Pin Diagrams

28-Pin SPDIP, SOIC

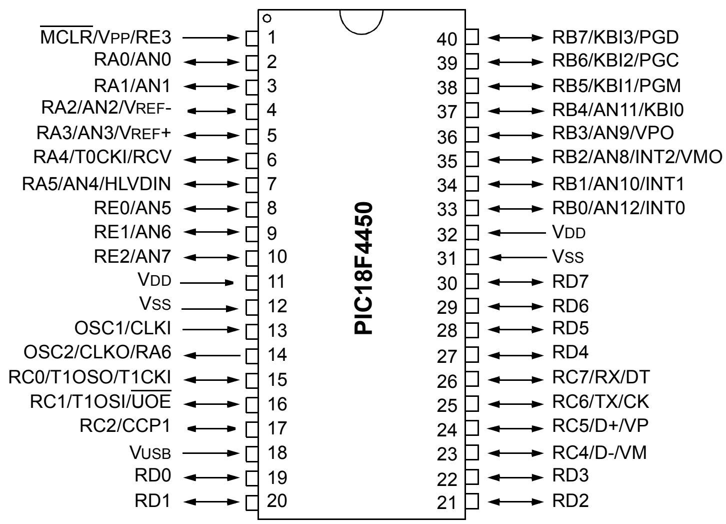


28-Pin QFN

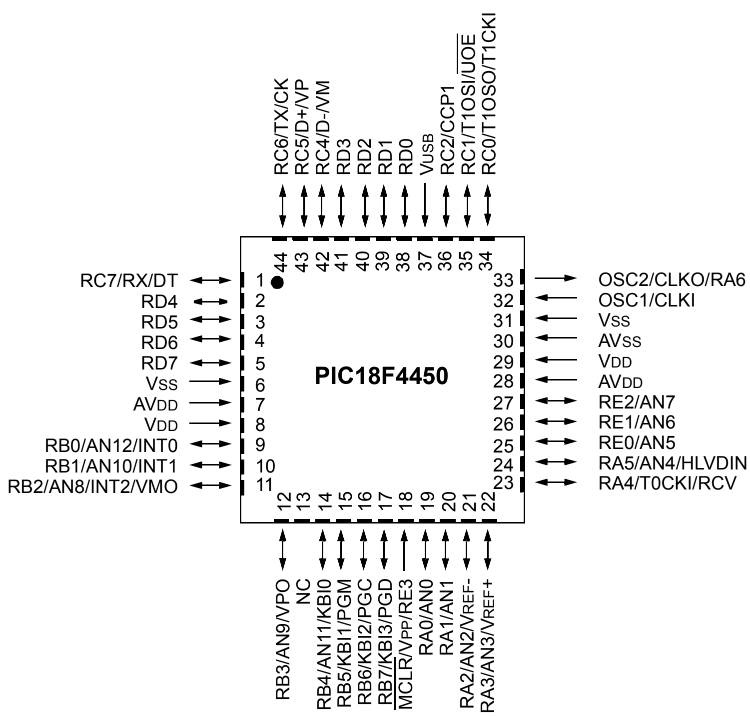


Pin Diagrams (Continued)

40-Pin PDIP

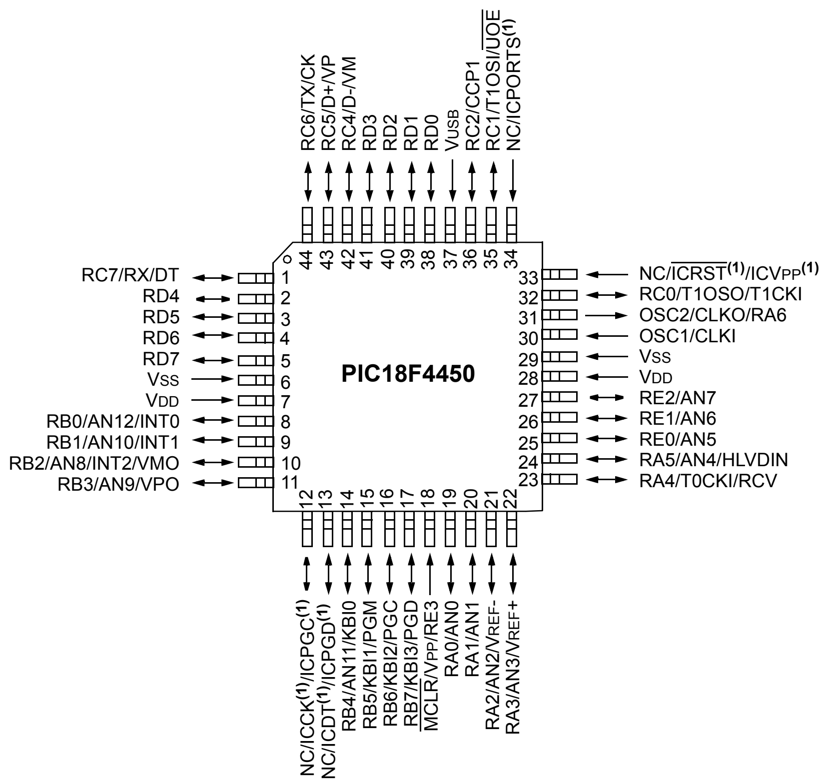


44-Pin QFN



Pin Diagrams (Continued)

44-Pin TQFP



Note 1: Special ICPORT features are available in select circumstances. For more information, see **Section 18.9 “Special ICPORT Features (Designated Packages Only)”**.

Table of Contents

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An errata sheet, describing minor operational differences from the data sheet and recommended workarounds, may exist for current devices. As device/documentation issues become known to us, we will publish an errata sheet. The errata will specify the revision of silicon and revision of document to which it applies.

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1.0 DEVICE OVERVIEW

This document contains device-specific information for the following devices:

- PIC18F2450
- PIC18F4450

This family of devices offers the advantages of all PIC18 microcontrollers – namely, high computational performance at an economical price – with the addition of high-endurance, Enhanced Flash program memory. In addition to these features, the PIC18F2450/4450 family introduces design enhancements that make these microcontrollers a logical choice for many high-performance, power sensitive applications.

1.1 New Core Features

1.1.1 nanoWatt TECHNOLOGY

All of the devices in the PIC18F2450/4450 family incorporate a range of features that can significantly reduce power consumption during operation. Key items include:

- **Alternate Run Modes:** By clocking the controller from the Timer1 source or the internal RC oscillator, power consumption during code execution can be reduced by as much as 90%.
- **Multiple Idle Modes:** The controller can also run with its CPU core disabled but the peripherals still active. In these states, power consumption can be reduced even further, to as little as 4% of normal operation requirements.
- **On-the-Fly Mode Switching:** The power-managed modes are invoked by user code during operation, allowing the user to incorporate power-saving ideas into their application's software design.
- **Low Consumption in Key Modules:** The power requirements for both Timer1 and the Watchdog Timer are minimized. See **Section 21.0 "Electrical Characteristics"** for values.

1.1.2 UNIVERSAL SERIAL BUS (USB)

Devices in the PIC18F2450/4450 family incorporate a fully featured Universal Serial Bus communications module that is compliant with the USB Specification Revision 2.0. The module supports both low-speed and full-speed communication for all supported data transfer types. It also incorporates its own on-chip transceiver and 3.3V regulator and supports the use of external transceivers and voltage regulators.

1.1.3 MULTIPLE OSCILLATOR OPTIONS AND FEATURES

All of the devices in the PIC18F2450/4450 family offer twelve different oscillator options, allowing users a wide range of choices in developing application hardware. These include:

- Four Crystal modes using crystals or ceramic resonators.
- Four External Clock modes, offering the option of using two pins (oscillator input and a divide-by-4 clock output) or one pin (oscillator input, with the second pin reassigned as general I/O).
- An INTRC source (approximately 31 kHz, stable over temperature and V_{DD}). This option frees an oscillator pin for use as an additional general purpose I/O.
- A Phase Lock Loop (PLL) frequency multiplier, available to both the High-Speed Crystal and External Oscillator modes, which allows a wide range of clock speeds from 4 MHz to 48 MHz.
- Asynchronous dual clock operation, allowing the USB module to run from a high-frequency oscillator while the rest of the microcontroller is clocked from an internal low-power oscillator.

The internal oscillator provides a stable reference source that gives the family additional features for robust operation:

- **Fail-Safe Clock Monitor:** This option constantly monitors the main clock source against a reference signal provided by the internal oscillator. If a clock failure occurs, the controller is switched to the internal oscillator, allowing for continued low-speed operation or a safe application shutdown.
- **Two-Speed Start-up:** This option allows the internal oscillator to serve as the clock source from Power-on Reset, or wake-up from Sleep mode, until the primary clock source is available.

1.2 Other Special Features

- **Memory Endurance:** The Enhanced Flash cells for program memory are rated to last for many thousands of erase/write cycles – up to 100,000.
- **Self-Programmability:** These devices can write to their own program memory spaces under internal software control. By using a bootloader routine, located in the protected Boot Block at the top of program memory, it becomes possible to create an application that can update itself in the field.
- **Extended Instruction Set:** The PIC18F2450/4450 family introduces an optional extension to the PIC18 instruction set, which adds 8 new instructions and an Indexed Literal Offset Addressing mode. This extension, enabled as a device configuration option, has been specifically designed to optimize re-entrant application code originally developed in high-level languages such as C.
- **Enhanced Addressable USART:** This serial communication module is capable of standard RS-232 operation and provides support for the LIN bus protocol. Other enhancements include Automatic Baud Rate Detection and a 16-bit Baud Rate Generator for improved resolution.
- **10-Bit A/D Converter:** This module incorporates programmable acquisition time, allowing for a channel to be selected and a conversion to be initiated, without waiting for a sampling period and thus, reducing code overhead.
- **Dedicated ICD/ICSP Port:** These devices introduce the use of debugger and programming pins that are not multiplexed with other micro-controller features. Offered as an option in select packages, this feature allows users to develop I/O intensive applications while retaining the ability to program and debug in the circuit.

1.3 Details on Individual Family Members

Devices in the PIC18F2450/4450 family are available in 28-pin and 40/44-pin packages. Block diagrams for the two groups are shown in Figure 1-1 and Figure 1-2.

The devices are differentiated from each other in the following two ways:

1. A/D channels (10 for 28-pin devices, 13 for 40/44-pin devices).
2. I/O ports (3 bidirectional ports and 1 input only port on 28-pin devices, 5 bidirectional ports on 40/44-pin devices).

All other features for devices in this family are identical. These are summarized in Table 1-1.

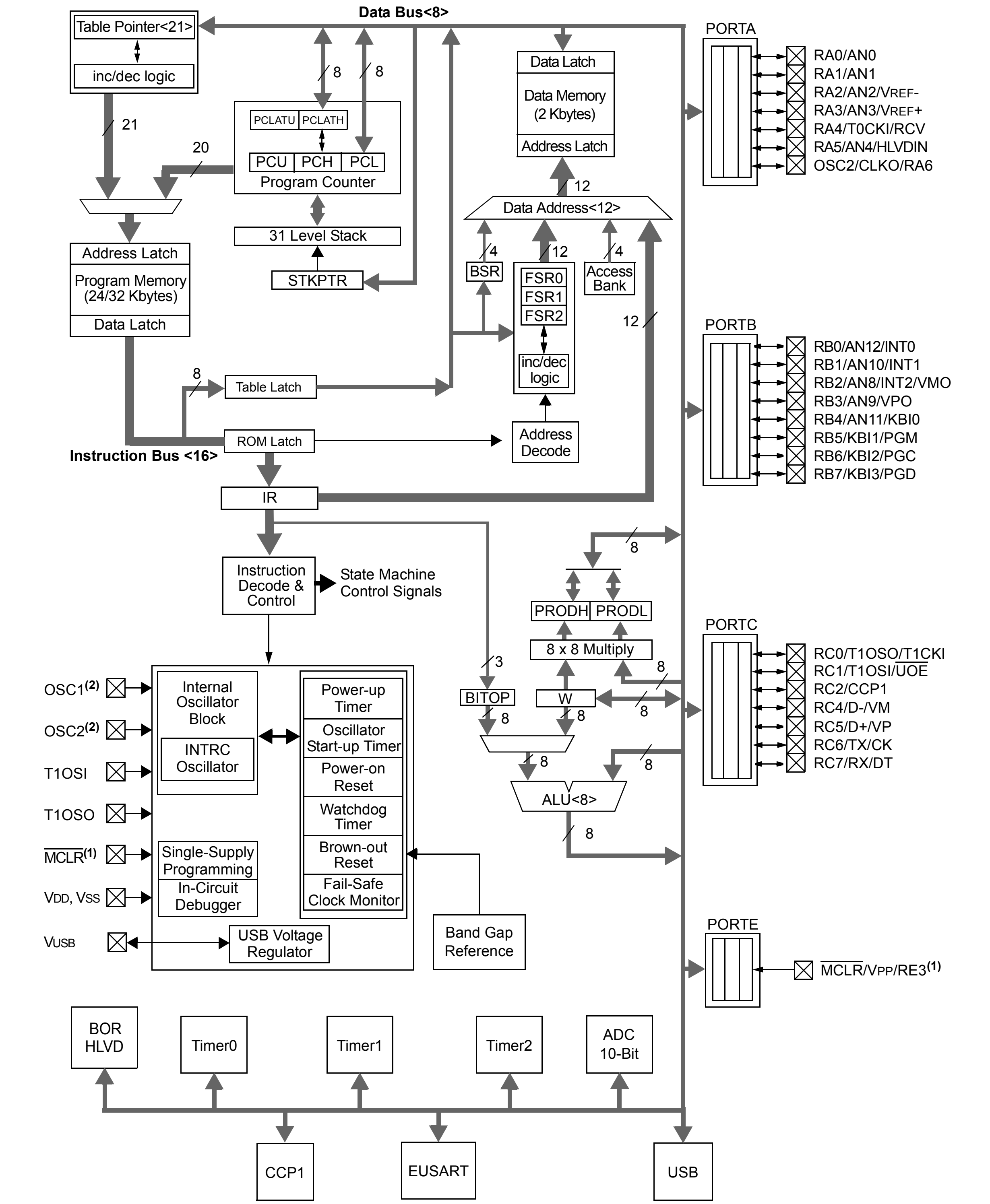
The pinouts for all devices are listed in Table 1-2 and Table 1-3.

Like all Microchip PIC18 devices, members of the PIC18F2450/4450 family are available as both standard and low-voltage devices. Standard devices with Enhanced Flash memory, designated with an “F” in the part number (such as PIC18**F**2450), accommodate an operating V_{DD} range of 4.2V to 5.5V. Low-voltage parts, designated by “LF” (such as PIC18**LF**2450), function over an extended V_{DD} range of 2.0V to 5.5V.

TABLE 1-1: DEVICE FEATURES

Features	PIC18F2450	PIC18F4450
Operating Frequency	DC – 48 MHz	DC – 48 MHz
Program Memory (Bytes)	16384	16384
Program Memory (Instructions)	8192	8192
Data Memory (Bytes)	768	768
Interrupt Sources	13	13
I/O Ports	Ports A, B, C, (E)	Ports A, B, C, D, E
Timers	3	3
Capture/Compare/PWM Modules	1	1
Enhanced USART	1	1
Universal Serial Bus (USB) Module	1	1
10-Bit Analog-to-Digital Module	10 Input Channels	13 Input Channels
Resets (and Delays)	POR, BOR, `RESET` Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT	POR, BOR, `RESET` Instruction, Stack Full, Stack Underflow (PWRT, OST), $\overline{\text{MCLR}}$ (optional), WDT
Programmable Low-Voltage Detect	Yes	Yes
Programmable Brown-out Reset	Yes	Yes
Instruction Set	75 Instructions; 83 with Extended Instruction Set enabled	75 Instructions; 83 with Extended Instruction Set enabled
Packages	28-Pin SPDIP 28-Pin SOIC 28-Pin QFN	40-Pin PDIP 44-Pin QFN 44-Pin TQFP

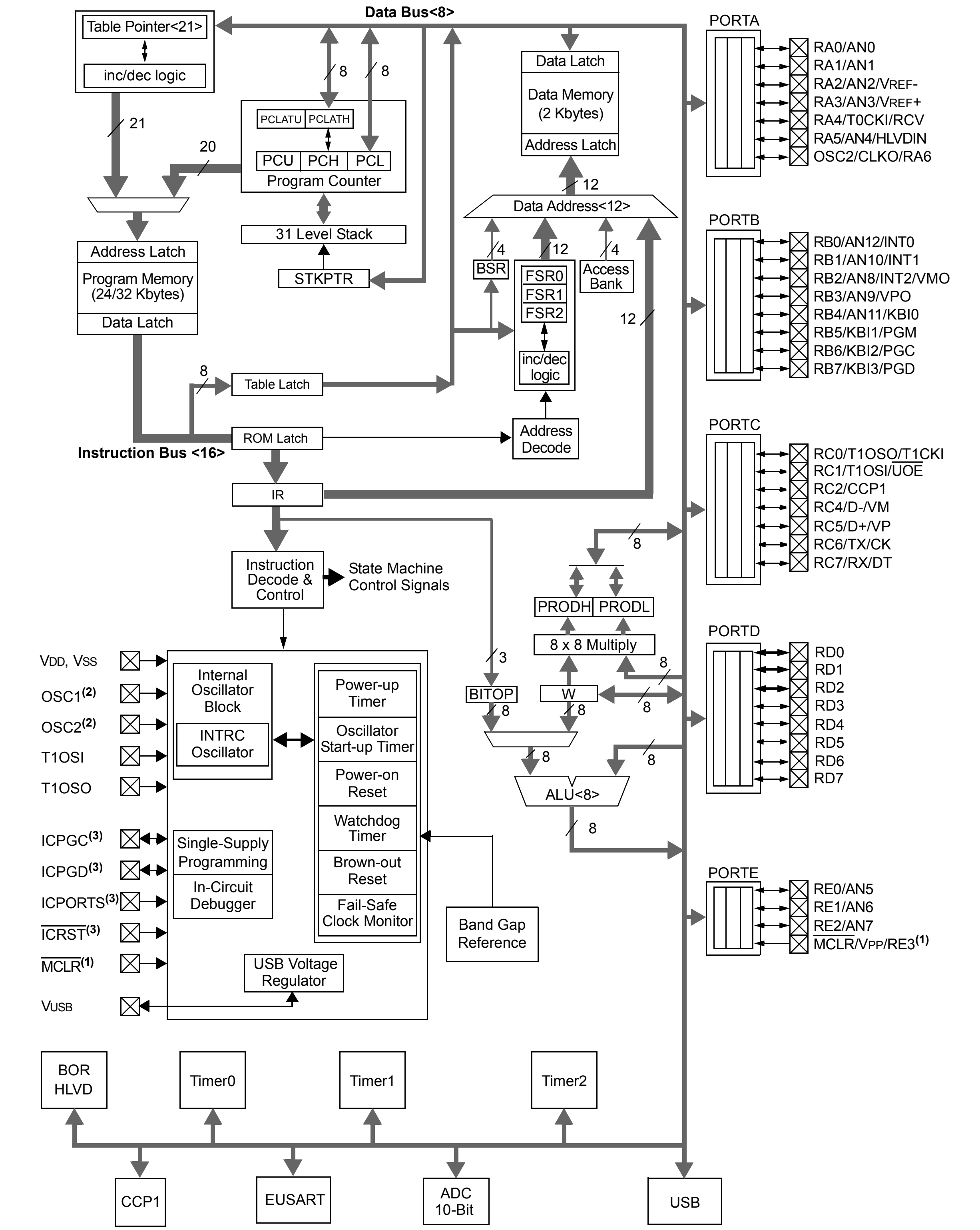
FIGURE 1-1: PIC18F2450 (28-PIN) BLOCK DIAGRAM



Note 1: RE3 is multiplexed with $\overline{MCLR}$ and is only available when the $\overline{MCLR}$ Resets are disabled.

2: OSC1/CLKI and OSC2/CLKO are only available in select oscillator modes and when these pins are not being used as digital I/O. Refer to **Section 2.0 "Oscillator Configurations"** for additional information.

FIGURE 1-2: PIC18F4450 (40/44-PIN) BLOCK DIAGRAM



Note 1: RE3 is multiplexed with MCLR and is only available when the MCLR Resets are disabled.

2: OSC1/CLKI and OSC2/CLKO are only available in select oscillator modes and when these pins are not being used as digital I/O. Refer to **Section 2.0 "Oscillator Configurations"** for additional information.

3: These pins are only available on 44-pin TQFP under certain conditions. Refer to **Section 18.9 "Special ICPORT Features (Designated Packages Only)"** for additional information.

TABLE 1-2: PIC18F2450 PINOUT I/O DESCRIPTIONS

Pin Name	Pin Number		Pin Type	Buffer Type	Description
	SPDIP, SOIC	QFN			
$\overline{MCLR}/V_{PP}$/RE3	1	26			Master Clear (input) or programming voltage (input).
$\overline{MCLR}$			I	ST	Master Clear (Reset) input. This pin is an active-low Reset to the device.
V_{PP}			P		Programming voltage input.
RE3			I	ST	Digital input.
OSC1/CLKI	9	6			Oscillator crystal or external clock input.
OSC1			I	Analog	Oscillator crystal input or external clock source input.
CLKI			I	Analog	External clock source input. Always associated with pin function OSC1. (See OSC2/CLKO pin.)
OSC2/CLKO/RA6	10	7			Oscillator crystal or clock output.
OSC2			O	—	Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO			O	—	In select modes, OSC2 pin outputs CLKO which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
RA6			I/O	TTL	General purpose I/O pin.

Legend: TTL = TTL compatible input; ST = Schmitt Trigger input with CMOS levels; O = Output; CMOS = CMOS compatible input or output; I = Input; P = Power

TABLE 1-2: PIC18F2450 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number		Pin Type	Buffer Type	Description
	SPDIP, SOIC	QFN			
					PORTA is a bidirectional I/O port.
RA0/AN0	2	27			
RA0			I/O	TTL	Digital I/O.
AN0			I	Analog	Analog input 0.
RA1/AN1	3	28			
RA1			I/O	TTL	Digital I/O.
AN1			I	Analog	Analog input 1.
RA2/AN2/VREF-	4	1			
RA2			I/O	TTL	Digital I/O.
AN2			I	Analog	Analog input 2.
VREF-			I	Analog	A/D reference voltage (low) input.
RA3/AN3/VREF+	5	2			
RA3			I/O	TTL	Digital I/O.
AN3			I	Analog	Analog input 3.
VREF+			I	Analog	A/D reference voltage (high) input.
RA4/T0CKI/RCV	6	3			
RA4			I/O	ST	Digital I/O.
T0CKI			I	ST	Timer0 external clock input.
RCV			I	TTL	External USB transceiver RCV input.
RA5/AN4/HLVDIN	7	4			
RA5			I/O	TTL	Digital I/O.
AN4			I	Analog	Analog input 4.
HLVDIN			I	Analog	High/Low-Voltage Detect input.
RA6	—	—	—	—	See the OSC2/CLKO/RA6 pin.

Legend: TTL = TTL compatible input; ST = Schmitt Trigger input with CMOS levels; O = Output; CMOS = CMOS compatible input or output; I = Input; P = Power

TABLE 1-2: PIC18F2450 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number SPDIP, SOIC	Pin Number QFN	Pin Type	Buffer Type	Description
					PORTB is a bidirectional I/O port. PORTB can be software programmed for internal weak pull-ups on all inputs.
RB0/AN12/INT0	21	18			
RB0			I/O	TTL	Digital I/O.
AN12			I	Analog	Analog input 12.
INT0			I	ST	External interrupt 0.
RB1/AN10/INT1	22	19			
RB1			I/O	TTL	Digital I/O.
AN10			I	Analog	Analog input 10.
INT1			I	ST	External interrupt 1.
RB2/AN8/INT2/VMO	23	20			
RB2			I/O	TTL	Digital I/O.
AN8			I	Analog	Analog input 8.
INT2			I	ST	External interrupt 2.
VMO			O	—	External USB transceiver VMO output.
RB3/AN9/VPO	24	21			
RB3			I/O	TTL	Digital I/O.
AN9			I	Analog	Analog input 9.
VPO			O	—	External USB transceiver VPO output.
RB4/AN11/KBI0	25	22			
RB4			I/O	TTL	Digital I/O.
AN11			I	Analog	Analog input 11.
KBI0			I	TTL	Interrupt-on-change pin.
RB5/KBI1/PGM	26	23			
RB5			I/O	TTL	Digital I/O.
KBI1			I	TTL	Interrupt-on-change pin.
PGM			I/O	ST	Low-Voltage ICSP™ Programming enable pin.
RB6/KBI2/PGC	27	24			
RB6			I/O	TTL	Digital I/O.
KBI2			I	TTL	Interrupt-on-change pin.
PGC			I/O	ST	In-Circuit Debugger and ICSP programming clock pin.
RB7/KBI3/PGD	28	25			
RB7			I/O	TTL	Digital I/O.
KBI3			I	TTL	Interrupt-on-change pin.
PGD			I/O	ST	In-Circuit Debugger and ICSP programming data pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

TABLE 1-2: PIC18F2450 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number		Pin Type	Buffer Type	Description
	SPDIP, SOIC	QFN			
					PORTC is a bidirectional I/O port.
RC0/T1OSO/T1CKI	11	8			
RC0			I/O	ST	Digital I/O.
T1OSO			O	—	Timer1 oscillator output.
T1CKI			I	ST	Timer1external clock input.
RC1/T1OSI/$\overline{UOE}$	12	9			
RC1			I/O	ST	Digital I/O.
T1OSI			I	CMOS	Timer1 oscillator input.
$\overline{UOE}$			O	—	External USB transceiver $\overline{OE}$ output.
RC2/CCP1	13	10			
RC2			I/O	ST	Digital I/O.
CCP1			I/O	ST	Capture 1 input/Compare 1 output/PWM1 output.
RC4/D-/VM	15	12			
RC4			I	TTL	Digital input.
D-			I/O	—	USB differential minus line (input/output).
VM			I	TTL	External USB transceiver VM input.
RC5/D+/VP	16	13			
RC5			I	TTL	Digital input.
D+			I/O	—	USB differential plus line (input/output).
VP			O	TTL	External USB transceiver VP input.
RC6/TX/CK	17	14			
RC6			I/O	ST	Digital I/O.
TX			O	—	EUSART asynchronous transmit.
CK			I/O	ST	EUSART synchronous clock (see RX/DT).
RC7/RX/DT	18	15			
RC7			I/O	ST	Digital I/O.
RX			I	ST	EUSART asynchronous receive.
DT			I/O	ST	EUSART synchronous data (see TX/CK).
RE3	—	—	—	—	See $\overline{MCLR}$/V_{PP}/RE3 pin.
V_{USB}	14	11	P	—	Internal USB 3.3V voltage regulator. Output, positive supply for internal USB transceiver.
V_{SS}	8, 19	5, 16	P	—	Ground reference for logic and I/O pins.
V_{DD}	20	17	P	—	Positive supply for logic and I/O pins.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

TABLE 1-3: PIC18F4450 PINOUT I/O DESCRIPTIONS

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
$\overline{MCLR}$/VPP/RE3	1	18	18			Master Clear (input) or programming voltage (input).
$\overline{MCLR}$				I	ST	Master Clear (Reset) input. This pin is an active-low Reset to the device.
VPP				P	—	Programming voltage input.
RE3				I	ST	Digital input.
OSC1/CLKI	13	32	30			Oscillator crystal or external clock input.
OSC1				I	Analog	Oscillator crystal input or external clock source input.
CLKI				I	Analog	External clock source input. Always associated with pin function OSC1. (See OSC2/CLKO pin.)
OSC2/CLKO/RA6	14	33	31			Oscillator crystal or clock output.
OSC2				O	—	Oscillator crystal output. Connects to crystal or resonator in Crystal Oscillator mode.
CLKO				O	—	In select modes, OSC2 pin outputs CLKO which has 1/4 the frequency of OSC1 and denotes the instruction cycle rate.
RA6				I/O	TTL	General purpose I/O pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{DEBUG}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4450 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTA is a bidirectional I/O port.
RA0/AN0	2	19	19			
RA0				I/O	TTL	Digital I/O.
AN0				I	Analog	Analog input 0.
RA1/AN1	3	20	20			
RA1				I/O	TTL	Digital I/O.
AN1				I	Analog	Analog input 1.
RA2/AN2/VREF-	4	21	21			
RA2				I/O	TTL	Digital I/O.
AN2				I	Analog	Analog input 2.
VREF-				I	Analog	A/D reference voltage (low) input.
RA3/AN3/VREF+	5	22	22			
RA3				I/O	TTL	Digital I/O.
AN3				I	Analog	Analog input 3.
VREF+				I	Analog	A/D reference voltage (high) input.
RA4/T0CKI/RCV	6	23	23			
RA4				I/O	ST	Digital I/O.
T0CKI				I	ST	Timer0 external clock input.
RCV				I	TTL	External USB transceiver RCV input.
RA5/AN4/HLVDIN	7	24	24			
RA5				I/O	TTL	Digital I/O.
AN4				I	Analog	Analog input 4.
HLVDIN				I	Analog	High/Low-Voltage Detect input.
RA6	—	—	—	—	—	See the OSC2/CLKO/RA6 pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output
ST = Schmitt Trigger input with CMOS levels; I = Input
O = Output; P = Power

Note 1: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{\text{DEBUG}}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4450 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTB is a bidirectional I/O port. PORTB can be software programmed for internal weak pull-ups on all inputs.
RB0/AN12/INT0	33	9	8			
RB0				I/O	TTL	Digital I/O.
AN12				I	Analog	Analog input 12.
INT0				I	ST	External interrupt 0.
RB1/AN10/INT1	34	10	9			
RB1				I/O	TTL	Digital I/O.
AN10				I	Analog	Analog input 10.
INT1				I	ST	External interrupt 1.
RB2/AN8/INT2/VMO	35	11	10			
RB2				I/O	TTL	Digital I/O.
AN8				I	Analog	Analog input 8.
INT2				I	ST	External interrupt 2.
VMO				O	—	External USB transceiver VMO output.
RB3/AN9/VPO	36	12	11			
RB3				I/O	TTL	Digital I/O.
AN9				I	Analog	Analog input 9.
VPO				O	—	External USB transceiver VPO output.
RB4/AN11/KBI0	37	14	14			
RB4				I/O	TTL	Digital I/O.
AN11				I	Analog	Analog input 11.
KBI0				I	TTL	Interrupt-on-change pin.
RB5/KBI1/PGM	38	15	15			
RB5				I/O	TTL	Digital I/O.
KBI1				I	TTL	Interrupt-on-change pin.
PGM				I/O	ST	Low-Voltage ICSP™ Programming enable pin.
RB6/KBI2/PGC	39	16	16			
RB6				I/O	TTL	Digital I/O.
KBI2				I	TTL	Interrupt-on-change pin.
PGC				I/O	ST	In-Circuit Debugger and ICSP programming clock pin.
RB7/KBI3/PGD	40	17	17			
RB7				I/O	TTL	Digital I/O.
KBI3				I	TTL	Interrupt-on-change pin.
PGD				I/O	ST	In-Circuit Debugger and ICSP programming data pin.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{\text{DEBUG}}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4450 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTC is a bidirectional I/O port.
RC0/T1OSO/T1CKI	15	34	32			
RC0				I/O	ST	Digital I/O.
T1OSO				O	—	Timer1 oscillator output.
T1CKI				I	ST	Timer1 external clock input.
RC1/T1OSI/$\overline{UOE}$	16	35	35			
RC1				I/O	ST	Digital I/O.
T1OSI				I	CMOS	Timer1 oscillator input.
$\overline{UOE}$				O	—	External USB transceiver $\overline{OE}$ output.
RC2/CCP1	17	36	36			
RC2				I/O	ST	Digital I/O.
CCP1				I/O	ST	Capture 1 input/Compare 1 output/PWM1 output.
RC4/D-/VM	23	42	42			
RC4				I	TTL	Digital input.
D-				I/O	—	USB differential minus line (input/output).
VM				I	TTL	External USB transceiver VM input.
RC5/D+/VP	24	43	43			
RC5				I	TTL	Digital input.
D+				I/O	—	USB differential plus line (input/output).
VP				I	TTL	External USB transceiver VP input.
RC6/TX/CK	25	44	44			
RC6				I/O	ST	Digital I/O.
TX				O	—	EUSART asynchronous transmit.
CK				I/O	ST	EUSART synchronous clock (see RX/DT).
RC7/RX/DT	26	1	1			
RC7				I/O	ST	Digital I/O.
RX				I	ST	EUSART asynchronous receive.
DT				I/O	ST	EUSART synchronous data (see TX/CK).

Legend: TTL = TTL compatible input; ST = Schmitt Trigger input with CMOS levels; O = Output; CMOS = CMOS compatible input or output; I = Input; P = Power

Note 1: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{DEBUG}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4450 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTD is a bidirectional I/O port.
RD0	19	38	38	I/O	ST	Digital I/O.
RD1	20	39	39	I/O	ST	Digital I/O.
RD2	21	40	40	I/O	ST	Digital I/O.
RD3	22	41	41	I/O	ST	Digital I/O.
RD4	27	2	2	I/O	ST	Digital I/O.
RD5	28	3	3	I/O	ST	Digital I/O.
RD6	29	4	4	I/O	ST	Digital I/O.
RD7	30	5	5	I/O	ST	Digital I/O.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{\text{DEBUG}}$ Configuration bit is cleared.

TABLE 1-3: PIC18F4450 PINOUT I/O DESCRIPTIONS (CONTINUED)

Pin Name	Pin Number			Pin Type	Buffer Type	Description
	PDIP	QFN	TQFP			
						PORTE is a bidirectional I/O port.
RE0/AN5	8	25	25			
RE0				I/O	ST	Digital I/O.
AN5				I	Analog	Analog input 5.
RE1/AN6	9	26	26			
RE1				I/O	ST	Digital I/O.
AN6				I	Analog	Analog input 6.
RE2/AN7	10	27	27			
RE2				I/O	ST	Digital I/O.
AN7				I	Analog	Analog input 7.
RE3	—	—	—	—	—	See $\overline{MCLR}$/VPP/RE3 pin.
VSS	12, 31	6, 30, 31	6, 29	P	—	Ground reference for logic and I/O pins.
VDD	11, 32	7, 8, 28, 29	7, 28	P	—	Positive supply for logic and I/O pins.
VUSB	18	37	37	P	—	Internal USB 3.3V voltage regulator output. Positive supply for internal USB transceiver.
NC/ICCK/ICPGC(1)	—	—	12			No Connect or dedicated ICD/ICSP™ port clock.
ICCK				I/O	ST	In-Circuit Debugger clock.
ICPGC				I/O	ST	ICSP programming clock.
NC/ICDT/ICPGD(1)	—	—	13			No Connect or dedicated ICD/ICSP port clock.
ICDT				I/O	ST	In-Circuit Debugger data.
ICPGD				I/O	ST	ICSP programming data.
NC/$\overline{ICRST}$/ICVPP(1)	—	—	33			No Connect or dedicated ICD/ICSP port Reset.
$\overline{ICRST}$				I	—	Master Clear (Reset) input.
ICVPP				P	—	Programming voltage input.
NC/ICPORTS(1)	—	—	34	P	—	No Connect or 28-pin device emulation.
ICPORTS						Enable 28-pin device emulation when connected to VSS.
NC	—	13	—	—	—	No Connect.

Legend: TTL = TTL compatible input; CMOS = CMOS compatible input or output; ST = Schmitt Trigger input with CMOS levels; I = Input; O = Output; P = Power

Note 1: These pins are No Connect unless the ICPRT Configuration bit is set. For NC/ICPORTS, the pin is No Connect unless ICPRT is set and the $\overline{DEBUG}$ Configuration bit is cleared.

NOTES:

2.0 OSCILLATOR CONFIGURATIONS

2.1 Overview

Devices in the PIC18F2450/4450 family incorporate a different oscillator and microcontroller clock system than the non-USB PIC18F devices. The addition of the USB module, with its unique requirements for a stable clock source, make it necessary to provide a separate clock source that is compliant with both USB low-speed and full-speed specifications.

To accommodate these requirements, PIC18F2450/4450 devices include a new clock branch to provide a 48 MHz clock for full-speed USB operation. Since it is driven from the primary clock source, an additional system of prescalers and postscalers has been added to accommodate a wide range of oscillator frequencies. An overview of the oscillator structure is shown in Figure 2-1.

Other oscillator features used in PIC18 enhanced microcontrollers, such as the internal RC oscillator and clock switching, remain the same. They are discussed later in this chapter.

2.1.1 OSCILLATOR CONTROL

The operation of the oscillator in PIC18F2450/4450 devices is controlled through two Configuration registers and two control registers. Configuration registers, CONFIG1L and CONFIG1H, select the oscillator mode and USB prescaler/postscaler options. As Configuration bits, these are set when the device is programmed and left in that configuration until the device is reprogrammed.

The OSCCON register (Register 2-1) selects the Active Clock mode; it is primarily used in controlling clock switching in power-managed modes. Its use is discussed in **Section 2.4.1 "Oscillator Control Register"**.

2.2 Oscillator Types

PIC18F2450/4450 devices can be operated in twelve distinct oscillator modes. In contrast with the non-USB PIC18 enhanced microcontrollers, four of these modes involve the use of two oscillator types at once. Users can program the FOSC3:FOSC0 Configuration bits to select one of these modes:

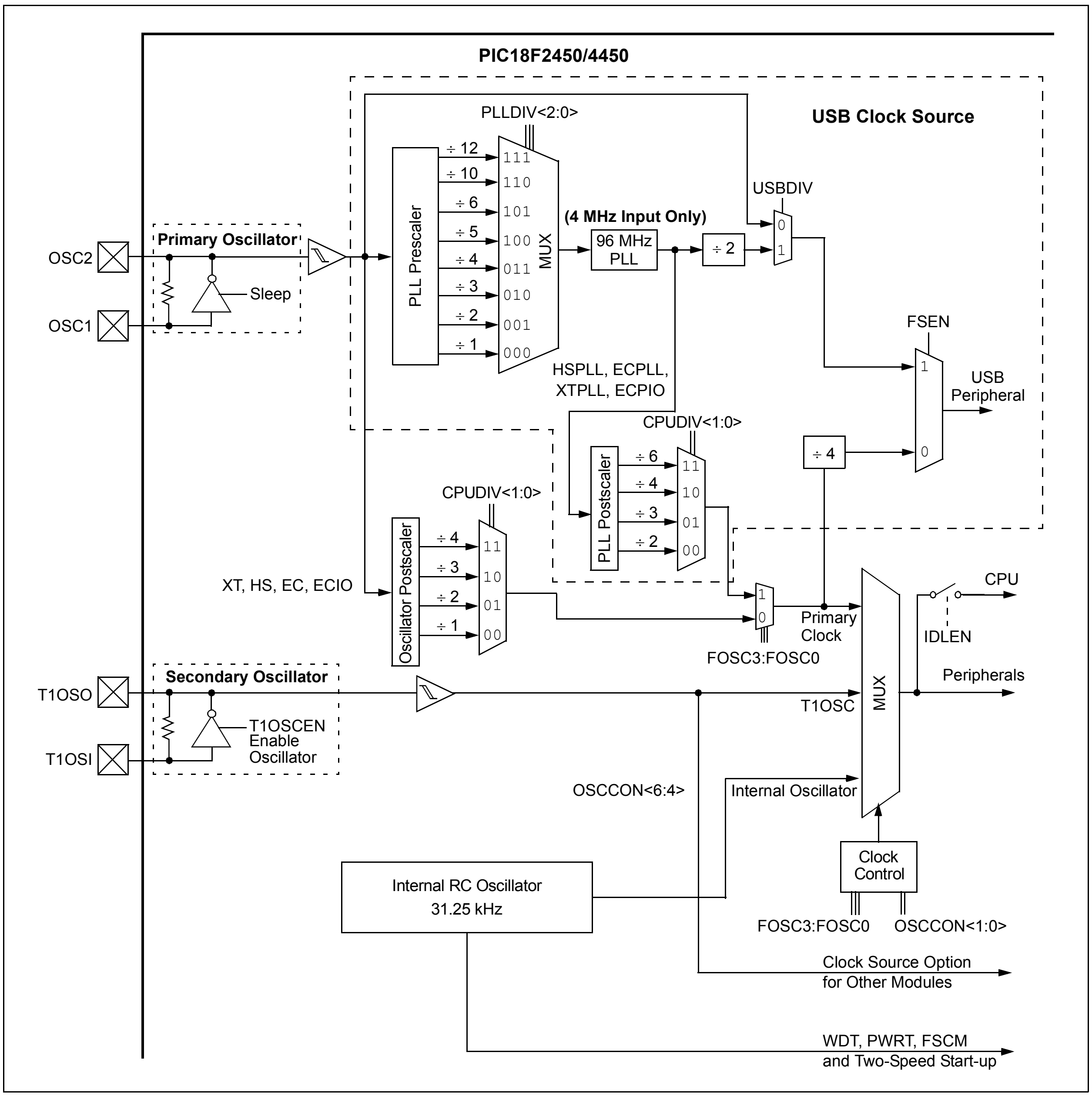
1. XT — Crystal/Resonator
2. XTPLL — Crystal/Resonator with PLL Enabled
3. HS — High-Speed Crystal/Resonator
4. HSPLL — High-Speed Crystal/Resonator with PLL Enabled
5. EC — External Clock with FOSC/4 Output
6. ECIO — External Clock with I/O on RA6
7. ECPLL — External Clock with PLL Enabled and FOSC/4 Output on RA6
8. ECPIO — External Clock with PLL Enabled, I/O on RA6
9. INTHS — Internal Oscillator used as Microcontroller Clock Source, HS Oscillator used as USB Clock Source
10. INTXT — Internal Oscillator used as Microcontroller Clock Source, XT Oscillator used as USB Clock Source
11. INTIO — Internal Oscillator used as Microcontroller Clock Source, EC Oscillator used as USB Clock Source, Digital I/O on RA6
12. INTCKO — Internal Oscillator used as Microcontroller Clock Source, EC Oscillator used as USB Clock Source, FOSC/4 Output on RA6

2.2.1 OSCILLATOR MODES AND USB OPERATION

Because of the unique requirements of the USB module, a different approach to clock operation is necessary. In previous PIC® microcontrollers, all core and peripheral clocks were driven by a single oscillator source; the usual sources were primary, secondary or the internal oscillator. With PIC18F2450/4450 devices, the primary oscillator becomes part of the USB module and cannot be associated to any other clock source. Thus, the USB module must be clocked from the primary clock source; however, the microcontroller core and other peripherals can be separately clocked from the secondary or internal oscillators as before.

Because of the timing requirements imposed by USB, an internal clock of either 6 MHz or 48 MHz is required while the USB module is enabled. Fortunately, the microcontroller and other peripherals are not required to run at this clock speed when using the primary oscillator. There are numerous options to achieve the USB module clock requirement and still provide flexibility for clocking the rest of the device from the primary oscillator source. These are detailed in **Section 2.3 "Oscillator Settings for USB"**.

FIGURE 2-1: PIC18F2450/4450 CLOCK DIAGRAM



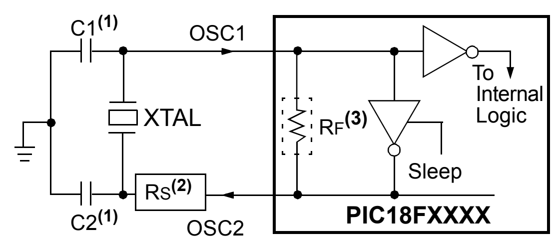
2.2.2 CRYSTAL OSCILLATOR/CERAMIC RESONATORS

In HS, HSPLL, XT and XTPLL Oscillator modes, a crystal or ceramic resonator is connected to the OSC1 and OSC2 pins to establish oscillation. Figure 2-2 shows the pin connections.

The oscillator design requires the use of a parallel cut crystal.

Note:	Use of a series cut crystal may give a frequency out of the crystal manufacturer's specifications.

FIGURE 2-2: CRYSTAL/CERAMIC RESONATOR OPERATION (XT, HS OR HSPLL CONFIGURATION)



Note 1: See Table 2-1 and Table 2-2 for initial values of C1 and C2.

2: A series resistor (RS) may be required for AT strip cut crystals.

3: RF varies with the oscillator mode chosen.

TABLE 2-1: CAPACITOR SELECTION FOR CERAMIC RESONATORS

Typical Capacitor Values Used:			
Mode	**Freq**	**OSC1**	**OSC2**
XT	4.0 MHz	33 pF	33 pF
HS	8.0 MHz 16.0 MHz	27 pF 22 pF	27 pF 22 pF

Capacitor values are for design guidance only.

These capacitors were tested with the resonators listed below for basic start-up and operation. **These values are not optimized**.

Different capacitor values may be required to produce acceptable oscillator operation. The user should test the performance of the oscillator over the expected VDD and temperature range for the application.

See the notes following Table 2-2 for additional information.

Resonators Used:
4.0 MHz
8.0 MHz
16.0 MHz

TABLE 2-2: CAPACITOR SELECTION FOR CRYSTAL OSCILLATOR

Osc Type	Crystal Freq	Typical Capacitor Values Tested:	
		C1	**C2**
XT	4 MHz	27 pF	27 pF
HS	4 MHz	27 pF	27 pF
	8 MHz	22 pF	22 pF
	20 MHz	15 pF	15 pF

Capacitor values are for design guidance only.

These capacitors were tested with the crystals listed below for basic start-up and operation. **These values are not optimized.**

Different capacitor values may be required to produce acceptable oscillator operation. The user should test the performance of the oscillator over the expected VDD and temperature range for the application.

See the notes following this table for additional information.

Crystals Used:
4 MHz
8 MHz
20 MHz

Note 1: Higher capacitance increases the stability of oscillator but also increases the start-up time.

2: When operating below 3V VDD, or when using certain ceramic resonators at any voltage, it may be necessary to use the HS mode or switch to a crystal oscillator.

3: Since each resonator/crystal has its own characteristics, the user should consult the resonator/crystal manufacturer for appropriate values of external components.

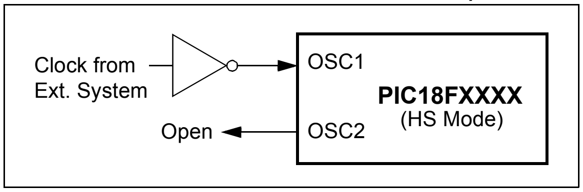
4: Rs may be required to avoid overdriving crystals with low drive level specification.

5: Always verify oscillator performance over the VDD and temperature range that is expected for the application.

An internal postscaler allows users to select a clock frequency other than that of the crystal or resonator. Frequency division is determined by the CPUDIV Configuration bits. Users may select a clock frequency of the oscillator frequency, or 1/2, 1/3 or 1/4 of the frequency.

An external clock may also be used when the microcontroller is in HS Oscillator mode. In this case, the OSC2/CLKO pin is left open (Figure 2-3).

FIGURE 2-3: EXTERNAL CLOCK INPUT OPERATION (HS OSC CONFIGURATION)

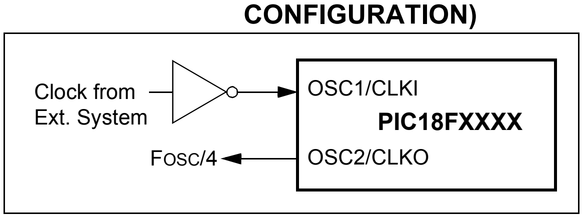


2.2.3 EXTERNAL CLOCK INPUT

The EC, ECIO, ECPLL and ECPIO Oscillator modes require an external clock source to be connected to the OSC1 pin. There is no oscillator start-up time required after a Power-on Reset or after an exit from Sleep mode.

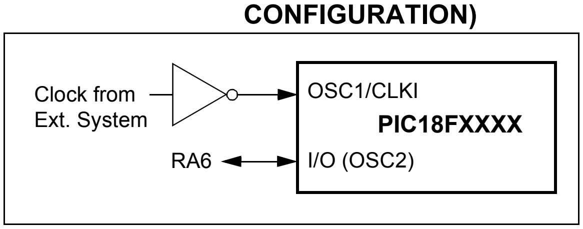
In the EC and ECPLL Oscillator modes, the oscillator frequency divided by 4 is available on the OSC2 pin. This signal may be used for test purposes or to synchronize other logic. Figure 2-4 shows the pin connections for the EC Oscillator mode.

FIGURE 2-4: EXTERNAL CLOCK INPUT OPERATION (EC AND ECPLL CONFIGURATION)



The ECIO and ECPIO Oscillator modes function like the EC and ECPLL modes, except that the OSC2 pin becomes an additional general purpose I/O pin. The I/O pin becomes bit 6 of PORTA (RA6). Figure 2-5 shows the pin connections for the ECIO Oscillator mode.

FIGURE 2-5: EXTERNAL CLOCK INPUT OPERATION (ECIO AND ECPIO CONFIGURATION)



The internal postscaler for reducing clock frequency in XT and HS modes is also available in EC and ECIO modes.

2.2.4 PLL FREQUENCY MULTIPLIER

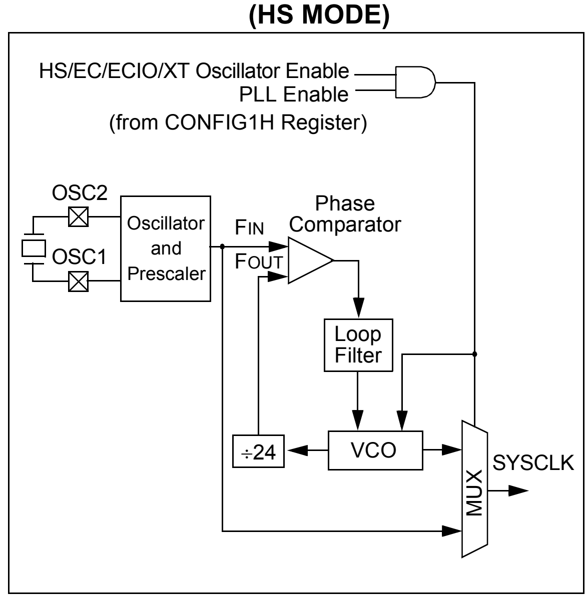
PIC18F2450/4450 devices include a Phase Locked Loop (PLL) circuit. This is provided specifically for USB applications with lower speed oscillators and can also be used as a microcontroller clock source.

The PLL is enabled in HSPLL, XTPLL, ECPLL and ECPIO Oscillator modes. It is designed to produce a fixed 96 MHz reference clock from a fixed 4 MHz input. The output can then be divided and used for both the USB and the microcontroller core clock. Because the PLL has a fixed frequency input and output, there are eight prescaling options to match the oscillator input frequency to the PLL.

There is also a separate postscaler option for deriving the microcontroller clock from the PLL. This allows the USB peripheral and microcontroller to use the same oscillator input and still operate at different clock speeds. In contrast to the postscaler for XT, HS and EC modes, the available options are 1/2, 1/3, 1/4 and 1/6 of the PLL output.

The HSPLL, ECPLL and ECPIO modes make use of the HS mode oscillator for frequencies up to 48 MHz. The prescaler divides the oscillator input by up to 12 to produce the 4 MHz drive for the PLL. The XTPLL mode can only use an input frequency of 4 MHz which drives the PLL directly.

FIGURE 2-6: PLL BLOCK DIAGRAM (HS MODE)



2.2.5 INTERNAL OSCILLATOR

The PIC18F2450/4450 devices include an internal RC oscillator (INTRC) which provides a nominal 31 kHz output. INTRC is enabled if it is selected as the device clock source; it is also enabled automatically when any of the following are enabled:

- Power-up Timer
- Fail-Safe Clock Monitor
- Watchdog Timer
- Two-Speed Start-up

These features are discussed in greater detail in **Section 18.0 “Special Features of the CPU”**.

2.2.5.1 Internal Oscillator Modes

When the internal oscillator is used as the microcontroller clock source, one of the other oscillator modes (External Clock or External Crystal/Resonator) must be used as the USB clock source. The choice of USB clock source is determined by the particular internal oscillator mode.

There are four distinct modes available:

1. INTHS mode: The USB clock is provided by the oscillator in HS mode.
2. INTXT mode: The USB clock is provided by the oscillator in XT mode.
3. INTCKO mode: The USB clock is provided by an external clock input on OSC1/CLKI; the OSC2/CLKO pin outputs FOSC/4.
4. INTIO mode: The USB clock is provided by an external clock input on OSC1/CLKI; the OSC2/CLKO pin functions as a digital I/O (RA6).

Of these four modes, only INTIO mode frees up an additional pin (OSC2/CLKO/RA6) for port I/O use.

2.3 Oscillator Settings for USB

When the PIC18F2450/4450 is used for USB connectivity, it must have either a 6 MHz or 48 MHz clock for USB operation, depending on whether Low-Speed or Full-Speed mode is being used. This may require some forethought in selecting an oscillator frequency and programming the device.

The full range of possible oscillator configurations compatible with USB operation is shown in Table 2-3.

2.3.1 LOW-SPEED OPERATION

The USB clock for Low-Speed mode is derived from the primary oscillator chain and not directly from the PLL. It is divided by 4 to produce the actual 6 MHz clock. Because of this, the microcontroller can only use a clock frequency of 24 MHz when the USB module is active and the controller clock source is one of the primary oscillator modes (XT, HS or EC, with or without the PLL).

This restriction does not apply if the microcontroller clock source is the secondary oscillator or internal oscillator.

2.3.2 RUNNING DIFFERENT USB AND MICROCONTROLLER CLOCKS

The USB module, in either mode, can run asynchronously with respect to the microcontroller core and other peripherals. This means that applications can use the primary oscillator for the USB clock while the microcontroller runs from a separate clock source at a lower speed. If it is necessary to run the entire application from only one clock source, full-speed operation provides a greater selection of microcontroller clock frequencies.

TABLE 2-3: OSCILLATOR CONFIGURATION OPTIONS FOR USB OPERATION

Input Oscillator Frequency	PLL Division (PLLDIV2:PLLDIV0)	Clock Mode (FOSC3:FOSC0)	MCU Clock Division (CPUDIV1:CPUDIV0)	Microcontroller Clock Frequency
48 MHz	N/A(1)	EC, ECIO	None (00)	48 MHz
			÷2 (01)	**24 MHz**
			÷3 (10)	16 MHz
			÷4 (11)	12 MHz
48 MHz	÷12 (111)	EC, ECIO	None (00)	48 MHz
			÷2 (01)	**24 MHz**
			÷3 (10)	16 MHz
			÷4 (11)	12 MHz
		ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
40 MHz	÷10 (110)	EC, ECIO	None (00)	40 MHz
			÷2 (01)	20 MHz
			÷3 (10)	13.33 MHz
			÷4 (11)	10 MHz
		ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
24 MHz	÷6 (101)	HS, EC, ECIO	None (00)	**24 MHz**
			÷2 (01)	12 MHz
			÷3 (10)	8 MHz
			÷4 (11)	6 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
20 MHz	÷5 (100)	HS, EC, ECIO	None (00)	20 MHz
			÷2 (01)	10 MHz
			÷3 (10)	6.67 MHz
			÷4 (11)	5 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
16 MHz	÷4 (011)	HS, EC, ECIO	None (00)	16 MHz
			÷2 (01)	8 MHz
			÷3 (10)	5.33 MHz
			÷4 (11)	4 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz

Legend: All clock frequencies, except 24 MHz, are exclusively associated with full-speed USB operation (USB clock of 48 MHz). **Bold** is used to highlight clock selections that are compatible with low-speed USB operation (system clock of 24 MHz, USB clock of 6 MHz).

Note 1: Only valid when the USBDIV Configuration bit is cleared.

TABLE 2-3: OSCILLATOR CONFIGURATION OPTIONS FOR USB OPERATION (CONTINUED)

Input Oscillator Frequency	PLL Division (PLLDIV2:PLLDIV0)	Clock Mode (FOSC3:FOSC0)	MCU Clock Division (CPUDIV1:CPUDIV0)	Microcontroller Clock Frequency
12 MHz	÷3 (010)	HS, EC, ECIO	None (00)	12 MHz
			÷2 (01)	6 MHz
			÷3 (10)	4 MHz
			÷4 (11)	3 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
8 MHz	÷2 (001)	HS, EC, ECIO	None (00)	8 MHz
			÷2 (01)	4 MHz
			÷3 (10)	2.67 MHz
			÷4 (11)	2 MHz
		HSPLL, ECPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz
4 MHz	÷1 (000)	XT, HS, EC, ECIO	None (00)	4 MHz
			÷2 (01)	2 MHz
			÷3 (10)	1.33 MHz
			÷4 (11)	1 MHz
		HSPLL, ECPLL, XTPLL, ECPIO	÷2 (00)	48 MHz
			÷3 (01)	32 MHz
			÷4 (10)	**24 MHz**
			÷6 (11)	16 MHz

Legend: All clock frequencies, except 24 MHz, are exclusively associated with full-speed USB operation (USB clock of 48 MHz). **Bold** is used to highlight clock selections that are compatible with low-speed USB operation (system clock of 24 MHz, USB clock of 6 MHz).

Note 1: Only valid when the USBDIV Configuration bit is cleared.

2.4 Clock Sources and Oscillator Switching

Like previous PIC18 enhanced devices, the PIC18F2450/4450 family includes a feature that allows the device clock source to be switched from the main oscillator to an alternate, low-frequency clock source. PIC18F2450/4450 devices offer two alternate clock sources. When an alternate clock source is enabled, the various power-managed operating modes are available.

Essentially, there are three clock sources for these devices:

- Primary oscillators
- Secondary oscillators
- Internal oscillator

The **primary oscillators** include the External Crystal and Resonator modes, the External Clock modes and the internal oscillator. The particular mode is defined by the FOSC3:FOSC0 Configuration bits. The details of these modes are covered earlier in this chapter.

The **secondary oscillators** are those external sources not connected to the OSC1 or OSC2 pins. These sources may continue to operate even after the controller is placed in a power-managed mode.

PIC18F2450/4450 devices offer the Timer1 oscillator as a secondary oscillator. This oscillator, in all power-managed modes, is often the time base for functions such as a Real-Time Clock (RTC). Most often, a 32.768 kHz watch crystal is connected between the RC0/T1OSO/T1CKI and RC1/T1OSI/$\overline{\text{UOE}}$ pins. Like the XT and HS Oscillator mode circuits, loading capacitors are also connected from each pin to ground. The Timer1 oscillator is discussed in greater detail in **Section 11.3 "Timer1 Oscillator"**.

In addition to being a primary clock source, the **internal oscillator** is available as a power-managed mode clock source. The INTRC source is also used as the clock source for several special features, such as the WDT and Fail-Safe Clock Monitor.

2.4.1 OSCILLATOR CONTROL REGISTER

The OSCCON register (Register 2-1) controls several aspects of the device clock's operation, both in full-power operation and in power-managed modes.

The System Clock Select bits, SCS1:SCS0, select the clock source. The available clock sources are the primary clock (defined by the FOSC3:FOSC0 Configuration bits), the secondary clock (Timer1 oscillator) and the internal oscillator. The clock source changes immediately, after one or more of the bits is written to, following a brief clock transition interval. The SCS bits are cleared on all forms of Reset.

INTRC always remains the clock source for features such as the Watchdog Timer and the Fail-Safe Clock Monitor.

The OSTS and T1RUN bits indicate which clock source is currently providing the device clock. The OSTS bit indicates that the Oscillator Start-up Timer (OST) has timed out and the primary clock is providing the device clock in primary clock modes. The T1RUN bit (T1CON<6>) indicates when the Timer1 oscillator is providing the device clock in secondary clock modes. In power-managed modes, only one of these three bits will be set at any time. If none of these bits are set, the INTRC is providing the clock or the internal oscillator has just started and is not yet stable.

The IDLEN bit determines if the device goes into Sleep mode, or one of the Idle modes, when the `SLEEP` instruction is executed.

The use of the flag and control bits in the OSCCON register is discussed in more detail in **Section 3.0 "Power-Managed Modes"**.

Note 1:	The Timer1 oscillator must be enabled to select the secondary clock source. The Timer1 oscillator is enabled by setting the T1OSCEN bit in the Timer1 Control register (T1CON<3>). If the Timer1 oscillator is not enabled, then any attempt to select a secondary clock source will be ignored.
2:	It is recommended that the Timer1 oscillator be operating and stable prior to switching to it as the clock source; otherwise, a very long delay may occur while the Timer1 oscillator starts.

2.4.2 OSCILLATOR TRANSITIONS

PIC18F2450/4450 devices contain circuitry to prevent clock "glitches" when switching between clock sources. A short pause in the device clock occurs during the clock switch. The length of this pause is the sum of two cycles of the old clock source and three to four cycles of the new clock source. This formula assumes that the new clock source is stable.

Clock transitions are discussed in greater detail in **Section 3.1.2 "Entering Power-Managed Modes"**.

REGISTER 2-1: OSCCON: OSCILLATOR CONTROL REGISTER

R/W-0	U-0	U-0	U-0	R(1)	U-0	R/W-0	R/W-0
IDLEN	—	—	—	OSTS	—	SCS1	SCS0
bit 7							bit 0

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

bit 7 **IDLEN:** Idle Enable bit
1 = Device enters Idle mode on `SLEEP` instruction
0 = Device enters Sleep mode on `SLEEP` instruction

bit 6-4 **Unimplemented:** Read as ‘0’

bit 3 **OSTS:** Oscillator Start-up Time-out Status bit(1)
1 = Oscillator Start-up Timer time-out has expired; primary oscillator is running
0 = Oscillator Start-up Timer time-out is running; primary oscillator is not ready

bit 2 **Unimplemented:** Read as ‘0’

bit 1-0 **SCS1:SCS0:** System Clock Select bits
1x = Internal oscillator
01 = Timer1 oscillator
00 = Primary oscillator

Note 1: Depends on the state of the IESO Configuration bit.

2.5 Effects of Power-Managed Modes on the Various Clock Sources

When PRI_IDLE mode is selected, the designated primary oscillator continues to run without interruption. For all other power-managed modes, the oscillator using the OSC1 pin is disabled. Unless the USB module is enabled, the OSC1 pin (and OSC2 pin if used by the oscillator) will stop oscillating.

In secondary clock modes (SEC_RUN and SEC_IDLE), the Timer1 oscillator is operating and providing the device clock. The Timer1 oscillator may also run in all power-managed modes if required to clock Timer1.

In internal oscillator modes (RC_RUN and RC_IDLE), the internal oscillator provides the device clock source. The 31 kHz INTRC output can be used directly to provide the clock and may be enabled to support various special features regardless of the power-managed mode (see **Section 18.2 "Watchdog Timer (WDT)"**, **Section 18.3 "Two-Speed Start-up"** and **Section 18.4 "Fail-Safe Clock Monitor"** for more information on WDT, Fail-Safe Clock Monitor and Two-Speed Start-up).

Regardless of the Run or Idle mode selected, the USB clock source will continue to operate. If the device is operating from a crystal or resonator-based oscillator, that oscillator will continue to clock the USB module. The core and all other modules will switch to the new clock source.

If the Sleep mode is selected, all clock sources are stopped. Since all the transistor switching currents have been stopped, Sleep mode achieves the lowest current consumption of the device (only leakage currents).

Sleep mode should never be invoked while the USB module is operating and connected. The only exception is when the device has been issued a "Suspend" command over the USB. Once the module has suspended operation and shifted to a low-power state, the microcontroller may be safely put into Sleep mode.

Enabling any on-chip feature that will operate during Sleep will increase the current consumed during Sleep. The INTRC is required to support WDT operation. The Timer1 oscillator may be operating to support a Real-Time Clock. Other features may be operating that do not require a device clock source (i.e., PSP, INTx pins and others). Peripherals that may add significant current consumption are listed in **Section 21.2 "DC Characteristics: Power-Down and Supply Current"**.

2.6 Power-up Delays

Power-up delays are controlled by two timers, so that no external Reset circuitry is required for most applications. The delays ensure that the device is kept in Reset until the device power supply is stable under normal circumstances and the primary clock is operating and stable. For additional information on power-up delays, see **Section 4.5 "Device Reset Timers"**.

The first timer is the Power-up Timer (PWRT), which provides a fixed delay on power-up (parameter 33, Table 21-10). It is enabled by clearing (= 0) the $\overline{\text{PWRTEN}}$ Configuration bit.

The second timer is the Oscillator Start-up Timer (OST), intended to keep the chip in Reset until the crystal oscillator is stable (XT and HS modes). The OST does this by counting 1024 oscillator cycles before allowing the oscillator to clock the device.

When the HSPLL Oscillator mode is selected, the device is kept in Reset for an additional 2 ms following the HS mode OST delay, so the PLL can lock to the incoming clock frequency.

There is a delay of interval, T_{CSD} (parameter 38, Table 21-10), following POR, while the controller becomes ready to execute instructions. This delay runs concurrently with any other delays. This may be the only delay that occurs when any of the EC or internal oscillator modes are used as the primary clock source.

TABLE 2-4: OSC1 AND OSC2 PIN STATES IN SLEEP MODE

Oscillator Mode	OSC1 Pin	OSC2 Pin
INTCKO	Floating, pulled by external clock	At logic low (clock/4 output)
INTIO	Floating, pulled by external clock	Configured as PORTA, bit 6
ECIO, ECPIO	Floating, pulled by external clock	Configured as PORTA, bit 6
EC	Floating, pulled by external clock	At logic low (clock/4 output)
XT and HS	Feedback inverter disabled at quiescent voltage level	Feedback inverter disabled at quiescent voltage level

Note: See Table 4-2 in **Section 4.0 "Reset"** for time-outs due to Sleep and $\overline{\text{MCLR}}$ Reset.

3.0 POWER-MANAGED MODES

PIC18F2450/4450 devices offer a total of seven operating modes for more efficient power management. These modes provide a variety of options for selective power conservation in applications where resources may be limited (i.e., battery-powered devices).

There are three categories of power-managed modes:

- Run modes
- Idle modes
- Sleep mode

These categories define which portions of the device are clocked and sometimes, what speed. The Run and Idle modes may use any of the three available clock sources (primary, secondary or internal oscillator); the Sleep mode does not use a clock source.

The power-managed modes include several power-saving features offered on previous PIC® microcontrollers. One is the clock switching feature, offered in other PIC18 devices, allowing the controller to use the Timer1 oscillator in place of the primary oscillator. Also included is the Sleep mode, offered by all PIC microcontrollers, where all device clocks are stopped.

3.1 Selecting Power-Managed Modes

Selecting a power-managed mode requires two decisions: if the CPU is to be clocked or not and the selection of a clock source. The IDLEN bit (OSCCON<7>) controls CPU clocking, while the SCS1:SCS0 bits (OSCCON<1:0>) select the clock source. The individual modes, bit settings, clock sources and affected modules are summarized in Table 3-1.

3.1.1 CLOCK SOURCES

The SCS1:SCS0 bits allow the selection of one of three clock sources for power-managed modes. They are:

- The primary clock, as defined by the FOSC3:FOSC0 Configuration bits
- The secondary clock (the Timer1 oscillator)
- The internal oscillator (for RC modes)

3.1.2 ENTERING POWER-MANAGED MODES

Switching from one power-managed mode to another begins by loading the OSCCON register. The SCS1:SCS0 bits select the clock source and determine which Run or Idle mode is to be used. Changing these bits causes an immediate switch to the new clock source, assuming that it is running. The switch may also be subject to clock transition delays. These are discussed in **Section 3.1.3 "Clock Transitions and Status Indicators"** and subsequent sections.

Entry to the power-managed Idle or Sleep modes is triggered by the execution of a `SLEEP` instruction. The actual mode that results depends on the status of the IDLEN bit.

Depending on the current mode and the mode being switched to, a change to a power-managed mode does not always require setting all of these bits. Many transitions may be done by changing the oscillator select bits, or changing the IDLEN bit, prior to issuing a `SLEEP` instruction. If the IDLEN bit is already configured correctly, it may only be necessary to perform a `SLEEP` instruction to switch to the desired mode.

TABLE 3-1: POWER-MANAGED MODES

Mode	OSCCON Bits		Module Clocking		Available Clock and Oscillator Source
	IDLEN(1)	SCS1:SCS0	CPU	Peripherals	
Sleep	0	N/A	Off	Off	None – all clocks are disabled
PRI_RUN	N/A	00	Clocked	Clocked	Primary – all oscillator modes. This is the normal full-power execution mode.
SEC_RUN	N/A	01	Clocked	Clocked	Secondary – Timer1 oscillator
RC_RUN	N/A	1x	Clocked	Clocked	Internal oscillator(2)
PRI_IDLE	1	00	Off	Clocked	Primary – all oscillator modes
SEC_IDLE	1	01	Off	Clocked	Secondary – Timer1 oscillator
RC_IDLE	1	1x	Off	Clocked	Internal oscillator(2)

Note 1: IDLEN reflects its value when the `SLEEP` instruction is executed.

2: Clock is INTRC source.

3.1.3 CLOCK TRANSITIONS AND STATUS INDICATORS

The length of the transition between clock sources is the sum of two cycles of the old clock source and three to four cycles of the new clock source. This formula assumes that the new clock source is stable.

Two bits indicate the current clock source and its status. They are:

- OSTS (OSCCON<3>)
- T1RUN (T1CON<6>)

In general, only one of these bits will be set while in a given power-managed mode. When the OSTS bit is set, the primary clock is providing the device clock. When the T1RUN bit is set, the Timer1 oscillator is providing the clock.

> **Note:** Executing a `SLEEP` instruction does not necessarily place the device into Sleep mode. It acts as the trigger to place the controller into either the Sleep mode, or one of the Idle modes, depending on the setting of the IDLEN bit.

3.1.4 MULTIPLE SLEEP COMMANDS

The power-managed mode that is invoked with the `SLEEP` instruction is determined by the setting of the IDLEN bit at the time the instruction is executed. If another `SLEEP` instruction is executed, the device will enter the power-managed mode specified by IDLEN at that time. If IDLEN has changed, the device will enter the new power-managed mode specified by the new setting.

3.2 Run Modes

In the Run modes, clocks to both the core and peripherals are active. The difference between these modes is the clock source.

3.2.1 PRI_RUN MODE

The PRI_RUN mode is the normal, full-power execution mode of the microcontroller. This is also the default mode upon a device Reset unless Two-Speed Start-up is enabled (see **Section 18.3 "Two-Speed Start-up"** for details). In this mode, the OSTS bit is set.

3.2.2 SEC_RUN MODE

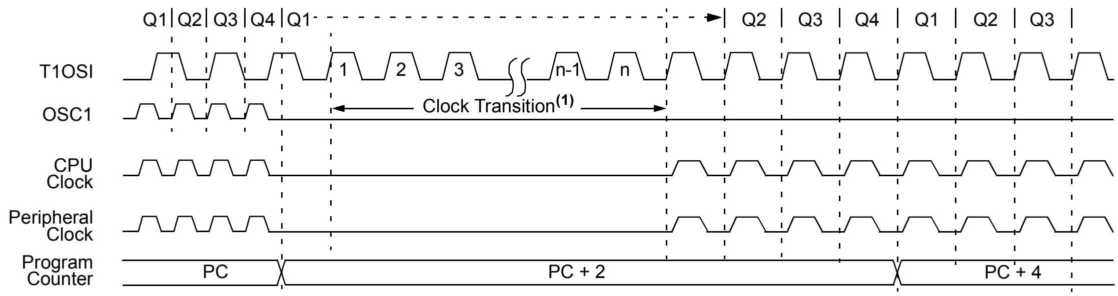
The SEC_RUN mode is the compatible mode to the "clock switching" feature offered in other PIC18 devices. In this mode, the CPU and peripherals are clocked from the Timer1 oscillator. This gives users the option of lower power consumption while still using a high accuracy clock source.

SEC_RUN mode is entered by setting the SCS1:SCS0 bits to '`01`'. The device clock source is switched to the Timer1 oscillator (see Figure 3-1), the primary oscillator is shut down, the T1RUN bit (T1CON<6>) is set and the OSTS bit is cleared.

> **Note:** The Timer1 oscillator should already be running prior to entering SEC_RUN mode. If the T1OSCEN bit is not set when the SCS1:SCS0 bits are set to '`01`', entry to SEC_RUN mode will not occur. If the Timer1 oscillator is enabled but not yet running, device clocks will be delayed until the oscillator has started. In such situations, initial oscillator operation is far from stable and unpredictable operation may result.

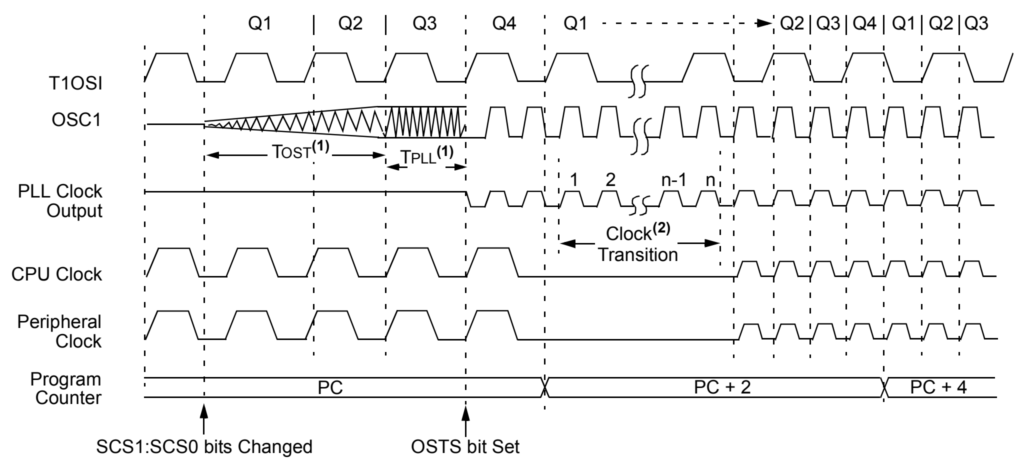
On transitions from SEC_RUN mode to PRI_RUN mode, the peripherals and CPU continue to be clocked from the Timer1 oscillator while the primary clock is started. When the primary clock becomes ready, a clock switch back to the primary clock occurs (see Figure 3-2). When the clock switch is complete, the T1RUN bit is cleared, the OSTS bit is set and the primary clock is providing the clock. The IDLEN and SCS bits are not affected by the wake-up; the Timer1 oscillator continues to run.

FIGURE 3-1: TRANSITION TIMING FOR ENTRY TO SEC_RUN MODE



Note 1: Clock transition typically occurs within 2-4 TOSC.

FIGURE 3-2: TRANSITION TIMING FROM SEC_RUN MODE TO PRI_RUN MODE (HSPLL)



Note 1: TOST = 1024 TOSC; TPLL = 2 ms (approx). These intervals are not shown to scale.
2: Clock transition typically occurs within 2-4 TOSC.

3.2.3 RC_RUN MODE

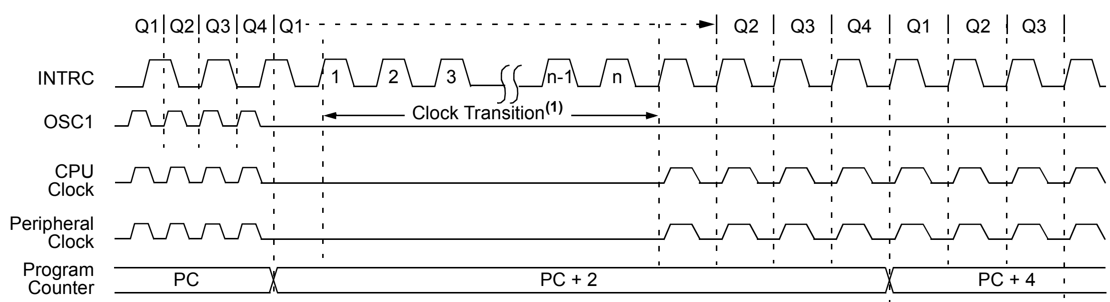
In RC_RUN mode, the CPU and peripherals are clocked from the internal oscillator; the primary clock is shut down. When using the INTRC source, this mode provides the best power conservation of all the Run modes while still executing code. It works well for user applications which are not highly timing sensitive or do not require high-speed clocks at all times.

If the primary clock source is the internal oscillator (INTRC), there are no distinguishable differences between the PRI_RUN and RC_RUN modes during execution. However, a clock switch delay will occur during entry to and exit from RC_RUN mode. Therefore, if the primary clock source is the internal oscillator, the use of RC_RUN mode is not recommended.

This mode is entered by setting SCS1 to '1'. Although it is ignored, it is recommended that SCS0 also be cleared; this is to maintain software compatibility with future devices. When the clock source is switched to the INTRC (see Figure 3-3), the primary oscillator is shut down and the OSTS bit is cleared.

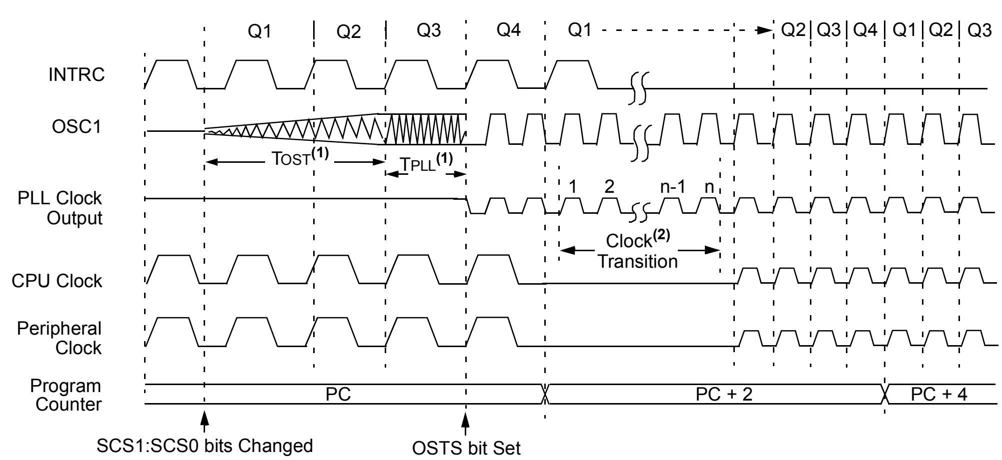
On transitions from RC_RUN mode to PRI_RUN mode, the device continues to be clocked from the INTRC while the primary clock is started. When the primary clock becomes ready, a clock switch to the primary clock occurs (see Figure 3-4). When the clock switch is complete, the OSTS bit is set and the primary clock is providing the device clock. The IDLEN and SCS bits are not affected by the switch. The INTRC source will continue to run if either the WDT or the Fail-Safe Clock Monitor is enabled.

FIGURE 3-3: TRANSITION TIMING TO RC_RUN MODE



Note 1: Clock transition typically occurs within 2-4 TOSC.

FIGURE 3-4: TRANSITION TIMING FROM RC_RUN MODE TO PRI_RUN MODE



Note 1: TOST = 1024 TOSC; TPLL = 2 ms (approx). These intervals are not shown to scale.
2: Clock transition typically occurs within 2-4 TOSC.

3.3 Sleep Mode

The power-managed Sleep mode in the PIC18F2450/4450 devices is identical to the legacy Sleep mode offered in all other PIC microcontrollers. It is entered by clearing the IDLEN bit (the default state on device Reset) and executing the `SLEEP` instruction. This shuts down the selected oscillator (Figure 3-5). All clock source status bits are cleared.

Entering the Sleep mode from any other mode does not require a clock switch. This is because no clocks are needed once the controller has entered Sleep. If the WDT is selected, the INTRC source will continue to operate. If the Timer1 oscillator is enabled, it will also continue to run.

When a wake event occurs in Sleep mode (by interrupt, Reset or WDT time-out), the device will not be clocked until the clock source selected by the SCS1:SCS0 bits becomes ready (see Figure 3-6), or it will be clocked from the internal oscillator if either the Two-Speed Start-up or the Fail-Safe Clock Monitor are enabled (see **Section 18.0 "Special Features of the CPU"**). In either case, the OSTS bit is set when the primary clock is providing the device clocks. The IDLEN and SCS bits are not affected by the wake-up.

3.4 Idle Modes

The Idle modes allow the controller's CPU to be selectively shut down while the peripherals continue to operate. Selecting a particular Idle mode allows users to further manage power consumption.

If the IDLEN bit is set to '`1`' when a `SLEEP` instruction is executed, the peripherals will be clocked from the clock source selected using the SCS1:SCS0 bits; however, the CPU will not be clocked. The clock source status bits are not affected. Setting IDLEN and executing a `SLEEP` instruction provides a quick method of switching from a given Run mode to its corresponding Idle mode.

If the WDT is selected, the INTRC source will continue to operate. If the Timer1 oscillator is enabled, it will also continue to run.

Since the CPU is not executing instructions, the only exits from any of the Idle modes are by interrupt, WDT time-out or a Reset. When a wake event occurs, CPU execution is delayed by an interval of T_{CSD} (parameter 38, Table 21-10) while it becomes ready to execute code. When the CPU begins executing code, it resumes with the same clock source for the current Idle mode. For example, when waking from RC_IDLE mode, the internal oscillator will clock the CPU and peripherals (in other words, RC_RUN mode). The IDLEN and SCS bits are not affected by the wake-up.

While in any Idle mode or Sleep mode, a WDT time-out will result in a WDT wake-up to the Run mode currently specified by the SCS1:SCS0 bits.

FIGURE 3-5: TRANSITION TIMING FOR ENTRY TO SLEEP MODE

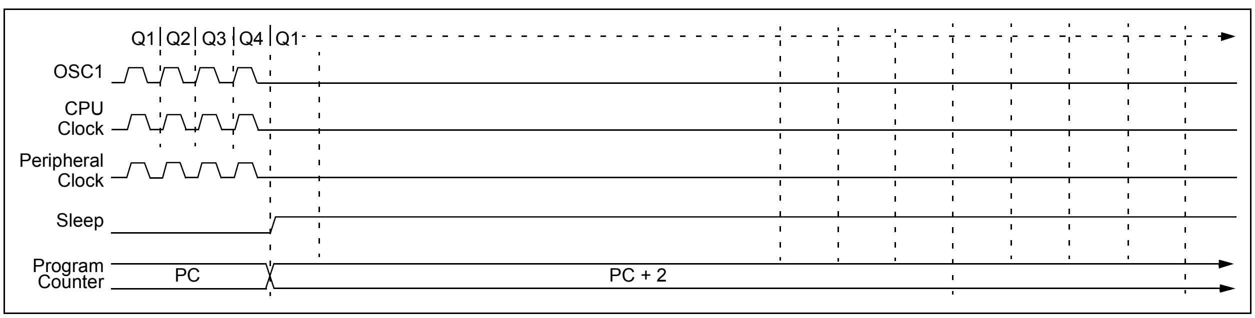
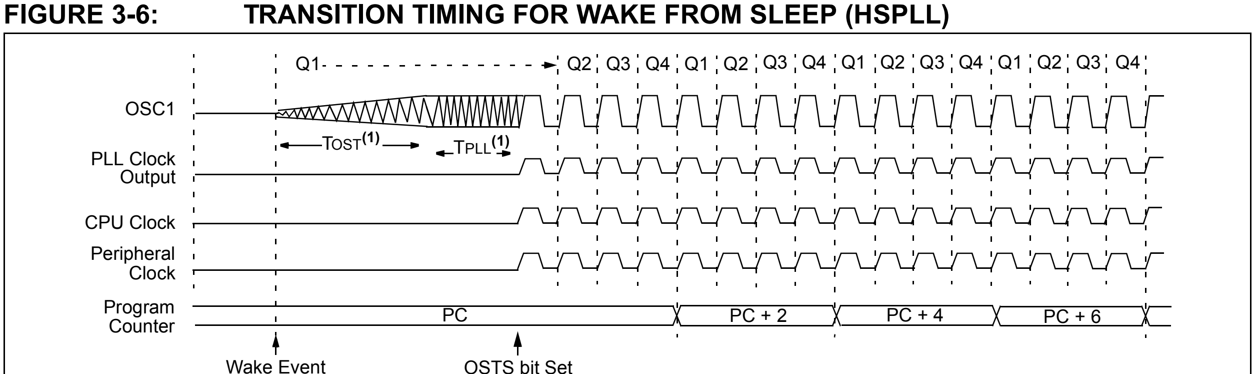


FIGURE 3-6: TRANSITION TIMING FOR WAKE FROM SLEEP (HSPLL)



Note 1: T_{OST} = 1024 T_{OSC}; T_{PLL} = 2 ms (approx). These intervals are not shown to scale.

3.4.1 PRI_IDLE MODE

This mode is unique among the three low-power Idle modes in that it does not disable the primary device clock. For timing sensitive applications, this allows for the fastest resumption of device operation, with its more accurate primary clock source, since the clock source does not have to "warm up" or transition from another oscillator.

PRI_IDLE mode is entered from PRI_RUN mode by setting the IDLEN bit and executing a `SLEEP` instruction. If the device is in another Run mode, set IDLEN first, then clear the SCS bits and execute `SLEEP`. Although the CPU is disabled, the peripherals continue to be clocked from the primary clock source specified by the FOSC3:FOSC0 Configuration bits. The OSTS bit remains set (see Figure 3-7).

When a wake event occurs, the CPU is clocked from the primary clock source. A delay of interval TCSD is required between the wake event and when code execution starts. This is required to allow the CPU to become ready to execute instructions. After the wake-up, the OSTS bit remains set. The IDLEN and SCS bits are not affected by the wake-up (see Figure 3-8).

3.4.2 SEC_IDLE MODE

In SEC_IDLE mode, the CPU is disabled but the peripherals continue to be clocked from the Timer1 oscillator. This mode is entered from SEC_RUN by setting the IDLEN bit and executing a `SLEEP` instruction. If the device is in another Run mode, set IDLEN first, then set SCS1:SCS0 to '`01`' and execute `SLEEP`. When the clock source is switched to the Timer1 oscillator, the primary oscillator is shut down, the OSTS bit is cleared and the T1RUN bit is set.

When a wake event occurs, the peripherals continue to be clocked from the Timer1 oscillator. After an interval of TCSD following the wake event, the CPU begins executing code being clocked by the Timer1 oscillator. The IDLEN and SCS bits are not affected by the wake-up; the Timer1 oscillator continues to run (see Figure 3-8).

Note:	The Timer1 oscillator should already be running prior to entering SEC_IDLE mode. If the T1OSCEN bit is not set when the `SLEEP` instruction is executed, the `SLEEP` instruction will be ignored and entry to SEC_IDLE mode will not occur. If the Timer1 oscillator is enabled but not yet running, peripheral clocks will be delayed until the oscillator has started. In such situations, initial oscillator operation is far from stable and unpredictable operation may result.

FIGURE 3-7: TRANSITION TIMING FOR ENTRY TO IDLE MODE

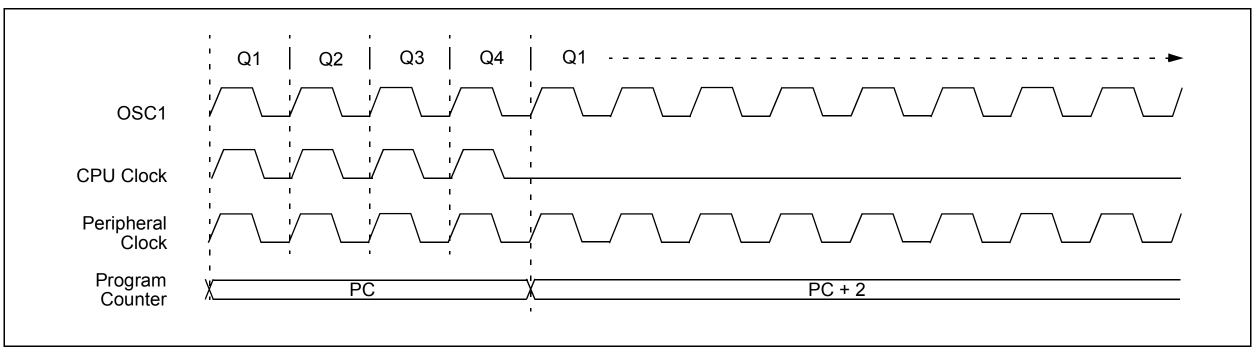
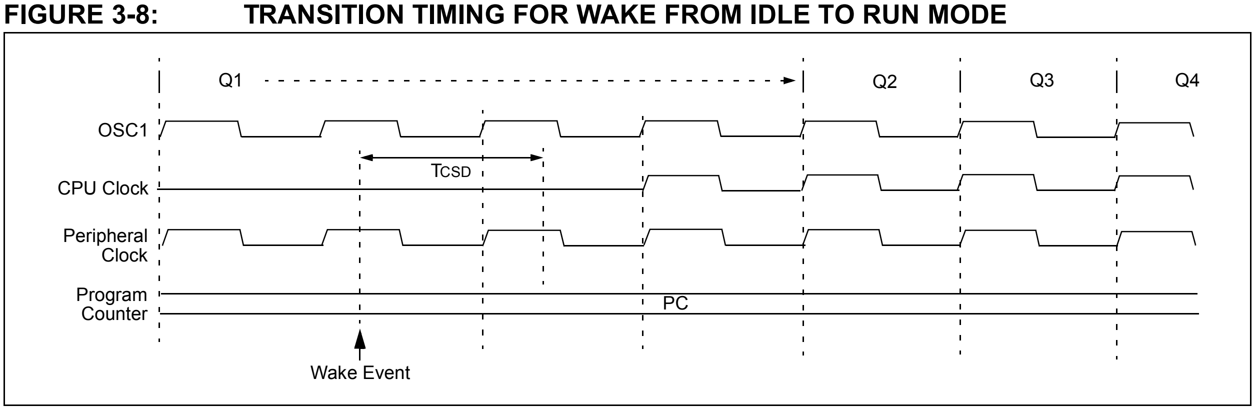


FIGURE 3-8: TRANSITION TIMING FOR WAKE FROM IDLE TO RUN MODE



3.4.3 RC_IDLE MODE

In RC_IDLE mode, the CPU is disabled but the peripherals continue to be clocked from the internal oscillator, INTRC. This mode allows for controllable power conservation during Idle periods.

From RC_RUN, this mode is entered by setting the IDLEN bit and executing a `SLEEP` instruction. If the device is in another Run mode, first set IDLEN, then set the SCS1 bit and execute `SLEEP`. Although its value is ignored, it is recommended that SCS0 also be cleared; this is to maintain software compatibility with future devices. When the clock source is switched to the INTRC, the primary oscillator is shut down and the OSTS bit is cleared.

When a wake event occurs, the peripherals continue to be clocked from the INTRC. After a delay of T_{CSD} following the wake event, the CPU begins executing code being clocked by the INTRC. The IDLEN and SCS bits are not affected by the wake-up. The INTRC source will continue to run if either the WDT or the Fail-Safe Clock Monitor is enabled.

3.5 Exiting Idle and Sleep Modes

An exit from Sleep mode or any of the Idle modes is triggered by an interrupt, a Reset or a WDT time-out. This section discusses the triggers that cause exits from power-managed modes. The clocking subsystem actions are discussed in each of the power-managed modes (see **Section 3.2 “Run Modes”, Section 3.3 “Sleep Mode”** and **Section 3.4 “Idle Modes”**).

3.5.1 EXIT BY INTERRUPT

Any of the available interrupt sources can cause the device to exit from an Idle mode, or the Sleep mode, to a Run mode. To enable this functionality, an interrupt source must be enabled by setting its enable bit in one of the INTCON or PIE registers. The exit sequence is initiated when the corresponding interrupt flag bit is set.

On all exits from Idle or Sleep modes by interrupt, code execution branches to the interrupt vector if the GIE/GIEH bit (INTCON<7>) is set. Otherwise, code execution continues or resumes without branching (see **Section 8.0 “Interrupts”**).

A fixed delay of interval, T_{CSD}, following the wake event, is required when leaving Sleep and Idle modes. This delay is required for the CPU to prepare for execution. Instruction execution resumes on the first clock cycle following this delay.

3.5.2 EXIT BY WDT TIME-OUT

A WDT time-out will cause different actions depending on which power-managed mode the device is in when the time-out occurs.

If the device is not executing code (all Idle modes and Sleep mode), the time-out will result in an exit from the power-managed mode (see **Section 3.2 “Run Modes”** and **Section 3.3 “Sleep Mode”**). If the device is executing code (all Run modes), the time-out will result in a WDT Reset (see **Section 18.2 “Watchdog Timer (WDT)”**).

3.5.3 EXIT BY RESET

Normally, the device is held in Reset by the Oscillator Start-up Timer (OST) until the primary clock becomes ready. At that time, the OSTS bit is set and the device begins executing code.

The exit delay time from Reset to the start of code execution depends on both the clock sources before and after the wake-up and the type of oscillator if the new clock source is the primary clock. Exit delays are summarized in Table 3-2.

Code execution can begin before the primary clock becomes ready. If either the Two-Speed Start-up (see **Section 18.3 “Two-Speed Start-up”**) or Fail-Safe Clock Monitor (see **Section 18.4 “Fail-Safe Clock Monitor”**) is enabled, the device may begin execution as soon as the Reset source has cleared. Execution is clocked by the INTRC driven by the internal oscillator. Execution is clocked by the internal oscillator until either the primary clock becomes ready or a power-managed mode is entered before the primary clock becomes ready; the primary clock is then shut down.

3.5.4 EXIT WITHOUT AN OSCILLATOR START-UP DELAY

Certain exits from power-managed modes do not invoke the OST at all. There are two cases:

- PRI_IDLE mode, where the primary clock source is not stopped; and
- The primary clock source is not any of the XT or HS modes

In these instances, the primary clock source either does not require an oscillator start-up delay, since it is already running (PRI_IDLE), or normally does not require an oscillator start-up delay (EC and any internal oscillator modes). However, a fixed delay of interval TCSD following the wake event is still required when leaving Sleep and Idle modes to allow the CPU to prepare for execution. Instruction execution resumes on the first clock cycle following this delay.

TABLE 3-2: EXIT DELAY ON WAKE-UP BY RESET FROM SLEEP MODE OR ANY IDLE MODE (BY CLOCK SOURCES)

Microcontroller Clock Source		Exit Delay	Clock Ready Status Bit (OSCCON)
Before Wake-up	**After Wake-up**		
Primary Device Clock (PRI_IDLE mode)	XT, HS	None	OSTS
	XTPLL, HSPLL		
	EC		
	INTRC(1)		
T1OSC or INTRC(1)	XT, HS	TOST(3)	OSTS
	XTPLL, HSPLL	TOST + t_{rc}(3)	
	EC	TCSD(2)	
	INTRC(1)	TIOBST(4)	
INTRC(1)	XT, HS	TOST(3)	OSTS
	XTPLL, HSPLL	TOST + t_{rc}(3)	
	EC	TCSD(2)	
	INTRC(1)	None	
None (Sleep mode)	XT, HS	TOST(3)	OSTS
	XTPLL, HSPLL	TOST + t_{rc}(3)	
	EC	TCSD(2)	
	INTRC(1)	TIOBST(4)	

Note 1: In this instance, refers specifically to the 31 kHz INTRC clock source.

2: TCSD (parameter 38, Table 21-10) is a required delay when waking from Sleep and all Idle modes and runs concurrently with any other required delays (see **Section 3.4 “Idle Modes”**).

3: TOST is the Oscillator Start-up Timer period (parameter 32, Table 21-10). t_{rc} is the PLL lock time-out (parameter F12, Table 21-7); it is also designated as TPLL.

4: Execution continues during TIOBST (parameter 39, Table 21-10), the INTRC stabilization period.

4.0 RESET

The PIC18F2450/4450 devices differentiate between various kinds of Reset:

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

This section discusses Resets generated by $\overline{\text{MCLR}}$, POR and BOR, and covers the operation of the various start-up timers. Stack Reset events are covered in **Section 5.1.2.4 "Stack Full and Underflow Resets"**. WDT Resets are covered in **Section 18.2 "Watchdog Timer (WDT)"**.

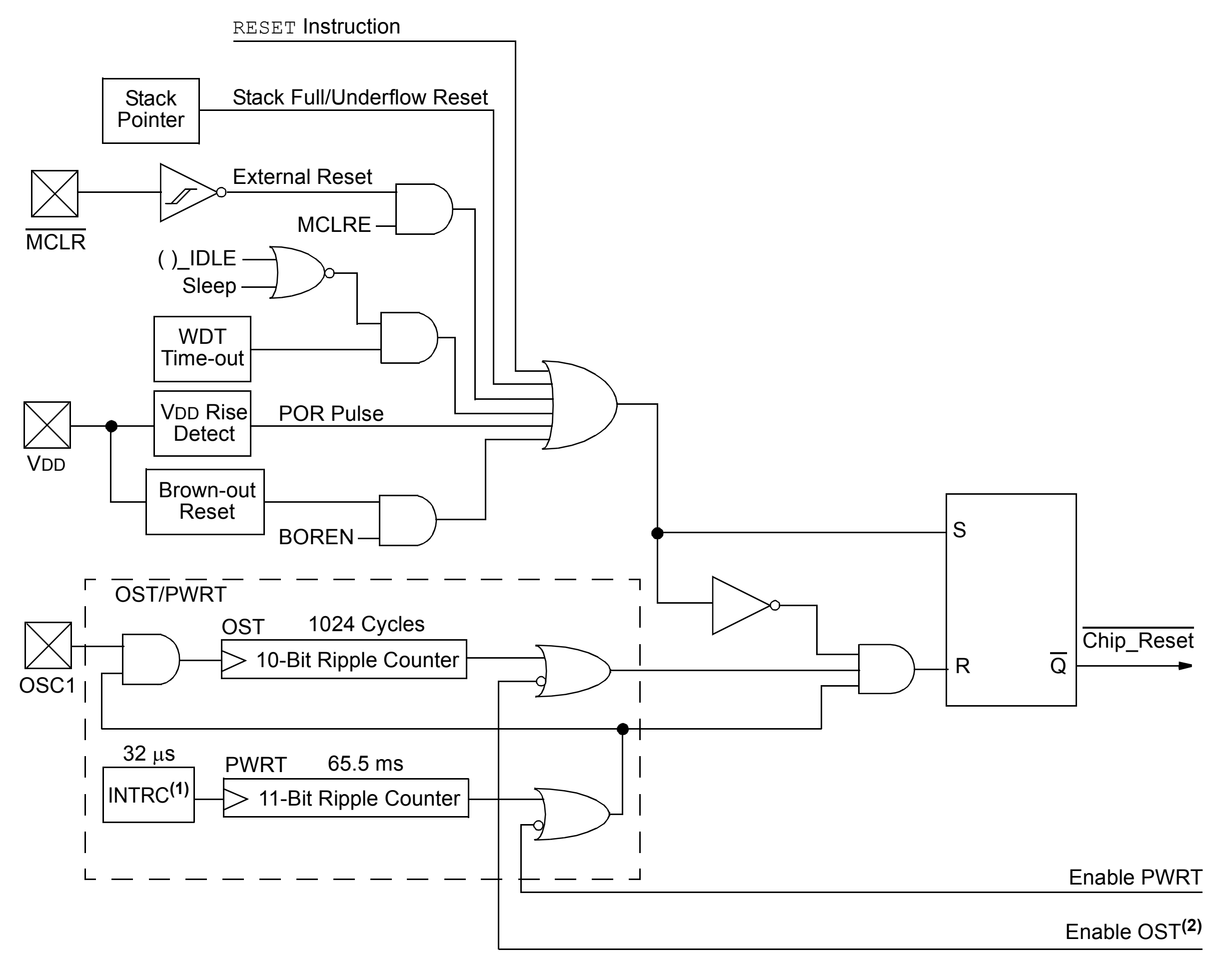
A simplified block diagram of the on-chip Reset circuit is shown in Figure 4-1.

