

5.6 Oscillator Control Registers

REGISTER 5-1: OSCCON: OSCILLATOR CONTROL REGISTER

R/W-0/0	R/W-0/0	R/W-1/1	R/W-1/1	R/W-1/1	U-0	R/W-0/0	R/W-0/0
SPLLEN	IRCF<3:0>				—	SCS<1:0>	
bit 7					bit 0		

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7

SPLLEN: Software PLL Enable bit

If PLEN in Configuration Word 1 = 1:

SPLLEN bit is ignored. 4x PLL is always enabled (subject to oscillator requirements)

If PLEN in Configuration Word 1 = 0:

1 = 4x PLL is enabled

0 = 4x PLL is disabled

bit 6-3

IRCF<3:0>: Internal Oscillator Frequency Select bits

000x = 31 kHz LF

0010 = 31.25 kHz MF

0011 = 31.25 kHz HF⁽¹⁾

0100 = 62.5 kHz MF

0101 = 125 kHz MF

0110 = 250 kHz MF

0111 = 500 kHz MF (default upon Reset)

1000 = 125 kHz HF⁽¹⁾

1001 = 250 kHz HF⁽¹⁾

1010 = 500 kHz HF⁽¹⁾

1011 = 1 MHz HF

1100 = 2 MHz HF

1101 = 4 MHz HF

1110 = 8 MHz or 32 MHz HF (see [Section 5.2.2.1 "HFINTOSC"](#))

1111 = 16 MHz HF

bit 2

Unimplemented: Read as '0'

bit 1-0

SCS<1:0>: System Clock Select bits

1x = Internal oscillator block

01 = Timer1 oscillator

00 = Clock determined by FOSC<2:0> in Configuration Word 1.

Note 1: Duplicate frequency derived from HFINTOSC.

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REGISTER 5-2: OSCSTAT: OSCILLATOR STATUS REGISTER

R-1/q	R-0/q	R-q/q	R-0/q	R-0/q	R-q/q	R-0/0	R-0/q
T1OSCR	PLL R	OSTS	HFIOFR	HFIOFL	MFIOFR	LFIOFR	HFIOFS
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

q = Conditional

bit 7 **T1OSCR:** Timer1 Oscillator Ready bit

If T1OSCR = 1:

1 = Timer1 oscillator is ready

0 = Timer1 oscillator is not ready

If T1OSCR = 0:

1 = Timer1 clock source is always ready

bit 6 **PLL R** 4x PLL Ready bit

1 = 4x PLL is ready

0 = 4x PLL is not ready

bit 5 **OSTS:** Oscillator Start-up Time-out Status bit

1 = Running from the clock defined by the FOSC<2:0> bits of the Configuration Word 1

0 = Running from an internal oscillator (FOSC<2:0> = 100)

bit 4 **HFIOFR:** High Frequency Internal Oscillator Ready bit

1 = HFINTOSC is ready

0 = HFINTOSC is not ready

bit 3 **HFIOFL:** High Frequency Internal Oscillator Locked bit

1 = HFINTOSC is at least 2% accurate

0 = HFINTOSC is not 2% accurate

bit 2 **MFIOFR:** Medium Frequency Internal Oscillator Ready bit

1 = MFINTOSC is ready

0 = MFINTOSC is not ready

bit 1 **LFIOFR:** Low Frequency Internal Oscillator Ready bit

1 = LFINTOSC is ready

0 = LFINTOSC is not ready

bit 0 **HFIOFS:** High Frequency Internal Oscillator Stable bit

1 = HFINTOSC is at least 0.5% accurate

0 = HFINTOSC is not 0.5% accurate

REGISTER 5-3: OSCTUNE: OSCILLATOR TUNING REGISTER

U-0	U-0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
—	—	TUN<5:0>					
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7-6 **Unimplemented:** Read as '0'

bit 5-0 **TUN<5:0>:** Frequency Tuning bits

011111 = Maximum frequency

011110 =

•

•

•

000001 =

000000 = Oscillator module is running at the factory-calibrated frequency.

111111 =

•

•

•

100000 = Minimum frequency

TABLE 5-2: SUMMARY OF REGISTERS ASSOCIATED WITH CLOCK SOURCES

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
OSCCON	SPLLEN	IRCF3	IRCF2	IRCF1	IRCF0	—	SCS1	SCS0	65
OSCSTAT	T1OSCR	PLLRC	OSTS	HFIOFR	HFIOFL	MFIOFR	LFIOFR	HFIOFS	66
OSCTUNE	—	—	TUN5	TUN4	TUN3	TUN2	TUN1	TUN0	67
PIE2	OSFIE	C2IE	C1IE	EEIE	BCL1IE	—	—	CCP2IE ⁽¹⁾	94
PIR2	OSFIF	C2IF	C1IF	EEIF	BCL1IF	—	—	CCP2IF ⁽¹⁾	97
T1CON	TMR1CS1	TMR1CS0	T1CKPS1	T1CKPS0	T1OSCEN	T1SYNC	—	TMR1ON	187

Legend: — = unimplemented locations read as '0'. Shaded cells are not used by clock sources.

Note 1: PIC16(L)F1827 only.