4.1 RCON Register

Device Reset events are tracked through the RCON register (Register 4-1). The lower five bits of the register indicate that a specific Reset event has occurred. In most cases, these bits can only be cleared by the event and must be set by the application after the event. The state of these flag bits, taken together, can be read to indicate the type of Reset that just occurred. This is described in more detail in **Section 4.6 "Reset State of Registers"**.

The RCON register also has control bits for setting interrupt priority (IPEN) and software control of the BOR (SBOREN). Interrupt priority is discussed in **Section 8.0 "Interrupts"**. BOR is covered in **Section 4.4 "Brown-out Reset (BOR)"**.

FIGURE 4-1: SIMPLIFIED BLOCK DIAGRAM OF ON-CHIP RESET CIRCUIT



Note 1: This is the INTRC source from the internal oscillator and is separate from the RC oscillator of the CLKI pin.

2: See Table 4-2 for time-out situations.

REGISTER 4-1: RCON: RESET CONTROL REGISTER

R/W-0	R/W-1[(1)]	U-0	R/W-1	R-1	R-1	R/W-0[(2)]	R/W-0
IPEN	SBOREN	—	$\overline{\text{RI}}$	$\overline{\text{TO}}$	$\overline{\text{PD}}$	$\overline{\text{POR}}$	$\overline{\text{BOR}}$
bit 7							bit 0

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

bit 7 **IPEN:** Interrupt Priority Enable bit
1 = Enable priority levels on interrupts
0 = Disable priority levels on interrupts (PIC16CXXX Compatibility mode)

bit 6 **SBOREN:** BOR Software Enable bit[(1)]
If BOREN1:BOREN0 = 01:
1 = BOR is enabled
0 = BOR is disabled
If BOREN1:BOREN0 = 00, 10 or 11:
Bit is disabled and read as ‘0’.

bit 5 **Unimplemented:** Read as ‘0’

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

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

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

bit 1 **$\overline{\text{POR}}$:** Power-on Reset Status bit[(2)]
1 = A Power-on Reset has not occurred (set by firmware only)
0 = A Power-on Reset occurred (must be set in software after a Power-on Reset occurs)

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

Note 1: If SBOREN is enabled, its Reset state is ‘1’; otherwise, it is ‘0’.
2: The actual Reset value of $\overline{\text{POR}}$ is determined by the type of device Reset. See the notes following this register and **Section 4.6 “Reset State of Registers”** for additional information.

> **Note 1:** It is recommended that the $\overline{\text{POR}}$ bit be set after a Power-on Reset has been detected so that subsequent Power-on Resets may be detected.
> **2:** Brown-out Reset is said to have occurred when $\overline{\text{BOR}}$ is ‘0’ and $\overline{\text{POR}}$ is ‘1’ (assuming that $\overline{\text{POR}}$ was set to ‘1’ by software immediately after a Power-on Rest).

4.2 Master Clear Reset ($\overline{MCLR}$)

The $\overline{MCLR}$ pin provides a method for triggering an external Reset of the device. A Reset is generated by holding the pin low. These devices have a noise filter in the $\overline{MCLR}$ Reset path which detects and ignores small pulses.

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

In PIC18F2450/4450 devices, the $\overline{MCLR}$ input can be disabled with the MCLRE Configuration bit. When $\overline{MCLR}$ is disabled, the pin becomes a digital input. See **Section 9.5 "PORTE, TRISE and LATE Registers"** for more information.

4.3 Power-on Reset (POR)

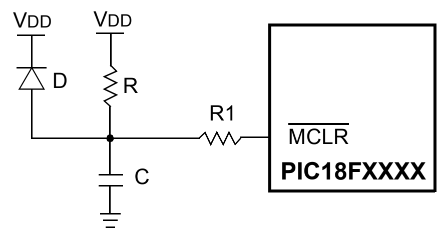
A Power-on Reset pulse is generated on-chip whenever VDD rises above a certain threshold. This allows the device to start in the initialized state when VDD is adequate for operation.

To take advantage of the POR circuitry, tie the $\overline{MCLR}$ pin through a resistor (1 kΩ to 10 kΩ) 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, **Section269 "DC Characteristics"**). For a slow rise time, see Figure 4-2.

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.

POR events are captured by the $\overline{POR}$ bit (RCON<1>). The state of the bit is set to '0' whenever a Power-on Reset occurs; it does not change for any other Reset event. $\overline{POR}$ is not reset to '1' by any hardware event. To capture multiple events, the user manually resets the bit to '1' in software following any Power-on Reset.

FIGURE 4-2: 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 ≥ 1 kΩ will limit any current flowing into $\overline{MCLR}$ from external capacitor C, in the event of $\overline{MCLR}$/VPP pin breakdown, due to Electrostatic Discharge (ESD) or Electrical Overstress (EOS).

4.4 Brown-out Reset (BOR)

PIC18F2450/4450 devices implement a BOR circuit that provides the user with a number of configuration and power-saving options. The BOR is controlled by the BORV1:BORV0 and BOREN1:BOREN0 Configuration bits. There are a total of four BOR configurations which are summarized in Table 4-1.

The BOR threshold is set by the BORV1:BORV0 bits. If BOR is enabled (any values of BOREN1:BOREN0 except '00'), any drop of V_{DD} below V_{BOR} (parameter D005, **Section 269 "DC Characteristics: Supply Voltage"**) for greater than T_{BOR} (parameter 35, Table 21-10) will reset the device. A Reset may or may not occur if V_{DD} falls below V_{BOR} for less than T_{BOR}. The chip will remain in Brown-out Reset until V_{DD} rises above V_{BOR}.

If the Power-up Timer is enabled, it will be invoked after V_{DD} rises above V_{BOR}; it then will keep the chip in Reset for an additional time delay, T_{PWRT} (parameter 33, Table 21-10). If V_{DD} drops below V_{BOR} 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 V_{DD} rises above V_{BOR}, the Power-up Timer will execute the additional time delay.

BOR and the Power-on Timer (PWRT) are independently configured. Enabling BOR Reset does not automatically enable the PWRT.

4.4.1 SOFTWARE ENABLED BOR

When BOREN1:BOREN0 = 01, the BOR can be enabled or disabled by the user in software. This is done with the control bit, SBOREN (RCON<6>). Setting SBOREN enables the BOR to function as previously described. Clearing SBOREN disables the BOR entirely. The SBOREN bit operates only in this mode; otherwise, it is read as '0'.

Placing the BOR under software control gives the user the additional flexibility of tailoring the application to its environment without having to reprogram the device to change BOR configuration. It also allows the user to tailor device power consumption in software by eliminating the incremental current that the BOR consumes. While the BOR current is typically very small, it may have some impact in low-power applications.

Note:	Even when BOR is under software control, the BOR Reset voltage level is still set by the BORV1:BORV0 Configuration bits. It cannot be changed in software.

4.4.2 DETECTING BOR

When Brown-out Reset is enabled, the $\overline{\text{BOR}}$ bit always resets to '0' on any Brown-out Reset or Power-on Reset event. This makes it difficult to determine if a Brown-out Reset event has occurred just by reading the state of $\overline{\text{BOR}}$ alone. A more reliable method is to simultaneously check the state of both $\overline{\text{POR}}$ and $\overline{\text{BOR}}$. This assumes that the $\overline{\text{POR}}$ bit is reset to '1' in software immediately after any Power-on Reset event. IF $\overline{\text{BOR}}$ is '0' while $\overline{\text{POR}}$ is '1', it can be reliably assumed that a Brown-out Reset event has occurred.

4.4.3 DISABLING BOR IN SLEEP MODE

When BOREN1:BOREN0 = 10, the BOR remains under hardware control and operates as previously described. Whenever the device enters Sleep mode, however, the BOR is automatically disabled. When the device returns to any other operating mode, BOR is automatically re-enabled.

This mode allows for applications to recover from brown-out situations, while actively executing code, when the device requires BOR protection the most. At the same time, it saves additional power in Sleep mode by eliminating the small incremental BOR current.

TABLE 4-1: BOR CONFIGURATIONS

BOR Configuration		Status of SBOREN (RCON<6>)	BOR Operation
BOREN1	**BOREN0**		
0	0	Unavailable	BOR disabled; must be enabled by reprogramming the Configuration bits.
0	1	Available	BOR enabled in software; operation controlled by SBOREN.
1	0	Unavailable	BOR enabled in hardware in Run and Idle modes, disabled during Sleep mode.
1	1	Unavailable	BOR enabled in hardware; must be disabled by reprogramming the Configuration bits.

4.5 Device Reset Timers

PIC18F2450/4450 devices incorporate three separate on-chip timers that help regulate the Power-on Reset process. Their main function is to ensure that the device clock is stable before code is executed. These timers are:

- Power-up Timer (PWRT)
- Oscillator Start-up Timer (OST)
- PLL Lock Time-out

4.5.1 POWER-UP TIMER (PWRT)

The Power-up Timer (PWRT) of the PIC18F2450/4450 devices is an 11-bit counter which uses the INTRC source as the clock input. This yields an approximate time interval of 2048 x 32 μs = 65.6 ms. While the PWRT is counting, the device is held in Reset.

The power-up time delay depends on the INTRC clock and will vary from chip to chip due to temperature and process variation. See DC parameter 33 (Table 21-10) for details.

The PWRT is enabled by clearing the $\overline{\text{PWRTEN}}$ Configuration bit.

4.5.2 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 33, Table 21-10). This ensures that the crystal oscillator or resonator has started and stabilized.

The OST time-out is invoked only for XT, HS and HSPLL modes and only on Power-on Reset or on exit from most power-managed modes.

4.5.3 PLL LOCK TIME-OUT

With the PLL enabled in its PLL mode, the time-out sequence following a Power-on Reset is slightly different from other oscillator modes. A separate 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 (T_{PLL}) is typically 2 ms and follows the oscillator start-up time-out.

4.5.4 TIME-OUT SEQUENCE

On power-up, the time-out sequence is as follows:

1. After the POR condition has cleared, PWRT time-out is invoked (if enabled).
2. Then, the OST is activated.

The total time-out will vary based on oscillator configuration and the status of the PWRT. Figure 4-3, Figure 4-4, Figure 4-5, Figure 4-6 and Figure 4-7 all depict time-out sequences on power-up, with the Power-up Timer enabled and the device operating in HS Oscillator mode. Figure 4-3 through Figure 4-6 also apply to devices operating in XT mode. For devices in RC mode and with the PWRT disabled, on the other hand, there will be no time-out at all.

Since the time-outs occur from the POR pulse, if $\overline{\text{MCLR}}$ is kept low long enough, all time-outs will expire. Bringing $\overline{\text{MCLR}}$ high will begin execution immediately (Figure 4-5). This is useful for testing purposes or to synchronize more than one PIC18FXXXX device operating in parallel.

TABLE 4-2: TIME-OUT IN VARIOUS SITUATIONS

Oscillator Configuration	Power-up(2) and Brown-out		Exit from Power-Managed Mode
	$\overline{\text{PWRTEN}}$ = 0	$\overline{\text{PWRTEN}}$ = 1	
HS, XT	66 ms(1) + 1024 T_{OSC}	1024 T_{OSC}	1024 T_{OSC}
HSPLL, XTPLL	66 ms(1) + 1024 T_{OSC} + 2 ms(2)	1024 T_{OSC} + 2 ms(2)	1024 T_{OSC} + 2 ms(2)
EC, ECIO	66 ms(1)	—	—
ECPLL, ECPIO	66 ms(1) + 2 ms(2)	2 ms(2)	2 ms(2)
INTIO, INTCKO	66 ms(1)	—	—
INTHS, INTXT	66 ms(1) + 1024 T_{OSC}	1024 T_{OSC}	1024 T_{OSC}

Note 1: 66 ms (65.5 ms) is the nominal Power-up Timer (PWRT) delay.

2: 2 ms is the nominal time required for the PLL to lock.

FIGURE 4-3: TIME-OUT SEQUENCE ON POWER-UP ($\overline{MCLR}$ TIED TO V_{DD}, V_{DD} RISE < T_{PWRT})

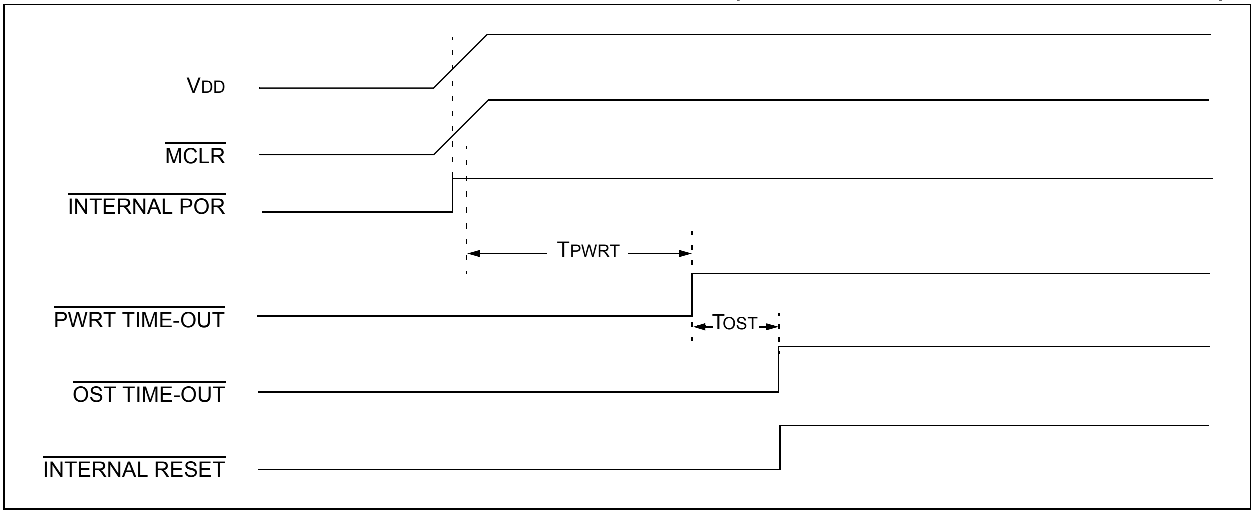


FIGURE 4-4: TIME-OUT SEQUENCE ON POWER-UP ($\overline{MCLR}$ NOT TIED TO V_{DD}): CASE 1

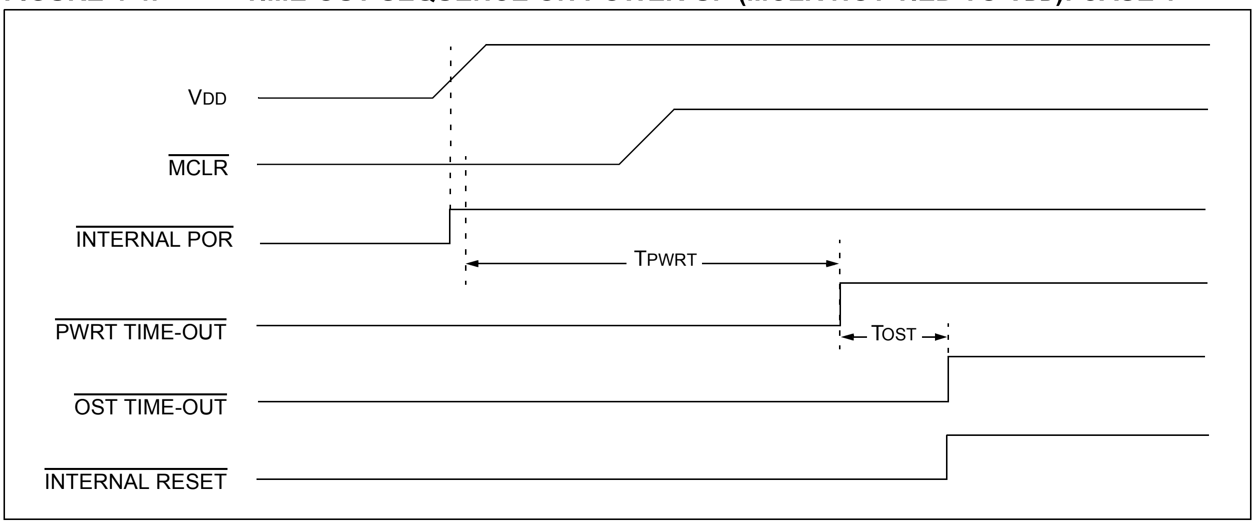


FIGURE 4-5: TIME-OUT SEQUENCE ON POWER-UP ($\overline{MCLR}$ NOT TIED TO V_{DD}): CASE 2

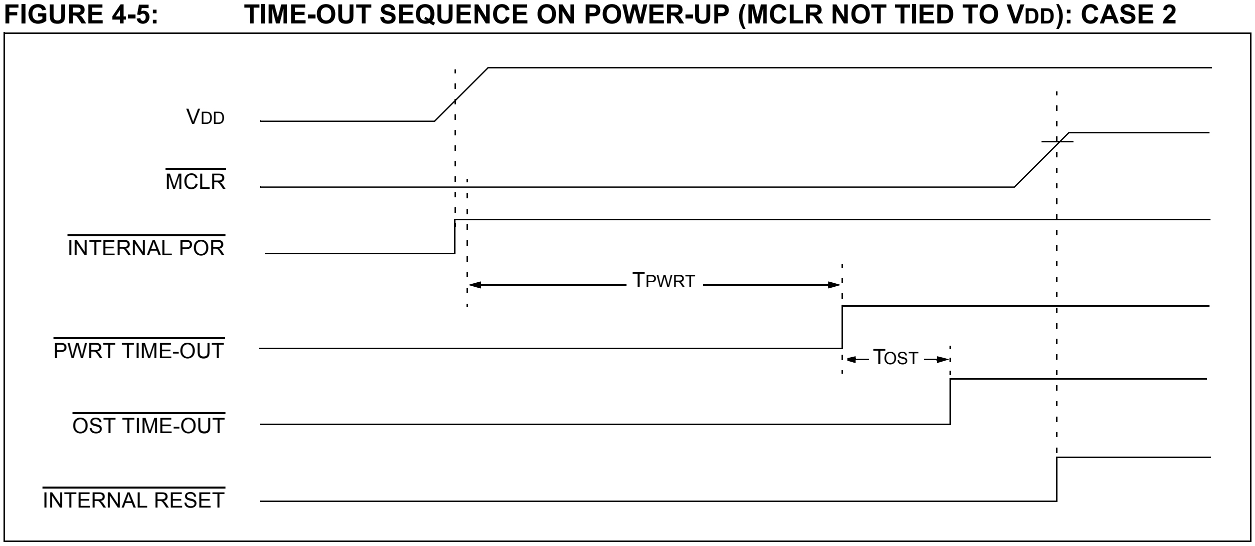


FIGURE 4-6: SLOW RISE TIME ($\overline{MCLR}$ TIED TO V_{DD}, V_{DD} RISE > T_{PWRT})

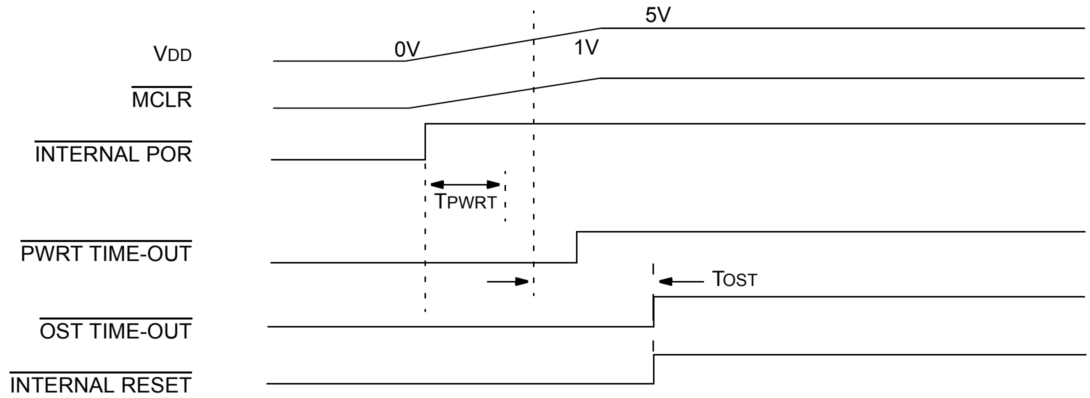
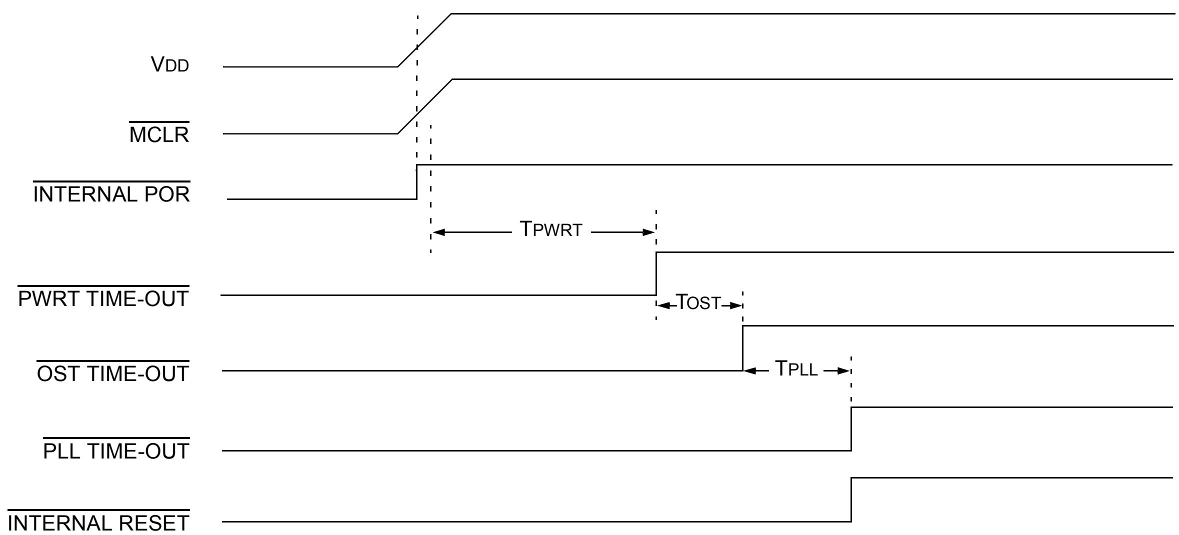


FIGURE 4-7: TIME-OUT SEQUENCE ON POR w/PLL ENABLED ($\overline{MCLR}$ TIED TO V_{DD})



Note: T_{OST} = 1024 clock cycles.
$T_{PLL} \approx$ 2 ms max. First three stages of the Power-up Timer.

4.6 Reset State of Registers

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" depending on the type of Reset that occurred.

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, $\overline{RI}$, $\overline{TO}$, $\overline{PD}$, $\overline{POR}$ and $\overline{BOR}$, are set or cleared differently in different Reset situations as indicated in Table 4-3. These bits are used in software to determine the nature of the Reset.

Table 4-4 describes the Reset states for all of the Special Function Registers. These are categorized by Power-on and Brown-out Resets, Master Clear and WDT Resets and WDT wake-ups.

TABLE 4-3: STATUS BITS, THEIR SIGNIFICANCE AND THE INITIALIZATION CONDITION FOR RCON REGISTER

Condition	Program Counter	RCON Register						STKPTR Register	
		SBOREN	$\overline{RI}$	$\overline{TO}$	$\overline{PD}$	$\overline{POR}$	$\overline{BOR}$	STKFUL	STKUNF
Power-on Reset	0000h	1	1	1	1	0	0	0	0
RESET instruction	0000h	u(2)	0	u	u	u	u	u	u
Brown-out Reset	0000h	u(2)	1	1	1	u	0	u	u
$\overline{MCLR}$ Reset during power-managed Run modes	0000h	u(2)	u	1	u	u	u	u	u
$\overline{MCLR}$ Reset during power-managed Idle modes and Sleep mode	0000h	u(2)	u	1	0	u	u	u	u
WDT time-out during full-power or power-managed Run modes	0000h	u(2)	u	0	u	u	u	u	u
$\overline{MCLR}$ Reset during full-power execution	0000h	u(2)	u	u	u	u	u	u	u
Stack Full Reset (STVREN = 1)	0000h	u(2)	u	u	u	u	u	1	u
Stack Underflow Reset (STVREN = 1)	0000h	u(2)	u	u	u	u	u	u	1
Stack Underflow Error (not an actual Reset, STVREN = 0)	0000h	u(2)	u	u	u	u	u	u	1
WDT time-out during power-managed Idle or Sleep modes	PC + 2	u(2)	u	0	0	u	u	u	u
Interrupt exit from power-managed modes	PC + 2(1)	u(2)	u	u	0	u	u	u	u

Legend: u = unchanged

Note 1: When the wake-up is due to an interrupt and the GIEH or GIEL bit is set, the PC is loaded with the interrupt vector (008h or 0018h).

2: Reset state is '1' for POR and unchanged for all other Resets when software BOR is enabled (BOREN1:BOREN0 Configuration bits = 01 and SBOREN = 1); otherwise, the Reset state is '0'.

TABLE 4-4: INITIALIZATION CONDITIONS FOR ALL REGISTERS

Register	Applicable Devices		Power-on Reset, Brown-out Reset	$\overline{\text{MCLR}}$ Resets, WDT Reset, RESET Instruction, Stack Resets	Wake-up via WDT or Interrupt
TOSU	2450	4450	---0 0000	---0 0000	---0 uuuu(1)
TOSH	2450	4450	0000 0000	0000 0000	uuuu uuuu(1)
TOSL	2450	4450	0000 0000	0000 0000	uuuu uuuu(1)
STKPTR	2450	4450	00-0 0000	uu-0 0000	uu-u uuuu(1)
PCLATU	2450	4450	---0 0000	---0 0000	---u uuuu
PCLATH	2450	4450	0000 0000	0000 0000	uuuu uuuu
PCL	2450	4450	0000 0000	0000 0000	PC + 2(3)
TBLPTRU	2450	4450	--00 0000	--00 0000	--uu uuuu
TBLPTRH	2450	4450	0000 0000	0000 0000	uuuu uuuu
TBLPTRL	2450	4450	0000 0000	0000 0000	uuuu uuuu
TABLAT	2450	4450	0000 0000	0000 0000	uuuu uuuu
PRODH	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
PRODL	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
INTCON	2450	4450	0000 000x	0000 000u	uuuu uuuu(2)
INTCON2	2450	4450	1111 -1-1	1111 -1-1	uuuu -u-u(2)
INTCON3	2450	4450	11-0 0-00	11-0 0-00	uu-u u-uu(2)
INDF0	2450	4450	N/A	N/A	N/A
POSTINC0	2450	4450	N/A	N/A	N/A
POSTDEC0	2450	4450	N/A	N/A	N/A
PREINC0	2450	4450	N/A	N/A	N/A
PLUSW0	2450	4450	N/A	N/A	N/A
FSR0H	2450	4450	---- 0000	---- 0000	---- uuuu
FSR0L	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
WREG	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
INDF1	2450	4450	N/A	N/A	N/A
POSTINC1	2450	4450	N/A	N/A	N/A
POSTDEC1	2450	4450	N/A	N/A	N/A
PREINC1	2450	4450	N/A	N/A	N/A
PLUSW1	2450	4450	N/A	N/A	N/A
FSR1H	2450	4450	---- 0000	---- 0000	---- uuuu
FSR1L	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
BSR	2450	4450	---- 0000	---- 0000	---- uuuu

Legend: u = unchanged, x = unknown, - = unimplemented bit, read as '0', q = value depends on condition. Shaded cells indicate conditions do not apply for the designated device.

Note 1: When the wake-up is due to an interrupt and the GIEL or GIEH bit is set, the TOSU, TOSH and TOSL are updated with the current value of the PC. The STKPTR is modified to point to the next location in the hardware stack.

2: One or more bits in the INTCONx or PIRx registers will be affected (to cause wake-up).

3: When the wake-up is due to an interrupt and the GIEL or GIEH bit is set, the PC is loaded with the interrupt vector (0008h or 0018h).

4: See Table 4-3 for Reset value for specific condition.

5: PORTA<6>, LATA<6> and TRISA<6> are enabled depending on the oscillator mode selected. When not enabled as PORTA pins, they are disabled and read '0'.

TABLE 4-4: INITIALIZATION CONDITIONS FOR ALL REGISTERS (CONTINUED)

Register	Applicable Devices		Power-on Reset, Brown-out Reset	$\overline{MCLR}$ Resets, WDT Reset, RESET Instruction, Stack Resets	Wake-up via WDT or Interrupt
INDF2	2450	4450	N/A	N/A	N/A
POSTINC2	2450	4450	N/A	N/A	N/A
POSTDEC2	2450	4450	N/A	N/A	N/A
PREINC2	2450	4450	N/A	N/A	N/A
PLUSW2	2450	4450	N/A	N/A	N/A
FSR2H	2450	4450	---- 0000	---- 0000	---- uuuu
FSR2L	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
STATUS	2450	4450	---x xxxx	---u uuuu	---u uuuu
TMR0H	2450	4450	0000 0000	0000 0000	uuuu uuuu
TMR0L	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
T0CON	2450	4450	1111 1111	1111 1111	uuuu uuuu
OSCCON	2450	4450	0--- q-00	0--- 0-q0	u--- u-qu
HLVDCON	2450	4450	0-00 0101	0-00 0101	u-uu uuuu
WDTCON	2450	4450	---- ---0	---- ---0	---- ---u
RCON(4)	2450	4450	0q-1 11q0	0q-q qquu	uq-u qquu
TMR1H	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
TMR1L	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
T1CON	2450	4450	0000 0000	u0uu uuuu	uuuu uuuu
TMR2	2450	4450	0000 0000	0000 0000	uuuu uuuu
PR2	2450	4450	1111 1111	1111 1111	1111 1111
T2CON	2450	4450	-000 0000	-000 0000	-uuu uuuu
ADRESH	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
ADRESL	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
ADCON0	2450	4450	--00 0000	--00 0000	--uu uuuu
ADCON1	2450	4450	--00 qqqq	--00 qqqq	--uu uuuu
ADCON2	2450	4450	0-00 0000	0-00 0000	u-uu uuuu
CCPR1H	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
CCPR1L	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
CCP1CON	2450	4450	--00 0000	--00 0000	--uu uuuu
BAUDCON	2450	4450	01-0 0-00	01-0 0-00	uu-u u-uu
SPBRG	2450	4450	0000 0000	0000 0000	uuuu uuuu
RCREG	2450	4450	0000 0000	0000 0000	uuuu uuuu

Legend: u = unchanged, x = unknown, - = unimplemented bit, read as '0', q = value depends on condition. Shaded cells indicate conditions do not apply for the designated device.

Note 1: When the wake-up is due to an interrupt and the GIEL or GIEH bit is set, the TOSU, TOSH and TOSL are updated with the current value of the PC. The STKPTR is modified to point to the next location in the hardware stack.

2: One or more bits in the INTCONx or PIRx registers will be affected (to cause wake-up).

3: When the wake-up is due to an interrupt and the GIEL or GIEH bit is set, the PC is loaded with the interrupt vector (0008h or 0018h).

4: See Table 4-3 for Reset value for specific condition.

5: PORTA<6>, LATA<6> and TRISA<6> are enabled depending on the oscillator mode selected. When not enabled as PORTA pins, they are disabled and read '0'.

TABLE 4-4: INITIALIZATION CONDITIONS FOR ALL REGISTERS (CONTINUED)

Register	Applicable Devices		Power-on Reset, Brown-out Reset	MCLR Resets, WDT Reset, RESET Instruction, Stack Resets	Wake-up via WDT or Interrupt
TXREG	2450	4450	0000 0000	0000 0000	uuuu uuuu
TXSTA	2450	4450	0000 0010	0000 0010	uuuu uuuu
RCSTA	2450	4450	0000 000x	0000 000x	uuuu uuuu
EECON2	2450	4450	0000 0000	0000 0000	0000 0000
EECON1	2450	4450	-x-0 x00-	-u-0 u00-	-u-0 u00-
IPIR2	2450	4450	1-1- -1--	1-1- -1--	u-u- -u--
PIR2	2450	4450	0-0- -0--	0-0- -0--	u-u- -u--(2)
PIE2	2450	4450	0-0- -0--	0-0- -0--	u-u- -u--
IPR1	2450	4450	-111 -111	-111 -111	-uuu -uuu
PIR1	2450	4450	-000 -000	-000 -000	-uuu -uuu(2)
PIE1	2450	4450	-000 -000	-000 -000	-uuu -uuu
TRISE	2450	4450	---- -111	---- -111	---- -uuu
TRISD	2450	4450	1111 1111	1111 1111	uuuu uuuu
TRISC	2450	4450	11-- -111	11-- -111	uu-- -uuu
TRISB	2450	4450	1111 1111	1111 1111	uuuu uuuu
TRISA(5)	2450	4450	-111 1111(5)	-111 1111(5)	-uuu uuuu(5)
LATE	2450	4450	---- -xxx	---- -uuu	---- -uuu
LATD	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
LATC	2450	4450	xx-- -xxx	uu-- -uuu	uu-- -uuu
LATB	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
LATA(5)	2450	4450	-xxx xxxx(5)	-uuu uuuu(5)	-uuu uuuu(5)
PORTE	2450	4450	---- x000	---- x000	---- uuuu
PORTD	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
PORTC	2450	4450	xxxx -xxx	uuuu -uuu	uuuu -uuu
PORTB	2450	4450	xxxx xxxx	uuuu uuuu	uuuu uuuu
PORTA(5)	2450	4450	-x0x 0000(5)	-u0u 0000(5)	-uuu uuuu(5)
UEP15	2450	4450	---0 0000	---0 0000	---u uuuu
UEP14	2450	4450	---0 0000	---0 0000	---u uuuu
UEP13	2450	4450	---0 0000	---0 0000	---u uuuu
UEP12	2450	4450	---0 0000	---0 0000	---u uuuu
UEP11	2450	4450	---0 0000	---0 0000	---u uuuu
UEP10	2450	4450	---0 0000	---0 0000	---u uuuu

Legend: u = unchanged, x = unknown, - = unimplemented bit, read as '0', q = value depends on condition. Shaded cells indicate conditions do not apply for the designated device.

Note 1: When the wake-up is due to an interrupt and the GIEL or GIEH bit is set, the TOSU, TOSH and TOSL are updated with the current value of the PC. The STKPTR is modified to point to the next location in the hardware stack.

2: One or more bits in the INTCONx or PIRx registers will be affected (to cause wake-up).

3: When the wake-up is due to an interrupt and the GIEL or GIEH bit is set, the PC is loaded with the interrupt vector (0008h or 0018h).

4: See Table 4-3 for Reset value for specific condition.

5: PORTA<6>, LATA<6> and TRISA<6> are enabled depending on the oscillator mode selected. When not enabled as PORTA pins, they are disabled and read '0'.

TABLE 4-4: INITIALIZATION CONDITIONS FOR ALL REGISTERS (CONTINUED)

Register	Applicable Devices		Power-on Reset, Brown-out Reset	MCLR Resets, WDT Reset, RESET Instruction, Stack Resets	Wake-up via WDT or Interrupt
UEP9	2450	4450	---0 0000	---0 0000	---u uuuu
UEP8	2450	4450	---0 0000	---0 0000	---u uuuu
UEP7	2450	4450	---0 0000	---0 0000	---u uuuu
UEP6	2450	4450	---0 0000	---0 0000	---u uuuu
UEP5	2450	4450	---0 0000	---0 0000	---u uuuu
UEP4	2450	4450	---0 0000	---0 0000	---u uuuu
UEP3	2450	4450	---0 0000	---0 0000	---u uuuu
UEP2	2450	4450	---0 0000	---0 0000	---u uuuu
UEP1	2450	4450	---0 0000	---0 0000	---u uuuu
UEP0	2450	4450	---0 0000	---0 0000	---u uuuu
UCFG	2450	4450	00-0 0000	00-0 0000	uu-u uuuu
UADDR	2450	4450	-000 0000	-000 0000	-uuu uuuu
UCON	2450	4450	-0x0 000-	-0x0 000-	-uuu uuu-
USTAT	2450	4450	-xxx xxx-	-xxx xxx-	-uuu uuu-
UEIE	2450	4450	0--0 0000	0--0 0000	u--u uuuu
UEIR	2450	4450	0--0 0000	0--0 0000	u--u uuuu
UIE	2450	4450	-000 0000	-000 0000	-uuu uuuu
UIR	2450	4450	-000 0000	-000 0000	-uuu uuuu
UFRMH	2450	4450	---- -xxx	---- -xxx	---- -uuu
UFRML	2450	4450	xxxx xxxx	xxxx xxxx	uuuu uuuu

Legend: u = unchanged, x = unknown, - = unimplemented bit, read as '0', q = value depends on condition. Shaded cells indicate conditions do not apply for the designated device.

Note 1: When the wake-up is due to an interrupt and the GIEL or GIEH bit is set, the TOSU, TOSH and TOSL are updated with the current value of the PC. The STKPTR is modified to point to the next location in the hardware stack.

2: One or more bits in the INTCONx or PIRx registers will be affected (to cause wake-up).

3: When the wake-up is due to an interrupt and the GIEL or GIEH bit is set, the PC is loaded with the interrupt vector (0008h or 0018h).

4: See Table 4-3 for Reset value for specific condition.

5: PORTA<6>, LATA<6> and TRISA<6> are enabled depending on the oscillator mode selected. When not enabled as PORTA pins, they are disabled and read '0'.

5.0 MEMORY ORGANIZATION

There are two types of memory in PIC18F2450/4450 microcontroller devices:

- Program Memory
- Data RAM

As Harvard architecture devices, the data and program memories use separate busses; this allows for concurrent access of the two memory spaces.

Additional detailed information on the operation of the Flash program memory is provided in **Section 6.0 "Flash Program Memory"**.

5.1 Program Memory Organization

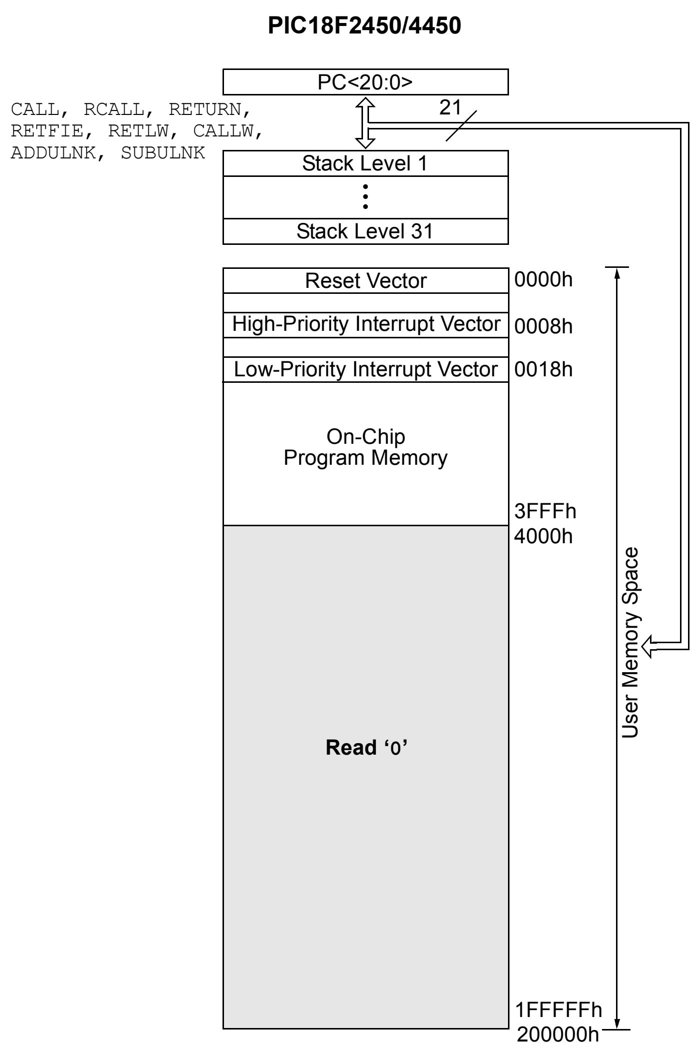
PIC18 microcontrollers implement a 21-bit program counter which is capable of addressing a 2-Mbyte program memory space. Accessing a location between the upper boundary of the physically implemented memory and the 2-Mbyte address will return all '0's (a NOP instruction).

The PIC18F2450 and PIC18F4450 each have 16 Kbytes of Flash memory and can store up to 8192 single-word instructions.

PIC18 devices have two interrupt vectors. The Reset vector address is at 0000h and the interrupt vector addresses are at 0008h and 0018h.

The program memory maps for PIC18F2450 and PIC18F4450 devices are shown in Figure 5-1.

FIGURE 5-1: PROGRAM MEMORY MAP AND STACK FOR PIC18F2450/4450 DEVICES



5.1.1 PROGRAM COUNTER

The Program Counter (PC) specifies the address of the instruction to fetch for execution. The PC is 21 bits wide and is contained in three separate 8-bit registers. The low byte, known as the PCL register, is both readable and writable. The high byte, or PCH register, contains the PC<15:8> bits; it is not directly readable or writable. Updates to the PCH register are performed through the PCLATH register. The upper byte is called PCU. This register contains the PC<20:16> bits; it is also not directly readable or writable. Updates to the PCU register are performed through the PCLATU register.

The contents of PCLATH and PCLATU are transferred to the program counter by any operation that writes PCL. Similarly, the upper two bytes of the program counter are transferred to PCLATH and PCLATU by an operation that reads PCL. This is useful for computed offsets to the PC (see **Section 5.1.4.1 “Computed GOTO”**).

The PC addresses bytes in the program memory. To prevent the PC from becoming misaligned with word instructions, the Least Significant bit of PCL is fixed to a value of ‘0’. The PC increments by 2 to address sequential instructions in the program memory.

The CALL, RCALL and GOTO program branch instructions write to the program counter directly. For these instructions, the contents of PCLATH and PCLATU are not transferred to the program counter.

5.1.2 RETURN ADDRESS STACK

The return address stack allows any combination of up to 31 program calls and interrupts to occur. The PC is pushed onto the stack when a CALL or RCALL instruction is executed or an interrupt is Acknowledged. The PC value is pulled off the stack on a RETURN, RETLW or a RETFIE instruction. PCLATU and PCLATH are not affected by any of the RETURN or CALL instructions.

The stack operates as a 31-word by 21-bit RAM and a 5-bit Stack Pointer, STKPTR. The stack space is not part of either program or data space. The Stack Pointer is readable and writable and the address on the top of the stack is readable and writable through the Top-of-Stack Special Function Registers. Data can also be pushed to, or popped from the stack, using these registers.

A CALL type instruction causes a push onto the stack. The Stack Pointer is first incremented and the location pointed to by the Stack Pointer is written with the contents of the PC (already pointing to the instruction following the CALL). A RETURN type instruction causes a pop from the stack. The contents of the location pointed to by the STKPTR are transferred to the PC and then the Stack Pointer is decremented.

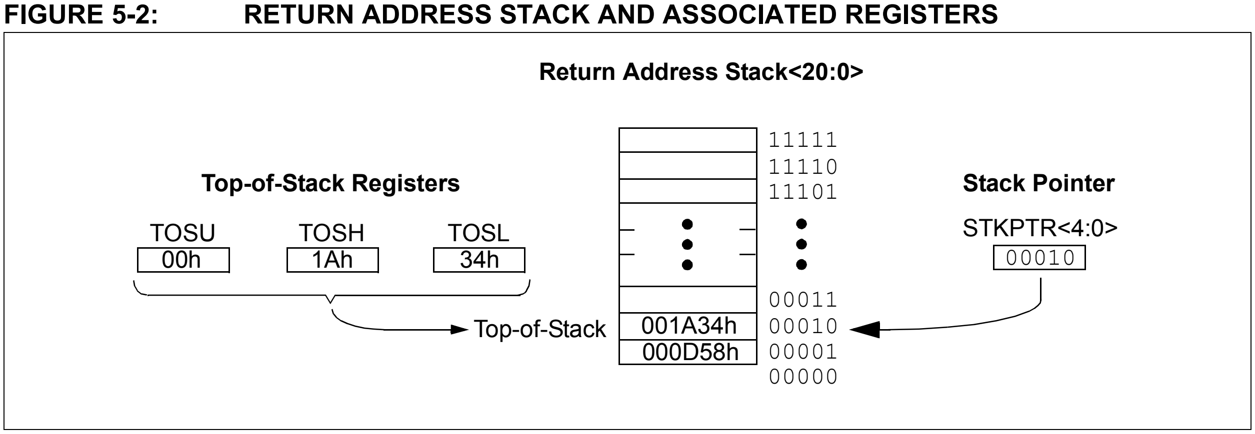
The Stack Pointer is initialized to ‘00000’ after all Resets. There is no RAM associated with the location corresponding to a Stack Pointer value of ‘00000’; this is only a Reset value. Status bits indicate if the stack is full, has overflowed or has underflowed.

5.1.2.1 Top-of-Stack Access

Only the top of the return address stack (TOS) is readable and writable. A set of three registers, TOSU:TOSH:TOSL, hold the contents of the stack location pointed to by the STKPTR register (Figure 5-2). This allows users to implement a software stack if necessary. After a CALL, RCALL or interrupt, the software can read the pushed value by reading the TOSU:TOSH:TOSL registers. These values can be placed on a user-defined software stack. At return time, the software can return these values to TOSU:TOSH:TOSL and do a return.

The user must disable the global interrupt enable bits while accessing the stack to prevent inadvertent stack corruption.

FIGURE 5-2: RETURN ADDRESS STACK AND ASSOCIATED REGISTERS



5.1.2.2 Return Stack Pointer (STKPTR)

The STKPTR register (Register 5-1) contains the Stack Pointer value, the STKFUL (Stack Full) status bit and the STKUNF (Stack Underflow) status bit. The value of the Stack Pointer can be 0 through 31. The Stack Pointer increments before values are pushed onto the stack and decrements after values are popped off the stack. On Reset, the Stack Pointer value will be zero. The user may read and write the Stack Pointer value. This feature can be used by a Real-Time Operating System (RTOS) for return stack maintenance.

After the PC is pushed onto the stack 31 times (without popping any values off the stack), the STKFUL bit is set. The STKFUL bit is cleared by software or by a POR.

The action that takes place when the stack becomes full depends on the state of the STVREN (Stack Overflow Reset Enable) Configuration bit. (Refer to **Section 18.1 "Configuration Bits"** for a description of the device Configuration bits.) If STVREN is set (default), the 31st push will push the (PC + 2) value onto the stack, set the STKFUL bit and reset the device. The STKFUL bit will remain set and the Stack Pointer will be set to zero.

If STVREN is cleared, the STKFUL bit will be set on the 31st push and the Stack Pointer will increment to 31. Any additional pushes will not overwrite the 31st push and the STKPTR will remain at 31.

When the stack has been popped enough times to unload the stack, the next pop will return a value of zero to the PC and sets the STKUNF bit, while the Stack Pointer remains at zero. The STKUNF bit will remain set until cleared by software or until a POR occurs.

Note:	Returning a value of zero to the PC on an underflow has the effect of vectoring the program to the Reset vector, where the stack conditions can be verified and appropriate actions can be taken. This is not the same as a Reset, as the contents of the SFRs are not affected.

5.1.2.3 `PUSH` and `POP` Instructions

Since the Top-of-Stack is readable and writable, the ability to push values onto the stack and pull values off the stack, without disturbing normal program execution, is a desirable feature. The PIC18 instruction set includes two instructions, `PUSH` and `POP`, that permit the TOS to be manipulated under software control. TOSU, TOSH and TOSL can be modified to place data or a return address on the stack.

The `PUSH` instruction places the current PC value onto the stack. This increments the Stack Pointer and loads the current PC value onto the stack.

The `POP` instruction discards the current TOS by decrementing the Stack Pointer. The previous value pushed onto the stack then becomes the TOS value.

REGISTER 5-1: STKPTR: STACK POINTER REGISTER

R/C-0	R/C-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
STKFUL(1)	STKUNF(1)	—	SP4	SP3	SP2	SP1	SP0
bit 7							bit 0

Legend:	C = Clearable bit		
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

bit 7 **STKFUL:** Stack Full Flag bit(1)
`1` = Stack became full or overflowed
`0` = Stack has not become full or overflowed

bit 6 **STKUNF:** Stack Underflow Flag bit(1)
`1` = Stack underflow occurred
`0` = Stack underflow did not occur

bit 5 **Unimplemented:** Read as '`0`'

bit 4-0 **SP4:SP0:** Stack Pointer Location bits

Note 1: Bit 7 and bit 6 are cleared by user software or by a POR.

5.1.2.4 Stack Full and Underflow Resets

Device Resets on stack overflow and stack underflow conditions are enabled by setting the STVREN bit in Configuration Register 4L. When STVREN is set, a full or underflow condition will set the appropriate STKFUL or STKUNF bit and then cause a device Reset. When STVREN is cleared, a full or underflow condition will set the appropriate STKFUL or STKUNF bit but not cause a device Reset. The STKFUL or STKUNF bits are cleared by user software or a Power-on Reset.

5.1.3 FAST REGISTER STACK

A Fast Register Stack is provided for the STATUS, WREG and BSR registers to provide a “fast return” option for interrupts. Each stack is only one level deep and is neither readable nor writable. It is loaded with the current value of the corresponding register when the processor vectors for an interrupt. All interrupt sources will push values into the stack registers. The values in the registers are then loaded back into their associated registers if the `RETFIE, FAST` instruction is used to return from the interrupt.

If both low and high-priority interrupts are enabled, the stack registers cannot be used reliably to return from low-priority interrupts. If a high-priority interrupt occurs while servicing a low-priority interrupt, the stack register values stored by the low-priority interrupt will be overwritten. In these cases, users must save the key registers in software during a low-priority interrupt.

If interrupt priority is not used, all interrupts may use the Fast Register Stack for returns from interrupt. If no interrupts are used, the Fast Register Stack can be used to restore the STATUS, WREG and BSR registers at the end of a subroutine call. To use the Fast Register Stack for a subroutine call, a `CALL label, FAST` instruction must be executed to save the STATUS, WREG and BSR registers to the Fast Register Stack. A `RETURN, FAST` instruction is then executed to restore these registers from the Fast Register Stack.

Example 5-1 shows a source code example that uses the Fast Register Stack during a subroutine call and return.

EXAMPLE 5-1: FAST REGISTER STACK CODE EXAMPLE

```
CALL  SUB1, FAST     ;STATUS, WREG, BSR
                     ;SAVED IN FAST REGISTER
                     ;STACK
      •
      •

SUB1  •
      •
      RETURN, FAST   ;RESTORE VALUES SAVED
                     ;IN FAST REGISTER STACK
```

5.1.4 LOOK-UP TABLES IN PROGRAM MEMORY

There may be programming situations that require the creation of data structures, or look-up tables, in program memory. For PIC18 devices, look-up tables can be implemented in two ways:

- Computed `GOTO`
- Table Reads

5.1.4.1 Computed `GOTO`

A computed `GOTO` is accomplished by adding an offset to the program counter. An example is shown in Example 5-2.

A look-up table can be formed with an `ADDWF PCL` instruction and a group of `RETLW nn` instructions. The W register is loaded with an offset into the table before executing a call to that table. The first instruction of the called routine is the `ADDWF PCL` instruction. The next instruction executed will be one of the `RETLW nn` instructions that returns the value ‘`nn`’ to the calling function.

The offset value (in WREG) specifies the number of bytes that the program counter should advance and should be multiples of 2 (LSb = `0`).

In this method, only one data byte may be stored in each instruction location and room on the return address stack is required.

EXAMPLE 5-2: COMPUTED `GOTO` USING AN OFFSET VALUE

```
        MOVF    OFFSET, W
        CALL    TABLE
ORG     nn00h
TABLE   ADDWF   PCL
        RETLW   nnh
        RETLW   nnh
        RETLW   nnh
        .
        .
        .
```

5.1.4.2 Table Reads and Table Writes

A better method of storing data in program memory allows two bytes of data to be stored in each instruction location.

Look-up table data may be stored two bytes per program word by using table reads and writes. The Table Pointer (TBLPTR) register specifies the byte address and the Table Latch (TABLAT) register contains the data that is read from or written to program memory. Data is transferred to or from program memory one byte at a time.

Table read and table write operations are discussed further in **Section 6.1 “Table Reads and Table Writes”**.

5.2 PIC18 Instruction Cycle

5.2.1 CLOCKING SCHEME

The microcontroller clock input, whether from an internal or external source, is internally divided by four to generate four non-overlapping quadrature clocks (Q1, Q2, Q3 and Q4). Internally, the program counter is incremented on every Q1; the instruction is fetched from the program memory and latched into the Instruction Register (IR) during Q4. The instruction is decoded and executed during the following Q1 through Q4. The clocks and instruction execution flow are shown in Figure 5-3.

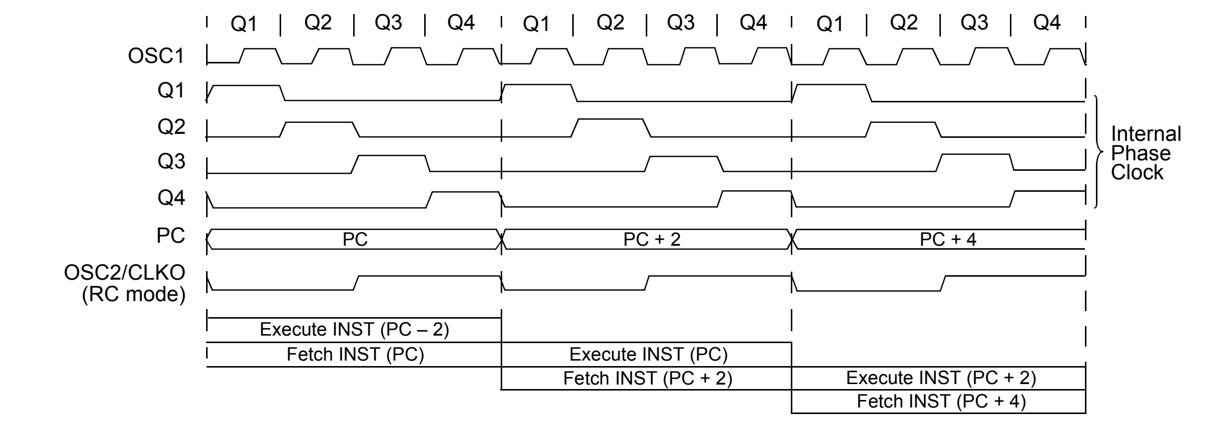
5.2.2 INSTRUCTION FLOW/PIPELINING

An "Instruction Cycle" consists of four Q cycles: Q1 through Q4. The instruction fetch and execute are pipelined in such a manner that a fetch takes one instruction cycle, while the decode and execute takes another instruction cycle. However, due to the pipelining, each instruction effectively executes in one cycle. If an instruction causes the program counter to change (e.g., `GOTO`), then two cycles are required to complete the instruction (Example 5-3).

A fetch cycle begins with the Program Counter (PC) incrementing in Q1.

In the execution cycle, the fetched instruction is latched into the Instruction Register (IR) in cycle Q1. This instruction is then decoded and executed during the Q2, Q3 and Q4 cycles. Data memory is read during Q2 (operand read) and written during Q4 (destination write).

FIGURE 5-3: CLOCK/INSTRUCTION CYCLE



EXAMPLE 5-3: INSTRUCTION PIPELINE FLOW

	TCY0	TCY1	TCY2	TCY3	TCY4	TCY5
`1. MOVLW 55h`	Fetch 1	Execute 1				
`2. MOVWF PORTB`		Fetch 2	Execute 2			
`3. BRA SUB_1`			Fetch 3	Execute 3		
`4. BSF PORTA, BIT3 (Forced NOP)`				Fetch 4	Flush (`NOP`)	
`5. Instruction @ address SUB_1`					Fetch SUB_1	Execute SUB_1

Note: All instructions are single cycle, except for any program branches. These take two cycles since the fetch instruction is "flushed" from the pipeline while the new instruction is being fetched and then executed.

5.2.3 INSTRUCTIONS IN PROGRAM MEMORY

The program memory is addressed in bytes. Instructions are stored as two bytes or four bytes in program memory. The Least Significant Byte of an instruction word is always stored in a program memory location with an even address (LSb = `0`). To maintain alignment with instruction boundaries, the PC increments in steps of 2 and the LSb will always read '`0`' (see **Section 5.1.1 "Program Counter"**).

Figure 5-4 shows an example of how instruction words are stored in the program memory.

The `CALL` and `GOTO` instructions have the absolute program memory address embedded into the instruction. Since instructions are always stored on word boundaries, the data contained in the instruction is a word address. The word address is written to PC<20:1>, which accesses the desired byte address in program memory. Instruction #2 in Figure 5-4 shows how the instruction, `GOTO 0006h`, is encoded in the program memory. Program branch instructions, which encode a relative address offset, operate in the same manner. The offset value stored in a branch instruction represents the number of single-word instructions that the PC will be offset by. **Section 19.0 "Instruction Set Summary"** provides further details of the instruction set.

FIGURE 5-4: INSTRUCTIONS IN PROGRAM MEMORY

Program Memory Byte Locations →

			LSB = 1	LSB = 0	Word Address ↓
					000000h
					000002h
					000004h
					000006h
Instruction 1:	`MOVLW`	`055h`	0Fh	55h	000008h
Instruction 2:	`GOTO`	`0006h`	EFh	03h	00000Ah
			F0h	00h	00000Ch
Instruction 3:	`MOVFF`	`123h, 456h`	C1h	23h	00000Eh
			F4h	56h	000010h
					000012h
					000014h

5.2.4 TWO-WORD INSTRUCTIONS

The standard PIC18 instruction set has four two-word instructions: `CALL`, `MOVFF`, `GOTO` and `LSFR`. In all cases, the second word of the instructions always has '`1111`' as its four Most Significant bits; the other 12 bits are literal data, usually a data memory address.

The use of '`1111`' in the 4 MSbs of an instruction specifies a special form of `NOP`. If the instruction is executed in proper sequence, immediately after the first word, the data in the second word is accessed and used by the instruction sequence. If the first word is skipped for some reason and the second word is executed by itself, a `NOP` is executed instead. This is necessary for cases when the two-word instruction is preceded by a conditional instruction that changes the PC. Example 5-4 shows how this works.

> **Note:** See **Section 5.5 "Program Memory and the Extended Instruction Set"** for information on two-word instruction in the extended instruction set.

EXAMPLE 5-4: TWO-WORD INSTRUCTIONS

CASE 1:

Object Code	Source Code
0110 0110 0000 0000	`TSTFSZ REG1 ; is RAM location 0?`
1100 0001 0010 0011	`MOVFF REG1, REG2 ; No, skip this word`
1111 0100 0101 0110	`; Execute this word as a NOP`
0010 0100 0000 0000	`ADDWF REG3 ; continue code`

CASE 2:

Object Code	Source Code
0110 0110 0000 0000	`TSTFSZ REG1 ; is RAM location 0?`
1100 0001 0010 0011	`MOVFF REG1, REG2 ; Yes, execute this word`
1111 0100 0101 0110	`; 2nd word of instruction`
0010 0100 0000 0000	`ADDWF REG3 ; continue code`

5.3 Data Memory Organization

Note:	The operation of some aspects of data memory are changed when the PIC18 extended instruction set is enabled. See **Section 5.6 "Data Memory and the Extended Instruction Set"** for more information.

The data memory in PIC18 devices 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 memory space is divided into as many as 16 banks that contain 256 bytes each. PIC18F2450/4450 devices implement three complete banks, for a total of 768 bytes. Figure 5-5 shows the data memory organization for the devices.

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 scratchpad operations in the user's application. Any read of an unimplemented location will read as '0's.

The instruction set and architecture allow operations across all banks. The entire data memory may be accessed by Direct, Indirect or Indexed Addressing modes. Addressing modes are discussed later in this subsection.

To ensure that commonly used registers (SFRs and select GPRs) can be accessed in a single cycle, PIC18 devices implement an Access Bank. This is a 256-byte memory space that provides fast access to SFRs and the lower portion of GPR Bank 0 without using the BSR. **Section 5.3.3 "Access Bank"** provides a detailed description of the Access RAM.

5.3.1 USB RAM

Bank 4 of the data memory is actually mapped to special dual port RAM. When the USB module is disabled, the GPRs in these banks are used like any other GPR in the data memory space.

When the USB module is enabled, the memory in this bank is allocated as buffer RAM for USB operation. This area is shared between the microcontroller core and the USB Serial Interface Engine (SIE) and is used to transfer data directly between the two.

It is theoretically possible to use this area of USB RAM that is not allocated as USB buffers for normal scratch-pad memory or other variable storage. In practice, the dynamic nature of buffer allocation makes this risky at best. Bank 4 is also used for USB buffer management when the module is enabled and should not be used for any other purposes during that time.

Additional information on USB RAM and buffer operation is provided in **Section 14.0 "Universal Serial Bus (USB)"**.

5.3.2 BANK SELECT REGISTER (BSR)

Large areas of data memory require an efficient addressing scheme to make rapid access to any address possible. Ideally, this means that an entire address does not need to be provided for each read or write operation. For PIC18 devices, this is accomplished with a RAM banking scheme. This divides the memory space into 16 contiguous banks of 256 bytes. Depending on the instruction, each location can be addressed directly by its full 12-bit address, or an 8-bit low-order address and a 4-bit Bank Pointer.

Most instructions in the PIC18 instruction set make use of the Bank Pointer, known as the Bank Select Register (BSR). This SFR holds the 4 Most Significant bits of a location's address; the instruction itself includes the 8 Least Significant bits. Only the four lower bits of the BSR are implemented (BSR3:BSR0). The upper four bits are unused; they will always read '0' and cannot be written to. The BSR can be loaded directly by using the `MOVLB` instruction.

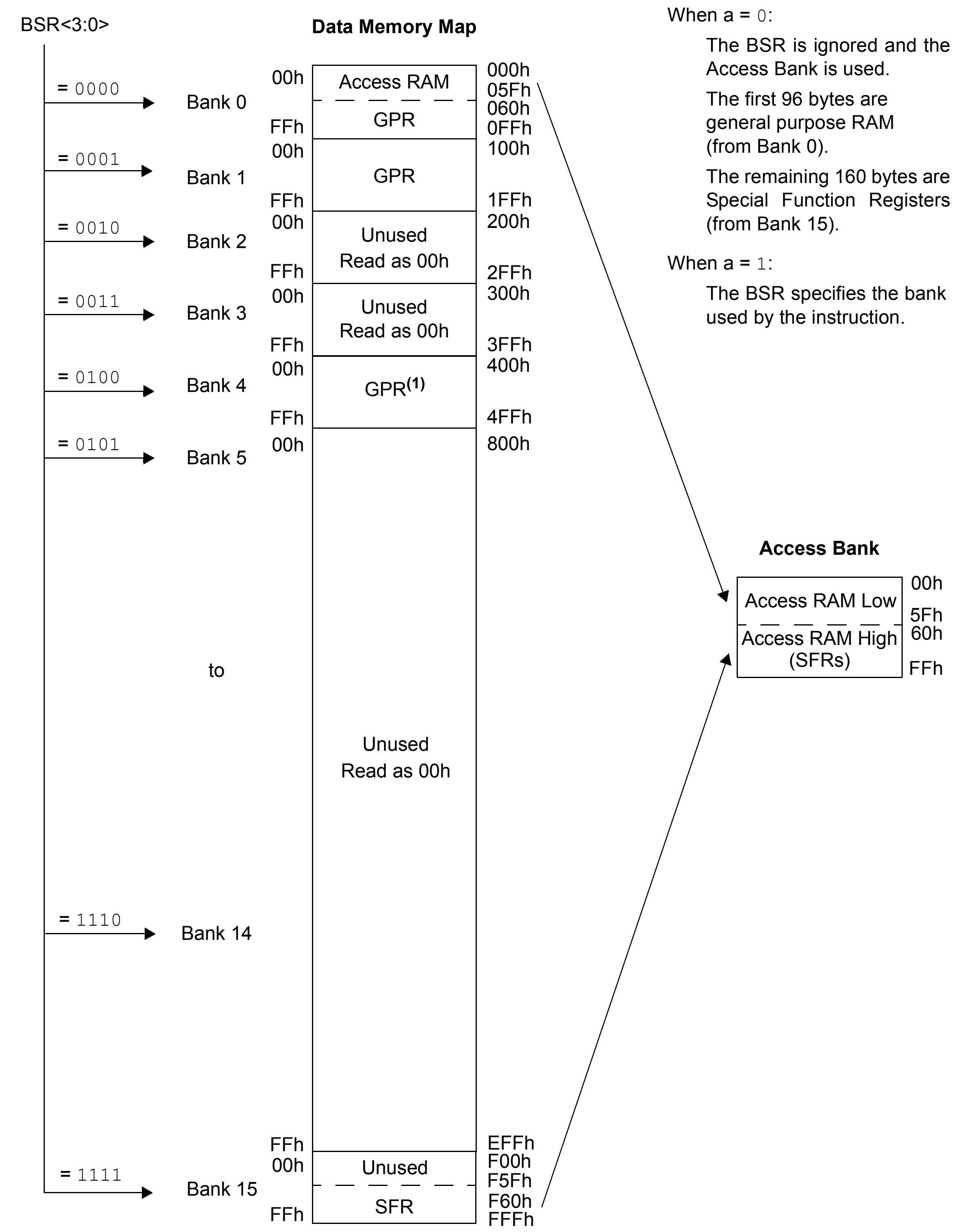
The value of the BSR indicates the bank in data memory. The eight bits in the instruction show the location in the bank and can be thought of as an offset from the bank's lower boundary. The relationship between the BSR's value and the bank division in data memory is shown in Figure 5-6.

Since up to 16 registers may share the same low-order address, the user must always be careful to ensure that the proper bank is selected before performing a data read or write. For example, writing what should be program data to an 8-bit address of F9h, while the BSR is 0Fh, will end up resetting the program counter.

While any bank can be selected, only those banks that are actually implemented can be read or written to. Writes to unimplemented banks are ignored, while reads from unimplemented banks will return '0's. Even so, the STATUS register will still be affected as if the operation was successful. The data memory map in Figure 5-6 indicates which banks are implemented.

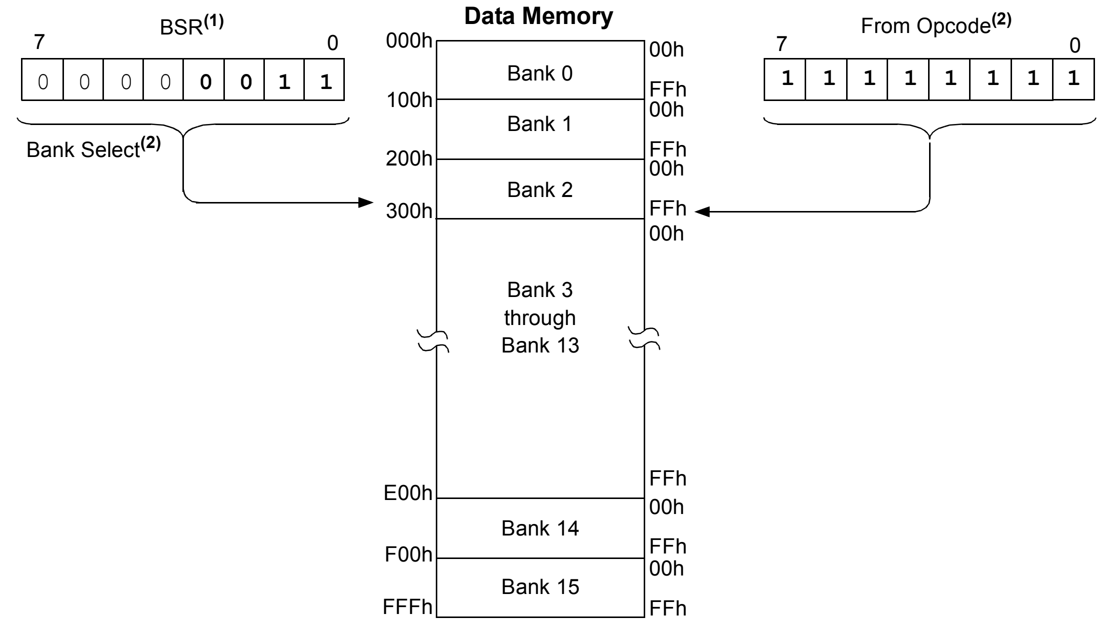
In the core PIC18 instruction set, only the `MOVFF` instruction fully specifies the 12-bit address of the source and target registers. This instruction ignores the BSR completely when it executes. All other instructions include only the low-order address as an operand and must use either the BSR or the Access Bank to locate their target registers.

FIGURE 5-5: DATA MEMORY MAP FOR PIC18F2450/4450 DEVICES



Note 1: This bank also serve as RAM buffer for USB operation. See **Section 5.3.1 "USB RAM"** for more information.

FIGURE 5-6: USE OF THE BANK SELECT REGISTER (DIRECT ADDRESSING)



Note 1: The Access RAM bit of the instruction can be used to force an override of the selected bank (BSR<3:0>) to the registers of the Access Bank.

2: The `MOVFF` instruction embeds the entire 12-bit address in the instruction.

5.3.3 ACCESS BANK

While the use of the BSR, with an embedded 8-bit address, allows users to address the entire range of data memory, it also means that the user must always ensure that the correct bank is selected. Otherwise, data may be read from or written to the wrong location. This can be disastrous if a GPR is the intended target of an operation but an SFR is written to instead. Verifying and/or changing the BSR for each read or write to data memory can become very inefficient.

To streamline access for the most commonly used data memory locations, the data memory is configured with an Access Bank, which allows users to access a mapped block of memory without specifying a BSR. The Access Bank consists of the first 96 bytes of memory (00h-5Fh) in Bank 0 and the last 160 bytes of memory (60h-FFh) in Block 15. The lower half is known as the "Access RAM" and is composed of GPRs. The upper half is where the device's SFRs are mapped. These two areas are mapped contiguously in the Access Bank and can be addressed in a linear fashion by an 8-bit address (Figure 5-5).

The Access Bank is used by core PIC18 instructions that include the Access RAM bit (the 'a' parameter in the instruction). When 'a' is equal to '`1`', the instruction uses the BSR and the 8-bit address included in the opcode for the data memory address. When 'a' is '`0`', however, the instruction is forced to use the Access Bank address map; the current value of the BSR is ignored entirely.

Using this "forced" addressing allows the instruction to operate on a data address in a single cycle without updating the BSR first. For 8-bit addresses of 60h and above, this means that users can evaluate and operate on SFRs more efficiently. The Access RAM below 60h is a good place for data values that the user might need to access rapidly, such as immediate computational results or common program variables. Access RAM also allows for faster and more code efficient context saving and switching of variables.

The mapping of the Access Bank is slightly different when the extended instruction set is enabled (XINST Configuration bit = `1`). This is discussed in more detail in **Section 5.6.3 "Mapping the Access Bank in Indexed Literal Offset Mode"**.

5.3.4 GENERAL PURPOSE REGISTER FILE

PIC18 devices may have banked memory in the GPR area. This is data RAM which is available for use by all instructions. GPRs start at the bottom of Bank 0 (address 000h) and grow upwards towards the bottom of the SFR area. GPRs are not initialized by a Power-on Reset and are unchanged on all other Resets.

5.3.5 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 in the data memory space. SFRs start at the top of data memory and extend downward to occupy the top segment of Bank 15, from F60h to FFFh. A list of these registers is given in Table 5-1 and Table 5-2.

The SFRs can be classified into two sets: those associated with the "core" device functionality (ALU, Resets and interrupts) and those related to the peripheral functions. The Reset and interrupt registers are described in their respective chapters, while the ALU's STATUS register is described later in this section. Registers related to the operation of a peripheral feature are described in the chapter for that peripheral.

The SFRs are typically distributed among the peripherals whose functions they control. Unused SFR locations are unimplemented and read as '0's.

TABLE 5-1: SPECIAL FUNCTION REGISTER MAP FOR PIC18F2450/4450 DEVICES

Address	Name	Address	Name	Address	Name	Address	Name	Address	Name
FFFh	TOSU	FDFh	INDF2(1)	FBFh	CCPR1H	F9Fh	IPR1	F7Fh	UEP15
FFEh	TOSH	FDEh	POSTINC2(1)	FBEh	CCPR1L	F9Eh	PIR1	F7Eh	UEP14
FFDh	TOSL	FDDh	POSTDEC2(1)	FBDh	CCP1CON	F9Dh	PIE1	F7Dh	UEP13
FFCh	STKPTR	FDCh	PREINC2(1)	FBCh	—(2)	F9Ch	—(2)	F7Ch	UEP12
FFBh	PCLATU	FDBh	PLUSW2(1)	FBBh	—(2)	F9Bh	—(2)	F7Bh	UEP11
FFAh	PCLATH	FDAh	FSR2H	FBAh	—(2)	F9Ah	—(2)	F7Ah	UEP10
FF9h	PCL	FD9h	FSR2L	FB9h	—(2)	F99h	—(2)	F79h	UEP9
FF8h	TBLPTRU	FD8h	STATUS	FB8h	BAUDCON	F98h	—(2)	F78h	UEP8
FF7h	TBLPTRH	FD7h	TMR0H	FB7h	—(2)	F97h	—(2)	F77h	UEP7
FF6h	TBLPTRL	FD6h	TMR0L	FB6h	—(2)	F96h	TRISE(3)	F76h	UEP6
FF5h	TABLAT	FD5h	T0CON	FB5h	—(2)	F95h	TRISD(3)	F75h	UEP5
FF4h	PRODH	FD4h	—(2)	FB4h	—(2)	F94h	TRISC	F74h	UEP4
FF3h	PRODL	FD3h	OSCCON	FB3h	—(2)	F93h	TRISB	F73h	UEP3
FF2h	INTCON	FD2h	HLVDCON	FB2h	—(2)	F92h	TRISA	F72h	UEP2
FF1h	INTCON2	FD1h	WDTCON	FB1h	—(2)	F91h	—(2)	F71h	UEP1
FF0h	INTCON3	FD0h	RCON	FB0h	SPBRGH	F90h	—(2)	F70h	UEP0
FEFh	INDF0(1)	FCFh	TMR1H	FAFh	SPBRG	F8Fh	—(2)	F6Fh	UCFG
FEEh	POSTINC0(1)	FCEh	TMR1L	FAEh	RCREG	F8Eh	—(2)	F6Eh	UADDR
FEDh	POSTDEC0(1)	FCDh	T1CON	FADh	TXREG	F8Dh	LATE(3)	F6Dh	UCON
FECh	PREINC0(1)	FCCh	TMR2	FACh	TXSTA	F8Ch	LATD(3)	F6Ch	USTAT
FEBh	PLUSW0(1)	FCBh	PR2	FABh	RCSTA	F8Bh	LATC	F6Bh	UEIE
FEAh	FSR0H	FCAh	T2CON	FAAh	—(2)	F8Ah	LATB	F6Ah	UEIR
FE9h	FSR0L	FC9h	—(2)	FA9h	—(2)	F89h	LATA	F69h	UIE
FE8h	WREG	FC8h	—(2)	FA8h	—(2)	F88h	—(2)	F68h	UIR
FE7h	INDF1(1)	FC7h	—(2)	FA7h	EECON2(1)	F87h	—(2)	F67h	UFRMH
FE6h	POSTINC1(1)	FC6h	—(2)	FA6h	EECON1	F86h	—(2)	F66h	UFRML
FE5h	POSTDEC1(1)	FC5h	—(2)	FA5h	—(2)	F85h	—(2)	F65h	—(2)
FE4h	PREINC1(1)	FC4h	ADRESH	FA4h	—(2)	F84h	PORTE	F64h	—(2)
FE3h	PLUSW1(1)	FC3h	ADRESL	FA3h	—(2)	F83h	PORTD(3)	F63h	—(2)
FE2h	FSR1H	FC2h	ADCON0	FA2h	IPR2	F82h	PORTC	F62h	—(2)
FE1h	FSR1L	FC1h	ADCON1	FA1h	PIR2	F81h	PORTB	F61h	—(2)
FE0h	BSR	FC0h	ADCON2	FA0h	PIE2	F80h	PORTA	F60h	—(2)

Note 1: Not a physical register.
2: Unimplemented registers are read as '0'.
3: These registers are implemented only on 40/44-pin devices.

TABLE 5-2: REGISTER FILE SUMMARY (PIC18F2450/4450)

File Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on POR, BOR	Details on Page:
TOSU	—	—	—	Top-of-Stack Upper Byte (TOS<20:16>)					---0 0000	49, 54
TOSH	Top-of-Stack High Byte (TOS<15:8>)								0000 0000	49, 54
TOSL	Top-of-Stack Low Byte (TOS<7:0>)								0000 0000	49, 54
STKPTR	STKFUL	STKUNF	—	SP4	SP3	SP2	SP1	SP0	00-0 0000	49, 55
PCLATU	—	—	—	Holding Register for PC<20:16>					---0 0000	49, 54
PCLATH	Holding Register for PC<15:8>								0000 0000	49, 54
PCL	PC Low Byte (PC<7:0>)								0000 0000	49, 54
TBLPTRU	—	—	bit 21[(1)]	Program Memory Table Pointer Upper Byte (TBLPTR<20:16>)					--00 0000	49, 76
TBLPTRH	Program Memory Table Pointer High Byte (TBLPTR<15:8>)								0000 0000	49, 76
TBLPTRL	Program Memory Table Pointer Low Byte (TBLPTR<7:0>)								0000 0000	49, 76
TABLAT	Program Memory Table Latch								0000 0000	49, 76
PRODH	Product Register High Byte								xxxx xxxx	49, 83
PRODL	Product Register Low Byte								xxxx xxxx	49, 83
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	0000 000x	49, 87
INTCON2	$\overline{\text{RBPU}}$	INTEDG0	INTEDG1	INTEDG2	—	TMR0IP	—	RBIP	1111 -1-1	49, 88
INTCON3	INT2IP	INT1IP	—	INT2IE	INT1IE	—	INT2IF	INT1IF	11-0 0-00	49, 89
INDF0	Uses contents of FSR0 to address data memory – value of FSR0 not changed (not a physical register)								N/A	49, 68
POSTINC0	Uses contents of FSR0 to address data memory – value of FSR0 post-incremented (not a physical register)								N/A	49, 69
POSTDEC0	Uses contents of FSR0 to address data memory – value of FSR0 post-decremented (not a physical register)								N/A	49, 69
PREINC0	Uses contents of FSR0 to address data memory – value of FSR0 pre-incremented (not a physical register)								N/A	49, 69
PLUSW0	Uses contents of FSR0 to address data memory – value of FSR0 pre-incremented (not a physical register) – value of FSR0 offset by W								N/A	49, 69
FSR0H	—	—	—	—	Indirect Data Memory Address Pointer 0 High Byte				---- 0000	49, 68
FSR0L	Indirect Data Memory Address Pointer 0 Low Byte								xxxx xxxx	49, 68
WREG	Working Register								xxxx xxxx	49,
INDF1	Uses contents of FSR1 to address data memory – value of FSR1 not changed (not a physical register)								N/A	49, 68
POSTINC1	Uses contents of FSR1 to address data memory – value of FSR1 post-incremented (not a physical register)								N/A	49, 69
POSTDEC1	Uses contents of FSR1 to address data memory – value of FSR1 post-decremented (not a physical register)								N/A	49, 69
PREINC1	Uses contents of FSR1 to address data memory – value of FSR1 pre-incremented (not a physical register)								N/A	49, 69
PLUSW1	Uses contents of FSR1 to address data memory – value of FSR1 pre-incremented (not a physical register) – value of FSR1 offset by W								N/A	49, 69
FSR1H	—	—	—	—	Indirect Data Memory Address Pointer 1 High Byte				---- 0000	49, 68
FSR1L	Indirect Data Memory Address Pointer 1 Low Byte								xxxx xxxx	49, 68
BSR	—	—	—	—	Bank Select Register				---- 0000	49, 59
INDF2	Uses contents of FSR2 to address data memory – value of FSR2 not changed (not a physical register)								N/A	50, 68
POSTINC2	Uses contents of FSR2 to address data memory – value of FSR2 post-incremented (not a physical register)								N/A	50, 69
POSTDEC2	Uses contents of FSR2 to address data memory – value of FSR2 post-decremented (not a physical register)								N/A	50, 69
PREINC2	Uses contents of FSR2 to address data memory – value of FSR2 pre-incremented (not a physical register)								N/A	50, 69
PLUSW2	Uses contents of FSR2 to address data memory – value of FSR2 pre-incremented (not a physical register) – value of FSR2 offset by W								N/A	50, 69
FSR2H	—	—	—	—	Indirect Data Memory Address Pointer 2 High Byte				---- 0000	50, 68
FSR2L	Indirect Data Memory Address Pointer 2 Low Byte								xxxx xxxx	50, 68
STATUS	—	—	—	N	OV	Z	DC	C	---x xxxx	50, 66
TMR0H	Timer0 Register High Byte								0000 0000	50, 113
TMR0L	Timer0 Register Low Byte								xxxx xxxx	50, 113
T0CON	TMR0ON	T08BIT	T0CS	T0SE	PSA	T0PS2	T0PS1	T0PS0	1111 1111	50, 111

Legend: x = unknown, u = unchanged, - = unimplemented, q = value depends on condition. Shaded cells are unimplemented, read as '0'.

Note 1: Bit 21 of the TBLPTRU allows access to the device Configuration bits.

2: The SBOREN bit is only available when BOREN<1:0> = 01; otherwise, the bit reads as '0'.

3: These registers and/or bits are not implemented on 28-pin devices and are read as '0'. Reset values are shown for 40/44-pin devices; individual unimplemented bits should be interpreted as '-'.

4: RA6 is configured as a port pin based on various primary oscillator modes. When the port pin is disabled, all of the associated bits read '0'.

5: RE3 is only available as a port pin when the MCLRE Configuration bit is clear; otherwise, the bit reads as '0'.

6: RC5 and RC4 are only available as port pins when the USB module is disabled (UCON<3> = 0).

TABLE 5-2: REGISTER FILE SUMMARY (PIC18F2450/4450) (CONTINUED)

File Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on POR, BOR	Details on Page:
OSCCON	IDLEN	—	—	—	OSTS	—	SCS1	SCS0	0--- q-00	50, 31
HLVDCON	VDIRMAG	—	IRVST	HLVDEN	HLVDL3	HLVDL2	HLVDL1	HLVDL0	0-00 0101	50, 185
WDTCON	—	—	—	—	—	—	—	SWDTEN	--- ---0	50, 204
RCON	IPEN	SBOREN(2)	—	$\overline{\text{RI}}$	$\overline{\text{TO}}$	$\overline{\text{PD}}$	$\overline{\text{POR}}$	$\overline{\text{BOR}}$	0q-1 11q0	50, 42
TMR1H	Timer1 Register High Byte								xxxx xxxx	50, 120
TMR1L	Timer1 Register Low Byte								xxxx xxxx	50, 120
T1CON	RD16	T1RUN	T1CKPS1	T1CKPS0	T1OSCEN	$\overline{\text{T1SYNC}}$	TMR1CS	TMR1ON	0000 0000	50, 115
TMR2	Timer2 Register								0000 0000	50, 122
PR2	Timer2 Period Register								1111 1111	50, 122
T2CON	—	T2OUTPS3	T2OUTPS2	T2OUTPS1	T2OUTPS0	TMR2ON	T2CKPS1	T2CKPS0	-000 0000	50, 121
ADRESH	A/D Result Register High Byte								xxxx xxxx	50, 184
ADRESL	A/D Result Register Low Byte								xxxx xxxx	50, 184
ADCON0	—	—	CHS3	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	ADON	--00 0000	50, 175
ADCON1	—	—	VCFG1	VCFG0	PCFG3	PCFG2	PCFG1	PCFG0	--00 qqqq	50, 176
ADCON2	ADFM	—	ACQT2	ACQT1	ACQT0	ADCS2	ADCS1	ADCS0	0-00 0000	50, 177
CCPR1H	Capture/Compare/PWM Register 1 High Byte								xxxx xxxx	50, 124
CCPR1L	Capture/Compare/PWM Register 1 Low Byte								xxxx xxxx	50, 124
CCP1CON	—	—	DC1B1	DC1B0	CCP1M3	CCP1M2	CCP1M1	CCP1M0	--00 0000	50, 123,
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	01-0 0-00	51, 156,
SPBRGH	EUSART Baud Rate Generator Register High Byte								0000 0000	50, 157
SPBRG	EUSART Baud Rate Generator Register Low Byte								0000 0000	50, 157
RCREG	EUSART Receive Register								0000 0000	50, 165
TXREG	EUSART Transmit Register								0000 0000	51, 163
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	0000 0010	51, 154
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	0000 000x	51, 155
EECON2	Data Memory Control Register 2 (not a physical register)								0000 0000	51, 74
EECON1	—	CFGS	—	FREE	WRERR	WREN	WR	—	-x-0 x00-	51, 75
IPR2	OSCFIP	—	USBIP	—	—	HLVDIP	—	—	1-1- -1--	51, 95
PIR2	OSCFIF	—	USBIF	—	—	HLVDIF	—	—	0-0- -0--	51, 91
PIE2	OSCFIE	—	USBIE	—	—	HLVDIE	—	—	0-0- -0--	51, 93
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	-111 -111	51, 94
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	-000 -000	51, 90
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	-000 -000	51, 92
TRISE(3)	—	—	—	—	—	TRISE2	TRISE1	TRISE0	---- -111	51, 110
TRISD(3)	TRISD7	TRISD6	TRISD5	TRISD4	TRISD3	TRISD2	TRISD1	TRISD0	1111 1111	51, 108
TRISC	TRISC7	TRISC6	—	—	—	TRISC2	TRISC1	TRISC0	11-- -111	51, 106
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	1111 1111	51, 103
TRISA	—	TRISA6(4)	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	-111 1111	51, 100
LATE(3)	—	—	—	—	—	LATE2	LATE1	LATE0	---- -xxx	51, 110
LATD(3)	LATD7	LATD6	LATD5	LATD4	LATD3	LATD2	LATD1	LATD0	xxxx xxxx	51, 108
LATC	LATC7	LATC6	—	—	—	LATC2	LATC1	LATC0	xx-- -xxx	51, 106
LATB	LATB7	LATB6	LATB5	LATB4	LATB3	LATB2	LATB1	LATB0	xxxx xxxx	51, 103
LATA	—	LATA6(4)	LATA5	LATA4	LATA3	LATA2	LATA1	LATA0	-xxx xxxx	51, 100
PORTE	—	—	—	—	RE3(5)	RE2(3)	RE1(3)	RE0(3)	---- x000	51, 109
PORTD(3)	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD0	xxxx xxxx	51, 108

Legend: x = unknown, u = unchanged, - = unimplemented, q = value depends on condition. Shaded cells are unimplemented, read as '0'.

Note 1: Bit 21 of the TBLPTRU allows access to the device Configuration bits.

2: The SBOREN bit is only available when BOREN<1:0> = 01; otherwise, the bit reads as '0'.

3: These registers and/or bits are not implemented on 28-pin devices and are read as '0'. Reset values are shown for 40/44-pin devices; individual unimplemented bits should be interpreted as '-'.

4: RA6 is configured as a port pin based on various primary oscillator modes. When the port pin is disabled, all of the associated bits read '0'.

5: RE3 is only available as a port pin when the MCLRE Configuration bit is clear; otherwise, the bit reads as '0'.

6: RC5 and RC4 are only available as port pins when the USB module is disabled (UCON<3> = 0).

TABLE 5-2: REGISTER FILE SUMMARY (PIC18F2450/4450) (CONTINUED)

File Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Value on POR, BOR	Details on Page:
PORTC	RC7	RC6	RC5(6)	RC4(6)	—	RC2	RC1	RC0	xxxx -xxx	51, 106
PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0	xxxx xxxx	51, 100
PORTA	—	RA6(4)	RA5	RA4	RA3	RA2	RA1	RA0	-x0x 0000	51, 100
UEP15	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	51, 135
UEP14	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	51, 135
UEP13	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	51, 135
UEP12	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	51, 135
UEP11	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	51, 135
UEP10	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	51, 135
UEP9	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UEP8	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UEP7	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UEP6	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UEP5	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UEP4	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UEP3	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UEP2	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UEP1	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UEP0	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	---0 0000	52, 135
UCFG	UTEYE	UOEMON	—	UPUEN	UTRDIS	FSEN	PPB1	PPB0	00-0 0000	52, 132
UADDR	—	ADDR6	ADDR5	ADDR4	ADDR3	ADDR2	ADDR1	ADDR0	-000 0000	52, 136
UCON	—	PPBRST	SE0	PKTDIS	USBEN	RESUME	SUSPND	—	-0x0 000-	52, 130
USTAT	—	ENDP3	ENDP2	ENDP1	ENDP0	DIR	PPBI	—	-xxx xxx-	52, 134
UEIE	BTSEE	—	—	BTOEE	DFN8EE	CRC16EE	CRC5EE	PIDEE	0--0 0000	52, 148
UEIR	BTSEF	—	—	BTOEF	DFN8EF	CRC16EF	CRC5EF	PIDEF	0--0 0000	52, 147
UIE	—	SOFIE	STALLIE	IDLEIE	TRNIE	ACTVIE	UERRIE	URSTIE	-000 0000	52, 146
UIR	—	SOFIF	STALLIF	IDLEIF	TRNIF	ACTVIF	UERRIF	URSTIF	-000 0000	52, 144
UFRMH	—	—	—	—	—	FRM10	FRM9	FRM8	---- -xxx	52, 136
UFRML	FRM7	FRM6	FRM5	FRM4	FRM3	FRM2	FRM1	FRM0	xxxx xxxx	52, 136

Legend: x = unknown, u = unchanged, - = unimplemented, q = value depends on condition. Shaded cells are unimplemented, read as '0'.

Note 1: Bit 21 of the TBLPTRU allows access to the device Configuration bits.

2: The SBOREN bit is only available when BOREN<1:0> = 01; otherwise, the bit reads as '0'.

3: These registers and/or bits are not implemented on 28-pin devices and are read as '0'. Reset values are shown for 40/44-pin devices; individual unimplemented bits should be interpreted as '-'.

4: RA6 is configured as a port pin based on various primary oscillator modes. When the port pin is disabled, all of the associated bits read '0'.

5: RE3 is only available as a port pin when the MCLRE Configuration bit is clear; otherwise, the bit reads as '0'.

6: RC5 and RC4 are only available as port pins when the USB module is disabled (UCON<3> = 0).

5.3.6 STATUS REGISTER

The STATUS register, shown in Register 5-2, contains the arithmetic status of the ALU. As with any other SFR, it can be the operand for any instruction.

If the STATUS register is the destination for an instruction that affects the Z, DC, C, OV or N bits, the results of the instruction are not written; instead, the STATUS register is updated according to the instruction performed. Therefore, the result of an instruction with the STATUS register as its destination may be different than intended. As an example, `CLRF STATUS` will set the Z bit and leave the remaining Status bits unchanged (‘`000u u1uu`’).

It is recommended that only `BCF`, `BSF`, `SWAPF`, `MOVFF` and `MOVWF` instructions are used to alter the STATUS register because these instructions do not affect the Z, C, DC, OV or N bits in the STATUS register.

For other instructions that do not affect Status bits, see the instruction set summaries in Table 19-2 and Table 19-3.

Note:	The C and DC bits operate as the $\overline{\text{Borrow}}$ and $\overline{\text{Digit Borrow}}$ bits, respectively, in subtraction.

REGISTER 5-2: STATUS REGISTER

U-0	U-0	U-0	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x
—	—	—	N	OV	Z	DC(1)	C(2)
bit 7							bit 0

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

bit 7-5 **Unimplemented:** Read as ‘0’

bit 4 **N:** Negative bit
This bit is used for signed arithmetic (2’s complement). It indicates whether the result was negative (ALU MSB = 1).
1 = Result was negative
0 = Result was positive

bit 3 **OV:** Overflow bit
This bit is used for signed arithmetic (2’s complement). It indicates an overflow of the 7-bit magnitude which causes the sign bit (bit 7 of the result) to change state.
1 = Overflow occurred for signed arithmetic (in this arithmetic operation)
0 = No overflow occurred

bit 2 **Z:** Zero bit
1 = The result of an arithmetic or logic operation is zero
0 = The result of an arithmetic or logic operation is not zero

bit 1 **DC:** Digit Carry/$\overline{\text{Borrow}}$ bit(1)
For `ADDWF`, `ADDLW`, `SUBLW` and `SUBWF` instructions:
1 = A carry-out from the 4th low-order bit of the result occurred
0 = No carry-out from the 4th low-order bit of the result

bit 0 **C:** Carry/$\overline{\text{Borrow}}$ bit(2)
For `ADDWF`, `ADDLW`, `SUBLW` and `SUBWF` instructions:
1 = A carry-out from the Most Significant bit of the result occurred
0 = No carry-out from the Most Significant bit of the result occurred

Note 1: For $\overline{\text{borrow}}$, the polarity is reversed. A subtraction is executed by adding the 2’s complement of the second operand. For rotate (`RRF`, `RLF`) instructions, this bit is loaded with either bit 4 or bit 3 of the source register.

2: For $\overline{\text{borrow}}$, the polarity is reversed. A subtraction is executed by adding the 2’s complement of the second operand. For rotate (`RRF`, `RLF`) instructions, this bit is loaded with either the high or low-order bit of the source register.

5.4 Data Addressing Modes

Note:	The execution of some instructions in the core PIC18 instruction set are changed when the PIC18 extended instruction set is enabled. See **Section 5.6 "Data Memory and the Extended Instruction Set"** for more information.

While the program memory can be addressed in only one way – through the program counter – information in the data memory space can be addressed in several ways. For most instructions, the addressing mode is fixed. Other instructions may use up to three modes, depending on which operands are used and whether or not the extended instruction set is enabled.

The addressing modes are:

- Inherent
- Literal
- Direct
- Indirect

An additional addressing mode, Indexed Literal Offset, is available when the extended instruction set is enabled (XINST Configuration bit = `1`). Its operation is discussed in greater detail in **Section 5.6.1 "Indexed Addressing with Literal Offset"**.

5.4.1 INHERENT AND LITERAL ADDRESSING

Many PIC18 control instructions do not need any argument at all; they either perform an operation that globally affects the device or they operate implicitly on one register. This addressing mode is known as Inherent Addressing. Examples include `SLEEP`, `RESET` and `DAW`.

Other instructions work in a similar way but require an additional explicit argument in the opcode. This is known as Literal Addressing mode because they require some literal value as an argument. Examples include `ADDLW` and `MOVLW`, which respectively, add or move a literal value to the W register. Other examples include `CALL` and `GOTO`, which include a 20-bit program memory address.

5.4.2 DIRECT ADDRESSING

Direct Addressing mode specifies all or part of the source and/or destination address of the operation within the opcode itself. The options are specified by the arguments accompanying the instruction.

In the core PIC18 instruction set, bit-oriented and byte-oriented instructions use some version of Direct Addressing by default. All of these instructions include some 8-bit literal address as their Least Significant Byte. This address specifies either a register address in one of the banks of data RAM (**Section 5.3.4 "General Purpose Register File"**) or a location in the Access Bank (**Section 5.3.3 "Access Bank"**) as the data source for the instruction.

The Access RAM bit 'a' determines how the address is interpreted. When 'a' is '`1`', the contents of the BSR (**Section 5.3.2 "Bank Select Register (BSR)"**) are used with the address to determine the complete 12-bit address of the register. When 'a' is '`0`', the address is interpreted as being a register in the Access Bank. Addressing that uses the Access RAM is sometimes also known as Direct Forced Addressing mode.

A few instructions, such as `MOVFF`, include the entire 12-bit address (either source or destination) in their opcodes. In these cases, the BSR is ignored entirely.

The destination of the operation's results is determined by the destination bit 'd'. When 'd' is '`1`', the results are stored back in the source register, overwriting its original contents. When 'd' is '`0`', the results are stored in the W register. Instructions without the 'd' argument have a destination that is implicit in the instruction; their destination is either the target register being operated on or the W register.

5.4.3 INDIRECT ADDRESSING

Indirect Addressing allows the user to access a location in data memory without giving a fixed address in the instruction. This is done by using File Select Registers (FSRs) as pointers to the locations to be read or written to. Since the FSRs are themselves located in RAM as Special Function Registers, they can also be directly manipulated under program control. This makes FSRs very useful in implementing data structures, such as tables and arrays in data memory.

The registers for Indirect Addressing are also implemented with Indirect File Operands (INDFs) that permit automatic manipulation of the pointer value with auto-incrementing, auto-decrementing or offsetting with another value. This allows for efficient code, using loops, such as the example of clearing an entire RAM bank in Example 5-5.

EXAMPLE 5-5: HOW TO CLEAR RAM (BANK 1) USING INDIRECT ADDRESSING

```
        LFSR   FSR0, 100h ;
NEXT    CLRF   POSTINC0    ; Clear INDF
                           ; register then
                           ; inc pointer
        BTFSS  FSR0H, 1    ; All done with
                           ; Bank1?
        BRA    NEXT        ; NO, clear next
CONTINUE                   ; YES, continue
```

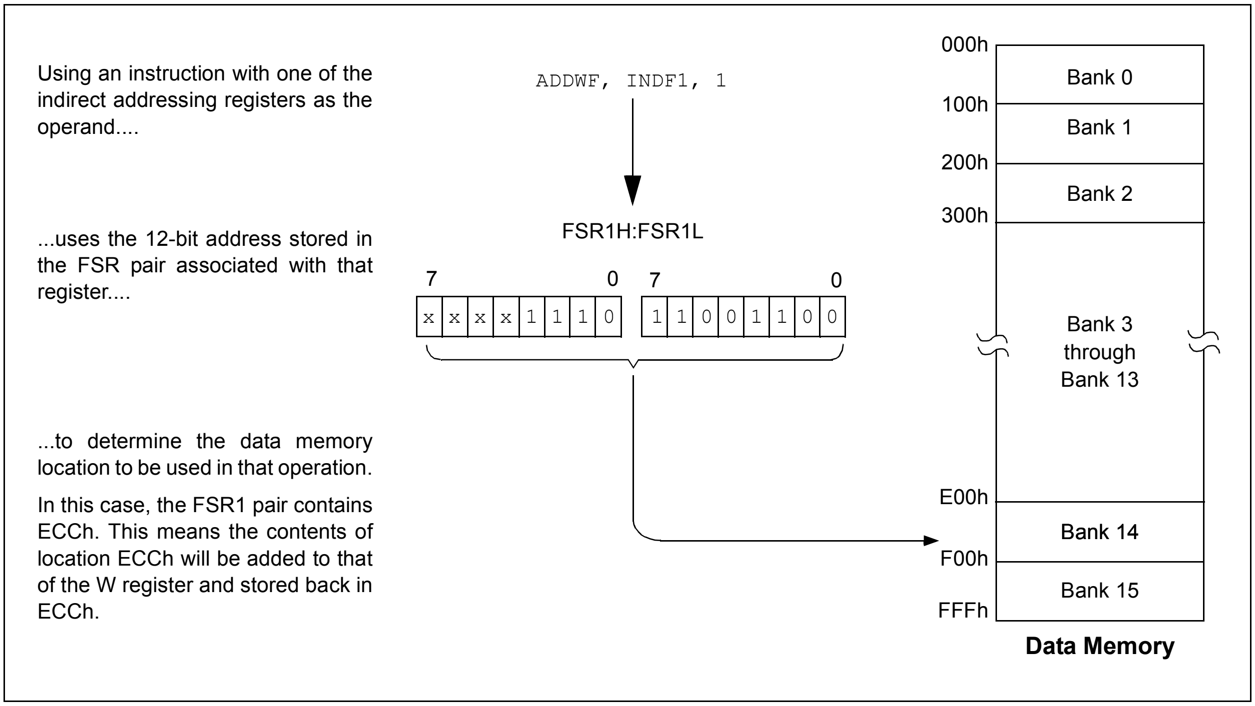
5.4.3.1 FSR Registers and the INDF Operand

At the core of Indirect Addressing are three sets of registers: FSR0, FSR1 and FSR2. Each represents a pair of 8-bit registers: FSRnH and FSRnL. The four upper bits of the FSRnH register are not used, so each FSR pair holds a 12-bit value. This represents a value that can address the entire range of the data memory in a linear fashion. The FSR register pairs, then, serve as pointers to data memory locations.