TABLE 5-3: SUMMARY OF CONFIGURATION WORD ASSOCIATED WITH CLOCK SOURCES

Name	Bits	Bit -/7	Bit -/6	Bit 13/5	Bit 12/4	Bit 11/3	Bit 10/2	Bit 9/1	Bit 8/0	Register on Page
CONFIG1	13:8	—	—	FCMEN	IESO	CLKOUTEN	BOREN1	BOREN0	CPD	50
	7:0	CP	MCLRE	PWRTÉ	WDTE1	WDTE0	FOSC2	FOSC1	FOSC0	

Legend: — = unimplemented locations read as '0'. Shaded cells are not used by clock sources.

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NOTES:

6.0 REFERENCE CLOCK MODULE

The reference clock module provides the ability to send a divided clock to the clock output pin of the device (CLKR) and provide a secondary internal clock source to the modulator module. This module is available in all oscillator configurations and allows the user to select a greater range of clock submultiples to drive external devices in the application. The reference clock module includes the following features:

- System clock is the source
- Available in all oscillator configurations
- Programmable clock divider
- Output enable to a port pin
- Selectable duty cycle
- Slew rate control

The reference clock module is controlled by the CLKRCON register ([Register 6-1](#)) and is enabled when setting the CLKREN bit. To output the divided clock signal to the CLKR port pin, the CLKROE bit must be set. The CLKRDIV<2:0> bits enable the selection of 8 different clock divider options. The CLKRDC<1:0> bits can be used to modify the duty cycle of the output clock⁽¹⁾. The CLKRSLR bit controls slew rate limiting.

Note 1: If the base clock rate is selected without a divider, the output clock will always have a duty cycle equal to that of the source clock, unless a 0% duty cycle is selected. If the clock divider is set to base clock/2, then 25% and 75% duty cycle accuracy will be dependent upon the source clock.

For information on using the reference clock output with the modulator module, see [Section 23.0 “Data Signal Modulator”](#).

6.1 Slew Rate

The slew rate limitation on the output port pin can be disabled. The slew rate limitation can be removed by clearing the CLKRSLR bit in the CLKRCON register.

6.2 Effects of a Reset

Upon any device Reset, the reference clock module is disabled. The user's firmware is responsible for initializing the module before enabling the output. The registers are reset to their default values.

6.3 Conflicts with the CLKR Pin

There are two cases when the reference clock output signal cannot be output to the CLKR pin, if:

- LP, XT or HS Oscillator mode is selected.
- CLKOUT function is enabled.

Even if either of these cases are true, the module can still be enabled and the reference clock signal may be used in conjunction with the modulator module.

6.3.1 OSCILLATOR MODES

If LP, XT or HS oscillator modes are selected, the OSC2/CLKR pin must be used as an oscillator input pin and the CLKR output cannot be enabled. See [Section 5.2 “Clock Source Types”](#) for more information on different oscillator modes.

6.3.2 CLKOUT FUNCTION

The CLKOUT function has a higher priority than the reference clock module. Therefore, if the CLKOUT function is enabled by the CLKOUTEN bit in Configuration Word 1, Fosc/4 will always be output on the port pin. Reference [Section 4.0 “Device Configuration”](#) for more information.

6.4 Operation During Sleep

As the reference clock module relies on the system clock as its source, and the system clock is disabled in Sleep, the module does not function in Sleep, even if an external clock source or the Timer1 clock source is configured as the system clock. The module outputs will remain in their current state until the device exits Sleep.

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6.5 Reference Clock Control Register

REGISTER 6-1: CLKRCON: REFERENCE CLOCK CONTROL REGISTER

R/W-0/0	R/W-0/0	R/W-1/1	R/W-1/1	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
CLKREN	CLKROE	CLKRSLR	CLKRDC<1:0>	CLKRDIV<2:0>			
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7 **CLKREN:** Reference Clock Module Enable bit
1 = Reference Clock module is enabled
0 = Reference Clock module is disabled
- bit 6 **CLKROE:** Reference Clock Output Enable bit⁽³⁾
1 = Reference Clock output is enabled on CLKR pin
0 = Reference Clock output disabled on CLKR pin
- bit 5 **CLKRSLR:** Reference Clock Slew Rate Control limiting enable bit
1 = Slew Rate limiting is enabled
0 = Slew Rate limiting is disabled
- bit 4-3 **CLKRDC<1:0>:** Reference Clock Duty Cycle bits
11 = Clock outputs duty cycle of 75%
10 = Clock outputs duty cycle of 50%
01 = Clock outputs duty cycle of 25%
00 = Clock outputs duty cycle of 0%
- bit 2-0 **CLKRDIV<2:0>** Reference Clock Divider bits
111 = Base clock value divided by 128
110 = Base clock value divided by 64
101 = Base clock value divided by 32
100 = Base clock value divided by 16
011 = Base clock value divided by 8
010 = Base clock value divided by 4
001 = Base clock value divided by 2⁽¹⁾
000 = Base clock value⁽²⁾

Note 1: In this mode, the 25% and 75% duty cycle accuracy will be dependent on the source clock duty cycle.

2: In this mode, the duty cycle will always be equal to the source clock duty cycle, unless a duty cycle of 0% is selected.

3: To route CLKR to pin, $\overline{\text{CLKOUTEN}}$ of Configuration Word 1 = 1 is required. $\overline{\text{CLKOUTEN}}$ of Configuration Word 1 = 0 will result in $F_{\text{OSC}}/4$. See [Section 6.3 “Conflicts with the CLKR Pin”](#) for details.

TABLE 6-1: SUMMARY OF REGISTERS ASSOCIATED WITH REFERENCE CLOCK SOURCES

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
CLKRCON	CLKREN	CLKROE	CLKRSLR	CLKRDC1	CLKRDC0	CLKRDIV2	CLKRDIV1	CLKRDIV0	70

Legend: — = unimplemented locations read as '0'. Shaded cells are not used by reference clock sources.

TABLE 6-2: SUMMARY OF CONFIGURATION WORD WITH REFERENCE CLOCK SOURCES

Name	Bits	Bit -/7	Bit -/6	Bit 13/5	Bit 12/4	Bit 11/3	Bit 10/2	Bit 9/1	Bit 8/0	Register on Page
CONFIG1	13:8	—	—	FCMEN	IESO	CLKOUTEN	BOREN1	BOREN0	CPD	44
	7:0	CP	MCLRE	PWRTÉ	WDTE1	WDTE0	FOSC2	FOSC1	FOSC0	

Legend: — = unimplemented locations read as '0'. Shaded cells are not used by reference clock sources.

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NOTES:

7.0 RESETS

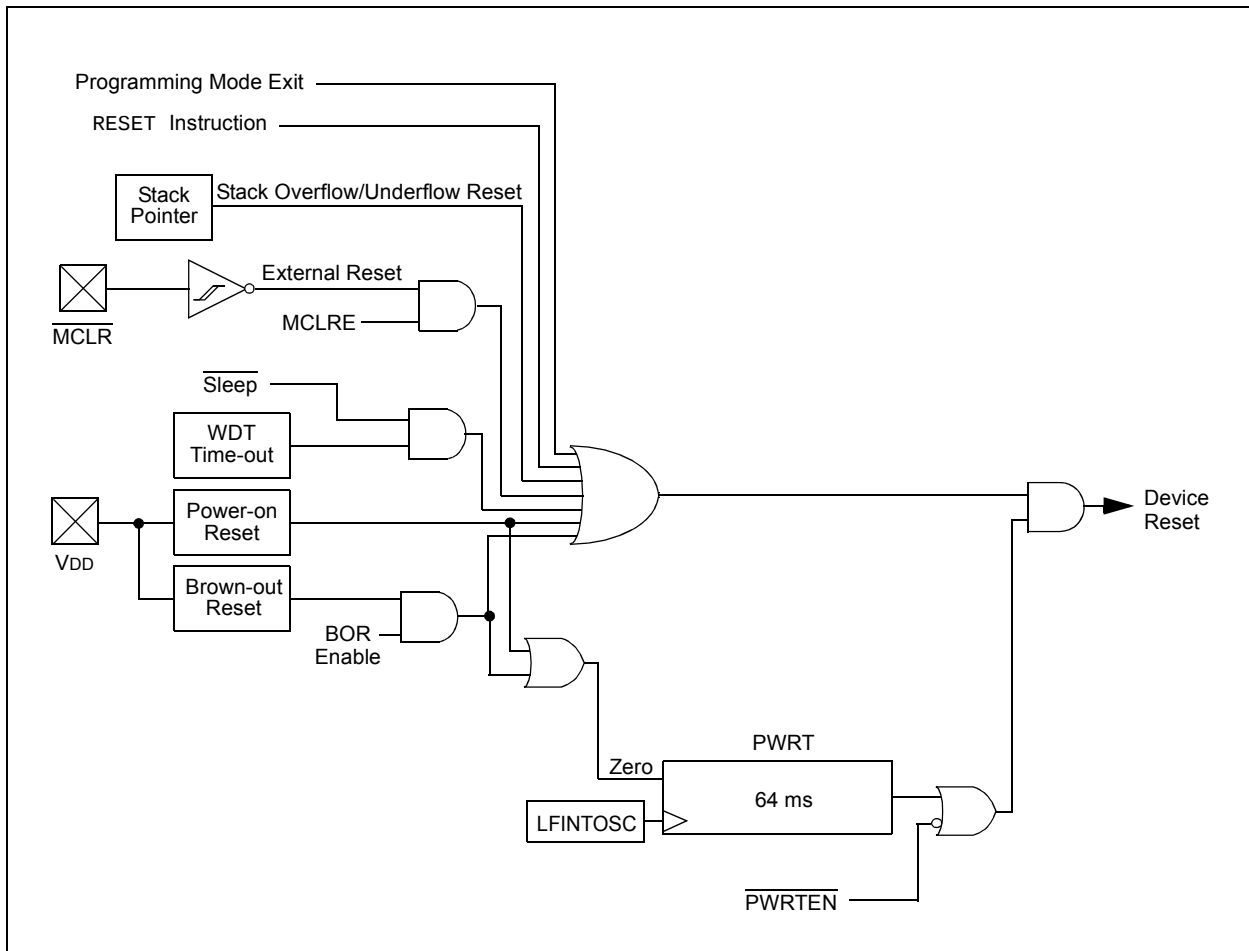
There are multiple ways to reset this device:

- Power-on Reset (POR)
- Brown-out Reset (BOR)
- MCLR Reset
- WDT Reset
- RESET instruction
- Stack Overflow
- Stack Underflow
- Programming mode exit

To allow VDD to stabilize, an optional power-up timer can be enabled to extend the Reset time after a BOR or POR event.