Indirect Addressing is accomplished with a set of Indirect File Operands, INDF0 through INDF2. These can be thought of as "virtual" registers; they are mapped in the SFR space but are not physically implemented. Reading or writing to a particular INDF register actually accesses its corresponding FSR register pair. A read from INDF1, for example, reads the data at the address indicated by FSR1H:FSR1L. Instructions that use the INDF registers as operands actually use the contents of their corresponding FSR as a pointer to the instruction's target. The INDF operand is just a convenient way of using the pointer.

Because Indirect Addressing uses a full 12-bit address, data RAM banking is not necessary. Thus, the current contents of the BSR and the Access RAM bit have no effect on determining the target address.

FIGURE 5-7: INDIRECT ADDRESSING



5.4.3.2 FSR Registers and POSTINC, POSTDEC, PREINC and PLUSW

In addition to the INDF operand, each FSR register pair also has four additional indirect operands. Like INDF, these are "virtual" registers that cannot be indirectly read or written to. Accessing these registers actually accesses the associated FSR register pair, but also performs a specific action on it stored value. They are:

- POSTDEC: accesses the FSR value, then automatically decrements it by '1' afterwards
- POSTINC: accesses the FSR value, then automatically increments it by '1' afterwards
- PREINC: increments the FSR value by '1', then uses it in the operation
- PLUSW: adds the signed value of the W register (range of -127 to 128) to that of the FSR and uses the new value in the operation.

In this context, accessing an INDF register uses the value in the FSR registers without changing them. Similarly, accessing a PLUSW register gives the FSR value offset by that in the W register; neither value is actually changed in the operation. Accessing the other virtual registers changes the value of the FSR registers.

Operations on the FSRs with POSTDEC, POSTINC and PREINC affect the entire register pair; that is, rollovers of the FSRnL register from FFh to 00h carry over to the FSRnH register. On the other hand, results of these operations do not change the value of any flags in the STATUS register (e.g., Z, N, OV, etc.).

The PLUSW register can be used to implement a form of Indexed Addressing in the data memory space. By manipulating the value in the W register, users can reach addresses that are fixed offsets from pointer addresses. In some applications, this can be used to implement some powerful program control structure, such as software stacks, inside of data memory.

5.4.3.3 Operations by FSRs on FSRs

Indirect Addressing operations that target other FSRs or virtual registers represent special cases. For example, using an FSR to point to one of the virtual registers will not result in successful operations. As a specific case, assume that FSR0H:FSR0L contains FE7h, the address of INDF1. Attempts to read the value of INDF1, using INDF0 as an operand, will return 00h. Attempts to write to INDF1, using INDF0 as the operand, will result in a NOP.

On the other hand, using the virtual registers to write to an FSR pair may not occur as planned. In these cases, the value will be written to the FSR pair but without any incrementing or decrementing. Thus, writing to INDF2 or POSTDEC2 will write the same value to the FSR2H:FSR2L.

Since the FSRs are physical registers mapped in the SFR space, they can be manipulated through all direct operations. Users should proceed cautiously when working on these registers, particularly if their code uses Indirect Addressing.

Similarly, operations by Indirect Addressing are generally permitted on all other SFRs. Users should exercise the appropriate caution that they do not inadvertently change settings that might affect the operation of the device.

5.5 Program Memory and the Extended Instruction Set

The operation of program memory is unaffected by the use of the extended instruction set.

Enabling the extended instruction set adds eight additional two-word commands to the existing PIC18 instruction set: ADDFSR, ADDULNK, CALLW, MOVSF, MOVSS, PUSHL, SUBFSR and SUBULNK. These instructions are executed as described in **Section 5.2.4 "Two-Word Instructions"**.

5.6 Data Memory and the Extended Instruction Set

Enabling the PIC18 extended instruction set (XINST Configuration bit = 1) significantly changes certain aspects of data memory and its addressing. Specifically, the use of the Access Bank for many of the core PIC18 instructions is different. This is due to the introduction of a new addressing mode for the data memory space. This mode also alters the behavior of Indirect Addressing using FSR2 and its associated operands.

What does not change is just as important. The size of the data memory space is unchanged, as well as its linear addressing. The SFR map remains the same. Core PIC18 instructions can still operate in both Direct and Indirect Addressing mode; inherent and literal instructions do not change at all. Indirect Addressing with FSR0 and FSR1 also remains unchanged.

5.6.1 INDEXED ADDRESSING WITH LITERAL OFFSET

Enabling the PIC18 extended instruction set changes the behavior of Indirect Addressing using the FSR2 register pair and its associated file operands. Under the proper conditions, instructions that use the Access Bank – that is, most bit-oriented and byte-oriented instructions – can invoke a form of Indexed Addressing using an offset specified in the instruction. This special addressing mode is known as Indexed Addressing with Literal Offset or Indexed Literal Offset mode.

When using the extended instruction set, this addressing mode requires the following:

- The use of the Access Bank is forced ('a' = 0); and
- The file address argument is less than or equal to 5Fh.

Under these conditions, the file address of the instruction is not interpreted as the lower byte of an address (used with the BSR in Direct Addressing), or as an 8-bit address in the Access Bank. Instead, the value is interpreted as an offset value to an Address Pointer specified by FSR2. The offset and the contents of FSR2 are added to obtain the target address of the operation.

5.6.2 INSTRUCTIONS AFFECTED BY INDEXED LITERAL OFFSET MODE

Any of the core PIC18 instructions that can use Direct Addressing are potentially affected by the Indexed Literal Offset Addressing mode. This includes all byte-oriented and bit-oriented instructions, or almost one-half of the standard PIC18 instruction set. Instructions that only use Inherent or Literal Addressing modes are unaffected.

Additionally, byte-oriented and bit-oriented instructions are not affected if they do not use the Access Bank (Access RAM bit is '1') or include a file address of 60h or above. Instructions meeting these criteria will continue to execute as before. A comparison of the different possible addressing modes when the extended instruction set is enabled in shown in Figure 5-8.

Those who desire to use byte-oriented or bit-oriented instructions in the Indexed Literal Offset mode should note the changes to assembler syntax for this mode. This is described in more detail in **Section 19.2.1 "Extended Instruction Syntax"**.

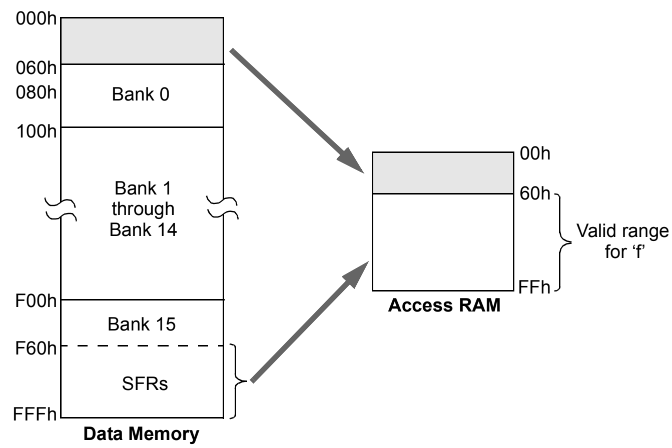
FIGURE 5-8: COMPARING ADDRESSING OPTIONS FOR BIT-ORIENTED AND BYTE-ORIENTED INSTRUCTIONS (EXTENDED INSTRUCTION SET ENABLED)

EXAMPLE INSTRUCTION: `ADDWF, f, d, a` (Opcode: `0010 01da ffff ffff`)

When a = `0` and f ≥ 60h:

The instruction executes in Direct Forced mode. ‘f’ is interpreted as a location in the Access RAM between 060h and 0FFh. This is the same as the SFRs or locations F60h to 0FFh (Bank 15) of data memory.

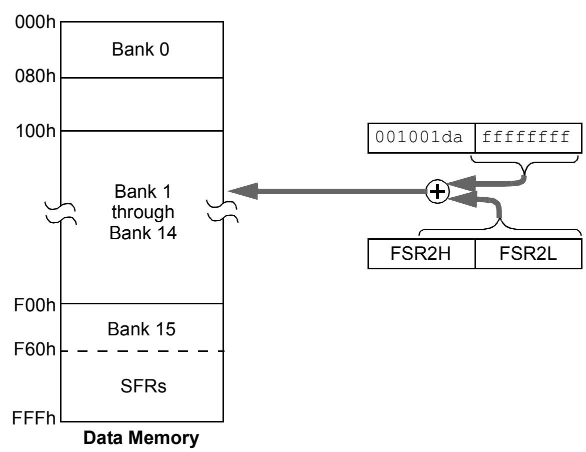
Locations below 60h are not available in this addressing mode.



When a = `0` and f ≤ 5Fh:

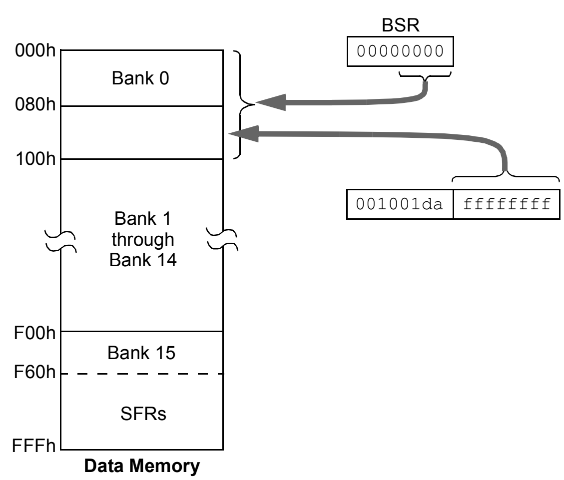
The instruction executes in Indexed Literal Offset mode. ‘f’ is interpreted as an offset to the address value in FSR2. The two are added together to obtain the address of the target register for the instruction. The address can be anywhere in the data memory space.

Note that in this mode, the correct syntax is now:
`ADDWF [k], d`
where ‘k’ is the same as ‘f’.



When a = `1` (all values of f):

The instruction executes in Direct mode (also known as Direct Long mode). ‘f’ is interpreted as a location in one of the 16 banks of the data memory space. The bank is designated by the Bank Select Register (BSR). The address can be in any implemented bank in the data memory space.



5.6.3 MAPPING THE ACCESS BANK IN INDEXED LITERAL OFFSET MODE

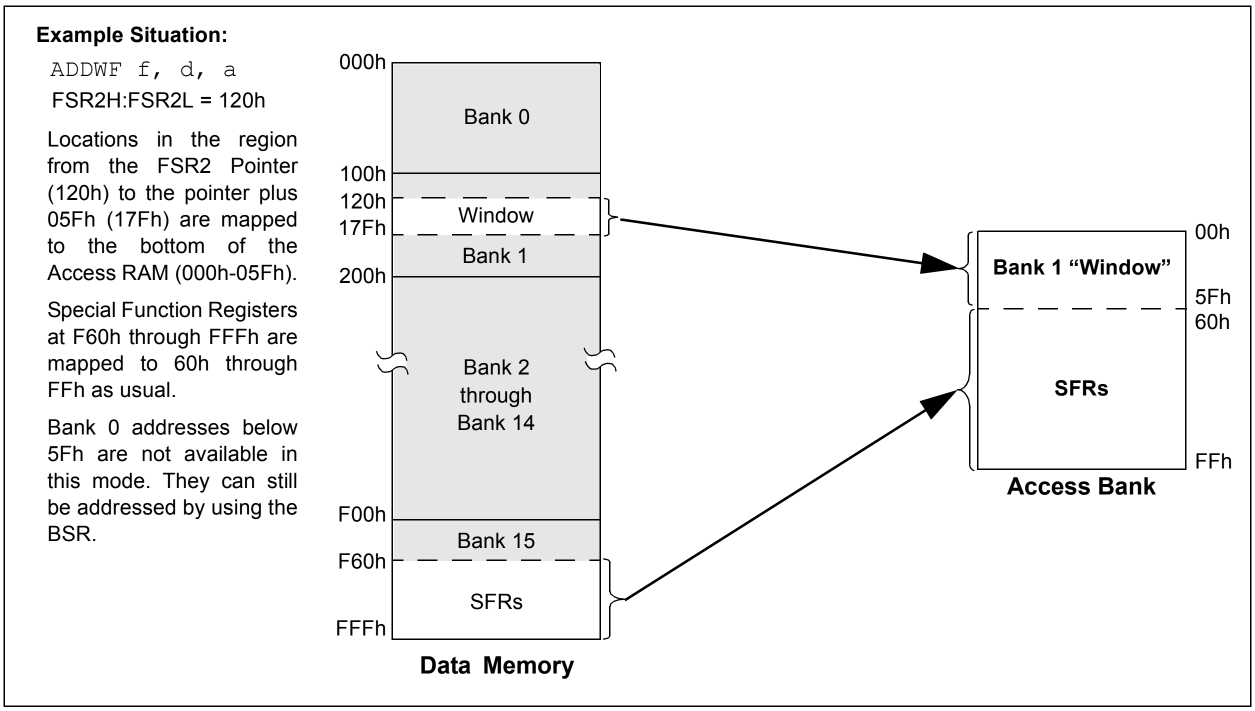
The use of Indexed Literal Offset Addressing mode effectively changes how the lower portion of Access RAM (00h to 5Fh) is mapped. Rather than containing just the contents of the bottom half of Bank 0, this mode maps the contents from Bank 0 and a user-defined "window" that can be located anywhere in the data memory space. The value of FSR2 establishes the lower boundary of the addresses mapped into the window, while the upper boundary is defined by FSR2 plus 95 (5Fh). Addresses in the Access RAM above 5Fh are mapped as previously described (see **Section 5.3.3 "Access Bank"**). An example of Access Bank remapping in this addressing mode is shown in Figure 5-9.

Remapping of the Access Bank applies *only* to operations using the Indexed Literal Offset mode. Operations that use the BSR (Access RAM bit is '1') will continue to use Direct Addressing as before. Any indirect or indexed operation that explicitly uses any of the indirect file operands (including FSR2) will continue to operate as standard Indirect Addressing. Any instruction that uses the Access Bank, but includes a register address of greater than 05Fh, will use Direct Addressing and the normal Access Bank map.

5.6.4 BSR IN INDEXED LITERAL OFFSET MODE

Although the Access Bank is remapped when the extended instruction set is enabled, the operation of the BSR remains unchanged. Direct Addressing, using the BSR to select the data memory bank, operates in the same manner as previously described.

FIGURE 5-9: REMAPPING THE ACCESS BANK WITH INDEXED LITERAL OFFSET ADDRESSING



6.0 FLASH PROGRAM MEMORY

The Flash program memory is readable, writable and erasable, during normal operation over the entire VDD range.

A read from program memory is executed on one byte at a time. A write to program memory is executed on blocks of 16 bytes at a time. Program memory is erased in blocks of 64 bytes at a time. A Bulk Erase operation may not be issued from user code.

Writing or erasing program memory will cease instruction fetches until the operation is complete. The program memory cannot be accessed during the write or erase, therefore, code cannot execute. An internal programming timer terminates program memory writes and erases.

A value written to program memory does not need to be a valid instruction. Executing a program memory location that forms an invalid instruction results in a NOP.

6.1 Table Reads and Table Writes

In order to read and write program memory, there are two operations that allow the processor to move bytes between the program memory space and the data RAM:

- Table Read (TBLRD)
- Table Write (TBLWT)

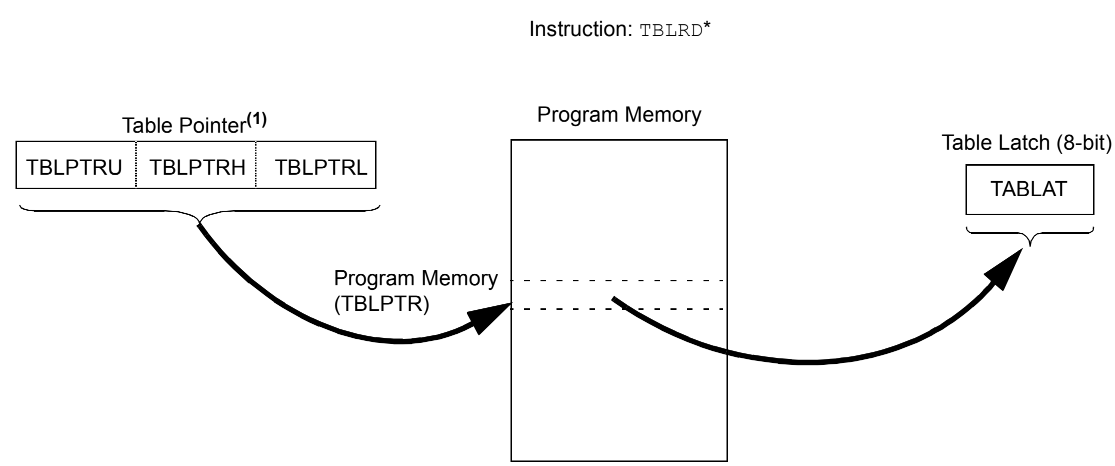
The program memory space is 16 bits wide, while the data RAM space is 8 bits wide. Table reads and table writes move data between these two memory spaces through an 8-bit register (TABLAT).

Table read operations retrieve data from program memory and place it into the data RAM space. Figure 6-1 shows the operation of a table read with program memory and data RAM.

Table write operations store data from the data memory space into holding registers in program memory. The procedure to write the contents of the holding registers into program memory is detailed in **Section 6.5 "Writing to Flash Program Memory"**. Figure 6-2 shows the operation of a table write with program memory and data RAM.

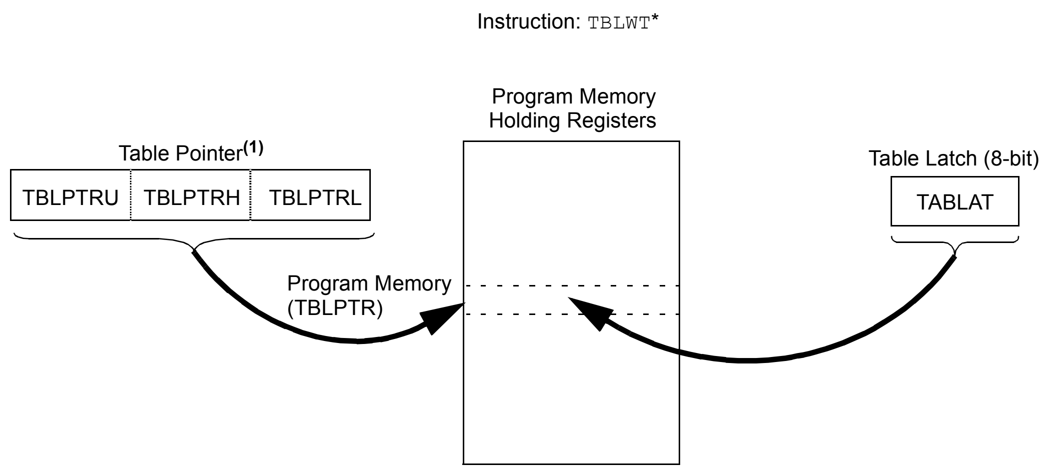
Table operations work with byte entities. A table block containing data, rather than program instructions, is not required to be word-aligned. Therefore, a table block can start and end at any byte address. If a table write is being used to write executable code into program memory, program instructions will need to be word-aligned.

FIGURE 6-1: TABLE READ OPERATION



Note 1: Table Pointer register points to a byte in program memory.

FIGURE 6-2: TABLE WRITE OPERATION



Note 1: Table Pointer actually points to one of 16 holding registers, the address of which is determined by TBLPTRL<3:0>. The process for physically writing data to the program memory array is discussed in **Section 6.5 "Writing to Flash Program Memory"**.

6.2 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

6.2.1 EECON1 AND EECON2 REGISTERS

The EECON1 register (Register 6-1) is the control register for memory accesses. The EECON2 register is not a physical register; it is used exclusively in the memory write and erase sequences. Reading EECON2 will read all '0's.

The CFGS control bit determines if the access will be to the Configuration/Calibration registers or to program memory.

The FREE bit, when set, will allow a program memory erase operation. When FREE 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 in hardware when the WREN bit is set and cleared when the internal programming timer expires and the write operation is complete.

Note:	During normal operation, the WRERR is read as '1'. This can indicate that a write operation was prematurely terminated by a Reset or a write operation was attempted improperly.

The WR control bit initiates write operations. The bit cannot be cleared, only set, in software; it is cleared in hardware at the completion of the write operation.

REGISTER 6-1: EECON1: MEMORY CONTROL REGISTER 1

U-0	R/W-x	U-0	R/W-0	R/W-x	R/W-0	R/S-0	U-0
—	CFGS	—	FREE	WRERR(1)	WREN	WR	—
bit 7							bit 0

Legend:	S = Settable bit		
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

bit 7 **Unimplemented:** Read as '0'

bit 6 **CFGS:** Flash Program or Configuration Select bit
1 = Access Configuration registers
0 = Access Flash program

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

bit 4 **FREE:** Flash Row Erase Enable bit
1 = Erase the program memory row addressed by TBLPTR on the next WR command (cleared by completion of erase operation)
0 = Perform write-only

bit 3 **WRERR:** Flash Program Error Flag bit(1)
1 = A write operation is prematurely terminated (any Reset during self-timed programming in normal operation or an improper write attempt)
0 = The write operation completed

bit 2 **WREN:** Flash Program Write Enable bit
1 = Allows write cycles to Flash program
0 = Inhibits write cycles to Flash program

bit 1 **WR:** Write Control bit
1 = Initiates a program memory erase cycle or write cycle
(The operation is self-timed and the bit is cleared by hardware once write is complete.
The WR bit can only be set (not cleared) in software.)
0 = Write cycle complete

bit 0 **Unimplemented:** Read as '0'

Note 1: When a WRERR occurs, the CFGS bit is not cleared. This allows tracing of the error condition.

6.2.2 TABLE LATCH REGISTER (TABLAT)

The Table Latch (TABLAT) is an 8-bit register mapped into the SFR space. The Table Latch register is used to hold 8-bit data during data transfers between program memory and data RAM.

6.2.3 TABLE POINTER REGISTER (TBLPTR)

The Table Pointer (TBLPTR) register addresses a byte within the program memory. The TBLPTR is comprised of three SFR registers: Table Pointer Upper Byte, Table Pointer High Byte and Table Pointer Low Byte (TBLPTRU:TBLPTRH:TBLPTRL). These three registers join to form a 22-bit wide pointer. The low-order 21 bits allow the device to address up to 2 Mbytes of program memory space. The 22nd bit allows access to the device ID, the user ID and the Configuration bits.

The Table Pointer, TBLPTR, is used by the `TBLRD` and `TBLWT` instructions. These instructions can update the TBLPTR in one of four ways based on the table operation. These operations are shown in Table 6-1. These operations on the TBLPTR only affect the low-order 21 bits.

6.2.4 TABLE POINTER BOUNDARIES

TBLPTR is used in reads, writes and erases of the Flash program memory.

When a `TBLRD` is executed, all 22 bits of the TBLPTR determine which byte is read from program memory into TABLAT.

When a `TBLWT` is executed, the four LSbs of the Table Pointer register (TBLPTR<3:0>) determine which of the 16 program memory holding registers is written to. When the timed write to program memory begins (via the WR bit), the 16 MSbs of the TBLPTR (TBLPTR<21:4>) determine which program memory block of 16 bytes is written to. For more detail, see **Section 6.5 "Writing to Flash Program Memory"**.

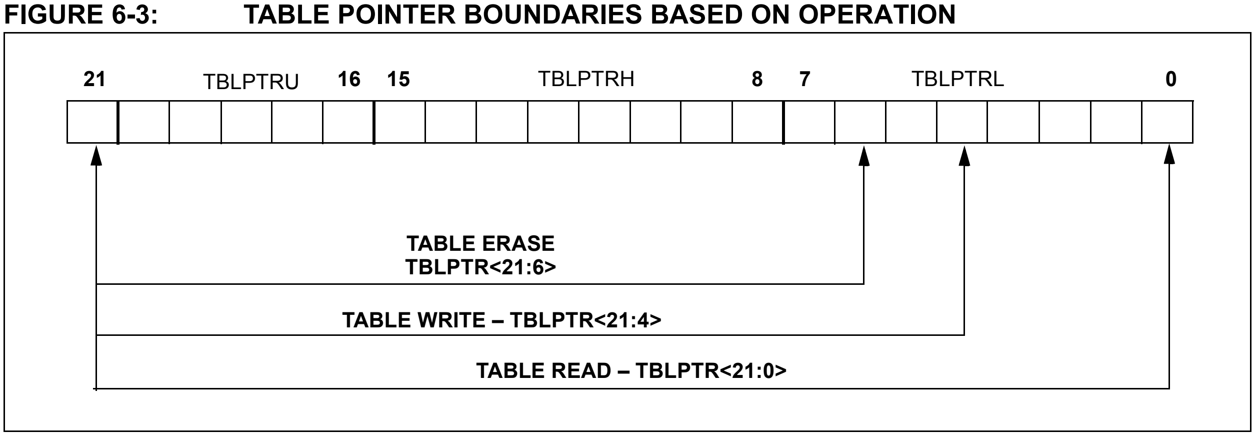
When an erase of program memory is executed, the 16 MSbs of the Table Pointer register (TBLPTR<21:6>) point to the 64-byte block that will be erased. The Least Significant bits (TBLPTR<5:0>) are ignored.

Figure 6-3 describes the relevant boundaries of the TBLPTR based on Flash program memory operations.

TABLE 6-1: TABLE POINTER OPERATIONS WITH `TBLRD` AND `TBLWT` INSTRUCTIONS

Example	Operation on Table Pointer
`TBLRD*` `TBLWT*`	TBLPTR is not modified
`TBLRD*+` `TBLWT*+`	TBLPTR is incremented after the read/write
`TBLRD*-` `TBLWT*-`	TBLPTR is decremented after the read/write
`TBLRD+*` `TBLWT+*`	TBLPTR is incremented before the read/write

FIGURE 6-3: TABLE POINTER BOUNDARIES BASED ON OPERATION



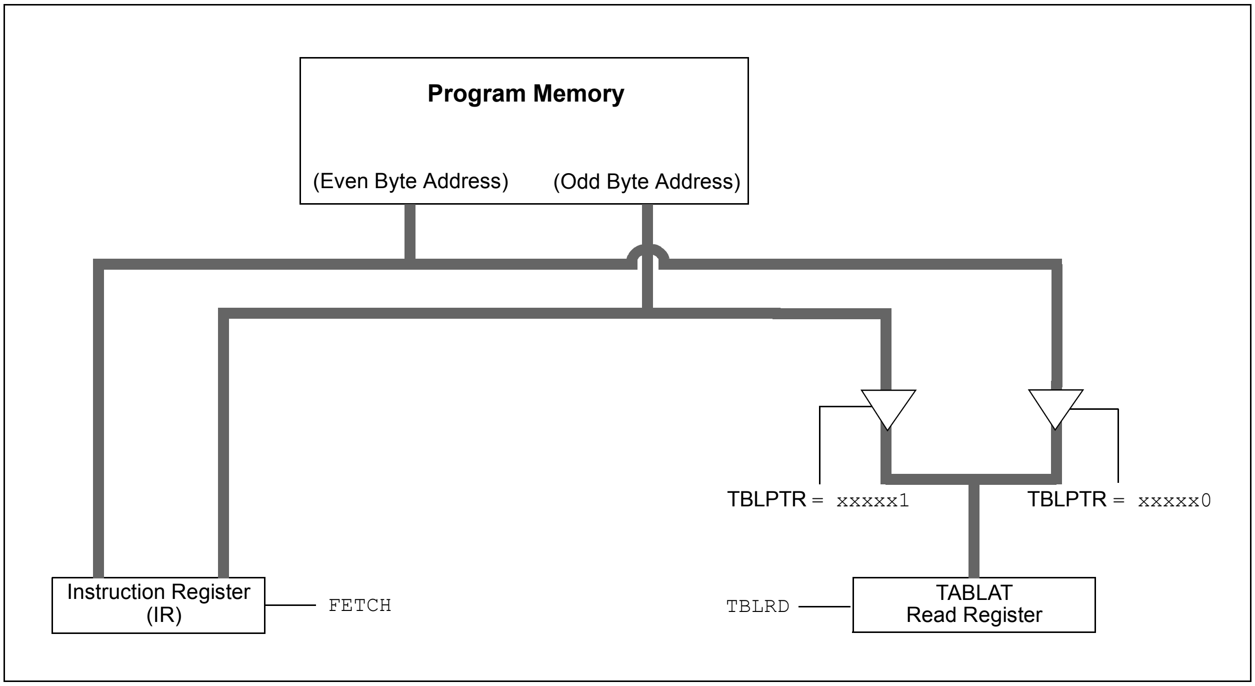
6.3 Reading the Flash Program Memory

The TBLRD instruction is used to retrieve data from program memory and places it into data RAM. Table reads from program memory are performed one byte at a time.

TBLPTR points to a byte address in program space. Executing TBLRD places the byte pointed to into TABLAT. In addition, TBLPTR can be modified automatically for the next table read operation.

The internal program memory is typically organized by words. The Least Significant bit of the address selects between the high and low bytes of the word. Figure 6-4 shows the interface between the internal program memory and the TABLAT.

FIGURE 6-4: READS FROM FLASH PROGRAM MEMORY



EXAMPLE 6-1: READING A FLASH PROGRAM MEMORY WORD

```
            MOVLW     CODE_ADDR_UPPER          ; Load TBLPTR with the base
            MOVWF     TBLPTRU                  ; address of the word
            MOVLW     CODE_ADDR_HIGH
            MOVWF     TBLPTRH
            MOVLW     CODE_ADDR_LOW
            MOVWF     TBLPTRL
READ_WORD
            TBLRD*+                            ; read into TABLAT and increment
            MOVF      TABLAT, W                ; get data
            MOVWF     WORD_EVEN
            TBLRD*+                            ; read into TABLAT and increment
            MOVF      TABLAT, W                ; get data
            MOVF      WORD_ODD
```

6.4 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 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.

6.4.1 FLASH PROGRAM MEMORY ERASE SEQUENCE

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

1. Load Table Pointer register with address of row being erased.
2. Set the EECON1 register for the erase operation:
   - clear the CFGS bit to access program memory;
   - set WREN bit to enable writes;
   - set FREE bit to enable the erase.
3. Disable interrupts.
4. Write 55h to EECON2.
5. Write 0AAh 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 6-2: 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
                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
    Required    MOVLW   55h
    Sequence    MOVWF   EECON2             ; write 55h
                MOVLW   0AAh
                MOVWF   EECON2             ; write 0AAh
                BSF     EECON1, WR         ; start erase (CPU stall)
                BSF     INTCON, GIE        ; re-enable interrupts
```

6.5 Writing to Flash Program Memory

The minimum programming block is 8 words or 16 bytes. Word or byte programming is not supported.

Table writes are used internally to load the holding registers needed to program the Flash memory. There are 16 holding registers used by the table writes for programming.

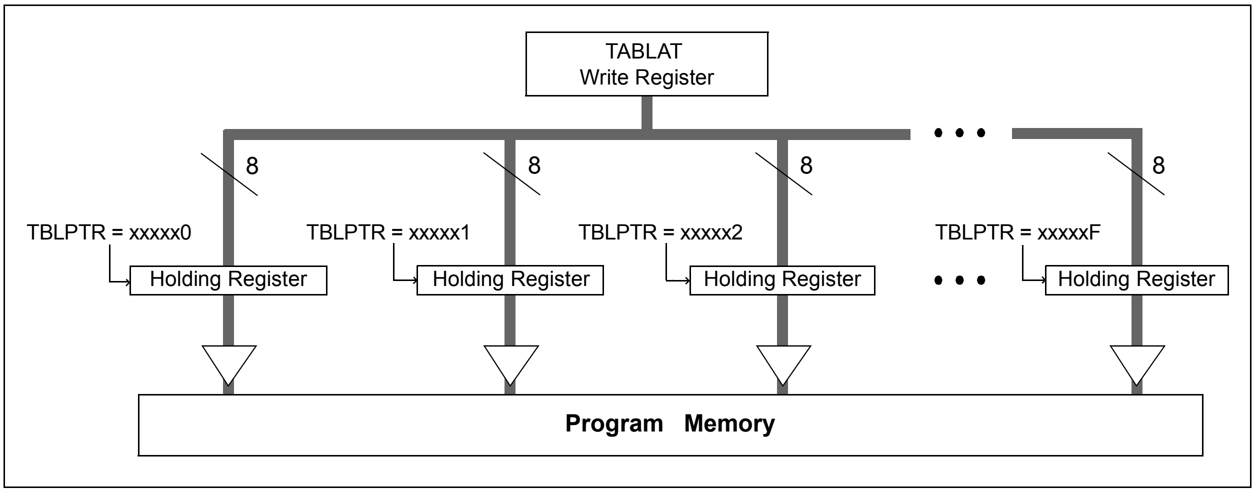
Since the Table Latch (TABLAT) is only a single byte, the `TBLWT` instruction may need to be executed 16 times for each programming operation. All of the table write operations will essentially be short writes because only the holding registers are written. At the end of updating the 16 holding registers, the EECON1 register must be written to in order to start the programming operation with a long write.

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

The write/erase voltages are generated by an on-chip charge pump, rated to operate over the voltage range of the device.

Note:	The default value of the holding registers on device Resets and after write operations is FFh. A write of FFh to a holding register does not modify that byte. This means that individual bytes of program memory may be modified, provided that the change does not attempt to change any bit from a '0' to a '1'. When modifying individual bytes, it is not necessary to load all 16 holding registers before executing a write operation.

FIGURE 6-5: TABLE WRITES TO FLASH PROGRAM MEMORY



6.5.1 FLASH PROGRAM MEMORY WRITE SEQUENCE

The sequence of events for programming an internal program memory location should be:

1. Read 64 bytes into RAM.
2. Update data values in RAM as necessary.
3. Load Table Pointer register with address being erased.
4. Execute the Row Erase procedure.
5. Load Table Pointer register with address of first byte being written.
6. Write 16 bytes into the holding registers with auto-increment.
7. Set the EECON1 register for the write operation:
   - clear the CFGS bit to access program memory;
   - set WREN to enable byte writes.
8. Disable interrupts.
9. Write 55h to EECON2.
10. Write 0AAh to EECON2.
11. Set the WR bit. This will begin the write cycle.
12. The CPU will stall for duration of the write (about 2 ms using internal timer).
13. Re-enable interrupts.
14. Repeat steps 6 through 14 once more to write 64 bytes.
15. Verify the memory (table read).

This procedure will require about 8 ms to update one row of 64 bytes of memory. An example of the required code is given in Example 6-3.

Note:	Before setting the WR bit, the Table Pointer address needs to be within the intended address range of the 16 bytes in the holding register.

EXAMPLE 6-3: WRITING TO FLASH PROGRAM MEMORY

```
              MOVLW     D'64'                  ; number of bytes in erase block
              MOVWF     COUNTER
              MOVLW     BUFFER_ADDR_HIGH       ; point to buffer
              MOVWF     FSR0H
              MOVLW     BUFFER_ADDR_LOW
              MOVWF     FSR0L
              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
READ_BLOCK
              TBLRD*+                          ; read into TABLAT, and inc
              MOVF      TABLAT, W              ; get data
              MOVWF     POSTINC0               ; store data
              DECFSZ    COUNTER                ; done?
              BRA       READ_BLOCK             ; repeat
MODIFY_WORD
              MOVLW     DATA_ADDR_HIGH         ; point to buffer
              MOVWF     FSR0H
              MOVLW     DATA_ADDR_LOW
              MOVWF     FSR0L
              MOVLW     NEW_DATA_LOW           ; update buffer word
              MOVWF     POSTINC0
              MOVLW     NEW_DATA_HIGH
              MOVWF     INDF0
ERASE_BLOCK
              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
              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     0AAh
              MOVWF     EECON2                 ; write 0AAh
              BSF       EECON1, WR             ; start erase (CPU stall)
              BSF       INTCON, GIE            ; re-enable interrupts
              TBLRD*-                          ; dummy read decrement
              MOVLW     BUFFER_ADDR_HIGH       ; point to buffer
              MOVWF     FSR0H
              MOVLW     BUFFER_ADDR_LOW
              MOVWF     FSR0L
              MOVLW     D'4'
              MOVWF     COUNTER1
WRITE_BUFFER_BACK
              MOVLW     D'16'                  ; number of bytes in holding register
              MOVWF     COUNTER
WRITE_BYTE_TO_HREGS
              MOVF      POSTINC0, W            ; get low byte of buffer data
              MOVWF     TABLAT                 ; present data to table latch
              TBLWT+*                          ; write data, perform a short write
                                               ; to internal TBLWT holding register.
              DECFSZ    COUNTER                ; loop until buffers are full
              BRA       WRITE_WORD_TO_HREGS
```


EXAMPLE 6-3: WRITING TO FLASH PROGRAM MEMORY (CONTINUED)

```
PROGRAM_MEMORY
              BCF         EECON1, CFGS          ; access Flash program memory
              BSF         EECON1, WREN          ; enable write to memory
              BCF         INTCON, GIE           ; disable interrupts

              MOVLW       55h
   Required   MOVWF       EECON2                ; write 55h
   Sequence   MOVLW       0AAh
              MOVWF       EECON2                ; write 0AAh
              BSF         EECON1, WR            ; start program (CPU stall)
              DECFSZ      COUNTER1
              BRA         WRITE_BUFFER_BACK
              BSF         INTCON, GIE           ; re-enable interrupts
              BCF         EECON1, WREN          ; disable write to memory
```

6.5.2 WRITE VERIFY

Depending on the application, good programming practice may dictate that the value written to the memory should be verified against the original value. This should be used in applications where excessive writes can stress bits near the specification limit.

6.5.3 UNEXPECTED TERMINATION OF WRITE OPERATION

If a write is terminated by an unplanned event, such as loss of power or an unexpected Reset, the memory location just programmed should be verified and reprogrammed if needed. If the write operation is interrupted by a $\overline{\text{MCLR}}$ Reset or a WDT time-out Reset during normal operation, the user can check the WRERR bit and rewrite the location(s) as needed.

6.5.4 PROTECTION AGAINST SPURIOUS WRITES

To protect against spurious writes to Flash program memory, the write initiate sequence must also be followed. See **Section 18.0 "Special Features of the CPU"** for more detail.

6.6 Flash Program Operation During Code Protection

See **Section 18.5 "Program Verification and Code Protection"** for details on code protection of Flash program memory.

TABLE 6-2: REGISTERS ASSOCIATED WITH PROGRAM FLASH MEMORY

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
TBLPTRU	—	—	bit 21	Program Memory Table Pointer Upper Byte (TBLPTR<20:16>)					49
TBPLTRH	Program Memory Table Pointer High Byte (TBLPTR<15:8>)								49
TBLPTRL	Program Memory Table Pointer Low Byte (TBLPTR<7:0>)								49
TABLAT	Program Memory Table Latch								49
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
EECON2	Data Memory Control Register 2 (not a physical register)								51
EECON1	—	CFGS	—	FREE	WRERR	WREN	WR	—	51
IPR2	OSCFIP	—	USBIP	—	—	HLVDIP	—	—	51
PIR2	OSCFIF	—	USBIF	—	—	HLVDIF	—	—	51
PIE2	OSCFIE	—	USBIE	—	—	HLVDIE	—	—	51

Legend: — = unimplemented, read as '0'. Shaded cells are not used during Flash access.

NOTES:

7.0 8 x 8 HARDWARE MULTIPLIER

7.1 Introduction

All PIC18 devices include an 8 x 8 hardware multiplier as part of the ALU. The multiplier performs an unsigned operation and yields a 16-bit result that is stored in the product register pair, PRODH:PRODL. The multiplier's operation does not affect any flags in the STATUS register.

Making multiplication a hardware operation allows it to be completed in a single instruction cycle. This has the advantages of higher computational throughput and reduced code size for multiplication algorithms and allows the PIC18 devices to be used in many applications previously reserved for digital signal processors. A comparison of various hardware and software multiply operations, along with the savings in memory and execution time, is shown in Table 7-1.

7.2 Operation

Example 7-1 shows the instruction sequence for an 8 x 8 unsigned multiplication. Only one instruction is required when one of the arguments is already loaded in the WREG register.

Example 7-2 shows the sequence to do an 8 x 8 signed multiplication. To account for the sign bits of the arguments, each argument's Most Significant bit (MSb) is tested and the appropriate subtractions are done.

EXAMPLE 7-1: 8 x 8 UNSIGNED MULTIPLY ROUTINE

```
MOVF    ARG1, W     ;
MULWF   ARG2        ; ARG1 * ARG2 ->
                    ; PRODH:PRODL
```

EXAMPLE 7-2: 8 x 8 SIGNED MULTIPLY ROUTINE

```
MOVF    ARG1, W
MULWF   ARG2        ; ARG1 * ARG2 ->
                    ; PRODH:PRODL
BTFSC   ARG2, SB    ; Test Sign Bit
SUBWF   PRODH, F    ; PRODH = PRODH
                    ;         - ARG1
MOVF    ARG2, W
BTFSC   ARG1, SB    ; Test Sign Bit
SUBWF   PRODH, F    ; PRODH = PRODH
                    ;         - ARG2
```

TABLE 7-1: PERFORMANCE COMPARISON FOR VARIOUS MULTIPLY OPERATIONS

Routine	Multiply Method	Program Memory (Words)	Cycles (Max)	Time		
				@ 40 MHz	@ 10 MHz	@ 4 MHz
8 x 8 unsigned	Without hardware multiply	13	69	6.9 μs	27.6 μs	69 μs
	Hardware multiply	1	1	100 ns	400 ns	1 μs
8 x 8 signed	Without hardware multiply	33	91	9.1 μs	36.4 μs	91 μs
	Hardware multiply	6	6	600 ns	2.4 μs	6 μs
16 x 16 unsigned	Without hardware multiply	21	242	24.2 μs	96.8 μs	242 μs
	Hardware multiply	28	28	2.8 μs	11.2 μs	28 μs
16 x 16 signed	Without hardware multiply	52	254	25.4 μs	102.6 μs	254 μs
	Hardware multiply	35	40	4.0 μs	16.0 μs	40 μs

Example 7-3 shows the sequence to do a 16 x 16 unsigned multiplication. Equation 7-1 shows the algorithm that is used. The 32-bit result is stored in four registers (RES3:RES0).

EQUATION 7-1: 16 x 16 UNSIGNED MULTIPLICATION ALGORITHM

$$
\begin{aligned}
RES3:RES0 &= ARG1H:ARG1L \bullet ARG2H:ARG2L \\
&= (ARG1H \bullet ARG2H \bullet 2^{16}) + \\
&\quad (ARG1H \bullet ARG2L \bullet 2^{8}) + \\
&\quad (ARG1L \bullet ARG2H \bullet 2^{8}) + \\
&\quad (ARG1L \bullet ARG2L)
\end{aligned}
$$

EXAMPLE 7-3: 16 x 16 UNSIGNED MULTIPLY ROUTINE

```
    MOVF    ARG1L, W
    MULWF   ARG2L           ; ARG1L * ARG2L->
                            ; PRODH:PRODL
    MOVFF   PRODH, RES1     ;
    MOVFF   PRODL, RES0     ;
;
    MOVF    ARG1H, W
    MULWF   ARG2H           ; ARG1H * ARG2H->
                            ; PRODH:PRODL
    MOVFF   PRODH, RES3     ;
    MOVFF   PRODL, RES2     ;
;
    MOVF    ARG1L, W
    MULWF   ARG2H           ; ARG1L * ARG2H->
                            ; PRODH:PRODL
    MOVF    PRODL, W        ;
    ADDWF   RES1, F         ; Add cross
    MOVF    PRODH, W        ; products
    ADDWFC  RES2, F         ;
    CLRF    WREG            ;
    ADDWFC  RES3, F         ;
;
    MOVF    ARG1H, W        ;
    MULWF   ARG2L           ; ARG1H * ARG2L->
                            ; PRODH:PRODL
    MOVF    PRODL, W        ;
    ADDWF   RES1, F         ; Add cross
    MOVF    PRODH, W        ; products
    ADDWFC  RES2, F         ;
    CLRF    WREG            ;
    ADDWFC  RES3, F         ;
```

Example 7-4 shows the sequence to do a 16 x 16 signed multiply. Equation 7-2 shows the algorithm used. The 32-bit result is stored in four registers (RES3:RES0). To account for the sign bits of the arguments, the MSb for each argument pair is tested and the appropriate subtractions are done.

EQUATION 7-2: 16 x 16 SIGNED MULTIPLICATION ALGORITHM

$$
\begin{aligned}
RES3:RES0 &= ARG1H:ARG1L \bullet ARG2H:ARG2L \\
&= (ARG1H \bullet ARG2H \bullet 2^{16}) + \\
&\quad (ARG1H \bullet ARG2L \bullet 2^{8}) + \\
&\quad (ARG1L \bullet ARG2H \bullet 2^{8}) + \\
&\quad (ARG1L \bullet ARG2L) + \\
&\quad (-1 \bullet ARG2H<7> \bullet ARG1H:ARG1L \bullet 2^{16}) + \\
&\quad (-1 \bullet ARG1H<7> \bullet ARG2H:ARG2L \bullet 2^{16})
\end{aligned}
$$

EXAMPLE 7-4: 16 x 16 SIGNED MULTIPLY ROUTINE

```
    MOVF    ARG1L, W
    MULWF   ARG2L           ; ARG1L * ARG2L ->
                            ; PRODH:PRODL
    MOVFF   PRODH, RES1     ;
    MOVFF   PRODL, RES0     ;
;
    MOVF    ARG1H, W
    MULWF   ARG2H           ; ARG1H * ARG2H ->
                            ; PRODH:PRODL
    MOVFF   PRODH, RES3     ;
    MOVFF   PRODL, RES2     ;
;
    MOVF    ARG1L,W
    MULWF   ARG2H           ; ARG1L * ARG2H ->
                            ; PRODH:PRODL
    MOVF    PRODL, W        ;
    ADDWF   RES1, F         ; Add cross
    MOVF    PRODH, W        ; products
    ADDWFC  RES2, F         ;
    CLRF    WREG            ;
    ADDWFC  RES3, F         ;
;
    MOVF    ARG1H, W        ;
    MULWF   ARG2L           ; ARG1H * ARG2L ->
                            ; PRODH:PRODL
    MOVF    PRODL, W        ;
    ADDWF   RES1, F         ; Add cross
    MOVF    PRODH, W        ; products
    ADDWFC  RES2, F         ;
    CLRF    WREG            ;
    ADDWFC  RES3, F         ;
;
    BTFSS   ARG2H, 7        ; ARG2H:ARG2L neg?
    BRA     SIGN_ARG1       ; no, check ARG1
    MOVF    ARG1L, W        ;
    SUBWF   RES2            ;
    MOVF    ARG1H, W        ;
    SUBWFB  RES3
;
SIGN_ARG1
    BTFSS   ARG1H, 7        ; ARG1H:ARG1L neg?
    BRA     CONT_CODE       ; no, done
    MOVF    ARG2L, W        ;
    SUBWF   RES2            ;
    MOVF    ARG2H, W        ;
    SUBWFB  RES3
;
CONT_CODE
   :
```

8.0 INTERRUPTS

The PIC18F2450/4450 devices have multiple interrupt sources and an interrupt priority feature that allows each interrupt source to be assigned a high-priority level or a low-priority level. The high-priority interrupt vector is at 000008h and the low-priority interrupt vector is at 000018h. High-priority interrupt events will interrupt any low-priority interrupts that may be in progress.

There are ten registers which are used to control interrupt operation. These registers are:

- RCON
- INTCON
- INTCON2
- INTCON3
- PIR1, PIR2
- PIE1, PIE2
- IPR1, IPR2

It is recommended that the Microchip header files supplied with MPLAB® IDE be used for the symbolic bit names in these registers. This allows the assembler/compiler to automatically take care of the placement of these bits within the specified register.

Each interrupt source has three bits to control its operation. The functions of these bits are:

- Flag bit to indicate that an interrupt event occurred
- Enable bit that allows program execution to branch to the interrupt vector address when the flag bit is set
- Priority bit to select high priority or low priority

The interrupt priority feature is enabled by setting the IPEN bit (RCON<7>). When interrupt priority is enabled, there are two bits which enable interrupts globally. Setting the GIEH bit (INTCON<7>) enables all interrupts that have the priority bit set (high priority). Setting the GIEL bit (INTCON<6>) enables all interrupts that have the priority bit cleared (low priority). When the interrupt flag, enable bit and appropriate global interrupt enable bit are set, the interrupt will vector immediately to address 000008h or 000018h, depending on the priority bit setting. Individual interrupts can be disabled through their corresponding enable bits.

When the IPEN bit is cleared (default state), the interrupt priority feature is disabled and interrupts are compatible with PIC® mid-range microcontrollers. In Compatibility mode, the interrupt priority bits for each source have no effect. INTCON<6> is the PEIE bit which enables/disables all peripheral interrupt sources. INTCON<7> is the GIE bit which enables/disables all interrupt sources. All interrupts branch to address 000008h in Compatibility mode.

When an interrupt is responded to, the global interrupt enable bit is cleared to disable further interrupts. If the IPEN bit is cleared, this is the GIE bit. If interrupt priority levels are used, this will be either the GIEH or GIEL bit. High-priority interrupt sources can interrupt a low-priority interrupt. Low-priority interrupts are not processed while high-priority interrupts are in progress.

The return address is pushed onto the stack and the PC is loaded with the interrupt vector address (000008h or 000018h). Once in the Interrupt Service Routine, the source(s) of the interrupt can be determined by polling the interrupt flag bits. The interrupt flag bits must be cleared in software before re-enabling interrupts to avoid recursive interrupts.

The "return from interrupt" instruction, `RETFIE`, exits the interrupt routine and sets the GIE bit (GIEH or GIEL if priority levels are used) which re-enables interrupts.

For external interrupt events, such as the INTx pins or the PORTB input change interrupt, the interrupt latency will be three to four instruction cycles. The exact latency is the same for one or two-cycle instructions. Individual interrupt flag bits are set regardless of the status of their corresponding enable bit or the GIE bit.

Note:	Do not use the `MOVFF` instruction to modify any of the interrupt control registers while **any** interrupt is enabled. Doing so may cause erratic microcontroller behavior.

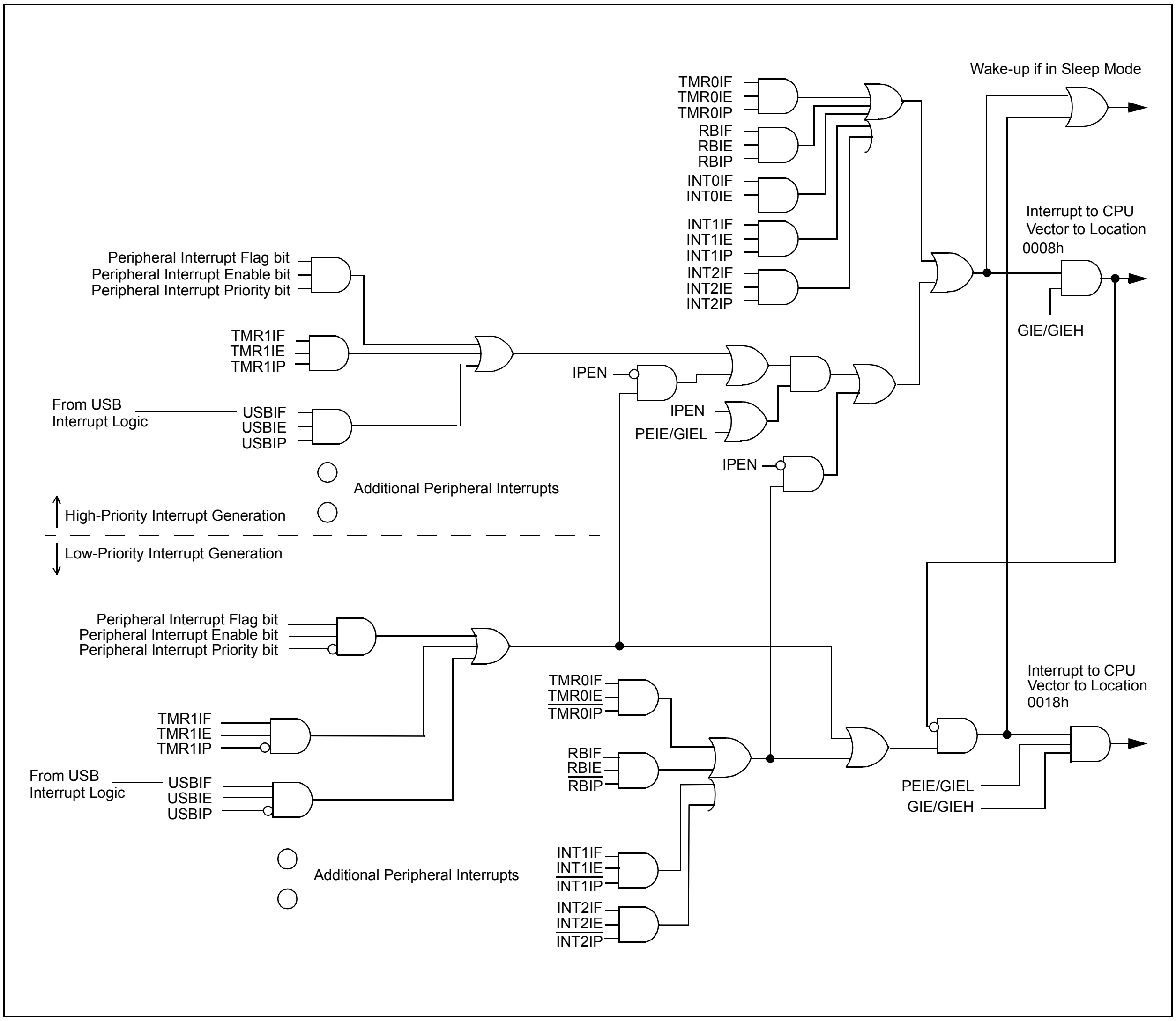
8.1 USB Interrupts

Unlike other peripherals, the USB module is capable of generating a wide range of interrupts for many types of events. These include several types of normal communication and status events and several module level error events.

To handle these events, the USB module is equipped with its own interrupt logic. The logic functions in a manner similar to the microcontroller level interrupt funnel, with each interrupt source having separate flag and enable bits. All events are funneled to a single device level interrupt, USBIF (PIR2<5>). Unlike the device level interrupt logic, the individual USB interrupt events cannot be individually assigned their own priority. This is determined at the device level interrupt funnel for all USB events by the USBIP bit.

For additional details on USB interrupt logic, refer to **Section 14.5 "USB Interrupts"**.

FIGURE 8-1: INTERRUPT LOGIC



8.2 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 interrupt 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: INTERRUPT CONTROL 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	RBIE	TMR0IF	INT0IF	RBIF(1)
bit 7							bit 0

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

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

bit 6 **PEIE/GIEL:** Peripheral Interrupt Enable bit
When IPEN = 0:
1 = Enables all unmasked peripheral interrupts
0 = Disables all peripheral interrupts
When IPEN = 1:
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:** 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:** RB Port Change Interrupt Flag bit(1)
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: A mismatch condition will continue to set this bit. Reading PORTB and waiting 1 T_{CY} will end the mismatch condition and allow the bit to be cleared.

REGISTER 8-2: INTCON2: INTERRUPT CONTROL REGISTER 2

R/W-1	R/W-1	R/W-1	R/W-1	U-0	R/W-1	U-0	R/W-1
$\overline{\text{RBPU}}$	INTEDG0	INTEDG1	INTEDG2	—	TMR0IP	—	RBIP
bit 7							bit 0

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

bit 7 **$\overline{\text{RBPU}}$:** PORTB Pull-up Enable bit
1 = All PORTB pull-ups are disabled
0 = PORTB pull-ups are enabled by individual port latch values

bit 6 **INTEDG0:** External Interrupt 0 Edge Select bit
1 = Interrupt on rising edge
0 = Interrupt on falling edge

bit 5 **INTEDG1:** External Interrupt 1 Edge Select bit
1 = Interrupt on rising edge
0 = Interrupt on falling edge

bit 4 **INTEDG2:** External Interrupt 2 Edge Select bit
1 = Interrupt on rising edge
0 = Interrupt on falling edge

bit 3 **Unimplemented:** Read as ‘0’

bit 2 **TMR0IP:** TMR0 Overflow Interrupt Priority bit
1 = High priority
0 = Low priority

bit 1 **Unimplemented:** Read as ‘0’

bit 0 **RBIP:** RB Port Change Interrupt Priority bit
1 = High priority
0 = Low priority

Note: Interrupt flag bits are set when an interrupt condition occurs regardless of the state of its corresponding enable bit or the global interrupt 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 8-3: INTCON3: INTERRUPT CONTROL REGISTER 3

R/W-1	R/W-1	U-0	R/W-0	R/W-0	U-0	R/W-0	R/W-0
INT2IP	INT1IP	—	INT2IE	INT1IE	—	INT2IF	INT1IF
bit 7							bit 0

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

bit 7 **INT2IP:** INT2 External Interrupt Priority bit
1 = High priority
0 = Low priority

bit 6 **INT1IP:** INT1 External Interrupt Priority bit
1 = High priority
0 = Low priority

bit 5 **Unimplemented:** Read as ‘0’

bit 4 **INT2IE:** INT2 External Interrupt Enable bit
1 = Enables the INT2 external interrupt
0 = Disables the INT2 external interrupt

bit 3 **INT1IE:** INT1 External Interrupt Enable bit
1 = Enables the INT1 external interrupt
0 = Disables the INT1 external interrupt

bit 2 **Unimplemented:** Read as ‘0’

bit 1 **INT2IF:** INT2 External Interrupt Flag bit
1 = The INT2 external interrupt occurred (must be cleared in software)
0 = The INT2 external interrupt did not occur

bit 0 **INT1IF:** INT1 External Interrupt Flag bit
1 = The INT1 external interrupt occurred (must be cleared in software)
0 = The INT1 external interrupt did not occur

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

8.3 PIR Registers

The PIR registers contain the individual flag bits for the peripheral interrupts. Due to the number of peripheral interrupt sources, there are two Peripheral Interrupt Request (Flag) registers (PIR1 and PIR2).

Note 1: Interrupt flag bits are set when an interrupt condition occurs regardless of the state of its corresponding enable bit or the Global Interrupt Enable bit, GIE (INTCON<7>).

2: User software should ensure the appropriate interrupt flag bits are cleared prior to enabling an interrupt and after servicing that interrupt.

REGISTER 8-4: PIR1: PERIPHERAL INTERRUPT REQUEST (FLAG) REGISTER 1

U-0	R/W-0	R-0	R-0	U-0	R/W-0	R/W-0	R/W-0
—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF
bit 7							bit 0

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

bit 7 **Unimplemented:** Read as '0'

bit 6 **ADIF:** A/D Converter Interrupt Flag bit
1 = An A/D conversion completed (must be cleared in software)
0 = The A/D conversion is not complete

bit 5 **RCIF:** EUSART Receive Interrupt Flag bit
1 = The EUSART receive buffer, RCREG, is full (cleared when RCREG is read)
0 = The EUSART receive buffer is empty

bit 4 **TXIF:** EUSART Transmit Interrupt Flag bit
1 = The EUSART transmit buffer, TXREG, is empty (cleared when TXREG is written)
0 = The EUSART transmit buffer is full

bit 3 **Unimplemented:** Read as '0'

bit 2 **CCP1IF:** CCP1 Interrupt Flag bit
<u>Capture mode:</u>
1 = A TMR1 register capture occurred (must be cleared in software)
0 = No TMR1 register capture occurred
<u>Compare mode:</u>
1 = A TMR1 register compare match occurred (must be cleared in software)
0 = No TMR1 register compare match occurred
<u>PWM mode:</u>
Unused in this mode.

bit 1 **TMR2IF:** TMR2 to PR2 Match Interrupt Flag bit
1 = TMR2 to PR2 match occurred (must be cleared in software)
0 = No TMR2 to PR2 match occurred

bit 0 **TMR1IF:** TMR1 Overflow Interrupt Flag bit
1 = TMR1 register overflowed (must be cleared in software)
0 = TMR1 register did not overflow

REGISTER 8-5: PIR2: PERIPHERAL INTERRUPT REQUEST (FLAG) REGISTER 2

R/W-0	U-0	R/W-0	U-0	U-0	R/W-0	U-0	U-0
OSCFIF	—	USBIF	—	—	HLVDIF	—	—
bit 7							bit 0

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

bit 7 **OSCFIF:** Oscillator Fail Interrupt Flag bit
1 = System oscillator failed, clock input has changed to INTRC (must be cleared in software)
0 = System clock operating

bit 6 **Unimplemented:** Read as ‘0’

bit 5 **USBIF:** USB Interrupt Flag bit
1 = USB has requested an interrupt (must be cleared in software)
0 = No USB interrupt request

bit 4-3 **Unimplemented:** Read as ‘0’

bit 2 **HLVDIF:** High/Low-Voltage Detect Interrupt Flag bit
1 = A high/low-voltage condition occurred
0 = No high/low-voltage event has occurred

bit 1-0 **Unimplemented:** Read as ‘0’

8.4 PIE Registers

The PIE registers contain the individual enable bits for the peripheral interrupts. Due to the number of peripheral interrupt sources, there are two Peripheral Interrupt Enable registers (PIE1 and PIE2). When IPEN = 0, the PEIE bit must be set to enable any of these peripheral interrupts.

REGISTER 8-6: PIE1: PERIPHERAL INTERRUPT ENABLE REGISTER 1

U-0	R/W-0	R/W-0	R/W-0	U-0	R/W-0	R/W-0	R/W-0
—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE
bit 7							bit 0

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

bit 7 **Unimplemented:** Read as ‘0’

bit 6 **ADIE:** A/D Converter Interrupt Enable bit
1 = Enables the A/D interrupt
0 = Disables the A/D interrupt

bit 5 **RCIE:** EUSART Receive Interrupt Enable bit
1 = Enables the EUSART receive interrupt
0 = Disables the EUSART receive interrupt

bit 4 **TXIE:** EUSART Transmit Interrupt Enable bit
1 = Enables the EUSART transmit interrupt
0 = Disables the EUSART transmit interrupt

bit 3 **Unimplemented:** Read as ‘0’

bit 2 **CCP1IE:** CCP1 Interrupt Enable bit
1 = Enables the CCP1 interrupt
0 = Disables the CCP1 interrupt

bit 1 **TMR2IE:** TMR2 to PR2 Match Interrupt Enable bit
1 = Enables the TMR2 to PR2 match interrupt
0 = Disables the TMR2 to PR2 match interrupt

bit 0 **TMR1IE:** TMR1 Overflow Interrupt Enable bit
1 = Enables the TMR1 overflow interrupt
0 = Disables the TMR1 overflow interrupt

REGISTER 8-7: PIE2: PERIPHERAL INTERRUPT ENABLE REGISTER 2

R/W-0	U-0	R/W-0	U-0	U-0	R/W-0	U-0	U-0
OSCFIE	—	USBIE	—	—	HLVDIE	—	—
bit 7							bit 0

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

bit 7 **OSCFIE:** Oscillator Fail Interrupt Enable bit
1 = Enabled
0 = Disabled

bit 6 **Unimplemented:** Read as ‘0’

bit 5 **USBIE:** USB Interrupt Enable bit
1 = Enabled
0 = Disabled

bit 4-3 **Unimplemented:** Read as ‘0’

bit 2 **HLVDIE:** High/Low-Voltage Detect Interrupt Enable bit
1 = Enabled
0 = Disabled

bit 1-0 **Unimplemented:** Read as ‘0’

8.5 IPR Registers

The IPR registers contain the individual priority bits for the peripheral interrupts. Due to the number of peripheral interrupt sources, there are two Peripheral Interrupt Priority registers (IPR1 and IPR2). Using the priority bits requires that the Interrupt Priority Enable (IPEN) bit be set.

REGISTER 8-8: IPR1: PERIPHERAL INTERRUPT PRIORITY REGISTER 1

U-0	R/W-1	R/W-1	R/W-1	U-0	R/W-1	R/W-1	R/W-1
—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP
bit 7							bit 0

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

bit 7 **Unimplemented:** Read as ‘0’

bit 6 **ADIP:** A/D Converter Interrupt Priority bit
1 = High priority
0 = Low priority

bit 5 **RCIP:** EUSART Receive Interrupt Priority bit
1 = High priority
0 = Low priority

bit 4 **TXIP:** EUSART Transmit Interrupt Priority bit
1 = High priority
0 = Low priority

bit 3 **Unimplemented:** Read as ‘0’

bit 2 **CCP1IP:** CCP1 Interrupt Priority bit
1 = High priority
0 = Low priority

bit 1 **TMR2IP:** TMR2 to PR2 Match Interrupt Priority bit
1 = High priority
0 = Low priority

bit 0 **TMR1IP:** TMR1 Overflow Interrupt Priority bit
1 = High priority
0 = Low priority

REGISTER 8-9: IPR2: PERIPHERAL INTERRUPT PRIORITY REGISTER 2

R/W-1	U-0	R/W-1	U-0	U-0	R/W-1	U-0	U-0
OSCFIP	—	USBIP	—	—	HLVDIP	—	—
bit 7							bit 0

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

bit 7 **OSCFIP:** Oscillator Fail Interrupt Priority bit
1 = High priority
0 = Low priority

bit 6 **Unimplemented:** Read as ‘0’

bit 5 **USBIP:** USB Interrupt Priority bit
1 = High priority
0 = Low priority

bit 4-3 **Unimplemented:** Read as ‘0’

bit 2 **HLVDIP:** High/Low-Voltage Detect Interrupt Priority bit
1 = High priority
0 = Low priority

bit 1-0 **Unimplemented:** Read as ‘0’

8.6 RCON Register

The RCON register contains flag bits which are used to determine the cause of the last Reset or wake-up from Idle or Sleep modes. RCON also contains the IPEN bit which enables interrupt priorities.

REGISTER 8-10: RCON: RESET CONTROL REGISTER

R/W-0	R/W-1(1)	U-0	R/W-1	R-1	R-1	R/W-0(2)	R/W-0
IPEN	SBOREN	—	$\overline{RI}$	$\overline{TO}$	$\overline{PD}$	$\overline{POR}$	$\overline{BOR}$
bit 7							bit 0

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

bit 7 **IPEN:** Interrupt Priority Enable bit
1 = Enable priority levels on interrupts
0 = Disable priority levels on interrupts (PIC16CXXX Compatibility mode)

bit 6 **SBOREN:** BOR Software Enable bit(1)
For details of bit operation, see Register 4-1.

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

bit 4 **$\overline{RI}$:** RESET Instruction Flag bit
For details of bit operation, see Register 4-1.

bit 3 **$\overline{TO}$:** Watchdog Time-out Flag bit
For details of bit operation, see Register 4-1.

bit 2 **$\overline{PD}$:** Power-Down Detection Flag bit
For details of bit operation, see Register 4-1.

bit 1 **$\overline{POR}$:** Power-on Reset Status bit(2)
For details of bit operation, see Register 4-1.

bit 0 **$\overline{BOR}$:** Brown-out Reset Status bit
For details of bit operation, see Register 4-1.

Note 1: If SBOREN is enabled, its Reset state is '1'; otherwise, it is '0'. See Register 4-1 for additional information.
2: The actual Reset value of $\overline{POR}$ is determined by the type of device Reset. See Register 4-1 for additional information.

8.7 INTx Pin Interrupts

External interrupts on the RB0/AN12/INT0, RB1/AN10/INT1and RB2/AN8/INT2/VMO pins are edge-triggered. If the corresponding INTEDGx bit in the INTCON2 register is set (= 1), the interrupt is triggered by a rising edge; if the bit is clear, the trigger is on the falling edge. When a valid edge appears on the RBx/INTx pin, the corresponding flag bit, INTxIF, is set. This interrupt can be disabled by clearing the corresponding enable bit, INTxIE. Flag bit, INTxIF, 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 the power-managed modes if bit, INTxIE, was set prior to going into the power-managed modes. If the Global Interrupt Enable bit, GIE, is set, the processor will branch to the interrupt vector following wake-up.

Interrupt priority for INT1 and INT2 is determined by the value contained in the interrupt priority bits, INT1IP (INTCON3<6>) and INT2IP (INTCON3<7>). There is no priority bit associated with INT0. It is always a high-priority interrupt source.

8.8 TMR0 Interrupt

In 8-bit mode (which is the default), an overflow in the TMR0 register (FFh $\rightarrow$ 00h) will set flag bit, TMR0IF. In 16-bit mode, an overflow in the TMR0H:TMR0L register pair (FFFFh $\rightarrow$ 0000h) will set TMR0IF. The interrupt can be enabled/disabled by setting/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 12.0 "Timer2 Module"** for further details on the Timer0 module.

8.9 PORTB Interrupt-on-Change

An input change on PORTB<7:4> sets flag bit, RBIF (INTCON<0>). The interrupt can be enabled/disabled by setting/clearing 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>).

8.10 Context Saving During Interrupts

During interrupts, the return PC address 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 5.3 "Data Memory Organization"**), the user may need to save the WREG, STATUS and BSR registers on entry to the Interrupt Service Routine. 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_TMEP located anywhere
;
; USER ISR CODE
;
MOVFF   BSR_TEMP, BSR           ; Restore BSR
MOVF    W_TEMP, W               ; Restore WREG
MOVFF   STATUS_TEMP, STATUS     ; Restore STATUS
```

NOTES:

9.0 I/O PORTS

Depending on the device selected and features enabled, there are up to five ports available. Some pins of the I/O ports are multiplexed with an alternate function from the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin.

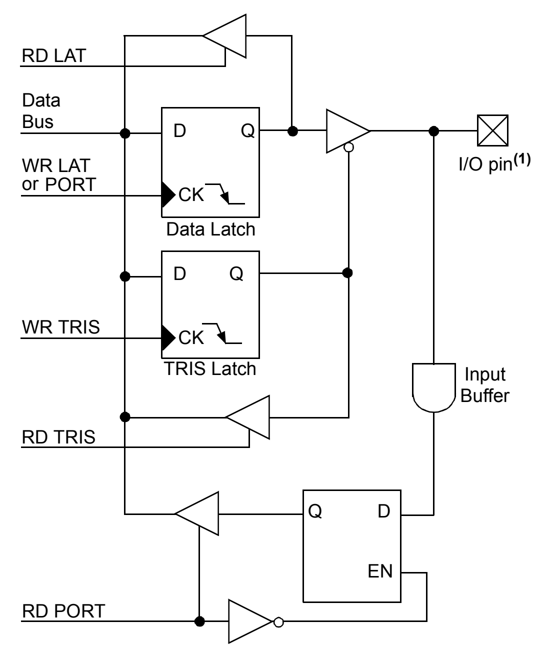
Each port has three registers for its operation. These registers are:

- TRIS register (Data Direction register)
- PORT register (reads the levels on the pins of the device)
- LAT register (Output Latch register)

The Output Latch register (LATA) is useful for read-modify-write operations on the value driven by the I/O pins.

A simplified model of a generic I/O port, without the interfaces to other peripherals, is shown in Figure 9-1.

FIGURE 9-1: GENERIC I/O PORT OPERATION



Note 1: I/O pins have diode protection to VDD and VSS.

9.1 PORTA, TRISA and LATA Registers

PORTA is an 8-bit wide, bidirectional port. The corresponding Data Direction register is TRISA. Setting a TRISA bit (= `1`) will make the corresponding PORTA pin an input (i.e., put the corresponding output driver in a high-impedance mode). Clearing a TRISA bit (= `0`) will make the corresponding PORTA pin an output (i.e., put the contents of the output latch on the selected pin).

Reading the PORTA register reads the status of the pins; writing to it will write to the port latch.

The Output Latch register (LATA) is also memory mapped. Read-modify-write operations on the LATA register read and write the latched output value for PORTA.

The RA4 pin is multiplexed with the Timer0 module clock input to become the RA4/T0CKI pin. The RA6 pin is multiplexed with the main oscillator pin; it is enabled as an oscillator or I/O pin by the selection of the main oscillator in Configuration Register 1H (see **Section 18.1 "Configuration Bits"** for details). When not used as a port pin, RA6 and its associated TRIS and LAT bits are read as '`0`'.

RA4 is also multiplexed with the USB module; it serves as a receiver input from an external USB transceiver. For details on configuration of the USB module, see **Section 14.2 "USB Status and Control"**.

Several PORTA pins are multiplexed with analog inputs. The operation of pins RA5 and RA3:RA0 as A/D Converter inputs is selected by clearing/setting the control bits in the ADCON1 register (A/D Control Register 1).

Note:	On a Power-on Reset, RA5 and RA3:RA0 are configured as analog inputs and read as '`0`'. RA4 is configured as a digital input.

All other PORTA pins have TTL input levels and full CMOS output drivers.

The TRISA register controls the direction of the RA pins, even when they are being used as analog inputs. The user must ensure the bits in the TRISA register are maintained set when using them as analog inputs.

EXAMPLE 9-1: INITIALIZING PORTA

```
CLRF    PORTA    ; Initialize PORTA by
                 ; clearing output
                 ; data latches
CLRF    LATA     ; Alternate method
                 ; to clear output
                 ; data latches
MOVLW   0Fh      ; Configure A/D
MOVWF   ADCON1   ; for digital inputs
MOVLW   0CFh     ; Value used to
                 ; initialize data
                 ; direction
MOVWF   TRISA    ; Set RA<3:0> as inputs
                 ; RA<5:4> as outputs
```


TABLE 9-1: PORTA I/O SUMMARY

Pin	Function	TRIS Setting	I/O	I/O Type	Description
RA0/AN0	RA0	0	OUT	DIG	LATA<0> data output; not affected by analog input.
		1	IN	TTL	PORTA<0> data input; disabled when analog input enabled.
	AN0	1	IN	ANA	A/D input channel 0. Default configuration on POR; does not affect digital output.
RA1/AN1	RA1	0	OUT	DIG	LATA<1> data output; not affected by analog input.
		1	IN	TTL	PORTA<1> data input; reads ‘0’ on POR.
	AN1	1	IN	ANA	A/D input channel 1. Default configuration on POR; does not affect digital output.
RA2/AN2/ VREF-	RA2	0	OUT	DIG	LATA<2> data output; not affected by analog input.
		1	IN	TTL	PORTA<2> data input. Disabled when analog functions enabled.
	AN2	1	IN	ANA	A/D input channel 2. Default configuration on POR; not affected by analog output.
	VREF-	1	IN	ANA	A/D voltage reference low input.
RA3/AN3/ VREF+	RA3	0	OUT	DIG	LATA<3> data output; not affected by analog input.
		1	IN	TTL	PORTA<3> data input; disabled when analog input enabled.
	AN3	1	IN	ANA	A/D input channel 3. Default configuration on POR.
	VREF+	1	IN	ANA	A/D voltage reference high input.
RA4/T0CKI/ RCV	RA4	0	OUT	DIG	LATA<4> data output; not affected by analog input.
		1	IN	ST	PORTA<4> data input; disabled when analog input enabled.
	T0CKI	1	IN	ST	Timer0 clock input.
	RCV	x	IN	TTL	External USB transceiver RCV input.
RA5/AN4/ HLVDIN	RA5	0	OUT	DIG	LATA<5> data output; not affected by analog input.
		1	IN	TTL	PORTA<5> data input; disabled when analog input enabled.
	AN4	1	IN	ANA	A/D input channel 4. Default configuration on POR.
	HLVDIN	1	IN	ANA	High/Low-Voltage Detect external trip point input.
OSC2/CLKO/ RA6	OSC2	x	OUT	ANA	Main oscillator feedback output connection (all XT and HS modes).
	CLKO	x	OUT	DIG	System cycle clock output (FOSC/4); available in EC, ECPLL and INTCKO modes.
	RA6	0	OUT	DIG	LATA<6> data output. Available only in ECIO, ECPIO and INTIO modes; otherwise, reads as ‘0’.
		1	IN	TTL	PORTA<6> data input. Available only in ECIO, ECPIO and INTIO modes; otherwise, reads as ‘0’.

Legend: OUT = Output, IN = Input, ANA = Analog Signal, DIG = Digital Output, ST = Schmitt Buffer Input, TTL = TTL Buffer Input, x = Don’t care (TRIS bit does not affect port direction or is overridden for this option)

TABLE 9-2: SUMMARY OF REGISTERS ASSOCIATED WITH PORTA

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
PORTA	—	RA6(1)	RA5	RA4	RA3	RA2	RA1	RA0	51
LATA	—	LATA6(1)	LATA5	LATA4	LATA3	LATA2	LATA1	LATA0	51
TRISA	—	TRISA6(1)	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	51
ADCON1	—	—	VCFG1	VCFG0	PCFG3	PCFG2	PCFG1	PCFG0	50
UCON	—	PPBRST	SE0	PKTDIS	USBEN	RESUME	SUSPND	—	52

Legend: — = unimplemented, read as ‘0’. Shaded cells are not used by PORTA.

Note 1: RA6 and its associated latch and data direction bits are enabled as I/O pins based on oscillator configuration; otherwise, they are read as ‘0’.

9.2 PORTB, TRISB and LATB Registers

PORTB is an 8-bit wide, bidirectional port. The corresponding Data Direction register is TRISB. Setting a TRISB bit (= 1) will make the corresponding PORTB pin an input (i.e., put the corresponding output driver in a high-impedance mode). Clearing a TRISB bit (= 0) will make the corresponding PORTB pin an output (i.e., put the contents of the output latch on the selected pin).

The Output Latch register (LATB) is also memory mapped. Read-modify-write operations on the LATB register read and write the latched output value for PORTB.

Each of the PORTB pins has a weak internal pull-up. A single control bit can turn on all the pull-ups. This is performed by clearing bit, $\overline{\text{RBPU}}$ (INTCON2<7>). The weak pull-up is automatically turned off when the port pin is configured as an output. The pull-ups are disabled on a Power-on Reset.

Note:	On a Power-on Reset, RB4:RB0 are configured as analog inputs by default and read as '0'; RB7:RB5 are configured as digital inputs. By programming the Configuration bit, PBADEN (CONFIG3H<1>), RB4:RB0 will alternatively be configured as digital inputs on POR.

Four of the PORTB pins (RB7:RB4) have an interrupt-on-change feature. Only pins configured as inputs can cause this interrupt to occur. Any RB7:RB4 pin configured as an output is excluded from the interrupt-on-change comparison. The pins are compared with the old value latched on the last read of PORTB. The "mismatch" outputs of RB7:RB4 are ORed together to generate the RB Port Change Interrupt with Flag bit, RBIF (INTCON<0>).

The interrupt-on-change can be used to wake the device from Sleep. The user, in the Interrupt Service Routine, can clear the interrupt in the following manner:

a) Any read or write of PORTB (except with the `MOVFF (ANY), PORTB` instruction). This will end the mismatch condition.
b) Wait one or more instruction cycles.
c) Clear flag bit, RBIF.

A mismatch condition will continue to set flag bit, RBIF. Reading PORTB will end the mismatch condition and allow flag bit, RBIF, to be cleared.

The interrupt-on-change feature is recommended for wake-up on key depression operation and operations where PORTB is only used for the interrupt-on-change feature. Polling of PORTB is not recommended while using the interrupt-on-change feature.

Pins, RB2 and RB3, are multiplexed with the USB peripheral and serve as the differential signal outputs for an external USB transceiver (TRIS configuration). Refer to **Section 14.2.2.2 "External Transceiver"** for additional information on configuring the USB module for operation with an external transceiver.

EXAMPLE 9-2: INITIALIZING PORTB

```
CLRF    PORTB   ; Initialize PORTB by
                ; clearing output
                ; data latches
CLRF    LATB    ; Alternate method
                ; to clear output
                ; data latches
MOVLW   0Eh     ; Set RB<4:0> as
MOVWF   ADCON1  ; digital I/O pins
                ; (required if config bit
                ; PBADEN is set)
MOVLW   0CFh    ; Value used to
                ; initialize data
                ; direction
MOVWF   TRISB   ; Set RB<3:0> as inputs
                ; RB<5:4> as outputs
                ; RB<7:6> as inputs
```

TABLE 9-3: PORTB I/O SUMMARY

Pin	Function	TRIS Setting	I/O	I/O Type	Description
RB0/AN12/ INT0	RB0	0	OUT	DIG	LATB<0> data output; not affected by analog input.
		1	IN	TTL	PORTB<0> data input; weak pull-up when $\overline{RBPU}$ bit is cleared. Disabled when analog input enabled.(1)
	AN12	1	IN	ANA	A/D input channel 12.(1)
	INT0	1	IN	ST	External interrupt 0 input.
RB1/AN10/ INT1	RB1	0	OUT	DIG	LATB<1> data output; not affected by analog input.
		1	IN	TTL	PORTB<1> data input; weak pull-up when $\overline{RBPU}$ bit is cleared. Disabled when analog input enabled.(1)
	AN10	1	IN	ANA	A/D input channel 10.(1)
	INT1	1	IN	ST	External interrupt 1 input.
RB2/AN8/ INT2/VMO	RB2	0	OUT	DIG	LATB<2> data output; not affected by analog input.
		1	IN	TTL	PORTB<2> data input; weak pull-up when $\overline{RBPU}$ bit is cleared. Disabled when analog input enabled.(1)
	AN8	1	IN	ANA	A/D input channel 8.(1)
	INT2	1	IN	ST	External interrupt 2 input.
	VMO	0	OUT	DIG	External USB transceiver VMO data output.
RB3/AN9/VPO	RB3	0	OUT	DIG	LATB<3> data output; not affected by analog input.
		1	IN	TTL	PORTB<3> data input; weak pull-up when $\overline{RBPU}$ bit is cleared. Disabled when analog input enabled.(1)
	AN9	1	IN	ANA	A/D input channel 9.(1)
	VPO	0	OUT	DIG	External USB transceiver VPO data output.
RB4/AN11/ KBI0	RB4	0	OUT	DIG	LATB<4> data output; not affected by analog input.
		1	IN	TTL	PORTB<4> data input; weak pull-up when $\overline{RBPU}$ bit is cleared. Disabled when analog input enabled.(1)
	AN11	1	IN	ANA	A/D input channel 11.(1)
	KBI0	1	IN	TTL	Interrupt-on-pin change.
RB5/KBI1/ PGM	RB5	0	OUT	DIG	LATB<5> data output.
		1	IN	TTL	PORTB<5> data input; weak pull-up when $\overline{RBPU}$ bit is cleared.
	KBI1	1	IN	TTL	Interrupt-on-pin change.
	PGM	x	IN	ST	Single-Supply Programming mode entry (ICSP™). Enabled by LVP Configuration bit; all other pin functions disabled.
RB6/KBI2/ PGC	RB6	0	OUT	DIG	LATB<6> data output.
		1	IN	TTL	PORTB<6> data input; weak pull-up when $\overline{RBPU}$ bit is cleared.
	KBI2	1	IN	TTL	Interrupt-on-pin change.
	PGC	x	IN	ST	Serial execution (ICSP) clock input for ICSP and ICD operation.(2)
RB7/KBI3/ PGD	RB7	0	OUT	DIG	LATB<7> data output.
		1	IN	TTL	PORTB<7> data input; weak pull-up when $\overline{RBPU}$ bit is cleared.
	KBI3	1	IN	TTL	Interrupt-on-pin change.
	PGD	x	OUT	DIG	Serial execution data output for ICSP and ICD operation.(2)
		x	IN	ST	Serial execution data input for ICSP and ICD operation.(2)

Legend: OUT = Output, IN = Input, ANA = Analog Signal, DIG = Digital Output, ST = Schmitt Buffer Input, TTL = TTL Buffer Input, x = Don't care (TRIS bit does not affect port direction or is overridden for this option)

Note 1: Configuration on POR is determined by PBADEN Configuration bit. Pins are configured as analog inputs when PBADEN is set and digital inputs when PBADEN is cleared.

2: All other pin functions are disabled when ICSP™ or ICD operation is enabled.

TABLE 9-4: SUMMARY OF REGISTERS ASSOCIATED WITH PORTB

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0	51
LATB	LATB7	LATB6	LATB5	LATB4	LATB3	LATB2	LATB1	LATB0	51
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	51
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
INTCON2	$\overline{\text{RBPU}}$	INTEDG0	INTEDG1	INTEDG2	—	TMR0IP	—	RBIP	49
INTCON3	INT2IP	INT1IP	—	INT2IE	INT1IE	—	INT2IF	INT1IF	49
ADCON1	—	—	VCFG1	VCFG0	PCFG3	PCFG2	PCFG1	PCFG0	50
UCON	—	PPBRST	SE0	PKTDIS	USBEN	RESUME	SUSPND	—	52

Legend: — = unimplemented, read as '0'. Shaded cells are not used by PORTB.

9.3 PORTC, TRISC and LATC Registers

PORTC is a 7-bit wide, bidirectional port. The corresponding Data Direction register is TRISC. Setting a TRISC bit (= `1`) will make the corresponding PORTC pin an input (i.e., put the corresponding output driver in a high-impedance mode). Clearing a TRISC bit (= `0`) will make the corresponding PORTC pin an output (i.e., put the contents of the output latch on the selected pin).

In PIC18F2450/4450 devices, the RC3 pin is not implemented.

The Output Latch register (LATC) is also memory mapped. Read-modify-write operations on the LATC register read and write the latched output value for PORTC.

PORTC is primarily multiplexed with serial communication modules, including the EUSART and the USB module (Table 9-5). Except for RC4 and RC5, PORTC uses Schmitt Trigger input buffers.

Pins RC4 and RC5 are multiplexed with the USB module. Depending on the configuration of the module, they can serve as the differential data lines for the on-chip USB transceiver, or the data inputs from an external USB transceiver. Both RC4 and RC5 have TTL input buffers instead of the Schmitt Trigger buffers on the other pins.

Unlike other PORTC pins, RC4 and RC5 do not have TRISC bits associated with them. As digital ports, they can only function as digital inputs. When configured for USB operation, the data direction is determined by the configuration and status of the USB module at a given time. If an external transceiver is used, RC4 and RC5 always function as inputs from the transceiver. If the on-chip transceiver is used, the data direction is determined by the operation being performed by the module at that time.

When the external transceiver is enabled, RC2 also serves as the output enable control to the transceiver. Additional information on configuring USB options is provided in **Section 14.2.2.2 "External Transceiver"**.

When enabling peripheral functions on PORTC pins other than RC4 and RC5, care should be taken in defining the TRIS bits. Some peripherals override the TRIS bit to make a pin an output, while other peripherals override the TRIS bit to make a pin an input. The user should refer to the corresponding peripheral section for the correct TRIS bit settings.

Note:	On a Power-on Reset, these pins, except RC4 and RC5, are configured as digital inputs. To use pins RC4 and RC5 as digital inputs, the USB module must be disabled (UCON<3> = `0`) and the on-chip USB transceiver must be disabled (UCFG<3> = `1`).

The contents of the TRISC register are affected by peripheral overrides. Reading TRISC always returns the current contents, even though a peripheral device may be overriding one or more of the pins.

EXAMPLE 9-3: INITIALIZING PORTC

```
CLRF    PORTC   ; Initialize PORTC by
                ; clearing output
                ; data latches
CLRF    LATC    ; Alternate method
                ; to clear output
                ; data latches
MOVLW   07h     ; Value used to
                ; initialize data
                ; direction
MOVWF   TRISC   ; RC<5:0> as outputs
                ; RC<7:6> as inputs
```

TABLE 9-5: PORTC I/O SUMMARY

Pin	Function	TRIS Setting	I/O	I/O Type	Description
RC0/T1OSO/ T1CKI	RC0	0	OUT	DIG	LATC<0> data output.
		1	IN	ST	PORTC<0> data input.
	T1OSO	x	OUT	ANA	Timer1 oscillator output; enabled when Timer1 oscillator enabled. Disables digital I/O.
	T1CKI	1	IN	ST	Timer1 counter input.
RC1/T1OSI/ $\overline{UOE}$	RC1	0	OUT	DIG	LATC<1> data output.
		1	IN	ST	PORTC<1> data input.
	T1OSI	x	IN	ANA	Timer1 oscillator input; enabled when Timer1 oscillator enabled. Disables digital I/O.
	$\overline{UOE}$	0	OUT	DIG	External USB transceiver $\overline{OE}$ output.
RC2/CCP1	RC2	0	OUT	DIG	LATC<2> data output.
		1	IN	ST	PORTC<2> data input.
	CCP1	0	OUT	DIG	CCP1 Compare and PWM output; takes priority over port data.
		1	IN	ST	CCP1 Capture input.
RC4/D-/VM	RC4	—(1)	IN	TTL	PORTC<4> data input; disabled when USB module or on-chip transceiver is enabled.
	D-	—(1)	OUT	XCVR	USB bus differential minus line output (internal transceiver).
		—(1)	IN	XCVR	USB bus differential minus line input (internal transceiver).
	VM	—(1)	IN	TTL	External USB transceiver VM input.
RC5/D+/VP	RC5	—(1)	IN	TTL	PORTC<5> data input; disabled when USB module or on-chip transceiver is enabled.
	D+	—(1)	OUT	XCVR	USB bus differential plus line output (internal transceiver).
		—(1)	IN	XCVR	USB bus differential plus line input (internal transceiver).
	VP	—(1)	IN	TTL	External USB transceiver VP input.
RC6/TX/CK	RC6	0	OUT	DIG	LATC<6> data output.
		1	IN	ST	PORTC<6> data input.
	TX	0	OUT	DIG	Asynchronous serial transmit data output (EUSART module); takes priority over port data. User must configure as output.
	CK	0	OUT	DIG	Synchronous serial clock output (EUSART module); takes priority over port data.
		1	IN	ST	Synchronous serial clock input (EUSART module).
RC7/RX/DT	RC7	0	OUT	DIG	LATC<7> data output.
		1	IN	ST	PORTC<7> data input.
	RX	1	IN	ST	Asynchronous serial receive data input (EUSART module).
	DT	1	OUT	DIG	Synchronous serial data output (EUSART module).
		1	IN	ST	Synchronous serial data input (EUSART module). User must configure as an input.

Legend: OUT = Output, IN = Input, ANA = Analog Signal, DIG = Digital Output, ST = Schmitt Buffer Input, TTL = TTL Buffer Input, XCVR = USB Transceiver, x = Don't care (TRIS bit does not affect port direction or is overridden for this option)

Note 1: RC4 and RC5 do not have corresponding TRISC bits. In Port mode, these pins are input only. USB data direction is determined by the USB configuration.

TABLE 9-6: SUMMARY OF REGISTERS ASSOCIATED WITH PORTC

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
PORTC	RC7	RC6	RC5(1)	RC4(1)	—	RC2	RC1	RC0	51
LATC	LATC7	LATC6	—	—	—	LATC2	LATC1	LATC0	51
TRISC	TRISC7	TRISC6	—	—	—	TRISC2	TRISC1	TRISC0	51
UCON	—	PPBRST	SE0	PKTDIS	USBEN	RESUME	SUSPND	—	52

Legend: — = unimplemented, read as '0'. Shaded cells are not used by PORTC.

Note 1: RC5 and RC4 are only available as port pins when the USB module is disabled (UCON<3> = 0).

9.4 PORTD, TRISD and LATD Registers

Note:	PORTD is only available on 40/44-pin devices.

PORTD is an 8-bit wide, bidirectional port. The corresponding Data Direction register is TRISD. Setting a TRISD bit (= 1) will make the corresponding PORTD pin an input (i.e., put the corresponding output driver in a high-impedance mode). Clearing a TRISD bit (= 0) will make the corresponding PORTD pin an output (i.e., put the contents of the output latch on the selected pin).

The Output Latch register (LATD) is also memory mapped. Read-modify-write operations on the LATD register read and write the latched output value for PORTD.

All pins on PORTD are implemented with Schmitt Trigger input buffers. Each pin is individually configurable as an input or output.

Note:	On a Power-on Reset, these pins are configured as digital inputs.

EXAMPLE 9-4: INITIALIZING PORTD

```
CLRF    PORTD   ; Initialize PORTD by
                ; clearing output
                ; data latches
CLRF    LATD    ; Alternate method
                ; to clear output
                ; data latches
MOVLW   0CFh    ; Value used to
                ; initialize data
                ; direction
MOVWF   TRISD   ; Set RD<3:0> as inputs
                ; RD<5:4> as outputs
                ; RD<7:6> as inputs
```

TABLE 9-7: PORTD I/O SUMMARY

Pin	Function	TRIS Setting	I/O	I/O Type	Description
RD0	RD0	0	OUT	DIG	LATD<0> data output.
		1	IN	ST	PORTD<0> data input.
RD1	RD1	0	OUT	DIG	LATD<1> data output.
		1	IN	ST	PORTD<1> data input.
RD2	RD2	0	OUT	DIG	LATD<2> data output.
		1	IN	ST	PORTD<2> data input.
RD3	RD3	0	OUT	DIG	LATD<3> data output.
		1	IN	ST	PORTD<3> data input.
RD4	RD4	0	OUT	DIG	LATD<4> data output.
		1	IN	ST	PORTD<4> data input.
RD5	RD5	0	OUT	DIG	LATD<5> data output
		1	IN	ST	PORTD<5> data input
RD6	RD6	0	OUT	DIG	LATD<6> data output.
		1	IN	ST	PORTD<6> data input.
RD7	RD7	0	OUT	DIG	LATD<7> data output.
		1	IN	ST	PORTD<7> data input.

Legend: OUT = Output, IN = Input, DIG = Digital Output, ST = Schmitt Buffer Input

TABLE 9-8: SUMMARY OF REGISTERS ASSOCIATED WITH PORTD

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
PORTD(1)	RD7	RD6	RD5	RD4	RD3	RD2	RD1	RD0	51
LATD(1)	LATD7	LATD6	LATD5	LATD4	LATD3	LATD2	LATD1	LATD0	51
TRISD(1)	TRISD7	TRISD6	TRISD5	TRISD4	TRISD3	TRISD2	TRISD1	TRISD0	51

Note 1: These registers and/or bits are unimplemented on 28-pin devices.

9.5 PORTE, TRISE and LATE Registers

Depending on the particular PIC18F2450/4450 device selected, PORTE is implemented in two different ways.

For 40/44-pin devices, PORTE is a 4-bit wide port. Three pins (RE0/AN5, RE1/AN6 and RE2/AN7) are individually configurable as inputs or outputs. These pins have Schmitt Trigger input buffers. When selected as an analog input, these pins will read as '0's.

The corresponding Data Direction register is TRISE. Setting a TRISE bit (= 1) will make the corresponding PORTE pin an input (i.e., put the corresponding output driver in a high-impedance mode). Clearing a TRISE bit (= 0) will make the corresponding PORTE pin an output (i.e., put the contents of the output latch on the selected pin).

TRISE controls the direction of the RE pins, even when they are being used as analog inputs. The user must make sure to keep the pins configured as inputs when using them as analog inputs.

Note:	On a Power-on Reset, RE2:RE0 are configured as analog inputs.

The Output Latch register (LATE) is also memory mapped. Read-modify-write operations on the LATE register read and write the latched output value for PORTE.

The fourth pin of PORTE ($\overline{MCLR}$/VPP/RE3) is an input only pin. Its operation is controlled by the MCLRE Configuration bit. When selected as a port pin (MCLRE = 0), it functions as a digital input only pin; as such, it does not have TRIS or LAT bits associated with its operation. Otherwise, it functions as the device's Master Clear input. In either configuration, RE3 also functions as the programming voltage input during programming.

Note:	On a Power-on Reset, RE3 is enabled as a digital input only if Master Clear functionality is disabled.

EXAMPLE 9-5: INITIALIZING PORTE

```
CLRF    PORTE   ; Initialize PORTE by
                ; clearing output
                ; data latches
CLRF    LATE    ; Alternate method
                ; to clear output
                ; data latches
MOVLW   0Ah     ; Configure A/D
MOVWF   ADCON1  ; for digital inputs
MOVLW   03h     ; Value used to
                ; initialize data
                ; direction
MOVWF   TRISC   ; Set RE<0> as inputs
                ; RE<1> as inputs
                ; RE<2> as outputs
```

9.5.1 PORTE IN 28-PIN DEVICES

For 28-pin devices, PORTE is only available when Master Clear functionality is disabled (MCLRE = 0). In these cases, PORTE is a single bit, input only port comprised of RE3 only. The pin operates as previously described.

REGISTER 9-1: PORTE REGISTER

U-0	U-0	U-0	U-0	R/W-x	R/W-0	R/W-0	R/W-0
—	—	—	—	RE3[(1,2)]	RE2[(3)]	RE1[(3)]	RE0[(3)]
bit 7							bit 0

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

bit 7-4 **Unimplemented:** Read as '0'

bit 3-0 **RE3:RE0:** PORTE Data Input bits[(1,2,3)]

Note 1: implemented only when Master Clear functionality is disabled (MCLRE Configuration bit = 0); otherwise, read as '0'.

2: RE3 is the only PORTE bit implemented on both 28-pin and 40/44-pin devices. All other bits are implemented only when PORTE is implemented (i.e., 40/44-pin devices).

3: Unimplemented in 28-pin devices; read as '0'.

TABLE 9-9: PORTE I/O SUMMARY

Pin	Function	TRIS Setting	I/O	I/O Type	Description
RE0/AN5	RE0	0	OUT	DIG	LATE<0> data output; not affected by analog input.
		1	IN	ST	PORTE<0> data input; disabled when analog input enabled.
	AN5	1	IN	ANA	A/D input channel 5; default configuration on POR.
RE1/AN6	RE1	0	OUT	DIG	LATE<1> data output; not affected by analog input.
		1	IN	ST	PORTE<1> data input; disabled when analog input enabled.
	AN6	1	IN	ANA	A/D input channel 6; default configuration on POR.
RE2/AN7	RE2	0	OUT	DIG	LATE<2> data output; not affected by analog input.
		1	IN	ST	PORTE<2> data input; disabled when analog input enabled.
	AN7	1	IN	ANA	A/D input channel 7; default configuration on POR.
$\overline{MCLR}$/VPP/ RE3	$\overline{MCLR}$	—(1)	IN	ST	External Master Clear input; enabled when MCLRE Configuration bit is set.
	VPP	—(1)	IN	ANA	High-voltage detection, used for ICSP™ mode entry detection. Always available regardless of pin mode.
	RE3	—(1)	IN	ST	PORTE<3> data input; enabled when MCLRE Configuration bit is clear.

Legend: OUT = Output, IN = Input, ANA = Analog Signal, DIG = Digital Output, ST = Schmitt Buffer Input.
Note 1: RE3 does not have a corresponding TRISE<3> bit. This pin is always an input regardless of mode.

TABLE 9-10: SUMMARY OF REGISTERS ASSOCIATED WITH PORTE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
PORTE	—	—	—	—	RE3(1,2)	RE2(3)	RE1(3)	RE0(3)	51
LATE(3)	—	—	—	—	—	LATE2	LATE1	LATE0	51
TRISE(3)	—	—	—	—	—	TRISE2	TRISE1	TRISE0	51
ADCON1	—	—	VCFG1	VCFG0	PCFG3	PCFG2	PCFG1	PCFG0	50

Legend: — = unimplemented, read as '0'
Note 1: Implemented only when Master Clear functionality is disabled (MCLRE Configuration bit = 0); otherwise, read as '0'.
2: RE3 is the only PORTE bit implemented on both 28-pin and 40/44-pin devices. All other bits are implemented only when PORTE is implemented (i.e., 40/44-pin devices).
3: These registers and/or bits are unimplemented on 28-pin devices.

10.0 TIMER0 MODULE

The Timer0 module incorporates the following features:

- Software selectable operation as a timer or counter in both 8-bit or 16-bit modes
- Readable and writable registers
- Dedicated 8-bit, software programmable prescaler
- Selectable clock source (internal or external)
- Edge select for external clock
- Interrupt on overflow

The T0CON register (Register 10-1) controls all aspects of the module's operation, including the prescale selection. It is both readable and writable.

A simplified block diagram of the Timer0 module in 8-bit mode is shown in Figure 10-1. Figure 10-2 shows a simplified block diagram of the Timer0 module in 16-bit mode.

REGISTER 10-1: T0CON: TIMER0 CONTROL REGISTER

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
TMR0ON	T08BIT	T0CS	T0SE	PSA	T0PS2	T0PS1	T0PS0
bit 7							bit 0

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

bit 7 **TMR0ON:** Timer0 On/Off Control bit
1 = Enables Timer0
0 = Stops Timer0

bit 6 **T08BIT**: Timer0 8-Bit/16-Bit Control bit
1 = Timer0 is configured as an 8-bit timer/counter
0 = Timer0 is configured as a 16-bit timer/counter

bit 5 **T0CS**: Timer0 Clock Source Select bit
1 = Transition on T0CKI pin
0 = Internal instruction cycle clock (CLKO)

bit 4 **T0SE**: Timer0 Source Edge Select bit
1 = Increment on high-to-low transition on T0CKI pin
0 = Increment on low-to-high transition on T0CKI pin

bit 3 **PSA**: Timer0 Prescaler Assignment bit
1 = TImer0 prescaler is not assigned. Timer0 clock input bypasses prescaler.
0 = Timer0 prescaler is assigned. Timer0 clock input comes from prescaler output.

bit 2-0 **T0PS2:T0PS0**: Timer0 Prescaler Select bits
111 = 1:256 Prescale value
110 = 1:128 Prescale value
101 = 1:64 Prescale value
100 = 1:32 Prescale value
011 = 1:16 Prescale value
010 = 1:8 Prescale value
001 = 1:4 Prescale value
000 = 1:2 Prescale value

10.1 Timer0 Operation

Timer0 can operate as either a timer or a counter; the mode is selected by clearing the T0CS bit (T0CON<5>). In Timer mode, the module increments on every clock by default unless a different prescaler value is selected (see **Section 10.3 "Prescaler"**). If the TMR0 register is written to, the increment is inhibited for the following two instruction cycles. The user can work around this by writing an adjusted value to the TMR0 register.

The Counter mode is selected by setting the T0CS bit (= `1`). In Counter mode, Timer0 increments either on every rising or falling edge of pin RA4/T0CKI. The incrementing edge is determined by the Timer0 Source Edge Select bit, T0SE (T0CON<4>); clearing this bit selects the rising edge. Restrictions on the external clock input are discussed below.

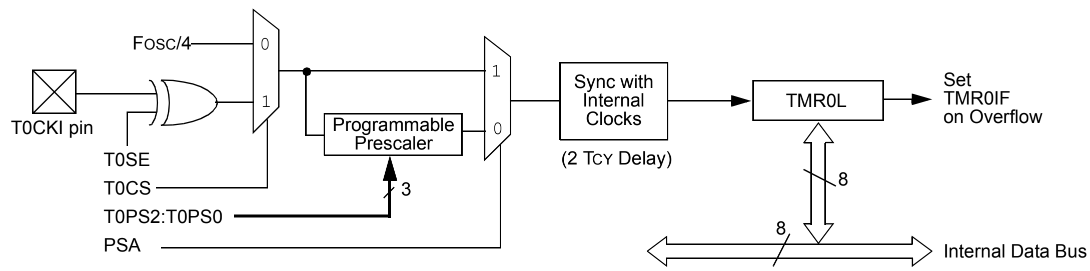
An external clock source can be used to drive Timer0; however, it must meet certain requirements to ensure that the external clock can be synchronized with the internal phase clock (TOSC). There is a delay between synchronization and the onset of incrementing the timer/counter.

10.2 Timer0 Reads and Writes in 16-Bit Mode

TMR0H is not the actual high byte of Timer0 in 16-bit mode; it is actually a buffered version of the real high byte of Timer0, which is not directly readable nor writable (refer to Figure 10-2). 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.

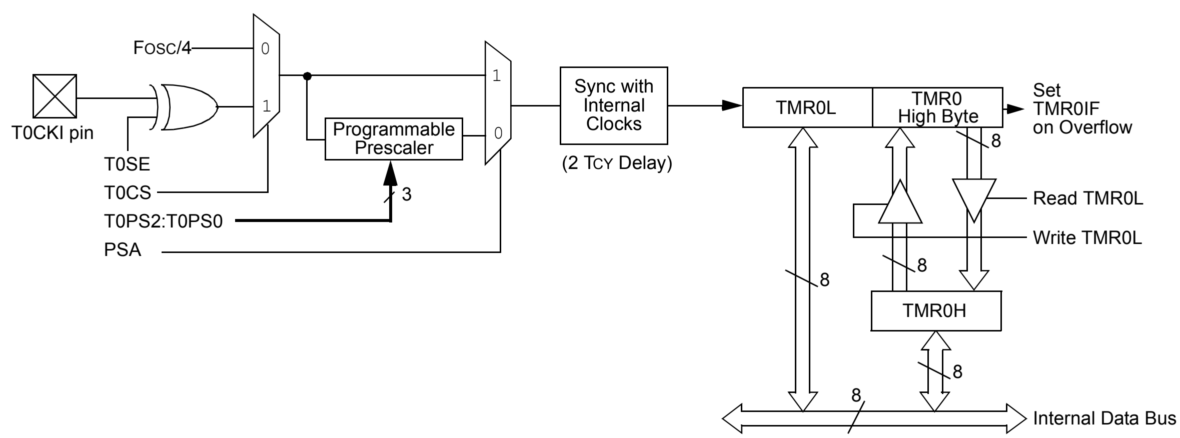
Similarly, a write to the high byte of Timer0 must also take place through the TMR0H Buffer register. The high byte is updated with the contents of TMR0H when a write occurs to TMR0L. This allows all 16 bits of Timer0 to be updated at once.

FIGURE 10-1: TIMER0 BLOCK DIAGRAM (8-BIT MODE)



Note: Upon Reset, Timer0 is enabled in 8-bit mode with clock input from T0CKI maximum prescale.

FIGURE 10-2: TIMER0 BLOCK DIAGRAM (16-BIT MODE)



Note: Upon Reset, Timer0 is enabled in 8-bit mode with clock input from T0CKI maximum prescale.

10.3 Prescaler

An 8-bit counter is available as a prescaler for the Timer0 module. The prescaler is not directly readable or writable; its value is set by the PSA and T0PS2:T0PS0 bits (T0CON<3:0>) which determine the prescaler assignment and prescale ratio.

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

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

> **Note:** Writing to TMR0 when the prescaler is assigned to Timer0 will clear the prescaler count but will not change the prescaler assignment.

10.3.1 SWITCHING PRESCALER ASSIGNMENT

The prescaler assignment is fully under software control and can be changed "on-the-fly" during program execution.

10.4 Timer0 Interrupt

The TMR0 interrupt is generated when the TMR0 register overflows from FFh to 00h in 8-bit mode, or from FFFFh to 0000h in 16-bit mode. This overflow sets the TMR0IF flag bit. The interrupt can be masked by clearing the TMR0IE bit (INTCON<5>). Before re-enabling the interrupt, the TMR0IF bit must be cleared in software by the Interrupt Service Routine.

Since Timer0 is shut down in Sleep mode, the TMR0 interrupt cannot awaken the processor from Sleep.

TABLE 10-1: REGISTERS ASSOCIATED WITH TIMER0

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
TMR0L	Timer0 Register Low Byte								50
TMR0H	Timer0 Register High Byte								50
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
T0CON	TMR0ON	T08BIT	T0CS	T0SE	PSA	T0PS2	T0PS1	T0PS0	50
TRISA	—	TRISA6(1)	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	51

Legend: — = unimplemented locations, read as '0'. Shaded cells are not used by Timer0.

Note 1: RA6 is configured as a port pin based on various primary oscillator modes. When the port pin is disabled, all of the associated bits read '0'.

NOTES:

11.0 TIMER1 MODULE

The Timer1 timer/counter module incorporates these features:

- Software selectable operation as a 16-bit timer or counter
- Readable and writable 8-bit registers (TMR1H and TMR1L)
- Selectable clock source (internal or external) with device clock or Timer1 oscillator internal options
- Interrupt on overflow
- Module Reset on CCP Special Event Trigger
- Device clock status flag (T1RUN)

A simplified block diagram of the Timer1 module is shown in Figure 11-1. A block diagram of the module's operation in Read/Write mode is shown in Figure 11-2.

The module incorporates its own low-power oscillator to provide an additional clocking option. The Timer1 oscillator can also be used as a low-power clock source for the microcontroller in power-managed operation.

Timer1 can also be used to provide Real-Time Clock (RTC) functionality to applications with only a minimal addition of external components and code overhead.

Timer1 is controlled through the T1CON Control register (Register 11-1). It also contains the Timer1 Oscillator Enable bit (T1OSCEN). Timer1 can be enabled or disabled by setting or clearing control bit, TMR1ON (T1CON<0>).

REGISTER 11-1: T1CON: TIMER1 CONTROL REGISTER

R/W-0	R-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
RD16	T1RUN	T1CKPS1	T1CKPS0	T1OSCEN	$\overline{\text{T1SYNC}}$	TMR1CS	TMR1ON
bit 7							bit 0

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

bit 7 **RD16:** 16-Bit Read/Write Mode Enable bit
1 = Enables register read/write of Timer1 in one 16-bit operation
0 = Enables register read/write of Timer1 in two 8-bit operations

bit 6 **T1RUN:** Timer1 System Clock Status bit
1 = Device clock is derived from Timer1 oscillator
0 = Device clock is derived from another source

bit 5-4 **T1CKPS1:T1CKPS0:** Timer1 Input Clock Prescale Select bits
11 = 1:8 Prescale value
10 = 1:4 Prescale value
01 = 1:2 Prescale value
00 = 1:1 Prescale value

bit 3 **T1OSCEN:** Timer1 Oscillator Enable bit
1 = Timer1 oscillator is enabled
0 = Timer1 oscillator is shut off
The oscillator inverter and feedback resistor are turned off to eliminate power drain.

bit 2 **$\overline{\text{T1SYNC}}$:** Timer1 External Clock Input Synchronization Select bit
When TMR1CS = 1:
1 = Do not synchronize external clock input
0 = Synchronize external clock input
When TMR1CS = 0:
This bit is ignored. Timer1 uses the internal clock when TMR1CS = 0.

bit 1 **TMR1CS:** Timer1 Clock Source Select bit
1 = External clock from RC0/T1OSO/T1CKI pin (on the rising edge)
0 = Internal clock (FOSC/4)

bit 0 **TMR1ON:** Timer1 On bit
1 = Enables Timer1
0 = Stops Timer1

11.1 Timer1 Operation

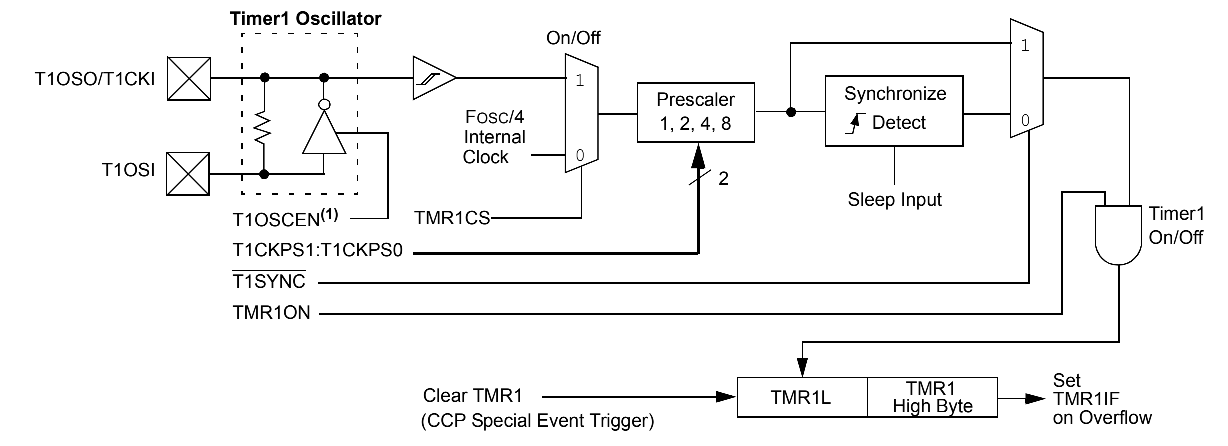
Timer1 can operate in one of these modes:

- Timer
- Synchronous Counter
- Asynchronous Counter

The operating mode is determined by the clock select bit, TMR1CS (T1CON<1>). When TMR1CS is cleared (= 0), Timer1 increments on every internal instruction cycle (FOSC/4). When the bit is set, Timer1 increments on every rising edge of the Timer1 external clock input or the Timer1 oscillator, if enabled.

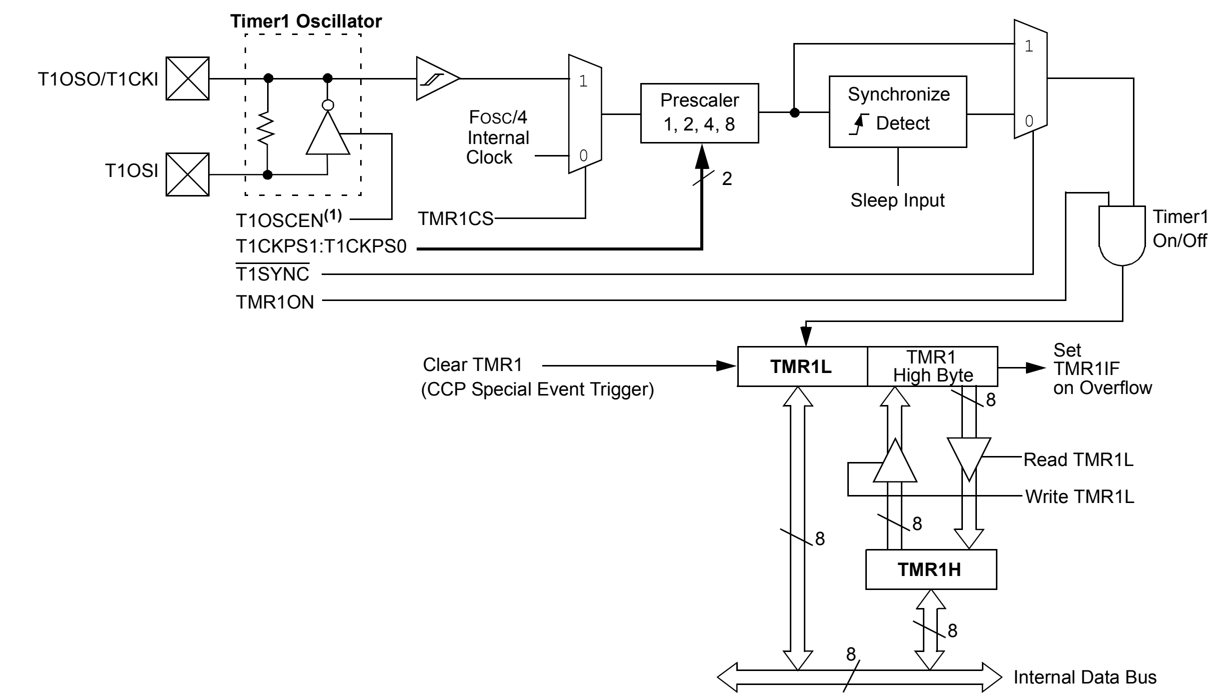
When Timer1 is enabled, the RC1/T1OSI/$\overline{\text{UOE}}$ and RC0/T1OSO/T1CKI pins become inputs. This means the values of TRISC<1:0> are ignored and the pins are read as '0'.

FIGURE 11-1: TIMER1 BLOCK DIAGRAM



Note 1: When enable bit, T1OSCEN, is cleared, the inverter and feedback resistor are turned off to eliminate power drain.

FIGURE 11-2: TIMER1 BLOCK DIAGRAM (16-BIT READ/WRITE MODE)



Note 1: When enable bit, T1OSCEN, is cleared, the inverter and feedback resistor are turned off to eliminate power drain.

11.2 Timer1 16-Bit Read/Write Mode

Timer1 can be configured for 16-bit reads and writes (see Figure 11-2). When the RD16 control bit (T1CON<7>) is set, the address for TMR1H is mapped to a buffer register for the high byte of Timer1. A read from TMR1L will load the contents of the high byte of Timer1 into the Timer1 high byte buffer. This provides the user with the ability to accurately read all 16 bits of Timer1 without having to determine whether a read of the high byte, followed by a read of the low byte, has become invalid due to a rollover between reads.

A write to the high byte of Timer1 must also take place through the TMR1H Buffer register. The Timer1 high byte is updated with the contents of TMR1H when a write occurs to TMR1L. This allows a user to write all 16 bits to both the high and low bytes of Timer1 at once.

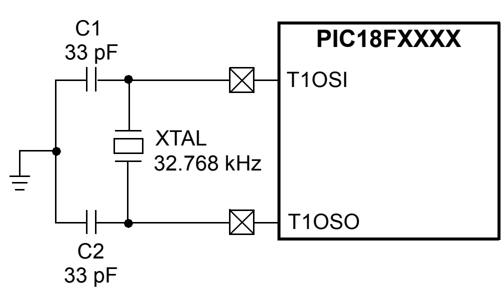
The high byte of Timer1 is not directly readable or writable in this mode. All reads and writes must take place through the Timer1 High Byte Buffer register. Writes to TMR1H do not clear the Timer1 prescaler. The prescaler is only cleared on writes to TMR1L.

11.3 Timer1 Oscillator

An on-chip crystal oscillator circuit is incorporated between pins T1OSI (input) and T1OSO (amplifier output). It is enabled by setting the Timer1 Oscillator Enable bit, T1OSCEN (T1CON<3>). The oscillator is a low-power circuit rated for 32 kHz crystals. It will continue to run during all power-managed modes. The circuit for a typical LP oscillator is shown in Figure 11-3. Table 11-1 shows the capacitor selection for the Timer1 oscillator.

The user must provide a software time delay to ensure proper start-up of the Timer1 oscillator.

FIGURE 11-3: EXTERNAL COMPONENTS FOR THE TIMER1 LP OSCILLATOR



Note: See the Notes with Table 11-1 for additional information about capacitor selection.

TABLE 11-1: CAPACITOR SELECTION FOR THE TIMER OSCILLATOR[2,3,4]

Osc Type	Freq	C1	C2
LP	32 kHz	27 pF[1]	27 pF[1]

Note 1: Microchip suggests these values as a starting point in validating the oscillator circuit.

2: Higher capacitance increases the stability of the oscillator but also increases the start-up time.

3: Since each resonator/crystal has its own characteristics, the user should consult the resonator/crystal manufacturer for appropriate values of external components.

4: Capacitor values are for design guidance only.

11.3.1 USING TIMER1 AS A CLOCK SOURCE

The Timer1 oscillator is also available as a clock source in power-managed modes. By setting the clock select bits, SCS1:SCS0 (OSCCON<1:0>), to '`01`', the device switches to SEC_RUN mode. Both the CPU and peripherals are clocked from the Timer1 oscillator. If the IDLEN bit (OSCCON<7>) is cleared and a `SLEEP` instruction is executed, the device enters SEC_IDLE mode. Additional details are available in **Section 3.0 "Power-Managed Modes"**.

Whenever the Timer1 oscillator is providing the clock source, the Timer1 system clock status flag, T1RUN (T1CON<6>), is set. This can be used to determine the controller's current clocking mode. It can also indicate the clock source being currently used by the Fail-Safe Clock Monitor. If the Clock Monitor is enabled and the Timer1 oscillator fails while providing the clock, polling the T1RUN bit will indicate whether the clock is being provided by the Timer1 oscillator or another source.

11.3.2 LOW-POWER TIMER1 OPTION

The Timer1 oscillator can operate at two distinct levels of power consumption based on device configuration. When the LPT1OSC Configuration bit is set, the Timer1 oscillator operates in a low-power mode. When LPT1OSC is not set, Timer1 operates at a higher power level. Power consumption for a particular mode is relatively constant, regardless of the device's operating mode. The default Timer1 configuration is the higher power mode.

As the Low-Power Timer1 mode tends to be more sensitive to interference, high noise environments may cause some oscillator instability. The low-power option is, therefore, best suited for low noise applications where power conservation is an important design consideration.

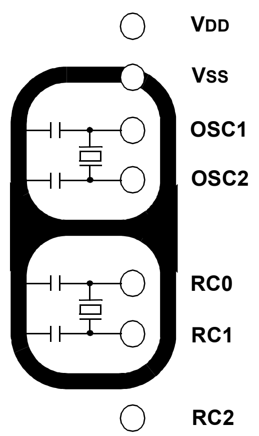
11.3.3 TIMER1 OSCILLATOR LAYOUT CONSIDERATIONS

The Timer1 oscillator circuit draws very little power during operation. Due to the low-power nature of the oscillator, it may also be sensitive to rapidly changing signals in close proximity.

The oscillator circuit, shown in Figure 11-3, should be located as close as possible to the microcontroller. There should be no circuits passing within the oscillator circuit boundaries other than V_{SS} or V_{DD}.

If a high-speed circuit must be located near the oscillator (such as the CCP1 pin in Output Compare or PWM mode, or the primary oscillator using the OSC2 pin), a grounded guard ring around the oscillator circuit, as shown in Figure 11-4, may be helpful when used on a single-sided PCB or in addition to a ground plane.

FIGURE 11-4: OSCILLATOR CIRCUIT WITH GROUNDED GUARD RING



Note: Not drawn to scale.

11.4 Timer1 Interrupt

The TMR1 register pair (TMR1H:TMR1L) increments from 0000h to FFFFh and rolls over to 0000h. The Timer1 interrupt, if enabled, is generated on overflow which is latched in interrupt flag bit, TMR1IF (PIR1<0>). This interrupt can be enabled or disabled by setting or clearing the Timer1 Interrupt Enable bit, TMR1IE (PIE1<0>).

11.5 Resetting Timer1 Using the CCP Special Event Trigger

If the CCP module is configured in Compare mode to generate a Special Event Trigger (CCP1M3:CCP1M0 = `1011`), this signal will reset Timer1. The trigger from CCP1 will also start an A/D conversion if the A/D module is enabled (see **Section 13.3.4 "Special Event Trigger"** for more information).

The module must be configured as either a timer or a synchronous counter to take advantage of this feature. When used this way, the CCPRH:CCPRL register pair effectively becomes a period register for Timer1.

If Timer1 is running in Asynchronous Counter mode, this Reset operation may not work.

In the event that a write to Timer1 coincides with a Special Event Trigger, the write operation will take precedence.

Note:	The Special Event Triggers from the CCP1 module will not set the TMR1IF interrupt flag bit (PIR1<0>).

11.6 Using Timer1 as a Real-Time Clock

Adding an external LP oscillator to Timer1 (such as the one described in **Section 11.3 "Timer1 Oscillator"**) gives users the option to include RTC functionality to their applications. This is accomplished with an inexpensive watch crystal to provide an accurate time base and several lines of application code to calculate the time. When operating in Sleep mode and using a battery or supercapacitor as a power source, it can completely eliminate the need for a separate RTC device and battery backup.

The application code routine, `RTCisr`, shown in Example 11-1, demonstrates a simple method to increment a counter at one-second intervals using an Interrupt Service Routine. Incrementing the TMR1 register pair to overflow triggers the interrupt and calls the routine which increments the seconds counter by one. Additional counters for minutes and hours are incremented as the previous counter overflows.

Since the register pair is 16 bits wide, counting up to overflow the register directly from a 32.768 kHz clock would take 2 seconds. To force the overflow at the required one-second intervals, it is necessary to preload it. The simplest method is to set the MSb of TMR1H with a `BSF` instruction. Note that the TMR1L register is never preloaded or altered; doing so may introduce cumulative error over many cycles.

For this method to be accurate, Timer1 must operate in Asynchronous mode and the Timer1 overflow interrupt must be enabled (PIE1<0> = `1`) as shown in the routine, `RTCinit`. The Timer1 oscillator must also be enabled and running at all times.

11.7 Considerations in Asynchronous Counter Mode

Following a Timer1 interrupt and an update to the TMR1 registers, the Timer1 module uses a falling edge on its clock source to trigger the next register update on the rising edge. If the update is completed after the clock input has fallen, the next rising edge will not be counted.

If the application can reliably update TMR1 before the timer input goes low, no additional action is needed. Otherwise, an adjusted update can be performed following a later Timer1 increment. This can be done by monitoring TMR1L within the interrupt routine until it increments, and then updating the TMR1H:TMR1L register pair while the clock is low, or one-half of the period of the clock source. Assuming that Timer1 is being used as a Real-Time Clock, the clock source is a 32.768 kHz crystal oscillator. In this case, one-half period of the clock is 15.25 μs.

The Real-Time Clock application code in Example 11-1 shows a typical ISR for Timer1, as well as the optional code required if the update cannot be done reliably within the required interval.

EXAMPLE 11-1: IMPLEMENTING A REAL-TIME CLOCK USING A TIMER1 INTERRUPT SERVICE

```
RTCinit
         MOVLW    80h             ; Preload TMR1 register pair
         MOVWF    TMR1H           ; for 1 second overflow
         CLRF     TMR1L
         MOVLW    b'00001111'     ; Configure for external clock,
         MOVWF    T1CON           ; Asynchronous operation, external oscillator
         CLRF     secs            ; Initialize timekeeping registers
         CLRF     mins            ;
         MOVLW    .12
         MOVWF    hours
         BSF      PIE1, TMR1IE    ; Enable Timer1 interrupt
         RETURN
RTCisr
                                  ; Insert the next 4 lines of code when TMR1
                                  ; cannot be reliably updated before clock pulse goes low
         BTFSC    TMR1L,0         ; wait for TMR1L to become clear
         BRA      $-2             ; (may already be clear)
         BTFSS    TMR1L,0         ; wait for TMR1L to become set
         BRA      $-2             ; TMR1 has just incremented
                                  ; If TMR1 update can be completed before clock pulse goes low
                                  ; Start ISR here
         BSF      TMR1H, 7        ; Preload for 1 sec overflow
         BCF      PIR1, TMR1IF    ; Clear interrupt flag
         INCF     secs, F         ; Increment seconds
         MOVLW    .59             ; 60 seconds elapsed?
         CPFSGT   secs
         RETURN                   ; No, done
         CLRF     secs            ; Clear seconds
         INCF     mins, F         ; Increment minutes
         MOVLW    .59             ; 60 minutes elapsed?
         CPFSGT   mins
         RETURN                   ; No, done
         CLRF     mins            ; clear minutes
         INCF     hours, F        ; Increment hours
         MOVLW    .23             ; 24 hours elapsed?
         CPFSGT   hours
         RETURN                   ; No, done
         CLRF     hours           ; Reset hours
         RETURN                   ; Done
```

TABLE 11-2: REGISTERS ASSOCIATED WITH TIMER1 AS A TIMER/COUNTER

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
TMR1L	Timer1 Register Low Byte								50
TMR1H	TImer1 Register High Byte								50
T1CON	RD16	T1RUN	T1CKPS1	T1CKPS0	T1OSCEN	$\overline{\text{T1SYNC}}$	TMR1CS	TMR1ON	50

Legend: — = unimplemented, read as '0'. Shaded cells are not used by the Timer1 module.

12.0 TIMER2 MODULE

The Timer2 module timer incorporates the following features:

- 8-Bit Timer and Period Registers (TMR2 and PR2, respectively)
- Readable and Writable (both registers)
- Software Programmable Prescaler (1:1, 1:4 and 1:16)
- Software Programmable Postscaler (1:1 through 1:16)
- Interrupt on TMR2 to PR2 Match

The module is controlled through the T2CON register (Register 12-1) which enables or disables the timer and configures the prescaler and postscaler. Timer2 can be shut off by clearing control bit, TMR2ON (T2CON<2>), to minimize power consumption.

A simplified block diagram of the module is shown in Figure 12-1.

12.1 Timer2 Operation

In normal operation, TMR2 is incremented from 00h on each clock (FOSC/4). A 2-bit counter/prescaler on the clock input gives direct input, divide-by-4 and divide-by-16 prescale options. These are selected by the prescaler control bits, T2CKPS1:T2CKPS0 (T2CON<1:0>). The value of TMR2 is compared to that of the period register, PR2, on each clock cycle. When the two values match, the comparator generates a match signal as the timer output. This signal also resets the value of TMR2 to 00h on the next cycle and drives the output counter/postscaler (see **Section 12.2 "Timer2 Interrupt"**).

The TMR2 and PR2 registers are both directly readable and writable. The TMR2 register is cleared on any device Reset, while the PR2 register initializes at FFh. Both the prescaler and postscaler counters are cleared on the following events:

- a write to the TMR2 register
- a write to the T2CON register
- any device Reset (Power-on Reset, $\overline{\text{MCLR}}$ Reset, Watchdog Timer Reset or Brown-out Reset)

TMR2 is not cleared when T2CON is written.

REGISTER 12-1: T2CON: TIMER2 CONTROL REGISTER

U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	T2OUTPS3	T2OUTPS2	T2OUTPS1	T2OUTPS0	TMR2ON	T2CKPS1	T2CKPS0
bit 7							bit 0

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

bit 7 **Unimplemented:** Read as '0'

bit 6-3 **T2OUTPS3:T2OUTPS0**: Timer2 Output Postscale Select bits
0000 = 1:1 Postscale
0001 = 1:2 Postscale
•
•
•
1111 = 1:16 Postscale

bit 2 **TMR2ON**: Timer2 On bit
1 = Timer2 is on
0 = Timer2 is off

bit 1-0 **T2CKPS1:T2CKPS0**: Timer2 Clock Prescale Select bits
00 = Prescaler is 1
01 = Prescaler is 4
1x = Prescaler is 16

12.2 Timer2 Interrupt

Timer2 also can generate an optional device interrupt. The Timer2 output signal (TMR2 to PR2 match) provides the input for the 4-bit output counter/postscaler. This counter generates the TMR2 match interrupt flag which is latched in TMR2IF (PIR1<1>). The interrupt is enabled by setting the TMR2 Match Interrupt Enable bit, TMR2IE (PIE1<1>).

A range of 16 postscale options (from 1:1 through 1:16 inclusive) can be selected with the postscaler control bits, T2OUTPS3:T2OUTPS0 (T2CON<6:3>).

12.3 TMR2 Output

The unscaled output of TMR2 is available primarily to the CCP module, where it is used as a time base for operations in PWM mode.

FIGURE 12-1: TIMER2 BLOCK DIAGRAM

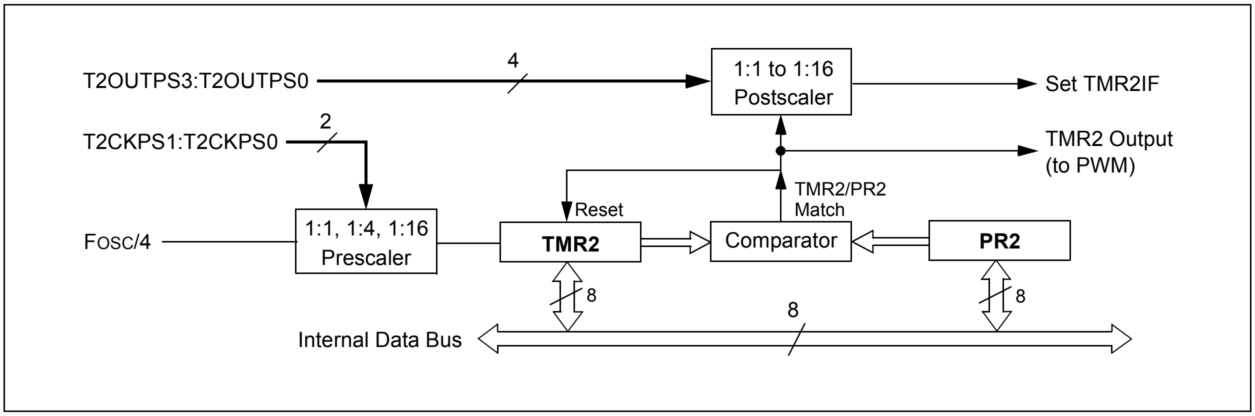


TABLE 12-1: REGISTERS ASSOCIATED WITH TIMER2 AS A TIMER/COUNTER

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
TMR2	Timer2 Register								50
T2CON	—	T2OUTPS3	T2OUTPS2	T2OUTPS1	T2OUTPS0	TMR2ON	T2CKPS1	T2CKPS0	50
PR2	Timer2 Period Register								50

Legend: — = unimplemented, read as '0'. Shaded cells are not used by the Timer2 module.

13.0 CAPTURE/COMPARE/PWM (CCP) MODULE

PIC18F2450/4450 devices have one CCP (Capture/Compare/PWM) module. The module contains a 16-bit register, which can operate as a 16-bit Capture register, a 16-bit Compare register or a PWM Master/Slave Duty Cycle register.

REGISTER 13-1: CCP1CON: CAPTURE/COMPARE/PWM CONTROL REGISTER

U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	DC1B1	DC1B0	CCP1M3	CCP1M2	CCP1M1	CCP1M0
bit 7							bit 0

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

bit 7-6 **Unimplemented:** Read as ‘0’

bit 5-4 **DC1B1:DC1B0**: PWM Duty Cycle for CCP Module bits

Capture mode:
Unused.

Compare mode:
Unused.

PWM mode:
These bits are the two LSbs (bit 1 and bit 0) of the 10-bit PWM duty cycle. The eight MSbs of the duty cycle are found in CCPR1L.

bit 3-0 **CCP1M3:CCP1M0**: CCP Module Mode Select bits

0000 = Capture/Compare/PWM disabled (resets CCP module)
0001 = Reserved
0010 = Compare mode: toggle output on match (CCP1IF bit is set)
0011 = Reserved
0100 = Capture mode: every falling edge
0101 = Capture mode: every rising edge
0110 = Capture mode: every 4th rising edge
0111 = Capture mode: every 16th rising edge
1000 = Compare mode: initialize CCP1 pin low; on compare match, force CCP1 pin high (CCP1IF bit is set)
1001 = Compare mode: initialize CCP1 pin high; on compare match, force CCP1 pin low (CCP1IF bit is set)
1010 = Compare mode: generate software interrupt on compare match (CCP1IF bit is set, CCP1 pin reflects I/O state)
1011 = Compare mode: trigger special event, reset timer and start A/D conversion on CCP1 match (CCP1IF bit is set)
11xx = PWM mode

13.1 CCP Module Configuration

The Capture/Compare/PWM module is associated with a control register (generically, CCP1CON) and a data register (CCPR1). The data register, in turn, is comprised of two 8-bit registers: CCPR1L (low byte) and CCPR1H (high byte). All registers are both readable and writable.

13.1.1 CCP MODULE AND TIMER RESOURCES

The CCP module utilizes Timer1 or Timer2, depending on the mode selected. Timer1 is available to the module in Capture or Compare modes, while Timer2 is available for modules in PWM mode.

TABLE 13-1: CCP MODE – TIMER RESOURCE

CCP Mode	Timer Resource
Capture	Timer1
Compare	Timer1
PWM	Timer2

In Timer1 in Asynchronous Counter mode, the capture operation will not work.

13.2 Capture Mode

In Capture mode, the CCPR1H:CCPR1L register pair captures the 16-bit value of the TMR1 register when an event occurs on the corresponding CCP1 pin. An event is defined as one of the following:

- every falling edge
- every rising edge
- every 4th rising edge
- every 16th rising edge

The event is selected by the mode select bits, CCP1M3:CCP1M0 (CCP1CON<3:0>). When a capture is made, the interrupt request flag bit, CCP1IF, is set; it must be cleared in software. If another capture occurs before the value in register CCPR1 is read, the old captured value is overwritten by the new captured value.

13.2.1 CCP1 PIN CONFIGURATION

In Capture mode, the CCP1 pin should be configured as an input by setting the corresponding TRIS direction bit.

Note:	If RC2/CCP1 is configured as an output, a write to the port can cause a capture condition.

13.2.2 SOFTWARE INTERRUPT

When the Capture mode is changed, a false capture interrupt may be generated. The user should keep the CCP1IE interrupt enable bit clear to avoid false interrupts. The interrupt flag bit, CCP1IF, should also be cleared following any such change in operating mode.

13.2.3 CCP PRESCALER

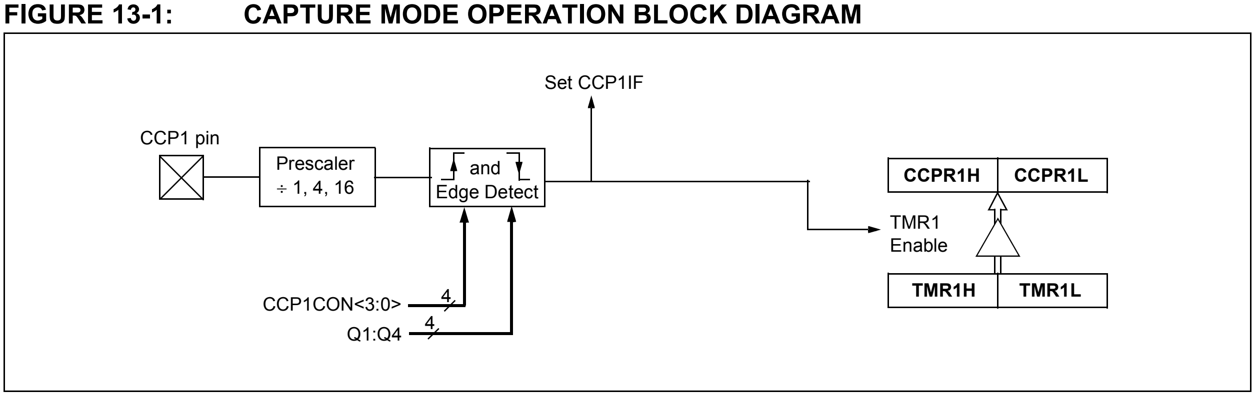
There are four prescaler settings in Capture mode. They are specified as part of the operating mode selected by the mode select bits (CCP1M3:CCP1M0). Whenever the CCP module is turned off or Capture mode is disabled, the prescaler counter is cleared. This means that any Reset will clear the prescaler counter.

Switching from one capture prescaler to another may generate an interrupt. Also, the prescaler counter will not be cleared, therefore, the first capture may be from a non-zero prescaler. Example 13-1 shows the recommended method for switching between capture prescalers. This example also clears the prescaler counter and will not generate the "false" interrupt.

EXAMPLE 13-1: CHANGING BETWEEN CAPTURE PRESCALERS (CCP1 SHOWN)

```
CLRF   CCP1CON        ; Turn CCP module off
MOVLW  NEW_CAPT_PS    ; Load WREG with the
                      ; new prescaler mode
                      ; value and CCP ON
MOVWF  CCP1CON        ; Load CCP1CON with
                      ; this value
```

FIGURE 13-1: CAPTURE MODE OPERATION BLOCK DIAGRAM



13.3 Compare Mode

In Compare mode, the 16-bit CCPR1 register value is constantly compared against the TMR1 register pair value. When a match occurs, the CCP1 pin can be:

- driven high
- driven low
- toggled (high-to-low or low-to-high)
- remain unchanged (that is, reflects the state of the I/O latch)

The action on the pin is based on the value of the mode select bits (CCP1M3:CCP1M0). At the same time, the interrupt flag bit, CCP1IF, is set.

13.3.1 CCP1 PIN CONFIGURATION

The user must configure the CCP1 pin as an output by clearing the appropriate TRIS bit.

Note:	Clearing the CCP1CON register will force the RC2 compare output latch to the default low level.

13.3.2 TIMER1 MODE SELECTION

Timer1 must be running in Timer mode, or Synchronized Counter mode, if the CCP module is using the compare feature. In Asynchronous Counter mode, the compare operation may not work.

13.3.3 SOFTWARE INTERRUPT MODE

When the Generate Software Interrupt mode is chosen (CCP1M3:CCP1M0 = `1010`), the CCP1 pin is not affected. Only a CCP interrupt is generated, if enabled, and the CCP1IE bit is set.

13.3.4 SPECIAL EVENT TRIGGER

The CCP module is equipped with a Special Event Trigger. This is an internal hardware signal generated in Compare mode to trigger actions by other modules. The Special Event Trigger is enabled by selecting the Compare Special Event Trigger mode (CCP1M3:CCP1M0 = `1011`).

For the CCP module, the Special Event Trigger resets the Timer1 register pair. This allows the CCPR1 registers to serve as a programmable period register for the Timer1.

The Special Event Trigger for CCP1 can also start an A/D conversion. In order to do this, the A/D Converter must already be enabled.

FIGURE 13-2: COMPARE MODE OPERATION BLOCK DIAGRAM

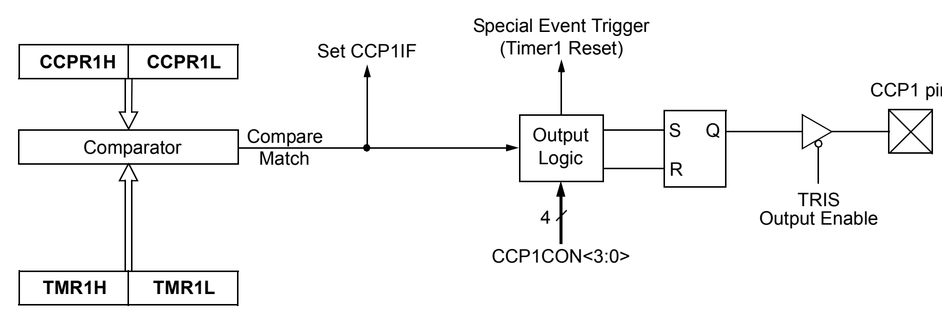


TABLE 13-2: REGISTERS ASSOCIATED WITH CAPTURE, COMPARE, TIMER1

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
RCON	IPEN	SBOREN[(1)]	—	$\overline{\text{RI}}$	$\overline{\text{TO}}$	$\overline{\text{PD}}$	$\overline{\text{POR}}$	$\overline{\text{BOR}}$	50
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
TRISC	TRISC7	TRISC6	—	—	—	TRISC2	TRISC1	TRISC0	51
TMR1L	Timer1 Register Low Byte								50
TMR1H	Timer1 Register High Byte								50
T1CON	RD16	T1RUN	T1CKPS1	T1CKPS0	T1OSCEN	$\overline{\text{T1SYNC}}$	TMR1CS	TMR1ON	50
CCPR1L	Capture/Compare/PWM Register 1 Low Byte								50
CCPR1H	Capture/Compare/PWM Register 1 High Byte								50
CCP1CON	—	—	DC1B1	DC1B0	CCP1M3	CCP1M2	CCP1M1	CCP1M0	50

Legend: — = unimplemented, read as '0'. Shaded cells are not used by capture/compare and Timer1.

Note 1: The SBOREN bit is only available when BOREN<1:0> = 01; otherwise, the bit reads as '0'.

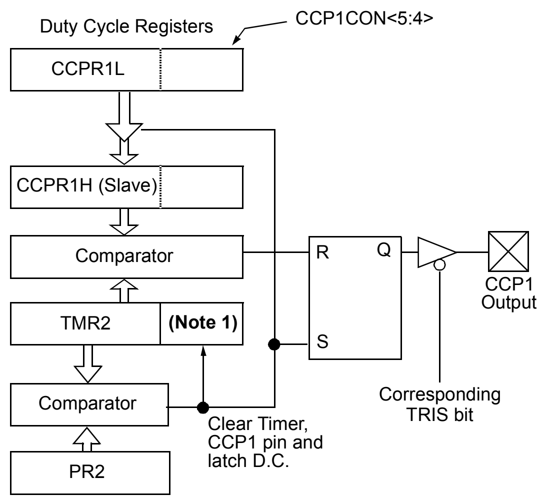
13.4 PWM Mode

In Pulse-Width Modulation (PWM) mode, the CCP1 pin produces up to a 10-bit resolution PWM output.

Figure 13-3 shows a simplified block diagram of the CCP module in PWM mode.

For a step-by-step procedure on how to set up the CCP module for PWM operation, see **Section 13.4.3 “Setup for PWM Operation”**.

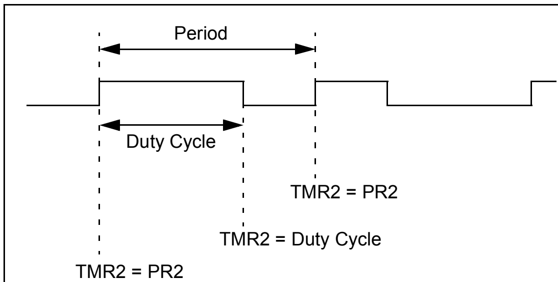
FIGURE 13-3: SIMPLIFIED PWM BLOCK DIAGRAM



Note 1: The 8-bit TMR2 value is concatenated with the 2-bit internal Q clock, or 2 bits of the prescaler, to create the 10-bit time base.

A PWM output (Figure 13-4) has a time base (period) and a time that the output stays high (duty cycle). The frequency of the PWM is the inverse of the period (1/period).

FIGURE 13-4: PWM OUTPUT



13.4.1 PWM PERIOD

The PWM period is specified by writing to the PR2 register. The PWM period can be calculated using the following formula:

EQUATION 13-1:

$$\text{PWM Period} = [(\text{PR2}) + 1] \bullet 4 \bullet \text{TOSC} \bullet (\text{TMR2 Prescale Value})$$

PWM frequency is defined as 1/[PWM period].

When TMR2 is equal to PR2, the following three events occur on the next increment cycle:

- TMR2 is cleared
- The CCP1 pin is set (exception: if PWM duty cycle = 0%, the CCP1 pin will not be set)
- The PWM duty cycle is latched from CCPR1L into CCPR1H

Note:	The Timer2 postscalers (see **Section 12.0 “Timer2 Module”**) are not used in the determination of the PWM frequency. The postscaler could be used to have a servo update rate at a different frequency than the PWM output.

13.4.2 PWM DUTY CYCLE

The PWM duty cycle is specified by writing to the CCPR1L register and to the CCP1CON<5:4> bits. Up to 10-bit resolution is available. The CCPR1L contains the eight MSbs and the CCP1CON<5:4> bits contain the two LSbs. This 10-bit value is represented by CCPR1L:CCP1CON<5:4>. Equation 13-2 is used to calculate the PWM duty cycle in time:

EQUATION 13-2:

$$\text{PWM Duty Cycle} = (\text{CCPR1L:CCP1CON<5:4>}) \bullet \text{TOSC} \bullet (\text{TMR2 Prescale Value})$$

CCPR1L and CCP1CON<5:4> can be written to at any time, but the duty cycle value is not latched into CCPR1H until after a match between PR2 and TMR2 occurs (i.e., the period is complete). In PWM mode, CCPR1H is a read-only register.

The CCPR1H register and a 2-bit internal latch are used to double-buffer the PWM duty cycle. This double-buffering is essential for glitchless PWM operation.

When the CCPR1H and 2-bit latch match TMR2, concatenated with an internal 2-bit Q clock or 2 bits of the TMR2 prescaler, the CCP1 pin is cleared.

The maximum PWM resolution (bits) for a given PWM frequency is given by the equation:

EQUATION 13-3:

$$\text{PWM Resolution (max)} = \frac{\log\left(\frac{F_{OSC}}{F_{PWM}}\right)}{\log(2)}\ \text{bits}$$

> **Note:** If the PWM duty cycle value is longer than the PWM period, the CCP1 pin will not be cleared.

13.4.3 SETUP FOR PWM OPERATION

The following steps should be taken when configuring the CCP module for PWM operation:

1. Set the PWM period by writing to the PR2 register.
2. Set the PWM duty cycle by writing to the CCPR1L register and CCP1CON<5:4> bits.
3. Make the CCP1 pin an output by clearing the appropriate TRIS bit.
4. Set the TMR2 prescale value, then enable Timer2 by writing to T2CON.
5. Configure the CCP module for PWM operation.

TABLE 13-3: EXAMPLE PWM FREQUENCIES AND RESOLUTIONS AT 40 MHz

PWM Frequency	2.44 kHz	9.77 kHz	39.06 kHz	156.25 kHz	312.50 kHz	416.67 kHz
Timer Prescaler (1, 4, 16)	16	4	1	1	1	1
PR2 Value	FFh	FFh	FFh	3Fh	1Fh	17h
Maximum Resolution (bits)	10	10	10	8	7	6.58

TABLE 13-4: REGISTERS ASSOCIATED WITH PWM AND TIMER2

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
RCON	IPEN	SBOREN(1)	—	$\overline{RI}$	$\overline{TO}$	$\overline{PD}$	$\overline{POR}$	$\overline{BOR}$	50
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
TRISC	TRISC7	TRISC6	—	—	—	TRISC2	TRISC1	TRISC0	51
TMR2	Timer2 Register								50
PR2	Timer2 Period Register								50
T2CON	—	T2OUTPS3	T2OUTPS2	T2OUTPS1	T2OUTPS0	TMR2ON	T2CKPS1	T2CKPS0	50
CCPR1L	Capture/Compare/PWM Register 1 Low Byte								50
CCPR1H	Capture/Compare/PWM Register 1 High Byte								50
CCP1CON	—	—	DC1B1	DC1B0	CCP1M3	CCP1M2	CCP1M1	CCP1M0	50

Legend: — = unimplemented, read as ‘0’. Shaded cells are not used by PWM or Timer2.

Note 1: The SBOREN bit is only available when BOREN<1:0> = 01; otherwise, the bit reads as ‘0’.

14.0 UNIVERSAL SERIAL BUS (USB)

This section describes the details of the USB peripheral. Because of the very specific nature of the module, knowledge of USB is expected. Some high-level USB information is provided in **Section 14.9 "Overview of USB"** only for application design reference. Designers are encouraged to refer to the official specification published by the USB Implementers Forum (USB-IF) for the latest information. USB Specification Revision 2.0 is the most current specification at the time of publication of this document.

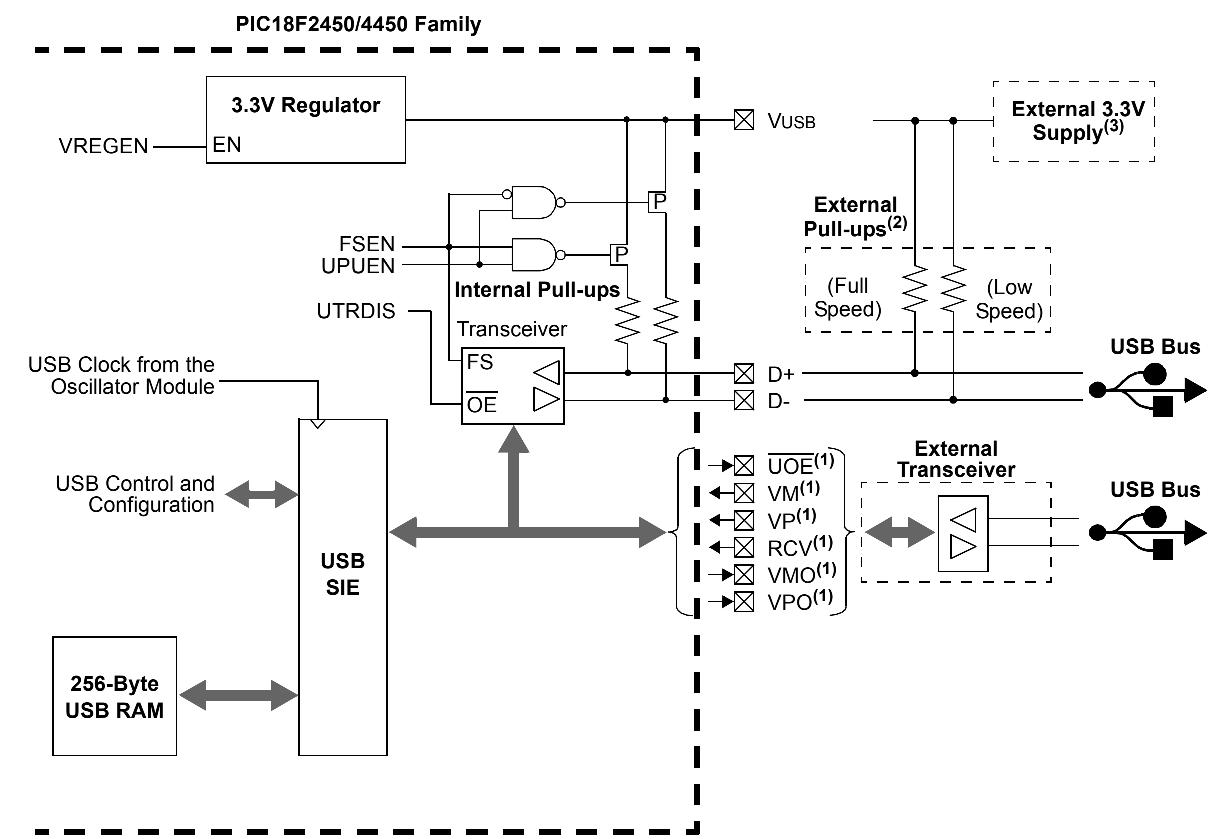
14.1 Overview of the USB Peripheral

The PIC18F2450/4450 device family contains a full-speed and low-speed, compatible USB Serial Interface Engine (SIE) that allows fast communication between any USB host and the PIC® microcontroller. The SIE can be interfaced directly to the USB, utilizing the internal transceiver, or it can be connected through an external transceiver. An internal 3.3V regulator is also available to power the internal transceiver in 5V applications.

Some special hardware features have been included to improve performance. Dual port memory in the device's data memory space (USB RAM) has been supplied to share direct memory access between the microcontroller core and the SIE. Buffer descriptors are also provided, allowing users to freely program endpoint memory usage within the USB RAM space.

Figure 14-1 presents a general overview of the USB peripheral and its features.

FIGURE 14-1: USB PERIPHERAL AND OPTIONS



Note 1: This signal is only available if the internal transceiver is disabled (UTRDIS = 1).

2: The pull-ups can be supplied either from the VUSB pin or from an external 3.3V supply.

3: Do not enable the internal regulator when using an external 3.3V supply.

14.2 USB Status and Control

The operation of the USB module is configured and managed through three control registers. In addition, a total of 22 registers are used to manage the actual USB transactions. The registers are:

- USB Control register (UCON)
- USB Configuration register (UCFG)
- USB Transfer Status register (USTAT)
- USB Device Address register (UADDR)
- Frame Number registers (UFRMH:UFRML)
- Endpoint Enable registers 0 through 15 (UEPn)

14.2.1 USB CONTROL REGISTER (UCON)

The USB Control register (Register 14-1) contains bits needed to control the module behavior during transfers. The register contains bits that control the following:

- Main USB Peripheral Enable
- Ping-Pong Buffer Pointer Reset
- Control of the Suspend Mode
- Packet Transfer Disable

In addition, the USB Control register contains a status bit, SE0 (UCON<5>), which is used to indicate the occurrence of a single-ended zero on the bus. When the USB module is enabled, this bit should be monitored to determine whether the differential data lines have come out of a single-ended zero condition. This helps to differentiate the initial power-up state from the USB Reset signal.

The overall operation of the USB module is controlled by the USBEN bit (UCON<3>). Setting this bit activates the module and resets all of the PPBI bits in the Buffer Descriptor Table to '0'. This bit also activates the on-chip voltage regulator, if enabled. Thus, this bit can be used as a soft attach/detach to the USB. Although all status and control bits are ignored when this bit is clear, the module needs to be fully preconfigured prior to setting this bit.

REGISTER 14-1: UCON: USB CONTROL REGISTER

U-0	R/W-0	R-x	R/C-0	R/W-0	R/W-0	R/W-0	U-0
—	PPBRST	SE0	PKTDIS	USBEN	RESUME	SUSPND	—
bit 7							bit 0

Legend:	C = Clearable bit		
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

bit 7 **Unimplemented:** Read as '0'

bit 6 **PPBRST:** Ping-Pong Buffers Reset bit
1 = Reset all Ping-Pong Buffer Pointers to the EVEN Buffer Descriptor (BD) banks
0 = Ping-Pong Buffer Pointers not being reset

bit 5 **SE0:** Live Single-Ended Zero Flag bit
1 = Single-ended zero active on the USB bus
0 = No single-ended zero detected

bit 4 **PKTDIS:** Packet Transfer Disable bit
1 = SIE token and packet processing disabled, automatically set when a SETUP token is received
0 = SIE token and packet processing enabled

bit 3 **USBEN:** USB Module Enable bit
1 = USB module and supporting circuitry enabled (device attached)
0 = USB module and supporting circuitry disabled (device detached)

bit 2 **RESUME:** Resume Signaling Enable bit
1 = Resume signaling activated
0 = Resume signaling disabled

bit 1 **SUSPND:** Suspend USB bit
1 = USB module and supporting circuitry in Power Conserve mode, SIE clock inactive
0 = USB module and supporting circuitry in normal operation, SIE clock clocked at the configured rate

bit 0 **Unimplemented**: Read as '0'

The PPBRST bit (UCON<6>) controls the Reset status when Double-Buffering mode (ping-pong buffering) is used. When the PPBRST bit is set, all Ping-Pong Buffer Pointers are set to the EVEN buffers. PPBRST has to be cleared by firmware. This bit is ignored in buffering modes not using ping-pong buffering.

The PKTDIS bit (UCON<4>) is a flag indicating that the SIE has disabled packet transmission and reception. This bit is set by the SIE when a SETUP token is received to allow setup processing. This bit cannot be set by the microcontroller, only cleared; clearing it allows the SIE to continue transmission and/or reception. Any pending events within the Buffer Descriptor Table will still be available, indicated within the USTAT register's FIFO buffer.

The RESUME bit (UCON<2>) allows the peripheral to perform a remote wake-up by executing Resume signaling. To generate a valid remote wake-up, firmware must set RESUME for 10 ms and then clear the bit. For more information on Resume signaling, see Sections 7.1.7.5, 11.4.4 and 11.9 in the USB 2.0 Specification.

The SUSPND bit (UCON<1>) places the module and supporting circuitry (i.e., voltage regulator) in a low-power mode. The input clock to the SIE is also disabled. This bit should be set by the software in response to an IDLEIF interrupt. It should be reset by the microcontroller firmware after an ACTVIF interrupt is observed. When this bit is active, the device remains attached to the bus but the transceiver outputs remain Idle. The voltage on the VUSB pin may vary depending on the value of this bit. Setting this bit before a IDLEIF request will result in unpredictable bus behavior.

Note:	While in Suspend mode, a typical bus powered USB device is limited to 500 μA of current. This is the complete current drawn by the PIC microcontroller and its supporting circuitry. Care should be taken to assure minimum current draw when the device enters Suspend mode.

14.2.2 USB CONFIGURATION REGISTER (UCFG)

Prior to communicating over USB, the module's associated internal and/or external hardware must be configured. Most of the configuration is performed with the UCFG register (Register 14-2). The separate USB voltage regulator (see **Section 14.2.2.8 "Internal Regulator"**) is controlled through the Configuration registers.

The UFCG register contains most of the bits that control the system level behavior of the USB module. These include:

- Bus Speed (full speed versus low speed)
- On-Chip Transceiver Enable
- Ping-Pong Buffer Usage

The UCFG register also contains two bits which aid in module testing, debugging and USB certifications. These bits control output enable state monitoring and eye pattern generation.

Note:	The USB speed, transceiver and pull-up should only be configured during the module setup phase. It is not recommended to switch these settings while the module is enabled.

14.2.2.1 Internal Transceiver

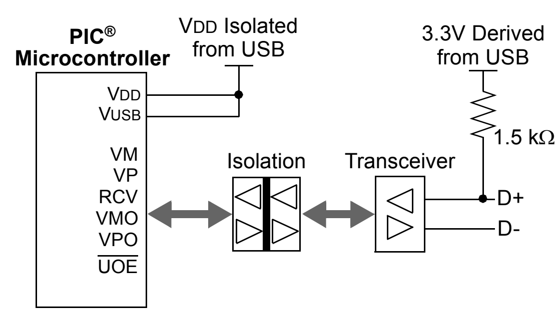
The USB peripheral has a built-in, USB 2.0, full-speed and low-speed compliant transceiver, internally connected to the SIE. This feature is useful for low-cost, single chip applications. The UTRDIS bit (UCFG<3>) controls the transceiver; it is enabled by default (UTRDIS = 0). The FSEN bit (UCFG<2>) controls the transceiver speed; setting the bit enables full-speed operation. The on-chip USB pull-up resistors are controlled by the UPUEN bit (UCFG<4>). They can only be selected when the on-chip transceiver is enabled.

The USB specification requires 3.3V operation for communications; however, the rest of the chip may be running at a higher voltage. Thus, the transceiver is supplied power from a separate source, VUSB.

14.2.2.2 External Transceiver

This module provides support for use with an off-chip transceiver. The off-chip transceiver is intended for applications where physical conditions dictate the location of the transceiver to be away from the SIE. For example, applications that require isolation from the USB could use an external transceiver through some isolation to the microcontroller's SIE (Figure 14-2). External transceiver operation is enabled by setting the UTRDIS bit.

FIGURE 14-2: TYPICAL EXTERNAL TRANSCEIVER WITH ISOLATION



Note: The above setting shows a simplified schematic for a full-speed configuration using an external transceiver with isolation.

REGISTER 14-2: UCFG: USB CONFIGURATION REGISTER

R/W-0	R/W-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
UTEYE	UOEMON(1)	—	UPUEN(2,3)	UTRDIS(2)	FSEN(2)	PPB1	PPB0
bit 7							bit 0

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

bit 7 **UTEYE:** USB Eye Pattern Test Enable bit
1 = Eye pattern test enabled
0 = Eye pattern test disabled

bit 6 **UOEMON:** USB $\overline{\text{OE}}$ Monitor Enable bit(1)
1 = $\overline{\text{UOE}}$ signal active; it indicates intervals during which the D+/D- lines are driving
0 = $\overline{\text{UOE}}$ signal inactive

bit 5 **Unimplemented:** Read as ‘0’

bit 4 **UPUEN:** USB On-Chip Pull-up Enable bit(2,3)
1 = On-chip pull-up enabled (pull-up on D+ with FSEN = 1 or D- with FSEN = 0)
0 = On-chip pull-up disabled

bit 3 **UTRDIS:** On-Chip Transceiver Disable bit(2)
1 = On-chip transceiver disabled; digital transceiver interface enabled
0 = On-chip transceiver active

bit 2 **FSEN:** Full-Speed Enable bit(2)
1 = Full-speed device: controls transceiver edge rates; requires input clock at 48 MHz
0 = Low-speed device: controls transceiver edge rates; requires input clock at 6 MHz

bit 1-0 **PPB1:PPB0:** Ping-Pong Buffers Configuration bits
11 = Enabled for all endpoints except Endpoint 0
10 = EVEN/ODD ping-pong buffers enabled for all endpoints
01 = EVEN/ODD ping-pong buffer enabled for OUT Endpoint 0
00 = EVEN/ODD ping-pong buffers disabled

Note 1: If UTRDIS is set, the $\overline{\text{UOE}}$ signal will be active independent of the UOEMON bit setting.
2: The UPUEN, UTRDIS and FSEN bits should never be changed while the USB module is enabled. These values must be preconfigured prior to enabling the module.
3: This bit is only valid when the on-chip transceiver is active (UTRDIS = 0); otherwise, it is ignored.

There are 6 signals from the module to communicate with and control an external transceiver:

- VM: Input from the single-ended D- line
- VP: Input from the single-ended D+ line
- RCV: Input from the differential receiver
- VMO: Output to the differential line driver
- VPO: Output to the differential line driver
- $\overline{\text{UOE}}$: Output enable

The VPO and VMO signals are outputs from the SIE to the external transceiver. The RCV signal is the output from the external transceiver to the SIE; it represents the differential signals from the serial bus translated into a single pulse train. The VM and VP signals are used to report conditions on the serial bus to the SIE that can’t be captured with the RCV signal. The combinations of states of these signals and their interpretation are listed in Table 14-1 and Table 14-2.

TABLE 14-1: DIFFERENTIAL OUTPUTS TO TRANSCEIVER

VPO	VMO	Bus State
0	0	Single-Ended Zero
0	1	Differential '0'
1	0	Differential '1'
1	1	Illegal Condition

TABLE 14-2: SINGLE-ENDED INPUTS FROM TRANSCEIVER

VP	VM	Bus State
0	0	Single-Ended Zero
0	1	Low Speed
1	0	High Speed
1	1	Error

The $\overline{\text{UOE}}$ signal toggles the state of the external transceiver. This line is pulled low by the device to enable the transmission of data from the SIE to an external device.

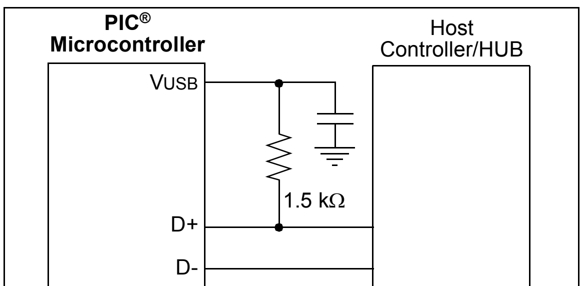
14.2.2.3 Internal Pull-up Resistors

The PIC18F2450/4450 devices have built-in pull-up resistors designed to meet the requirements for low-speed and full-speed USB. The UPUEN bit (UCFG<4>) enables the internal pull-ups. Figure 14-1 shows the pull-ups and their control.

14.2.2.4 Pull-up Resistors

The PIC18F2450/4450 devices require an external pull-up resistor to meet the requirements for low-speed and full-speed USB. Either an external 3.3V supply or the VUSB pin may be used to pull up D+ or D-. The pull-up resistor must be 1.5 kΩ (±5%) as required by the USB specifications. Figure 14-3 shows an example with the VUSB pin.

FIGURE 14-3: EXTERNAL CIRCUITRY



Note: The above setting shows a typical connection for a full-speed configuration using an on-chip regulator and an external pull-up resistor.

14.2.2.5 Ping-Pong Buffer Configuration

The usage of ping-pong buffers is configured using the PPB1:PPB0 bits. Refer to **Section 14.4.4 "Ping-Pong Buffering"** for a complete explanation of the ping-pong buffers.

14.2.2.6 USB Output Enable Monitor

The USB $\overline{\text{OE}}$ monitor provides indication as to whether the SIE is listening to the bus or actively driving the bus. This is enabled by default when using an external transceiver or when UCFG<6> = 1.

The USB $\overline{\text{OE}}$ monitoring is useful for initial system debugging, as well as scope triggering during eye pattern generation tests.

14.2.2.7 Eye Pattern Test Enable

An automatic eye pattern test can be generated by the module when the UCFG<7> bit is set. The eye pattern output will be observable based on module settings, meaning that the user is first responsible for configuring the SIE clock settings, pull-up resistor and Transceiver mode. In addition, the module has to be enabled.

Once UTEYE is set, the module emulates a switch from a receive to transmit state and will start transmitting a J-K-J-K bit sequence (K-J-K-J for full speed). The sequence will be repeated indefinitely while the Eye Pattern Test mode is enabled.

Note that this bit should never be set while the module is connected to an actual USB system. This test mode is intended for board verification to aid with USB certification tests. It is intended to show a system developer the noise integrity of the USB signals which can be affected by board traces, impedance mismatches and proximity to other system components. It does not properly test the transition from a receive to a transmit state. Although the eye pattern is not meant to replace the more complex USB certification test, it should aid during first order system debugging.

14.2.2.8 Internal Regulator

The PIC18F2450/4450 devices have a built-in 3.3V regulator to provide power to the internal transceiver and provide a source for the external pull-ups. An external 220 nF (±20%) capacitor is required for stability.

> **Note:** The drive from VUSB is sufficient to only drive an external pull-up in addition to the internal transceiver.

The regulator is disabled by default and can be enabled through the VREGEN Configuration bit. When enabled, the voltage is visible on pin VUSB. When the regulator is disabled, a 3.3V source must be provided through the VUSB pin for the internal transceiver. If the internal transceiver is disabled, VUSB is not used.

> **Note 1:** Do not enable the internal regulator if an external regulator is connected to VUSB.
>
> **2:** VDD must be greater than or equal to VUSB at all times, even with the regulator disabled.

14.2.3 USB STATUS REGISTER (USTAT)

The USB Status register reports the transaction status within the SIE. When the SIE issues a USB transfer complete interrupt, USTAT should be read to determine the status of the transfer. USTAT contains the transfer endpoint number, direction and Ping-Pong Buffer Pointer value (if used).

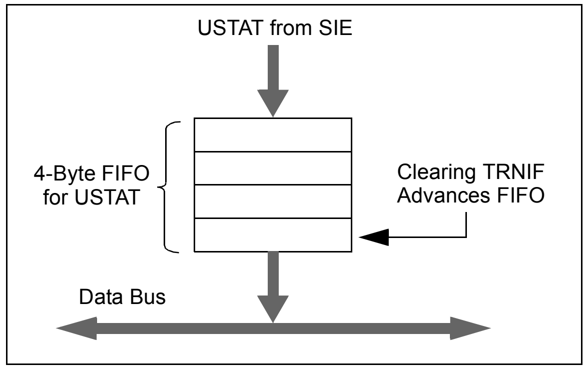
Note:	The data in the USB Status register is valid only when the TRNIF interrupt flag is asserted.

The USTAT register is actually a read window into a four-byte status FIFO, maintained by the SIE. It allows the microcontroller to process one transfer while the SIE processes additional endpoints (Figure 14-4). When the SIE completes using a buffer for reading or writing data, it updates the USTAT register. If another USB transfer is performed before a transaction complete interrupt is serviced, the SIE will store the status of the next transfer into the status FIFO.

Clearing the transfer complete flag bit, TRNIF, causes the SIE to advance the FIFO. If the next data in the FIFO holding register is valid, the SIE will reassert the interrupt within 6 TCY of clearing TRNIF. If no additional data is present, TRNIF will remain clear; USTAT data will no longer be reliable.

Note:	If an endpoint request is received while the USTAT FIFO is full, the SIE will automatically issue a NAK back to the host.

FIGURE 14-4: USTAT FIFO



REGISTER 14-3: USTAT: USB STATUS REGISTER

U-0	R-x	R-x	R-x	R-x	R-x	R-x	U-0
—	ENDP3	ENDP2	ENDP1	ENDP0	DIR	PPBI(1)	—
bit 7							bit 0

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

bit 7 **Unimplemented:** Read as '0'

bit 6-3 **ENDP3:ENDP0:** Encoded Number of Last Endpoint Activity bits
(represents the number of the BDT updated by the last USB transfer)
1111 = Endpoint 15
1110 = Endpoint 14
....
0001 = Endpoint 1
0000 = Endpoint 0

bit 2 **DIR:** Last BD Direction Indicator bit
1 = The last transaction was an IN token
0 = The last transaction was an OUT or SETUP token

bit 1 **PPBI:** Ping-Pong BD Pointer Indicator bit(1)
1 = The last transaction was to the ODD BD bank
0 = The last transaction was to the EVEN BD bank

bit 0 **Unimplemented:** Read as '0'

Note 1: This bit is only valid for endpoints with available EVEN and ODD BD registers.

14.2.4 USB ENDPOINT CONTROL

Each of the 16 possible bidirectional endpoints has its own independent control register, UEPn (where ‘n’ represents the endpoint number). Each register has an identical complement of control bits. The prototype is shown in Register 14-4.

The EPHSHK bit (UEPn<4>) controls handshaking for the endpoint; setting this bit enables USB handshaking. Typically, this bit is always set except when using isochronous endpoints.

The EPCONDIS bit (UEPn<3>) is used to enable or disable USB control operations (SETUP) through the endpoint. Clearing this bit enables SETUP transactions. Note that the corresponding EPINEN and EPOUTEN bits must be set to enable IN and OUT transactions. For Endpoint 0, this bit should always be cleared since the USB specifications identify Endpoint 0 as the default control endpoint.

The EPOUTEN bit (UEPn<2>) is used to enable or disable USB OUT transactions from the host. Setting this bit enables OUT transactions. Similarly, the EPINEN bit (UEPn<1>) enables or disables USB IN transactions from the host.

The EPSTALL bit (UEPn<0>) is used to indicate a STALL condition for the endpoint. If a STALL is issued on a particular endpoint, the EPSTALL bit for that endpoint pair will be set by the SIE. This bit remains set until it is cleared through firmware, or until the SIE is reset.

REGISTER 14-4: UEPn: USB ENDPOINT n CONTROL REGISTER (UEP0 THROUGH UEP15)

U-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL(1)
bit 7							bit 0

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

bit 7-5 **Unimplemented:** Read as ‘0’

bit 4 **EPHSHK:** Endpoint Handshake Enable bit
1 = Endpoint handshake enabled
0 = Endpoint handshake disabled (typically used for isochronous endpoints)

bit 3 **EPCONDIS:** Bidirectional Endpoint Control bit
If EPOUTEN = 1 and EPINEN = 1:
1 = Disable Endpoint n from control transfers; only IN and OUT transfers allowed
0 = Enable Endpoint n for control (SETUP) transfers; IN and OUT transfers also allowed

bit 2 **EPOUTEN:** Endpoint Output Enable bit
1 = Endpoint n output enabled
0 = Endpoint n output disabled

bit 1 **EPINEN:** Endpoint Input Enable bit
1 = Endpoint n input enabled
0 = Endpoint n input disabled

bit 0 **EPSTALL:** Endpoint Stall Indicator bit
1 = Endpoint n has issued one or more STALL packets
0 = Endpoint n has not issued any STALL packets

14.2.5 USB ADDRESS REGISTER (UADDR)

The USB Address register contains the unique USB address that the peripheral will decode when active. UADDR is reset to 00h when a USB Reset is received, indicated by URSTIF, or when a Reset is received from the microcontroller. The USB address must be written by the microcontroller during the USB setup phase (enumeration) as part of the Microchip USB firmware support.

14.2.6 USB FRAME NUMBER REGISTERS (UFRMH:UFRML)

The Frame Number registers contain the 11-bit frame number. The low-order byte is contained in UFRML, while the three high-order bits are contained in UFRMH. The register pair is updated with the current frame number whenever a SOF token is received. For the microcontroller, these registers are read-only. The Frame Number register is primarily used for isochronous transfers.

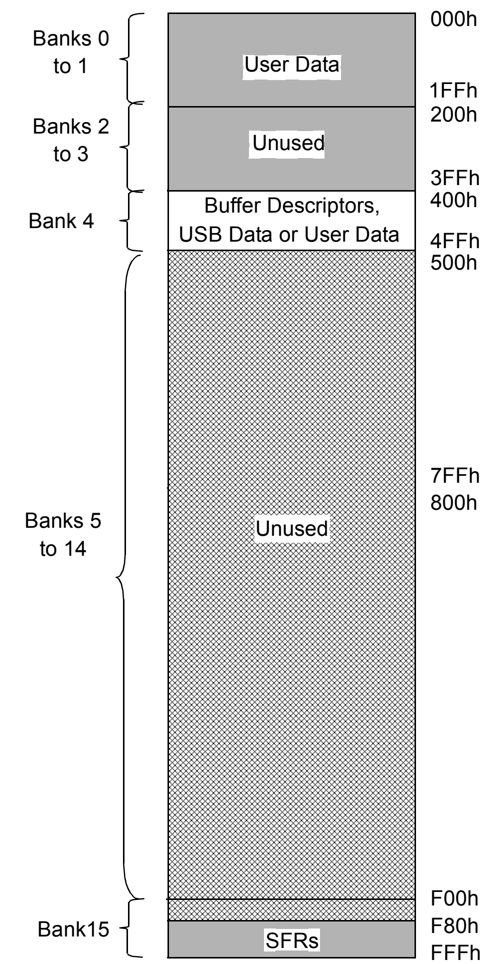
14.3 USB RAM

USB data moves between the microcontroller core and the SIE through a memory space known as the USB RAM. This is a special dual port memory that is mapped into the normal data memory space in Bank 4 (400h to 4FFh) for a total of 256 bytes (Figure 14-5).

Some portion of Bank 4 (400h through 4FFh) is used specifically for endpoint buffer control, while the remaining portion is available for USB data. Depending on the type of buffering being used, all but 8 bytes of Bank 4 may also be available for use as USB buffer space.

Although USB RAM is available to the microcontroller as data memory, the sections that are being accessed by the SIE should not be accessed by the microcontroller. A semaphore mechanism is used to determine the access to a particular buffer at any given time. This is discussed in **Section 14.4.1.1 "Buffer Ownership"**.

FIGURE 14-5: IMPLEMENTATION OF USB RAM IN DATA MEMORY SPACE



14.4 Buffer Descriptors and the Buffer Descriptor Table

The registers in Bank 4 are used specifically for endpoint buffer control in a structure known as the Buffer Descriptor Table (BDT). This provides a flexible method for users to construct and control endpoint buffers of various lengths and configuration.

The BDT is composed of Buffer Descriptors (BD) which are used to define and control the actual buffers in the USB RAM space. Each BD, in turn, consists of four registers, where n represents one of the 64 possible BDs (range of 0 to 63):

- BDnSTAT: BD Status register
- BDnCNT: BD Byte Count register
- BDnADRL: BD Address Low register
- BDnADRH: BD Address High register

BDs always occur as a four-byte block in the sequence, BDnSTAT:BDnCNT:BDnADRL:BDnADRH. The address of BDnSTAT is always an offset of (4n – 1) (in hexadecimal) from 400h, with n being the buffer descriptor number.

Depending on the buffering configuration used (**Section 14.4.4 “Ping-Pong Buffering”**), there are up to 32, 33 or 64 sets of buffer descriptors. At a minimum, the BDT must be at least 8 bytes long. This is because the USB specification mandates that every device must have Endpoint 0 with both input and output for initial setup. Depending on the endpoint and buffering configuration, the BDT can be as long as 256 bytes.

Although they can be thought of as Special Function Registers, the Buffer Descriptor Status and Address registers are not hardware mapped, as conventional microcontroller SFRs in Bank 15 are. If the endpoint corresponding to a particular BD is not enabled, its registers are not used. Instead of appearing as unimplemented addresses, however, they appear as available RAM. Only when an endpoint is enabled by setting the UEPn<1> bit does the memory at those addresses become functional as BD registers. As with any address in the data memory space, the BD registers have an indeterminate value on any device Reset.

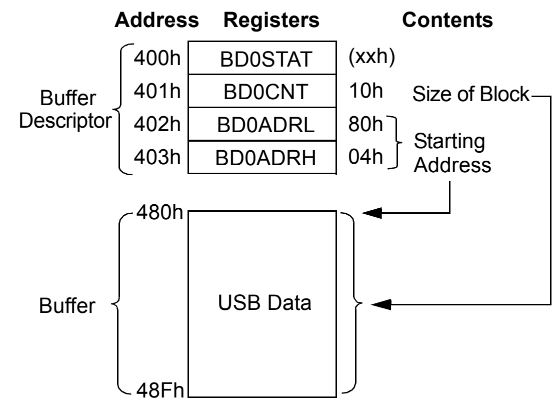
A total of 256 bytes of address space in Bank 4 is available for BDT and USB data RAM. In Ping-Pong Buffer mode, all the 16 bidirectional endpoints can not be implemented where BDT itself can be as long as 256 bytes. In the majority of USB applications, few endpoints are required to be implemented. Hence, a small portion of the 256 bytes will be used for BDT and the rest can be used for USB data.

An example of a BD for a 16-byte buffer, starting at 480h, is shown in Figure 14-6. A particular set of BD registers is only valid if the corresponding endpoint has been enabled using the UEPn register. All BD registers are available in USB RAM. The BD for each endpoint should be set up prior to enabling the endpoint.

14.4.1 BD STATUS AND CONFIGURATION

Buffer descriptors not only define the size of an endpoint buffer, but also determine its configuration and control. Most of the configuration is done with the BD Status register, BDnSTAT. Each BD has its own unique and correspondingly numbered BDnSTAT register.

FIGURE 14-6: EXAMPLE OF A BUFFER DESCRIPTOR



Note: Memory regions are not to scale.

Unlike other control registers, the bit configuration for the BDnSTAT register is context sensitive. There are two distinct configurations, depending on whether the microcontroller or the USB module is modifying the BD and buffer at a particular time. Only three bit definitions are shared between the two.

14.4.1.1 Buffer Ownership

Because the buffers and their BDs are shared between the CPU and the USB module, a simple semaphore mechanism is used to distinguish which is allowed to update the BD and associated buffers in memory.

This is done by using the UOWN bit (BDnSTAT<7>) as a semaphore to distinguish which is allowed to update the BD and associated buffers in memory. UOWN is the only bit that is shared between the two configurations of BDnSTAT.

When UOWN is clear, the BD entry is “owned” by the microcontroller core. When the UOWN bit is set, the BD entry and the buffer memory are “owned” by the USB peripheral. The core should not modify the BD or its corresponding data buffer during this time. Note that the microcontroller core can still read BDnSTAT while the SIE owns the buffer and vice versa.

The buffer descriptors have a different meaning based on the source of the register update. Prior to placing ownership with the USB peripheral, the user can configure the basic operation of the peripheral through the BDnSTAT bits. During this time, the byte count and buffer location registers can also be set.

When UOWN is set, the user can no longer depend on the values that were written to the BDs. From this point, the SIE updates the BDs as necessary, overwriting the original BD values. The BDnSTAT register is updated by the SIE with the token PID and the transfer count, BDnCNT, is updated.

The BDnSTAT byte of the BDT should always be the last byte updated when preparing to arm an endpoint. The SIE will clear the UOWN bit when a transaction has completed. The only exception to this is when KEN is enabled and/or BSTALL is enabled.

No hardware mechanism exists to block access when the UOWN bit is set. Thus, unexpected behavior can occur if the microcontroller attempts to modify memory when the SIE owns it. Similarly, reading such memory may produce inaccurate data until the USB peripheral returns ownership to the microcontroller.

14.4.1.2 BDnSTAT Register (CPU Mode)

When UOWN = 0, the microcontroller core owns the BD. At this point, the other seven bits of the register take on control functions.

The Data Toggle Sync Enable bit, DTSEN (BDnSTAT<3>), controls data toggle parity checking. Setting DTSEN enables data toggle synchronization by the SIE. When enabled, it checks the data packet's parity against the value of DTS (BDnSTAT<6>). If a packet arrives with an incorrect synchronization, the data will essentially be ignored. It will not be written to the USB RAM and the USB transfer complete interrupt flag will not be set. The SIE will send an ACK token back to the host to Acknowledge receipt, however. The effects of the DTSEN bit on the SIE are summarized in Table 14-3.

The Buffer Stall bit, BSTALL (BDnSTAT<2>), provides support for control transfers, usually one-time stalls on Endpoint 0. It also provides support for the SET_FEATURE/CLEAR_FEATURE commands specified in Chapter 9 of the USB specification; typically, continuous STALLs to any endpoint other than the default control endpoint.

The BSTALL bit enables buffer stalls. Setting BSTALL causes the SIE to return a STALL token to the host if a received token would use the BD in that location. The EPSTALL bit in the corresponding UEPn control register is set and a STALL interrupt is generated when a STALL is issued to the host. The UOWN bit remains set and the BDs are not changed unless a SETUP token is received. In this case, the STALL condition is cleared and the ownership of the BD is returned to the microcontroller core.

The BD9:BD8 bits (BDnSTAT<1:0>) store the two most significant digits of the SIE byte count; the lower 8 digits are stored in the corresponding BDnCNT register. See **Section 14.4.2 "BD Byte Count"** for more information.

TABLE 14-3: EFFECT OF DTSEN BIT ON ODD/EVEN (DATA0/DATA1) PACKET RECEPTION

OUT Packet from Host	BDnSTAT Settings		Device Response after Receiving Packet			
	DTSEN	DTS	Handshake	UOWN	TRNIF	BDnSTAT and USTAT Status
DATA0	1	0	ACK	0	1	Updated
DATA1	1	0	ACK	1	0	Not Updated
DATA1	1	1	ACK	0	1	Updated
DATA0	1	1	ACK	1	0	Not Updated
Either	0	x	ACK	0	1	Updated
Either, with error	x	x	NAK	1	0	Not Updated

Legend: x = don't care

REGISTER 14-5: BDnSTAT: BUFFER DESCRIPTOR n STATUS REGISTER (BD0STAT THROUGH BD63STAT), CPU MODE (DATA IS WRITTEN TO THE SIDE)

R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x
UOWN(1)	DTS(2)	—(3)	—(3)	DTSEN	BSTALL	BC9	BC8
bit 7							bit 0

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

bit 7 **UOWN:** USB Own bit(1)
0 = The microcontroller core owns the BD and its corresponding buffer

bit 6 **DTS:** Data Toggle Synchronization bit(2)
1 = Data 1 packet
0 = Data 0 packet

bit 5-4 **Reserved:** These bits should always be programmed to ‘0’(3)

bit 3 **DTSEN:** Data Toggle Synchronization Enable bit
1 = Data toggle synchronization is enabled; data packets with incorrect Sync value will be ignored except for a SETUP transaction, which is accepted even if the data toggle bits do not match.
0 = No data toggle synchronization is performed

bit 2 **BSTALL:** Buffer Stall Enable bit
1 = Buffer stall enabled; STALL handshake issued if a token is received that would use the BD in the given location (UOWN bit remains set, BD value is unchanged)
0 = Buffer stall disabled

bit 1-0 **BC9:BC8:** Byte Count 9 and 8 bits
The byte count bits represent the number of bytes that will be transmitted for an IN token or received during an OUT token. Together with BC<7:0>, the valid byte counts are 0-1023.

Note 1: This bit must be initialized by the user to the desired value prior to enabling the USB module.
2: This bit is ignored unless DTSEN = 1.
3: If these bits are set, USB communication may not work. Hence, these bits should always be maintained as ‘0’.

14.4.1.3 BDnSTAT Register (SIE Mode)

When the BD and its buffer are owned by the SIE, most of the bits in BDnSTAT take on a different meaning. The configuration is shown in Register 14-6. Once UOWN is set, any data or control settings previously written there by the user will be overwritten with data from the SIE.

The BDnSTAT register is updated by the SIE with the token Packet Identifier (PID) which is stored in BDnSTAT<5:3>. The transfer count in the corresponding BDnCNT register is updated. Values that overflow the 8-bit register carry over to the two most significant digits of the count, stored in BDnSTAT<1:0>.

14.4.2 BD BYTE COUNT

The byte count represents the total number of bytes that will be transmitted during an IN transfer. After an IN transfer, the SIE will return the number of bytes sent to the host.

For an OUT transfer, the byte count represents the maximum number of bytes that can be received and stored in USB RAM. After an OUT transfer, the SIE will return the actual number of bytes received. If the number of bytes received exceeds the corresponding byte count, the data packet will be rejected and a NAK handshake will be generated. When this happens, the byte count will not be updated.

The 10-bit byte count is distributed over two registers. The lower 8 bits of the count reside in the BDnCNT register. The upper two bits reside in BDnSTAT<1:0>. This represents a valid byte range of 0 to 1023.

14.4.3 BD ADDRESS VALIDATION

The BD Address register pair contains the starting RAM address location for the corresponding endpoint buffer. For an endpoint starting location to be valid, it must fall in the range of the USB RAM, 400h to 4FFh. No mechanism is available in hardware to validate the BD address.

If the value of the BD address does not point to an address in the USB RAM, or if it points to an address within another endpoint's buffer, data is likely to be lost or overwritten. Similarly, overlapping a receive buffer (OUT endpoint) with a BD location in use can yield unexpected results. When developing USB applications, the user may want to consider the inclusion of software-based address validation in their code.

REGISTER 14-6: BDnSTAT: BUFFER DESCRIPTOR n STATUS REGISTER (BD0STAT THROUGH BD63STAT), SIE MODE (DATA RETURNED BY THE SIDE TO THE MICROCONTROLLER)

R/W-x	U-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x	R/W-x
UOWN	—	PID3	PID2	PID1	PID0	BC9	BC8
bit 7							bit 0

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

bit 7 **UOWN:** USB Own bit
1 = The SIE owns the BD and its corresponding buffer

bit 6 **Reserved:** Not written by the SIE

bit 5-2 **PID3:PID0:** Packet Identifier bits
The received token PID value of the last transfer (IN, OUT or SETUP transactions only).

bit 1-0 **BC9:BC8:** Byte Count 9 and 8 bits
These bits are updated by the SIE to reflect the actual number of bytes received on an OUT transfer and the actual number of bytes transmitted on an IN transfer.

14.4.4 PING-PONG BUFFERING

An endpoint is defined to have a ping-pong buffer when it has two sets of BD entries: one set for an EVEN transfer and one set for an ODD transfer. This allows the CPU to process one BD while the SIE is processing the other BD. Double-buffering BDs in this way allows for maximum throughput to/from the USB.

The USB module supports three modes of operation:

- No ping-pong support
- Ping-pong buffer support for OUT Endpoint 0 only
- Ping-pong buffer support for all endpoints

The ping-pong buffer settings are configured using the PPB1:PPB0 bits in the UCFG register.

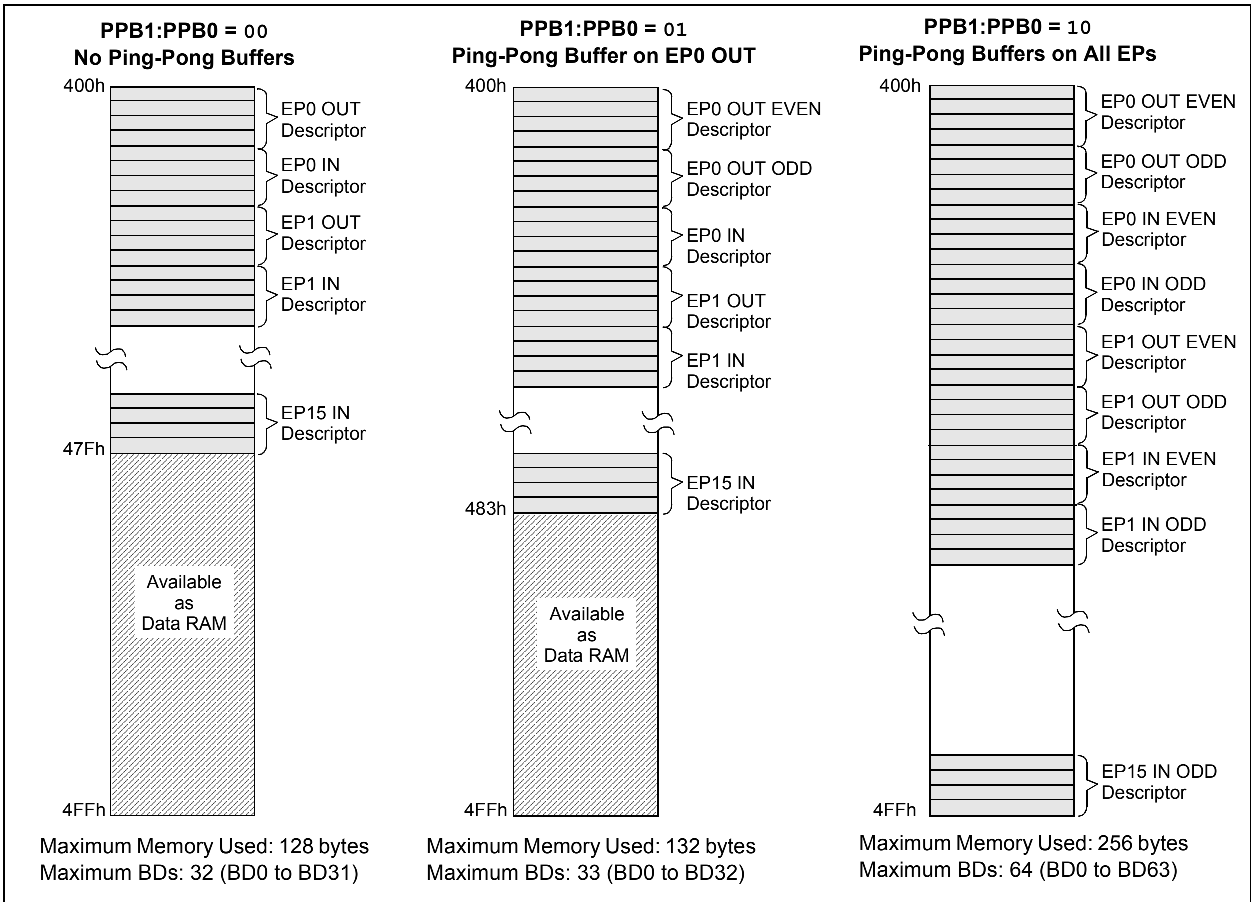
The USB module keeps track of the Ping-Pong Pointer individually for each endpoint. All pointers are initially reset to the EVEN BD when the module is enabled. After the completion of a transaction (UOWN cleared by the SIE), the pointer is toggled to the ODD BD. After the completion of the next transaction, the pointer is toggled back to the EVEN BD and so on.

The EVEN/ODD status of the last transaction is stored in the PPBI bit of the USTAT register. The user can reset all Ping-Pong Pointers to EVEN using the PPBRST bit.

Figure 14-7 shows the three different modes of operation and how USB RAM is filled with the BDs.

BDs have a fixed relationship to a particular endpoint, depending on the buffering configuration. The mapping of BDs to endpoints is detailed in Table 14-4. This relationship also means that gaps may occur in the BDT if endpoints are not enabled contiguously. This theoretically means that the BDs for disabled endpoints could be used as buffer space. In practice, users should avoid using such spaces in the BDT unless a method of validating BD addresses is implemented.

FIGURE 14-7: BUFFER DESCRIPTOR TABLE MAPPING FOR BUFFERING MODES



Note: Memory area not shown to scale.

TABLE 14-4: ASSIGNMENT OF BUFFER DESCRIPTORS FOR THE DIFFERENT BUFFERING MODES

Endpoint	BDs Assigned to Endpoint					
	Mode 0 (No Ping-Pong)		Mode 1 (Ping-Pong on EP0 OUT)		Mode 2 (Ping-Pong on all EPs)	
	Out	In	Out	In	Out	In
0	0	1	0 (E), 1 (O)	2	0 (E), 1 (O)	2 (E), 3 (O)
1	2	3	3	4	4 (E), 5 (O)	6 (E), 7 (O)
2	4	5	5	6	8 (E), 9 (O)	10 (E), 11 (O)
3	6	7	7	8	12 (E), 13 (O)	14 (E), 15 (O)
4	8	9	9	10	16 (E), 17 (O)	18 (E), 19 (O)
5	10	11	11	12	20 (E), 21 (O)	22 (E), 23 (O)
6	12	13	13	14	24 (E), 25 (O)	26 (E), 27 (O)
7	14	15	15	16	28 (E), 29 (O)	30 (E), 31 (O)
8	16	17	17	18	32 (E), 33 (O)	34 (E), 35 (O)
9	18	19	19	20	36 (E), 37 (O)	38 (E), 39 (O)
10	20	21	21	22	40 (E), 41 (O)	42 (E), 43 (O)
11	22	23	23	24	44 (E), 45 (O)	46 (E), 47 (O)
12	24	25	25	26	48 (E), 49 (O)	50 (E), 51 (O)
13	26	27	27	28	52 (E), 53 (O)	54 (E), 55 (O)
14	28	29	29	30	56 (E), 57 (O)	58 (E), 59 (O)
15	30	31	31	32	60 (E), 61 (O)	62 (E), 63 (O)

Legend: (E) = EVEN transaction buffer, (O) = ODD transaction buffer

TABLE 14-5: SUMMARY OF USB BUFFER DESCRIPTOR TABLE REGISTERS

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
BDnSTAT(1)	UOWN	DTS(4)	PID3(2)	PID2(2)	PID1(2) DTSEN(3)	PID0(2) BSTALL(3)	BC9	BC8
BDnCNT(1)	Byte Count							
BDnADRL(1)	Buffer Address Low							
BDnADRH(1)	Buffer Address High							

Note 1: For buffer descriptor registers, n may have a value of 0 to 63. For the sake of brevity, all 64 registers are shown as one generic prototype. All registers have indeterminate Reset values (`xxxx xxxx`).

2: Bits 5 through 2 of the BDnSTAT register are used by the SIE to return PID3:PID0 values once the register is turned over to the SIE (UOWN bit is set). Once the registers have been under SIE control, the values written for DTSEN and BSTALL are no longer valid.

3: Prior to turning the buffer descriptor over to the SIE (UOWN bit is cleared), bits 3 and 2 of the BDnSTAT register are used to configure the DTSEN and BSTALL settings.

4: This bit is ignored unless DTSEN = `1`.

14.5 USB Interrupts

The USB module can generate multiple interrupt conditions. To accommodate all of these interrupt sources, the module is provided with its own interrupt logic structure, similar to that of the microcontroller. USB interrupts are enabled with one set of control registers and trapped with a separate set of flag registers. All sources are funneled into a single USB interrupt request, USBIF (PIR2<5>), in the microcontroller's interrupt logic.

Figure 14-8 shows the interrupt logic for the USB module. There are two layers of interrupt registers in the USB module. The top level consists of overall USB status interrupts; these are enabled and flagged in the UIE and UIR registers, respectively. The second level consists of USB error conditions, which are enabled and flagged in the UEIR and UEIE registers. An interrupt condition in any of these triggers a USB Error Interrupt Flag (UERRIF) in the top level.

Interrupts may be used to trap routine events in a USB transaction. Figure 14-9 shows some common events within a USB frame and their corresponding interrupts.