A simplified block diagram of the On-Chip Reset Circuit is shown in [Figure 7-1](#).

FIGURE 7-1: SIMPLIFIED BLOCK DIAGRAM OF ON-CHIP RESET CIRCUIT



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7.1 Power-on Reset (POR)

The POR circuit holds the device in Reset until VDD has reached an acceptable level for minimum operation. Slow rising VDD, fast operating speeds or analog performance may require greater than minimum VDD. The PWRT, BOR or MCLR features can be used to extend the start-up period until all device operation conditions have been met.

7.1.1 POWER-UP TIMER (PWRT)

The Power-up Timer provides a nominal 64 ms time-out on POR or Brown-out Reset.

The device is held in Reset as long as PWRT is active. The PWRT delay allows additional time for the VDD to rise to an acceptable level. The Power-up Timer is enabled by clearing the PWRTE bit in Configuration Word 1.

The Power-up Timer starts after the release of the POR and BOR.

For additional information, refer to Application Note AN607, "Power-up Trouble Shooting" (DS00607).

7.2 Brown-Out Reset (BOR)

The BOR circuit holds the device in Reset when VDD reaches a selectable minimum level. Between the POR and BOR, complete voltage range coverage for execution protection can be implemented.

The Brown-out Reset module has four operating modes controlled by the BOREN<1:0> bits in Configuration Word 1. The four operating modes are:

- BOR is always on
- BOR is off when in Sleep
- BOR is controlled by software
- BOR is always off

Refer to [Table 7-1](#) for more information.

The Brown-out Reset voltage level is selectable by configuring the BORV bit in Configuration Word 2.

A VDD noise rejection filter prevents the BOR from triggering on small events. If VDD falls below VBOR for a duration greater than parameter TBORDC, the device will reset. See [Figure 7-2](#) for more information.

TABLE 7-1: BOR OPERATING MODES

BOREN<1:0>	SBOREN	Device Mode	BOR Mode	Device Operation upon release of POR	Device Operation upon wake- up from Sleep
11	X	X	Active	Waits for BOR ready ⁽¹⁾	
10	X	Awake	Active	Waits for BOR ready	
		Sleep	Disabled		
01	1	X	Active	Begins immediately	
	0		Disabled	Begins immediately	
00	X	X	Disabled	Begins immediately	
Note 1: Even though this case specifically waits for the BOR, the BOR is already operating, so there is no delay in start-up.					

7.2.1 BOR IS ALWAYS ON

When the BOREN bits of Configuration Word 1 are set to '11', the BOR is always on. The device start-up will be delayed until the BOR is ready and VDD is higher than the BOR threshold.

BOR protection is active during Sleep. The BOR does not delay wake-up from Sleep.

7.2.2 BOR IS OFF IN SLEEP

When the BOREN bits of Configuration Word 1 are set to '10', the BOR is on, except in Sleep. The device start-up will be delayed until the BOR is ready and VDD is higher than the BOR threshold.

BOR protection is not active during Sleep. The device wake-up will be delayed until the BOR is ready.

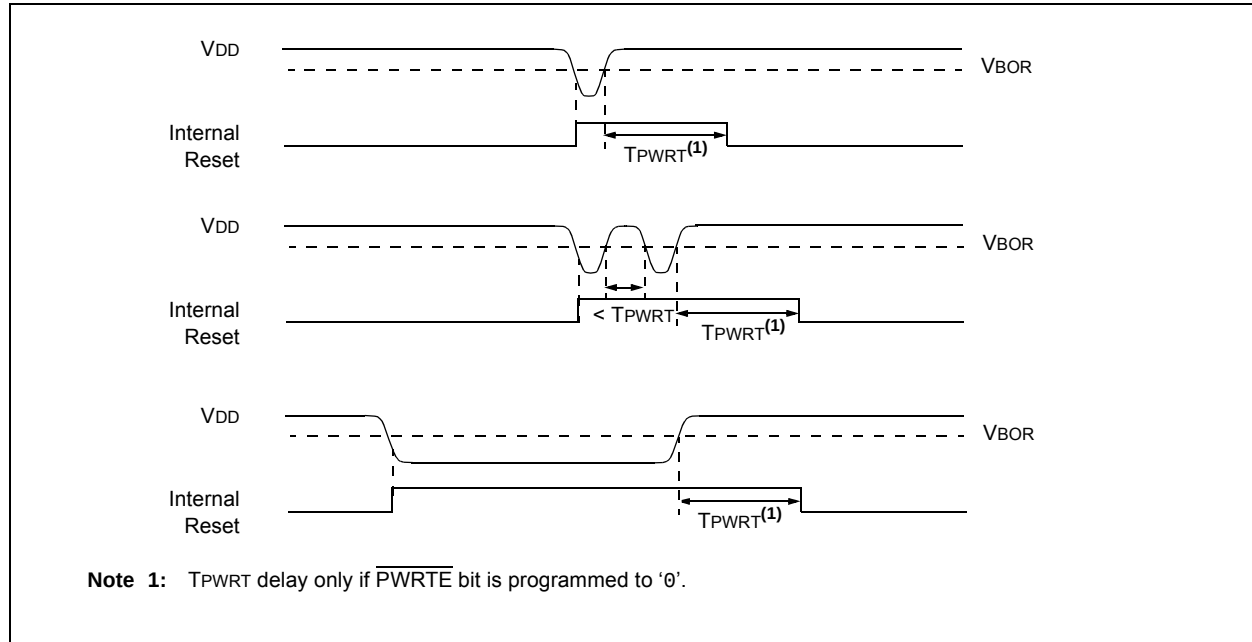
7.2.3 BOR CONTROLLED BY SOFTWARE

When the BOREN bits of Configuration Word 1 are set to '01', the BOR is controlled by the SBOREN bit of the BORCON register. The device start-up is not delayed by the BOR ready condition or the VDD level.