FIGURE 14-8: USB INTERRUPT LOGIC FUNNEL

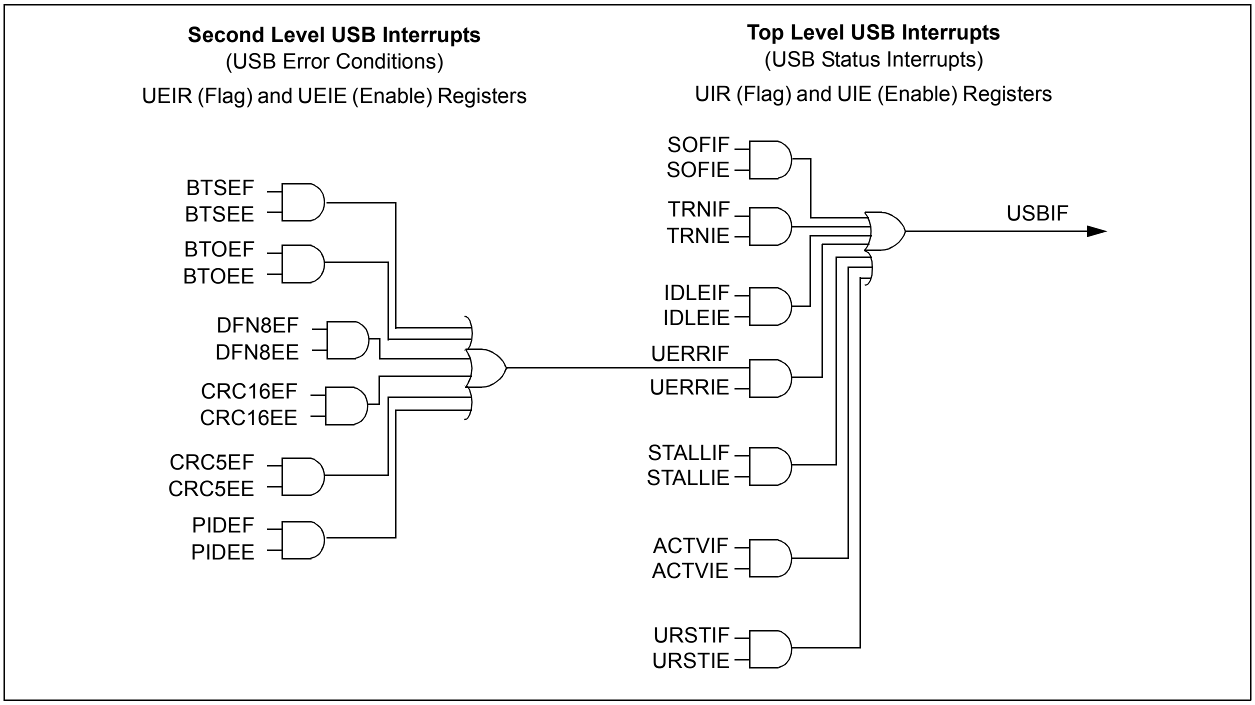
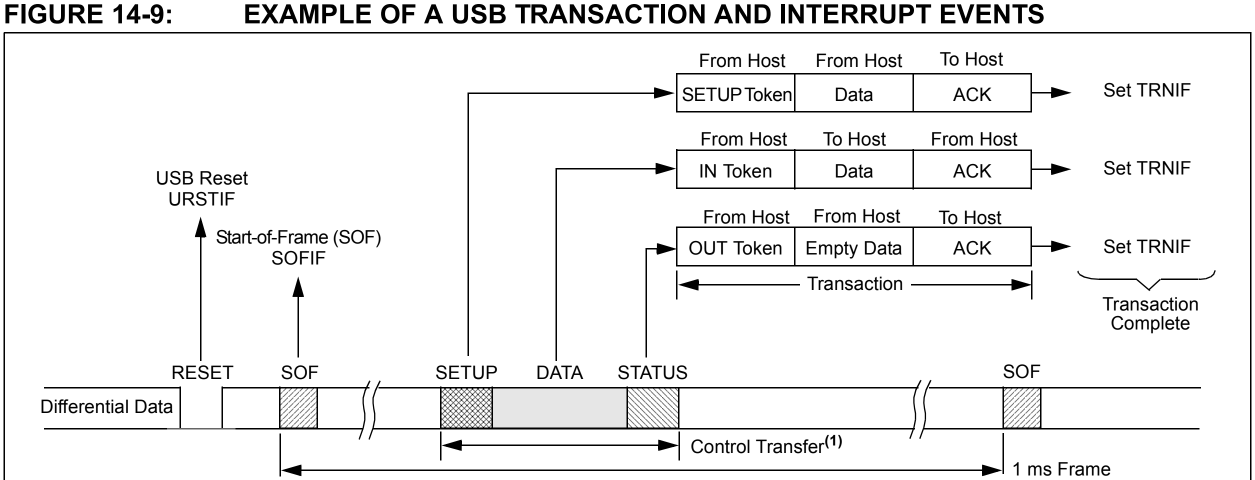


FIGURE 14-9: EXAMPLE OF A USB TRANSACTION AND INTERRUPT EVENTS



Note 1: The control transfer shown here is only an example showing events that can occur for every transaction. Typical control transfers will spread across multiple frames.

14.5.1 USB INTERRUPT STATUS REGISTER (UIR)

The USB Interrupt Status register (Register 14-7) contains the flag bits for each of the USB status interrupt sources. Each of these sources has a corresponding interrupt enable bit in the UIE register. All of the USB status flags are ORed together to generate the USBIF interrupt flag for the microcontroller's interrupt funnel.

Once an interrupt bit has been set by the SIE, it must be cleared by software by writing a '0'. The flag bits can also be set in software which can aid in firmware debugging.

When the USB module is in the Low-Power Suspend mode (UCON<1> = 1), the SIE does not get clocked. When in this state, the SIE cannot process packets, and therefore, cannot detect new interrupt conditions other than the Activity Detect Interrupt, Flag ACTVIF. The ACTVIF bit is typically used by USB firmware to detect when the microcontroller should bring the USB module out of the Low-Power Suspend mode (UCON<1> = 0).

REGISTER 14-7: UIR: USB INTERRUPT STATUS REGISTER

U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0	R/W-0
—	SOFIF	STALLIF	IDLEIF(1)	TRNIF(2)	ACTVIF(3)	UERRIF(4)	URSTIF
bit 7							bit 0

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

bit 7 **Unimplemented:** Read as '0'

bit 6 **SOFIF:** Start-of-Frame Token Interrupt bit
1 = A Start-of-Frame token received by the SIE
0 = No Start-of-Frame token received by the SIE

bit 5 **STALLIF:** A STALL Handshake Interrupt bit
1 = A STALL handshake was sent by the SIE
0 = A STALL handshake has not been sent

bit 4 **IDLEIF:** Idle Detect Interrupt bit(1)
1 = Idle condition detected (constant Idle state of 3 ms or more)
0 = No Idle condition detected

bit 3 **TRNIF:** Transaction Complete Interrupt bit(2)
1 = Processing of pending transaction is complete; read USTAT register for endpoint information
0 = Processing of pending transaction is not complete or no transaction is pending

bit 2 **ACTVIF:** Bus Activity Detect Interrupt bit(3)
1 = Activity on the D+/D- lines was detected
0 = No activity detected on the D+/D- lines

bit 1 **UERRIF:** USB Error Condition Interrupt bit(4)
1 = An unmasked error condition has occurred
0 = No unmasked error condition has occurred.

bit 0 **URSTIF:** USB Reset Interrupt bit
1 = Valid USB Reset occurred; 00h is loaded into UADDR register
0 = No USB Reset has occurred

Note 1: Once an Idle state is detected, the user may want to place the USB module in Suspend mode.
2: Clearing this bit will cause the USTAT FIFO to advance (valid only for IN, OUT and SETUP tokens).
3: This bit is typically unmasked only following the detection of a UIDLE interrupt event.
4: Only error conditions enabled through the UEIE register will set this bit. This bit is a status bit only and cannot be set or cleared by the user.

14.5.1.1 Bus Activity Detect Interrupt Bit (ACTVIF)

The ACTVIF bit cannot be cleared immediately after the USB module wakes up from Suspend or while the USB module is suspended. A few clock cycles are required to synchronize the internal hardware state machine before the ACTVIF bit can be cleared by firmware. Clearing the ACTVIF bit before the internal hardware is synchronized may not have an effect on the value of ACTVIF. Additionally, if the USB module uses the clock from the 96 MHz PLL source, then after clearing the SUSPND bit, the USB module may not be immediately operational while waiting for the 96 MHz PLL to lock. The application code should clear the ACTVIF bit as shown in Example 14-1.

Only one ACTVIF interrupt is generated when resuming from the USB bus Idle condition. If user firmware clears the ACTVIF bit, the bit will not immediately become set again, even when there is continuous bus traffic. Bus traffic must cease long enough to generate another IDLEIF condition before another ACTVIF interrupt can be generated.

EXAMPLE 14-1: CLEARING ACTVIF BIT (UIR<2>)

Assembly:

```
        BCF     UCON, SUSPND
LOOP:
        BTFSS   UIR, ACTVIF
        BRA     DONE
        BCF     UIR, ACTVIF
        BRA     LOOP
DONE
```

C:

```
UCONbits.SUSPND = 0;
while (UIRbits.ACTVIF){UIRbits.ACTVIF = 0};
```

14.5.2 USB INTERRUPT ENABLE REGISTER (UIE)

The USB Interrupt Enable register (Register 14-8) contains the enable bits for the USB status interrupt sources. Setting any of these bits will enable the respective interrupt source in the UIR register.

The values in this register only affect the propagation of an interrupt condition to the microcontroller's interrupt logic. The flag bits are still set by their interrupt conditions, allowing them to be polled and serviced without actually generating an interrupt.

REGISTER 14-8: UIE: USB INTERRUPT ENABLE REGISTER

U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	SOFIE	STALLIE	IDLEIE	TRNIE	ACTVIE	UERRIE	URSTIE
bit 7							bit 0

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

bit 7 **Unimplemented:** Read as '0'

bit 6 **SOFIE:** Start-of-Frame Token Interrupt Enable bit
1 = Start-of-Frame token interrupt enabled
0 = Start-of-Frame token interrupt disabled

bit 5 **STALLIE:** STALL Handshake Interrupt Enable bit
1 = STALL interrupt enabled
0 = STALL interrupt disabled

bit 4 **IDLEIE:** Idle Detect Interrupt Enable bit
1 = Idle detect interrupt enabled
0 = Idle detect interrupt disabled

bit 3 **TRNIE:** Transaction Complete Interrupt Enable bit
1 = Transaction interrupt enabled
0 = Transaction interrupt disabled

bit 2 **ACTVIE:** Bus Activity Detect Interrupt Enable bit
1 = Bus activity detect interrupt enabled
0 = Bus activity detect interrupt disabled

bit 1 **UERRIE:** USB Error Interrupt Enable bit
1 = USB error interrupt enabled
0 = USB error interrupt disabled

bit 0 **URSTIE:** USB Reset Interrupt Enable bit
1 = USB Reset interrupt enabled
0 = USB Reset interrupt disabled

14.5.3 USB ERROR INTERRUPT STATUS REGISTER (UEIR)

The USB Error Interrupt Status register (Register 14-9) contains the flag bits for each of the error sources within the USB peripheral. Each of these sources is controlled by a corresponding interrupt enable bit in the UEIE register. All of the USB error flags are ORed together to generate the USB Error Interrupt Flag (UERRIF) at the top level of the interrupt logic.

Each error bit is set as soon as the error condition is detected. Thus, the interrupt will typically not correspond with the end of a token being processed.

Once an interrupt bit has been set by the SIE, it must be cleared by software by writing a ‘0’.

REGISTER 14-9: UEIR: USB ERROR INTERRUPT STATUS REGISTER

R/C-0	U-0	U-0	R/C-0	R/C-0	R/C-0	R/C-0	R/C-0
BTSEF	—	—	BTOEF	DFN8EF	CRC16EF	CRC5EF	PIDEF
bit 7							bit 0

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

bit 7 **BTSEF:** Bit Stuff Error Flag bit
1 = A bit stuff error has been detected
0 = No bit stuff error

bit 6-5 **Unimplemented:** Read as ‘0’

bit 4 **BTOEF:** Bus Turnaround Time-out Error Flag bit
1 = Bus turnaround time-out has occurred (more than 16 bit times of Idle from previous EOP elapsed)
0 = No bus turnaround time-out

bit 3 **DFN8EF:** Data Field Size Error Flag bit
1 = The data field was not an integral number of bytes
0 = The data field was an integral number of bytes

bit 2 **CRC16EF:** CRC16 Failure Flag bit
1 = The CRC16 failed
0 = The CRC16 passed

bit 1 **CRC5EF:** CRC5 Host Error Flag bit
1 = The token packet was rejected due to a CRC5 error
0 = The token packet was accepted

bit 0 **PIDEF:** PID Check Failure Flag bit
1 = PID check failed
0 = PID check passed

14.5.4 USB ERROR INTERRUPT ENABLE REGISTER (UEIE)

The USB Error Interrupt Enable register (Register 14-10) contains the enable bits for each of the USB error interrupt sources. Setting any of these bits will enable the respective error interrupt source in the UEIR register to propagate into the UERR bit at the top level of the interrupt logic.

As with the UIE register, the enable bits only affect the propagation of an interrupt condition to the microcontroller's interrupt logic. The flag bits are still set by their interrupt conditions, allowing them to be polled and serviced without actually generating an interrupt.

REGISTER 14-10: UEIE: USB ERROR INTERRUPT ENABLE REGISTER

R/W-0	U-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
BTSEE	—	—	BTOEE	DFN8EE	CRC16EE	CRC5EE	PIDEE
bit 7							bit 0

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

bit 7	**BTSEE:** Bit Stuff Error Interrupt Enable bit 1 = Bit stuff error interrupt enabled 0 = Bit stuff error interrupt disabled
bit 6-5	**Unimplemented:** Read as '0'
bit 4	**BTOEE:** Bus Turnaround Time-out Error Interrupt Enable bit 1 = Bus turnaround time-out error interrupt enabled 0 = Bus turnaround time-out error interrupt disabled
bit 3	**DFN8EE:** Data Field Size Error Interrupt Enable bit 1 = Data field size error interrupt enabled 0 = Data field size error interrupt disabled
bit 2	**CRC16EE:** CRC16 Failure Interrupt Enable bit 1 = CRC16 failure interrupt enabled 0 = CRC16 failure interrupt disabled
bit 1	**CRC5EE:** CRC5 Host Error Interrupt Enable bit 1 = CRC5 host error interrupt enabled 0 = CRC5 host error interrupt disabled
bit 0	**PIDEE:** PID Check Failure Interrupt Enable bit 1 = PID check failure interrupt enabled 0 = PID check failure interrupt disabled

14.6 USB Power Modes

Many USB applications will likely have several different sets of power requirements and configuration. The most common power modes encountered are Bus Power Only, Self-Power Only and Dual Power with Self-Power Dominance. The most common cases are presented here.

14.6.1 BUS POWER ONLY

In Bus Power Only mode, all power for the application is drawn from the USB (Figure 14-10). This is effectively the simplest power method for the device.

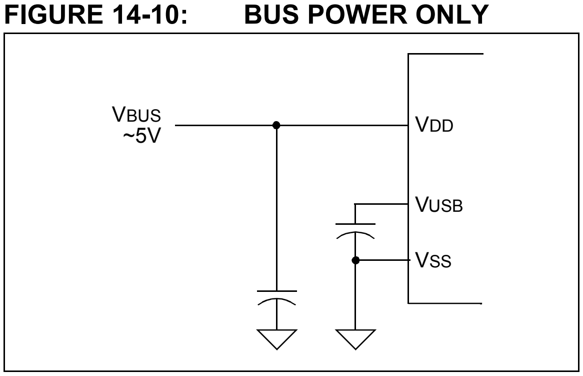
In order to meet the inrush current requirements of the USB 2.0 specifications, the total effective capacitance appearing across VBUS and ground must be no more than 10 μF; otherwise, some kind of inrush limiting is required. For more details, see Section 7.2.4 of the USB 2.0 specification.

According to the USB 2.0 specification, all USB devices must also support a Low-Power Suspend mode. In the USB Suspend mode, devices must consume no more than 500 A (or 2.5 mA for high-powered devices that are capable of remote wake-up) from the 5V VBUS line of the USB cable.

The host signals the USB device to enter the Suspend mode by stopping all USB traffic to that device for more than 3 ms. This condition will set the IDLEIF bit in the UIR register.

During the USB Suspend mode, the D+ or D- pull-up resistor must remain active, which will consume some of the allowed suspend current: 500A/2.5 mA budget.

FIGURE 14-10: BUS POWER ONLY



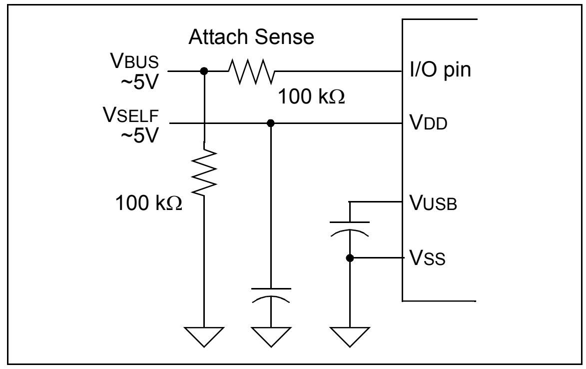
14.6.2 SELF-POWER ONLY

In Self-Power Only mode, the USB application provides its own power, with very little power being pulled from the USB. Figure 14-11 shows an example. Note that an attach indication is added to show when the USB has been connected and the host is actively powering VBUS.

In order to meet compliance specifications, the USB module (and the D+ or D- pull-up resistor) should not be enabled until the host actively drives VBUS high. One of the I/O pins may be used for this purpose.

The application should never source any current onto the 5V VBUS pin of the USB cable.

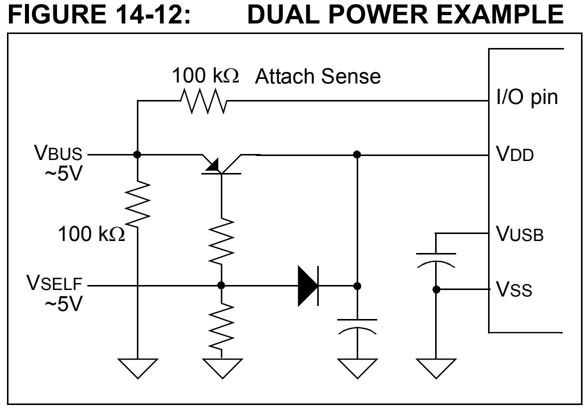
FIGURE 14-11: SELF-POWER ONLY



14.6.3 DUAL POWER WITH SELF-POWER DOMINANCE

Some applications may require a dual power option. This allows the application to use internal power primarily, but switch to power from the USB when no internal power is available. Figure 14-12 shows a simple Dual Power with Self-Power Dominance example, which automatically switches between Self-Power Only and USB Bus Power Only modes.

FIGURE 14-12: DUAL POWER EXAMPLE



Dual power devices must also meet all of the special requirements for inrush current and Suspend mode current, and must not enable the USB module until VBUS is driven high. For descriptions of those requirements, see **Section 14.6.1 “Bus Power Only”** and **Section 14.6.2 “Self-Power Only”**. Additionally, dual power devices must never source current onto the 5V VUSB pin of the USB cable.

Note:	Users should keep in mind the limits for devices drawing power from the USB. According to USB Specification 2.0, this cannot exceed 100 mA per low-power device or 500 mA per high-power device.

14.7 Oscillator

The USB module has specific clock requirements. For full-speed operation, the clock source must be 48 MHz. Even so, the microcontroller core and other peripherals are not required to run at that clock speed or even from the same clock source. Available clocking options are described in detail in **Section 2.3 "Oscillator Settings for USB"**.

14.8 USB Firmware and Drivers

Microchip provides a number of application-specific resources, such as USB firmware and driver support. Refer to www.microchip.com for the latest firmware and driver support.

TABLE 14-6: REGISTERS ASSOCIATED WITH USB MODULE OPERATION(1)

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Details on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
IPR2	OSCFIP	—	USBIP	—	—	HLVDIP	—	—	51
PIR2	OSCFIF	—	USBIF	—	—	HLVDIF	—	—	51
PIE2	OSCFIE	—	USBIE	—	—	HLVDIE	—	—	51
UCON	—	PPBRST	SE0	PKTDIS	USBEN	RESUME	SUSPND	—	52
UCFG	UTEYE	UOEMON	—	UPUEN	UTRDIS	FSEN	PPB1	PPB0	52
USTAT	—	ENDP3	ENDP2	ENDP1	ENDP0	DIR	PPBI	—	52
UADDR	—	ADDR6	ADDR5	ADDR4	ADDR3	ADDR2	ADDR1	ADDR0	52
UFRML	FRM7	FRM6	FRM5	FRM4	FRM3	FRM2	FRM1	FRM0	52
UFRMH	—	—	—	—	—	FRM10	FRM9	FRM8	52
UIR	—	SOFIF	STALLIF	IDLEIF	TRNIF	ACTVIF	UERRIF	URSTIF	52
UIE	—	SOFIE	STALLIE	IDLEIE	TRNIE	ACTVIE	UERRIE	URSTIE	52
UEIR	BTSEF	—	—	BTOEF	DFN8EF	CRC16EF	CRC5EF	PIDEF	52
UEIE	BTSEE	—	—	BTOEE	DFN8EE	CRC16EE	CRC5EE	PIDEE	52
UEP0	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP1	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP2	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP3	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP4	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP5	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP6	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP7	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP8	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP9	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	52
UEP10	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	51
UEP11	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	51
UEP12	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	51
UEP13	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	51
UEP14	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	51
UEP15	—	—	—	EPHSHK	EPCONDIS	EPOUTEN	EPINEN	EPSTALL	51

Legend: — = unimplemented, read as '0'. Shaded cells are not used by the USB module.

Note 1: This table includes only those hardware mapped SFRs located in Bank 15 of the data memory space. The Buffer Descriptor registers, which are mapped into Bank 4 and are not true SFRs, are listed separately in Table 14-5.

14.9 Overview of USB

This section presents some of the basic USB concepts and useful information necessary to design a USB device. Although much information is provided in this section, there is a plethora of information provided within the USB specifications and class specifications. Thus, the reader is encouraged to refer to the USB specifications for more information (www.usb.org). If you are very familiar with the details of USB, then this section serves as a basic, high-level refresher of USB.

14.9.1 LAYERED FRAMEWORK

USB device functionality is structured into a layered framework graphically shown in Figure 14-13. Each level is associated with a functional level within the device. The highest layer, other than the device, is the configuration. A device may have multiple configurations. For example, a particular device may have multiple power requirements based on Self-Power Only or Bus Power Only modes.

For each configuration, there may be multiple interfaces. Each interface could support a particular mode of that configuration.

Below the interface is the endpoint(s). Data is directly moved at this level. There can be as many as 16 bidirectional endpoints. Endpoint 0 is always a control endpoint and by default, when the device is on the bus, Endpoint 0 must be available to configure the device.

14.9.2 FRAMES

Information communicated on the bus is grouped into 1 ms time slots, referred to as frames. Each frame can contain many transactions to various devices and endpoints. Figure 14-9 shows an example of a transaction within a frame.

14.9.3 TRANSFERS

There are four transfer types defined in the USB specification.

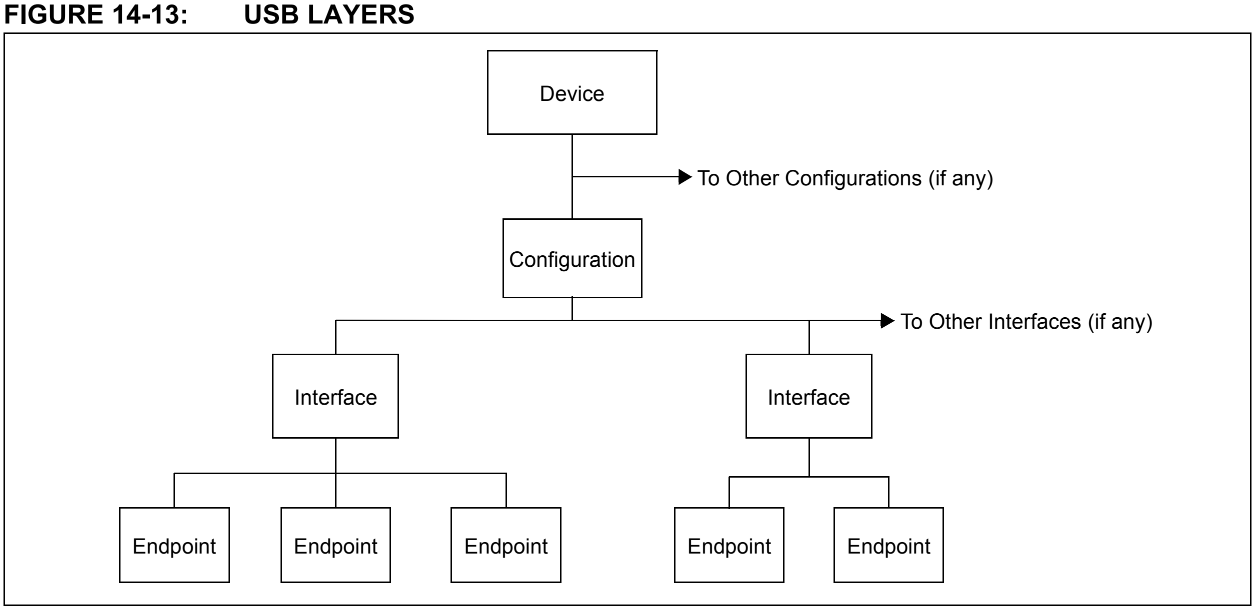
- **Isochronous:** This type provides a transfer method for large amounts of data (up to 1023 bytes) with timely delivery ensured; however, the data integrity is not ensured. This is good for streaming applications where small data loss is not critical, such as audio.
- **Bulk:** This type of transfer method allows for large amounts of data to be transferred with ensured data integrity; however, the delivery timeliness is not ensured.
- **Interrupt:** This type of transfer provides for ensured timely delivery for small blocks of data; plus data integrity is ensured.
- **Control:** This type provides for device setup control.

While full-speed devices support all transfer types, low-speed devices are limited to interrupt and control transfers only.

14.9.4 POWER

Power is available from the Universal Serial Bus. The USB specification defines the bus power requirements. Devices may either be self-powered or bus powered. Self-powered devices draw power from an external source, while bus powered devices use power supplied from the bus.

FIGURE 14-13: USB LAYERS



The USB specification limits the power taken from the bus. Each device is ensured 100 mA at approximately 5V (one-unit load). Additional power may be requested, up to a maximum of 500 mA. Note that power above a one-unit load is a request and the host or hub is not obligated to provide the extra current. Thus, a device capable of consuming more than a one-unit load must be able to maintain a low-power configuration of a one-unit load or less, if necessary.

The USB specification also defines a Suspend mode. In this situation, current must be limited to 500 μA, averaged over 1 second. A device must enter a Suspend state after 3 ms of inactivity (i.e., no SOF tokens for 3 ms). A device entering Suspend mode must drop current consumption within 10 ms after Suspend mode. Likewise, when signaling a wake-up, the device must signal a wake-up within 10 ms of drawing current above the Suspend limit.

14.9.5 ENUMERATION

When the device is initially attached to the bus, the host enters an enumeration process in an attempt to identify the device. Essentially, the host interrogates the device, gathering information such as power consumption, data rates and sizes, protocol and other descriptive information; descriptors contain this information. A typical enumeration process would be as follows:

1. USB Reset: Reset the device. Thus, the device is not configured and does not have an address (address 0).
2. Get Device Descriptor: The host requests a small portion of the device descriptor.
3. USB Reset: Reset the device again.
4. Set Address: The host assigns an address to the device.
5. Get Device Descriptor: The host retrieves the device descriptor, gathering info such as manufacturer, type of device, maximum control packet size.
6. Get configuration descriptors.
7. Get any other descriptors.
8. Set a configuration.

The exact enumeration process depends on the host.

14.9.6 DESCRIPTORS

There are eight different standard descriptor types of which five are most important for this device.

14.9.6.1 Device Descriptor

The device descriptor provides general information, such as manufacturer, product number, serial number, the class of the device and the number of configurations. There is only one device descriptor.

14.9.6.2 Configuration Descriptor

The configuration descriptor provides information on the power requirements of the device and how many different interfaces are supported when in this configuration. There may be more than one configuration for a device (i.e., low-power and high-power configurations).

14.9.6.3 Interface Descriptor

The interface descriptor details the number of endpoints used in this interface, as well as the class of the interface. There may be more than one interface for a configuration.

14.9.6.4 Endpoint Descriptor

The endpoint descriptor identifies the transfer type (**Section 14.9.3 "Transfers"**) and direction, as well as some other specifics for the endpoint. There may be many endpoints in a device and endpoints may be shared in different configurations.

14.9.6.5 String Descriptor

Many of the previous descriptors reference one or more string descriptors. String descriptors provide human readable information about the layer (**Section 14.9.1 "Layered Framework"**) they describe. Often these strings show up in the host to help the user identify the device. String descriptors are generally optional to save memory and are encoded in a unicode format.

14.9.7 BUS SPEED

Each USB device must indicate its bus presence and speed to the host. This is accomplished through a 1.5 kΩ resistor which is connected to the bus at the time of the attachment event.

Depending on the speed of the device, the resistor either pulls up the D+ or D- line to 3.3V. For a low-speed device, the pull-up resistor is connected to the D- line. For a full-speed device, the pull-up resistor is connected to the D+ line.

14.9.8 CLASS SPECIFICATIONS AND DRIVERS

USB specifications include class specifications which operating system vendors optionally support. Examples of classes include Audio, Mass Storage, Communications and Human Interface (HID). In most cases, a driver is required at the host side to 'talk' to the USB device. In custom applications, a driver may need to be developed. Fortunately, drivers are available for most common host systems for the most common classes of devices. Thus, these drivers can be reused.

15.0 ENHANCED UNIVERSAL SYNCHRONOUS RECEIVER TRANSMITTER (EUSART)

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. It can also 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 and so on.

The Enhanced Universal Synchronous Receiver Transmitter (EUSART) module implements additional features, including Automatic Baud Rate Detection (ABD) and calibration, automatic wake-up on Sync Break reception and 12-bit Break character transmit. These features make it ideally suited for use in Local Interconnect Network bus (LIN bus) systems.

The EUSART can be configured in the following modes:

- Asynchronous (full-duplex) with:
  - Auto-wake-up on character reception
  - Auto-baud calibration
  - 12-bit Break character transmission
- Synchronous – Master (half-duplex) with selectable clock polarity
- Synchronous – Slave (half-duplex) with selectable clock polarity

The pins of the Enhanced USART are multiplexed with PORTC. In order to configure RC6/TX/CK and RC7/RX/DT as an EUSART:

- bit SPEN (RCSTA<7>) must be set (= `1`)
- bit TRISC<7> must be set (= `1`)
- bit TRISC<6> must be cleared (= `0`) for Asynchronous and Synchronous Master modes or set (= `1`) for Synchronous Slave mode

Note:	The EUSART control will automatically reconfigure the pin from input to output as needed.

The operation of the Enhanced USART module is controlled through three registers:

- Transmit Status and Control (TXSTA)
- Receive Status and Control (RCSTA)
- Baud Rate Control (BAUDCON)

These are detailed on the following pages in Register 15-1, Register 15-2 and Register 15-3, respectively.

REGISTER 15-1: TXSTA: TRANSMIT STATUS AND CONTROL REGISTER

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-1	R/W-0
CSRC	TX9	TXEN(1)	SYNC	SENDB	BRGH	TRMT	TX9D
bit 7							bit 0

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

bit 7 **CSRC:** Clock Source Select bit
Asynchronous mode:
Don’t care.
Synchronous mode:
1 = Master mode (clock generated internally from BRG)
0 = Slave mode (clock from external source)

bit 6 **TX9:** 9-Bit Transmit Enable bit
1 = Selects 9-bit transmission
0 = Selects 8-bit transmission

bit 5 **TXEN:** Transmit Enable bit(1)
1 = Transmit enabled
0 = Transmit disabled

bit 4 **SYNC:** EUSART Mode Select bit
1 = Synchronous mode
0 = Asynchronous mode

bit 3 **SENDB:** Send Break Character bit
Asynchronous mode:
1 = Send Sync Break on next transmission (cleared by hardware upon completion)
0 = Sync Break transmission completed
Synchronous mode:
Don’t care.

bit 2 **BRGH:** High Baud Rate Select bit
Asynchronous mode:
1 = High speed
0 = Low speed
Synchronous mode:
Unused in this mode.

bit 1 **TRMT:** Transmit Shift Register Status bit
1 = TSR empty
0 = TSR full

bit 0 **TX9D:** 9th bit of Transmit Data
Can be address/data bit or a parity bit.

Note 1: SREN/CREN overrides TXEN in Sync mode with the exception that SREN has no effect in Synchronous Slave mode.

REGISTER 15-2: RCSTA: RECEIVE STATUS AND CONTROL REGISTER

R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R-0	R-0	R-x
SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D
bit 7							bit 0

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

bit 7 **SPEN:** Serial Port Enable bit
1 = Serial port enabled (configures RX/DT and TX/CK pins as serial port pins)
0 = Serial port disabled (held in Reset)

bit 6 **RX9:** 9-Bit Receive Enable bit
1 = Selects 9-bit reception
0 = Selects 8-bit reception

bit 5 **SREN:** Single Receive Enable bit
Asynchronous mode:
Don’t care.
Synchronous mode – Master:
1 = Enables single receive
0 = Disables single receive
This bit is cleared after reception is complete.
Synchronous mode – Slave:
Don’t care.

bit 4 **CREN:** Continuous Receive Enable bit
Asynchronous mode:
1 = Enables receiver
0 = Disables receiver
Synchronous mode:
1 = Enables continuous receive until enable bit CREN is cleared (CREN overrides SREN)
0 = Disables continuous receive

bit 3 **ADDEN:** Address Detect Enable bit
Asynchronous mode 9-bit (RX9 = 1):
1 = Enables address detection, enables interrupt and loads the receive buffer when RSR<8> is set
0 = Disables address detection, all bytes are received and ninth bit can be used as parity bit
Asynchronous mode 8-bit (RX9 = 0):
Don’t care.

bit 2 **FERR:** Framing Error bit
1 = Framing error (can be updated by reading RCREG register and receiving next valid byte)
0 = No framing error

bit 1 **OERR:** Overrun Error bit
1 = Overrun error (can be cleared by clearing bit CREN)
0 = No overrun error

bit 0 **RX9D:** 9th bit of Received Data
This can be address/data bit or a parity bit and must be calculated by user firmware.

REGISTER 15-3: BAUDCON: BAUD RATE CONTROL REGISTER

R/W-0	R-1	U-0	R/W-0	R/W-0	U-0	R/W-0	R/W-0
ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN
bit 7							bit 0

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

bit 7 **ABDOVF**: Auto-Baud Acquisition Rollover Status bit
1 = A BRG rollover has occurred during Auto-Baud Rate Detect mode (must be cleared in software)
0 = No BRG rollover has occurred

bit 6 **RCIDL**: Receive Operation Idle Status bit
1 = Receive operation is Idle
0 = Receive operation is active

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

bit 4 **SCKP**: Synchronous Clock Polarity Select bit
Asynchronous mode:
Unused in this mode.
Synchronous mode:
1 = Idle state for clock (CK) is a high level
0 = Idle state for clock (CK) is a low level

bit 3 **BRG16:** 16-Bit Baud Rate Register Enable bit
1 = 16-bit Baud Rate Generator – SPBRGH and SPBRG
0 = 8-bit Baud Rate Generator – SPBRG only (Compatible mode), SPBRGH value ignored

bit 2 **Unimplemented:** Read as '0'

bit 1 **WUE:** Wake-up Enable bit
Asynchronous mode:
1 = EUSART will continue to sample the RX pin – interrupt generated on falling edge; bit cleared in hardware on following rising edge
0 = RX pin not monitored or rising edge detected
Synchronous mode:
Unused in this mode.

bit 0 **ABDEN**: Auto-Baud Detect Enable bit
Asynchronous mode:
1 = Enable baud rate measurement on the next character. Requires reception of a Sync field (55h); cleared in hardware upon completion.
0 = Baud rate measurement disabled or completed
Synchronous mode:
Unused in this mode.

15.1 Baud Rate Generator (BRG)

The BRG is a dedicated, 8-bit or 16-bit generator that supports both the Asynchronous and Synchronous modes of the EUSART. By default, the BRG operates in 8-bit mode. Setting the BRG16 bit (BAUDCON<3>) selects 16-bit mode.

The SPBRGH:SPBRG register pair controls the period of a free-running timer. In Asynchronous mode, bits BRGH (TXSTA<2>) and BRG16 (BAUDCON<3>) also control the baud rate. In Synchronous mode, BRGH is ignored. Table 15-1 shows the formula for computation of the baud rate for different EUSART modes which only apply in Master mode (internally generated clock).

Given the desired baud rate and FOSC, the nearest integer value for the SPBRGH:SPBRG registers can be calculated using the formulas in Table 15-1. From this, the error in baud rate can be determined. An example calculation is shown in Example 15-1. Typical baud rates and error values for the various Asynchronous modes are shown in Table 15-2. It may be advantageous to use the high baud rate (BRGH = 1) or the 16-bit BRG to reduce the baud rate error, or achieve a slow baud rate for a fast oscillator frequency.

Writing a new value to the SPBRGH:SPBRG registers causes the BRG timer to be reset (or cleared). This ensures the BRG does not wait for a timer overflow before outputting the new baud rate.

15.1.1 OPERATION IN POWER-MANAGED MODES

The device clock is used to generate the desired baud rate. When one of the power-managed modes is entered, the new clock source may be operating at a different frequency. This may require an adjustment to the value in the SPBRG register pair.

15.1.2 SAMPLING

The data on the RX pin is sampled three times by a majority detect circuit to determine if a high or a low level is present at the RX pin.

TABLE 15-1: BAUD RATE FORMULAS

Configuration Bits			BRG/EUSART Mode	Baud Rate Formula
SYNC	**BRG16**	**BRGH**		
0	0	0	8-Bit/Asynchronous	FOSC/[64 (n + 1)]
0	0	1	8-Bit/Asynchronous	FOSC/[16 (n + 1)]
0	1	0	16-Bit/Asynchronous	
0	1	1	16-Bit/Asynchronous	FOSC/[4 (n + 1)]
1	0	x	8-Bit/Synchronous	
1	1	x	16-Bit/Synchronous	

Legend: x = Don't care, n = Value of SPBRGH:SPBRG register pair

EXAMPLE 15-1: CALCULATING BAUD RATE ERROR

For a device with FOSC of 16 MHz, desired baud rate of 9600, Asynchronous mode, 8-bit BRG:
Desired Baud Rate = FOSC/(64 ([SPBRGH:SPBRG] + 1)
Solving for SPBRGH:SPBRG:
X = ((FOSC/Desired Baud Rate)/64) – 1
= ((16000000/9600)/64) – 1
= [25.042] = 25
Calculated Baud Rate = 16000000/(64 (25 + 1))
= 9615
Error = (Calculated Baud Rate – Desired Baud Rate)/Desired Baud Rate
= (9615 – 9600)/9600 = 0.16%

TABLE 15-2: REGISTERS ASSOCIATED WITH BAUD RATE GENERATOR

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	51
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	51
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	51
SPBRGH	EUSART Baud Rate Generator Register High Byte								50
SPBRG	EUSART Baud Rate Generator Register Low Byte								50

Legend: — = unimplemented, read as '0'. Shaded cells are not used by the BRG.

TABLE 15-3: BAUD RATES FOR ASYNCHRONOUS MODES

BAUD RATE (K)	SYNC = 0, BRGH = 0, BRG16 = 0											
	FOSC = 40.000 MHz			FOSC = 20.000 MHz			FOSC = 10.000 MHz			FOSC = 8.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	—	—	—	—	—	—	—	—	—	—	—	—
1.2	—	—	—	1.221	1.73	255	1.202	0.16	129	1.201	-0.16	103
2.4	2.441	1.73	255	2.404	0.16	129	2.404	0.16	64	2.403	-0.16	51
9.6	9.615	0.16	64	9.766	1.73	31	9.766	1.73	15	9.615	-0.16	12
19.2	19.531	1.73	31	19.531	1.73	15	19.531	1.73	7	—	—	—
57.6	56.818	-1.36	10	62.500	8.51	4	52.083	-9.58	2	—	—	—
115.2	125.000	8.51	4	104.167	-9.58	2	78.125	-32.18	1	—	—	—

BAUD RATE (K)	SYNC = 0, BRGH = 0, BRG16 = 0								
	FOSC = 4.000 MHz			FOSC = 2.000 MHz			FOSC = 1.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	0.300	0.16	207	0.300	-0.16	103	0.300	-0.16	51
1.2	1.202	0.16	51	1.201	-0.16	25	1.201	-0.16	12
2.4	2.404	0.16	25	2.403	-0.16	12	—	—	—
9.6	8.929	-6.99	6	—	—	—	—	—	—
19.2	20.833	8.51	2	—	—	—	—	—	—
57.6	62.500	8.51	0	—	—	—	—	—	—
115.2	62.500	-45.75	0	—	—	—	—	—	—

BAUD RATE (K)	SYNC = 0, BRGH = 1, BRG16 = 0											
	FOSC = 40.000 MHz			FOSC = 20.000 MHz			FOSC = 10.000 MHz			FOSC = 8.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	—	—	—	—	—	—	—	—	—	—	—	—
1.2	—	—	—	—	—	—	—	—	—	—	—	—
2.4	—	—	—	—	—	—	2.441	1.73	255	2.403	-0.16	207
9.6	9.766	1.73	255	9.615	0.16	129	9.615	0.16	64	9.615	-0.16	51
19.2	19.231	0.16	129	19.231	0.16	64	19.531	1.73	31	19.230	-0.16	25
57.6	58.140	0.94	42	56.818	-1.36	21	56.818	-1.36	10	55.555	3.55	8
115.2	113.636	-1.36	21	113.636	-1.36	10	125.000	8.51	4	—	—	—

BAUD RATE (K)	SYNC = 0, BRGH = 1, BRG16 = 0								
	FOSC = 4.000 MHz			FOSC = 2.000 MHz			FOSC = 1.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	—	—	—	—	—	—	0.300	-0.16	207
1.2	1.202	0.16	207	1.201	-0.16	103	1.201	-0.16	51
2.4	2.404	0.16	103	2.403	-0.16	51	2.403	-0.16	25
9.6	9.615	0.16	25	9.615	-0.16	12	—	—	—
19.2	19.231	0.16	12	—	—	—	—	—	—
57.6	62.500	8.51	3	—	—	—	—	—	—
115.2	125.000	8.51	1	—	—	—	—	—	—

TABLE 15-3: BAUD RATES FOR ASYNCHRONOUS MODES (CONTINUED)

BAUD RATE (K)	SYNC = 0, BRGH = 0, BRG16 = 1											
	FOSC = 40.000 MHz			FOSC = 20.000 MHz			FOSC = 10.000 MHz			FOSC = 8.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	0.300	0.00	8332	0.300	0.02	4165	0.300	0.02	2082	0.300	-0.04	1665
1.2	1.200	0.02	2082	1.200	-0.03	1041	1.200	-0.03	520	1.201	-0.16	415
2.4	2.402	0.06	1040	2.399	-0.03	520	2.404	0.16	259	2.403	-0.16	207
9.6	9.615	0.16	259	9.615	0.16	129	9.615	0.16	64	9.615	-0.16	51
19.2	19.231	0.16	129	19.231	0.16	64	19.531	1.73	31	19.230	-0.16	25
57.6	58.140	0.94	42	56.818	-1.36	21	56.818	-1.36	10	55.555	3.55	8
115.2	113.636	-1.36	21	113.636	-1.36	10	125.000	8.51	4	—	—	—

BAUD RATE (K)	SYNC = 0, BRGH = 0, BRG16 = 1								
	FOSC = 4.000 MHz			FOSC = 2.000 MHz			FOSC = 1.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	0.300	0.04	832	0.300	-0.16	415	0.300	-0.16	207
1.2	1.202	0.16	207	1.201	-0.16	103	1.201	-0.16	51
2.4	2.404	0.16	103	2.403	-0.16	51	2.403	-0.16	25
9.6	9.615	0.16	25	9.615	-0.16	12	—	—	—
19.2	19.231	0.16	12	—	—	—	—	—	—
57.6	62.500	8.51	3	—	—	—	—	—	—
115.2	125.000	8.51	1	—	—	—	—	—	—

BAUD RATE (K)	SYNC = 0, BRGH = 1, BRG16 = 1 or SYNC = 1, BRG16 = 1											
	FOSC = 40.000 MHz			FOSC = 20.000 MHz			FOSC = 10.000 MHz			FOSC = 8.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	0.300	0.00	33332	0.300	0.00	16665	0.300	0.00	8332	0.300	-0.01	6665
1.2	1.200	0.00	8332	1.200	0.02	4165	1.200	0.02	2082	1.200	-0.04	1665
2.4	2.400	0.02	4165	2.400	0.02	2082	2.402	0.06	1040	2.400	-0.04	832
9.6	9.606	0.06	1040	9.596	-0.03	520	9.615	0.16	259	9.615	-0.16	207
19.2	19.193	-0.03	520	19.231	0.16	259	19.231	0.16	129	19.230	-0.16	103
57.6	57.803	0.35	172	57.471	-0.22	86	58.140	0.94	42	57.142	0.79	34
115.2	114.943	-0.22	86	116.279	0.94	42	113.636	-1.36	21	117.647	-2.12	16

BAUD RATE (K)	SYNC = 0, BRGH = 1, BRG16 = 1 or SYNC = 1, BRG16 = 1								
	FOSC = 4.000 MHz			FOSC = 2.000 MHz			FOSC = 1.000 MHz		
	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)	Actual Rate (K)	% Error	SPBRG value (decimal)
0.3	0.300	0.01	3332	0.300	-0.04	1665	0.300	-0.04	832
1.2	1.200	0.04	832	1.201	-0.16	415	1.201	-0.16	207
2.4	2.404	0.16	415	2.403	-0.16	207	2.403	-0.16	103
9.6	9.615	0.16	103	9.615	-0.16	51	9.615	-0.16	25
19.2	19.231	0.16	51	19.230	-0.16	25	19.230	-0.16	12
57.6	58.824	2.12	16	55.555	3.55	8	—	—	—
115.2	111.111	-3.55	8	—	—	—	—	—	—

15.1.3 AUTO-BAUD RATE DETECT

The Enhanced USART module supports the automatic detection and calibration of baud rate. This feature is active only in Asynchronous mode and while the WUE bit is clear.

The automatic baud rate measurement sequence (Figure 15-1) begins whenever a Start bit is received and the ABDEN bit is set. The calculation is self-averaging.

In the Auto-Baud Rate Detect (ABD) mode, the clock to the BRG is reversed. Rather than the BRG clocking the incoming RX signal, the RX signal is timing the BRG. In ABD mode, the internal Baud Rate Generator is used as a counter to time the bit period of the incoming serial byte stream.

Once the ABDEN bit is set, the state machine will clear the BRG and look for a Start bit. The Auto-Baud Rate Detection must receive a byte with the value 55h (ASCII “U”, which is also the LIN bus Sync character) in order to calculate the proper bit rate. The measurement is taken over both a low and a high bit time in order to minimize any effects caused by asymmetry of the incoming signal. After a Start bit, the SPBRG begins counting up, using the preselected clock source on the first rising edge of RX. After eight bits on the RX pin, or the fifth rising edge, an accumulated value totalling the proper BRG period is left in the SPBRGH:SPBRG register pair. Once the 5th edge is seen (this should correspond to the Stop bit), the ABDEN bit is automatically cleared.

If a rollover of the BRG occurs (an overflow from FFFFh to 0000h), the event is trapped by the ABDOVF status bit (BAUDCON<7>). It is set in hardware by BRG rollovers and can be set or cleared by the user in software. ABD mode remains active after rollover events and the ABDEN bit remains set (Figure 15-2).

While calibrating the baud rate period, the BRG registers are clocked at 1/8th the preconfigured clock rate. Note that the BRG clock will be configured by the BRG16 and BRGH bits. Independent of the BRG16 bit setting, both the SPBRG and SPBRGH will be used as a 16-bit counter. This allows the user to verify that no carry occurred for 8-bit modes by checking for 00h in the SPBRGH register. Refer to Table 15-4 for counter clock rates to the BRG.

While the ABD sequence takes place, the EUSART state machine is held in Idle. The RCIF interrupt is set once the fifth rising edge on RX is detected. The value in the RCREG needs to be read to clear the RCIF interrupt. The contents of RCREG should be discarded.

> **Note 1:** If the WUE bit is set with the ABDEN bit, Auto-Baud Rate Detection will occur on the byte *following* the Break character.
>
> **2:** It is up to the user to determine that the incoming character baud rate is within the range of the selected BRG clock source. Some combinations of oscillator frequency and EUSART baud rates are not possible due to bit error rates. Overall system timing and communication baud rates must be taken into consideration when using the Auto-Baud Rate Detection feature.

TABLE 15-4: BRG COUNTER CLOCK RATES

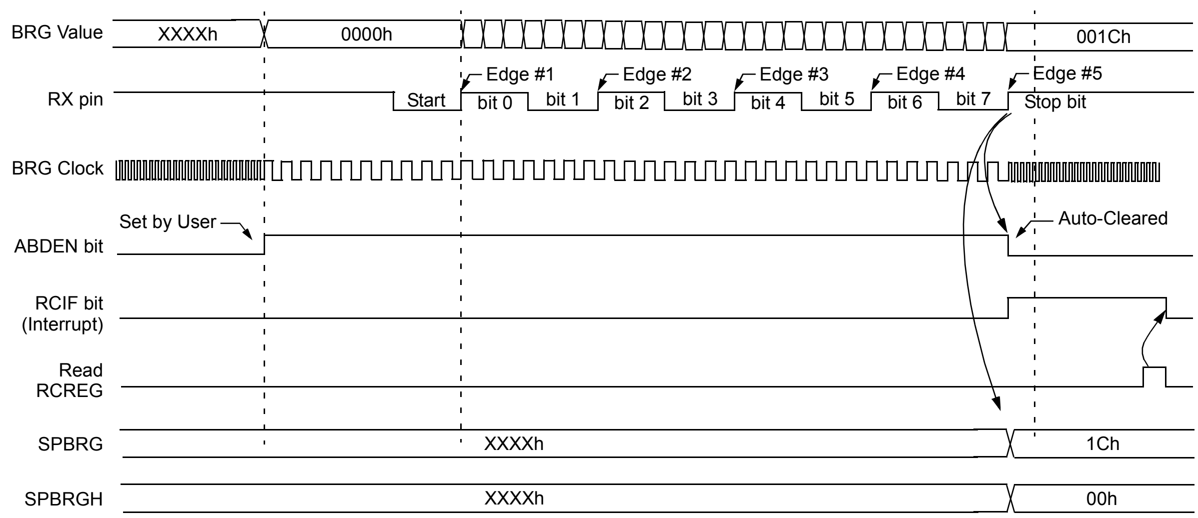
BRG16	BRGH	BRG Counter Clock
0	0	FOSC/512
0	1	FOSC/128
1	0	FOSC/128
1	1	FOSC/32

Note: During the ABD sequence, SPBRG and SPBRGH are both used as a 16-bit counter, independent of the BRG16 setting.

15.1.3.1 ABD and EUSART Transmission

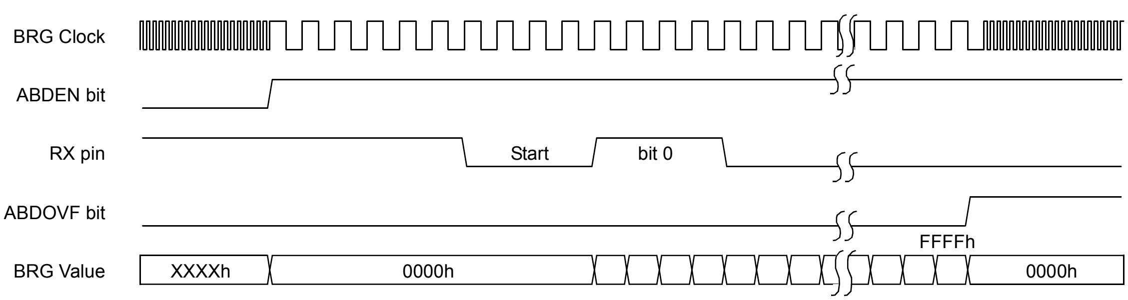
Since the BRG clock is reversed during ABD acquisition, the EUSART transmitter cannot be used during ABD. This means that whenever the ABDEN bit is set, TXREG cannot be written to. Users should also ensure that ABDEN does not become set during a transmit sequence. Failing to do this may result in unpredictable EUSART operation.

FIGURE 15-1: AUTOMATIC BAUD RATE CALCULATION



Note: The ABD sequence requires the EUSART module to be configured in Asynchronous mode and WUE = 0.

FIGURE 15-2: BRG OVERFLOW SEQUENCE



15.2 EUSART Asynchronous Mode

The Asynchronous mode of operation is selected by clearing the SYNC bit (TXSTA<4>). In this mode, the EUSART uses the standard Non-Return-to-Zero (NRZ) format (one Start bit, eight or nine data bits and one Stop bit). The most common data format is eight bits. An on-chip dedicated 8-bit/16-bit Baud Rate Generator can be used to derive standard baud rate frequencies from the oscillator.

The EUSART transmits and receives the LSb first. The EUSART's transmitter and receiver are functionally independent but use the same data format and baud rate. The Baud Rate Generator produces a clock, either x16 or x64 of the bit shift rate depending on the BRGH and BRG16 bits (TXSTA<2> and BAUDCON<3>). Parity is not supported by the hardware but can be implemented in software and stored as the ninth data bit.

When operating in Asynchronous mode, the EUSART module consists of the following important elements:

- Baud Rate Generator
- Sampling Circuit
- Asynchronous Transmitter
- Asynchronous Receiver
- Auto-Wake-up on Sync Break Character
- 12-Bit Break Character Transmit
- Auto-Baud Rate Detection

15.2.1 EUSART ASYNCHRONOUS TRANSMITTER

The EUSART transmitter block diagram is shown in Figure 15-3. The heart of the transmitter is the Transmit (Serial) Shift Register (TSR). The Shift register obtains its data from the Read/Write Transmit Buffer register, TXREG. The TXREG register is loaded with data in software. The TSR register is not loaded until the Stop bit has been transmitted from the previous load. As soon as the Stop bit is transmitted, the TSR is loaded with new data from the TXREG register (if available).

Once the TXREG register transfers the data to the TSR register (occurs in one T_{CY}), the TXREG register is empty and the TXIF flag bit (PIR1<4>) is set. This interrupt can be enabled or disabled by setting or clearing the interrupt enable bit, TXIE (PIE1<4>). TXIF will be set regardless of the state of TXIE; it cannot be cleared in software. TXIF is also not cleared immediately upon loading TXREG but becomes valid in the second instruction cycle following the load instruction. Polling TXIF immediately following a load of TXREG will return invalid results.

While TXIF indicates the status of the TXREG register, another bit, TRMT (TXSTA<1>), shows the status of the TSR register. TRMT is a read-only bit which is set when the TSR register is empty. No interrupt logic is tied to this bit so the user has to poll this bit in order to determine if the TSR register is empty.

Note 1:	The TSR register is not mapped in data memory so it is not available to the user.
2:	Flag bit, TXIF, is set when enable bit, TXEN, is set.

To set up an Asynchronous Transmission:

1. Initialize the SPBRGH:SPBRG registers for the appropriate baud rate. Set or clear the BRGH and BRG16 bits, as required, to achieve the desired baud rate.
2. Enable the asynchronous serial port by clearing bit, SYNC, and setting bit, SPEN.
3. If interrupts are desired, set enable bit, TXIE.
4. If 9-bit transmission is desired, set transmit bit, TX9. Can be used as address/data bit.
5. Enable the transmission by setting bit, TXEN, which will also set bit, TXIF.
6. If 9-bit transmission is selected, the ninth bit should be loaded in bit, TX9D.
7. Load data to the TXREG register (starts transmission).
8. If using interrupts, ensure that the GIE and PEIE bits in the INTCON register (INTCON<7:6>) are set.

FIGURE 15-3: EUSART TRANSMIT BLOCK DIAGRAM

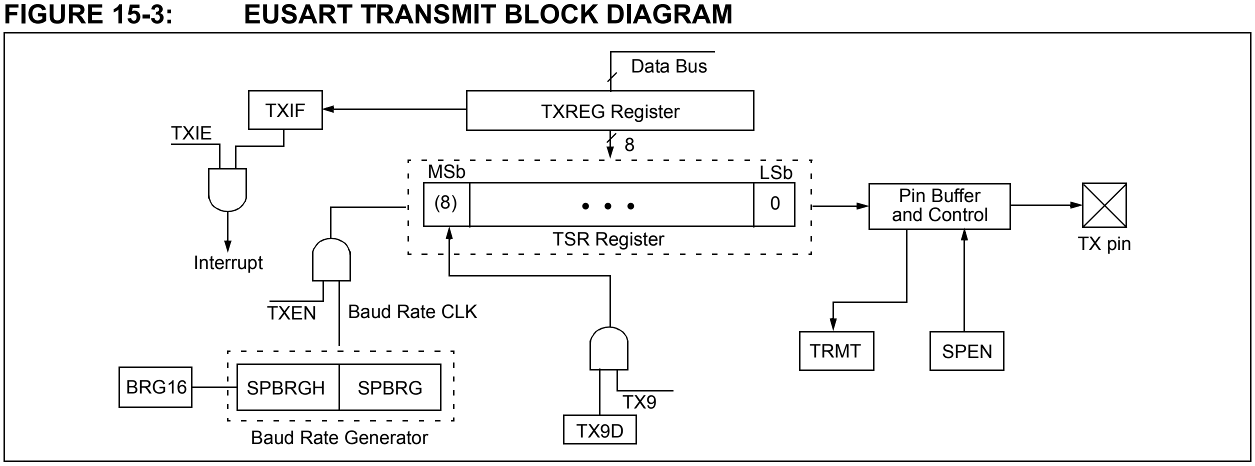


FIGURE 15-4: ASYNCHRONOUS TRANSMISSION

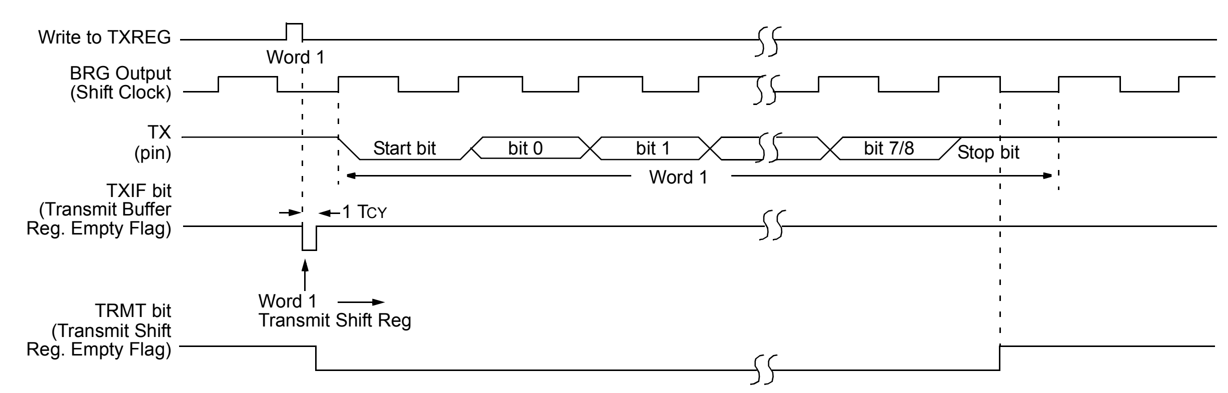
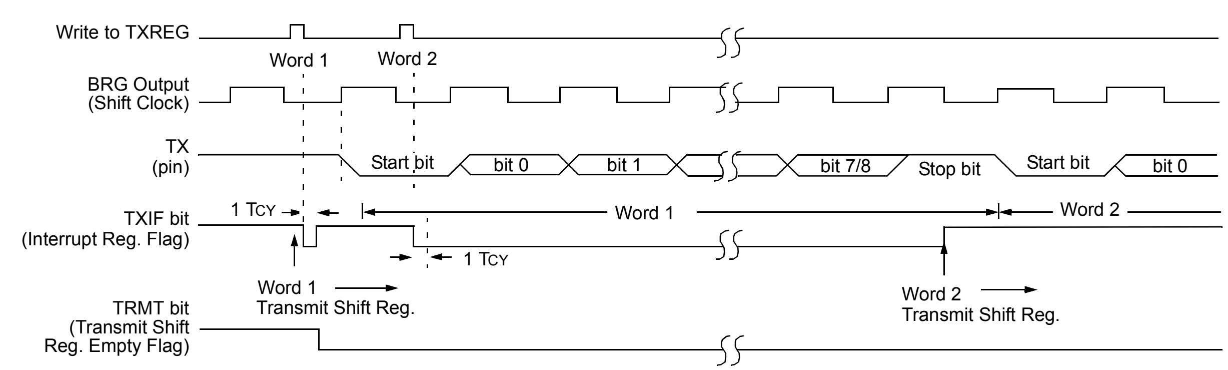


FIGURE 15-5: ASYNCHRONOUS TRANSMISSION (BACK-TO-BACK)



Note: This timing diagram shows two consecutive transmissions.

TABLE 15-5: REGISTERS ASSOCIATED WITH ASYNCHRONOUS TRANSMISSION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	51
TXREG	EUSART Transmit Register								51
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	51
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	51
SPBRGH	EUSART Baud Rate Generator Register High Byte								50
SPBRG	EUSART Baud Rate Generator Register Low Byte								50

Legend: — = unimplemented locations read as ‘0’. Shaded cells are not used for asynchronous transmission.

15.2.2 EUSART ASYNCHRONOUS RECEIVER

The receiver block diagram is shown in Figure 15-6. The data is received on the RX pin and drives the data recovery block. The data recovery block is actually a high-speed shifter operating at x16 times the baud rate, whereas the main receive serial shifter operates at the bit rate or at FOSC. This mode would typically be used in RS-232 systems.

To set up an Asynchronous Reception:

1. Initialize the SPBRGH:SPBRG registers for the appropriate baud rate. Set or clear the BRGH and BRG16 bits, as required, to achieve the desired baud rate.
2. Enable the asynchronous serial port by clearing bit, SYNC, and setting bit, SPEN.
3. If interrupts are desired, set enable bit, RCIE.
4. If 9-bit reception is desired, set bit, RX9.
5. Enable the reception by setting bit, CREN.
6. Flag bit, RCIF, will be set when reception is complete and an interrupt will be generated if enable bit, RCIE, was set.
7. Read the RCSTA register to get the ninth bit (if enabled) and determine if any error occurred during reception.
8. Read the 8-bit received data by reading the RCREG register.
9. If any error occurred, clear the error by clearing enable bit, CREN.
10. If using interrupts, ensure that the GIE and PEIE bits in the INTCON register (INTCON<7:6>) are set.

15.2.3 SETTING UP 9-BIT MODE WITH ADDRESS DETECT

This mode would typically be used in RS-485 systems. To set up an Asynchronous Reception with Address Detect Enable:

1. Initialize the SPBRGH:SPBRG registers for the appropriate baud rate. Set or clear the BRGH and BRG16 bits, as required, to achieve the desired baud rate.
2. Enable the asynchronous serial port by clearing the SYNC bit and setting the SPEN bit.
3. If interrupts are required, set the RCEN bit and select the desired priority level with the RCIP bit.
4. Set the RX9 bit to enable 9-bit reception.
5. Set the ADDEN bit to enable address detect.
6. Enable reception by setting the CREN bit.
7. The RCIF bit will be set when reception is complete. The interrupt will be Acknowledged if the RCIE and GIE bits are set.
8. Read the RCSTA register to determine if any error occurred during reception, as well as read bit 9 of data (if applicable).
9. Read RCREG to determine if the device is being addressed.
10. If any error occurred, clear the CREN bit.
11. If the device has been addressed, clear the ADDEN bit to allow all received data into the receive buffer and interrupt the CPU.

FIGURE 15-6: EUSART RECEIVE BLOCK DIAGRAM

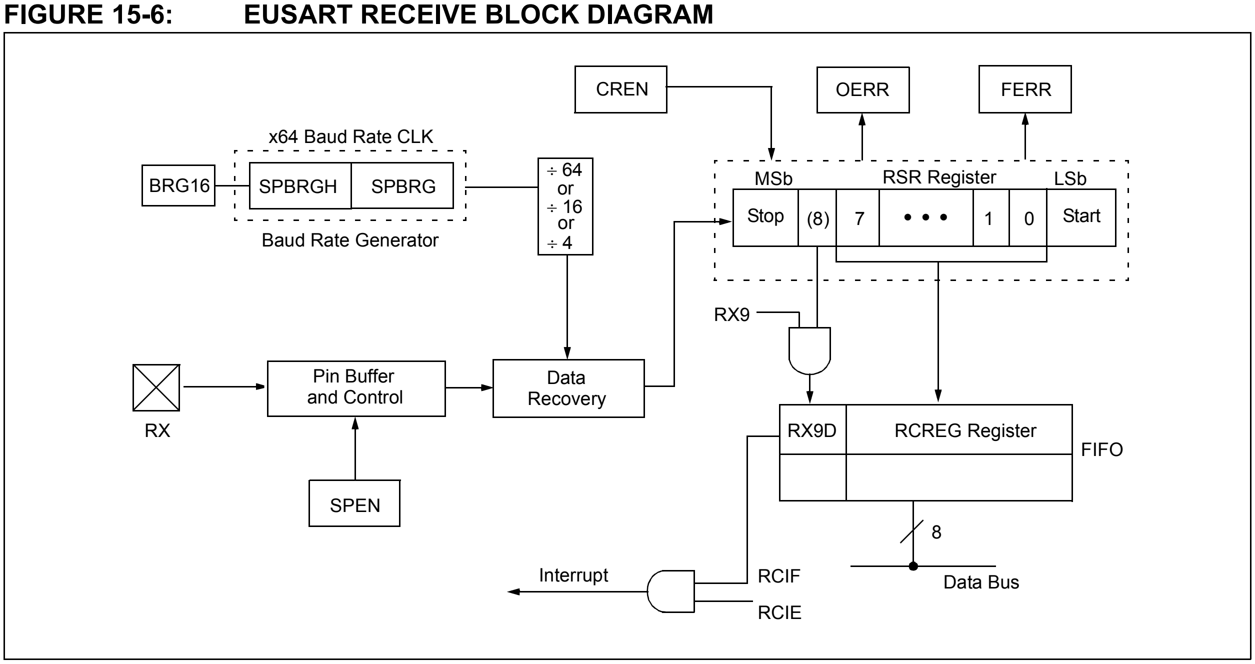
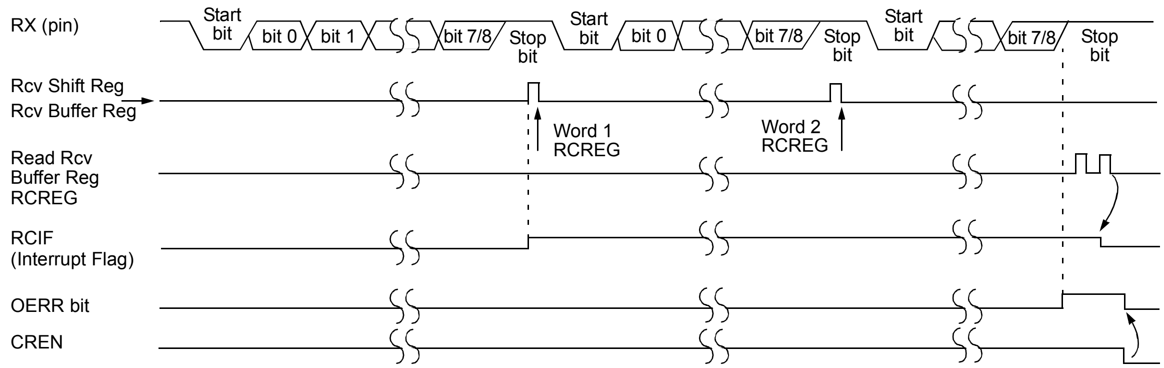


FIGURE 15-7: ASYNCHRONOUS RECEPTION



Note: This timing diagram shows three words appearing on the RX input. The RCREG (Receive Buffer) is read after the third word causing the OERR (Overrun Error) bit to be set.

TABLE 15-6: REGISTERS ASSOCIATED WITH ASYNCHRONOUS RECEPTION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	51
RCREG	EUSART Receive Register								50
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	51
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	51
SPBRGH	EUSART Baud Rate Generator Register High Byte								50
SPBRG	EUSART Baud Rate Generator Register Low Byte								50

Legend: — = unimplemented locations read as '0'. Shaded cells are not used for asynchronous reception.

15.2.4 AUTO-WAKE-UP ON SYNC BREAK CHARACTER

During Sleep mode, all clocks to the EUSART are suspended. Therefore, the Baud Rate Generator is inactive and proper byte reception cannot be performed. The auto-wake-up feature allows the controller to wake-up due to activity on the RX/DT line while the EUSART is operating in Asynchronous mode.

The auto-wake-up feature is enabled by setting the WUE bit (BAUDCON<1>). Once set, the typical receive sequence on RX/DT is disabled and the EUSART remains in an Idle state, monitoring for a wake-up event independent of the CPU mode. A wake-up event consists of a high-to-low transition on the RX/DT line. (This coincides with the start of a Sync Break or a Wake-up Signal character for the LIN protocol.)

Following a wake-up event, the module generates an RCIF interrupt. The interrupt is generated synchronously to the Q clocks in normal operating modes (Figure 15-8) and asynchronously if the device is in Sleep mode (Figure 15-9). The interrupt condition is cleared by reading the RCREG register.

The WUE bit is automatically cleared once a low-to-high transition is observed on the RX line following the wake-up event. At this point, the EUSART module is in Idle mode and returns to normal operation. This signals to the user that the Sync Break event is over.

15.2.4.1 Special Considerations Using Auto-Wake-up

Since auto-wake-up functions by sensing rising edge transitions on RX/DT, information with any state changes before the Stop bit may signal a false End-of-Character (EOC) and cause data or framing errors. To work properly, therefore, the initial character in the transmission must be all '0's. This can be 00h (8 bits) for standard RS-232 devices or 000h (12 bits) for LIN bus.

Oscillator start-up time must also be considered, especially in applications using oscillators with longer start-up intervals (i.e., XT or HS mode). The Sync Break (or Wake-up Signal) character must be of sufficient length and be followed by a sufficient interval to allow enough time for the selected oscillator to start and provide proper initialization of the EUSART.

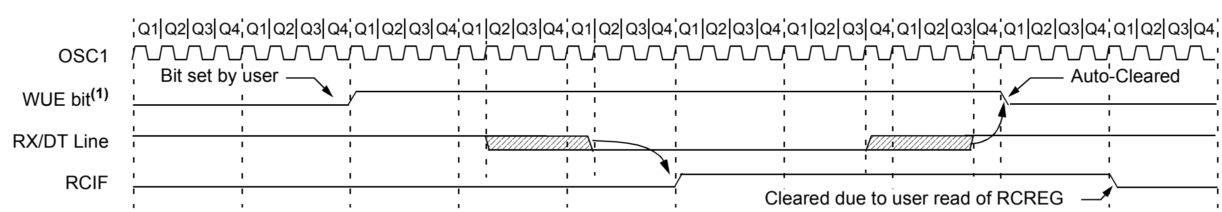
15.2.4.2 Special Considerations Using the WUE Bit

The timing of WUE and RCIF events may cause some confusion when it comes to determining the validity of received data. As noted, setting the WUE bit places the EUSART in an Idle mode. The wake-up event causes a receive interrupt by setting the RCIF bit. The WUE bit is cleared after this when a rising edge is seen on RX/DT. The interrupt condition is then cleared by reading the RCREG register. Ordinarily, the data in RCREG will be dummy data and should be discarded.

The fact that the WUE bit has been cleared (or is still set) and the RCIF flag is set should not be used as an indicator of the integrity of the data in RCREG. Users should consider implementing a parallel method in firmware to verify received data integrity.

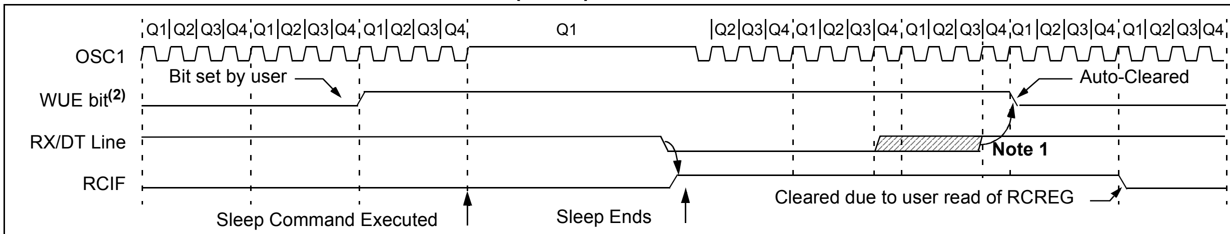
To assure that no actual data is lost, check the RCIDL bit to verify that a receive operation is not in process. If a receive operation is not occurring, the WUE bit may then be set just prior to entering the Sleep mode.

FIGURE 15-8: AUTO-WAKE-UP BIT (WUE) TIMINGS DURING NORMAL OPERATION



Note 1: The EUSART remains in Idle while the WUE bit is set.

FIGURE 15-9: AUTO-WAKE-UP BIT (WUE) TIMINGS DURING SLEEP



Note 1: If the wake-up event requires long oscillator warm-up time, the auto-clear of the WUE bit can occur while the *stposc* signal is still active. This sequence should not depend on the presence of Q clocks.

2: The EUSART remains in Idle while the WUE bit is set.

15.2.5 BREAK CHARACTER SEQUENCE

The EUSART module has the capability of sending the special Break character sequences that are required by the LIN bus standard. The Break character transmit consists of a Start bit, followed by twelve '0' bits and a Stop bit. The Frame Break character is sent whenever the SENDB and TXEN bits (TXSTA<3> and TXSTA<5>) are set while the Transmit Shift Register is loaded with data. Note that the value of data written to TXREG will be ignored and all '0's will be transmitted.

The SENDB bit is automatically reset by hardware after the corresponding Stop bit is sent. This allows the user to preload the transmit FIFO with the next transmit byte following the Break character (typically, the Sync character in the LIN specification).

Note that the data value written to the TXREG for the Break character is ignored. The write simply serves the purpose of initiating the proper sequence.

The TRMT bit indicates when the transmit operation is active or Idle, just as it does during normal transmission. See Figure 15-10 for the timing of the Break character sequence.

15.2.5.1 Break and Sync Transmit Sequence

The following sequence will send a message frame header made up of a Break, followed by an Auto-Baud Sync byte. This sequence is typical of a LIN bus master.

1. Configure the EUSART for the desired mode.
2. Set the TXEN and SENDB bits to set up the Break character.
3. Load the TXREG with a dummy character to initiate transmission (the value is ignored).
4. Write '55h' to TXREG to load the Sync character into the transmit FIFO buffer.
5. After the Break has been sent, the SENDB bit is reset by hardware. The Sync character now transmits in the preconfigured mode.

When the TXREG becomes empty, as indicated by the TXIF, the next data byte can be written to TXREG.

15.2.6 RECEIVING A BREAK CHARACTER

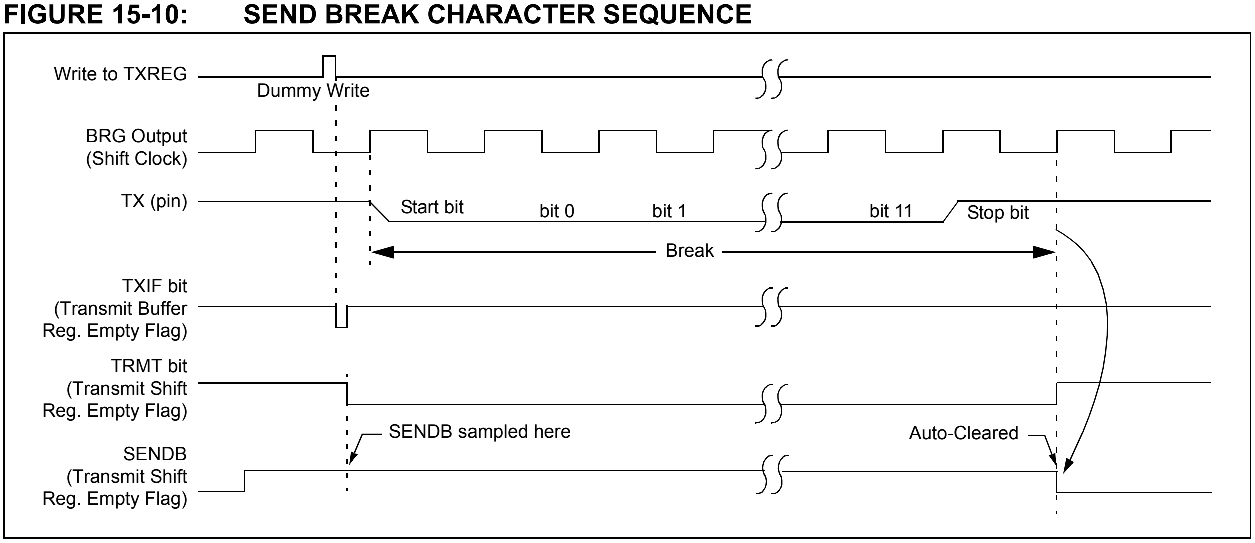
The Enhanced USART module can receive a Break character in two ways.

The first method forces configuration of the baud rate at a frequency of 9/13 the typical speed. This allows for the Stop bit transition to be at the correct sampling location (13 bits for Break versus Start bit and eight data bits for typical data).

The second method uses the auto-wake-up feature described in **Section 15.2.4 "Auto-Wake-up on Sync Break Character"**. By enabling this feature, the EUSART will sample the next two transitions on RX/DT, cause an RCIF interrupt and receive the next data byte followed by another interrupt.

Note that following a Break character, the user will typically want to enable the Auto-Baud Rate Detect feature. For both methods, the user can set the ABD bit once the TXIF interrupt is observed.

FIGURE 15-10: SEND BREAK CHARACTER SEQUENCE



15.3 EUSART Synchronous Master Mode

The Synchronous Master mode is entered by setting the CSRC bit (TXSTA<7>). In this mode, the data is transmitted in a half-duplex manner (i.e., transmission and reception do not occur at the same time). When transmitting data, the reception is inhibited and vice versa. Synchronous mode is entered by setting bit, SYNC (TXSTA<4>). In addition, enable bit, SPEN (RCSTA<7>), is set in order to configure the TX and RX pins to CK (clock) and DT (data) lines, respectively.

The Master mode indicates that the processor transmits the master clock on the CK line. Clock polarity is selected with the SCKP bit (BAUDCON<4>). Setting SCKP sets the Idle state on CK as high, while clearing the bit sets the Idle state as low. This option is provided to support Microwire devices with this module.

15.3.1 EUSART SYNCHRONOUS MASTER TRANSMISSION

The EUSART transmitter block diagram is shown in Figure 15-3. The heart of the transmitter is the Transmit (Serial) Shift Register (TSR). The Shift register obtains its data from the Read/Write Transmit Buffer register, TXREG. The TXREG register is loaded with data in software. The TSR register is not loaded until the last bit has been transmitted from the previous load. As soon as the last bit is transmitted, the TSR is loaded with new data from the TXREG (if available).

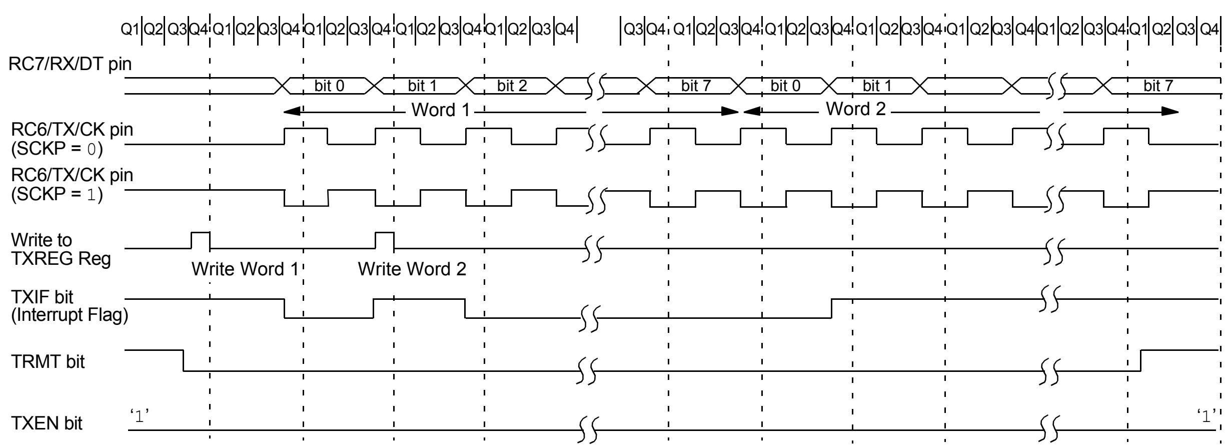
Once the TXREG register transfers the data to the TSR register (occurs in one TCYCLE), the TXREG register is empty and the TXIF flag bit (PIR1<4>) is set. The interrupt can be enabled or disabled by setting or clearing the interrupt enable bit, TXIE (PIE1<4>). TXIF is set regardless of the state of enable bit, TXIE; it cannot be cleared in software. It will reset only when new data is loaded into the TXREG register.

While flag bit, TXIF, indicates the status of the TXREG register, another bit, TRMT (TXSTA<1>), shows the status of the TSR register. TRMT is a read-only bit which is set when the TSR is empty. No interrupt logic is tied to this bit so the user must poll this bit in order to determine if the TSR register is empty. The TSR is not mapped in data memory so it is not available to the user.

To set up a Synchronous Master Transmission:

1. Initialize the SPBRGH:SPBRG registers for the appropriate baud rate. Set or clear the BRG16 bit, as required, to achieve the desired baud rate.
2. Enable the synchronous master serial port by setting bits, SYNC, SPEN and CSRC.
3. If interrupts are desired, set enable bit, TXIE.
4. If 9-bit transmission is desired, set bit, TX9.
5. Enable the transmission by setting bit, TXEN.
6. If 9-bit transmission is selected, the ninth bit should be loaded in bit, TX9D.
7. Start transmission by loading data to the TXREG register.
8. If using interrupts, ensure that the GIE and PEIE bits in the INTCON register (INTCON<7:6>) are set.

FIGURE 15-11: SYNCHRONOUS TRANSMISSION



Note: Sync Master mode (SPBRG = 0), continuous transmission of two 8-bit words.

FIGURE 15-12: SYNCHRONOUS TRANSMISSION (THROUGH TXEN)

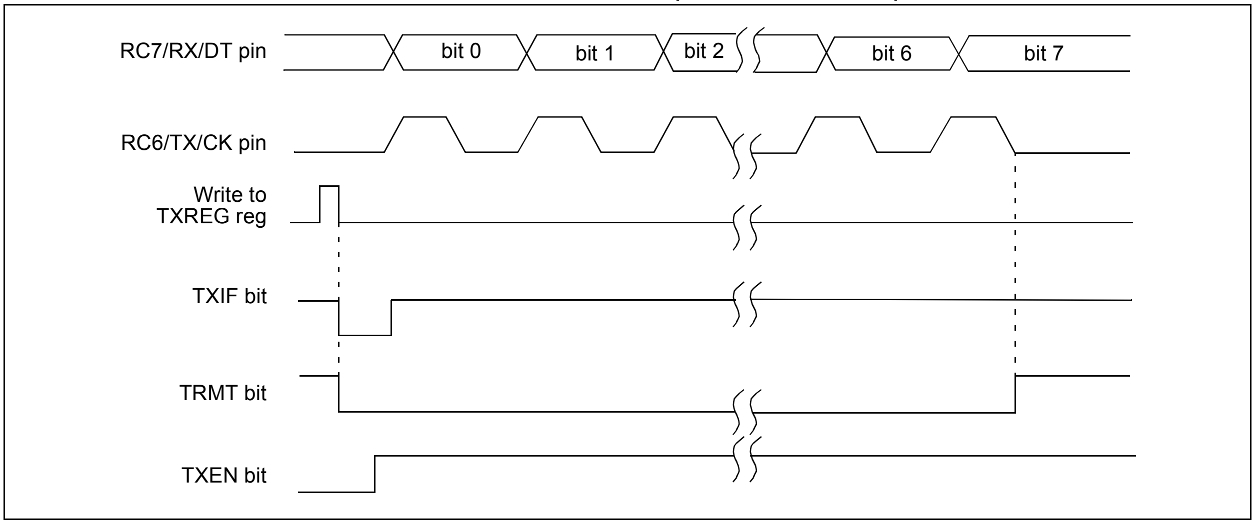


TABLE 15-7: REGISTERS ASSOCIATED WITH SYNCHRONOUS MASTER TRANSMISSION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	51
TXREG	EUSART Transmit Register								51
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	51
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	51
SPBRGH	EUSART Baud Rate Generator Register High Byte								50
SPBRG	EUSART Baud Rate Generator Register Low Byte								50

Legend: — = unimplemented, read as '0'. Shaded cells are not used for synchronous master transmission.

15.3.2 EUSART SYNCHRONOUS MASTER RECEPTION

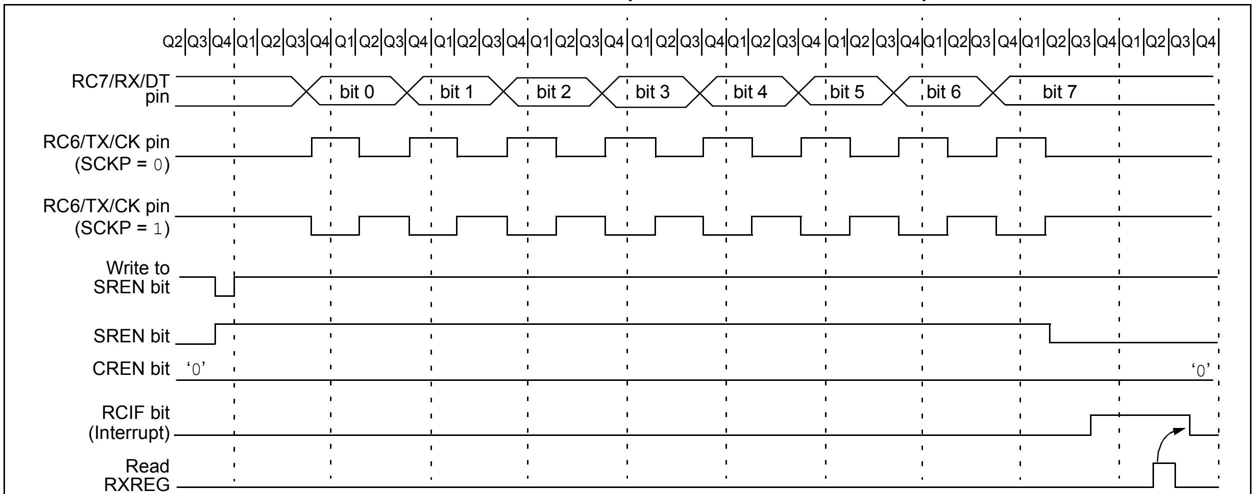
Once Synchronous mode is selected, reception is enabled by setting either the Single Receive Enable bit, SREN (RCSTA<5>), or the Continuous Receive Enable bit, CREN (RCSTA<4>). Data is sampled on the RX pin on the falling edge of the clock.

If enable bit, SREN, is set, only a single word is received. If enable bit, CREN, is set, the reception is continuous until CREN is cleared. If both bits are set, then CREN takes precedence.

To set up a Synchronous Master Reception:

1. Initialize the SPBRGH:SPBRG registers for the appropriate baud rate. Set or clear the BRG16 bit, as required, to achieve the desired baud rate.
2. Enable the synchronous master serial port by setting bits, SYNC, SPEN and CSRC.
3. Ensure bits, CREN and SREN, are clear.
4. If interrupts are desired, set enable bit, RCIE.
5. If 9-bit reception is desired, set bit, RX9.
6. If a single reception is required, set bit, SREN. For continuous reception, set bit, CREN.
7. Interrupt flag bit, RCIF, will be set when reception is complete and an interrupt will be generated if the enable bit, RCIE, was set.
8. Read the RCSTA register to get the ninth bit (if enabled) and determine if any error occurred during reception.
9. Read the 8-bit received data by reading the RCREG register.
10. If any error occurred, clear the error by clearing bit, CREN.
11. If using interrupts, ensure that the GIE and PEIE bits in the INTCON register (INTCON<7:6>) are set.

FIGURE 15-13: SYNCHRONOUS RECEPTION (MASTER MODE, SREN)



Note: Timing diagram demonstrates Sync Master mode with SREN bit = 1 and BRGH bit = 0.

TABLE 15-8: REGISTERS ASSOCIATED WITH SYNCHRONOUS MASTER RECEPTION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	51
RCREG	EUSART Receive Register								50
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	51
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	51
SPBRGH	EUSART Baud Rate Generator Register High Byte								51
SPBRG	EUSART Baud Rate Generator Register Low Byte								50

Legend: — = unimplemented, read as '0'. Shaded cells are not used for synchronous master reception.

15.4 EUSART Synchronous Slave Mode

Synchronous Slave mode is entered by clearing bit, CSRC (TXSTA<7>). This mode differs from the Synchronous Master mode in that the shift clock is supplied externally at the CK pin (instead of being supplied internally in Master mode). This allows the device to transfer or receive data while in any low-power mode.

15.4.1 EUSART SYNCHRONOUS SLAVE TRANSMIT

The operation of the Synchronous Master and Slave modes is identical, except in the case of Sleep mode.

If two words are written to the TXREG register and then the `SLEEP` instruction is executed, the following will occur:

a) The first word will immediately transfer to the TSR register and transmit.
b) The second word will remain in the TXREG register.
c) Flag bit, TXIF, will not be set.
d) When the first word has been shifted out of TSR, the TXREG register will transfer the second word to the TSR and flag bit, TXIF, will now be set.
e) If enable bit, TXIE, is set, the interrupt will wake the chip from Sleep. If the global interrupt is enabled, the program will branch to the interrupt vector.

To set up a Synchronous Slave Transmission:

1. Enable the synchronous slave serial port by setting bits, SYNC and SPEN, and clearing bit, CSRC.
2. Clear bits, CREN and SREN.
3. If interrupts are desired, set enable bit, TXIE.
4. If 9-bit transmission is desired, set bit, TX9.
5. Enable the transmission by setting enable bit, TXEN.
6. If 9-bit transmission is selected, the ninth bit should be loaded in bit, TX9D.
7. Start transmission by loading data to the TXREG register.
8. If using interrupts, ensure that the GIE and PEIE bits in the INTCON register (INTCON<7:6>) are set.

TABLE 15-9: REGISTERS ASSOCIATED WITH SYNCHRONOUS SLAVE TRANSMISSION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	51
TXREG	EUSART Transmit Register								51
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	51
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	51
SPBRGH	EUSART Baud Rate Generator Register High Byte								50
SPBRG	EUSART Baud Rate Generator Register Low Byte								50

Legend: — = unimplemented, read as '0'. Shaded cells are not used for synchronous slave transmission.

15.4.2 EUSART SYNCHRONOUS SLAVE RECEPTION

The operation of the Synchronous Master and Slave modes is identical, except in the case of Sleep or any Idle mode and bit, SREN, which is a “don’t care” in Slave mode.

If receive is enabled by setting the CREN bit prior to entering Sleep or any Idle mode, then a word may be received while in this low-power mode. Once the word is received, the RSR register will transfer the data to the RCREG register. If the RCIE enable bit is set, the interrupt generated will wake the chip from the low-power mode. If the global interrupt is enabled, the program will branch to the interrupt vector.

To set up a Synchronous Slave Reception:

1. Enable the synchronous master serial port by setting bits, SYNC and SPEN, and clearing bit, CSRC.
2. If interrupts are desired, set enable bit, RCIE.
3. If 9-bit reception is desired, set bit, RX9.
4. To enable reception, set enable bit, CREN.
5. Flag bit RCIF will be set when reception is complete. An interrupt will be generated if enable bit, RCIE, was set.
6. Read the RCSTA register to get the ninth bit (if enabled) and determine if any error occurred during reception.
7. Read the 8-bit received data by reading the RCREG register.
8. If any error occurred, clear the error by clearing bit, CREN.
9. If using interrupts, ensure that the GIE and PEIE bits in the INTCON register (INTCON<7:6>) are set.

TABLE 15-10: REGISTERS ASSOCIATED WITH SYNCHRONOUS SLAVE RECEPTION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	51
RCREG	EUSART Receive Register								50
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	51
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	51
SPBRGH	EUSART Baud Rate Generator Register High Byte								50
SPBRG	EUSART Baud Rate Generator Register Low Byte								50

Legend: — = unimplemented, read as ‘0’. Shaded cells are not used for synchronous slave reception.

NOTES:

16.0 10-BIT ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE

The Analog-to-Digital (A/D) Converter module has 10 inputs for the 28-pin devices and 13 for the 40/44-pin devices. This module allows conversion of an analog input signal to a corresponding 10-bit digital number.

The module has five registers:

- A/D Result High Register (ADRESH)
- A/D Result Low Register (ADRESL)
- A/D Control Register 0 (ADCON0)
- A/D Control Register 1 (ADCON1)
- A/D Control Register 2 (ADCON2)

The ADCON0 register, shown in Register 16-1, controls the operation of the A/D module. The ADCON1 register, shown in Register 16-2, configures the functions of the port pins. The ADCON2 register, shown in Register 16-3, configures the A/D clock source, programmed acquisition time and justification.

REGISTER 16-1: ADCON0: A/D CONTROL REGISTER 0

U0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
—	—	CHS3	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	ADON
bit 7							bit 0

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

bit 7-6 **Unimplemented:** Read as ‘0’

bit 5-2 **CHS3:CHS0:** Analog Channel Select bits
0000 = Channel 0 (AN0)
0001 = Channel 1 (AN1)
0010 = Channel 2 (AN2)
0011 = Channel 3 (AN3)
0100 = Channel 4 (AN4)
0101 = Channel 5 (AN5)(1,2)
0110 = Channel 6 (AN6)(1,2)
0111 = Channel 7 (AN7)(1,2)
1000 = Channel 8 (AN8)
1001 = Channel 9 (AN9)
1010 = Channel 10 (AN10)
1011 = Channel 11 (AN11)
1100 = Channel 12 (AN12
1101 = Unimplemented(2)
1110 = Unimplemented(2)
1111 = Unimplemented(2)

bit 1 **GO/$\overline{\text{DONE}}$:** A/D Conversion Status bit
<u>When ADON = 1:</u>
1 = A/D conversion in progress
0 = A/D Idle

bit 0 **ADON:** A/D On bit
1 = A/D Converter module is enabled
0 = A/D Converter module is disabled

Note 1: These channels are not implemented on 28-pin devices.
2: Performing a conversion on unimplemented channels will return a floating input measurement.

REGISTER 16-2: ADCON1: A/D CONTROL REGISTER 1

U-0	U-0	R/W-0	R/W-0	R/W-0(1)	R/W(1)	R/W(1)	R/W(1)
—	—	VCFG1	VCFG0	PCFG3	PCFG2	PCFG1	PCFG0
bit 7							bit 0

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

bit 7-6 **Unimplemented:** Read as ‘0’

bit 5 **VCFG1:** Voltage Reference Configuration bit (VREF- source)
1 = VREF- (AN2)
0 = VSS

bit 4 **VCFG0:** Voltage Reference Configuration bit (VREF+ source)
1 = VREF+ (AN3)
0 = VDD

bit 3-0 **PCFG3:PCFG0:** A/D Port Configuration Control bits:

PCFG3: PCFG0	AN12	AN11	AN10	AN9	AN8	AN7(2)	AN6(2)	AN5(2)	AN4	AN3	AN2	AN1	AN0
0000(1)	A	A	A	A	A	A	A	A	A	A	A	A	A
0001	A	A	A	A	A	A	A	A	A	A	A	A	A
0010	A	A	A	A	A	A	A	A	A	A	A	A	A
0011	D	A	A	A	A	A	A	A	A	A	A	A	A
0100	D	D	A	A	A	A	A	A	A	A	A	A	A
0101	D	D	D	A	A	A	A	A	A	A	A	A	A
0110	D	D	D	D	A	A	A	A	A	A	A	A	A
0111(1)	D	D	D	D	D	A	A	A	A	A	A	A	A
1000	D	D	D	D	D	D	A	A	A	A	A	A	A
1001	D	D	D	D	D	D	D	A	A	A	A	A	A
1010	D	D	D	D	D	D	D	D	A	A	A	A	A
1011	D	D	D	D	D	D	D	D	D	A	A	A	A
1100	D	D	D	D	D	D	D	D	D	D	A	A	A
1101	D	D	D	D	D	D	D	D	D	D	D	A	A
1110	D	D	D	D	D	D	D	D	D	D	D	D	A
1111	D	D	D	D	D	D	D	D	D	D	D	D	D

A = Analog input D = Digital I/O

Note 1: The POR value of the PCFG bits depends on the value of the PBADEN Configuration bit. When PBADEN = 1, PCFG<3:0> = 0000; when PBADEN = 0, PCFG<3:0> = 0111.

2: AN5 through AN7 are available only on 40/44-pin devices.

REGISTER 16-3: ADCON2: A/D CONTROL REGISTER 2

R/W-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	—	ACQT2	ACQT1	ACQT0	ADCS2	ADCS1	ADCS0
bit 7							bit 0

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

bit 7 **ADFM:** A/D Result Format Select bit
1 = Right justified
0 = Left justified

bit 6 **Unimplemented:** Read as ‘0’

bit 5-3 **ACQT2:ACQT0:** A/D Acquisition Time Select bits
111 = 20 TAD
110 = 16 TAD
101 = 12 TAD
100 = 8 TAD
011 = 6 TAD
010 = 4 TAD
001 = 2 TAD
000 = 0 TAD(1)

bit 2-0 **ADCS2:ADCS0:** A/D Conversion Clock Select bits
111 = FRC (clock derived from A/D RC oscillator)(1)
110 = FOSC/64
101 = FOSC/16
100 = FOSC/4
011 = FRC (clock derived from A/D RC oscillator)(1)
010 = FOSC/32
001 = FOSC/8
000 = FOSC/2

Note 1: If the A/D FRC clock source is selected, a delay of one TCY (instruction cycle) is added before the A/D clock starts. This allows the SLEEP instruction to be executed before starting a conversion.

The analog reference voltage is software selectable to either the device's positive and negative supply voltage (V_{DD} and V_{SS}) or the voltage level on the RA3/AN3/V_{REF}+ and RA2/AN2/V_{REF}- pins.