BOR protection begins as soon as the BOR circuit is ready. The status of the BOR circuit is reflected in the BORRDY bit of the BORCON register.

BOR protection is unchanged by Sleep.

FIGURE 7-2: BROWN-OUT SITUATIONS



REGISTER 7-1: BORCON: BROWN-OUT RESET CONTROL REGISTER

R/W-1/u	U-0	U-0	U-0	U-0	U-0	U-0	R-q/u
SBOREN	—	—	—	—	—	—	BORRDY
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	q = Value depends on condition

- bit 7 **SBOREN:** Software Brown-out Reset Enable bit
 If $\text{BOREN} < 1:0 >$ in Configuration Word 1 $\neq 01$:
 SBOREN is read/write, but has no effect on the BOR.
 If $\text{BOREN} < 1:0 >$ in Configuration Word 1 $= 01$:
 1 = BOR Enabled
 0 = BOR Disabled
- bit 6-1 **Unimplemented:** Read as '0'
- bit 0 **BORRDY:** Brown-out Reset Circuit Ready Status bit
 1 = The Brown-out Reset circuit is active
 0 = The Brown-out Reset circuit is inactive

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7.3 MCLR

The $\overline{\text{MCLR}}$ is an optional external input that can reset the device. The $\overline{\text{MCLR}}$ function is controlled by the MCLRE bit of Configuration Word 1 and the LVP bit of Configuration Word 2 (Table 7-2).

TABLE 7-2: $\overline{\text{MCLR}}$ CONFIGURATION

MCLRE	LVP	$\overline{\text{MCLR}}$
0	0	Disabled
1	0	Enabled
x	1	Enabled

7.3.1 MCLR ENABLED

When $\overline{\text{MCLR}}$ is enabled and the pin is held low, the device is held in Reset. The $\overline{\text{MCLR}}$ pin is connected to VDD through an internal weak pull-up.

The device has a noise filter in the $\overline{\text{MCLR}}$ Reset path. The filter will detect and ignore small pulses.

Note: A Reset does not drive the $\overline{\text{MCLR}}$ pin low.

7.3.2 MCLR DISABLED

When $\overline{\text{MCLR}}$ is disabled, the pin functions as a general purpose input and the internal weak pull-up is under software control. See Section 12.2 “PORTA Registers” for more information.

7.4 Watchdog Timer (WDT) Reset

The Watchdog Timer generates a Reset if the firmware does not issue a CLRWDI instruction within the time-out period. The TO and PD bits in the STATUS register are changed to indicate the WDT Reset. See Section 10.0 “Watchdog Timer” for more information.

7.5 RESET Instruction

A RESET instruction will cause a device Reset. The RI bit in the PCON register will be set to ‘0’. See Table 7-4 for default conditions after a RESET instruction has occurred.

7.6 Stack Overflow/Underflow Reset

The device can reset when the Stack Overflows or Underflows. The STKOVF or STKUNF bits of the PCON register indicate the Reset condition. These Resets are enabled by setting the STVREN bit in Configuration Word 2. See Section 3.4.2 “Overflow/Underflow Reset” for more information.

7.7 Programming Mode Exit

Upon exit of Programming mode, the device will behave as if a POR had just occurred.

7.8 Power-Up Timer

The Power-up Timer optionally delays device execution after a BOR or POR event. This timer is typically used to allow VDD to stabilize before allowing the device to start running.

The Power-up Timer is controlled by the $\overline{\text{PWRTE}}$ bit of Configuration Word 1.

7.9 Start-up Sequence

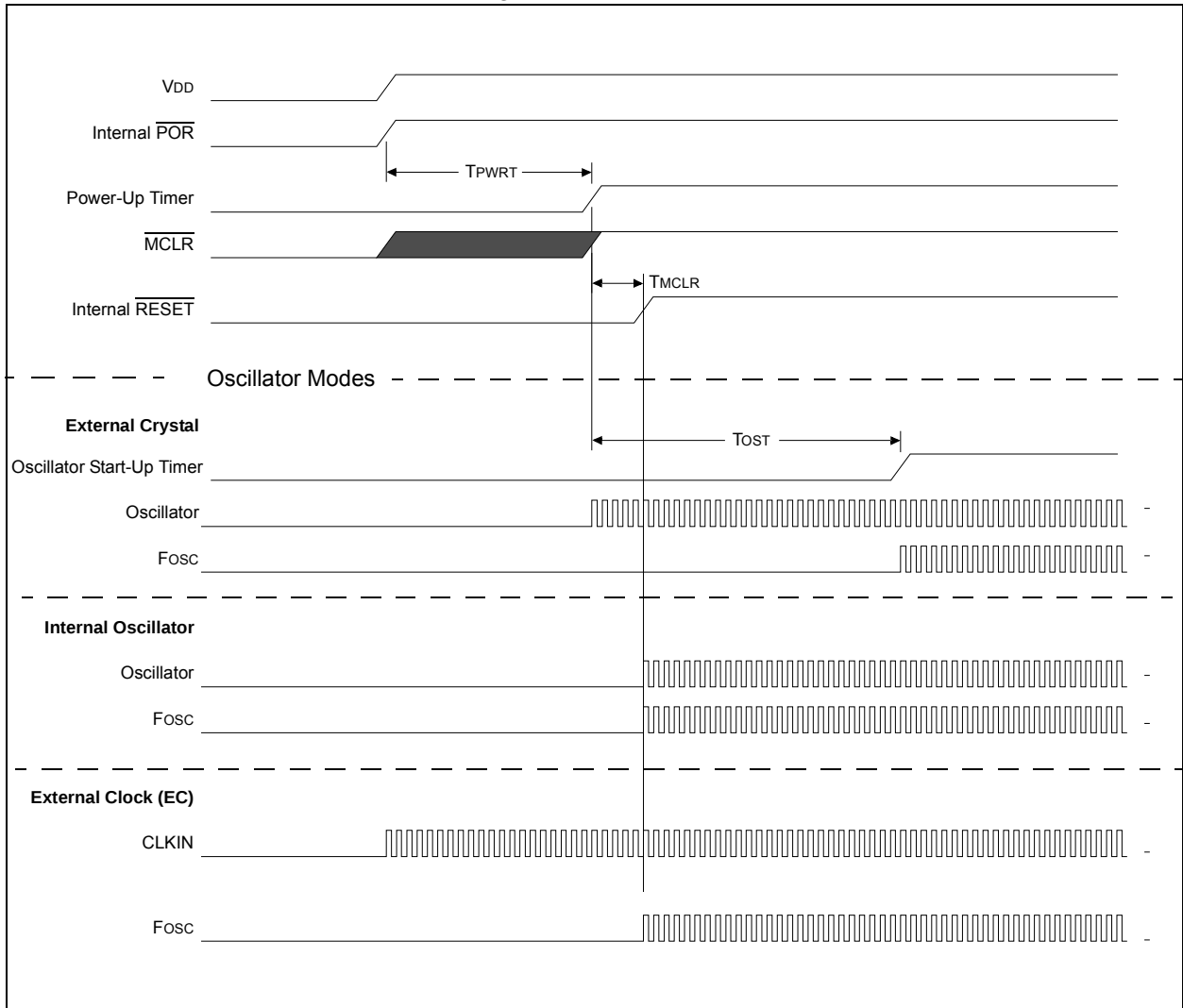
Upon the release of a POR or BOR, the following must occur before the device will begin executing:

1. Power-up Timer runs to completion (if enabled).
2. Oscillator start-up timer runs to completion (if required for oscillator source).
3. $\overline{\text{MCLR}}$ must be released (if enabled).

The total time-out will vary based on oscillator configuration and Power-up Timer configuration. See Section 5.0 “Oscillator Module (With Fail-Safe Clock Monitor)” for more information.

The Power-up Timer and oscillator start-up timer run independently of $\overline{\text{MCLR}}$ Reset. If $\overline{\text{MCLR}}$ is kept low long enough, the Power-up Timer and oscillator start-up timer will expire. Upon bringing $\overline{\text{MCLR}}$ high, the device will begin execution immediately (see Figure 7-3). This is useful for testing purposes or to synchronize more than one device operating in parallel.

FIGURE 7-3: RESET START-UP SEQUENCE



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7.10 Determining the Cause of a Reset

Upon any Reset, multiple bits in the STATUS and PCON register are updated to indicate the cause of the Reset. Table 7-3 and Table 7-4 show the Reset conditions of these registers.

TABLE 7-3: RESET STATUS BITS AND THEIR SIGNIFICANCE

STKOVF	STKUNF	RMCLR	RI	POR	BOR	TO	PD	Condition
0	0	1	1	0	x	1	1	Power-on Reset
0	0	1	1	0	x	0	x	Illegal, $\overline{TO}$ is set on $\overline{POR}$
0	0	1	1	0	x	x	0	Illegal, $\overline{PD}$ is set on $\overline{POR}$
0	0	1	1	u	0	1	1	Brown-out Reset
u	u	u	u	u	u	0	u	WDT Reset
u	u	u	u	u	u	0	0	WDT Wake-up from Sleep
u	u	u	u	u	u	1	0	Interrupt Wake-up from Sleep
u	u	0	u	u	u	u	u	$\overline{MCLR}$ Reset during normal operation
u	u	0	u	u	u	1	0	$\overline{MCLR}$ Reset during Sleep
u	u	u	0	u	u	u	u	RESET Instruction Executed
1	u	u	u	u	u	u	u	Stack Overflow Reset (STVREN = 1)
u	1	u	u	u	u	u	u	Stack Underflow Reset (STVREN = 1)

TABLE 7-4: RESET CONDITION FOR SPECIAL REGISTERS⁽²⁾

Condition	Program Counter	STATUS Register	PCON Register
Power-on Reset	0000h	---1 1000	00-- 110x
$\overline{MCLR}$ Reset during normal operation	0000h	---u uuuu	uu-- 0uuu
$\overline{MCLR}$ Reset during Sleep	0000h	---1 0uuu	uu-- 0uuu
WDT Reset	0000h	---0 uuuu	uu-- uuuu
WDT Wake-up from Sleep	PC + 1	---0 0uuu	uu-- uuuu
Brown-out Reset	0000h	---1 1uuu	00-- 11u0
Interrupt Wake-up from Sleep	PC + 1 ⁽¹⁾	---1 0uuu	uu-- uuuu
RESET Instruction Executed	0000h	---u uuuu	uu-- u0uu
Stack Overflow Reset (STVREN = 1)	0000h	---u uuuu	1u-- uuuu
Stack Underflow Reset (STVREN = 1)	0000h	---u uuuu	u1-- uuuu

Legend: u = unchanged, x = unknown, - = unimplemented bit, reads as '0'.