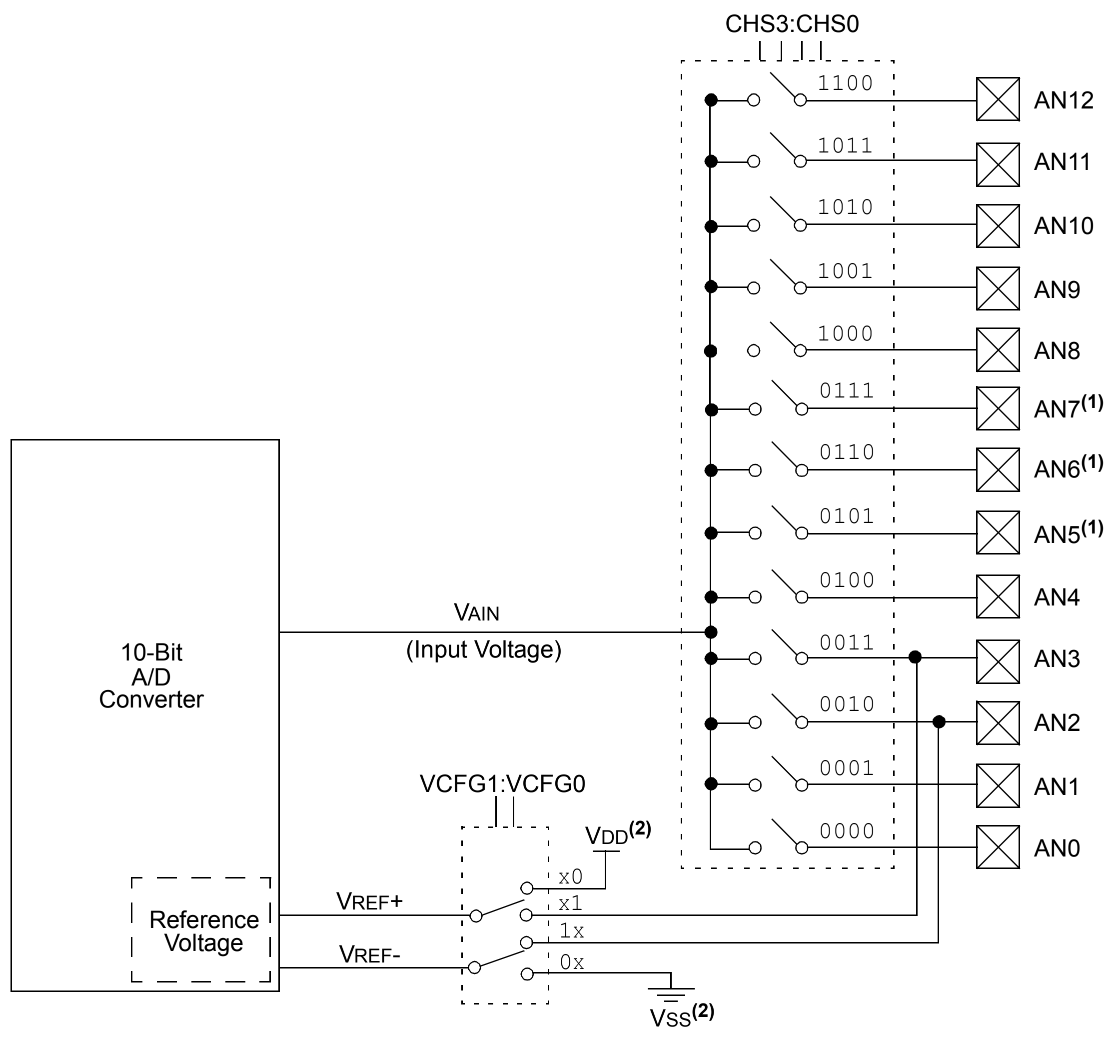
The A/D Converter has a unique feature of being able to operate while the device is in Sleep mode. To operate in Sleep, the A/D conversion clock must be derived from the A/D's internal RC oscillator.

The output of the sample and hold is the input into the converter, which generates the result via successive approximation.

A device Reset forces all registers to their Reset state. This forces the A/D module to be turned off and any conversion in progress is aborted.

Each port pin associated with the A/D Converter can be configured as an analog input or as a digital I/O. The ADRESH and ADRESL registers contain the result of the A/D conversion. When the A/D conversion is complete, the result is loaded into the ADRESH:ADRESL register pair, the GO/$\overline{DONE}$ bit (ADCON0 register) is cleared and A/D Interrupt Flag bit, ADIF, is set. The block diagram of the A/D module is shown in Figure 16-1.

FIGURE 16-1: A/D BLOCK DIAGRAM



Note 1: Channels AN5 through AN7 are not available on 28-pin devices.
2: I/O pins have diode protection to V_{DD} and V_{SS}.

The value in the ADRESH:ADRESL registers is not modified for a Power-on Reset. The ADRESH:ADRESL registers will contain unknown data after a Power-on Reset.

After the A/D module has been configured as desired, the selected channel must be acquired before the conversion is started. The analog input channels must have their corresponding TRIS bits selected as an input. To determine acquisition time, see **Section 16.1 "A/D Acquisition Requirements"**. After this acquisition time has elapsed, the A/D conversion can be started. An acquisition time can be programmed to occur between setting the GO/$\overline{\text{DONE}}$ bit and the actual start of the conversion.

The following steps should be followed to perform an A/D conversion:

1. Configure the A/D module:
   - Configure analog pins, voltage reference and digital I/O (ADCON1)
   - Select A/D input channel (ADCON0)
   - Select A/D acquisition time (ADCON2)
   - Select A/D conversion clock (ADCON2)
   - Turn on A/D module (ADCON0)
2. Configure A/D interrupt (if desired):
   - Clear ADIF bit
   - Set ADIE bit
   - Set GIE bit
3. Wait the required acquisition time (if required).
4. Start conversion:
   - Set GO/$\overline{\text{DONE}}$ bit (ADCON0 register)
5. Wait for A/D conversion to complete, by either:
   - Polling for the GO/$\overline{\text{DONE}}$ bit to be cleared

   OR
   - Waiting for the A/D interrupt
6. Read A/D Result registers (ADRESH:ADRESL); clear bit, ADIF, if required.
7. For next conversion, go to step 1 or step 2, as required. The A/D conversion time per bit is defined as T_{AD}. A minimum wait of 3 T_{AD} is required before the next acquisition starts.

FIGURE 16-2: A/D TRANSFER FUNCTION

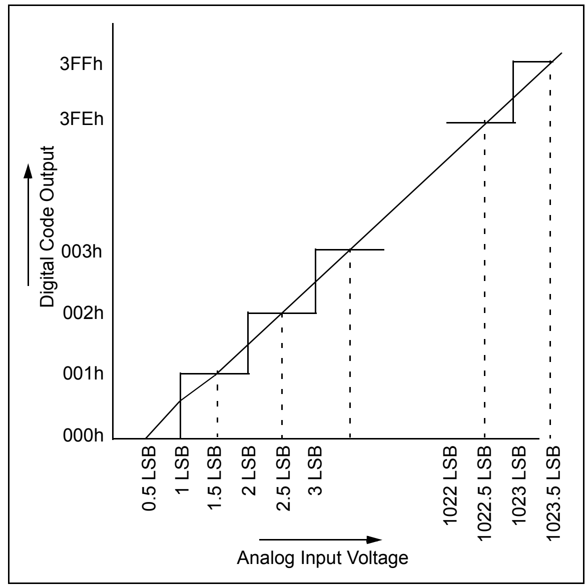
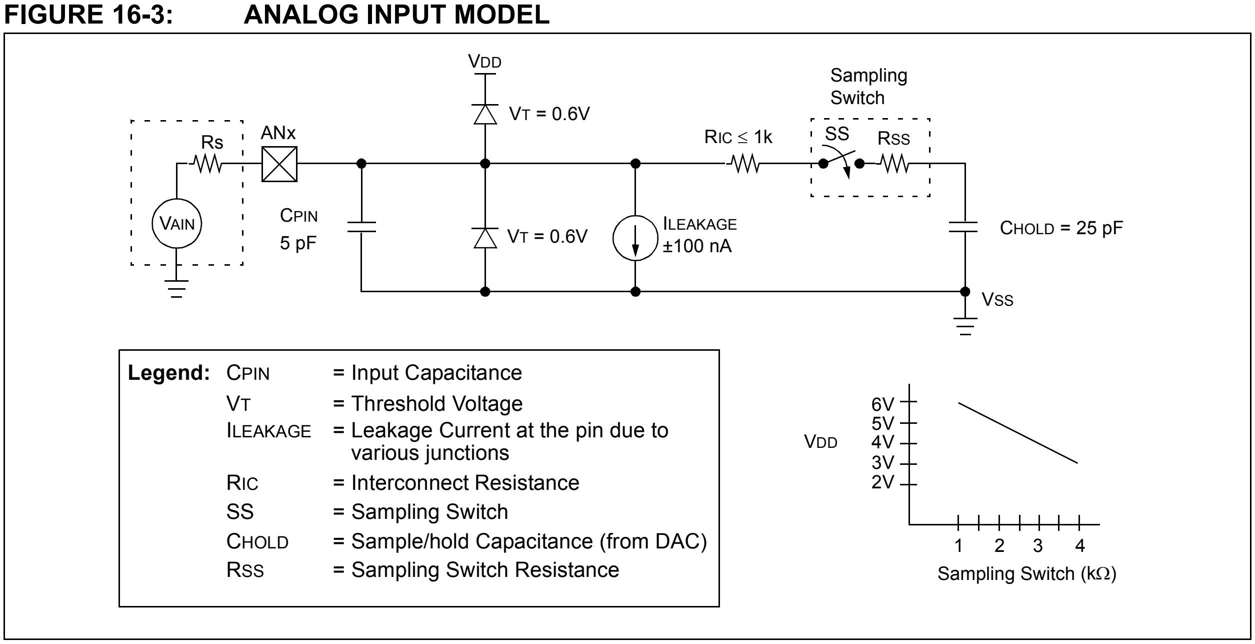


FIGURE 16-3: ANALOG INPUT MODEL



16.1 A/D Acquisition Requirements

For the A/D Converter to meet its specified accuracy, the charge holding capacitor (C_{HOLD}) must be allowed to fully charge to the input channel voltage level. The analog input model is shown in Figure 16-3. The source impedance (R_S) and the internal sampling switch (R_{SS}) impedance directly affect the time required to charge the capacitor C_{HOLD}. The sampling switch (R_{SS}) impedance varies over the device voltage (V_{DD}). The source impedance affects the offset voltage at the analog input (due to pin leakage current). **The maximum recommended impedance for analog sources is 2.5 kΩ**. After the analog input channel is selected (changed), the channel must be sampled for at least the minimum acquisition time before starting a conversion.

Note:	When the conversion is started, the holding capacitor is disconnected from the input pin.

To calculate the minimum acquisition time, Equation 16-1 may be used. This equation assumes that 1/2 LSb error is used (1024 steps for the A/D). The 1/2 LSb error is the maximum error allowed for the A/D to meet its specified resolution.

Example 16-3 shows the calculation of the minimum required acquisition time T_{ACQ}. This calculation is based on the following application system assumptions:

C_{HOLD}	=	25 pF
Rs	=	2.5 kΩ
Conversion Error	≤	1/2 LSb
V_{DD}	=	5V → R_{SS} = 2 kΩ
Temperature	=	85°C (system max.)

EQUATION 16-1: ACQUISITION TIME

$$T_{ACQ} = \text{Amplifier Settling Time} + \text{Holding Capacitor Charging Time} + \text{Temperature Coefficient}$$
$$= T_{AMP} + T_C + T_{COFF}$$

EQUATION 16-2: A/D MINIMUM CHARGING TIME

$$V_{HOLD} = (V_{REF} - (V_{REF}/2048)) \cdot (1 - e^{(-T_C/C_{HOLD}(R_{IC} + R_{SS} + R_S))})$$

or

$$T_C = -(C_{HOLD})(R_{IC} + R_{SS} + R_S) \ln(1/2048)$$

EQUATION 16-3: CALCULATING THE MINIMUM REQUIRED ACQUISITION TIME

$$T_{ACQ} = T_{AMP} + T_C + T_{COFF}$$

$$T_{AMP} = 0.2\ \mu s$$

$$T_{COFF} = (\text{Temp} - 25°C)(0.02\ \mu s/°C)$$
$$(85°C - 25°C)(0.02\ \mu s/°C)$$
$$1.2\ \mu s$$

Temperature coefficient is only required for temperatures > 25°C. Below 25°C, T_{COFF} = 0 ms.

$$T_C = -(C_{HOLD})(R_{IC} + R_{SS} + R_S) \ln(1/2047)\ \mu s$$
$$-(25\ pF)(1\ k\Omega + 2\ k\Omega + 2.5\ k\Omega) \ln(0.0004883)\ \mu s$$
$$1.05\ \mu s$$

$$T_{ACQ} = 0.2\ \mu s + 1\ \mu s + 1.2\ \mu s$$
$$2.4\ \mu s$$

16.2 Selecting and Configuring Acquisition Time

The ADCON2 register allows the user to select an acquisition time that occurs each time the GO/$\overline{DONE}$ bit is set. It also gives users the option to use an automatically determined acquisition time.

Acquisition time may be set with the ACQT2:ACQT0 bits (ADCON2<5:3>) which provide a range of 2 to 20 TAD. When the GO/$\overline{DONE}$ bit is set, the A/D module continues to sample the input for the selected acquisition time, then automatically begins a conversion. Since the acquisition time is programmed, there may be no need to wait for an acquisition time between selecting a channel and setting the GO/$\overline{DONE}$ bit.

Manual acquisition is selected when ACQT2:ACQT0 = `000`. When the GO/$\overline{DONE}$ bit is set, sampling is stopped and a conversion begins. The user is responsible for ensuring the required acquisition time has passed between selecting the desired input channel and setting the GO/$\overline{DONE}$ bit. This option is also the default Reset state of the ACQT2:ACQT0 bits and is compatible with devices that do not offer programmable acquisition times.

In either case, when the conversion is completed, the GO/$\overline{DONE}$ bit is cleared, the ADIF flag is set and the A/D begins sampling the currently selected channel again. If an acquisition time is programmed, there is nothing to indicate if the acquisition time has ended or if the conversion has begun.

16.3 Selecting the A/D Conversion Clock

The A/D conversion time per bit is defined as TAD. The A/D conversion requires 11 TAD per 10-bit conversion. The source of the A/D conversion clock is software selectable. There are seven possible options for TAD:

- 2 TOSC
- 4 TOSC
- 8 TOSC
- 16 TOSC
- 32 TOSC
- 64 TOSC
- Internal RC Oscillator

For correct A/D conversions, the A/D conversion clock (TAD) must be as short as possible but greater than the minimum TAD (see parameter 130 in Table 21-18 for more information).

Table 16-1 shows the resultant TAD times derived from the device operating frequencies and the A/D clock source selected.

TABLE 16-1: TAD vs. DEVICE OPERATING FREQUENCIES

AD Clock Source (TAD)		Maximum Device Frequency	
Operation	**ADCS2:ADCS0**	**PIC18FX450**	**PIC18LFX450(4)**
2 TOSC	`000`	2.86 MHz	1.43 MHz
4 TOSC	`100`	5.71 MHz	2.86 MHz
8 TOSC	`001`	11.43 MHz	5.72 MHz
16 TOSC	`101`	22.86 MHz	11.43 MHz
32 TOSC	`010`	45.71 MHz	22.86 MHz
64 TOSC	`110`	48.0 MHz	45.71 MHz
RC(3)	`x11`	1.00 MHz(1)	1.00 MHz(2)

Note 1: The RC source has a typical TAD time of 1.2 μs.

2: The RC source has a typical TAD time of 2.5 μs.

3: For device frequencies above 1 MHz, the device must be in Sleep for the entire conversion or the A/D accuracy may be out of specification.

4: Low-power devices only.

16.4 Operation in Power-Managed Modes

The selection of the automatic acquisition time and A/D conversion clock is determined in part by the clock source and frequency while in a power-managed mode.

If the A/D is expected to operate while the device is in a power-managed mode, the ACQT2:ACQT0 and ADCS2:ADCS0 bits in ADCON2 should be updated in accordance with the clock source to be used in that mode. After entering the mode, an A/D acquisition or conversion may be started. Once started, the device should continue to be clocked by the same clock source until the conversion has been completed.

If desired, the device may be placed into the corresponding Idle mode during the conversion. If the device clock frequency is less than 1 MHz, the A/D RC clock source should be selected.

Operation in the Sleep mode requires the A/D FRC clock to be selected. If bits ACQT2:ACQT0 are set to '000' and a conversion is started, the conversion will be delayed one instruction cycle to allow execution of the SLEEP instruction and entry to Sleep mode. The IDLEN bit (OSCCON<7>) must have already been cleared prior to starting the conversion.

16.5 Configuring Analog Port Pins

The ADCON1, TRISA, TRISB and TRISE registers all configure the A/D port pins. The port pins needed as analog inputs must have their corresponding TRIS bits set (input). If the TRIS bit is cleared (output), the digital output level (V_{OH} or V_{OL}) will be converted.

The A/D operation is independent of the state of the CHS3:CHS0 bits and the TRIS bits.

Note 1: When reading the PORT register, all pins configured as analog input channels will read as cleared (a low level). Pins configured as digital inputs will convert as analog inputs. Analog levels on a digitally configured input will be accurately converted.

2: Analog levels on any pin defined as a digital input may cause the digital input buffer to consume current out of the device's specification limits.

3: The PBADEN bit in Configuration Register 3H configures PORTB pins to reset as analog or digital pins by controlling how the PCFG0 bits in ADCON1 are reset.

16.6 A/D Conversions

Figure 16-4 shows the operation of the A/D Converter after the GO/DONE bit has been set and the ACQT2:ACQT0 bits are cleared. A conversion is started after the following instruction to allow entry into Sleep mode before the conversion begins.

Figure 16-5 shows the operation of the A/D Converter after the GO/DONE bit has been set, the ACQT2:ACQT0 bits are set to '010' and selecting a 4 TAD acquisition time before the conversion starts.

Clearing the GO/DONE bit during a conversion will abort the current conversion. The A/D Result register pair will NOT be updated with the partially completed A/D conversion sample. This means the ADRESH:ADRESL registers will continue to contain the value of the last completed conversion (or the last value written to the ADRESH:ADRESL registers).

After the A/D conversion is completed or aborted, a 2 TAD wait is required before the next acquisition can be started. After this wait, acquisition on the selected channel is automatically started.

Note:	The GO/DONE bit should **NOT** be set in the same instruction that turns on the A/D.

16.7 Discharge

The discharge phase is used to initialize the value of the capacitor array. The array is discharged before every sample. This feature helps to optimize the unity-gain amplifier as the circuit always needs to charge the capacitor array, rather than charge/discharge based on previous measurement values.

FIGURE 16-4: A/D CONVERSION TAD CYCLES (ACQT<2:0> = 000, TACQ = 0)

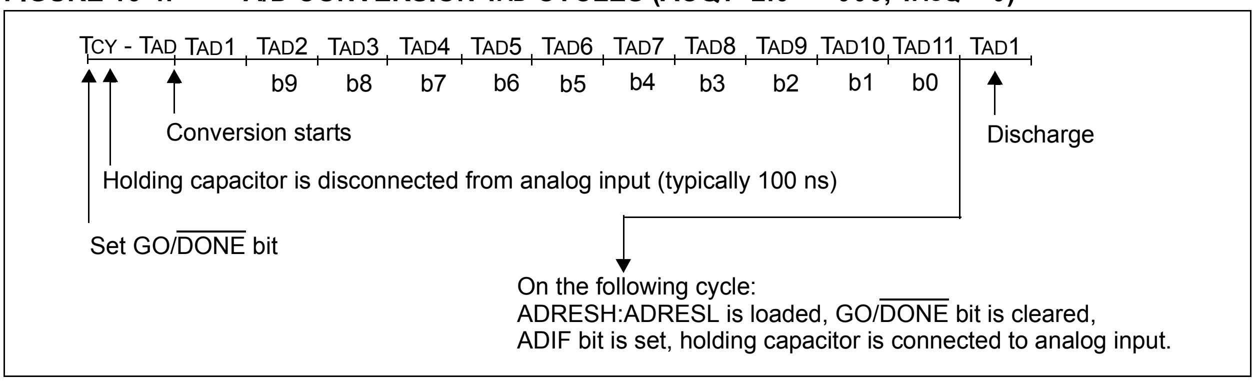
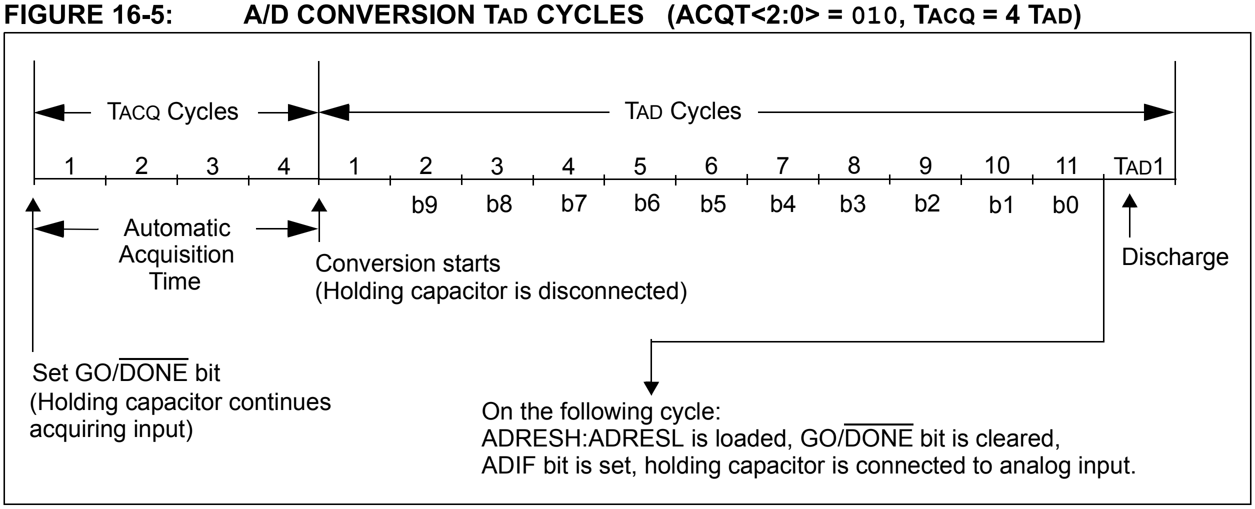


FIGURE 16-5: A/D CONVERSION TAD CYCLES (ACQT<2:0> = 010, TACQ = 4 TAD)



16.8 Use of the CCP1 Trigger

An A/D conversion can be started by the Special Event Trigger of the CCP1 module. This requires that the CCP1M3:CCP1M0 bits (CCP1CON<3:0>) be programmed as '1011' and that the A/D module is enabled (ADON bit is set). When the trigger occurs, the GO/$\overline{\text{DONE}}$ bit will be set, starting the A/D acquisition and conversion, and the Timer1 counter will be reset to zero. Timer1 is reset to automatically repeat the A/D acquisition period with minimal software overhead (moving ADRESH:ADRESL to the desired location). The appropriate analog input channel must be selected and the minimum acquisition period is either timed by the user, or an appropriate T_{ACQ} time selected before the Special Event Trigger sets the GO/$\overline{\text{DONE}}$ bit (starts a conversion).

If the A/D module is not enabled (ADON is cleared), the Special Event Trigger will be ignored by the A/D module but will still reset the Timer1 counter.

TABLE 16-2: REGISTERS ASSOCIATED WITH A/D OPERATION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR1	—	ADIF	RCIF	TXIF	—	CCP1IF	TMR2IF	TMR1IF	51
PIE1	—	ADIE	RCIE	TXIE	—	CCP1IE	TMR2IE	TMR1IE	51
IPR1	—	ADIP	RCIP	TXIP	—	CCP1IP	TMR2IP	TMR1IP	51
PIR2	OSCFIF	—	USBIF	—	—	HLVDIF	—	—	51
PIE2	OSCFIE	—	USBIE	—	—	HLVDIE	—	—	51
IPR2	OSCFIP	—	USBIP	—	—	HLVDIP	—	—	51
ADRESH	A/D Result Register High Byte								50
ADRESL	A/D Result Register Low Byte								50
ADCON0	—	—	CHS3	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	ADON	50
ADCON1	—	—	VCFG1	VCFG0	PCFG3	PCFG2	PCFG1	PCFG0	50
ADCON2	ADFM	—	ACQT2	ACQT1	ACQT0	ADCS2	ADCS1	ADCS0	50
PORTA	—	RA6(2)	RA5	RA4	RA3	RA2	RA1	RA0	51
TRISA	—	TRISA6(2)	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	51
PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0	51
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	51
LATB	LATB7	LATB6	LATB5	LATB4	LATB3	LATB2	LATB1	LATB0	51
PORTE	—	—	—	—	RE3(1,3)	RE2(4)	RE1(4)	RE0(4)	51
TRISE(4)	—	—	—	—	—	TRISE2(4)	TRISE1(4)	TRISE0(4)	51
LATE(4)	—	—	—	—	—	LATE2(4)	LATE1(4)	LATE0(4)	51

Legend: — = unimplemented, read as '0'. Shaded cells are not used for A/D conversion.

Note 1: Implemented only when Master Clear functionality is disabled (MCLRE Configuration bit = 0).

2: RA6 and its associated latch and data direction bits are enabled as I/O pins based on oscillator configuration; otherwise, they are read as '0'.

3: RE3 port bit is available only as an input pin when the MCLRE Configuration bit is '0'.

4: These registers and/or bits are not implemented on 28-pin devices.

17.0 HIGH/LOW-VOLTAGE DETECT (HLVD)

PIC18F2450/4450 devices have a High/Low-Voltage Detect module (HLVD). This is a programmable circuit that allows the user to specify both a device voltage trip point and the direction of change from that point. If the device experiences an excursion past the trip point in that direction, an interrupt flag is set. If the interrupt is enabled, the program execution will branch to the interrupt vector address and the software can then respond to the interrupt.

The High/Low-Voltage Detect Control register (Register 17-1) completely controls the operation of the HLVD module. This allows the circuitry to be "turned off" by the user under software control which minimizes the current consumption for the device.

The block diagram for the HLVD module is shown in Figure 17-1.

REGISTER 17-1: HLVDCON: HIGH/LOW-VOLTAGE DETECT CONTROL REGISTER

R/W-0	U-0	R-0	R/W-0	R/W-0	R/W-1	R/W-0	R/W-1
VDIRMAG	—	IRVST	HLVDEN	HLVDL3[(1)]	HLVDL2[(1)]	HLVDL1[(1)]	HLVDL0[(1)]
bit 7							bit 0

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

bit 7 **VDIRMAG:** Voltage Direction Magnitude Select bit
1 = Event occurs when voltage equals or exceeds trip point (HLVDL3:HLDVL0)
0 = Event occurs when voltage equals or falls below trip point (HLVDL3:HLVDL0)

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

bit 5 **IRVST:** Internal Reference Voltage Stable Flag bit
1 = Indicates that the voltage detect logic will generate the interrupt flag at the specified voltage trip point
0 = Indicates that the voltage detect logic will not generate the interrupt flag at the specified voltage trip point and the LVD interrupt should not be enabled

bit 4 **HLVDEN:** High/Low-Voltage Detect Power Enable bit
1 = HLVD enabled
0 = HLVD disabled

bit 3-0 **HLVDL3:HLVDL0:** Voltage Detection Limit bits[(1)]
1111 = Reserved
1110 = Maximum setting
.
.
.
0000 = Minimum setting

Note 1: See Table 21-4 in **Section 21.0 "Electrical Characteristics"** for specifications.

The module is enabled by setting the HLVDEN bit. Each time that the HLVD module is enabled, the circuitry requires some time to stabilize. The IRVST bit is a read-only bit and is used to indicate when the circuit is stable. The module can only generate an interrupt after the circuit is stable and IRVST is set.

The VDIRMAG bit determines the overall operation of the module. When VDIRMAG is cleared, the module monitors for drops in V_{DD} below a predetermined set point. When the bit is set, the module monitors for rises in V_{DD} above the set point.

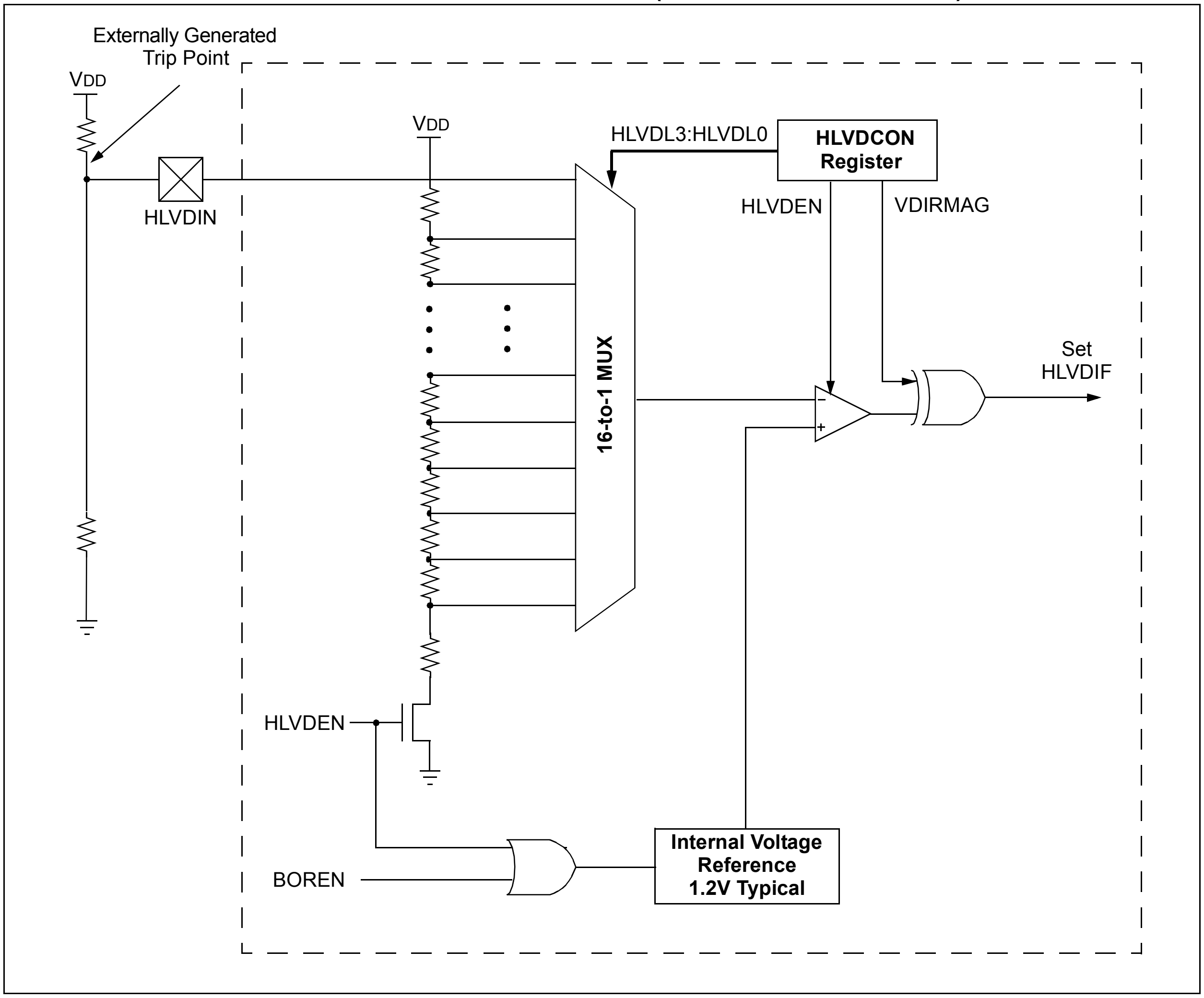
17.1 Operation

When the HLVD module is enabled, a comparator uses an internally generated reference voltage as the set point. The set point is compared with the trip point, where each node in the resistor divider represents a trip point voltage. The "trip point" voltage is the voltage level at which the device detects a high or low-voltage event, depending on the configuration of the module. When the supply voltage is equal to the trip point, the voltage tapped off of the resistor array is equal to the internal reference voltage generated by the voltage reference module. The comparator then generates an interrupt signal by setting the HLVDIF bit.

The trip point voltage is software programmable to any one of 16 values. The trip point is selected by programming the HLVDL3:HLVDL0 bits (HLVDCON<3:0>).

The HLVD module has an additional feature that allows the user to supply the trip voltage to the module from an external source. This mode is enabled when bits, HLVDL3:HLVDL0, are set to '1111'. In this state, the comparator input is multiplexed from the external input pin, HLVDIN. This gives users flexibility because it allows them to configure the High/Low-Voltage Detect interrupt to occur at any voltage in the valid operating range.

FIGURE 17-1: HLVD MODULE BLOCK DIAGRAM (WITH EXTERNAL INPUT)



17.2 HLVD Setup

The following steps are needed to set up the HLVD module:

1. Disable the module by clearing the HLVDEN bit (HLVDCON<4>).
2. Write the value to the HLVDL3:HLVDL0 bits that selects the desired HLVD trip point.
3. Set the VDIRMAG bit to detect high voltage (VDIRMAG = 1) or low voltage (VDIRMAG = 0).
4. Enable the HLVD module by setting the HLVDEN bit.
5. Clear the HLVD Interrupt Flag, HLVDIF (PIR2<2>), which may have been set from a previous interrupt.
6. Enable the HLVD interrupt, if interrupts are desired, by setting the HLVDIE and GIE/GIEH bits (PIE2<2> and INTCON<7>). An interrupt will not be generated until the IRVST bit is set.

17.3 Current Consumption

When the module is enabled, the HLVD comparator and voltage divider are enabled and will consume static current. The total current consumption, when enabled, is specified in electrical specification parameter D022 (**Section 270 "DC Characteristics"**).

Depending on the application, the HLVD module does not need to be operating constantly. To decrease the current requirements, the HLVD circuitry may only need to be enabled for short periods where the voltage is checked. After doing the check, the HLVD module may be disabled.

17.4 HLVD Start-up Time

The internal reference voltage of the HLVD module, specified in electrical specification parameter D420 (see Table 21-4 in **Section 21.0 "Electrical Characteristics"**), may be used by other internal circuitry, such as the Programmable Brown-out Reset. If the HLVD or other circuits using the voltage reference are disabled to lower the device's current consumption, the reference voltage circuit will require time to become stable before a low or high-voltage condition can be reliably detected. This start-up time, T_{IRVST}, is an interval that is independent of device clock speed. It is specified in electrical specification parameter 36 (Table 21-10).

The HLVD interrupt flag is not enabled until T_{IRVST} has expired and a stable reference voltage is reached. For this reason, brief excursions beyond the set point may not be detected during this interval. Refer to Figure 17-2 or Figure 17-3.

FIGURE 17-2: LOW-VOLTAGE DETECT OPERATION (VDIRMAG = 0)

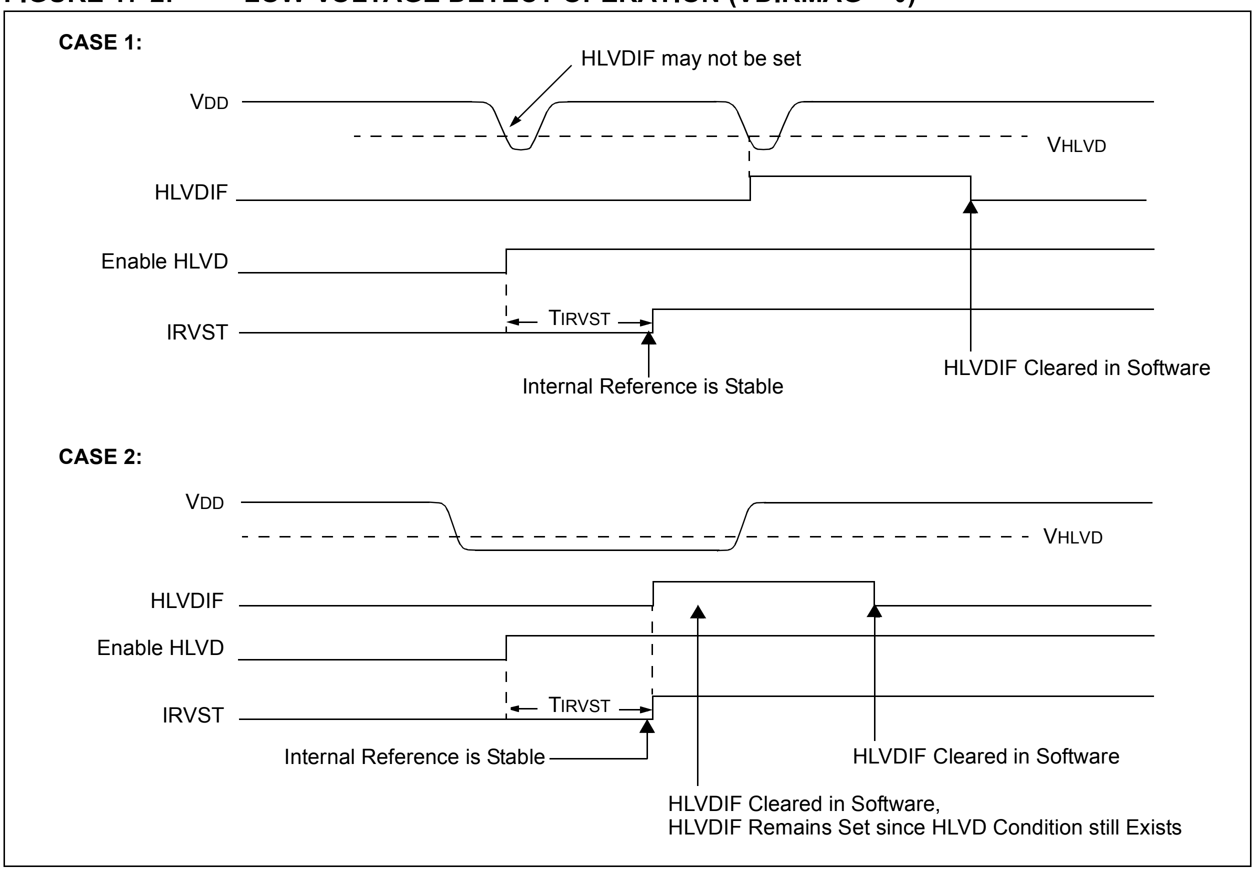
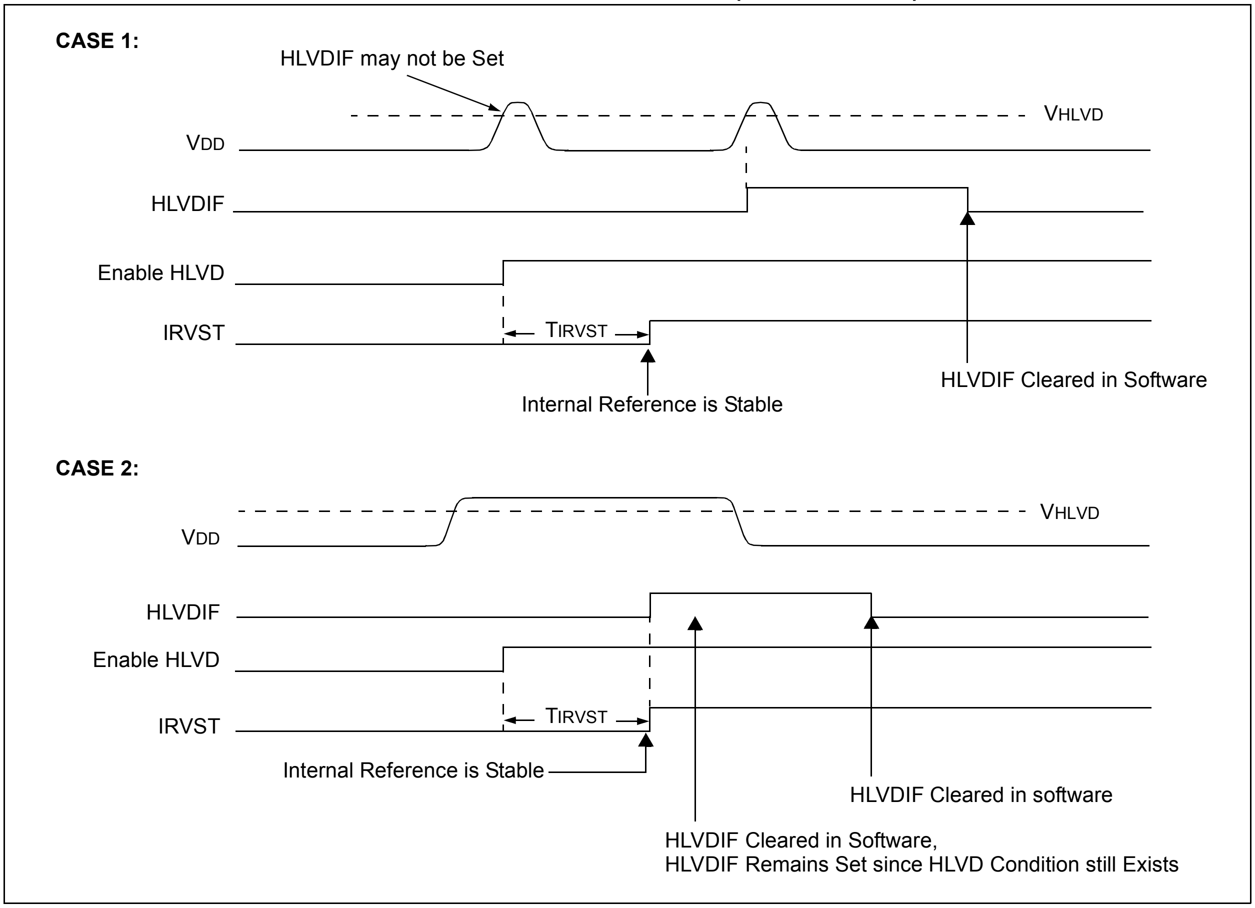


FIGURE 17-3: HIGH-VOLTAGE DETECT OPERATION (VDIRMAG = 1)

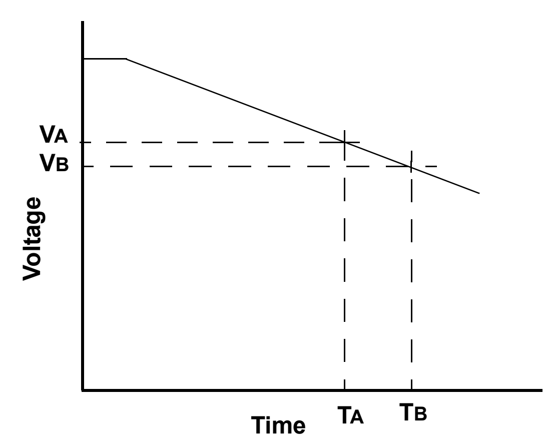


17.5 Applications

In many applications, the ability to detect a drop below or rise above a particular threshold is desirable. For example, the HLVD module could be periodically enabled to detect Universal Serial Bus (USB) attach or detach. This assumes the device is powered by a lower voltage source than the USB when detached. An attach would indicate a high-voltage detect from, for example, 3.3V to 5V (the voltage on USB) and vice versa for a detach. This feature could save a design a few extra components and an attach signal (input pin).

For general battery applications, Figure 17-4 shows a possible voltage curve. Over time, the device voltage decreases. When the device voltage reaches voltage, V_A, the HLVD logic generates an interrupt at time, T_A. The interrupt could cause the execution of an ISR, which would allow the application to perform "house-keeping tasks" and perform a controlled shutdown before the device voltage exits the valid operating range at T_B. The HLVD, thus, would give the application a time window, represented by the difference between T_A and T_B, to safely exit.

FIGURE 17-4: TYPICAL HIGH/LOW-VOLTAGE DETECT APPLICATION



Legend: V_A = HLVD trip point
V_B = Minimum valid device operating voltage

17.6 Operation During Sleep

When enabled, the HLVD circuitry continues to operate during Sleep. If the device voltage crosses the trip point, the HLVDIF bit will be set and the device will wake-up from Sleep. Device execution will continue from the interrupt vector address if interrupts have been globally enabled.

17.7 Effects of a Reset

A device Reset forces all registers to their Reset state. This forces the HLVD module to be turned off.

TABLE 17-1: REGISTERS ASSOCIATED WITH HIGH/LOW-VOLTAGE DETECT MODULE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
HLVDCON	VDIRMAG	—	IRVST	HLVDEN	HLVDL3	HLVDL2	HLVDL1	HLVDL0	50
INTCON	GIE/GIEH	PEIE/GIEL	TMR0IE	INT0IE	RBIE	TMR0IF	INT0IF	RBIF	49
PIR2	OSCFIF	—	USBIF	—	—	HLVDIF	—	—	51
PIE2	OSCFIE	—	USBIE	—	—	HLVDIE	—	—	51
IPR2	OSCFIP	—	USBIP	—	—	HLVDIP	—	—	51

Legend: — = unimplemented, read as '0'. Shaded cells are unused by the HLVD module.

NOTES:

18.0 SPECIAL FEATURES OF THE CPU

PIC18F2450/4450 devices include several features intended to maximize reliability and minimize cost through elimination of external components. These are:

- Oscillator Selection
- Resets:
  - Power-on Reset (POR)
  - Power-up Timer (PWRT)
  - Oscillator Start-up Timer (OST)
  - Brown-out Reset (BOR)
- Interrupts
- Watchdog Timer (WDT)
- Fail-Safe Clock Monitor (FSCM)
- Two-Speed Start-up
- Code Protection
- ID Locations
- In-Circuit Serial Programming (ICSP)

The oscillator can be configured for the application depending on frequency, power, accuracy and cost. All of the options are discussed in detail in **Section 2.0 "Oscillator Configurations"**.

A complete discussion of device Resets and interrupts is available in previous sections of this data sheet.

In addition to their Power-up and Oscillator Start-up Timers provided for Resets, PIC18F2450/4450 devices have a Watchdog Timer, which is either permanently enabled via the Configuration bits or software controlled (if configured as disabled).

The inclusion of an internal RC oscillator also provides the additional benefits of a Fail-Safe Clock Monitor (FSCM) and Two-Speed Start-up. FSCM provides for background monitoring of the peripheral clock and automatic switchover in the event of its failure. Two-Speed Start-up enables code to be executed almost immediately on start-up, while the primary clock source completes its start-up delays.

All of these features are enabled and configured by setting the appropriate Configuration register bits.

18.1 Configuration Bits

The Configuration bits can be programmed (read as '0') or left unprogrammed (read as '1') to select various device configurations. These bits are mapped starting at program memory location 300000h.

The user will note that address 300000h is beyond the user program memory space. In fact, it belongs to the configuration memory space (300000h-3FFFFFh), which can only be accessed using table reads and table writes.

Programming the Configuration registers is done in a manner similar to programming the Flash memory. The WR bit in the EECON1 register starts a self-timed write to the Configuration register. In normal operation mode, a `TBLWT` instruction, with the TBLPTR pointing to the Configuration register, sets up the address and the data for the Configuration register write. Setting the WR bit starts a long write to the Configuration register. The Configuration registers are written a byte at a time. To write or erase a configuration cell, a `TBLWT` instruction can write a '1' or a '0' into the cell. For additional details on Flash programming, refer to **Section 6.5 "Writing to Flash Program Memory"**.

TABLE 18-1: CONFIGURATION BITS AND DEVICE IDs

File Name		Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Default/ Unprogrammed Value
300000h	CONFIG1L	—	—	USBDIV	CPUDIV1	CPUDIV0	PLLDIV2	PLLDIV1	PLLDIV0	`--00 0111`
300001h	CONFIG1H	IESO	FCMEN	—	—	FOSC3	FOSC2	FOSC1	FOSC0	`00-- 0111`
300002h	CONFIG2L	—	—	VREGEN	BORV1	BORV0	BOREN1	BOREN0	$\overline{\text{PWRTEN}}$	`--01 1111`
300003h	CONFIG2H	—	—	—	WDTPS3	WDTPS2	WDTPS1	WDTPS0	WDTEN	`---1 1111`
300005h	CONFIG3H	MCLRE	—	—	—	—	LPT1OSC	PBADEN	—	`1--- -01-`
300006h	CONFIG4L	$\overline{\text{DEBUG}}$	XINST	ICPRT(2)	—	BBSIZ	LVP	—	STVREN	`100- 01-1`
300008h	CONFIG5L	—	—	—	—	—	—	CP1	CP0	`---- --11`
300009h	CONFIG5H	—	CPB	—	—	—	—	—	—	`-1-- ----`
30000Ah	CONFIG6L	—	—	—	—	—	—	WRT1	WRT0	`---- --11`
30000Bh	CONFIG6H	—	WRTB	WRTC	—	—	—	—	—	`-11- ----`
30000Ch	CONFIG7L	—	—	—	—	—	—	EBTR1	EBTR0	`---- --11`
30000Dh	CONFIG7H	—	EBTRB	—	—	—	—	—	—	`-1-- ----`
3FFFFEh	DEVID1	DEV2	DEV1	DEV0	REV4	REV3	REV2	REV1	REV0	`xxxx xxxx`(1)
3FFFFFh	DEVID2	DEV10	DEV9	DEV8	DEV7	DEV6	DEV5	DEV4	DEV3	`0001 0010`(1)

Legend: `x` = unknown, `u` = unchanged, - = unimplemented. Shaded cells are unimplemented, read as '0'.

Note 1: See Register 18-13 and Register 18-14 for device ID values. DEVID registers are read-only and cannot be programmed by the user.

2: Available only on PIC18F4450 devices in 44-pin TQFP packages. Always leave this bit clear in all other devices.

REGISTER 18-1: CONFIG1L: CONFIGURATION REGISTER 1 LOW (BYTE ADDRESS 300000h)

U-0	U-0	R/P-0	R/P-0	R/P-0	R/P-1	R/P-1	R/P-1
—	—	USBDIV	CPUDIV1	CPUDIV0	PLLDIV2	PLLDIV1	PLLDIV0
bit 7							bit 0

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

bit 7-6 **Unimplemented:** Read as ‘0’

bit 5 **USBDIV:** USB Clock Selection bit (used in Full-Speed USB mode only; UCFG:FSEN = 1)
1 = USB clock source comes from the 96 MHz PLL divided by 2
0 = USB clock source comes directly from the primary oscillator block with no postscale

bit 4-3 **CPUDIV1:CPUDIV0:** System Clock Postscaler Selection bits

For XT, HS, EC and ECIO Oscillator modes:
11 = Primary oscillator divided by 4 to derive system clock
10 = Primary oscillator divided by 3 to derive system clock
01 = Primary oscillator divided by 2 to derive system clock
00 = Primary oscillator used directly for system clock (no postscaler)

For XTPLL, HSPLL, ECPLL and ECPIO Oscillator modes:
11 = 96 MHz PLL divided by 6 to derive system clock
10 = 96 MHz PLL divided by 4 to derive system clock
01 = 96 MHz PLL divided by 3 to derive system clock
00 = 96 MHz PLL divided by 2 to derive system clock

bit 2-0 **PLLDIV2:PLLDIV0:** PLL Prescaler Selection bits
111 = Divide by 12 (48 MHz oscillator input)
110 = Divide by 10 (40 MHz oscillator input)
101 = Divide by 6 (24 MHz oscillator input)
100 = Divide by 5 (20 MHz oscillator input)
011 = Divide by 4 (16 MHz oscillator input)
010 = Divide by 3 (12 MHz oscillator input)
001 = Divide by 2 (8 MHz oscillator input)
000 = No prescale (4 MHz oscillator input drives PLL directly)

REGISTER 18-2: CONFIG1H: CONFIGURATION REGISTER 1 HIGH (BYTE ADDRESS 300001h)

R/P-0	R/P-0	U-0	U-0	R/P-0	R/P-1	R/P-1	R/P-1
IESO	FCMEN	—	—	FOSC3(1)	FOSC2(1)	FOSC1(1)	FOSC0(1)
bit 7							bit 0

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

bit 7 **IESO:** Internal/External Oscillator Switchover bit
1 = Oscillator Switchover mode enabled
0 = Oscillator Switchover mode disabled

bit 6 **FCMEN:** Fail-Safe Clock Monitor Enable bit
1 = Fail-Safe Clock Monitor enabled
0 = Fail-Safe Clock Monitor disabled

bit 5-4 **Unimplemented:** Read as ‘0’

bit 3-0 **FOSC3:FOSC0:** Oscillator Selection bits(1)
111x = HS oscillator, PLL enabled (HSPLL)
110x = HS oscillator (HS)
1011 = Internal oscillator, HS oscillator used by USB (INTHS)
1010 = Internal oscillator, XT used by USB (INTXT)
1001 = Internal oscillator, CLKO function on RA6, EC used by USB (INTCKO)
1000 = Internal oscillator, port function on RA6, EC used by USB (INTIO)
0111 = EC oscillator, PLL enabled, CLKO function on RA6 (ECPLL)
0110 = EC oscillator, PLL enabled, port function on RA6 (ECPIO)
0101 = EC oscillator, CLKO function on RA6 (EC)
0100 = EC oscillator, port function on RA6 (ECIO)
001x = XT oscillator, PLL enabled (XTPLL)
000x = XT oscillator (XT)

Note 1: The microcontroller and USB module both use the selected oscillator as their clock source in XT, HS and EC modes. The USB module uses the indicated XT, HS or EC oscillator as its clock source whenever the microcontroller uses the internal oscillator.

REGISTER 18-3: CONFIG2L: CONFIGURATION REGISTER 2 LOW (BYTE ADDRESS 300002h)

U-0	U-0	R/P-0	R/P-1	R/P-1	R/P-1	R/P-1	R/P-1
—	—	VREGEN	BORV1(1)	BORV0(1)	BOREN1(2)	BOREN0(2)	$\overline{\text{PWRTEN}}$(2)
bit 7							bit 0

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

bit 7-6 **Unimplemented:** Read as ‘0’

bit 5 **VREGEN:** USB Internal Voltage Regulator Enable bit
1 = USB voltage regulator enabled
0 = USB voltage regulator disabled

bit 4-3 **BORV1:BORV0:** Brown-out Reset Voltage bits(1)
11 = Minimum setting
.
.
.
00 = Maximum setting

bit 2-1 **BOREN1:BOREN0:** Brown-out Reset Enable bits(2)
11 = Brown-out Reset enabled in hardware only (SBOREN is disabled)
10 = Brown-out Reset enabled in hardware only and disabled in Sleep mode (SBOREN is disabled)
01 = Brown-out Reset enabled and controlled by software (SBOREN is enabled)
00 = Brown-out Reset disabled in hardware and software

bit 0 **$\overline{\text{PWRTEN}}$:** Power-up Timer Enable bit(2)
1 = PWRT disabled
0 = PWRT enabled

Note 1: See **Section 21.0 “Electrical Characteristics”** for the specifications.
2: The Power-up Timer is decoupled from Brown-out Reset, allowing these features to be independently controlled.

REGISTER 18-4: CONFIG2H: CONFIGURATION REGISTER 2 HIGH (BYTE ADDRESS 300003h)

U-0	U-0	U-0	R/P-1	R/P-1	R/P-1	R/P-1	R/P-1
—	—	—	WDTPS3	WDTPS2	WDTPS1	WDTPS0	WDTEN
bit 7							bit 0

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

bit 7-5 **Unimplemented:** Read as '0'

bit 4-1 **WDTPS3:WDTPS0:** Watchdog Timer Postscale Select bits

1111 = 1:32,768
1110 = 1:16,384
1101 = 1:8,192
1100 = 1:4,096
1011 = 1:2,048
1010 = 1:1,024
1001 = 1:512
1000 = 1:256
0111 = 1:128
0110 = 1:64
0101 = 1:32
0100 = 1:16
0011 = 1:8
0010 = 1:4
0001 = 1:2
0000 = 1:1

bit 0 **WDTEN:** Watchdog Timer Enable bit

1 = WDT enabled
0 = WDT disabled (control is placed on the SWDTEN bit)

REGISTER 18-5: CONFIG3H: CONFIGURATION REGISTER 3 HIGH (BYTE ADDRESS 300005h)

R/P-1	U-0	U-0	U-0	U-0	R/P-0	R/P-1	U-0
MCLRE	—	—	—	—	LPT1OSC	PBADEN	—
bit 7							bit 0

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

bit 7 **MCLRE:** $\overline{\text{MCLR}}$ Pin Enable bit
1 = $\overline{\text{MCLR}}$ pin enabled, RA5 input pin disabled
0 = RA5 input pin enabled, $\overline{\text{MCLR}}$ pin disabled

bit 6-3 **Unimplemented:** Read as ‘0’

bit 2 **LPT1OSC:** Low-Power Timer1 Oscillator Enable bit
1 = Timer1 configured for low-power operation
0 = Timer1 configured for higher power operation

bit 1 **PBADEN:** PORTB A/D Enable bit
(Affects ADCON1 Reset state. ADCON1 controls PORTB<4:0> pin configuration.)
1 = PORTB<4:0> pins are configured as analog input channels on Reset
0 = PORTB<4:0> pins are configured as digital I/O on Reset

bit 0 **Unimplemented:** Read as ‘0’

REGISTER 18-6: CONFIG4L: CONFIGURATION REGISTER 4 LOW (BYTE ADDRESS 300006h)

R/P-1	R/P-0	R/P-0	U-0	R/P-0	R/P-1	U-0	R/P-1
$\overline{\text{DEBUG}}$	XINST	ICPRT[(1)]	—	BBSIZ	LVP	—	STVREN
bit 7							bit 0

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

bit 7 **$\overline{\text{DEBUG}}$:** Background Debugger Enable bit
1 = Background debugger disabled, RB6 and RB7 configured as general purpose I/O pins
0 = Background debugger enabled, RB6 and RB7 are dedicated to In-Circuit Debug

bit 6 **XINST:** Extended Instruction Set Enable bit
1 = Instruction set extension and Indexed Addressing mode enabled
0 = Instruction set extension and Indexed Addressing mode disabled (Legacy mode)

bit 5 **ICPRT:** Dedicated In-Circuit Debug/Programming Port (ICPORT) Enable bit[(1)]
1 = ICPORT enabled
0 = ICPORT disabled

bit 4 **Unimplemented:** Read as ‘0’

bit 3 **BBSIZ:** Boot Block Size Select bit
1 = 2 kW boot block size
0 = 1 kW boot block size

bit 2 **LVP:** Single-Supply ICSP™ Enable bit
1 = Single-Supply ICSP enabled
0 = Single-Supply ICSP disabled

bit 1 **Unimplemented:** Read as ‘0’

bit 0 **STVREN:** Stack Full/Underflow Reset Enable bit
1 = Stack full/underflow will cause Reset
0 = Stack full/underflow will not cause Reset

Note 1: Available only on PIC18F4450 devices in 44-pin TQFP packages. Always leave this bit clear in all other devices.

REGISTER 18-7: CONFIG5L: CONFIGURATION REGISTER 5 LOW (BYTE ADDRESS 300008h)

U-0	U-0	U-0	U-0	U-0	U-0	R/C-1	R/C-1
—	—	—	—	—	—	CP1	CP0
bit 7							bit 0

Legend:		
R = Readable bit	C = Clearable bit	U = Unimplemented bit, read as ‘0’
-n = Value when device is unprogrammed		u = Unchanged from programmed state

bit 7-2 **Unimplemented:** Read as ‘0’

bit 1 **CP1:** Code Protection bit
1 = Block 1 (002000-003FFFh) is not code-protected
0 = Block 1 (002000-003FFFh) is code-protected

bit 0 **CP0:** Code Protection bit
1 = Block 0 (000800-001FFFh) or (001000-001FFFh) is not code-protected
0 = Block 0 (000800-001FFFh) or (001000-001FFFh) is code-protected

REGISTER 18-8: CONFIG5H: CONFIGURATION REGISTER 5 HIGH (BYTE ADDRESS 300009h)

U-0	R/C-1	U-0	U-0	U-0	U-0	U-0	U-0
—	CPB	—	—	—	—	—	—
bit 7							bit 0

Legend:		
R = Readable bit	C = Clearable bit	U = Unimplemented bit, read as ‘0’
-n = Value when device is unprogrammed		u = Unchanged from programmed state

bit 7 **Unimplemented:** Read as ‘0’

bit 6 **CPB:** Boot Block Code Protection bit
1 = Boot block (000000-0007FFh) or (000000-000FFFh) is not code-protected
0 = Boot block (000000-0007FFh) or (000000-000FFFh) is code-protected

bit 5-0 **Unimplemented:** Read as ‘0’

REGISTER 18-9: CONFIG6L: CONFIGURATION REGISTER 6 LOW (BYTE ADDRESS 30000Ah)

U-0	U-0	U-0	U-0	U-0	U-0	R/C-1	R/C-1
—	—	—	—	—	—	WRT1	WRT0
bit 7							bit 0

Legend:		
R = Readable bit	C = Clearable bit	U = Unimplemented bit, read as ‘0’
-n = Value when device is unprogrammed		u = Unchanged from programmed state

bit 7-2 **Unimplemented:** Read as ‘0’

bit 1 **WRT1:** Write Protection bit
1 = Block 1 (002000-003FFFh) is not write-protected
0 = Block 1 (002000-003FFFh) is write-protected

bit 0 **WRT0:** Write Protection bit
1 = Block 0 (000800-001FFFh) or (001000-001FFFh) is not write-protected
0 = Block 0 (000800-001FFFh) or (001000-001FFFh) is write-protected

REGISTER 18-10: CONFIG6H: CONFIGURATION REGISTER 6 HIGH (BYTE ADDRESS 30000Bh)

U-0	R/C-1	R-1	U-0	U-0	U-0	U-0	U-0
—	WRTB	WRTC[1]	—	—	—	—	—
bit 7							bit 0

Legend:		
R = Readable bit	C = Clearable bit	U = Unimplemented bit, read as ‘0’
-n = Value when device is unprogrammed		u = Unchanged from programmed state

bit 7 **Unimplemented:** Read as ‘0’

bit 6 **WRTB:** Boot Block Write Protection bit
1 = Boot block (000000-0007FFh) or (000000-000FFFh) is not write-protected
0 = Boot block (000000-0007FFh) or (000000-000FFFh) is write-protected

bit 5 **WRTC:** Configuration Register Write Protection bit[1]
1 = Configuration registers (300000-3000FFh) are not write-protected
0 = Configuration registers (300000-3000FFh) are write-protected

bit 4-0 **Unimplemented:** Read as ‘0’

Note 1: This bit is read-only in normal execution mode; it can be written only in Program mode.

REGISTER 18-11: CONFIG7L: CONFIGURATION REGISTER 7 LOW (BYTE ADDRESS 30000Ch)

U-0	U-0	U-0	U-0	U-0	U-0	R/C-1	R/C-1
—	—	—	—	—	—	EBTR1	EBTR0
bit 7							bit 0

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

bit 7-2 **Unimplemented:** Read as '0'

bit 1 **EBTR1:** Table Read Protection bit
1 = Block 1 (002000-003FFFh) is not protected from table reads executed in other blocks
0 = Block 1 (002000-003FFFh) is protected from table reads executed in other blocks

bit 0 **EBTR0:** Table Read Protection bit
1 = Block 0 (000800-001FFFh) or (001000-001FFFh) is not protected from table reads executed in other blocks
0 = Block 0 (000800-001FFFh) or (001000-001FFFh) is protected from table reads executed in other blocks

REGISTER 18-12: CONFIG7H: CONFIGURATION REGISTER 7 HIGH (BYTE ADDRESS 30000Dh)

U-0	R/C-1	U-0	U-0	U-0	U-0	U-0	U-0
—	EBTRB	—	—	—	—	—	—
bit 7							bit 0

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

bit 7 **Unimplemented:** Read as '0'

bit 6 **EBTRB:** Boot Block Table Read Protection bit
1 = Boot block (000000-0007FFh) or (000000-000FFFh) is not protected from table reads executed in other blocks
0 = Boot block (000000-0007FFh) or (000000-000FFFh) is protected from table reads executed in other blocks

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

REGISTER 18-13: DEVID1: DEVICE ID REGISTER 1 FOR PIC18F2450/4450 DEVICES

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

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

bit 7-5 **DEV2:DEV0:** Device ID bits
`001` = PIC18F2450
`000` = PIC18F4450

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

REGISTER 18-14: DEVID2: DEVICE ID REGISTER 2 FOR PIC18F2450/4450 DEVICES

R	R	R	R	R	R	R	R
DEV10[(1)]	DEV9[(1)]	DEV8[(1)]	DEV7[(1)]	DEV6[(1)]	DEV5[(1)]	DEV4[(1)]	DEV3[(1)]
bit 7							bit 0

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

bit 7-0 **DEV10:DEV3:** Device ID bits[(1)]
These bits are used with the DEV2:DEV0 bits in the DEVID1 register to identify the part number.
`0010 0100` = PIC18F2450/4450 devices

Note 1: These values for DEV10:DEV3 may be shared with other devices. The specific device is always identified by using the entire DEV10:DEV0 bit sequence.

18.2 Watchdog Timer (WDT)

For PIC18F2450/4450 devices, the WDT is driven by the INTRC source. When the WDT is enabled, the clock source is also enabled. The nominal WDT period is 4 ms and has the same stability as the INTRC oscillator.

The 4 ms period of the WDT is multiplied by a 16-bit postscaler. Any output of the WDT postscaler is selected by a multiplexer, controlled by bits in Configuration Register 2H. Available periods range from 4 ms to 131.072 seconds (2.18 minutes). The WDT and postscaler are cleared when any of the following events occur: a SLEEP or CLRWDT instruction is executed or a clock failure has occurred.

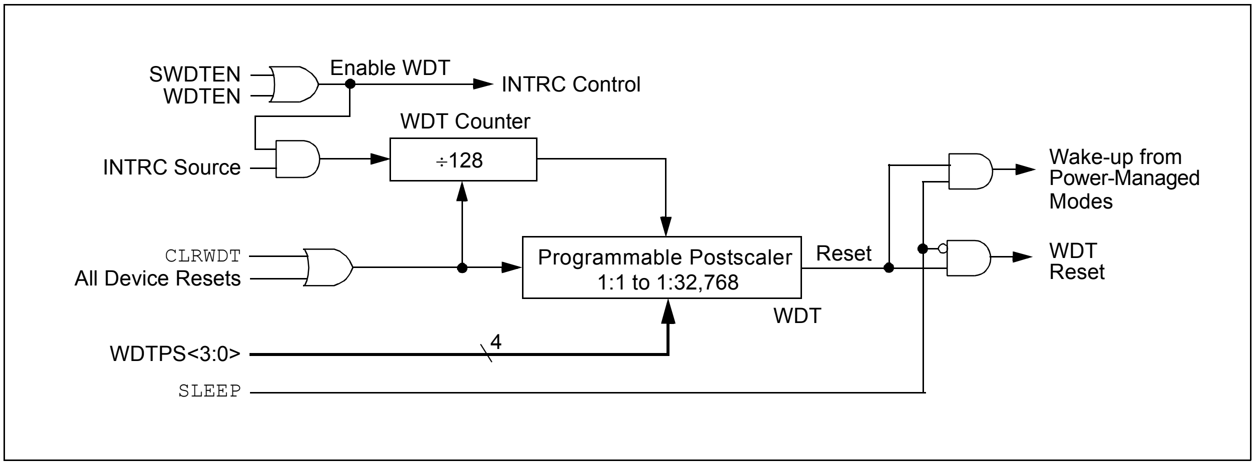
Note 1: The CLRWDT and SLEEP instructions clear the WDT and postscaler counts when executed.

2: When a CLRWDT instruction is executed, the postscaler count will be cleared.

18.2.1 CONTROL REGISTER

Register 18-15 shows the WDTCON register. This is a readable and writable register which contains a control bit that allows software to override the WDT enable Configuration bit, but only if the Configuration bit has disabled the WDT.

FIGURE 18-1: WDT BLOCK DIAGRAM



REGISTER 18-15: WDTCON: WATCHDOG TIMER CONTROL REGISTER

U-0	U-0	U-0	U-0	U-0	U-0	U-0	R/W-0
—	—	—	—	—	—	—	SWDTEN(1)
bit 7							bit 0

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

bit 7-1 **Unimplemented:** Read as ‘0’

bit 0 **SWDTEN:** Software Controlled Watchdog Timer Enable bit(1)
1 = Watchdog Timer is on
0 = Watchdog Timer is off

Note 1: This bit has no effect if the Configuration bit, WDTEN, is enabled.

TABLE 18-2: SUMMARY OF WATCHDOG TIMER REGISTERS

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
RCON	IPEN	SBOREN(1)	—	$\overline{RI}$	$\overline{TO}$	$\overline{PD}$	$\overline{POR}$	$\overline{BOR}$	50
WDTCON	—	—	—	—	—	—	—	SWDTEN	50

Legend: — = unimplemented, read as ‘0’. Shaded cells are not used by the Watchdog Timer.

Note 1: The SBOREN bit is only available when BOREN<1:0> = 01; otherwise, the bit reads as ‘0’.

18.3 Two-Speed Start-up

The Two-Speed Start-up feature helps to minimize the latency period, from oscillator start-up to code execution, by allowing the microcontroller to use the INTRC oscillator as a clock source until the primary clock source is available. It is enabled by setting the IESO Configuration bit.

Two-Speed Start-up should be enabled only if the primary oscillator mode is XT, HS, XTPLL or HSPLL (Crystal-Based modes). Other sources do not require an Oscillator Start-up Timer delay; for these, Two-Speed Start-up should be disabled.

When enabled, Resets and wake-ups from Sleep mode cause the device to configure itself to run from the internal oscillator as the clock source, following the time-out of the Power-up Timer after a Power-on Reset is enabled. This allows almost immediate code execution while the primary oscillator starts and the OST is running. Once the OST times out, the device automatically switches to PRI_RUN mode.

Because the OSCCON register is cleared on Reset events, the INTRC clock is used directly at its base frequency.

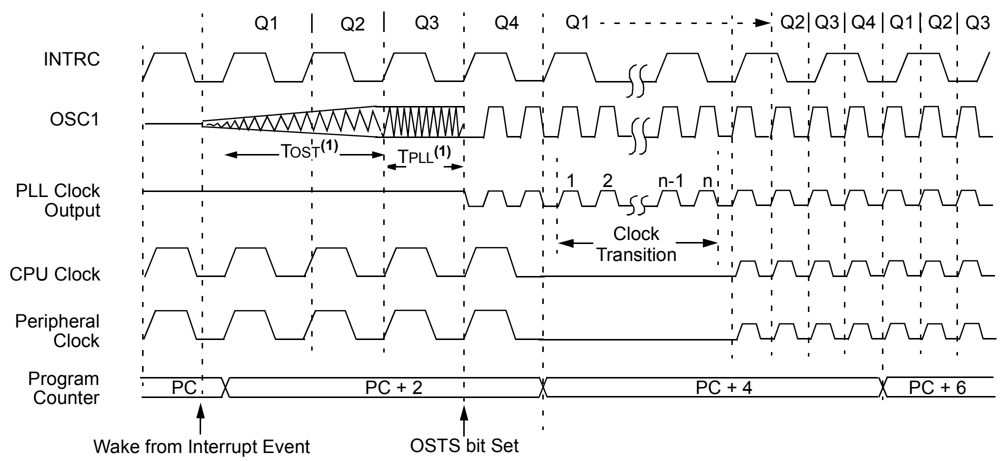
In all other power-managed modes, Two-Speed Start-up is not used. The device will be clocked by the currently selected clock source until the primary clock source becomes available. The setting of the IESO bit is ignored.

18.3.1 SPECIAL CONSIDERATIONS FOR USING TWO-SPEED START-UP

While using the INTRC oscillator in Two-Speed Start-up, the device still obeys the normal command sequences for entering power-managed modes, including serial `SLEEP` instructions (refer to **Section 3.1.4 "Multiple Sleep Commands"**). In practice, this means that user code can change the SCS1:SCS0 bit settings or issue `SLEEP` instructions before the OST times out. This would allow an application to briefly wake-up, perform routine "housekeeping" tasks and return to Sleep before the device starts to operate from the primary oscillator.

User code can also check if the primary clock source is currently providing the device clocking by checking the status of the OSTS bit (OSCCON<3>). If the bit is set, the primary oscillator is providing the clock. Otherwise, the internal oscillator is providing the clock during wake-up from Reset or Sleep mode.

FIGURE 18-2: TIMING TRANSITION FOR TWO-SPEED START-UP (INTRC TO HSPLL)



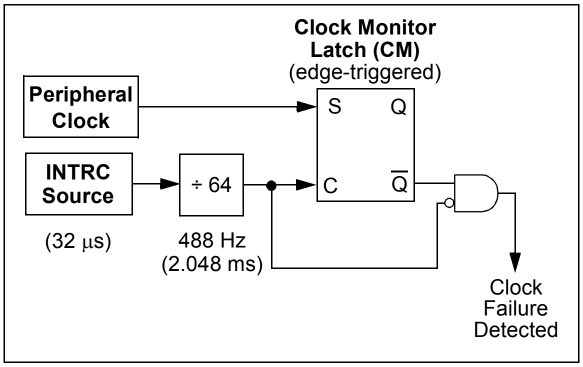
Note 1: T_{OST} = 1024 T_{OSC}; T_{PLL} = 2 ms (approx). These intervals are not shown to scale.

18.4 Fail-Safe Clock Monitor

The Fail-Safe Clock Monitor (FSCM) allows the microcontroller to continue operation in the event of an external oscillator failure by automatically switching the device clock to the internal oscillator. The FSCM function is enabled by setting the FCMEN Configuration bit.

When FSCM is enabled, the INTRC oscillator runs at all times to monitor clocks to peripherals and provide a backup clock in the event of a clock failure. Clock monitoring (shown in Figure 18-3) is accomplished by creating a sample clock signal, which is the INTRC output divided by 64. This allows ample time between FSCM sample clocks for a peripheral clock edge to occur. The peripheral device clock and the sample clock are presented as inputs to the Clock Monitor latch (CM). The CM is set on the falling edge of the device clock source, but cleared on the rising edge of the sample clock.

FIGURE 18-3: FSCM BLOCK DIAGRAM



Clock failure is tested for on the falling edge of the sample clock. If a sample clock falling edge occurs while CM is still set, a clock failure has been detected (Figure 18-4). This causes the following:

- the FSCM generates an oscillator fail interrupt by setting bit, OSCFIF (PIR2<7>);
- the device clock source is switched to the internal oscillator (OSCCON is not updated to show the current clock source – this is the fail-safe condition); and
- the WDT is reset.

The FSCM will detect failures of the primary or secondary clock sources only. If the internal oscillator fails, no failure would be detected, nor would any action be possible.

18.4.1 FSCM AND THE WATCHDOG TIMER

Both the FSCM and the WDT are clocked by the INTRC oscillator. Since the WDT operates with a separate divider and counter, disabling the WDT has no effect on the operation of the INTRC oscillator when the FSCM is enabled.

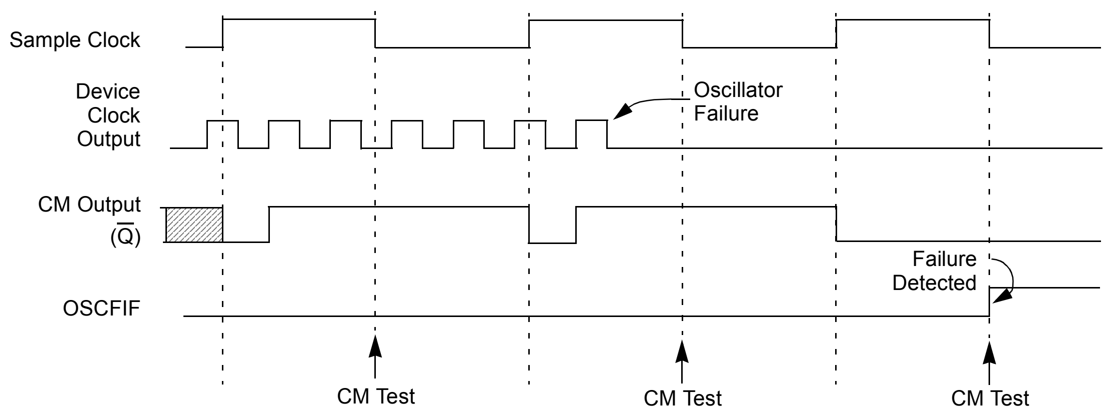
If the WDT is enabled with a small prescale value, a decrease in clock speed allows a WDT time-out to occur and a subsequent device Reset. For this reason, Fail-Safe Clock Monitor events also reset the WDT and postscaler, allowing it to start timing from when execution speed was changed and decreasing the likelihood of an erroneous time-out.

18.4.2 EXITING FAIL-SAFE OPERATION

The fail-safe condition is terminated by either a device Reset or by entering a power-managed mode. On Reset, the controller starts the primary clock source specified in Configuration Register 1H (with any start-up delays that are required for the oscillator mode, such as OST or PLL timer). The INTRC provides the device clock until the primary clock source becomes ready (similar to a Two-Speed Start-up). The clock source is then switched to the primary clock (indicated by the OSTS bit in the OSCCON register becoming set). The Fail-Safe Clock Monitor then resumes monitoring the peripheral clock.

The primary clock source may never become ready during start-up. In this case, operation is clocked by the INTRC. The OSCCON register will remain in its Reset state until a power-managed mode is entered.

FIGURE 18-4: FSCM TIMING DIAGRAM



Note: The device clock is normally at a much higher frequency than the sample clock. The relative frequencies in this example have been chosen for clarity.

18.4.3 FSCM INTERRUPTS IN POWER-MANAGED MODES

By entering a power-managed mode, the clock multiplexer selects the clock source selected by the OSCCON register. Fail-Safe Clock Monitoring of the power-managed clock source resumes in the power-managed mode.

If an oscillator failure occurs during power-managed operation, the subsequent events depend on whether or not the oscillator failure interrupt is enabled. If enabled (OSCFIF = `1`), code execution will be clocked by the INTRC. An automatic transition back to the failed clock source will not occur.

If the interrupt is disabled, subsequent interrupts while in Idle mode will cause the CPU to begin executing instructions while being clocked by the INTRC source.

18.4.4 POR OR WAKE-UP FROM SLEEP

The FSCM is designed to detect oscillator failure at any point after the device has exited Power-on Reset (POR) or low-power Sleep mode. When the primary device clock is either EC or INTRC, monitoring can begin immediately following these events.

For oscillator modes involving a crystal or resonator (HS, HSPLL or XT), the situation is somewhat different. Since the oscillator may require a start-up time considerably longer than the FCSM sample clock time, a false clock failure may be detected. To prevent this, the internal oscillator is automatically configured as the device clock and functions until the primary clock is stable (the OST and PLL timers have timed out). This is identical to Two-Speed Start-up mode. Once the primary clock is stable, the INTRC returns to its role as the FSCM source.

Note:	The same logic that prevents false oscillator failure interrupts on POR or wake from Sleep will also prevent the detection of the oscillator's failure to start at all following these events. This can be avoided by monitoring the OSTS bit and using a timing routine to determine if the oscillator is taking too long to start. Even so, no oscillator failure interrupt will be flagged.

As noted in **Section 18.3.1 "Special Considerations for Using Two-Speed Start-up"**, it is also possible to select another clock configuration and enter an alternate power-managed mode while waiting for the primary clock to become stable. When the new power-managed mode is selected, the primary clock is disabled.

18.5 Program Verification and Code Protection

The overall structure of the code protection on the PIC18 Flash devices differs significantly from other PIC® microcontrollers.

The user program memory is divided into three blocks. One of these is a boot block of 1 or 2 Kbytes. The remainder of the memory is divided into two blocks on binary boundaries.

Each of the three blocks has three code protection bits associated with them. They are:

- Code-Protect bit (CPx)
- Write-Protect bit (WRTx)
- External Block Table Read bit (EBTRx)

Figure 18-5 shows the program memory organization for 24 and 32-Kbyte devices and the specific code protection bit associated with each block. The actual locations of the bits are summarized in Table 18-3.

FIGURE 18-5: CODE-PROTECTED PROGRAM MEMORY FOR PIC18F2450/4450

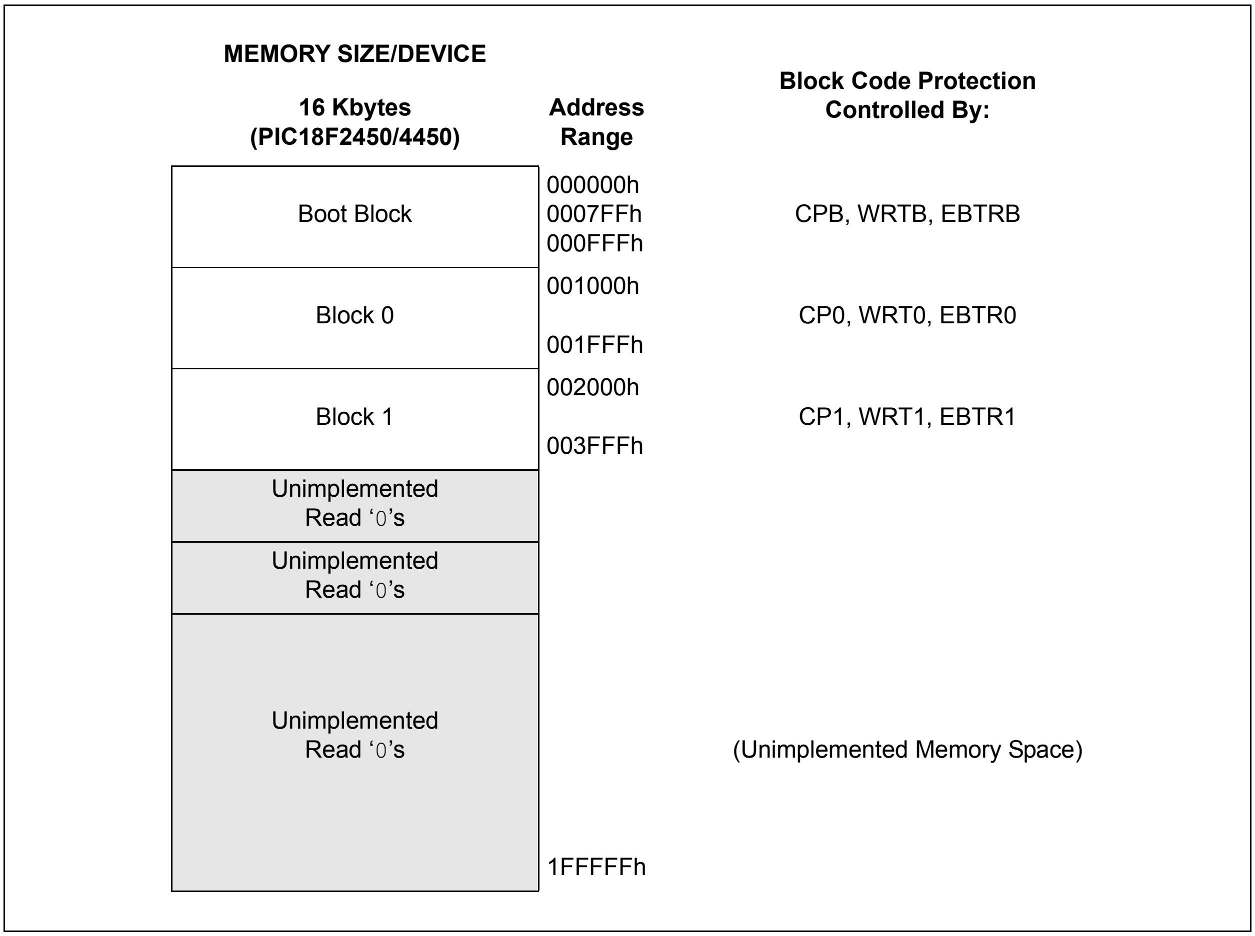


TABLE 18-3: SUMMARY OF CODE PROTECTION REGISTERS

File Name		Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
300008h	CONFIG5L	—	—	—	—	—	—	CP1	CP0
300009h	CONFIG5H	—	CPB	—	—	—	—	—	—
30000Ah	CONFIG6L	—	—	—	—	—	—	WRT1	WRT0
30000Bh	CONFIG6H	—	WRTB	WRTC	—	—	—	—	—
30000Ch	CONFIG7L	—	—	—	—	—	—	EBTR1	EBTR0
30000Dh	CONFIG7H	—	EBTRB	—	—	—	—	—	—

Legend: Shaded cells are unimplemented.

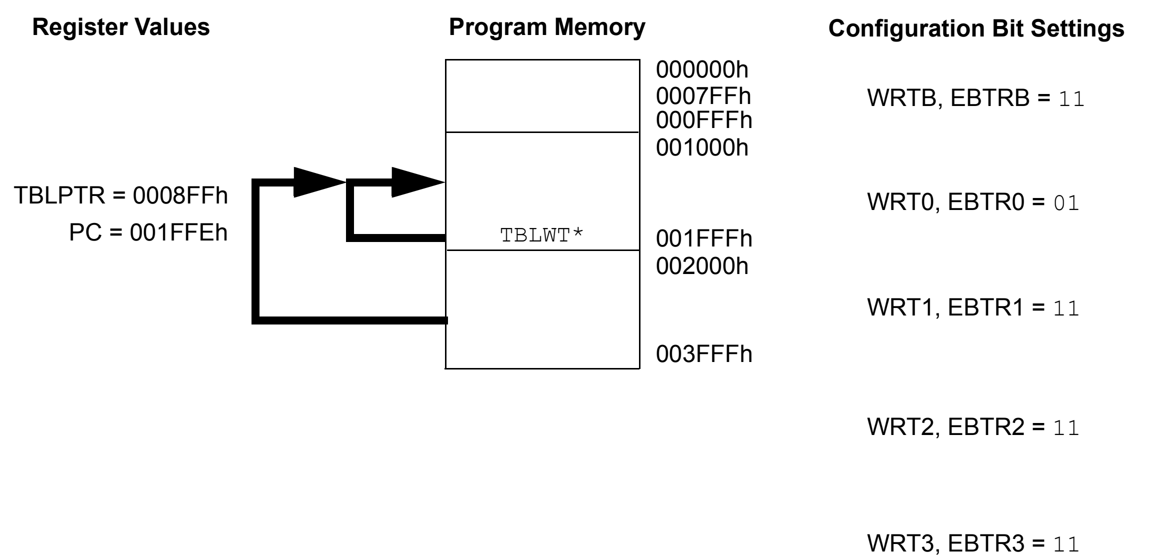
18.5.1 PROGRAM MEMORY CODE PROTECTION

The program memory may be read to or written from any location using the table read and table write instructions. The device ID may be read with table reads. The Configuration registers may be read and written with the table read and table write instructions.

In normal execution mode, the CPx bits have no direct effect. CPx bits inhibit external reads and writes. A block of user memory may be protected from table writes if the WRTx Configuration bit is '0'. The EBTRx bits control table reads. For a block of user memory with the EBTRx bit set to '0', a table read instruction that executes from within that block is allowed to read. A table read instruction that executes from a location outside of that block is not allowed to read and will result in reading '0's. Figure 18-6 through Figure 18-8 illustrate table write and table read protection.

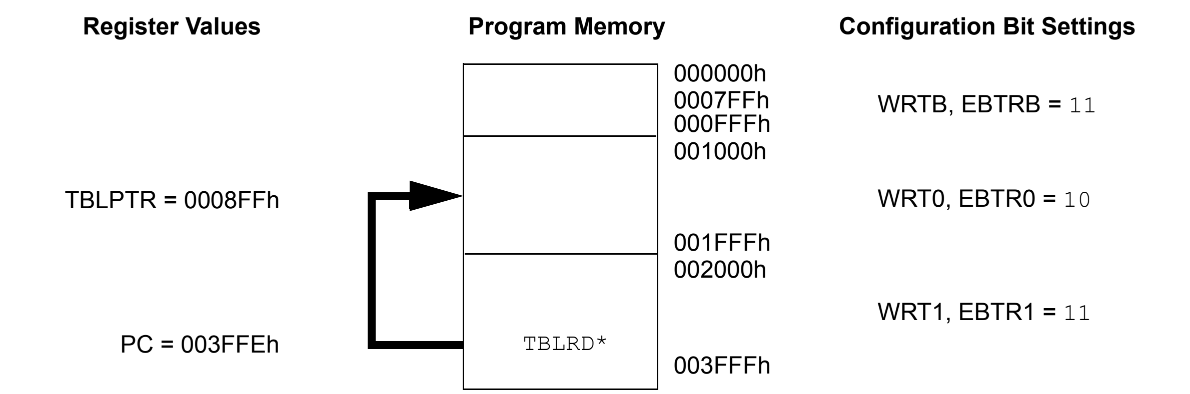
Note:	Code protection bits may only be written to a '0' from a '1' state. It is not possible to write a '1' to a bit in the '0' state. Code protection bits are only set to '1' by a full Chip Erase or Block Erase function. The full Chip Erase and Block Erase functions can only be initiated via ICSP operation or an external programmer.

FIGURE 18-6: TABLE WRITE (WRTx) DISALLOWED



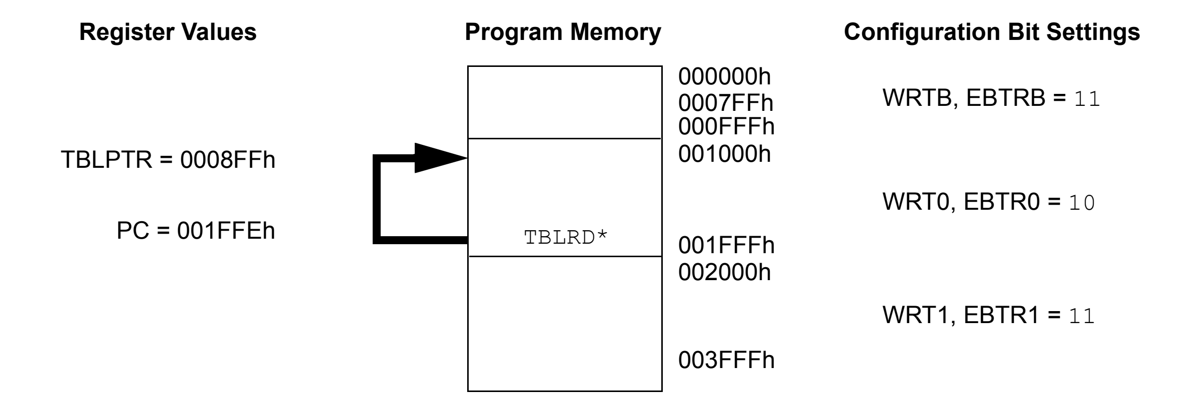
Results: All table writes disabled to Blockn whenever WRTx = 0.

FIGURE 18-7: EXTERNAL BLOCK TABLE READ (EBTRx) DISALLOWED



Results: All table reads from external blocks to Blockn are disabled whenever EBTRx = 0.
TABLAT register returns a value of '0'.

FIGURE 18-8: EXTERNAL BLOCK TABLE READ (EBTRx) ALLOWED



Results: Table reads permitted within Blockn, even when EBTRBx = 0.
TABLAT register returns the value of the data at the location TBLPTR.

18.5.2 CONFIGURATION REGISTER PROTECTION

The Configuration registers can be write-protected. The WRTC bit controls protection of the Configuration registers. In normal execution mode, the WRTC bit is readable only. WRTC can only be written via ICSP operation or an external programmer.

18.6 ID Locations

Eight memory locations (200000h-200007h) are designated as ID locations, where the user can store checksum or other code identification numbers. These locations are both readable and writable during normal execution through the `TBLRD` and `TBLWT` instructions or during program/verify. The ID locations can be read when the device is code-protected.

18.7 In-Circuit Serial Programming

PIC18F2450/4450 microcontrollers can be serially programmed while in the end application circuit. This is simply done with two lines for clock and data and three other lines for power, ground and the programming voltage. This allows customers to manufacture boards with unprogrammed devices and then program the microcontroller just before shipping the product. This also allows the most recent firmware or a custom firmware to be programmed.

18.8 In-Circuit Debugger

When the $\overline{\text{DEBUG}}$ Configuration bit is programmed to a '0', the In-Circuit Debugger functionality is enabled. This function allows simple debugging functions when used with MPLAB® IDE. When the microcontroller has this feature enabled, some resources are not available for general use. Table 18-4 shows which resources are required by the background debugger.

TABLE 18-4: DEBUGGER RESOURCES

I/O pins:	RB6, RB7
Stack:	2 levels
Program Memory:	512 bytes
Data Memory:	10 bytes

To use the In-Circuit Debugger function of the microcontroller, the design must implement In-Circuit Serial Programming connections to $\overline{\text{MCLR}}$/VPP/RE3, VDD, VSS, RB7 and RB6. This will interface to the In-Circuit Debugger module available from Microchip or one of the third party development tool companies.

18.9 Special ICPORT Features (Designated Packages Only)

Under specific circumstances, the No Connect (NC) pins of PIC18F4450 devices in 44-pin TQFP packages can provide additional functionality. These features are controlled by device Configuration bits and are available only in this package type and pin count.

18.9.1 DEDICATED ICD/ICSP PORT

The 44-pin TQFP devices can use NC pins to provide an alternate port for In-Circuit Debugging (ICD) and In-Circuit Serial Programming (ICSP). These pins are collectively known as the dedicated ICSP/ICD port, since they are not shared with any other function of the device.

When implemented, the dedicated port activates three NC pins to provide an alternate device Reset, data and clock ports. None of these ports overlap with standard I/O pins, making the I/O pins available to the user's application.

The dedicated ICSP/ICD port is enabled by setting the ICPRT Configuration bit. The port functions the same way as the legacy ICSP/ICD port on RB6/RB7. Table 18-5 identifies the functionally equivalent pins for ICSP and ICD purposes.

TABLE 18-5: EQUIVALENT PINS FOR LEGACY AND DEDICATED ICD/ICSP™ PORTS

Pin Name		Pin Type	Pin Function
Legacy Port	Dedicated Port		
$\overline{\text{MCLR}}$/VPP/RE3	NC/$\overline{\text{ICRST}}$/ICVPP	P	Device Reset and Programming Enable
RB6/KBI2/PGC	NC/ICCK/ICPGC	I	Serial Clock
RB7/KBI3/PGD	NC/ICDT/ICPGD	I/O	Serial Data

Legend: I = Input, O = Output, P = Power

Even when the dedicated port is enabled, the ICSP and ICD functions remain available through the legacy port. When V_{IHH} is seen on the MCLR/V_{PP}/RE3 pin, the state of the ICRST/ICV$_{PP}$ pin is ignored.

> **Note 1:** The ICPRT Configuration bit can only be programmed through the default ICSP port.
>
> **2:** The ICPRT Configuration bit must be maintained clear for all 28-pin and 40-pin devices; otherwise, unexpected operation may occur.

18.9.2 28-PIN EMULATION

PIC18F4450 devices in 44-pin TQFP packages also have the ability to change their configuration under external control for debugging purposes. This allows the device to behave as if it were a PIC18F2450/4450 28-pin device.

This 28-pin Configuration mode is controlled through a single pin, NC/ICPORTS. Connecting this pin to V_{SS} forces the device to function as a 28-pin device. Features normally associated with the 40/44-pin devices are disabled, along with their corresponding control registers and bits. On the other hand, connecting the pin to V_{DD} forces the device to function in its default configuration.

The configuration option is only available when background debugging and the dedicated ICD/ICSP port are both enabled (DEBUG Configuration bit is clear and ICPRT Configuration bit is set). When disabled, NC/ICPORTS is a No Connect pin.

18.10 Single-Supply ICSP Programming

The LVP Configuration bit enables Single-Supply ICSP Programming (formerly known as *Low-Voltage ICSP Programming* or *LVP)*. When Single-Supply Programming is enabled, the microcontroller can be programmed without requiring high voltage being applied to the MCLR/V_{PP}/RE3 pin, but the RB5/KBI1/PGM pin is then dedicated to controlling Program mode entry and is not available as a general purpose I/O pin.

While programming using Single-Supply Programming, V_{DD} is applied to the MCLR/V_{PP}/RE3 pin as in normal execution mode. To enter Programming mode, V_{DD} is applied to the PGM pin.

> **Note 1:** High-Voltage Programming is always available, regardless of the state of the LVP bit, by applying V_{IHH} to the MCLR pin.
>
> **2:** While in Low-Voltage ICSP Programming mode, the RB5 pin can no longer be used as a general purpose I/O pin and should be held low during normal operation.
>
> **3:** When using Low-Voltage ICSP Programming (LVP) and the pull-ups on PORTB are enabled, bit 5 in the TRISB register must be cleared to disable the pull-up on RB5 and ensure the proper operation of the device.
>
> **4:** If the device Master Clear is disabled, verify that either of the following is done to ensure proper entry into ICSP mode:
>
> a) Disable Low-Voltage Programming (CONFIG4L<2> = 0); or
>
> b) Make certain that RB5/KBI1/PGM is held low during entry into ICSP.

If Single-Supply ICSP Programming mode will not be used, the LVP bit can be cleared. RB5/KBI1/PGM then becomes available as the digital I/O pin, RB5. The LVP bit may be set or cleared only when using standard high-voltage programming (V_{IHH} applied to the MCLR/V_{PP}/RE3 pin). Once LVP has been disabled, only the standard high-voltage programming is available and must be used to program the device.

Memory that is not code-protected can be erased using either a Block Erase, or erased row by row, then written at any specified V_{DD}. If code-protected memory is to be erased, a Block Erase is required. If a Block Erase is to be performed when using Low-Voltage Programming, the device must be supplied with V_{DD} of 4.5V to 5.5V.

19.0 INSTRUCTION SET SUMMARY

PIC18F2450/4450 devices incorporate the standard set of 75 PIC18 core instructions, as well as an extended set of eight new instructions for the optimization of code that is recursive or that utilizes a software stack. The extended set is discussed later in this section.

19.1 Standard Instruction Set

The standard PIC18 instruction set adds many enhancements to the previous PIC MCU instruction sets, while maintaining an easy migration from these PIC MCU instruction sets. Most instructions are a single program memory word (16 bits) but there are four instructions that require two program memory locations.

Each single-word instruction is a 16-bit word divided into an opcode, which specifies the instruction type and one or more operands, which further specify the operation of the instruction.

The instruction set is highly orthogonal and is grouped into four basic categories:

- **Byte-oriented** operations
- **Bit-oriented** operations
- **Literal** operations
- **Control** operations

The PIC18 instruction set summary in Table 19-2 lists **byte-oriented**, **bit-oriented**, **literal** and **control** operations. Table 19-1 shows the opcode field descriptions.

Most **byte-oriented** instructions have three operands:

1. The file register (specified by ‘f’)
2. The destination of the result (specified by ‘d’)
3. The accessed memory (specified by ‘a’)

The file register designator, ‘f’, specifies which file register is to be used by the instruction. The destination designator, ‘d’, specifies where the result of the operation is to be placed. If ‘d’ is ‘0’, the result is placed in the WREG register. If ‘d’ is ‘1’, the result is placed in the file register specified in the instruction.

All **bit-oriented** instructions have three operands:

1. The file register (specified by ‘f’)
2. The bit in the file register (specified by ‘b’)
3. The accessed memory (specified by ‘a’)

The bit field designator ‘b’ selects the number of the bit affected by the operation, while the file register designator, ‘f’, represents the number of the file in which the bit is located.

The **literal** instructions may use some of the following operands:

- A literal value to be loaded into a file register (specified by ‘k’)
- The desired FSR register to load the literal value into (specified by ‘f’)
- No operand required (specified by ‘—’)

The **control** instructions may use some of the following operands:

- A program memory address (specified by ‘n’)
- The mode of the `CALL` or `RETURN` instructions (specified by ‘s’)
- The mode of the table read and table write instructions (specified by ‘m’)
- No operand required (specified by ‘—’)

All instructions are a single word, except for four double-word instructions. These instructions were made double-word to contain the required information in 32 bits. In the second word, the 4 MSbs are ‘1’s. If this second word is executed as an instruction (by itself), it will execute as a `NOP`.

All single-word instructions are executed in a single instruction cycle, unless a conditional test is true or the program counter is changed as a result of the instruction. In these cases, the execution takes two instruction cycles with the additional instruction cycle(s) executed as a `NOP`.

The double-word instructions execute in two instruction cycles.

One instruction cycle consists of four oscillator periods. Thus, for an oscillator frequency of 4 MHz, the normal instruction execution time is 1 μs. If a conditional test is true, or the program counter is changed as a result of an instruction, the instruction execution time is 2 μs. Two-word branch instructions (if true) would take 3 μs.

Figure 19-1 shows the general formats that the instructions can have. All examples use the convention ‘nnh’ to represent a hexadecimal number.

The instruction set summary, shown in Table 19-2, lists the standard instructions recognized by the Microchip MPASM™ Assembler.

Section 19.1.1 “Standard Instruction Set” provides a description of each instruction.