Note 1: When the wake-up is due to an interrupt and Global Enable bit (GIE) is set, the return address is pushed on the stack and PC is loaded with the interrupt vector (0004h) after execution of PC + 1.

2: If a Status bit is not implemented, that bit will be read as '0'.

7.11 Power Control (PCON) Register

The Power Control (PCON) register contains flag bits to differentiate between a:

- Power-on Reset ($\overline{\text{POR}}$)
- Brown-out Reset ($\overline{\text{BOR}}$)
- Reset Instruction Reset ($\overline{\text{RI}}$)
- $\overline{\text{MCLR}}$ Reset ($\overline{\text{RMCLR}}$)
- Stack Underflow Reset (STKUNF)
- Stack Overflow Reset (STKOVF)

The PCON register bits are shown in [Register 7-2](#).

REGISTER 7-2: PCON: POWER CONTROL REGISTER

R/W/HS-0/q	R/W/HS-0/q	U-0	U-0	R/W/HC-1/q	R/W/HC-1/q	R/W/HC-q/u	R/W/HC-q/u
STKOVF	STKUNF	—	—	$\overline{\text{RMCLR}}$	$\overline{\text{RI}}$	$\overline{\text{POR}}$	$\overline{\text{BOR}}$
bit 7							bit 0

Legend:

HC = Bit is cleared by hardware

HS = Bit is set by hardware

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-m/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

q = Value depends on condition

bit 7	STKOVF: Stack Overflow Flag bit 1 = A Stack Overflow occurred 0 = A Stack Overflow has not occurred or set to '0' by firmware
bit 6	STKUNF: Stack Underflow Flag bit 1 = A Stack Underflow occurred 0 = A Stack Underflow has not occurred or set to '0' by firmware
bit 5-4	Unimplemented: Read as '0'
bit 3	$\overline{\text{RMCLR}}$: $\overline{\text{MCLR}}$ Reset Flag bit 1 = A $\overline{\text{MCLR}}$ Reset has not occurred or set to '1' by firmware 0 = A $\overline{\text{MCLR}}$ Reset has occurred (set to '0' in hardware when a $\overline{\text{MCLR}}$ Reset occurs)
bit 2	$\overline{\text{RI}}$: RESET Instruction Flag bit 1 = A RESET instruction has not been executed or set to '1' by firmware 0 = A RESET instruction has been executed (set to '0' in hardware upon executing a RESET instruction)
bit 1	$\overline{\text{POR}}$: Power-on Reset Status bit 1 = No Power-on Reset occurred 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 = No Brown-out Reset occurred 0 = A Brown-out Reset occurred (must be set in software after a Power-on Reset or Brown-out Reset occurs)

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TABLE 7-5: SUMMARY OF REGISTERS ASSOCIATED WITH RESETS

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
BORCON	SBOREN	—	—	—	—	—	—	BORRDY	75
PCON	STKOVF	STKUNF	—	—	$\overline{\text{RMCLR}}$	$\overline{\text{RI}}$	$\overline{\text{POR}}$	$\overline{\text{BOR}}$	79
STATUS	—	—	—	$\overline{\text{TO}}$	$\overline{\text{PD}}$	Z	DC	C	21
WDTCN	—	—	WDTPS4	WDTPS3	WDTPS2	WDTPS1	WDTPS0	SWDTEN	99

Legend: — = unimplemented bit, reads as '0'. Shaded cells are not used by Resets.

Note 1: Other (non Power-up) Resets include MCLR Reset and Watchdog Timer Reset during normal operation.

8.0 INTERRUPTS

The interrupt feature allows certain events to preempt normal program flow. Firmware is used to determine the source of the interrupt and act accordingly. Some interrupts can be configured to wake the MCU from Sleep mode.