TABLE 19-1: OPCODE FIELD DESCRIPTIONS

Field	Description
a	RAM access bit a = 0: RAM location in Access RAM (BSR register is ignored) a = 1: RAM bank is specified by BSR register
bbb	Bit address within an 8-bit file register (0 to 7).
BSR	Bank Select Register. Used to select the current RAM bank.
C, DC, Z, OV, N	ALU Status bits: **C**arry, **D**igit **C**arry, **Z**ero, **Ov**erflow, **N**egative.
d	Destination select bit d = 0: store result in WREG d = 1: store result in file register f
dest	Destination: either the WREG register or the specified register file location.
f	8-bit register file address (00h to FFh) or 2-bit FSR designator (0h to 3h).
f_s	12-bit register file address (000h to FFFh). This is the source address.
f_d	12-bit register file address (000h to FFFh). This is the destination address.
GIE	Global Interrupt Enable bit.
k	Literal field, constant data or label (may be either an 8-bit, 12-bit or a 20-bit value).
label	Label name.
mm	The mode of the TBLPTR register for the table read and table write instructions. Only used with table read and table write instructions:
*	No change to register (such as TBLPTR with table reads and writes)
*+	Post-Increment register (such as TBLPTR with table reads and writes)
*-	Post-Decrement register (such as TBLPTR with table reads and writes)
+*	Pre-Increment register (such as TBLPTR with table reads and writes)
n	The relative address (2's complement number) for relative branch instructions or the direct address for Call/Branch and Return instructions.
PC	Program Counter.
PCL	Program Counter Low Byte.
PCH	Program Counter High Byte.
PCLATH	Program Counter High Byte Latch.
PCLATU	Program Counter Upper Byte Latch.
$\overline{PD}$	Power-Down bit.
PRODH	Product of Multiply High Byte.
PRODL	Product of Multiply Low Byte.
s	Fast Call/Return mode select bit s = 0: do not update into/from shadow registers s = 1: certain registers loaded into/from shadow registers (Fast mode)
TBLPTR	21-bit Table Pointer (points to a program memory location).
TABLAT	8-bit Table Latch.
$\overline{TO}$	Time-out bit.
TOS	Top-of-Stack.
u	Unused or unchanged.
WDT	Watchdog Timer.
WREG	Working register (accumulator).
x	Don't care ('0' or '1'). The assembler will generate code with x = 0. It is the recommended form of use for compatibility with all Microchip software tools.
z_s	7-bit offset value for indirect addressing of register files (source).
z_d	7-bit offset value for indirect addressing of register files (destination).
{ }	Optional argument.
[text]	Indicates an indexed address.
(text)	The contents of text.
[expr]<n>	Specifies bit n of the register indicated by the pointer, expr.
→	Assigned to.
< >	Register bit field.
∈	In the set of.
italics	User-defined term (font is Courier New).

FIGURE 19-1: GENERAL FORMAT FOR INSTRUCTIONS

Example Instruction

Byte-oriented file register operations

15 … 10	9	8	7 … 0
OPCODE	d	a	f (FILE #)

`ADDWF MYREG, W, B`

d = `0` for result destination to be WREG register
d = `1` for result destination to be file register (f)
a = `0` to force Access Bank
a = `1` for BSR to select bank
f = 8-bit file register address

Byte to Byte move operations (2-word)

15 … 12	11 … 0
OPCODE	f (Source FILE #)
`1111`	f (Destination FILE #)

`MOVFF MYREG1, MYREG2`

f = 12-bit file register address

Bit-oriented file register operations

15 … 12	11 … 9	8	7 … 0
OPCODE	b (BIT #)	a	f (FILE #)

`BSF MYREG, bit, B`

b = 3-bit position of bit in file register (f)
a = `0` to force Access Bank
a = `1` for BSR to select bank
f = 8-bit file register address

Literal operations

15 … 8	7 … 0
OPCODE	k (literal)

`MOVLW 7Fh`

k = 8-bit immediate value

Control operations

`CALL`, `GOTO` and Branch operations

15 … 8	7 … 0
OPCODE	n<7:0> (literal)

15 … 12	11 … 0
`1111`	n<19:8> (literal)

`GOTO Label`

n = 20-bit immediate value

15 … 9	8	7 … 0
OPCODE	S	n<7:0> (literal)

15 … 12	11 … 0
`1111`	n<19:8> (literal)

`CALL MYFUNC`

S = Fast bit

15 … 11	10 … 0
OPCODE	n<10:0> (literal)

`BRA MYFUNC`

15 … 8	7 … 0
OPCODE	n<7:0> (literal)

`BC MYFUNC`

TABLE 19-2: PIC18FXXXX INSTRUCTION SET

Mnemonic, Operands		Description	Cycles	16-Bit Instruction Word MSb … LSb	Status Affected	Notes
BYTE-ORIENTED OPERATIONS						
ADDWF	f, d, a	Add WREG and f	1	0010 01da ffff ffff	C, DC, Z, OV, N	1, 2
ADDWFC	f, d, a	Add WREG and Carry bit to f	1	0010 00da ffff ffff	C, DC, Z, OV, N	1, 2
ANDWF	f, d, a	AND WREG with f	1	0001 01da ffff ffff	Z, N	1,2
CLRF	f, a	Clear f	1	0110 101a ffff ffff	Z	2
COMF	f, d, a	Complement f	1	0001 11da ffff ffff	Z, N	1, 2
CPFSEQ	f, a	Compare f with WREG, Skip =	1 (2 or 3)	0110 001a ffff ffff	None	4
CPFSGT	f, a	Compare f with WREG, Skip >	1 (2 or 3)	0110 010a ffff ffff	None	4
CPFSLT	f, a	Compare f with WREG, Skip <	1 (2 or 3)	0110 000a ffff ffff	None	1, 2
DECF	f, d, a	Decrement f	1	0000 01da ffff ffff	C, DC, Z, OV, N	1, 2, 3, 4
DECFSZ	f, d, a	Decrement f, Skip if 0	1 (2 or 3)	0010 11da ffff ffff	None	1, 2, 3, 4
DCFSNZ	f, d, a	Decrement f, Skip if Not 0	1 (2 or 3)	0100 11da ffff ffff	None	1, 2
INCF	f, d, a	Increment f	1	0010 10da ffff ffff	C, DC, Z, OV, N	1, 2, 3, 4
INCFSZ	f, d, a	Increment f, Skip if 0	1 (2 or 3)	0011 11da ffff ffff	None	4
INFSNZ	f, d, a	Increment f, Skip if Not 0	1 (2 or 3)	0100 10da ffff ffff	None	1, 2
IORWF	f, d, a	Inclusive OR WREG with f	1	0001 00da ffff ffff	Z, N	1, 2
MOVF	f, d, a	Move f	1	0101 00da ffff ffff	Z, N	1
MOVFF	f_s, f_d	Move f_s (source) to 1st word f_d (destination) 2nd word	2	1100 ffff ffff ffff 1111 ffff ffff ffff	None	
MOVWF	f, a	Move WREG to f	1	0110 111a ffff ffff	None	
MULWF	f, a	Multiply WREG with f	1	0000 001a ffff ffff	None	1, 2
NEGF	f, a	Negate f	1	0110 110a ffff ffff	C, DC, Z, OV, N	
RLCF	f, d, a	Rotate Left f through Carry	1	0011 01da ffff ffff	C, Z, N	1, 2
RLNCF	f, d, a	Rotate Left f (No Carry)	1	0100 01da ffff ffff	Z, N	
RRCF	f, d, a	Rotate Right f through Carry	1	0011 00da ffff ffff	C, Z, N	
RRNCF	f, d, a	Rotate Right f (No Carry)	1	0100 00da ffff ffff	Z, N	
SETF	f, a	Set f	1	0110 100a ffff ffff	None	1, 2
SUBFWB	f, d, a	Subtract f from WREG with Borrow	1	0101 01da ffff ffff	C, DC, Z, OV, N	
SUBWF	f, d, a	Subtract WREG from f	1	0101 11da ffff ffff	C, DC, Z, OV, N	1, 2
SUBWFB	f, d, a	Subtract WREG from f with Borrow	1	0101 10da ffff ffff	C, DC, Z, OV, N	
SWAPF	f, d, a	Swap Nibbles in f	1	0011 10da ffff ffff	None	4
TSTFSZ	f, a	Test f, Skip if 0	1 (2 or 3)	0110 011a ffff ffff	None	1, 2
XORWF	f, d, a	Exclusive OR WREG with f	1	0001 10da ffff ffff	Z, N	

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 an 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 the 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 two-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.

TABLE 19-2: PIC18FXXXX INSTRUCTION SET (CONTINUED)

Mnemonic,	Operands	Description	Cycles	16-Bit Instruction Word MSb			LSb	Status Affected	Notes
BIT-ORIENTED OPERATIONS									
BCF	f, b, a	Bit Clear f	1	1001	bbba	ffff	ffff	None	1, 2
BSF	f, b, a	Bit Set f	1	1000	bbba	ffff	ffff	None	1, 2
BTFSC	f, b, a	Bit Test f, Skip if Clear	1 (2 or 3)	1011	bbba	ffff	ffff	None	3, 4
BTFSS	f, b, a	Bit Test f, Skip if Set	1 (2 or 3)	1010	bbba	ffff	ffff	None	3, 4
BTG	f, d, a	Bit Toggle f	1	0111	bbba	ffff	ffff	None	1, 2
CONTROL OPERATIONS									
BC	n	Branch if Carry	1 (2)	1110	0010	nnnn	nnnn	None	
BN	n	Branch if Negative	1 (2)	1110	0110	nnnn	nnnn	None	
BNC	n	Branch if Not Carry	1 (2)	1110	0011	nnnn	nnnn	None	
BNN	n	Branch if Not Negative	1 (2)	1110	0111	nnnn	nnnn	None	
BNOV	n	Branch if Not Overflow	1 (2)	1110	0101	nnnn	nnnn	None	
BNZ	n	Branch if Not Zero	1 (2)	1110	0001	nnnn	nnnn	None	
BOV	n	Branch if Overflow	1 (2)	1110	0100	nnnn	nnnn	None	
BRA	n	Branch Unconditionally	2	1101	0nnn	nnnn	nnnn	None	
BZ	n	Branch if Zero	1 (2)	1110	0000	nnnn	nnnn	None	
CALL	n, s	Call Subroutine 1st word	2	1110	110s	kkkk	kkkk	None	
		2nd word		1111	kkkk	kkkk	kkkk		
CLRWDT	—	Clear Watchdog Timer	1	0000	0000	0000	0100	$\overline{TO}$, $\overline{PD}$	
DAW	—	Decimal Adjust Wreg	1	0000	0000	0000	0111	C	
GOTO	n	Go To Address 1st word	2	1110	1111	kkkk	kkkk	None	
		2nd word		1111	kkkk	kkkk	kkkk		
NOP	—	No Operation	1	0000	0000	0000	0000	None	
NOP	—	No Operation	1	1111	xxxx	xxxx	xxxx	None	4
POP	—	Pop Top of Return Stack (TOS)	1	0000	0000	0000	0110	None	
PUSH	—	Push Top of Return Stack (TOS)	1	0000	0000	0000	0101	None	
RCALL	n	Relative Call	2	1101	1nnn	nnnn	nnnn	None	
RESET		Software Device Reset	1	0000	0000	1111	1111	All	
RETFIE	s	Return from Interrupt Enable	2	0000	0000	0001	000s	GIE/GIEH, PEIE/GIEL	
RETLW	k	Return with Literal in WREG	2	0000	1100	kkkk	kkkk	None	
RETURN	s	Return from Subroutine	2	0000	0000	0001	001s	None	
SLEEP	—	Go into Standby mode	1	0000	0000	0000	0011	$\overline{TO}$, $\overline{PD}$	

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 an 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 the 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 two-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.

TABLE 19-2: PIC18FXXXX INSTRUCTION SET (CONTINUED)

Mnemonic, Operands		Description	Cycles	16-Bit Instruction Word				Status Affected	Notes
				MSb			LSb		
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	2	1110	1110	00ff	kkkk	None	
		to FSR(f) 1st word		1111	0000	kkkk	kkkk		
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	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 an 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 the 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 two-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.

19.1.1 STANDARD INSTRUCTION SET

ADDLW **ADD Literal to W**

Syntax: ADDLW k

Operands: $0 \le k \le 255$

Operation: $(W) + k \rightarrow W$

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

Encoding:

0000	1111	kkkk	kkkk

Description: The contents of W are added to the 8-bit literal ‘k’ and the result is placed in W.

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal ‘k’	Process Data	Write to W

Example: `ADDLW 15h`

Before Instruction
W = 10h
After Instruction
W = 25h

ADDWF **ADD W to f**

Syntax: ADDWF f {,d {,a}}

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

Operation: $(W) + (f) \rightarrow dest$

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

Encoding:

0010	01da	ffff	ffff

Description: Add W to register ‘f’. 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 is selected. If ‘a’ is ‘1’, the BSR is used to select the GPR bank (default).
If ‘a’ is ‘0’ and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 “Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode”** for details.

Words: 1

Cycles: 1

Q Cycle Activity:

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

Example: `ADDWF REG, 0, 0`

Before Instruction
W = 17h
REG = 0C2h
After Instruction
W = 0D9h
REG = 0C2h

Note:	All PIC18 instructions may take an optional label argument, preceding the instruction mnemonic, for use in symbolic addressing. If a label is used, the instruction format then becomes: {label} instruction argument(s).

ADDWFC — ADD W and Carry bit to f

Syntax:	ADDWFC f {,d {,a}}
Operands:	0 ≤ f ≤ 255 d ∈ [0,1] a ∈ [0,1]
Operation:	(W) + (f) + (C) → dest
Status Affected:	N, OV, C, DC, Z
Encoding:	`0010` `00da` `ffff` `ffff`
Description:	Add W, the Carry flag and data memory location 'f'. If 'd' is '0', the result is placed in W. If 'd' is '1', the result is placed in data memory location 'f'. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `ADDWFC REG, 0, 1`

Before Instruction
- Carry bit = 1
- REG = 02h
- W = 4Dh

After Instruction
- Carry bit = 0
- REG = 02h
- W = 50h

ANDLW — AND Literal with W

Syntax:	ANDLW k
Operands:	0 ≤ k ≤ 255
Operation:	(W) .AND. k → W
Status Affected:	N, Z
Encoding:	`0000` `1011` `kkkk` `kkkk`
Description:	The contents of W are ANDed with the 8-bit literal 'k'. The result is placed in W.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Write to W

Example: `ANDLW 05Fh`

Before Instruction
- W = A3h

After Instruction
- W = 03h

ANDWF **AND W with f**

Syntax: ANDWF f {,d {,a}}

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

Operation: (W) .AND. (f) → dest

Status Affected: N, Z

Encoding:

0001	01da	ffff	ffff

Description: The contents of W are ANDed with register 'f'. 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 is selected. If 'a' is '1', the BSR is used to select the GPR bank (default).
If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.

Words: 1

Cycles: 1

Q Cycle Activity:

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

Example: `ANDWF REG, 0, 0`

Before Instruction
W = 17h
REG = C2h
After Instruction
W = 02h
REG = C2h

BC **Branch if Carry**

Syntax: BC n

Operands: $-128 \leq n \leq 127$

Operation: if Carry bit is '1',
(PC) + 2 + 2n → PC

Status Affected: None

Encoding:

1110	0010	nnnn	nnnn

Description: If the Carry bit is '1', then the program will branch.
The 2's complement number '2n' is added to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is then a two-cycle instruction.

Words: 1

Cycles: 1(2)

Q Cycle Activity:
If Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	Write to PC
No operation	No operation	No operation	No operation

If No Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	No operation

Example: `HERE BC 5`

Before Instruction
PC = address (HERE)
After Instruction
If Carry = 1;
PC = address (HERE + 12)
If Carry = 0;
PC = address (HERE + 2)

BCF **Bit Clear f**

Syntax:	BCF f, b {,a}
Operands:	$0 \leq f \leq 255$ $0 \leq b \leq 7$ $a \in [0,1]$
Operation:	$0 \rightarrow$ f<b>
Status Affected:	None
Encoding:	1001 bbba ffff ffff
Description:	Bit 'b' in register 'f' is cleared. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example:

```
BCF     FLAG_REG,  7, 0
```

Before Instruction
FLAG_REG = C7h
After Instruction
FLAG_REG = 47h

BN **Branch if Negative**

Syntax:	BN n
Operands:	$-128 \leq n \leq 127$
Operation:	if Negative bit is '1', (PC) + 2 + 2n $\rightarrow$ PC
Status Affected:	None
Encoding:	1110 0110 nnnn nnnn
Description:	If the Negative bit is '1', then the program will branch. The 2's complement number '2n' is added to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is then a two-cycle instruction.
Words:	1
Cycles:	1(2)

Q Cycle Activity:
If Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	Write to PC
No operation	No operation	No operation	No operation

If No Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	No operation

Example:

```
HERE      BN   Jump
```

Before Instruction
PC = address (HERE)
After Instruction
If Negative = 1;
PC = address (Jump)
If Negative = 0;
PC = address (HERE + 2)

BNC **Branch if Not Carry**

Syntax:	BNC n
Operands:	-128 ≤ n ≤ 127
Operation:	if Carry bit is '0', (PC) + 2 + 2n → PC
Status Affected:	None
Encoding:	`1110` `0011` `nnnn` `nnnn`
Description:	If the Carry bit is '0', then the program will branch. The 2's complement number '2n' is added to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is then a two-cycle instruction.
Words:	1
Cycles:	1(2)

Q Cycle Activity:
If Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	Write to PC
No operation	No operation	No operation	No operation

If No Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	No operation

Example: `HERE BNC Jump`

Before Instruction
PC = address (HERE)
After Instruction
If Carry = 0;
PC = address (Jump)
If Carry = 1;
PC = address (HERE + 2)

BNN **Branch if Not Negative**

Syntax:	BNN n
Operands:	-128 ≤ n ≤ 127
Operation:	if Negative bit is '0', (PC) + 2 + 2n → PC
Status Affected:	None
Encoding:	`1110` `0111` `nnnn` `nnnn`
Description:	If the Negative bit is '0', then the program will branch. The 2's complement number '2n' is added to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is then a two-cycle instruction.
Words:	1
Cycles:	1(2)

Q Cycle Activity:
If Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	Write to PC
No operation	No operation	No operation	No operation

If No Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	No operation

Example: `HERE BNN Jump`

Before Instruction
PC = address (HERE)
After Instruction
If Negative = 0;
PC = address (Jump)
If Negative = 1;
PC = address (HERE + 2)

BNOV	**Branch if Not Overflow**
Syntax:	BNOV n
Operands:	-128 ≤ n ≤ 127
Operation:	if Overflow bit is '0', (PC) + 2 + 2n → PC
Status Affected:	None
Encoding:	1110 | 0101 | nnnn | nnnn
Description:	If the Overflow bit is '0', then the program will branch. The 2's complement number '2n' is added to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is then a two-cycle instruction.
Words:	1
Cycles:	1(2)

Q Cycle Activity:
If Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	Write to PC
No operation	No operation	No operation	No operation

If No Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	No operation

Example: `HERE BNOV Jump`

Before Instruction
- PC = address (HERE)

After Instruction
- If Overflow = 0;
  - PC = address (Jump)
- If Overflow = 1;
  - PC = address (HERE + 2)

BNZ	**Branch if Not Zero**
Syntax:	BNZ n
Operands:	-128 ≤ n ≤ 127
Operation:	if Zero bit is '0', (PC) + 2 + 2n → PC
Status Affected:	None
Encoding:	1110 | 0001 | nnnn | nnnn
Description:	If the Zero bit is '0', then the program will branch. The 2's complement number '2n' is added to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is then a two-cycle instruction.
Words:	1
Cycles:	1(2)

Q Cycle Activity:
If Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	Write to PC
No operation	No operation	No operation	No operation

If No Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	No operation

Example: `HERE BNZ Jump`

Before Instruction
- PC = address (HERE)

After Instruction
- If Zero = 0;
  - PC = address (Jump)
- If Zero = 1;
  - PC = address (HERE + 2)

BRA **Unconditional Branch**

Syntax: BRA n

Operands: $-1024 \leq n \leq 1023$

Operation: $(PC) + 2 + 2n \rightarrow PC$

Status Affected: None

Encoding:

1101	0nnn	nnnn	nnnn

Description: Add the 2's complement number '2n' to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is a two-cycle instruction.

Words: 1

Cycles: 2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	Write to PC
No operation	No operation	No operation	No operation

Example: `HERE BRA Jump`

Before Instruction
PC = address `(HERE)`
After Instruction
PC = address `(Jump)`

BSF **Bit Set f**

Syntax: BSF f, b {,a}

Operands: $0 \leq f \leq 255$
$0 \leq b \leq 7$
$a \in [0,1]$

Operation: $1 \rightarrow f<b>$

Status Affected: None

Encoding:

1000	bbba	ffff	ffff

Description: Bit 'b' in register 'f' is set.
If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default).
If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.

Words: 1

Cycles: 1

Q Cycle Activity:

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

Example: `BSF FLAG_REG, 7, 1`

Before Instruction
FLAG_REG = 0Ah
After Instruction
FLAG_REG = 8Ah

BTFSC	Bit Test File, Skip if Clear
Syntax:	BTFSC f, b {,a}
Operands:	0 ≤ f ≤ 255 0 ≤ b ≤ 7 a ∈ [0,1]
Operation:	skip if (f<b>) = 0
Status Affected:	None
Encoding:	1011 | bbba | ffff | ffff
Description:	If bit 'b' in register 'f' is '0', then the next instruction is skipped. If bit 'b' is '0', then the next instruction fetched during the current instruction execution is discarded and a NOP is executed instead, making this a two-cycle instruction. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1(2) **Note:** 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	No operation

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE    BTFSC   FLAG, 1, 0
FALSE   :
TRUE    :
```

Before Instruction
PC = address (HERE)
After Instruction
If FLAG<1> = 0;
PC = address (TRUE)
If FLAG<1> = 1;
PC = address (FALSE)

BTFSS	Bit Test File, Skip if Set
Syntax:	BTFSS f, b {,a}
Operands:	0 ≤ f ≤ 255 0 ≤ b < 7 a ∈ [0,1]
Operation:	skip if (f<b>) = 1
Status Affected:	None
Encoding:	1010 | bbba | ffff | ffff
Description:	If bit 'b' in register 'f' is '1', then the next instruction is skipped. If bit 'b' is '1', then the next instruction fetched during the current instruction execution is discarded and a NOP is executed instead, making this a two-cycle instruction. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1(2) **Note:** 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	No operation

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE    BTFSS   FLAG, 1, 0
FALSE   :
TRUE    :
```

Before Instruction
PC = address (HERE)
After Instruction
If FLAG<1> = 0;
PC = address (FALSE)
If FLAG<1> = 1;
PC = address (TRUE)

BTG **Bit Toggle f**

Syntax:	BTG f, b {,a}
Operands:	$0 \leq f \leq 255$ $0 \leq b < 7$ $a \in [0,1]$
Operation:	$(\overline{f<b>}) \rightarrow f<b>$
Status Affected:	None
Encoding:	`0111` `bbba` `ffff` `ffff`
Description:	Bit 'b' in data memory location 'f' is inverted. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `BTG PORTC, 4, 0`

Before Instruction:
PORTC = `0111 0101` [75h]
After Instruction:
PORTC = `0110 0101` [65h]

BOV **Branch if Overflow**

Syntax:	BOV n
Operands:	$-128 \leq n \leq 127$
Operation:	if Overflow bit is '1', $(PC) + 2 + 2n \rightarrow PC$
Status Affected:	None
Encoding:	`1110` `0100` `nnnn` `nnnn`
Description:	If the Overflow bit is '1', then the program will branch. The 2's complement number '2n' is added to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is then a two-cycle instruction.
Words:	1
Cycles:	1(2)

Q Cycle Activity:
If Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	Write to PC
No operation	No operation	No operation	No operation

If No Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	No operation

Example: `HERE BOV Jump`

Before Instruction
PC = address `(HERE)`
After Instruction
If Overflow = 1;
PC = address `(Jump)`
If Overflow = 0;
PC = address `(HERE + 2)`

BZ **Branch if Zero**

Syntax:	BZ n
Operands:	-128 ≤ n ≤ 127
Operation:	if Zero bit is '1', (PC) + 2 + 2n → PC
Status Affected:	None
Encoding:	1110 | 0000 | nnnn | nnnn
Description:	If the Zero bit is '1', then the program will branch. The 2's complement number '2n' is added to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is then a two-cycle instruction.
Words:	1
Cycles:	1(2)

Q Cycle Activity:
If Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	Write to PC
No operation	No operation	No operation	No operation

If No Jump:

Q1	Q2	Q3	Q4
Decode	Read literal 'n'	Process Data	No operation

Example: `HERE BZ Jump`

Before Instruction
- PC = address (HERE)

After Instruction
- If Zero = 1;
  - PC = address (Jump)
- If Zero = 0;
  - PC = address (HERE + 2)

CALL **Subroutine Call**

Syntax:	CALL k {,s}
Operands:	0 ≤ k ≤ 1048575 s ∈ [0,1]
Operation:	(PC) + 4 → TOS, k → PC<20:1>; if s = 1, (W) → WS, (STATUS) → STATUSS, (BSR) → BSRS
Status Affected:	None
Encoding: 1st word (k<7:0>) 2nd word(k<19:8>)	1110 | 110s | $k_7$kkk | kkkk$_0$ 1111 | k_{19}kkk | kkkk | kkkk$_8$
Description:	Subroutine call of entire 2-Mbyte memory range. First, return address (PC + 4) is pushed onto the return stack. If 's' = 1, the W, STATUS and BSR registers are also pushed into their respective shadow registers, WS, STATUSS and BSRS. If 's' = 0, no update occurs (default). Then, the 20-bit value 'k' is loaded into PC<20:1>. CALL is a two-cycle instruction.
Words:	2
Cycles:	2

Q Cycle Activity:

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

Example: `HERE CALL THERE,1`

Before Instruction
- PC = address (HERE)

After Instruction
- PC = address (THERE)
- TOS = address (HERE + 4)
- WS = W
- BSRS = BSR
- STATUSS = STATUS

CLRF **Clear f**

Syntax: CLRF f {,a}

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

Operation: $000h \rightarrow f$,
$1 \rightarrow Z$

Status Affected: Z

Encoding:

0110	101a	ffff	ffff

Description: Clears the contents of the specified register.
If ‘a’ is ‘0’, the Access Bank is selected. If ‘a’ is ‘1’, the BSR is used to select the GPR bank (default).
If ‘a’ is ‘0’ and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 “Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode”** for details.

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register ‘f’	Process Data	Write register ‘f’

Example: `CLRF FLAG_REG,1`

Before Instruction
FLAG_REG = 5Ah
After Instruction
FLAG_REG = 00h

CLRWDT **Clear Watchdog Timer**

Syntax: CLRWDT

Operands: None

Operation: $000h \rightarrow$ WDT,
$000h \rightarrow$ WDT postscaler,
$1 \rightarrow \overline{TO}$,
$1 \rightarrow \overline{PD}$

Status Affected: $\overline{TO}$, $\overline{PD}$

Encoding:

0000	0000	0000	0100

Description: `CLRWDT` instruction resets the Watchdog Timer. It also resets the postscaler of the WDT. Status bits, $\overline{TO}$ and $\overline{PD}$, are set.

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	No operation	Process Data	No operation

Example: `CLRWDT`

Before Instruction
WDT Counter = ?
After Instruction
WDT Counter = 00h
WDT Postscaler = 0
$\overline{TO}$ = 1
$\overline{PD}$ = 1

COMF — Complement f

Syntax:	COMF f {,d {,a}}
Operands:	$0 \le f \le 255$ $d \in [0,1]$ $a \in [0,1]$
Operation:	$(\bar{f}) \rightarrow$ dest
Status Affected:	N, Z
Encoding:	`0001` `11da` `ffff` `ffff`
Description:	The contents of register 'f' are complemented. 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 is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `COMF REG, 0, 0`

Before Instruction
REG = 13h
After Instruction
REG = 13h
W = ECh

CPFSEQ — Compare f with W, Skip if f = W

Syntax:	CPFSEQ f {,a}
Operands:	$0 \le f \le 255$ $a \in [0,1]$
Operation:	(f) – (W), skip if (f) = (W) (unsigned comparison)
Status Affected:	None
Encoding:	`0110` `001a` `ffff` `ffff`
Description:	Compares the contents of data memory location 'f' to the contents of W by performing an unsigned subtraction. If 'f' = W, then the fetched instruction is discarded and a `NOP` is executed instead, making this a two-cycle instruction. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1(2) **Note:** 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	No operation

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE     CPFSEQ REG, 0
NEQUAL   :
EQUAL    :
```

Before Instruction
PC Address = `HERE`
W = ?
REG = ?
After Instruction
If REG = W;
PC = Address (`EQUAL`)
If REG ≠ W;
PC = Address (`NEQUAL`)

CPFSGT **Compare f with W, Skip if f > W**

Syntax:	CPFSGT f {,a}
Operands:	$0 \leq f \leq 255$ $a \in [0,1]$
Operation:	(f) – (W), skip if (f) > (W) (unsigned comparison)
Status Affected:	None
Encoding:	`0110` `010a` `ffff` `ffff`
Description:	Compares the contents of data memory location 'f' to the contents of the W by performing an unsigned subtraction. If the contents of 'f' are greater than the contents of WREG, then the fetched instruction is discarded and a `NOP` is executed instead, making this a two-cycle instruction. If 'a' is '`0`', the Access Bank is selected. If 'a' is '`1`', the BSR is used to select the GPR bank (default). If 'a' is '`0`' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1(2) **Note:** 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	No operation

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE      CPFSGT REG, 0
NGREATER  :
GREATER   :
```

Before Instruction
- PC = Address (`HERE`)
- W = ?

After Instruction
- If REG > W;
  - PC = Address (`GREATER`)
- If REG ≤ W;
  - PC = Address (`NGREATER`)

CPFSLT **Compare f with W, Skip if f < W**

Syntax:	CPFSLT f {,a}
Operands:	$0 \leq f \leq 255$ $a \in [0,1]$
Operation:	(f) – (W), skip if (f) < (W) (unsigned comparison)
Status Affected:	None
Encoding:	`0110` `000a` `ffff` `ffff`
Description:	Compares the contents of data memory location 'f' to the contents of W by performing an unsigned subtraction. If the contents of 'f' are less than the contents of W, then the fetched instruction is discarded and a `NOP` is executed instead, making this a two-cycle instruction. If 'a' is '`0`', the Access Bank is selected. If 'a' is '`1`', the BSR is used to select the GPR bank (default).
Words:	1
Cycles:	1(2) **Note:** 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	No operation

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE    CPFSLT REG, 1
NLESS   :
LESS    :
```

Before Instruction
- PC = Address (`HERE`)
- W = ?

After Instruction
- If REG < W;
- PC = Address (`LESS`)
- If REG ≥ W;
- PC = Address (`NLESS`)

DAW — Decimal Adjust W Register

Syntax:	DAW
Operands:	None
Operation:	If [W<3:0> > 9] or [DC = `1`] then, (W<3:0>) + 6 → W<3:0>; else, (W<3:0>) → W<3:0> If [W<7:4> + DC > 9] or [C = `1`] then, (W<7:4>) + 6 + DC → W<7:4>; else, (W<7:4>) + DC → W<7:4>
Status Affected:	C
Encoding:	`0000` `0000` `0000` `0111`
Description:	`DAW` adjusts the 8-bit value in W, resulting from the earlier addition of two variables (each in packed BCD format) and produces a correct packed BCD result.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register W	Process Data	Write W

Example 1: `DAW`

Before Instruction
- W = A5h
- C = 0
- DC = 0

After Instruction
- W = 05h
- C = 1
- DC = 0

Example 2:

Before Instruction
- W = CEh
- C = 0
- DC = 0

After Instruction
- W = 34h
- C = 1
- DC = 0

DECF — Decrement f

Syntax:	DECF f {,d {,a}}
Operands:	0 ≤ f ≤ 255 d ∈ [0,1] a ∈ [0,1]
Operation:	(f) – 1 → dest
Status Affected:	C, DC, N, OV, Z
Encoding:	`0000` `01da` `ffff` `ffff`
Description:	Decrement register 'f'. 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 is selected. If 'a' is '`1`', the BSR is used to select the GPR bank (default). If 'a' is '`0`' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `DECF CNT, 1, 0`

Before Instruction
- CNT = 01h
- Z = 0

After Instruction
- CNT = 00h
- Z = 1

DECFSZ	Decrement f, Skip if 0
Syntax:	DECFSZ f {,d {,a}}
Operands:	0 ≤ f ≤ 255 d ∈ [0,1] a ∈ [0,1]
Operation:	(f) – 1 → dest, skip if result = 0
Status Affected:	None
Encoding:	0010 11da ffff ffff
Description:	The contents of register 'f' are decremented. If 'd' is '0', the result is placed in W. If 'd' is '1', the result is placed back in register 'f' (default). If the result is '0', the next instruction, which is already fetched, is discarded and a NOP is executed instead, making it a two-cycle instruction. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1(2) **Note:** 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

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

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE      DECFSZ   CNT, 1, 1
          GOTO     LOOP
CONTINUE
```

Before Instruction
- PC = Address (HERE)

After Instruction
- CNT = CNT – 1
- If CNT = 0;
  - PC = Address (CONTINUE)
- If CNT ≠ 0;
  - PC = Address (HERE + 2)

DCFSNZ	Decrement f, Skip if Not 0
Syntax:	DCFSNZ f {,d {,a}}
Operands:	0 ≤ f ≤ 255 d ∈ [0,1] a ∈ [0,1]
Operation:	(f) – 1 → dest, skip if result ≠ 0
Status Affected:	None
Encoding:	0100 11da ffff ffff
Description:	The contents of register 'f' are decremented. If 'd' is '0', the result is placed in W. If 'd' is '1', the result is placed back in register 'f' (default). If the result is not '0', the next instruction, which is already fetched, is discarded and a NOP is executed instead, making it a two-cycle instruction. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1(2) **Note:** 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

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

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE    DCFSNZ  TEMP, 1, 0
ZERO    :
NZERO   :
```

Before Instruction
- TEMP = ?

After Instruction
- TEMP = TEMP – 1,
- If TEMP = 0;
  - PC = Address (ZERO)
- If TEMP ≠ 0;
  - PC = Address (NZERO)

GOTO — **Unconditional Branch**

Syntax: GOTO k

Operands: $0 \le k \le 1048575$

Operation: k → PC<20:1>

Status Affected: None

Encoding:

1st word (k<7:0>)	1110	1111	$k_7$kkk	kkkk$_0$
2nd word(k<19:8>)	1111	k_{19}kkk	kkkk	kkkk$_8$

Description: GOTO allows an unconditional branch anywhere within the 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: 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 is selected. If 'a' is '1', the BSR is used to select the GPR bank (default).
If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.

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 = FFh
Z = 0
C = ?
DC = ?

After Instruction
CNT = 00h
Z = 1
C = 1
DC = 1

INCFSZ **Increment f, Skip if 0**

Syntax:	INCFSZ f {,d {,a}}
Operands:	0 ≤ f ≤ 255 d ∈ [0,1] a ∈ [0,1]
Operation:	(f) + 1 → dest, skip if result = 0
Status Affected:	None
Encoding:	`0011` `11da` `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 the result is '0', the next instruction, which is already fetched, is discarded and a `NOP` is executed instead, making it a two-cycle instruction. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1(2) **Note:** 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

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

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE    INCFSZ   CNT, 1, 0
NZERO   :
ZERO    :
```

Before Instruction
PC = Address (HERE)
After Instruction
CNT = CNT + 1
If CNT = 0;
PC = Address (ZERO)
If CNT ≠ 0;
PC = Address (NZERO)

INFSNZ **Increment f, Skip if Not 0**

Syntax:	INFSNZ f {,d {,a}}
Operands:	0 ≤ f ≤ 255 d ∈ [0,1] a ∈ [0,1]
Operation:	(f) + 1 → dest, skip if result ≠ 0
Status Affected:	None
Encoding:	`0100` `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 the result is not '0', the next instruction, which is already fetched, is discarded and a `NOP` is executed instead, making it a two-cycle instruction. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1(2) **Note:** 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

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

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE    INFSNZ  REG, 1, 0
ZERO
NZERO
```

Before Instruction
PC = Address (HERE)
After Instruction
REG = REG + 1
If REG ≠ 0;
PC = Address (NZERO)
If REG = 0;
PC = Address (ZERO)

IORLW — Inclusive OR Literal with W

Syntax:	IORLW k
Operands:	$0 \le k \le 255$
Operation:	(W) .OR. k → W
Status Affected:	N, Z
Encoding:	`0000` `1001` `kkkk` `kkkk`
Description:	The contents of W are ORed with the 8-bit literal 'k'. The result is placed in W.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Write to W

<u>Example:</u> `IORLW 35h`

Before Instruction
W = 9Ah
After Instruction
W = BFh

IORWF — Inclusive OR W with f

Syntax:	IORWF f {,d {,a}}
Operands:	$0 \le f \le 255$ $d \in [0,1]$ $a \in [0,1]$
Operation:	(W) .OR. (f) → dest
Status Affected:	N, Z
Encoding:	`0001` `00da` `ffff` `ffff`
Description:	Inclusive OR W with register 'f'. 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 is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

<u>Example:</u> `IORWF RESULT, 0, 1`

Before Instruction
RESULT = 13h
W = 91h
After Instruction
RESULT = 13h
W = 93h

LFSR **Load FSR**

Syntax: LFSR f, k

Operands: $0 \le f \le 2$
$0 \le k \le 4095$

Operation: $k \rightarrow$ FSRf

Status Affected: None

Encoding:

1110 1111	1110 0000	00ff $k_7$kkk	k_{11}kkk kkkk

Description: The 12-bit literal 'k' is loaded into the File Select Register pointed to by 'f'.

Words: 2

Cycles: 2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k' MSB	Process Data	Write literal 'k' MSB to FSRfH
Decode	Read literal 'k' LSB	Process Data	Write literal 'k' to FSRfL

Example: `LFSR 2, 3ABh`

After Instruction
FSR2H = 03h
FSR2L = ABh

MOVF **Move f**

Syntax: MOVF f {,d {,a}}

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

Operation: $f \rightarrow$ dest

Status Affected: N, Z

Encoding:

0101	00da	ffff	ffff

Description: The contents of register 'f' are moved to a destination dependent upon the status of 'd'. If 'd' is '0', the result is placed in W. If 'd' is '1', the result is placed back in register 'f' (default). Location 'f' can be anywhere in the 256-byte bank.
If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default).
If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.

Words: 1

Cycles: 1

Q Cycle Activity:

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

Example: `MOVF REG, 0, 0`

Before Instruction
REG = 22h
W = FFh
After Instruction
REG = 22h
W = 22h

MOVFF **Move f to f**

Syntax:	MOVFF f_s,f_d
Operands:	$0 \le f_s \le 4095$ $0 \le f_d \le 4095$
Operation:	$(f_s) \rightarrow f_d$
Status Affected:	None

Encoding:

1st word (source)	`1100`	`ffff`	`ffff`	`ffff`$_s$
2nd word (destin.)	`1111`	`ffff`	`ffff`	`ffff`$_d$

Description: The contents of source register 'f_s' are moved to destination register 'f_d'. Location of source 'f_s' can be anywhere in the 4096-byte data space (000h to FFFh) and location of destination 'f_d' can also be anywhere from 000h to FFFh.
Either source or destination can be W (a useful special situation).
`MOVFF` is particularly useful for transferring a data memory location to a peripheral register (such as the transmit buffer or an I/O port).
The `MOVFF` instruction cannot use the PCL, TOSU, TOSH or TOSL as the destination register.

Words:	2
Cycles:	2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f' (src)	Process Data	No operation
Decode	No operation No dummy read	No operation	Write register 'f' (dest)

Example: `MOVFF REG1, REG2`

Before Instruction
REG1 = 33h
REG2 = 11h
After Instruction
REG1 = 33h
REG2 = 33h

MOVLB **Move Literal to Low Nibble in BSR**

Syntax:	MOVLW k
Operands:	$0 \le k \le 255$
Operation:	$k \rightarrow$ BSR
Status Affected:	None
Encoding:	`0000` `0001` `kkkk` `kkkk`
Description:	The 8-bit literal 'k' is loaded into the Bank Select Register (BSR). The value of BSR<7:4> always remains '`0`' regardless of the value of k_7:k_4.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Write literal 'k' to BSR

Example: `MOVLB 5`

Before Instruction
BSR Register = 02h
After Instruction
BSR Register = 05h

MOVLW **Move Literal to W**

Syntax:	MOVLW k
Operands:	$0 \le k \le 255$
Operation:	$k \rightarrow W$
Status Affected:	None
Encoding:	`0000` `1110` `kkkk` `kkkk`
Description:	The 8-bit literal 'k' is loaded into W.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Write to W

Example: `MOVLW 5Ah`

After Instruction
W = 5Ah

MOVWF **Move W to f**

Syntax:	MOVWF f {,a}
Operands:	$0 \le f \le 255$ $a \in [0,1]$
Operation:	$(W) \rightarrow f$
Status Affected:	None
Encoding:	`0110` `111a` `ffff` `ffff`
Description:	Move data from W to register 'f'. Location 'f' can be anywhere in the 256-byte bank. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `MOVWF REG, 0`

Before Instruction
W = 4Fh
REG = FFh
After Instruction
W = 4Fh
REG = 4Fh

MULLW **Multiply Literal with W**

Syntax:	MULLW k
Operands:	0 ≤ k ≤ 255
Operation:	(W) x k → PRODH:PRODL
Status Affected:	None
Encoding:	`0000` `1101` `kkkk` `kkkk`
Description:	An unsigned multiplication is carried out between the contents of W and the 8-bit literal 'k'. The 16-bit result is placed in PRODH:PRODL register pair. PRODH contains the high byte. W is unchanged. None of the Status flags are affected. Note that neither Overflow nor Carry is possible in this operation. A zero result is possible but not detected.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Write registers PRODH: PRODL

Example: `MULLW 0C4h`

Before Instruction
- W = E2h
- PRODH = ?
- PRODL = ?

After Instruction
- W = E2h
- PRODH = ADh
- PRODL = 08h

MULWF **Multiply W with f**

Syntax:	MULWF f {,a}
Operands:	0 ≤ f ≤ 255 a ∈ [0,1]
Operation:	(W) x (f) → PRODH:PRODL
Status Affected:	None
Encoding:	`0000` `001a` `ffff` `ffff`
Description:	An unsigned multiplication is carried out between the contents of W and the register file location 'f'. The 16-bit result is stored in the PRODH:PRODL register pair. PRODH contains the high byte. Both W and 'f' are unchanged. None of the Status flags are affected. Note that neither Overflow nor Carry is possible in this operation. A zero result is possible but not detected. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	Write registers PRODH: PRODL

Example: `MULWF REG, 1`

Before Instruction
- W = C4h
- REG = B5h
- PRODH = ?
- PRODL = ?

After Instruction
- W = C4h
- REG = B5h
- PRODH = 8Ah
- PRODL = 94h

NEGF	Negate f
Syntax:	NEGF f {,a}
Operands:	$0 \leq f \leq 255$ $a \in [0,1]$
Operation:	$(\bar{f}) + 1 \rightarrow f$
Status Affected:	N, OV, C, DC, Z
Encoding:	`0110` `110a` `ffff` `ffff`
Description:	Location 'f' is negated using two's complement. The result is placed in the data memory location 'f'. If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `NEGF REG, 1`

Before Instruction
REG = 0011 1010 [3Ah]
After Instruction
REG = 1100 0110 [C6h]

NOP	No Operation
Syntax:	NOP
Operands:	None
Operation:	No operation
Status Affected:	None
Encoding:	`0000` `0000` `0000` `0000` `1111` `xxxx` `xxxx` `xxxx`
Description:	No operation.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	No operation	No operation	No operation

Example:

None.

POP — Pop Top of Return Stack

Syntax:	POP
Operands:	None
Operation:	(TOS) → bit bucket
Status Affected:	None

Encoding:

0000	0000	0000	0110

Description: The TOS value is pulled off the return stack and is discarded. The TOS value then becomes the previous value that was pushed onto the return stack. This instruction is provided to enable the user to properly manage the return stack to incorporate a software stack.

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	No operation	Pop TOS value	No operation

Example:

```
POP
GOTO    NEW
```

Before Instruction
TOS = 0031A2h
Stack (1 level down) = 014332h

After Instruction
TOS = 014332h
PC = NEW

PUSH — Push Top of Return Stack

Syntax:	PUSH
Operands:	None
Operation:	(PC + 2) → TOS
Status Affected:	None

Encoding:

0000	0000	0000	0101

Description: The PC + 2 is pushed onto the top of the return stack. The previous TOS value is pushed down on the stack. This instruction allows implementing a software stack by modifying TOS and then pushing it onto the return stack.

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Push PC + 2 onto return stack	No operation	No operation

Example:

```
PUSH
```

Before Instruction
TOS = 345Ah
PC = 0124h

After Instruction
PC = 0126h
TOS = 0126h
Stack (1 level down) = 345Ah

RCALL Relative Call

Syntax:	RCALL n
Operands:	$-1024 \leq n \leq 1023$
Operation:	$(PC) + 2 \rightarrow TOS$, $(PC) + 2 + 2n \rightarrow PC$
Status Affected:	None
Encoding:	`1101` `1nnn` `nnnn` `nnnn`
Description:	Subroutine call with a jump up to 1K from the current location. First, return address (PC + 2) is pushed onto the stack. Then, add the 2's complement number '2n' to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be PC + 2 + 2n. This instruction is a two-cycle instruction.
Words:	1
Cycles:	2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'n' Push PC to stack	Process Data	Write to PC
No operation	No operation	No operation	No operation

Example: `HERE RCALL Jump`

Before Instruction
PC = Address `(HERE)`
After Instruction
PC = Address `(Jump)`
TOS = Address `(HERE + 2)`

RESET Reset

Syntax:	RESET
Operands:	None
Operation:	Reset all registers and flags that are affected by a $\overline{\text{MCLR}}$ Reset.
Status Affected:	All
Encoding:	`0000` `0000` `1111` `1111`
Description:	This instruction provides a way to execute a $\overline{\text{MCLR}}$ Reset in software.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Start Reset	No operation	No operation

Example: `RESET`

After Instruction
Registers = Reset Value
Flags* = Reset Value

RETFIE **Return from Interrupt**

Syntax:	RETFIE {s}
Operands:	s ∈ [0,1]
Operation:	(TOS) → PC, 1 → GIE/GIEH or PEIE/GIEL; if s = 1, (WS) → W, (STATUSS) → STATUS, (BSRS) → BSR, PCLATU, PCLATH are unchanged
Status Affected:	GIE/GIEH, PEIE/GIEL.
Encoding:	0000 0000 0001 000s
Description:	Return from interrupt. Stack is popped and Top-of-Stack (TOS) is loaded into the PC. Interrupts are enabled by setting either the high or low-priority global interrupt enable bit. If 's' = 1, the contents of the shadow registers WS, STATUSS and BSRS are loaded into their corresponding registers, W, STATUS and BSR. If 's' = 0, no update of these registers occurs (default).
Words:	1
Cycles:	2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	No operation	No operation	Pop PC from stack Set GIEH or GIEL
No operation	No operation	No operation	No operation

Example: RETFIE 1

After Interrupt

PC	=	TOS
W	=	WS
BSR	=	BSRS
STATUS	=	STATUSS
GIE/GIEH, PEIE/GIEL	=	1

RETLW **Return Literal to W**

Syntax:	RETLW k
Operands:	0 ≤ k ≤ 255
Operation:	k → W, (TOS) → PC, PCLATU, PCLATH are unchanged
Status Affected:	None
Encoding:	0000 1100 kkkk kkkk
Description:	W is loaded with the 8-bit literal 'k'. The program counter is loaded from the top of the stack (the return address). The high address latch (PCLATH) remains unchanged.
Words:	1
Cycles:	2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Pop PC from stack, Write to W
No operation	No operation	No operation	No operation

Example:

```
    CALL TABLE ; W contains table
               ; offset value
               ; W now has
               ; table value
   :
TABLE
    ADDWF PCL  ; W = offset
    RETLW k0   ; Begin table
    RETLW k1   ;
   :
   :
    RETLW kn   ; End of table
```

Before Instruction

W	=	07h

After Instruction

W	=	value of kn

RETURN	Return from Subroutine
Syntax:	RETURN {s}
Operands:	s ∈ [0,1]
Operation:	(TOS) → PC; if s = `1`, (WS) → W, (STATUSS) → STATUS, (BSRS) → BSR, PCLATU, PCLATH are unchanged
Status Affected:	None
Encoding:	`0000` `0000` `0001` `001s`
Description:	Return from subroutine. The stack is popped and the top of the stack (TOS) is loaded into the program counter. If 's'= `1`, the contents of the shadow registers WS, STATUSS and BSRS are loaded into their corresponding registers, W, STATUS and BSR. If 's' = `0`, no update of these registers occurs (default).
Words:	1
Cycles:	2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	No operation	Process Data	Pop PC from stack
No operation	No operation	No operation	No operation

Example: `RETURN`

After Instruction:
PC = TOS

RLCF	Rotate Left f through Carry
Syntax:	RLCF f {,d {,a}}
Operands:	0 ≤ f ≤ 255 d ∈ [0,1] a ∈ [0,1]
Operation:	(f<n>) → dest<n + 1>, (f<7>) → C, (C) → dest<0>
Status Affected:	C, N, Z
Encoding:	`0011` `01da` `ffff` `ffff`
Description:	The contents of register 'f' are rotated one bit to the left through the Carry flag. If 'd' is '`0`', the result is placed in W. If 'd' is '`1`', the result is stored back in register 'f' (default). If 'a' is '`0`', the Access Bank is selected. If 'a' is '`1`', the BSR is used to select the GPR bank (default). If 'a' is '`0`' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.

Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `RLCF REG, 0, 0`

Before Instruction
REG = `1110 0110`
C = 0
After Instruction
REG = `1110 0110`
W = `1100 1100`
C = 1

RLNCF — Rotate Left f (No Carry)

Syntax: RLNCF f {,d {,a}}

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

Operation: (f<n>) → dest<n + 1>,
(f<7>) → dest<0>

Status Affected: N, Z

Encoding:

0100	01da	ffff	ffff

Description: The contents of register ‘f’ are rotated one bit to the left. If ‘d’ is ‘0’, the result is placed in W. If ‘d’ is ‘1’, the result is stored back in register ‘f’ (default).
If ‘a’ is ‘0’, the Access Bank is selected. If ‘a’ is ‘1’, the BSR is used to select the GPR bank (default).
If ‘a’ is ‘0’ and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 “Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode”** for details.

Words: 1

Cycles: 1

Q Cycle Activity:

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

Example: `RLNCF REG, 1, 0`

Before Instruction
REG = 1010 1011
After Instruction
REG = 0101 0111

RRCF — Rotate Right f through Carry

Syntax: RRCF f {,d {,a}}

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

Operation: (f<n>) → dest<n – 1>,
(f<0>) → C,
(C) → dest<7>

Status Affected: C, N, Z

Encoding:

0011	00da	ffff	ffff

Description: The contents of register ‘f’ are rotated one bit to the right through the Carry flag. 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 is selected. If ‘a’ is ‘1’, the BSR is used to select the GPR bank (default).
If ‘a’ is ‘0’ and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 “Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode”** for details.

Words: 1

Cycles: 1

Q Cycle Activity:

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

Example: `RRCF REG, 0, 0`

Before Instruction
REG = 1110 0110
C = 0
After Instruction
REG = 1110 0110
W = 0111 0011
C = 0

RRNCF — Rotate Right f (No Carry)

Syntax:	RRNCF f {,d {,a}}
Operands:	$0 \leq f \leq 255$ $d \in [0,1]$ $a \in [0,1]$
Operation:	(f<n>) → dest<n – 1>, (f<0>) → dest<7>
Status Affected:	N, Z
Encoding:	`0100` `00da` `ffff` `ffff`
Description:	The contents of register ‘f’ are rotated one bit to the right. 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’ is ‘1’, then the bank will be selected as per the BSR value (default). If ‘a’ is ‘0’ and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 “Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode”** for details.

Words:	1
Cycles:	1

Q Cycle Activity:

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

Example 1: `RRNCF REG, 1, 0`

Before Instruction
REG = 1101 0111
After Instruction
REG = 1110 1011

Example 2: `RRNCF REG, 0, 0`

Before Instruction
W = ?
REG = 1101 0111
After Instruction
W = 1110 1011
REG = 1101 0111

SETF — Set f

Syntax:	SETF f {,a}
Operands:	$0 \leq f \leq 255$ $a \in [0,1]$
Operation:	FFh → f
Status Affected:	None
Encoding:	`0110` `100a` `ffff` `ffff`
Description:	The contents of the specified register are set to FFh. If ‘a’ is ‘0’, the Access Bank is selected. If ‘a’ is ‘1’, the BSR is used to select the GPR bank (default). If ‘a’ is ‘0’ and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 “Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode”** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register ‘f’	Process Data	Write register ‘f’

Example: `SETF REG,1`

Before Instruction
REG = 5Ah
After Instruction
REG = FFh

SLEEP **Enter Sleep Mode**

Syntax: SLEEP

Operands: None

Operation: 00h → WDT,
0 → WDT postscaler,
1 → $\overline{TO}$,
0 → $\overline{PD}$

Status Affected: $\overline{TO}$, $\overline{PD}$

Encoding:

0000	0000	0000	0011

Description: The Power-Down status bit ($\overline{PD}$) is cleared. The Time-out status bit ($\overline{TO}$) is set. Watchdog Timer and its postscaler are cleared.
The processor is put into Sleep mode with the oscillator stopped.

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	No operation	Process Data	Go to Sleep

Example: `SLEEP`

Before Instruction
$\overline{TO}$ = ?
$\overline{PD}$ = ?

After Instruction
$\overline{TO}$ = 1 †
$\overline{PD}$ = 0

† If WDT causes wake-up, this bit is cleared.

SUBFWB **Subtract f from W with Borrow**

Syntax: SUBFWB f {,d {,a}}

Operands: 0 ≤ f ≤ 255
d ∈ [0,1]
a ∈ [0,1]

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

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

Encoding:

0101	01da	ffff	ffff

Description: Subtract register 'f' and Carry flag (borrow) from W (2's complement method). If 'd' is '0', the result is stored in W. If 'd' is '1', the result is stored in register 'f' (default).
If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default).
If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever f ≤ 95 (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.

Words: 1

Cycles: 1

Q Cycle Activity:

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

Example 1: `SUBFWB REG, 1, 0`

Before Instruction
REG = 3
W = 2
C = 1

After Instruction
REG = FF
W = 2
C = 0
Z = 0
N = 1 ; result is negative

Example 2: `SUBFWB REG, 0, 0`

Before Instruction
REG = 2
W = 5
C = 1

After Instruction
REG = 2
W = 3
C = 1
Z = 0
N = 0 ; result is positive

Example 3: `SUBFWB REG, 1, 0`

Before Instruction
REG = 1
W = 2
C = 0

After Instruction
REG = 0
W = 2
C = 1
Z = 1 ; result is zero
N = 0

SUBLW — Subtract W from Literal

Syntax:	SUBLW k
Operands:	$0 \leq k \leq 255$
Operation:	$k - (W) \rightarrow W$
Status Affected:	N, OV, C, DC, Z
Encoding:	`0000` `1000` `kkkk` `kkkk`
Description	W is subtracted from the 8-bit literal 'k'. The result is placed in W.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Write to W

Example 1: `SUBLW 02h`

Before Instruction
W = 01h
C = ?
After Instruction
W = 01h
C = 1 ; result is positive
Z = 0
N = 0

Example 2: `SUBLW 02h`

Before Instruction
W = 02h
C = ?
After Instruction
W = 00h
C = 1 ; result is zero
Z = 1
N = 0

Example 3: `SUBLW 02h`

Before Instruction
W = 03h
C = ?
After Instruction
W = FFh ; (2's complement)
C = 0 ; result is negative
Z = 0
N = 1

SUBWF — Subtract W from f

Syntax:	SUBWF f {,d {,a}}
Operands:	$0 \leq f \leq 255$ $d \in [0,1]$ $a \in [0,1]$
Operation:	$(f) - (W) \rightarrow dest$
Status Affected:	N, OV, C, DC, Z
Encoding:	`0101` `11da` `ffff` `ffff`
Description:	Subtract W 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 is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example 1: `SUBWF REG, 1, 0`

Before Instruction
REG = 3
W = 2
C = ?
After Instruction
REG = 1
W = 2
C = 1 ; result is positive
Z = 0
N = 0

Example 2: `SUBWF REG, 0, 0`

Before Instruction
REG = 2
W = 2
C = ?
After Instruction
REG = 2
W = 0
C = 1 ; result is zero
Z = 1
N = 0

Example 3: `SUBWF REG, 1, 0`

Before Instruction
REG = 1
W = 2
C = ?
After Instruction
REG = FFh ;(2's complement)
W = 2
C = 0 ; result is negative
Z = 0
N = 1

SUBWFB **Subtract W from f with Borrow**

Syntax:	SUBWFB f {,d {,a}}
Operands:	$0 \le f \le 255$ $d \in [0,1]$ $a \in [0,1]$
Operation:	$(f) - (W) - (\overline{C}) \rightarrow$ 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 is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
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	=	19h	(0001 1001)
W	=	0Dh	(0000 1101)
C	=	1	

After Instruction

REG	=	0Ch	(0000 1011)
W	=	0Dh	(0000 1101)
C	=	1	
Z	=	0	
N	=	0	; result is positive

Example 2: `SUBWFB REG, 0, 0`

Before Instruction

REG	=	1Bh	(0001 1011)
W	=	1Ah	(0001 1010)
C	=	0	

After Instruction

REG	=	1Bh	(0001 1011)
W	=	00h	
C	=	1	
Z	=	1	; result is zero
N	=	0	

Example 3: `SUBWFB REG, 1, 0`

Before Instruction

REG	=	03h	(0000 0011)
W	=	0Eh	(0000 1101)
C	=	1	

After Instruction

REG	=	F5h	(1111 0100) ; [2's comp]
W	=	0Eh	(0000 1101)
C	=	0	
Z	=	0	
N	=	1	; result is negative

SWAPF **Swap f**

Syntax:	SWAPF f {,d {,a}}
Operands:	$0 \le f \le 255$ $d \in [0,1]$ $a \in [0,1]$
Operation:	(f<3:0>) $\rightarrow$ dest<7:4>, (f<7:4>) $\rightarrow$ 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 is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \le 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
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 = 53h

After Instruction

REG = 35h

TBLRD	Table Read
Syntax:	TBLRD (*; *+; *-; +*)
Operands:	None
Operation:	if TBLRD *, (Prog Mem (TBLPTR)) → TABLAT, TBLPTR – No Change; if TBLRD *+, (Prog Mem (TBLPTR)) → TABLAT, (TBLPTR) + 1 → TBLPTR; if TBLRD *-, (Prog Mem (TBLPTR)) → TABLAT, (TBLPTR) – 1 → TBLPTR; if TBLRD +*, (TBLPTR) + 1 → TBLPTR, (Prog Mem (TBLPTR)) → TABLAT
Status Affected:	None

Encoding:

0000	0000	0000	10nn nn=0 * =1 *+ =2 *- =3 +*

Description: This instruction is used to read the contents of Program Memory (P.M.). To address the program memory, a pointer called Table Pointer (TBLPTR) is used.

The TBLPTR (a 21-bit pointer) points to each byte in the program memory. TBLPTR has a 2-Mbyte address range.

TBLPTR<0> = 0: Least Significant Byte of Program Memory Word

TBLPTR<0> = 1: Most Significant Byte of Program Memory Word

The `TBLRD` instruction can modify the value of TBLPTR as follows:

- no change
- post-increment
- post-decrement
- pre-increment

Words: 1

Cycles: 2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	No operation	No operation	No operation
No operation	No operation (Read Program Memory)	No operation	No operation (Write TABLAT)

TBLRD — Table Read (Continued)

Example 1: `TBLRD *+ ;`

Before Instruction

TABLAT	=	55h
TBLPTR	=	00A356h
MEMORY (00A356h)	=	34h

After Instruction

TABLAT	=	34h
TBLPTR	=	00A357h

Example 2: `TBLRD +* ;`

Before Instruction

TABLAT	=	AAh
TBLPTR	=	01A357h
MEMORY (01A357h)	=	12h
MEMORY (01A358h)	=	34h

After Instruction

TABLAT	=	34h
TBLPTR	=	01A358h

TBLWT **Table Write**

Syntax:	TBLWT (*; *+; *-; +*)
Operands:	None
Operation:	if TBLWT*, (TABLAT) → Holding Register, TBLPTR – No Change; if TBLWT*+, (TABLAT) → Holding Register, (TBLPTR) + 1 → TBLPTR; if TBLWT*-, (TABLAT) → Holding Register, (TBLPTR) – 1 → TBLPTR; if TBLWT+*, (TBLPTR) + 1 → TBLPTR, (TABLAT) → Holding Register
Status Affected:	None

Encoding:

0000	0000	0000	11nn nn=0 * =1 *+ =2 *- =3 +*

Description: This instruction uses the 3 LSBs of TBLPTR to determine which of the 8 holding registers the TABLAT is written to. The holding registers are used to program the contents of Program Memory (P.M.). (Refer to **Section 6.0 “Flash Program Memory”** for additional details on programming Flash memory.)

The TBLPTR (a 21-bit pointer) points to each byte in the program memory. TBLPTR has a 2-Mbyte address range. The LSb of the TBLPTR selects which byte of the program memory location to access.

TBLPTR<0> = 0: Least Significant Byte of Program Memory Word
TBLPTR<0> = 1: Most Significant Byte of Program Memory Word

The `TBLWT` instruction can modify the value of TBLPTR as follows:

- no change
- post-increment
- post-decrement
- pre-increment

Words: 1

Cycles: 2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	No operation	No operation	No operation
No operation	No operation (Read TABLAT)	No operation	No operation (Write to Holding Register)

TBLWT **Table Write (Continued)**

Example 1: `TBLWT *+;`

Before Instruction
- TABLAT = 55h
- TBLPTR = 00A356h
- HOLDING REGISTER (00A356h) = FFh

After Instructions (table write completion)
- TABLAT = 55h
- TBLPTR = 00A357h
- HOLDING REGISTER (00A356h) = 55h

Example 2: `TBLWT +*;`

Before Instruction
- TABLAT = 34h
- TBLPTR = 01389Ah
- HOLDING REGISTER (01389Ah) = FFh
- HOLDING REGISTER (01389Bh) = FFh

After Instruction (table write completion)
- TABLAT = 34h
- TBLPTR = 01389Bh
- HOLDING REGISTER (01389Ah) = FFh
- HOLDING REGISTER (01389Bh) = 34h

TSTFSZ **Test f, Skip if 0**

Syntax: TSTFSZ f {,a}

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

Operation: skip if f = 0

Status Affected: None

Encoding:

0110	011a	ffff	ffff

Description: If 'f' = 0, the next instruction fetched during the current instruction execution is discarded and a NOP is executed, making this a two-cycle instruction.
If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default).
If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.

Words: 1

Cycles: 1(2)
Note: 3 cycles if skip and followed by a 2-word instruction.

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register 'f'	Process Data	No operation

If skip:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation

If skip and followed by 2-word instruction:

Q1	Q2	Q3	Q4
No operation	No operation	No operation	No operation
No operation	No operation	No operation	No operation

Example:

```
HERE     TSTFSZ  CNT, 1
NZERO    :
ZERO     :
```

Before Instruction
PC = Address (HERE)
After Instruction
If CNT = 00h,
PC = Address (ZERO)
If CNT ≠ 00h,
PC = Address (NZERO)

XORLW **Exclusive OR Literal with W**

Syntax: XORLW k

Operands: $0 \leq k \leq 255$

Operation: (W) .XOR. k → W

Status Affected: N, Z

Encoding:

0000	1010	kkkk	kkkk

Description: The contents of W are XORed with the 8-bit literal 'k'. The result is placed in W.

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Write to W

Example: XORLW 0AFh

Before Instruction
W = B5h
After Instruction
W = 1Ah

XORWF	Exclusive OR W with f
Syntax:	XORWF f {,d {,a}}
Operands:	$0 \leq f \leq 255$ $d \in [0,1]$ $a \in [0,1]$
Operation:	(W) .XOR. (f) $\rightarrow$ dest
Status Affected:	N, Z
Encoding:	`0001` `10da` `ffff` `ffff`
Description:	Exclusive OR the contents of W with register 'f'. If 'd' is '0', the result is stored in W. If 'd' is '1', the result is stored back in the register 'f' (default). If 'a' is '0', the Access Bank is selected. If 'a' is '1', the BSR is used to select the GPR bank (default). If 'a' is '0' and the extended instruction set is enabled, this instruction operates in Indexed Literal Offset Addressing mode whenever $f \leq 95$ (5Fh). See **Section 19.2.3 "Byte-Oriented and Bit-Oriented Instructions in Indexed Literal Offset Mode"** for details.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `XORWF REG, 1, 0`

Before Instruction
REG = AFh
W = B5h
After Instruction
REG = 1Ah
W = B5h

19.2 Extended Instruction Set

In addition to the standard 75 instructions of the PIC18 instruction set, PIC18F2450/4450 devices also provide an optional extension to the core CPU functionality. The added features include eight additional instructions that augment indirect and indexed addressing operations and the implementation of Indexed Literal Offset Addressing mode for many of the standard PIC18 instructions.

The additional features of the extended instruction set are disabled by default. To enable them, users must set the XINST Configuration bit.

The instructions in the extended set can all be classified as literal operations, which either manipulate the File Select Registers, or use them for Indexed Addressing. Two of the instructions, `ADDFSR` and `SUBFSR`, each have an additional special instantiation for using FSR2. These versions (`ADDULNK` and `SUBULNK`) allow for automatic return after execution.

The extended instructions are specifically implemented to optimize re-entrant program code (that is, code that is recursive or that uses a software stack) written in high-level languages, particularly C. Among other things, they allow users working in high-level languages to perform certain operations on data structures more efficiently. These include:

- Dynamic allocation and deallocation of software stack space when entering and leaving subroutines
- Function Pointer invocation
- Software Stack Pointer manipulation
- Manipulation of variables located in a software stack

A summary of the instructions in the extended instruction set is provided in Table 19-3. Detailed descriptions are provided in **Section 19.2.2 "Extended Instruction Set"**. The opcode field descriptions in Table 19-1 (page 214) apply to both the standard and extended PIC18 instruction sets.

Note:	The instruction set extension and the Indexed Literal Offset Addressing mode were designed for optimizing applications written in C; the user may likely never use these instructions directly in assembler. The syntax for these commands is provided as a reference for users who may be reviewing code that has been generated by a compiler.

19.2.1 EXTENDED INSTRUCTION SYNTAX

Most of the extended instructions use indexed arguments, using one of the File Select Registers and some offset to specify a source or destination register. When an argument for an instruction serves as part of Indexed Addressing, it is enclosed in square brackets ("[ ]"). This is done to indicate that the argument is used as an index or offset. The MPASM™ Assembler will flag an error if it determines that an index or offset value is not bracketed.

When the extended instruction set is enabled, brackets are also used to indicate index arguments in byte-oriented and bit-oriented instructions. This is in addition to other changes in their syntax. For more details, see **Section 19.2.3.1 "Extended Instruction Syntax with Standard PIC18 Commands"**.

Note:	In the past, square brackets have been used to denote optional arguments in the PIC18 and earlier instruction sets. In this text and going forward, optional arguments are denoted by braces ("{ }").

TABLE 19-3: EXTENSIONS TO THE PIC18 INSTRUCTION SET

Mnemonic, Operands		Description		Cycles	16-Bit Instruction Word MSb			LSb	Status Affected
ADDFSR	f, k	Add Literal to FSR		1	1110	1000	ffkk	kkkk	None
ADDULNK	k	Add Literal to FSR2 and Return		2	1110	1000	11kk	kkkk	None
CALLW		Call Subroutine using WREG		2	0000	0000	0001	0100	None
MOVSF	z_s, f_d	Move z_s (source) to	1st word	2	1110	1011	0zzz	zzzz	None
		f_d (destination)	2nd word		1111	ffff	ffff	ffff	
MOVSS	z_s, z_d	Move z_s (source) to	1st word	2	1110	1011	1zzz	zzzz	None
		z_d (destination)	2nd word		1111	xxxx	xzzz	zzzz	
PUSHL	k	Store Literal at FSR2, Decrement FSR2		1	1110	1010	kkkk	kkkk	None
SUBFSR	f, k	Subtract Literal from FSR		1	1110	1001	ffkk	kkkk	None
SUBULNK	k	Subtract Literal from FSR2 and Return		2	1110	1001	11kk	kkkk	None

19.2.2 EXTENDED INSTRUCTION SET

ADDFSR **Add Literal to FSR**

Syntax:	ADDFSR f, k
Operands:	0 ≤ k ≤ 63 f ∈ [0, 1, 2]
Operation:	FSR(f) + k → FSR(f)
Status Affected:	None
Encoding:	`1110` `1000` `ffkk` `kkkk`
Description:	The 6-bit literal 'k' is added to the contents of the FSR specified by 'f'.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Write to FSR

Example: `ADDFSR 2, 23h`

Before Instruction
FSR2 = 03FFh
After Instruction
FSR2 = 0422h

ADDULNK **Add Literal to FSR2 and Return**

Syntax:	ADDULNK k
Operands:	0 ≤ k ≤ 63
Operation:	FSR2 + k → FSR2, (TOS) → PC
Status Affected:	None
Encoding:	`1110` `1000` `11kk` `kkkk`
Description:	The 6-bit literal 'k' is added to the contents of FSR2. A `RETURN` is then executed by loading the PC with the TOS. The instruction takes two cycles to execute; a `NOP` is performed during the second cycle. This may be thought of as a special case of the `ADDFSR` instruction, where f = 3 (binary '`11`'); it operates only on FSR2.
Words:	1
Cycles:	2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read literal 'k'	Process Data	Write to FSR
No Operation	No Operation	No Operation	No Operation

Example: `ADDULNK 23h`

Before Instruction
FSR2 = 03FFh
PC = 0100h
After Instruction
FSR2 = 0422h
PC = (TOS)

Note: All PIC18 instructions may take an optional label argument preceding the instruction mnemonic for use in symbolic addressing. If a label is used, the instruction syntax then becomes: {label} instruction argument(s).

CALLW **Subroutine Call Using WREG**

Syntax:	CALLW
Operands:	None
Operation:	(PC + 2) $\rightarrow$ TOS, (W) $\rightarrow$ PCL, (PCLATH) $\rightarrow$ PCH, (PCLATU) $\rightarrow$ PCU
Status Affected:	None
Encoding:	`0000` `0000` `0001` `0100`
Description	First, the return address (PC + 2) is pushed onto the return stack. Next, the contents of W are written to PCL; the existing value is discarded. Then the contents of PCLATH and PCLATU are latched into PCH and PCU, respectively. The second cycle is executed as a `NOP` instruction while the new next instruction is fetched. Unlike `CALL`, there is no option to update W, STATUS or BSR.
Words:	1
Cycles:	2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read WREG	Push PC to stack	No operation
No operation	No operation	No operation	No operation

Example: `HERE CALLW`

Before Instruction

PC	=	address `(HERE)`
PCLATH	=	10h
PCLATU	=	00h
W	=	06h

After Instruction

PC	=	001006h
TOS	=	address `(HERE + 2)`
PCLATH	=	10h
PCLATU	=	00h
W	=	06h

MOVSF **Move Indexed to f**

Syntax:	MOVSF [z_s], f_d
Operands:	$0 \le z_s \le 127$ $0 \le f_d \le 4095$
Operation:	$((FSR2) + z_s) \rightarrow f_d$
Status Affected:	None

Encoding:

1st word (source)	`1110`	`1011`	`0zzz`	$zzzz_s$
2nd word (destin.)	`1111`	`ffff`	`ffff`	$ffff_d$

Description:	The contents of the source register are moved to destination register 'f_d'. The actual address of the source register is determined by adding the 7-bit literal offset 'z_s' in the first word to the value of FSR2. The address of the destination register is specified by the 12-bit literal 'f_d' in the second word. Both addresses can be anywhere in the 4096-byte data space (000h to FFFh). The `MOVSF` instruction cannot use the PCL, TOSU, TOSH or TOSL as the destination register. If the resultant source address points to an indirect addressing register, the value returned will be 00h.
Words:	2
Cycles:	2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Determine source addr	Determine source addr	Read source reg
Decode	No operation No dummy read	No operation	Write register 'f' (dest)

Example: `MOVSF [05h], REG2`

Before Instruction

FSR2	=	80h
Contents of 85h	=	33h
REG2	=	11h

After Instruction

FSR2	=	80h
Contents of 85h	=	33h
REG2	=	33h

MOVSS **Move Indexed to Indexed**

Syntax:	MOVSS [z_s], [z_d]
Operands:	$0 \le z_s \le 127$ $0 \le z_d \le 127$
Operation:	$((FSR2) + z_s) \rightarrow ((FSR2) + z_d)$
Status Affected:	None

Encoding:

1st word (source)	1110	1011	1zzz	$zzzz_s$
2nd word (dest.)	1111	xxxx	xzzz	$zzzz_d$

Description: The contents of the source register are moved to the destination register. The addresses of the source and destination registers are determined by adding the 7-bit literal offsets 'z_s' or 'z_d', respectively, to the value of FSR2. Both registers can be located anywhere in the 4096-byte data memory space (000h to FFFh).
The `MOVSS` instruction cannot use the PCL, TOSU, TOSH or TOSL as the destination register.
If the resultant source address points to an indirect addressing register, the value returned will be 00h. If the resultant destination address points to an indirect addressing register, the instruction will execute as a `NOP`.

Words: 2

Cycles: 2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Determine source addr	Determine source addr	Read source reg
Decode	Determine dest addr	Determine dest addr	Write to dest reg

Example: `MOVSS [05h], [06h]`

Before Instruction
- FSR2 = 80h
- Contents of 85h = 33h
- Contents of 86h = 11h

After Instruction
- FSR2 = 80h
- Contents of 85h = 33h
- Contents of 86h = 33h

PUSHL **Store Literal at FSR2, Decrement FSR2**

Syntax:	PUSHL k
Operands:	$0 \le k \le 255$
Operation:	$k \rightarrow (FSR2)$, $FSR2 - 1 \rightarrow FSR2$
Status Affected:	None

Encoding:

1111	1010	kkkk	kkkk

Description: The 8-bit literal 'k' is written to the data memory address specified by FSR2. FSR2 is decremented by '1' after the operation. This instruction allows users to push values onto a software stack.

Words: 1

Cycles: 1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read 'k'	Process data	Write to destination

Example: `PUSHL 08h`

Before Instruction
- FSR2H:FSR2L = 01ECh
- Memory (01ECh) = 00h

After Instruction
- FSR2H:FSR2L = 01EBh
- Memory (01ECh) = 08h

SUBFSR **Subtract Literal from FSR**

Syntax:	SUBFSR f, k
Operands:	0 ≤ k ≤ 63 f ∈ [0, 1, 2]
Operation:	FSRf – k → FSRf
Status Affected:	None
Encoding:	`1110` `1001` `ffkk` `kkkk`
Description:	The 6-bit literal ‘k’ is subtracted from the contents of the FSR specified by ‘f’.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `SUBFSR 2, 23h`

Before Instruction
FSR2 = 03FFh

After Instruction
FSR2 = 03DCh

SUBULNK **Subtract Literal from FSR2 and Return**

Syntax:	SUBULNK k
Operands:	0 ≤ k ≤ 63
Operation:	FSR2 – k → FSR2, (TOS) → PC
Status Affected:	None
Encoding:	`1110` `1001` `11kk` `kkkk`
Description:	The 6-bit literal ‘k’ is subtracted from the contents of the FSR2. A `RETURN` is then executed by loading the PC with the TOS. The instruction takes two cycles to execute; a `NOP` is performed during the second cycle. This may be thought of as a special case of the `SUBFSR` instruction, where f = 3 (binary ‘`11`’); it operates only on FSR2.
Words:	1
Cycles:	2

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read register ‘f’	Process Data	Write to destination
No Operation	No Operation	No Operation	No Operation

Example: `SUBULNK 23h`

Before Instruction
FSR2 = 03FFh
PC = 0100h

After Instruction
FSR2 = 03DCh
PC = (TOS)

19.2.3 BYTE-ORIENTED AND BIT-ORIENTED INSTRUCTIONS IN INDEXED LITERAL OFFSET MODE

Note:	Enabling the PIC18 instruction set extension may cause legacy applications to behave erratically or fail entirely.

In addition to eight new commands in the extended set, enabling the extended instruction set also enables Indexed Literal Offset Addressing mode (**Section 5.6.1 "Indexed Addressing with Literal Offset"**). This has a significant impact on the way that many commands of the standard PIC18 instruction set are interpreted.

When the extended set is disabled, addresses embedded in opcodes are treated as literal memory locations: either as a location in the Access Bank ('a' = `0`) or in a GPR bank designated by the BSR ('a' = `1`). When the extended instruction set is enabled and 'a' = `0`, however, a file register argument of 5Fh or less is interpreted as an offset from the pointer value in FSR2 and not as a literal address. For practical purposes, this means that all instructions that use the Access RAM bit as an argument – that is, all byte-oriented and bit-oriented instructions, or almost half of the core PIC18 instructions – may behave differently when the extended instruction set is enabled.

When the content of FSR2 is 00h, the boundaries of the Access RAM are essentially remapped to their original values. This may be useful in creating backward compatible code. If this technique is used, it may be necessary to save the value of FSR2 and restore it when moving back and forth between C and assembly routines in order to preserve the Stack Pointer. Users must also keep in mind the syntax requirements of the extended instruction set (see **Section 19.2.3.1 "Extended Instruction Syntax with Standard PIC18 Commands"**).

Although the Indexed Literal Offset Addressing mode can be very useful for dynamic stack and pointer manipulation, it can also be very annoying if a simple arithmetic operation is carried out on the wrong register. Users who are accustomed to the PIC18 programming must keep in mind that, when the extended instruction set is enabled, register addresses of 5Fh or less are used for Indexed Literal Offset Addressing.

Representative examples of typical byte-oriented and bit-oriented instructions in the Indexed Literal Offset Addressing mode are provided on the following page to show how execution is affected. The operand conditions shown in the examples are applicable to all instructions of these types.

19.2.3.1 Extended Instruction Syntax with Standard PIC18 Commands

When the extended instruction set is enabled, the file register argument, 'f', in the standard byte-oriented and bit-oriented commands is replaced with the literal offset value, 'k'. As already noted, this occurs only when 'f' is less than or equal to 5Fh. When an offset value is used, it must be indicated by square brackets ("[ ]"). As with the extended instructions, the use of brackets indicates to the compiler that the value is to be interpreted as an index or an offset. Omitting the brackets, or using a value greater than 5Fh within brackets, will generate an error in the MPASM Assembler.

If the index argument is properly bracketed for Indexed Literal Offset Addressing mode, the Access RAM argument is never specified; it will automatically be assumed to be '`0`'. This is in contrast to standard operation (extended instruction set disabled) when 'a' is set on the basis of the target address. Declaring the Access RAM bit in this mode will also generate an error in the MPASM Assembler.

The destination argument, 'd', functions as before.

In the latest versions of the MPASM assembler, language support for the extended instruction set must be explicitly invoked. This is done with either the command line option, `/y`, or the PE directive in the source listing.

19.2.4 CONSIDERATIONS WHEN ENABLING THE EXTENDED INSTRUCTION SET

It is important to note that the extensions to the instruction set may not be beneficial to all users. In particular, users who are not writing code that uses a software stack may not benefit from using the extensions to the instruction set.

Additionally, the Indexed Literal Offset Addressing mode may create issues with legacy applications written to the PIC18 assembler. This is because instructions in the legacy code may attempt to address registers in the Access Bank below 5Fh. Since these addresses are interpreted as literal offsets to FSR2 when the instruction set extension is enabled, the application may read or write to the wrong data addresses.

When porting an application to the PIC18F2450/4450, it is very important to consider the type of code. A large, re-entrant application that is written in 'C' and would benefit from efficient compilation will do well when using the instruction set extensions. Legacy applications that heavily use the Access Bank will most likely not benefit from using the extended instruction set.

ADDWF — ADD W to Indexed (Indexed Literal Offset mode)

Syntax:	ADDWF [k] {,d}
Operands:	$0 \le k \le 95$ $d \in [0,1]$
Operation:	(W) + ((FSR2) + k) → dest
Status Affected:	N, OV, C, DC, Z
Encoding:	`0010` `01d0` `kkkk` `kkkk`
Description:	The contents of W are added to the contents of the register indicated by FSR2, offset by the value ‘k’. If ‘d’ is ‘0’, the result is stored in W. If ‘d’ is ‘1’, the result is stored back in register ‘f’ (default).
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read ‘k’	Process Data	Write to destination

Example: `ADDWF [OFST] ,0`

Before Instruction

W	=	17h
OFST	=	2Ch
FSR2	=	0A00h
Contents of 0A2Ch	=	20h

After Instruction

W	=	37h
Contents of 0A2Ch	=	20h

BSF — Bit Set Indexed (Indexed Literal Offset mode)

Syntax:	BSF [k], b
Operands:	$0 \le f \le 95$ $0 \le b \le 7$
Operation:	1 → ((FSR2) + k)<b>
Status Affected:	None
Encoding:	`1000` `bbb0` `kkkk` `kkkk`
Description:	Bit ‘b’ of the register indicated by FSR2, offset by the value ‘k’, is set.
Words:	1
Cycles:	1

Q Cycle Activity:

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

Example: `BSF [FLAG_OFST], 7`

Before Instruction

FLAG_OFST	=	0Ah
FSR2	=	0A00h
Contents of 0A0Ah	=	55h

After Instruction

Contents of 0A0Ah	=	D5h

SETF — Set Indexed (Indexed Literal Offset mode)

Syntax:	SETF [k]
Operands:	$0 \le k \le 95$
Operation:	FFh → ((FSR2) + k)
Status Affected:	None
Encoding:	`0110` `1000` `kkkk` `kkkk`
Description:	The contents of the register indicated by FSR2, offset by ‘k’, are set to FFh.
Words:	1
Cycles:	1

Q Cycle Activity:

Q1	Q2	Q3	Q4
Decode	Read ‘k’	Process Data	Write register

Example: `SETF [OFST]`

Before Instruction

OFST	=	2Ch
FSR2	=	0A00h
Contents of 0A2Ch	=	00h

After Instruction

Contents of 0A2Ch	=	FFh

19.2.5 SPECIAL CONSIDERATIONS WITH MICROCHIP MPLAB® IDE TOOLS

The latest versions of Microchip's software tools have been designed to fully support the extended instruction set of the PIC18F2450/4450 family of devices. This includes the MPLAB C18 C compiler, MPASM Assembly language and MPLAB Integrated Development Environment (IDE).

When selecting a target device for software development, MPLAB IDE will automatically set default Configuration bits for that device. The default setting for the XINST Configuration bit is '0', disabling the extended instruction set and Indexed Literal Offset Addressing mode. For proper execution of applications developed to take advantage of the extended instruction set, XINST must be set during programming.

To develop software for the extended instruction set, the user must enable support for the instructions and the Indexed Addressing mode in their language tool(s). Depending on the environment being used, this may be done in several ways:

- A menu option, or dialog box within the environment, that allows the user to configure the language tool and its settings for the project
- A command line option
- A directive in the source code

These options vary between different compilers, assemblers and development environments. Users are encouraged to review the documentation accompanying their development systems for the appropriate information.

20.0 DEVELOPMENT SUPPORT

The PIC® microcontrollers are supported with a full range of hardware and software development tools:

- Integrated Development Environment
  - MPLAB® IDE Software
- Assemblers/Compilers/Linkers
  - MPASM™ Assembler
  - MPLAB C18 and MPLAB C30 C Compilers
  - MPLINK™ Object Linker/
    MPLIB™ Object Librarian
  - MPLAB ASM30 Assembler/Linker/Library
- Simulators
  - MPLAB SIM Software Simulator
- Emulators
  - MPLAB ICE 2000 In-Circuit Emulator
  - MPLAB REAL ICE™ In-Circuit Emulator
- In-Circuit Debugger
  - MPLAB ICD 2
- Device Programmers
  - PICSTART® Plus Development Programmer
  - MPLAB PM3 Device Programmer
  - PICkit™ 2 Development Programmer
- Low-Cost Demonstration and Development Boards and Evaluation Kits

20.1 MPLAB Integrated Development Environment Software

The MPLAB IDE software brings an ease of software development previously unseen in the 8/16-bit micro-controller market. The MPLAB IDE is a Windows® operating system-based application that contains:

- A single graphical interface to all debugging tools
  - Simulator
  - Programmer (sold separately)
  - Emulator (sold separately)
  - In-Circuit Debugger (sold separately)
- A full-featured editor with color-coded context
- A multiple project manager
- Customizable data windows with direct edit of contents
- High-level source code debugging
- Visual device initializer for easy register initialization
- Mouse over variable inspection
- Drag and drop variables from source to watch windows
- Extensive on-line help
- Integration of select third party tools, such as HI-TECH Software C Compilers and IAR C Compilers

The MPLAB IDE allows you to:

- Edit your source files (either assembly or C)
- One touch assemble (or compile) and download to PIC MCU emulator and simulator tools (automatically updates all project information)
- Debug using:
  - Source files (assembly or C)
  - Mixed assembly and C
  - Machine code

MPLAB IDE supports multiple debugging tools in a single development paradigm, from the cost-effective simulators, through low-cost in-circuit debuggers, to full-featured emulators. This eliminates the learning curve when upgrading to tools with increased flexibility and power.

20.2 MPASM Assembler

The MPASM Assembler is a full-featured, universal macro assembler for all PIC MCUs.

The MPASM Assembler generates relocatable object files for the MPLINK Object Linker, Intel® standard HEX files, MAP files to detail memory usage and symbol reference, absolute LST files that contain source lines and generated machine code and COFF files for debugging.

The MPASM Assembler features include:

- Integration into MPLAB IDE projects
- User-defined macros to streamline assembly code
- Conditional assembly for multi-purpose source files
- Directives that allow complete control over the assembly process

20.3 MPLAB C18 and MPLAB C30 C Compilers

The MPLAB C18 and MPLAB C30 Code Development Systems are complete ANSI C compilers for Microchip's PIC18 and PIC24 families of microcontrollers and the dsPIC30 and dsPIC33 family of digital signal controllers. These compilers provide powerful integration capabilities, superior code optimization and ease of use not found with other compilers.

For easy source level debugging, the compilers provide symbol information that is optimized to the MPLAB IDE debugger.

20.4 MPLINK Object Linker/ MPLIB Object Librarian

The MPLINK Object Linker combines relocatable objects created by the MPASM Assembler and the MPLAB C18 C Compiler. It can link relocatable objects from precompiled libraries, using directives from a linker script.

The MPLIB Object Librarian manages the creation and modification of library files of precompiled code. When a routine from a library is called from a source file, only the modules that contain that routine will be linked in with the application. This allows large libraries to be used efficiently in many different applications.

The object linker/library features include:

- Efficient linking of single libraries instead of many smaller files
- Enhanced code maintainability by grouping related modules together
- Flexible creation of libraries with easy module listing, replacement, deletion and extraction

20.5 MPLAB ASM30 Assembler, Linker and Librarian

MPLAB ASM30 Assembler produces relocatable machine code from symbolic assembly language for dsPIC30F devices. MPLAB C30 C Compiler uses the assembler to produce its object file. The assembler generates relocatable object files that can then be archived or linked with other relocatable object files and archives to create an executable file. Notable features of the assembler include:

- Support for the entire dsPIC30F instruction set
- Support for fixed-point and floating-point data
- Command line interface
- Rich directive set
- Flexible macro language
- MPLAB IDE compatibility

20.6 MPLAB SIM Software Simulator

The MPLAB SIM Software Simulator allows code development in a PC-hosted environment by simulating the PIC MCUs and dsPIC® DSCs on an instruction level. On any given instruction, the data areas can be examined or modified and stimuli can be applied from a comprehensive stimulus controller. Registers can be logged to files for further run-time analysis. The trace buffer and logic analyzer display extend the power of the simulator to record and track program execution, actions on I/O, most peripherals and internal registers.

The MPLAB SIM Software Simulator fully supports symbolic debugging using the MPLAB C18 and MPLAB C30 C Compilers, and the MPASM and MPLAB ASM30 Assemblers. The software simulator offers the flexibility to develop and debug code outside of the hardware laboratory environment, making it an excellent, economical software development tool.

20.7 MPLAB ICE 2000 High-Performance In-Circuit Emulator

The MPLAB ICE 2000 In-Circuit Emulator is intended to provide the product development engineer with a complete microcontroller design tool set for PIC microcontrollers. Software control of the MPLAB ICE 2000 In-Circuit Emulator is advanced by the MPLAB Integrated Development Environment, which allows editing, building, downloading and source debugging from a single environment.

The MPLAB ICE 2000 is a full-featured emulator system with enhanced trace, trigger and data monitoring features. Interchangeable processor modules allow the system to be easily reconfigured for emulation of different processors. The architecture of the MPLAB ICE 2000 In-Circuit Emulator allows expansion to support new PIC microcontrollers.

The MPLAB ICE 2000 In-Circuit Emulator system has been designed as a real-time emulation system with advanced features that are typically found on more expensive development tools. The PC platform and Microsoft® Windows® 32-bit operating system were chosen to best make these features available in a simple, unified application.

20.8 MPLAB REAL ICE In-Circuit Emulator System

MPLAB REAL ICE In-Circuit Emulator System is Microchip's next generation high-speed emulator for Microchip Flash DSC and MCU devices. It debugs and programs PIC® Flash MCUs and dsPIC® Flash DSCs with the easy-to-use, powerful graphical user interface of the MPLAB Integrated Development Environment (IDE), included with each kit.

The MPLAB REAL ICE probe is connected to the design engineer's PC using a high-speed USB 2.0 interface and is connected to the target with either a connector compatible with the popular MPLAB ICD 2 system (RJ11) or with the new high-speed, noise tolerant, Low-Voltage Differential Signal (LVDS) interconnection (CAT5).

MPLAB REAL ICE is field upgradeable through future firmware downloads in MPLAB IDE. In upcoming releases of MPLAB IDE, new devices will be supported, and new features will be added, such as software breakpoints and assembly code trace. MPLAB REAL ICE offers significant advantages over competitive emulators including low-cost, full-speed emulation, real-time variable watches, trace analysis, complex breakpoints, a ruggedized probe interface and long (up to three meters) interconnection cables.

20.9 MPLAB ICD 2 In-Circuit Debugger

Microchip's In-Circuit Debugger, MPLAB ICD 2, is a powerful, low-cost, run-time development tool, connecting to the host PC via an RS-232 or high-speed USB interface. This tool is based on the Flash PIC MCUs and can be used to develop for these and other PIC MCUs and dsPIC DSCs. The MPLAB ICD 2 utilizes the in-circuit debugging capability built into the Flash devices. This feature, along with Microchip's In-Circuit Serial Programming™ (ICSP™) protocol, offers cost-effective, in-circuit Flash debugging from the graphical user interface of the MPLAB Integrated Development Environment. This enables a designer to develop and debug source code by setting breakpoints, single stepping and watching variables, and CPU status and peripheral registers. Running at full speed enables testing hardware and applications in real time. MPLAB ICD 2 also serves as a development programmer for selected PIC devices.

20.10 MPLAB PM3 Device Programmer

The MPLAB PM3 Device Programmer is a universal, CE compliant device programmer with programmable voltage verification at V_{DDMIN} and V_{DDMAX} for maximum reliability. It features a large LCD display (128 x 64) for menus and error messages and a modular, detachable socket assembly to support various package types. The ICSP™ cable assembly is included as a standard item. In Stand-Alone mode, the MPLAB PM3 Device Programmer can read, verify and program PIC devices without a PC connection. It can also set code protection in this mode. The MPLAB PM3 connects to the host PC via an RS-232 or USB cable. The MPLAB PM3 has high-speed communications and optimized algorithms for quick programming of large memory devices and incorporates an SD/MMC card for file storage and secure data applications.

20.11 PICSTART Plus Development Programmer

The PICSTART Plus Development Programmer is an easy-to-use, low-cost, prototype programmer. It connects to the PC via a COM (RS-232) port. MPLAB Integrated Development Environment software makes using the programmer simple and efficient. The PICSTART Plus Development Programmer supports most PIC devices in DIP packages up to 40 pins. Larger pin count devices, such as the PIC16C92X and PIC17C76X, may be supported with an adapter socket. The PICSTART Plus Development Programmer is CE compliant.

20.12 PICkit 2 Development Programmer

The PICkit™ 2 Development Programmer is a low-cost programmer and selected Flash device debugger with an easy-to-use interface for programming many of Microchip's baseline, mid-range and PIC18F families of Flash memory microcontrollers. The PICkit 2 Starter Kit includes a prototyping development board, twelve sequential lessons, software and HI-TECH's PICC™ Lite C compiler, and is designed to help get up to speed quickly using PIC® microcontrollers. The kit provides everything needed to program, evaluate and develop applications using Microchip's powerful, mid-range Flash memory family of microcontrollers.

20.13 Demonstration, Development and Evaluation Boards

A wide variety of demonstration, development and evaluation boards for various PIC MCUs and dsPIC DSCs allows quick application development on fully functional systems. Most boards include prototyping areas for adding custom circuitry and provide application firmware and source code for examination and modification.

The boards support a variety of features, including LEDs, temperature sensors, switches, speakers, RS-232 interfaces, LCD displays, potentiometers and additional EEPROM memory.

The demonstration and development boards can be used in teaching environments, for prototyping custom circuits and for learning about various microcontroller applications.

In addition to the PICDEM™ and dsPICDEM™ demonstration/development board series of circuits, Microchip has a line of evaluation kits and demonstration software for analog filter design, KEELOQ® security ICs, CAN, IrDA®, PowerSmart battery management, SEEVAL® evaluation system, Sigma-Delta ADC, flow rate sensing, plus many more.

Check the Microchip web page (www.microchip.com) for the complete list of demonstration, development and evaluation kits.

21.0 ELECTRICAL CHARACTERISTICS

Absolute Maximum Ratings(†)

Ambient temperature under bias .... -40°C to +85°C
Storage temperature .... -65°C to +150°C
Voltage on any pin with respect to V_{SS} (except V_{DD} and $\overline{MCLR}$) .... -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
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 all ports .... 200 mA
Maximum current sourced by all ports .... 200 mA

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

2: Voltage spikes below V_{SS} at the $\overline{MCLR}$/V_{PP}/RE3 pin, inducing currents greater than 80 mA, may cause latch-up. Thus, a series resistor of 50-100Ω should be used when applying a “low” level to the $\overline{MCLR}$/V_{PP}/RE3 pin, rather than pulling this pin directly to V_{SS}.

† **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 21-1: PIC18F2450/4450 VOLTAGE-FREQUENCY GRAPH (INDUSTRIAL)

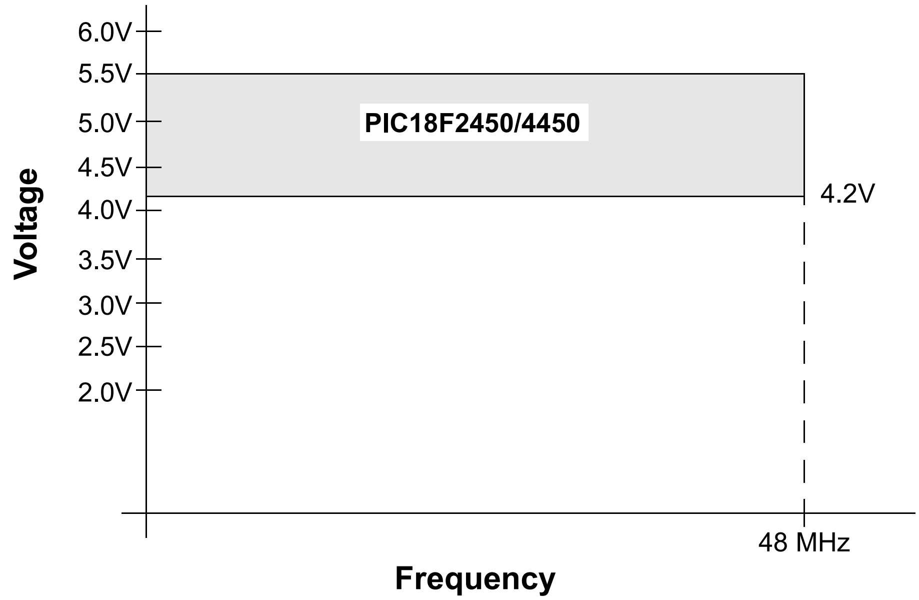
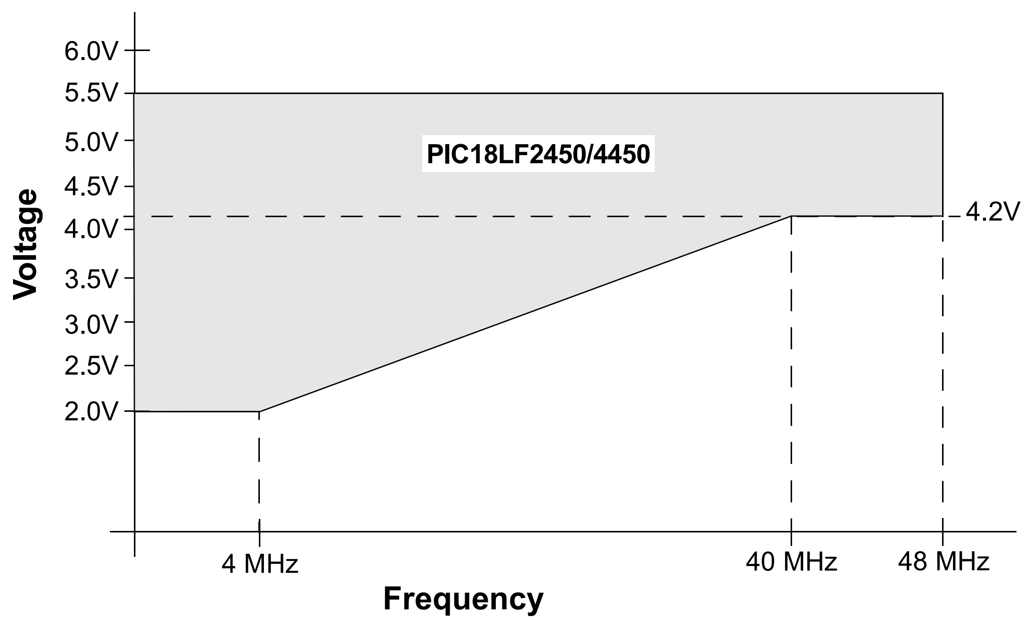


FIGURE 21-2: PIC18LF2450/4450 VOLTAGE-FREQUENCY GRAPH (INDUSTRIAL)



For $2.0V \leq V_{DD} < 4.2V$: $F_{MAX} = (16.36 MHz/V) (V_{DDAPPMIN} – 2.0V) + 4 MHz$
For $4.2V \leq V_{DD}$: $F_{MAX} = 48 MHz$

Note: $V_{DDAPPMIN}$ is the minimum voltage of the PIC® device in the application.

21.1 DC Characteristics: Supply Voltage PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial)

PIC18LF2450/4450 (Industrial)			Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial				
PIC18F2450/4450 (Industrial)			**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial				
Param No.	**Symbol**	**Characteristic**	**Min**	**Typ**	**Max**	**Units**	**Conditions**
D001	V_{DD}	**Supply Voltage**	2.0	—	5.5	V	EC, HS, XT and Internal Oscillator modes
			3.0	—	5.5	V	HSPLL, XTPLL, ECPIO and ECPLL Oscillator modes
D002	V_{DR}	**RAM Data Retention Voltage**(1)	1.5	—	—	V	
D003	V_{POR}	**VDD Start Voltage** to ensure internal Power-on Reset signal	—	—	0.7	V	See **Section 4.3 "Power-on Reset (POR)"** for details
D004	S_{VDD}	**VDD Rise Rate** to Ensure Internal Power-on Reset Signal	0.05	—	—	V/ms	See **Section 4.3 "Power-on Reset (POR)"** for details
D005	V_{BOR}	**Brown-out Reset Voltage**					
		BORV1:BORV0 = 11	2.00	2.11	2.22	V	
		BORV1:BORV0 = 10	2.65	2.79	2.93	V	
		BORV1:BORV0 = 01	4.11	4.33	4.55	V	
		BORV1:BORV0 = 00	4.36	4.59	4.82	V	

Legend: Shading of rows is to assist in readability of the table.

Note 1: This is the limit to which VDD can be lowered in Sleep mode, or during a device Reset, without losing RAM data.

21.2 DC Characteristics: Power-Down and Supply Current PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial)

PIC18LF2450/4450 (Industrial)		Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial				
PIC18F2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial				
Param No.	**Device**	**Typ**	**Max**	**Units**	**Conditions**	
	Power-Down Current (IPD)(1)					
	PIC18LF2450/4450	0.1	0.95	μA	-40°C	VDD = 2.0V (**Sleep** mode)
		0.1	1.0	μA	+25°C	
		0.1	5.0	μA	+85°C	
	PIC18LF2450/4450	0.1	1.4	μA	-40°C	VDD = 3.0V (**Sleep** mode)
		0.1	2.0	μA	+25°C	
		1.5	8.0	μA	+85°C	
	All devices	0.1	19	μA	-40°C	VDD = 5.0V (**Sleep** mode)
		0.1	2.0	μA	+25°C	
		2.5	15	μA	+85°C	

Legend: Shading of rows is to assist in readability of the table.

Note 1: The power-down current in Sleep mode does not depend on the oscillator type. Power-down current is measured with the part in Sleep mode, with all I/O pins in high-impedance state and tied to VDD or VSS and all features that add delta current disabled (such as WDT, Timer1 Oscillator, BOR, etc.).

2: The supply current is mainly a function of operating voltage, frequency and mode. Other factors, such as I/O pin loading and switching rate, oscillator type and circuit, internal code execution pattern and temperature, also have an impact on the current consumption.
The test conditions for all IDD measurements in active operation mode are:
OSC1 = external square wave, from rail-to-rail; all I/O pins tri-stated, pulled to VDD or VSS;
$\overline{MCLR}$ = VDD; WDT enabled/disabled as specified.

3: Standard low-cost 32 kHz crystals have an operating temperature range of -10°C to +70°C. Extended temperature crystals are available at a much higher cost.

4: BOR and HLVD enable internal band gap reference. With both modules enabled, current consumption will be less than the sum of both specifications.

21.2 DC Characteristics: Power-Down and Supply Current PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial) (Continued)

PIC18LF2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
PIC18F2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
Param No.	**Device**	**Typ**	**Max**	**Units**	**Conditions**		
	Supply Current (IDD)(2)						
	PIC18LF2450/4450	10	32	μA	-40°C	VDD = 2.0V	FOSC = 31 kHz (**RC_RUN** mode, INTRC source)
		10	30	μA	+25°C		
		12	29	μA	+85°C		
	PIC18LF2450/4450	35	63	μA	-40°C	VDD = 3.0V	
		30	60	μA	+25°C		
		25	57	μA	+85°C		
	All devices	95	168	μA	-40°C	VDD = 5.0V	
		75	160	μA	+25°C		
		65	152	μA	+85°C		
	PIC18LF2450/4450	2.3	8	μA	-40°C	VDD = 2.0V	FOSC = 31 kHz (**RC_IDLE** mode, INTRC source)
		2.5	8	μA	+25°C		
		3.3	11	μA	+85°C		
	PIC18LF2450/4450	3.3	11	μA	-40°C	VDD = 3.0V	
		3.6	11	μA	+25°C		
		4.0	15	μA	+85°C		
	All devices	6.5	16	μA	-40°C	VDD = 5.0V	
		7.0	16	μA	+25°C		
		9.0	36	μA	+85°C		

Legend: Shading of rows is to assist in readability of the table.

Note 1: The power-down current in Sleep mode does not depend on the oscillator type. Power-down current is measured with the part in Sleep mode, with all I/O pins in high-impedance state and tied to VDD or VSS and all features that add delta current disabled (such as WDT, Timer1 Oscillator, BOR, etc.).

2: The supply current is mainly a function of operating voltage, frequency and mode. Other factors, such as I/O pin loading and switching rate, oscillator type and circuit, internal code execution pattern and temperature, also have an impact on the current consumption.
The test conditions for all IDD measurements in active operation mode are:
OSC1 = external square wave, from rail-to-rail; all I/O pins tri-stated, pulled to VDD or VSS;
$\overline{\text{MCLR}}$ = VDD; WDT enabled/disabled as specified.

3: Standard low-cost 32 kHz crystals have an operating temperature range of -10°C to +70°C. Extended temperature crystals are available at a much higher cost.

4: BOR and HLVD enable internal band gap reference. With both modules enabled, current consumption will be less than the sum of both specifications.

21.2 DC Characteristics: Power-Down and Supply Current PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial) (Continued)

PIC18LF2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
PIC18F2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
Param No.	**Device**	**Typ**	**Max**	**Units**	**Conditions**		
	Supply Current (IDD)[2]						
	PIC18LF2450/4450	200	500	μA	-40°C	VDD = 2.0V	FOSC = 1 MHz (**PRI_RUN**, EC oscillator)
		200	500	μA	+25°C		
		200	500	μA	+85°C		
	PIC18LF2450/4450	500	650	μA	-40°C	VDD = 3.0V	
		400	650	μA	+25°C		
		360	650	μA	+85°C		
	All devices	1.0	1.6	mA	-40°C	VDD = 5.0V	
		0.9	1.5	mA	+25°C		
		0.8	1.4	mA	+85°C		
	PIC18LF2450/4450	0.53	2.0	mA	-40°C	VDD = 2.0V	FOSC = 4 MHz (**PRI_RUN**, EC oscillator)
		0.53	2.0	mA	+25°C		
		0.55	2.0	mA	+85°C		
	PIC18LF2450/4450	1.0	3.0	mA	-40°C	VDD = 3.0V	
		0.9	3.0	mA	+25°C		
		0.9	3.0	mA	+85°C		
	All devices	2.0	6.0	mA	-40°C	VDD = 5.0V	
		1.9	6.0	mA	+25°C		
		1.8	6.0	mA	+85°C		
	All devices	11.0	35	mA	-40°C	VDD = 4.2V	FOSC = 40 MHz (**PRI_RUN**, EC oscillator)
		11.0	35	mA	+25°C		
		11.3	35	mA	+85°C		
	All devices	14.0	40	mA	-40°C	VDD = 5.0V	
		14.0	40	mA	+25°C		
		14.5	40	mA	+85°C		
	All devices	20	40	mA	-40°C	VDD = 4.2V	FOSC = 48 MHz (**PRI_RUN**, EC oscillator)
		20	40	mA	+25°C		
		20	40	mA	+85°C		
	All devices	25	50	mA	-40°C	VDD = 5.0V	
		25	50	mA	+25°C		
		25	50	mA	+85°C		

Legend: Shading of rows is to assist in readability of the table.

Note 1: The power-down current in Sleep mode does not depend on the oscillator type. Power-down current is measured with the part in Sleep mode, with all I/O pins in high-impedance state and tied to VDD or VSS and all features that add delta current disabled (such as WDT, Timer1 Oscillator, BOR, etc.).

2: The supply current is mainly a function of operating voltage, frequency and mode. Other factors, such as I/O pin loading and switching rate, oscillator type and circuit, internal code execution pattern and temperature, also have an impact on the current consumption.
The test conditions for all IDD measurements in active operation mode are:
OSC1 = external square wave, from rail-to-rail; all I/O pins tri-stated, pulled to VDD or VSS;
MCLR = VDD; WDT enabled/disabled as specified.

3: Standard low-cost 32 kHz crystals have an operating temperature range of -10°C to +70°C. Extended temperature crystals are available at a much higher cost.

4: BOR and HLVD enable internal band gap reference. With both modules enabled, current consumption will be less than the sum of both specifications.

21.2 DC Characteristics: Power-Down and Supply Current PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial) (Continued)

PIC18LF2450/4450 (Industrial)		Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
PIC18F2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
Param No.	**Device**	**Typ**	**Max**	**Units**	**Conditions**		
	Supply Current (IDD)(2)						
	PIC18LF2450/4450	50	130	μA	-40°C	VDD = 2.0V	FOSC = 1 MHz (**PRI_IDLE** mode, EC oscillator)
		50	120	μA	+25°C		
		50	115	μA	+85°C		
	PIC18LF2450/4450	75	270	μA	-40°C	VDD = 3.0V	
		80	250	μA	+25°C		
		80	240	μA	+85°C		
	All devices	150	480	μA	-40°C	VDD = 5.0V	
		150	450	μA	+25°C		
		150	430	μA	+85°C		
	PIC18LF2450/4450	190	475	μA	-40°C	VDD = 2.0V	FOSC = 4 MHz (**PRI_IDLE** mode, EC oscillator)
		195	450	μA	+25°C		
		200	430	μA	+85°C		
	PIC18LF2450/4450	295	900	μA	-40°C	VDD = 3.0V	
		300	850	μA	+25°C		
		310	810	μA	+85°C		
	All devices	560	1.5	mA	-40°C	VDD = 5.0V	
		570	1.4	mA	+25°C		
		580	1.3	mA	+85°C		
	All devices	4.4	16	mA	-40°C	VDD = 4.2V	FOSC = 40 MHz (**PRI_IDLE** mode, EC oscillator)
		4.5	16	mA	+25°C		
		4.6	16	mA	+85°C		
	All devices	5.5	18	mA	-40°C	VDD = 5.0V	
		5.6	18	mA	+25°C		
		5.8	18	mA	+85°C		
	All devices	8.0	18	mA	-40°C	VDD = 4.2V	FOSC = 48 MHz (**PRI_IDLE** mode, EC oscillator)
		8.1	18	mA	+25°C		
		8.2	18	mA	+85°C		
	All devices	9.8	21	mA	-40°C	VDD = 5.0V	
		10.0	21	mA	+25°C		
		10.5	21	mA	+85°C		

Legend: Shading of rows is to assist in readability of the table.

Note 1: The power-down current in Sleep mode does not depend on the oscillator type. Power-down current is measured with the part in Sleep mode, with all I/O pins in high-impedance state and tied to VDD or VSS and all features that add delta current disabled (such as WDT, Timer1 Oscillator, BOR, etc.).

2: The supply current is mainly a function of operating voltage, frequency and mode. Other factors, such as I/O pin loading and switching rate, oscillator type and circuit, internal code execution pattern and temperature, also have an impact on the current consumption.
The test conditions for all IDD measurements in active operation mode are:
OSC1 = external square wave, from rail-to-rail; all I/O pins tri-stated, pulled to VDD or VSS;
MCLR = VDD; WDT enabled/disabled as specified.

3: Standard low-cost 32 kHz crystals have an operating temperature range of -10°C to +70°C. Extended temperature crystals are available at a much higher cost.

4: BOR and HLVD enable internal band gap reference. With both modules enabled, current consumption will be less than the sum of both specifications.

21.2 DC Characteristics: Power-Down and Supply Current PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial) (Continued)

PIC18LF2450/4450 (Industrial)		Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
PIC18F2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
Param No.	**Device**	**Typ**	**Max**	**Units**	**Conditions**		
	Supply Current (IDD)(2)						
	PIC18LF2450/4450	13	40	μA	-40°C	VDD = 2.0V	FOSC = 32 kHz(3) (**SEC_RUN** mode, Timer1 as clock)
		15	40	μA	+25°C		
		17	40	μA	+85°C		
	PIC18LF2450/4450	40	76	μA	-40°C	VDD = 3.0V	
		32	70	μA	+25°C		
		25	67	μA	+85°C		
	All devices	100	150	μA	-40°C	VDD = 5.0V	
		80	150	μA	+25°C		
		70	150	μA	+85°C		
	PIC18LF2450/4450	5.6	12	μA	-40°C	VDD = 2.0V	FOSC = 32 kHz(3) (**SEC_IDLE** mode, Timer1 as clock)
		7.0	12	μA	+25°C		
		8.3	12	μA	+85°C		
	PIC18LF2450/4450	6.5	15	μA	-40°C	VDD = 3.0V	
		8.0	15	μA	+25°C		
		9.5	15	μA	+85°C		
	All devices	8.7	25	μA	-40°C	VDD = 5.0V	
		10.2	25	μA	+25°C		
		13.0	36	μA	+85°C		

Legend: Shading of rows is to assist in readability of the table.

Note 1: The power-down current in Sleep mode does not depend on the oscillator type. Power-down current is measured with the part in Sleep mode, with all I/O pins in high-impedance state and tied to VDD or VSS and all features that add delta current disabled (such as WDT, Timer1 Oscillator, BOR, etc.).

2: The supply current is mainly a function of operating voltage, frequency and mode. Other factors, such as I/O pin loading and switching rate, oscillator type and circuit, internal code execution pattern and temperature, also have an impact on the current consumption.
The test conditions for all IDD measurements in active operation mode are:
OSC1 = external square wave, from rail-to-rail; all I/O pins tri-stated, pulled to VDD or VSS;
$\overline{MCLR}$ = VDD; WDT enabled/disabled as specified.

3: Standard low-cost 32 kHz crystals have an operating temperature range of -10°C to +70°C. Extended temperature crystals are available at a much higher cost.

4: BOR and HLVD enable internal band gap reference. With both modules enabled, current consumption will be less than the sum of both specifications.

21.2 DC Characteristics: Power-Down and Supply Current PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial) (Continued)

PIC18LF2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
PIC18F2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
Param No.	**Device**	**Typ**	**Max**	**Units**	**Conditions**		
D022 (ΔIWDT)	**Module Differential Currents (ΔIWDT, ΔIBOR, ΔILVD, ΔIOSCB, ΔIAD)**						
	Watchdog Timer	1.3	3.8	μA	-40°C	VDD = 2.0V	
		1.5	3.8	μA	+25°C		
		2.3	3.8	μA	+85°C		
		1.8	4.6	μA	-40°C	VDD = 3.0V	
		2.0	4.6	μA	+25°C		
		3.0	4.6	μA	+85°C		
		3.3	10	μA	-40°C	VDD = 5.0V	
		3.6	10	μA	+25°C		
		3.9	10	μA	+85°C		
D022A (ΔIBOR)	**Brown-out Reset(4)**	40	52	μA	-40°C to +85°C	VDD = 3.0V	
		45	63	μA	-40°C to +85°C	VDD = 5.0V	
		0	2	μA	-40°C to +85°C		Sleep mode, BOREN1:BOREN0 = 10
D022B (ΔILVD)	**High/Low-Voltage Detect(4)**	22	47	μA	-40°C to +85°C	VDD = 2.0V	
		25	58	μA	-40°C to +85°C	VDD = 3.0V	
		29	69	μA	-40°C to +85°C	VDD = 5.0V	
D025 (ΔIOSCB)	**Timer1 Oscillator**	1.5	4.5	μA	-40°C	VDD = 2.0V	32 kHz on Timer1(3)
		1.2	4.5	μA	+25°C		
		1.6	4.5	μA	+85°C		
		1.7	6.0	μA	-40°C	VDD = 3.0V	32 kHz on Timer1(3)
		1.8	6.0	μA	+25°C		
		2.0	6.0	μA	+85°C		
		1.4	8.0	μA	-40°C	VDD = 5.0V	32 kHz on Timer1(3)
		1.5	8.0	μA	+25°C		
		1.9	8.0	μA	+85°C		
D026 (ΔIAD)	**A/D Converter**	0.2	2.0	μA	-40°C to +85°C	VDD = 2.0V	A/D on, not converting
		0.2	2.0	μA	-40°C to +85°C	VDD = 3.0V	
		0.2	2.0	μA	-40°C to +85°C	VDD = 5.0V	

Legend: Shading of rows is to assist in readability of the table.

Note 1: The power-down current in Sleep mode does not depend on the oscillator type. Power-down current is measured with the part in Sleep mode, with all I/O pins in high-impedance state and tied to VDD or VSS and all features that add delta current disabled (such as WDT, Timer1 Oscillator, BOR, etc.).

2: The supply current is mainly a function of operating voltage, frequency and mode. Other factors, such as I/O pin loading and switching rate, oscillator type and circuit, internal code execution pattern and temperature, also have an impact on the current consumption.
The test conditions for all IDD measurements in active operation mode are:
OSC1 = external square wave, from rail-to-rail; all I/O pins tri-stated, pulled to VDD or VSS;
$\overline{\text{MCLR}}$ = VDD; WDT enabled/disabled as specified.

3: Standard low-cost 32 kHz crystals have an operating temperature range of -10°C to +70°C. Extended temperature crystals are available at a much higher cost.

4: BOR and HLVD enable internal band gap reference. With both modules enabled, current consumption will be less than the sum of both specifications.

21.2 DC Characteristics: Power-Down and Supply Current PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial) (Continued)

PIC18LF2450/4450 (Industrial)		Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ T_A ≤ +85°C for industrial					
PIC18F2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ T_A ≤ +85°C for industrial					
Param No.	**Device**	**Typ**	**Max**	**Units**	**Conditions**		
	USB and Related Module Differential Currents (ΔI_{USBX}, ΔI_{PLL}, ΔI_{UREG})						
ΔI_{USBX}	**USB Module with On-Chip Transceiver**	8.0	14.5	mA	+25°C	V_{DD} = 3.3V	
		12.4	20	mA	+25°C	V_{DD} = 5.0V	
ΔI_{PLL}	**96 MHz PLL (Oscillator Module)**	1.2	3.0	mA	+25°C	V_{DD} = 3.3V	
		1.2	4.8	mA	+25°C	V_{DD} = 5.0V	
ΔI_{UREG}	**USB Internal Voltage Regulator**	80	125	μA	+25°C	V_{DD} = 5.0V	USB Idle, UCON<SUSPND> = 1

Legend: Shading of rows is to assist in readability of the table.

Note 1: The power-down current in Sleep mode does not depend on the oscillator type. Power-down current is measured with the part in Sleep mode, with all I/O pins in high-impedance state and tied to V_{DD} or V_{SS} and all features that add delta current disabled (such as WDT, Timer1 Oscillator, BOR, etc.).

2: The supply current is mainly a function of operating voltage, frequency and mode. Other factors, such as I/O pin loading and switching rate, oscillator type and circuit, internal code execution pattern and temperature, also have an impact on the current consumption.
The test conditions for all I_{DD} measurements in active operation mode are:
OSC1 = external square wave, from rail-to-rail; all I/O pins tri-stated, pulled to V_{DD} or V_{SS};
$\overline{MCLR}$ = V_{DD}; WDT enabled/disabled as specified.

3: Standard low-cost 32 kHz crystals have an operating temperature range of -10°C to +70°C. Extended temperature crystals are available at a much higher cost.

4: BOR and HLVD enable internal band gap reference. With both modules enabled, current consumption will be less than the sum of both specifications.

21.2 DC Characteristics: Power-Down and Supply Current PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial) (Continued)

PIC18LF2450/4450 (Industrial)		Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
PIC18F2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
Param No.	**Device**	**Typ**	**Max**	**Units**	**Conditions**		
ITUSB	**Total USB Run Currents (ITUSB)(2)**						
	Primary Run with USB Module, PLL and USB Voltage Regulator	29	65	mA	-40°C	VDD = 5.0V	EC+PLL 4 MHz input, 48 MHz PRI_RUN, USB module enabled in Full-Speed mode, USB VREG enabled, no bus traffic
		29	65	mA	+25°C	VDD = 5.0V	
		29	65	mA	+85°C	VDD = 5.0V	

Legend: Shading of rows is to assist in readability of the table.

Note 1: The power-down current in Sleep mode does not depend on the oscillator type. Power-down current is measured with the part in Sleep mode, with all I/O pins in high-impedance state and tied to VDD or VSS and all features that add delta current disabled (such as WDT, Timer1 Oscillator, BOR, etc.).

2: The supply current is mainly a function of operating voltage, frequency and mode. Other factors, such as I/O pin loading and switching rate, oscillator type and circuit, internal code execution pattern and temperature, also have an impact on the current consumption.
The test conditions for all IDD measurements in active operation mode are:
OSC1 = external square wave, from rail-to-rail; all I/O pins tri-stated, pulled to VDD or VSS;
$\overline{\text{MCLR}}$ = VDD; WDT enabled/disabled as specified.

3: Standard low-cost 32 kHz crystals have an operating temperature range of -10°C to +70°C. Extended temperature crystals are available at a much higher cost.

4: BOR and HLVD enable internal band gap reference. With both modules enabled, current consumption will be less than the sum of both specifications.

21.3 DC Characteristics: PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial)

DC CHARACTERISTICS			Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial			
Param No.	**Sym**	**Characteristic**	**Min**	**Max**	**Units**	**Conditions**
	VIL	**Input Low Voltage**				
		I/O Ports (except RC4/RC5 in USB mode):				
D030		with TTL Buffer	VSS	0.15 VDD	V	VDD < 4.5V
D030A			—	0.8	V	4.5V ≤ VDD ≤ 5.5V
D032		$\overline{\text{MCLR}}$	VSS	0.2 VDD	V	
D032A		OSC1 and T1OSI	VSS	0.3 VDD	V	XT, HS, HSPLL modes(1)
D033		OSC1	VSS	0.2 VDD	V	EC mode(1)
	VIH	**Input High Voltage**				
		I/O Ports (except RC4/RC5 in USB mode):				
D040		with TTL Buffer	0.25 VDD + 0.8V	VDD	V	VDD < 4.5V
D040A			2.0	VDD	V	4.5V ≤ VDD ≤ 5.5V
D042		$\overline{\text{MCLR}}$	0.8 VDD	VDD	V	
D042A		OSC1 and T1OSI	0.7 VDD	VDD	V	XT, HS, HSPLL modes(1)
D043		OSC1	0.8 VDD	VDD	V	EC mode(1)
	IIL	**Input Leakage Current(2,3)**				
D060		I/O Ports (except D+ and D-)	—	±200	nA	VDD = 5V
			—	±50	nA	VDD = 3V
D061		$\overline{\text{MCLR}}$	—	±1	μA	Vss ≤ VPIN ≤ VDD
D063		OSC1	—	±1	μA	Vss ≤ VPIN ≤ VDD
	IPU	**Weak Pull-up Current**				
D070	IPURB	PORTB Weak Pull-up Current	50	400	μA	VDD = 5V, VPIN = VSS

Note 1: In RC oscillator configuration, the OSC1/CLKI pin is a Schmitt Trigger input. It is not recommended that the PIC® microcontroller be driven with an external clock while in RC mode.

2: The leakage current on the $\overline{\text{MCLR}}$ pin is strongly dependent on the applied voltage level. The specified levels represent normal operating conditions. Higher leakage current may be measured at different input voltages.

3: Negative current is defined as current sourced by the pin.

4: Parameter is characterized but not tested.

21.3 DC Characteristics: PIC18F2450/4450 (Industrial) PIC18LF2450/4450 (Industrial) (Continued)

DC CHARACTERISTICS			Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial			
Param No.	Sym	Characteristic	Min	Max	Units	Conditions
	V_{OL}	**Output Low Voltage**				
D080		I/O Ports (except RC4/RC5 in USB mode)	—	0.6	V	I_{OL} = 8.5 mA, V_{DD} = 4.5V, -40°C to +85°C
D083		OSC2/CLKO (EC, ECIO modes)	—	0.6	V	I_{OL} = 1.6 mA, V_{DD} = 4.5V, -40°C to +85°C
	V_{OH}	**Output High Voltage**(3)				
D090		I/O Ports (except RC4/RC5 in USB mode)	V_{DD} – 0.7	—	V	I_{OH} = -3.0 mA, V_{DD} = 4.5V, -40°C to +85°C
D092		OSC2/CLKO (EC, ECIO, ECPIO modes)	V_{DD} – 0.7	—	V	I_{OH} = -1.3 mA, V_{DD} = 4.5V, -40°C to +85°C
		Capacitive Loading Specs on Output Pins				
D100(4)	C_{OSC2}	OSC2 pin	—	15	pF	In XT and HS modes when external clock is used to drive OSC1
D101	C_{IO}	All I/O pins and OSC2 (in RC mode)	—	50	pF	To meet the AC Timing Specifications

Note 1: In RC oscillator configuration, the OSC1/CLKI pin is a Schmitt Trigger input. It is not recommended that the PIC® microcontroller be driven with an external clock while in RC mode.

2: The leakage current on the $\overline{MCLR}$ pin is strongly dependent on the applied voltage level. The specified levels represent normal operating conditions. Higher leakage current may be measured at different input voltages.

3: Negative current is defined as current sourced by the pin.

4: Parameter is characterized but not tested.

TABLE 21-1: MEMORY PROGRAMMING REQUIREMENTS

DC Characteristics			Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial				
Param No.	**Sym**	**Characteristic**	**Min**	**Typ†**	**Max**	**Units**	**Conditions**
		Internal Program Memory Programming Specifications(1)					
D110	VIHH	Voltage on $\overline{\text{MCLR}}$/VPP/RE3 pin	9.00	—	13.25	V	**(Note 2)**
D113	IDDP	Supply Current during Programming	—	—	10	mA	
		Program Flash Memory					
D130	EP	Cell Endurance	10K	100K	—	E/W	-40°C to +85°C
D131	VPR	VDD for Read	VMIN	—	5.5	V	VMIN = Minimum operating voltage
D132	VIE	VDD for Block Erase	4.5	—	5.5	V	Using ICSP™ port
D132A	VIW	VDD for Externally Timed Erase or Write	3.0	—	5.5	V	Using ICSP port
D132B	VPEW	VDD for Self-Timed Write	VMIN	—	5.5	V	VMIN = Minimum operating voltage
D133	TIE	ICSP™ Block Erase Cycle Time	—	4	—	ms	VDD > 4.5V
D133A	TIW	ICSP Erase or Write Cycle Time (externally timed)	1	—	—	ms	VDD > 4.5V
D133A	TIW	Self-Timed Write Cycle Time	—	2	—	ms	
D134	TRETD	Characteristic Retention	40	100	—	Year	Provided no other specifications are violated

† Data in “Typ” column is at 5.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

Note 1: These specifications are for programming the on-chip program memory through the use of table write instructions.

2: Required only if Single-Supply Programming is disabled.

TABLE 21-2: USB MODULE SPECIFICATIONS

Operating Conditions: -40°C < TA < +85°C (unless otherwise stated).							
Param No.	**Sym**	**Characteristic**	**Min**	**Typ**	**Max**	**Units**	**Comments**
D313	V_{USB}	USB Voltage	3.0	—	3.6	V	Voltage on bus must be in this range for proper USB operation
D314	I_{IL}	Input Leakage on D+ or D- pin	—	—	±1	μA	$V_{SS} \le V_{PIN} \le V_{DD}$; pin at high-impedance
D315	V_{ILUSB}	Input Low Voltage for USB Buffer	—	—	0.8	V	For V_{USB} range
D316	V_{IHUSB}	Input High Voltage for USB Buffer	2.0	—	—	V	For V_{USB} range
D317	V_{CRS}	Crossover Voltage	1.3		2.0	V	Voltage range for D+ and D- crossover to occur
D318	V_{DIFS}	Differential Input Sensitivity	—	—	0.2	V	The difference between D+ and D- must exceed this value while V_{CM} is met
D319	V_{CM}	Differential Common Mode Range	0.8	—	2.5	V	
D320	Z_{OUT}	Driver Output Impedance	28	—	44	Ω	
D321	V_{OL}	Voltage Output Low	0.0	—	0.3	V	1.5 kΩ load connected to 3.6V
D322	V_{OH}	Voltage Output High	2.8	—	3.6	V	15 kΩ load connected to ground

TABLE 21-3: USB INTERNAL VOLTAGE REGULATOR SPECIFICATIONS

Operating Conditions: -40°C < TA < +85°C (unless otherwise stated).							
Param No.	**Sym**	**Characteristics**	**Min**	**Typ**	**Max**	**Units**	**Comments**
D323	V_{USBANA}	Regulator Output Voltage	3.0	—	3.6	V	V_{DD} > 4.0V(1)
D324	C_{USB}	External Filter Capacitor Value	220	470	—	nF	Low ESR

Note 1: If device V_{DD} is less than 4.0V, the internal USB voltage regulator should be disabled and an external 3.0-3.6V supply should be provided on V_{USB}.

FIGURE 21-3: HIGH/LOW-VOLTAGE DETECT CHARACTERISTICS

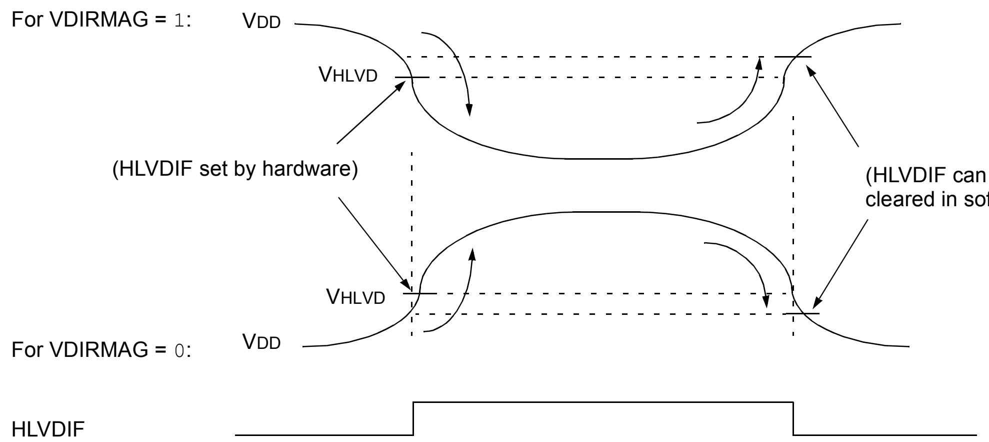


TABLE 21-4: HIGH/LOW-VOLTAGE DETECT CHARACTERISTICS

Standard Operating Conditions (unless otherwise stated)
Operating temperature -40°C ≤ TA ≤ +85°C for industrial

Param No.	Sym	Characteristic		Min	Typ	Max	Units	Conditions
D420		HLVD Voltage on VDD Transition High-to-Low	HLVDL<3:0> = 0000	2.06	2.17	2.28	V	
			HLVDL<3:0> = 0001	2.12	2.23	2.34	V	
			HLVDL<3:0> = 0010	2.24	2.36	2.48	V	
			HLVDL<3:0> = 0011	2.32	2.44	2.56	V	
			HLVDL<3:0> = 0100	2.47	2.60	2.73	V	
			HLVDL<3:0> = 0101	2.65	2.79	2.93	V	
			HLVDL<3:0> = 0110	2.74	2.89	3.04	V	
			HLVDL<3:0> = 0111	2.96	3.12	3.28	V	
			HLVDL<3:0> = 1000	3.22	3.39	3.56	V	
			HLVDL<3:0> = 1001	3.37	3.55	3.73	V	
			HLVDL<3:0> = 1010	3.52	3.71	3.90	V	
			HLVDL<3:0> = 1011	3.70	3.90	4.10	V	
			HLVDL<3:0> = 1100	3.90	4.11	4.32	V	
			HLVDL<3:0> = 1101	4.11	4.33	4.55	V	
			HLVDL<3:0> = 1110	4.36	4.59	4.82	V	

21.4 AC (Timing) Characteristics

21.4.1 TIMING PARAMETER SYMBOLOGY

The timing parameter symbols have been created using one of the following formats:

1. TppS2ppS
2. TppS

T			
F	Frequency	T	Time
Lowercase letters (pp) and their meanings:			
pp			
		mc	$\overline{\text{MCLR}}$
cc	CCP1	osc	OSC1
ck	CLKO	wr	$\overline{\text{WR}}$
dt	Data in	t0	T0CKI
io	I/O port	t1	T1CKI
:Uppercase Letters and their meanings			
S			
F	Fall	P	Period
H	High	R	Rise
I	Invalid (High-Impedance)	V	Valid
L	Low	Z	High-Impedance
		High	High
		Low	Low

21.4.2 TIMING CONDITIONS

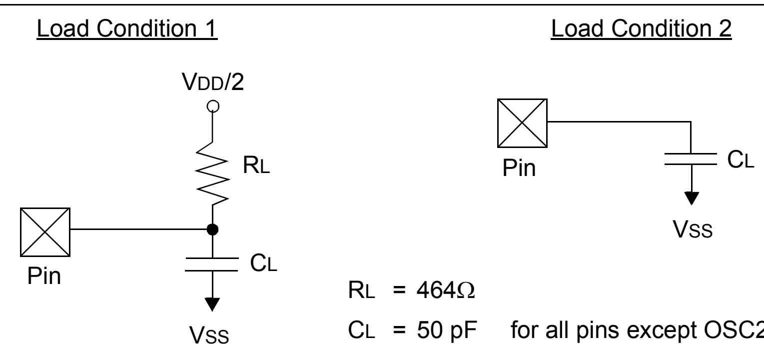
The temperature and voltages specified in Table 21-5 apply to all timing specifications unless otherwise noted. Figure 21-4 specifies the load conditions for the timing specifications.

Note:	Because of space limitations, the generic terms "PIC18FXXXX" and "PIC18LFXXXX" are used throughout this section to refer to the PIC18F2450/4450 and PIC18LF2450/4450 families of devices specifically and only those devices.

TABLE 21-5: TEMPERATURE AND VOLTAGE SPECIFICATIONS – AC

AC CHARACTERISTICS	**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ T_A ≤ +85°C for industrial Operating voltage V_{DD} range as described in DC spec **Section 21.1** and **Section 21.3** . LF parts operate for industrial temperatures only.

FIGURE 21-4: LOAD CONDITIONS FOR DEVICE TIMING SPECIFICATIONS



R_L = 464Ω

C_L = 50 pF for all pins except OSC2/CLKO and including D and E outputs as ports

21.4.3 TIMING DIAGRAMS AND SPECIFICATIONS

FIGURE 21-5: EXTERNAL CLOCK TIMING (ALL MODES EXCEPT PLL)

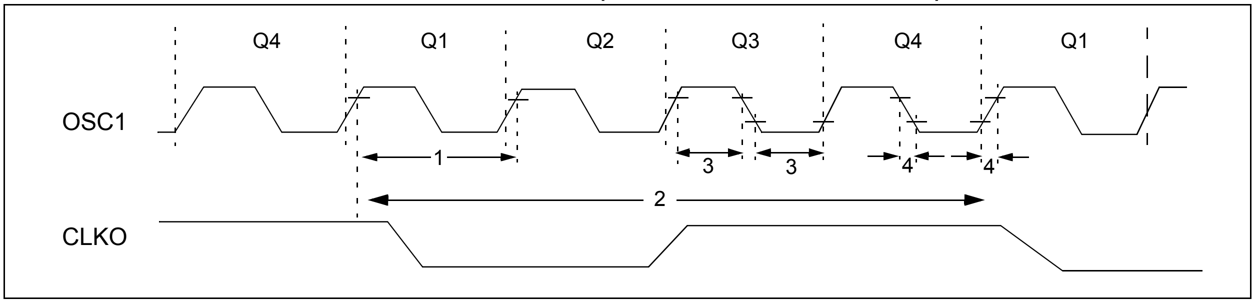


TABLE 21-6: EXTERNAL CLOCK TIMING REQUIREMENTS

Param. No.	Symbol	Characteristic	Min	Max	Units	Conditions
1A	FOSC	External CLKI Frequency(1)	DC	48	MHz	EC, ECIO Oscillator modes
		Oscillator Frequency(1)	0.2	1	MHz	XT, XTPLL Oscillator modes
			4	25	MHz	HS Oscillator mode
			4	25	MHz	HSPLL Oscillator mode
1	TOSC	External CLKI Period(1)	20.8	—	ns	EC, ECIO Oscillator modes
		Oscillator Period(1)	1,000	5,000	ns	XT Oscillator mode
			40	250	ns	HS Oscillator mode
			40	250	ns	HSPLL Oscillator mode
2	TCY	Instruction Cycle Time(1)	83.3	—	ns	TCY = 4/FOSC
3	TosL, TosH	External Clock in (OSC1) High or Low Time	30	—	ns	XT Oscillator mode
			10	—	ns	HS Oscillator mode
4	TosR, TosF	External Clock in (OSC1) Rise or Fall Time	—	20	ns	XT Oscillator mode
			—	7.5	ns	HS Oscillator mode

Note 1: Instruction cycle period (TCY) equals four times the input oscillator time base period for all configurations except PLL. All specified values are based on characterization data for that particular oscillator type under standard operating conditions with the device executing code. Exceeding these specified limits may result in an unstable oscillator operation and/or higher than expected current consumption. All devices are tested to operate at “min.” values with an external clock applied to the OSC1/CLKI pin. When an external clock input is used, the “max.” cycle time limit is “DC” (no clock) for all devices.

TABLE 21-7: PLL CLOCK TIMING SPECIFICATIONS (VDD = 3.0V TO 5.5V)

Param No.	Sym	Characteristic	Min	Typ†	Max	Units	Conditions
F10	FOSC	Oscillator Frequency Range	4	—	48	MHz	
F11	FSYS	On-Chip VCO System Frequency	—	96	—	MHz	
F12	t_{rc}	PLL Start-up Time (lock time)	—	—	2	ms	
F13	ΔCLK	CLKO Stability (jitter)	-0.25	—	+0.25	%	

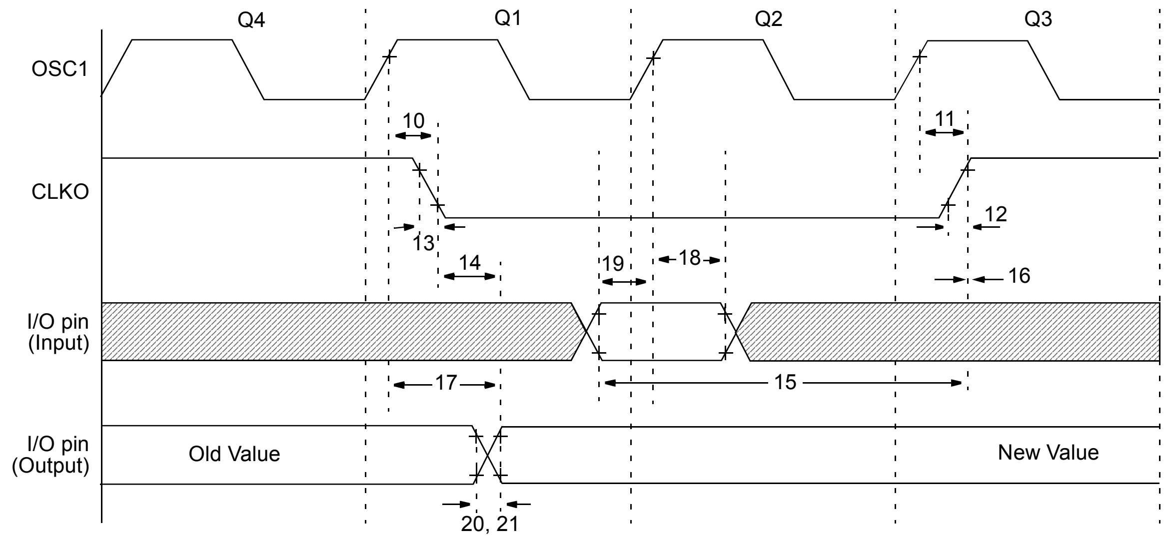
† Data in "Typ" column is at 5V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

TABLE 21-8: AC CHARACTERISTICS: INTERNAL RC ACCURACY PIC18F2450/4450 (INDUSTRIAL) PIC18LF2450/4450 (INDUSTRIAL)

PIC18LF2450/4450 (Industrial)		Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
PIC18F2450/4450 (Industrial)		**Standard Operating Conditions (unless otherwise stated)** Operating temperature -40°C ≤ TA ≤ +85°C for industrial					
Param No.	**Device**	**Min**	**Typ**	**Max**	**Units**	**Conditions**	
	INTRC Accuracy @ Freq = 31 kHz(1)						
	PIC18LF2450/4450	26.562	—	35.938	kHz	-40°C to +85°C	VDD = 2.7-3.3V
	PIC18F2450/4450	26.562	—	35.938	kHz	-40°C to +85°C	VDD = 4.5-5.5V

Legend: Shading of rows is to assist in readability of the table.
Note 1: INTRC frequency after calibration.

FIGURE 21-6: CLKO AND I/O TIMING



Note: Refer to Figure 21-4 for load conditions.

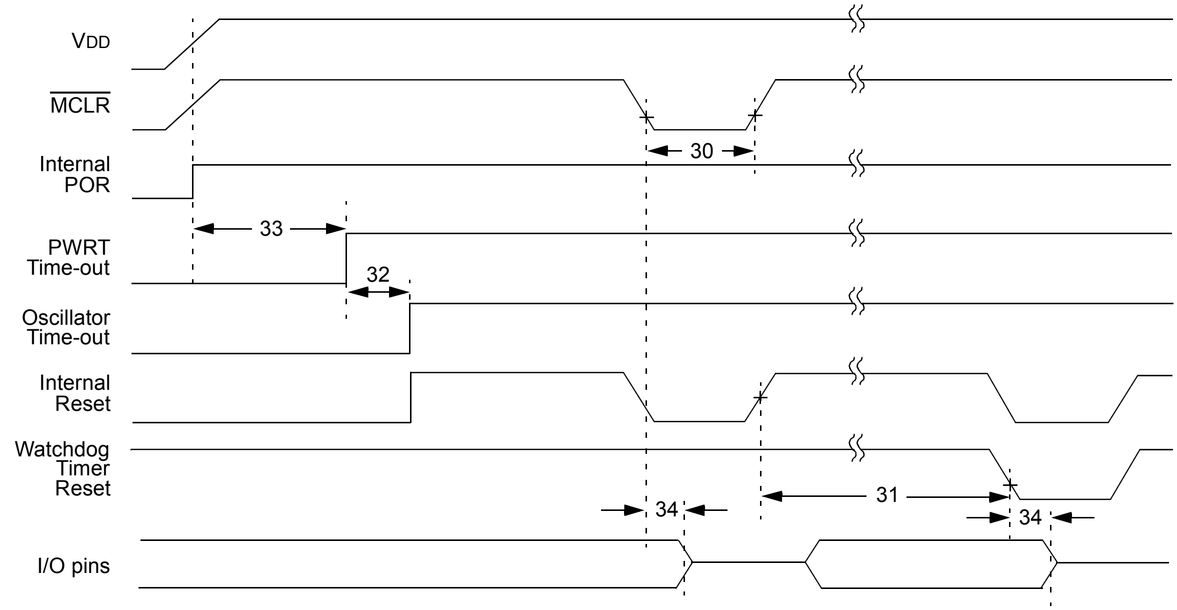
TABLE 21-9: CLKO AND I/O TIMING REQUIREMENTS

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	VDD = 2.0V
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 = 2.0V
21	TioF	Port Output Fall Time	PIC18**F**XXXX	—	10	25	ns	
21A			PIC18**LF**XXXX	—	—	60	ns	VDD = 2.0V
22†	TINP	INTx Pin High or Low Time		TCY	—	—	ns	
23†	TRBP	RB7:RB4 Change Interrupt High or Low Time		TCY	—	—	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 21-7: RESET, WATCHDOG TIMER, OSCILLATOR START-UP TIMER AND POWER-UP TIMER TIMING



Note: Refer to Figure 21-4 for load conditions.

FIGURE 21-8: BROWN-OUT RESET TIMING

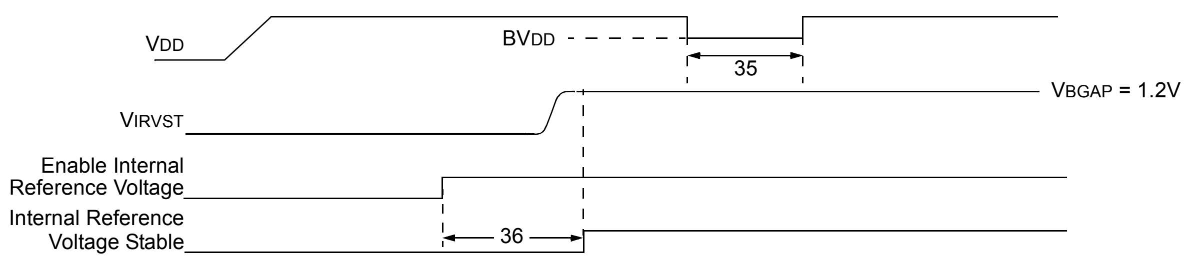
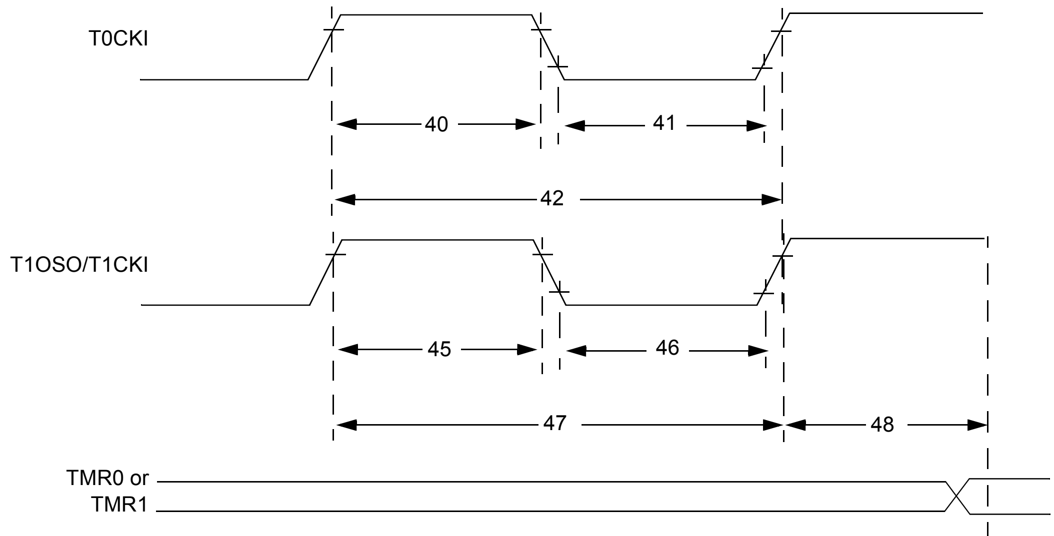


TABLE 21-10: RESET, WATCHDOG TIMER, OSCILLATOR START-UP TIMER, POWER-UP TIMER AND BROWN-OUT RESET REQUIREMENTS

Param. No.	Symbol	Characteristic	Min	Typ	Max	Units	Conditions
30	TmcL	$\overline{\text{MCLR}}$ Pulse Width (low)	2	—	—	μs	
31	TWDT	Watchdog Timer Time-out Period (no postscaler)	—	4.00	4.6	ms	
32	TOST	Oscillator Start-up Timer Period	1024 TOSC	—	1024 TOSC	—	TOSC = OSC1 period
33	TPWRT	Power-up Timer Period	—	65.5	75	ms	
34	TIOZ	I/O High-Impedance from $\overline{\text{MCLR}}$ Low or Watchdog Timer Reset	—	2	—	μs	
35	TBOR	Brown-out Reset Pulse Width	200	—	—	μs	VDD ≤ BVDD (see D005)
36	TIRVST	Time for Internal Reference Voltage to become Stable	—	20	50	μs	
37	TLVD	Low-Voltage Detect Pulse Width	200	—	—	μs	VDD ≤ VLVD
38	TCSD	CPU Start-up Time	5	—	10	μs	
39	TIOBST	Time for INTRC to Stabilize	—	1	—	ms	

FIGURE 21-9: TIMER0 AND TIMER1 EXTERNAL CLOCK TIMINGS

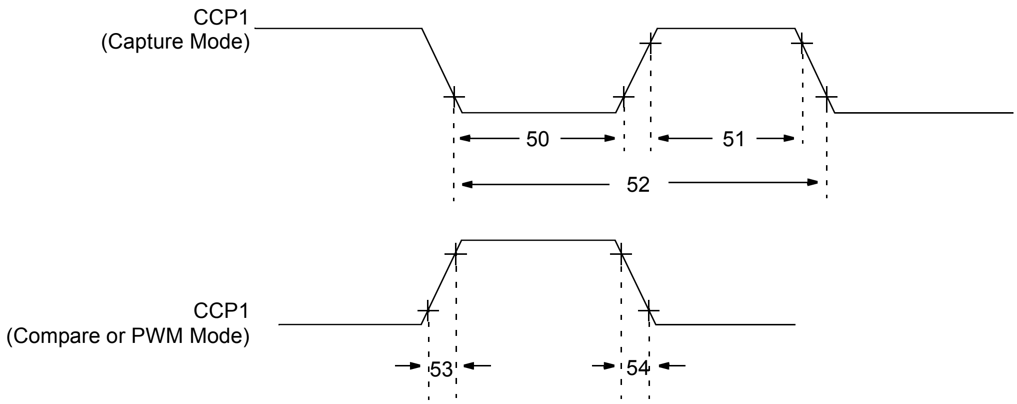


Note: Refer to Figure 21-4 for load conditions.

TABLE 21-11: TIMER0 AND TIMER1 EXTERNAL CLOCK REQUIREMENTS

Param No.	Symbol	Characteristic			Min	Max	Units	Conditions
40	Tt0H	T0CKI High Pulse Width		No prescaler	0.5 TCY + 20	—	ns	
				With prescaler	10	—	ns	
41	Tt0L	T0CKI Low Pulse Width		No prescaler	0.5 TCY + 20	—	ns	
				With prescaler	10	—	ns	
42	Tt0P	T0CKI Period		No prescaler	TCY + 10	—	ns	
				With prescaler	Greater of: 20 ns or (TCY + 40)/N	—	ns	N = prescale value (1, 2, 4,..., 256)
45	Tt1H	T1CKI High Time	Synchronous, no prescaler		0.5 TCY + 20	—	ns	
			Synchronous, with prescaler	PIC18**F**XXXX	10	—	ns	
				PIC18**LF**XXXX	25	—	ns	VDD = 2.0V
			Asynchronous	PIC18**F**XXXX	30	—	ns	
				PIC18**LF**XXXX	50	—	ns	VDD = 2.0V
46	Tt1L	T1CKI Low Time	Synchronous, no prescaler		0.5 TCY + 5	—	ns	
			Synchronous, with prescaler	PIC18**F**XXXX	10	—	ns	
				PIC18**LF**XXXX	25	—	ns	VDD = 2.0V
			Asynchronous	PIC18**F**XXXX	30	—	ns	
				PIC18**LF**XXXX	50	—	ns	VDD = 2.0V
47	Tt1P	T1CKI Input Period	Synchronous		Greater of: 20 ns or (TCY + 40)/N	—	ns	N = prescale value (1, 2, 4, 8)
			Asynchronous		60	—	ns	
	Ft1	T1CKI Oscillator Input Frequency Range			DC	50	kHz	
48	Tcke2tmrl	Delay from External T1CKI Clock Edge to Timer Increment			2 TOSC	7 TOSC	—	

FIGURE 21-10: CAPTURE/COMPARE/PWM TIMINGS (CCP MODULE)

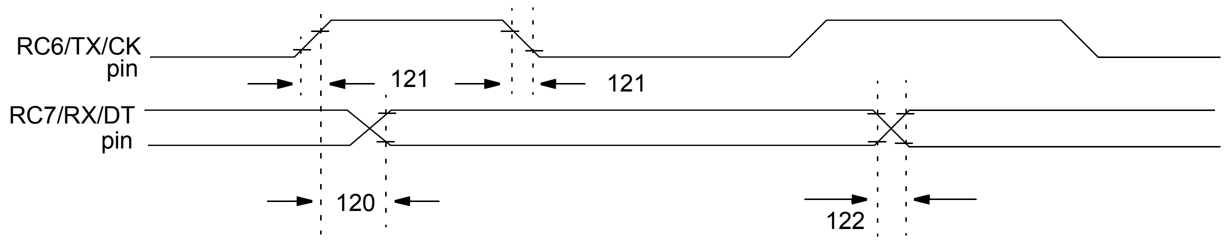


Note: Refer to Figure 21-4 for load conditions.

TABLE 21-12: CAPTURE/COMPARE/PWM REQUIREMENTS

Param No.	Symbol	Characteristic			Min	Max	Units	Conditions
50	TccL	CCP1 Input Low Time	No prescaler		0.5 TCY + 20	—	ns	
			With prescaler	PIC18**F**XXXX	10	—	ns	
				PIC18**LF**XXXX	20	—	ns	VDD = 2.0V
51	TccH	CCP1 Input High Time	No prescaler		0.5 TCY + 20	—	ns	
			With prescaler	PIC18**F**XXXX	10	—	ns	
				PIC18**LF**XXXX	20	—	ns	VDD = 2.0V
52	TccP	CCP1 Input Period			$\frac{3\ T_{CY} + 40}{N}$	—	ns	N = prescale value (1, 4 or 16)
53	TccR	CCP1 Output Fall Time		PIC18**F**XXXX	—	25	ns	
				PIC18**LF**XXXX	—	45	ns	VDD = 2.0V
54	TccF	CCP1 Output Fall Time		PIC18**F**XXXX	—	25	ns	
				PIC18**LF**XXXX	—	45	ns	VDD = 2.0V

FIGURE 21-11: EUSART SYNCHRONOUS TRANSMISSION (MASTER/SLAVE) TIMING

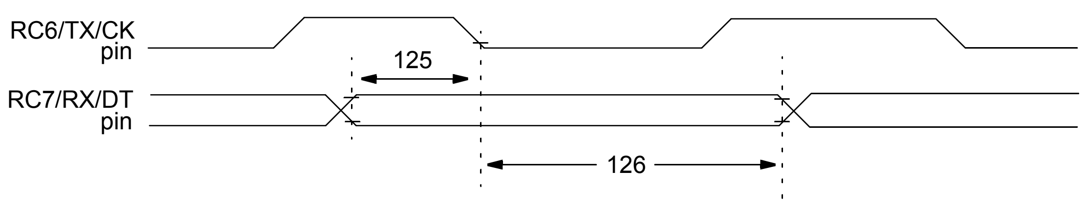


Note: Refer to Figure 21-4 for load conditions.

TABLE 21-13: EUSART SYNCHRONOUS TRANSMISSION REQUIREMENTS

Param No.	Symbol	Characteristic		Min	Max	Units	Conditions
120	TckH2dtV	SYNC XMIT (MASTER & SLAVE) Clock High to Data Out Valid	PIC18**F**XXXX	—	40	ns	
			PIC18**LF**XXXX	—	100	ns	VDD = 2.0V
121	Tckrf	Clock Out Rise Time and Fall Time (Master mode)	PIC18**F**XXXX	—	20	ns	
			PIC18**LF**XXXX	—	50	ns	VDD = 2.0V
122	Tdtrf	Data Out Rise Time and Fall Time	PIC18**F**XXXX	—	20	ns	
			PIC18**LF**XXXX	—	50	ns	VDD = 2.0V

FIGURE 21-12: EUSART SYNCHRONOUS RECEIVE (MASTER/SLAVE) TIMING



Note: Refer to Figure 21-4 for load conditions.

TABLE 21-14: EUSART SYNCHRONOUS RECEIVE REQUIREMENTS

Param. No.	Symbol	Characteristic	Min	Max	Units	Conditions
125	TDTV2CKL	SYNC RCV (MASTER & SLAVE) Data Hold before CK ↓ (DT hold time)	10	—	ns	
126	TCKL2DTL	Data Hold after CK ↓ (DT hold time)	15	—	ns	

FIGURE 21-13: USB SIGNAL TIMING

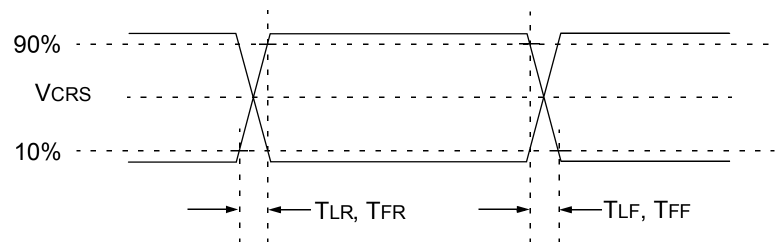


TABLE 21-15: USB LOW-SPEED TIMING REQUIREMENTS

Param No.	Symbol	Characteristic	Min	Typ	Max	Units	Conditions
	T_{LR}	Transition Rise Time	75	—	300	ns	C_L = 200 to 600 pF
	T_{LF}	Transition Fall Time	75	—	300	ns	C_L = 200 to 600 pF
	T_{LRFM}	Rise/Fall Time Matching	80	—	125	%	

TABLE 21-16: USB FULL-SPEED REQUIREMENTS

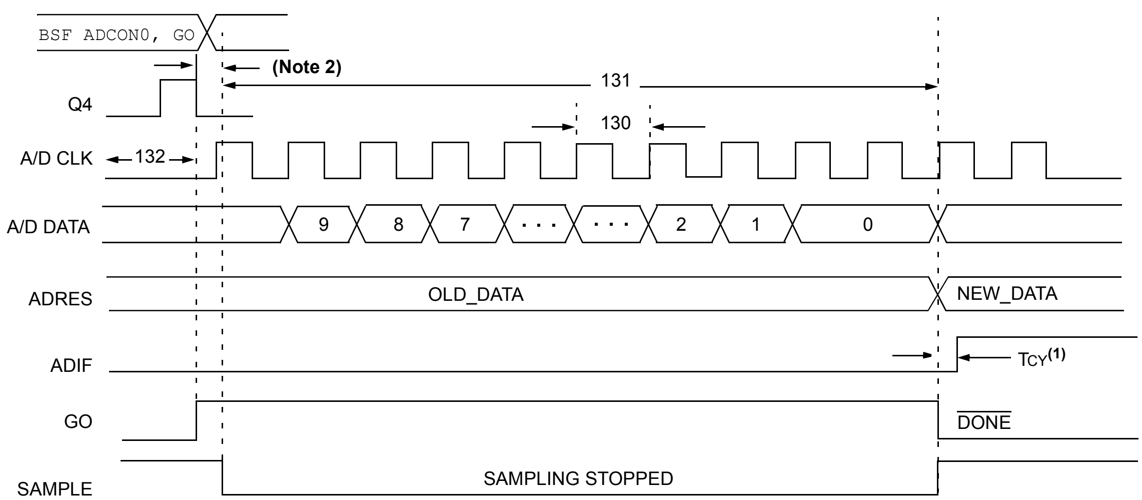
Param No.	Symbol	Characteristic	Min	Typ	Max	Units	Conditions
	T_{FR}	Transition Rise Time	4	—	20	ns	C_L = 50 pF
	T_{FF}	Transition Fall Time	4	—	20	ns	C_L = 50 pF
	T_{FRFM}	Rise/Fall Time Matching	90	—	111.1	%	

TABLE 21-17: A/D CONVERTER CHARACTERISTICS: PIC18F2450/4450 (INDUSTRIAL) PIC18LF2450/4450 (INDUSTRIAL)

Param No.	Symbol	Characteristic	Min	Typ	Max	Units	Conditions
A01	NR	Resolution	—	—	10	bit	ΔVREF ≥ 3.0V
A03	EIL	Integral Linearity Error	—	—	<±1	LSb	ΔVREF ≥ 3.0V
A04	EDL	Differential Linearity Error	—	—	<±1	LSb	ΔVREF ≥ 3.0V
A06	EOFF	Offset Error	—	—	<±2	LSb	ΔVREF ≥ 3.0V
A07	EGN	Gain Error	—	—	<±1	LSb	ΔVREF ≥ 3.0V
A10	—	Monotonicity	Guaranteed(1)			—	VSS ≤ VAIN ≤ VREF
A20	ΔVREF	Reference Voltage Range (VREFH – VREFL)	1.8 3	— —	— —	V V	VDD < 3.0V VDD ≥ 3.0V
A21	VREFH	Reference Voltage High	VSS	—	VREFH	V	
A22	VREFL	Reference Voltage Low	VSS – 0.3V	—	VDD – 3.0V	V	
A25	VAIN	Analog Input Voltage	VREFL	—	VREFH	V	
A30	ZAIN	Recommended Impedance of Analog Voltage Source	—	—	2.5	kΩ	
A50	IREF	VREF Input Current(2)	— —	— —	5 150	μA μA	During VAIN acquisition. During A/D conversion cycle.

Note 1: The A/D conversion result never decreases with an increase in the input voltage and has no missing codes.
2: VREFH current is from RA3/AN3/VREF+ pin or VDD, whichever is selected as the VREFH source. VREFL current is from RA2/AN2/VREF- pin or VSS, whichever is selected as the VREFL source.

FIGURE 21-14: A/D CONVERSION TIMING



Note 1: If the A/D clock source is selected as RC, a time of TCY is added before the A/D clock starts. This allows the `SLEEP` instruction to be executed.
2: This is a minimal RC delay (typically 100 ns), which also disconnects the holding capacitor from the analog input.

TABLE 21-18: A/D CONVERSION REQUIREMENTS

Param No.	Symbol	Characteristic		Min	Max	Units	Conditions
130	TAD	A/D Clock Period	PIC18**F**XXXX	0.7	25(1)	μs	TOSC based, VREF ≥ 3.0V
			PIC18**LF**XXXX	1.4	25(1)	μs	VDD = 2.0V, TOSC based, VREF full range
			PIC18**F**XXXX	2.0	6.0	μs	A/D RC mode
			PIC18**LF**XXXX	3.0	9.0	μs	VDD = 2.0V, A/D RC mode
131	TCNV	Conversion Time (not including acquisition time)(2)		11	12	TAD	
132	TACQ	Acquisition Time(3)		15 10	— —	μs μs	-40°C to +85°C 0°C ≤ to ≤ +85°C
135	TSWC	Switching Time from Convert → Sample		—	**(Note 4)**		
137	TDIS	Discharge Time		0.2	—	μs	

Note 1: The time of the A/D clock period is dependent on the device frequency and the TAD clock divider.

2: ADRES registers may be read on the following TCY cycle.

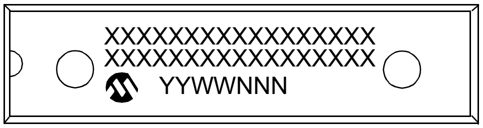
3: The time for the holding capacitor to acquire the "New" input voltage when the voltage changes full scale after the conversion (VDD to VSS or VSS to VDD). The source impedance (RS) on the input channels is 50Ω.

4: On the following cycle of the device clock.

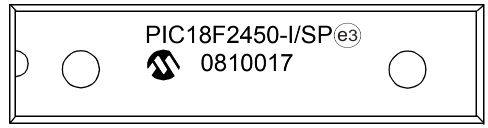
22.0 PACKAGING INFORMATION

22.1 Package Marking Information

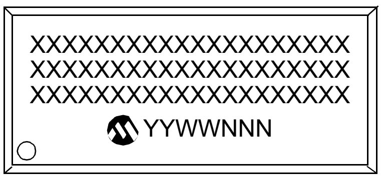
28-Lead SPDIP (Skinny DIP)



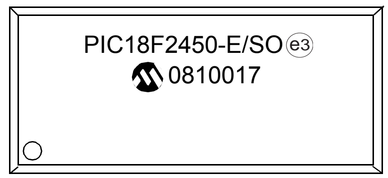
Example



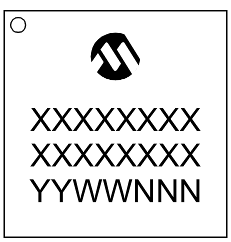
28-Lead SOIC



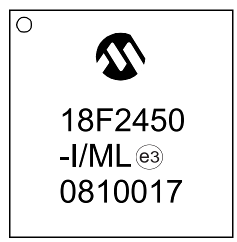
Example



28-Lead QFN



Example

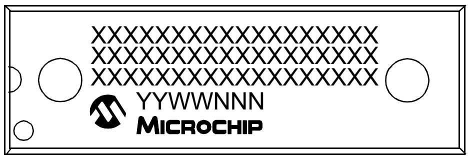


Legend:	XX...X	Customer-specific information
	Y	Year code (last digit of calendar year)
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week '01')
	NNN	Alphanumeric traceability code
	(e3)	Pb-free JEDEC designator for Matte Tin (Sn)
	*	This package is Pb-free. The Pb-free JEDEC designator ((e3)) can be found on the outer packaging for this package.

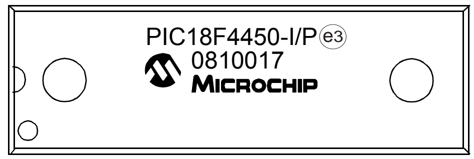
Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line, thus limiting the number of available characters for customer-specific information.

Package Marking Information (Continued)

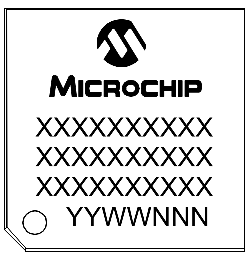
40-Lead PDIP



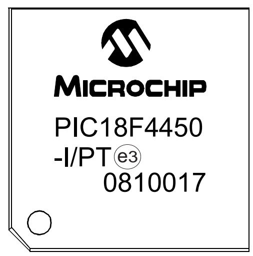
Example



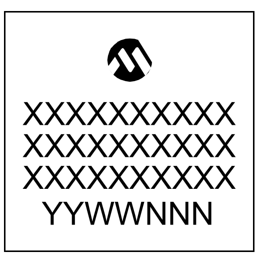
44-Lead TQFP



Example



44-Lead QFN



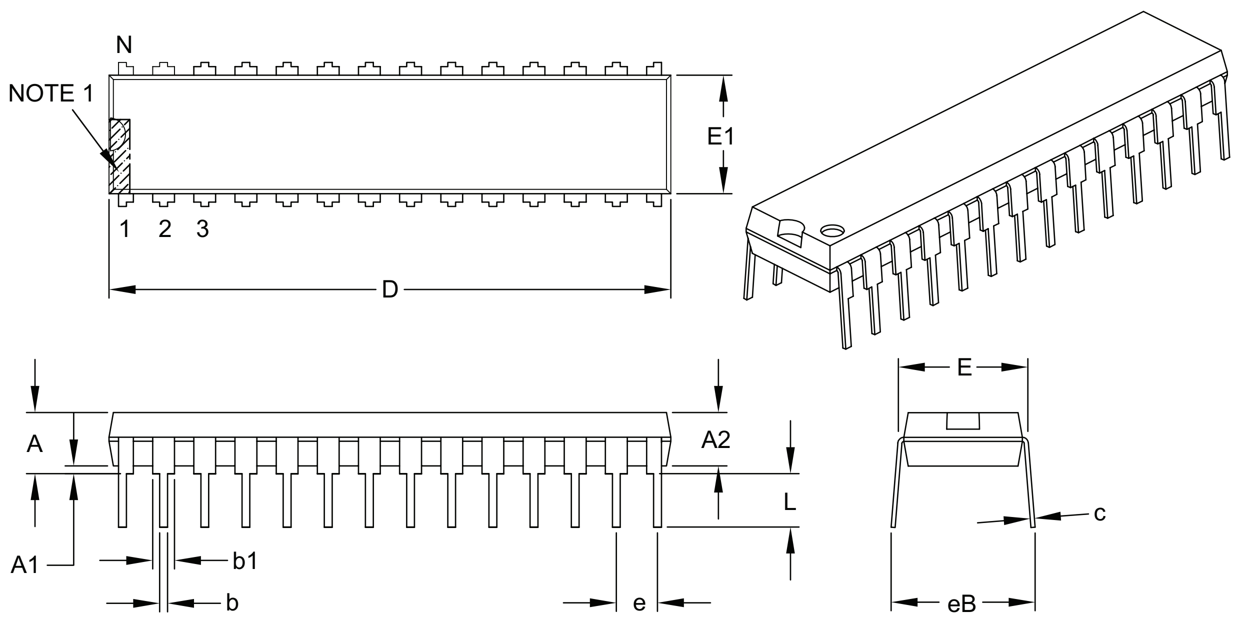
Example

22.2 Package Details

The following sections give the technical details of the packages.

[illegible] Lead Skinny Plastic Dual In Line [illegible] SP [illegible] – [illegible] mil Body [SPDIP]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at http [illegible] www microchip com packaging



Units		INCHES		
Dimension Limits		MIN	NOM	MAX
Number of Pins	N	[illegible]		
Pitch	e	[illegible] BSC		
Top to Seating Plane	A	–	–	[illegible]
Molded Package Thickness	A[illegible]	[illegible]	[illegible]	[illegible]
Base to Seating Plane	A[illegible]	[illegible]	–	–
Shoulder to Shoulder Width	E	[illegible]	[illegible]	[illegible]
Molded Package Width	E[illegible]	[illegible]	[illegible]	[illegible]
Overall Length	D	[illegible]	[illegible]	[illegible]
Tip to Seating Plane	L	[illegible]	[illegible]	[illegible]
Lead Thickness	c	[illegible]	[illegible]	[illegible]
Upper Lead Width	b[illegible]	[illegible]	[illegible]	[illegible]
Lower Lead Width	b	[illegible]	[illegible]	[illegible]
Overall Row Spacing §	eB	–	–	[illegible]

Notes:

[illegible] Pin [illegible] visual index feature may vary, but must be located within the hatched area.

[illegible] § Significant Characteristic.

[illegible] Dimensions D and E [illegible] do not include mold flash or protrusions. Mold flash or protrusions shall not exceed [illegible] per side.

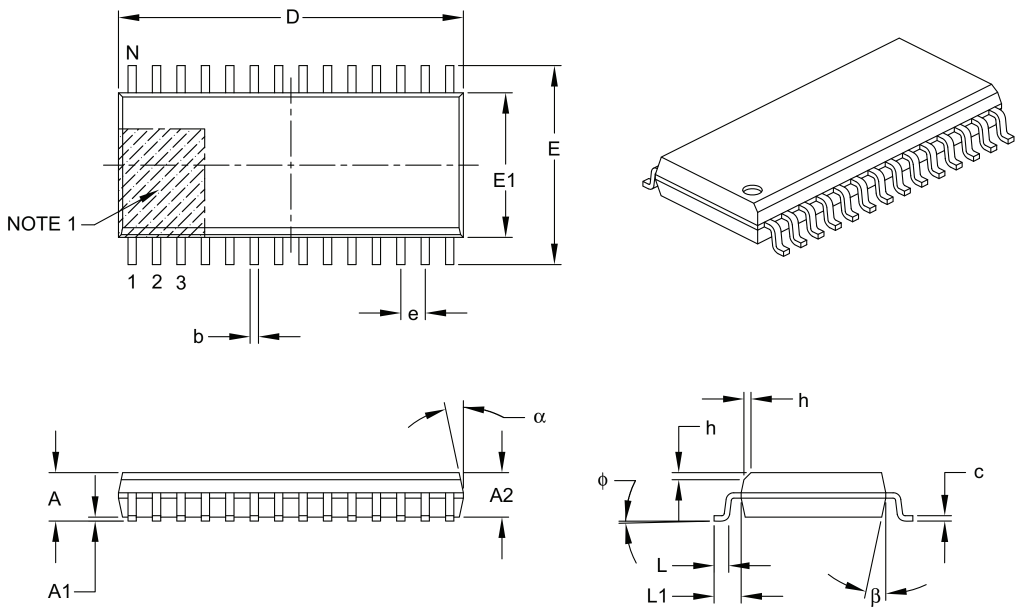
[illegible] Dimensioning and tolerancing per ASME Y [illegible] M.

BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing C[illegible]B

Lead Plastic Small Outline SO – Wide mm Body [SOIC]

Note	For the most current package drawings please see the Microchip Packaging Specification located at http www microchip com packaging



Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Number of Pins	N	[illegible]		
Pitch	e	BSC		
Overall Height	A	–	–	[illegible]
Molded Package Thickness	A	[illegible]	–	–
Standoff §	A	[illegible]	–	[illegible]
Overall Width	E	BSC		
Molded Package Width	E	BSC		
Overall Length	D	BSC		
Chamfer optional	h	[illegible]	–	[illegible]
Foot Length	L	[illegible]	–	[illegible]
Footprint	L	REF		
Foot Angle Top	φ	°	–	°
Lead Thickness	c	[illegible]	–	[illegible]
Lead Width	b	[illegible]	–	[illegible]
Mold Draft Angle Top	α	°	–	°
Mold Draft Angle Bottom	β	°	–	°

Notes

Pin visual index feature may vary but must be located within the hatched area

§ Significant Characteristic

Dimensions D and E do not include mold flash or protrusions Mold flash or protrusions shall not exceed mm per side

Dimensioning and tolerancing per ASME Y M

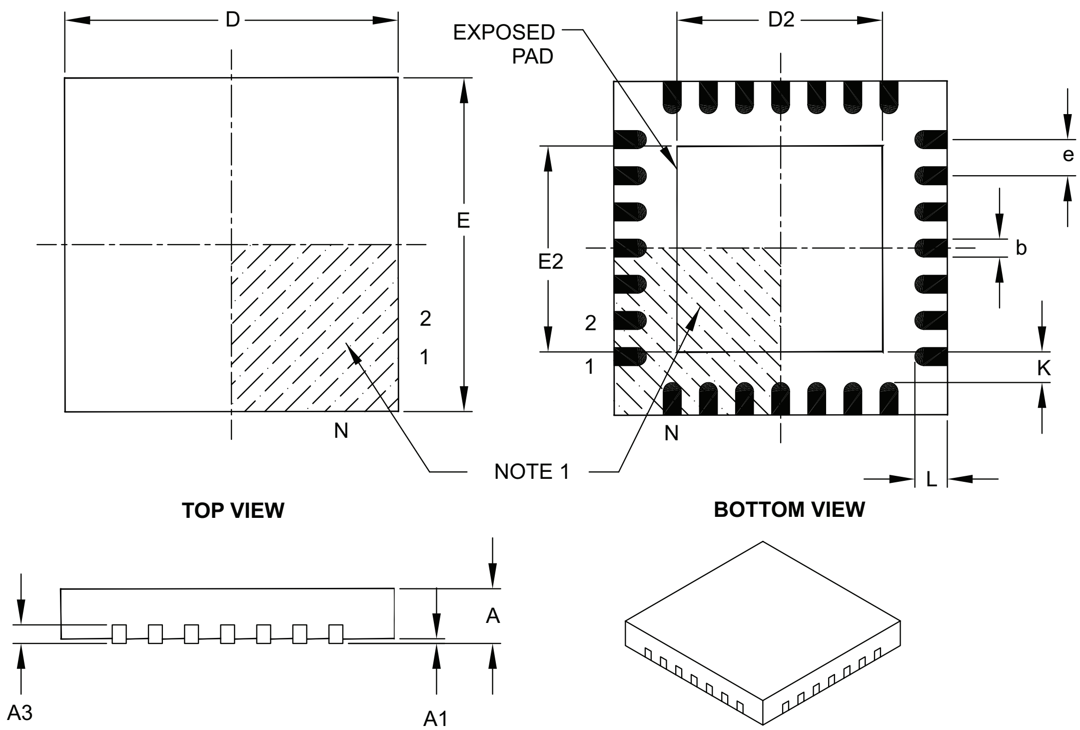
BSC Basic Dimension Theoretically exact value shown without tolerances

REF Reference Dimension usually without tolerance for information purposes only

Microchip Technology Drawing C B

[illegible]Lead Plastic Quad Flat No Lead Package [illegible]ML[illegible] – [illegible]x[illegible]mm Body [QFN] with [illegible]mm Contact Length

Note:	For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Number of Pins	N	[illegible]		
Pitch	e	[illegible] BSC		
Overall Height	A	[illegible]	[illegible]	[illegible]
Standoff	A[illegible]	[illegible]	[illegible]	[illegible]
Contact Thickness	A[illegible]	[illegible] REF		
Overall Width	E	[illegible] BSC		
Exposed Pad Width	E[illegible]	[illegible]	[illegible]	[illegible]
Overall Length	D	[illegible] BSC		
Exposed Pad Length	D[illegible]	[illegible]	[illegible]	[illegible]
Contact Width	b	[illegible]	[illegible]	[illegible]
Contact Length	L	[illegible]	[illegible]	[illegible]
Contact-to-Exposed Pad	K	[illegible]	–	–

Notes:

[illegible] Pin [illegible] visual index feature may vary, but must be located within the hatched area.

[illegible] Package is saw singulated.

[illegible] Dimensioning and tolerancing per ASME Y[illegible]M.

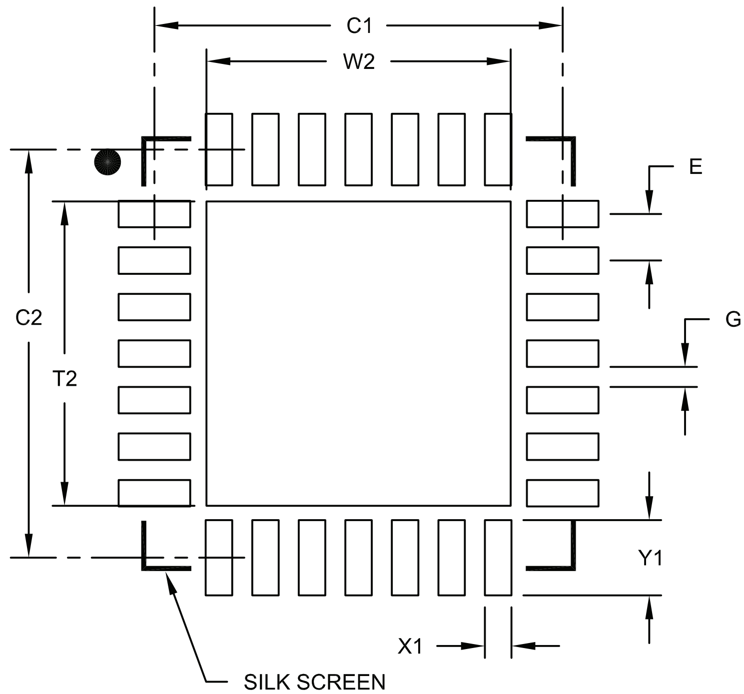
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C[illegible]B

Lead Plastic Quad Flat No Lead Package ML – x mm Body [QFN] with mm Contact Length

Note For the most current package drawings please see the Microchip Packaging Specification located at http www microchip com packaging



RECOMMENDED LAND PATTERN

Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Contact Pitch	E		0.65 BSC	
Optional Center Pad Width	W2			4.25
Optional Center Pad Length	T2			4.25
Contact Pad Spacing	C1		5.70	
Contact Pad Spacing	C2		5.70	
Contact Pad Width (X28)	X1			0.37
Contact Pad Length (X28)	Y1			1.00
Distance Between Pads	G	0.20		

Notes:

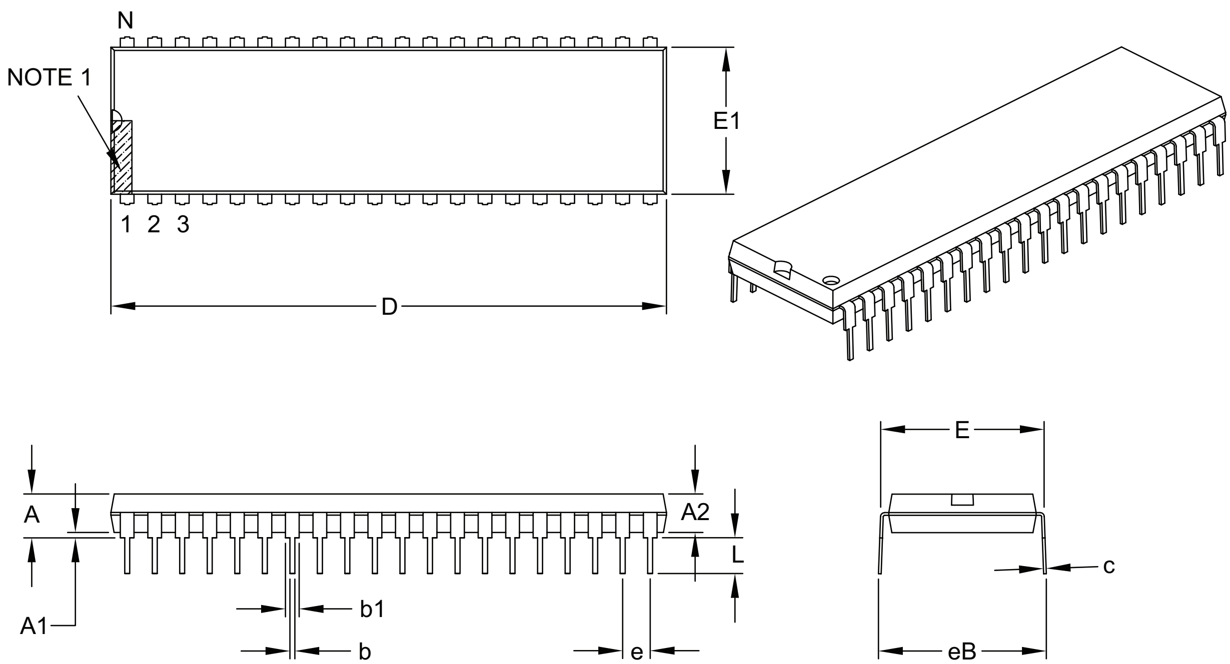
1. Dimensioning and tolerancing per ASME Y14.5M

   BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2105A

[illegible]Lead Plastic Dual In Line [illegible]P[illegible] – [illegible] mil Body [PDIP]

Note[illegible]	For the most current package drawings[illegible] please see the Microchip Packaging Specification located at[illegible] http[illegible]www[illegible]microchip[illegible]com[illegible]packaging



Units		INCHES		
Dimension Limits		MIN	NOM	MAX
Number of Pins	N	[illegible]		
Pitch	e	[illegible] BSC		
Top to Seating Plane	A	–	–	[illegible]
Molded Package Thickness	A[illegible]	[illegible]	–	[illegible]
Base to Seating Plane	A[illegible]	[illegible]	–	–
Shoulder to Shoulder Width	E	[illegible]	–	[illegible]
Molded Package Width	E[illegible]	[illegible]	–	[illegible]
Overall Length	D	[illegible]	–	[illegible]
Tip to Seating Plane	L	[illegible]	–	[illegible]
Lead Thickness	c	[illegible]	–	[illegible]
Upper Lead Width	b[illegible]	[illegible]	–	[illegible]
Lower Lead Width	b	[illegible]	–	[illegible]
Overall Row Spacing [illegible] §	eB	–	–	[illegible]

Notes[illegible]

[illegible] Pin [illegible] visual index feature may vary[illegible] but must be located within the hatched area[illegible]

[illegible] § Significant Characteristic[illegible]

[illegible] Dimensions D and E[illegible] do not include mold flash or protrusions[illegible] Mold flash or protrusions shall not exceed [illegible] per side[illegible]

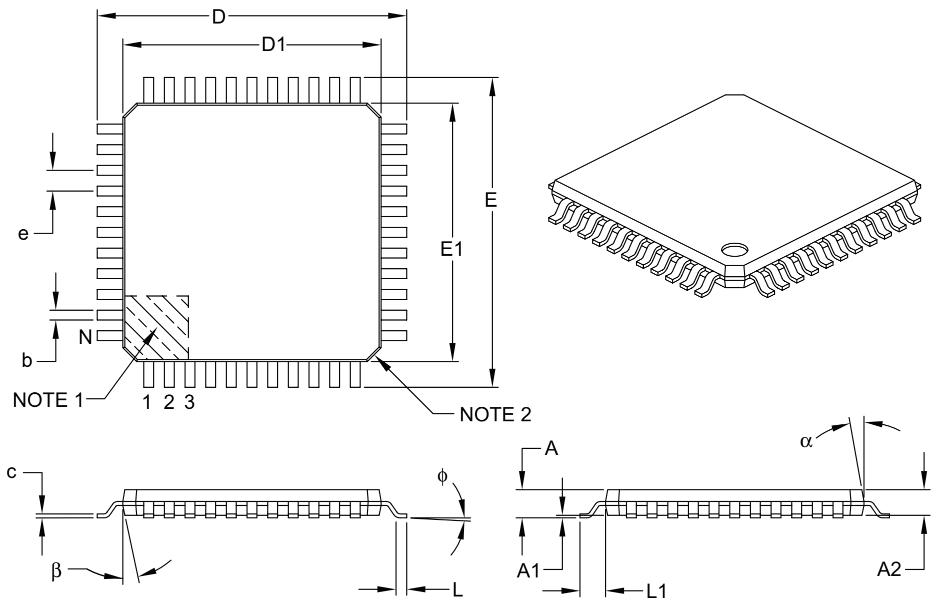
[illegible] Dimensioning and tolerancing per ASME Y[illegible]M[illegible]

BSC[illegible] Basic Dimension[illegible] Theoretically exact value shown without tolerances[illegible]

Microchip Technology Drawing C[illegible]B

[illegible]Lead Plastic Thin Quad Flatpack [illegible]PT[illegible] – [illegible]x[illegible]x[illegible]mm Body[illegible]mm [TQFP]

Note[illegible] For the most current package drawings[illegible] please see the Microchip Packaging Specification located at[illegible] http[illegible]www[illegible]microchip[illegible]com[illegible]packaging



		MILLIMETERS		
	Units			
Dimension Limits		MIN	NOM	MAX
Number of Leads	N	[illegible]		
Lead Pitch	e	[illegible] BSC		
Overall Height	A	–	–	[illegible]
Molded Package Thickness	A[illegible]	[illegible]	[illegible]	[illegible]
Standoff [illegible]	A[illegible]	[illegible]	–	[illegible]
Foot Length	L	[illegible]	[illegible]	[illegible]
Footprint	L[illegible]	[illegible] REF		
Foot Angle	φ	[illegible]°	[illegible]°	[illegible]°
Overall Width	E	[illegible] BSC		
Overall Length	D	[illegible] BSC		
Molded Package Width	E[illegible]	[illegible] BSC		
Molded Package Length	D[illegible]	[illegible] BSC		
Lead Thickness	c	[illegible]	–	[illegible]
Lead Width	b	[illegible]	[illegible]	[illegible]
Mold Draft Angle Top	α	[illegible]°	[illegible]°	[illegible]°
Mold Draft Angle Bottom	β	[illegible]°	[illegible]°	[illegible]°

Notes[illegible]

[illegible] Pin [illegible] visual index feature may vary[illegible] but must be located within the hatched area[illegible]

[illegible] Chamfers at corners are optional[illegible] size may vary[illegible]

[illegible] Dimensions D[illegible] and E[illegible] do not include mold flash or protrusions[illegible] Mold flash or protrusions shall not exceed [illegible] mm per side[illegible]

[illegible] Dimensioning and tolerancing per ASME Y[illegible]M[illegible]

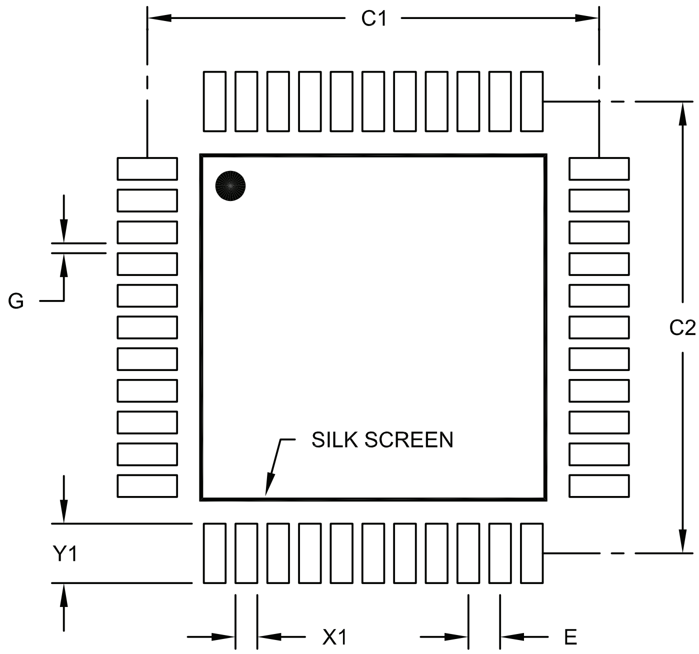
BSC[illegible] Basic Dimension[illegible] Theoretically exact value shown without tolerances[illegible]

REF[illegible] Reference Dimension[illegible] usually without tolerance[illegible] for information purposes only[illegible]

Microchip Technology Drawing C[illegible]B

Lead Plastic Thin Quad Flatpack PT – x x mm Body mm [TQFP]

Note	For the most current package drawings please see the Microchip Packaging Specification located at http www microchip com packaging



RECOMMENDED LAND PATTERN

		Units	MILLIMETERS	
Dimension Limits		MIN	NOM	MAX
Contact Pitch	E		0.80 BSC	
Contact Pad Spacing	C1		11.40	
Contact Pad Spacing	C2		11.40	
Contact Pad Width (X44)	X1			0.55
Contact Pad Length (X44)	Y1			1.50
Distance Between Pads	G	0.25		

Notes:

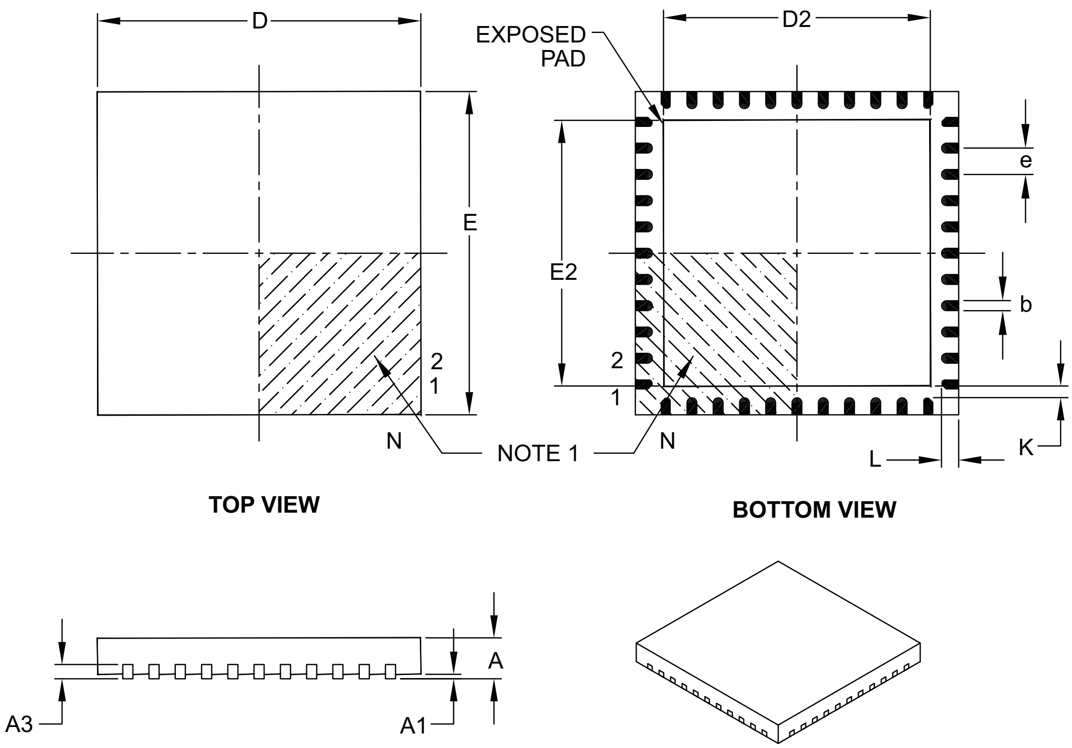
1. Dimensioning and tolerancing per ASME Y14.5M

   BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2076A

[illegible]-Lead Plastic Quad Flat, No Lead Package (ML) – [illegible] x [illegible] mm Body [QFN]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Number of Pins	N		[illegible]	
Pitch	e		[illegible] BSC	
Overall Height	A	[illegible]	[illegible]	[illegible]
Standoff	A[illegible]	[illegible]	[illegible]	[illegible]
Contact Thickness	A[illegible]		[illegible] REF	
Overall Width	E		[illegible] BSC	
Exposed Pad Width	E[illegible]	[illegible]	[illegible]	[illegible]
Overall Length	D		[illegible] BSC	
Exposed Pad Length	D[illegible]	[illegible]	[illegible]	[illegible]
Contact Width	b	[illegible]	[illegible]	[illegible]
Contact Length	L	[illegible]	[illegible]	[illegible]
Contact-to-Exposed Pad	K	[illegible]	–	–

Notes:

[illegible] Pin [illegible] visual index feature may vary, but must be located within the hatched area.

[illegible] Package is saw singulated.

[illegible] Dimensioning and tolerancing per ASME Y[illegible]M.

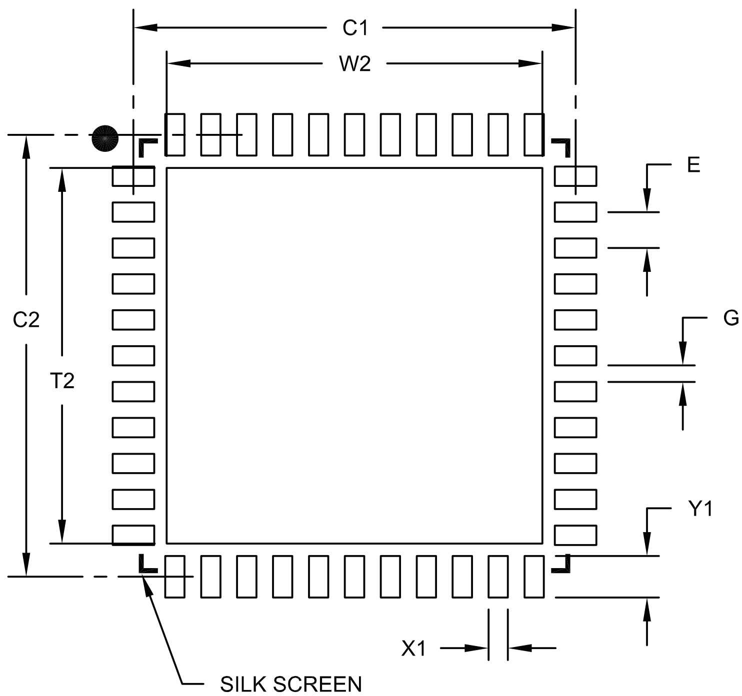
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C[illegible]B

44-Lead Plastic Quad Flat, No Lead Package (ML) – 8x8 mm Body [QFN]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging



RECOMMENDED LAND PATTERN

Units		MILLIMETERS		
Dimension Limits		MIN	NOM	MAX
Contact Pitch	E		0.65 BSC	
Optional Center Pad Width	W2			6.80
Optional Center Pad Length	T2			6.80
Contact Pad Spacing	C1		8.00	
Contact Pad Spacing	C2		8.00	
Contact Pad Width (X44)	X1			0.35
Contact Pad Length (X44)	Y1			0.80
Distance Between Pads	G	0.25		

Notes:

1. Dimensioning and tolerancing per ASME Y14.5M

BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2103A

NOTES:

APPENDIX A: REVISION HISTORY

Revision A (January 2006)

Original data sheet for PIC18F2450/4450 devices.

Revision B (January 2007)

Example 11-1 and Figure 14-1 have been updated, **Section 14.5.1.1 "Bus Activity Detect Interrupt Bit (ACTVIF)"** and **Section 14.2.2.3 "Internal Pull-up Resistors"** have been added, the Electrical Specifications in **Section 21.0 "Electrical Characteristics"** have been updated, the package diagrams in **Section 22.2 "Package Details"** have been updated and there have been minor corrections to the data sheet text.

Revision C (August 2007)

The Electrical Specifications in **Section 21.2 "DC Characteristics: Power-Down and Supply Current"** have been updated and the package diagrams in **Section 22.2 "Package Details"** have been updated.

Revision D (March 2008)

Minor edits to **Section 14.0 "Universal Serial Bus (USB)"**, **Section 16.0 "10-Bit Analog-to-Digital Converter (A/D) Module"**, **Section 18.0 "Special Features of the CPU"** and **Section 21.0 "Electrical Characteristics"**.

APPENDIX B: DEVICE DIFFERENCES

The differences between the devices listed in this data sheet are shown in Table B-1.

TABLE B-1: DEVICE DIFFERENCES

Features	PIC18F2450	PIC18F4450
Program Memory (Bytes)	16384	16384
Program Memory (Instructions)	8192	8192
Interrupt Sources	13	13
I/O Ports	Ports A, B, C, (E)	Ports A, B, C, D, E
Capture/Compare/PWM Modules	1	1
10-Bit Analog-to-Digital Module	10 Input Channels	13 Input Channels
Packages	28-Pin SPDIP 28-Pin SOIC 28-Pin QFN	40-Pin PDIP 44-Pin TQFP 44-Pin QFN

APPENDIX C: CONVERSION CONSIDERATIONS

This appendix discusses the considerations for converting from previous versions of a device to the ones listed in this data sheet. Typically, these changes are due to the differences in the process technology used. An example of this type of conversion is from a PIC16C74A to a PIC16C74B.

Not Applicable

APPENDIX D: MIGRATION FROM BASELINE TO ENHANCED DEVICES

This section discusses how to migrate from a Baseline device (i.e., PIC16C5X) to an Enhanced MCU device (i.e., PIC18FXXX).

The following are the list of modifications over the PIC16C5X microcontroller family:

Not Currently Available

APPENDIX E: MIGRATION FROM MID-RANGE TO ENHANCED DEVICES

A detailed discussion of the differences between the Mid-Range MCU devices (i.e., PIC16CXXX) and the Enhanced devices (i.e., PIC18FXXX) is provided in *AN716, "Migrating Designs from PIC16C74A/74B to PIC18C442"*. The changes discussed, while device specific, are generally applicable to all Mid-Range to Enhanced device migrations.

This Application Note is available as Literature Number DS00716.

APPENDIX F: MIGRATION FROM HIGH-END TO ENHANCED DEVICES

A detailed discussion of the migration pathway and differences between the High-End MCU devices (i.e., PIC17CXXX) and the Enhanced devices (i.e., PIC18FXXX) is provided in *AN726, "PIC17CXXX to PIC18CXXX Migration"*. This Application Note is available as Literature Number DS00726.

INDEX

Q

R

S

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PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

PART NO.	X	/XX	XXX
Device	Temperature Range	Package	Pattern

Device	PIC18F2450[(1)], PIC18F4450[(1)], PIC18F2450T[(2)], PIC18F4450T[(2)]; V_{DD} range 4.2V to 5.5V PIC18LF2450[(1)], PIC18LF4450[(1)], PIC18LF2450T[(2)], PIC18LF4450T[(2)]; V_{DD} range 2.0V to 5.5V
Temperature Range	I = -40°C to +85°C (Industrial) E = -40°C to +125°C (Extended)
Package	PT = TQFP (Thin Quad Flatpack) SO = SOIC SP = Skinny Plastic DIP P = PDIP ML = QFN
Pattern	QTP, SQTP, Code or Special Requirements (blank otherwise)

Examples:

a) PIC18LF4450-I/P 301 = Industrial temp., PDIP package, Extended V_{DD} limits, QTP pattern #301.

b) PIC18LF2450-I/SO = Industrial temp., SOIC package, Extended V_{DD} limits.

c) PIC18F4450-I/P = Industrial temp., PDIP package, normal V_{DD} limits.

Note 1: F = Standard Voltage Range
LF = Wide Voltage Range

2: T = in tape and reel TQFP packages only.

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