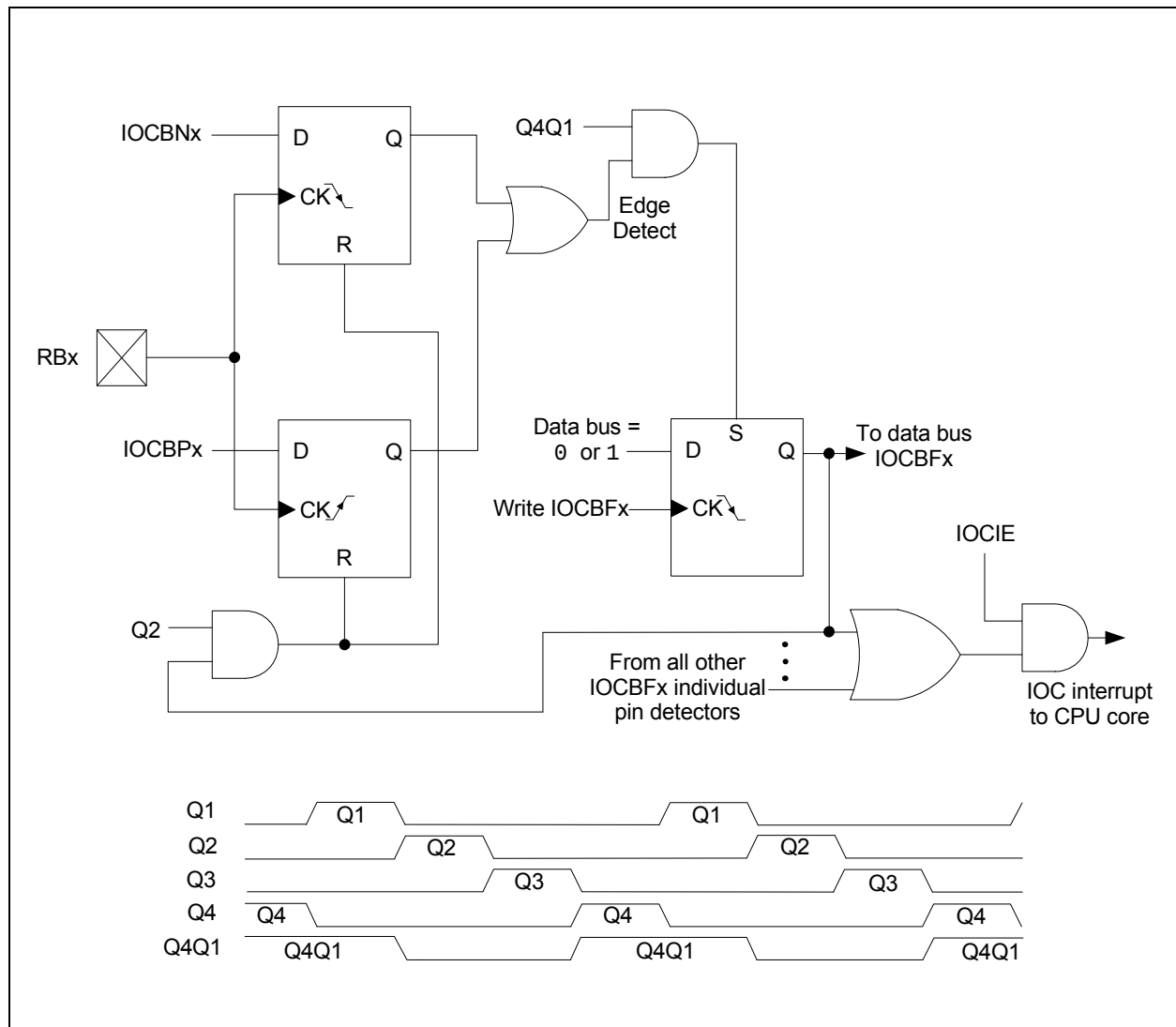
This chapter contains the following information for Interrupts:

- Operation
- Interrupt Latency
- Interrupts During Sleep
- INT Pin
- Automatic Context Saving

Many peripherals produce Interrupts. Refer to the corresponding chapters for details.

A block diagram of the interrupt logic is shown in Figure 8-1.

FIGURE 8-1: INTERRUPT LOGIC



8.1 Operation

Interrupts are disabled upon any device Reset. They are enabled by setting the following bits:

- GIE bit of the INTCON register
- Interrupt Enable bit(s) for the specific interrupt events)
- PEIE bit of the INTCON register (if the Interrupt Enable bit of the interrupt event is contained in the PIRx registers)

The INTCON, PIRx registers record individual interrupts via interrupt flag bits. Interrupt flag bits will be set, regardless of the status of the GIE, PEIE and individual interrupt enable bits.

The following events happen when an interrupt event occurs while the GIE bit is set:

- Current prefetched instruction is flushed
- GIE bit is cleared
- Current Program Counter (PC) is pushed onto the stack
- Critical registers are automatically saved to the shadow registers (See “[Section 8.5 “Automatic Context Saving”](#).”)
- PC is loaded with the interrupt vector 0004h

The firmware within the Interrupt Service Routine (ISR) should determine the source of the interrupt by polling the interrupt flag bits. The interrupt flag bits must be cleared before exiting the ISR to avoid repeated interrupts. Because the GIE bit is cleared, any interrupt that occurs while executing the ISR will be recorded through its interrupt flag, but will not cause the processor to redirect to the interrupt vector.

The RETFIE instruction exits the ISR by popping the previous address from the stack, restoring the saved context from the shadow registers and setting the GIE bit.

For additional information on a specific interrupt's operation, refer to its peripheral chapter.

Note 1: Individual interrupt flag bits are set, regardless of the state of any other enable bits.

2: All interrupts will be ignored while the GIE bit is cleared. Any interrupt occurring while the GIE bit is clear will be serviced when the GIE bit is set again.

8.2 Interrupt Latency

Interrupt latency is defined as the time from when the interrupt event occurs to the time code execution at the interrupt vector begins. The latency for synchronous interrupts is 3 or 4 instruction cycles. For asynchronous interrupts, the latency is 3 to 5 instruction cycles, depending on when the interrupt occurs. See [Figure 8-2](#) and [Figure 8.3](#) for more details.

FIGURE 8-2: INTERRUPT LATENCY

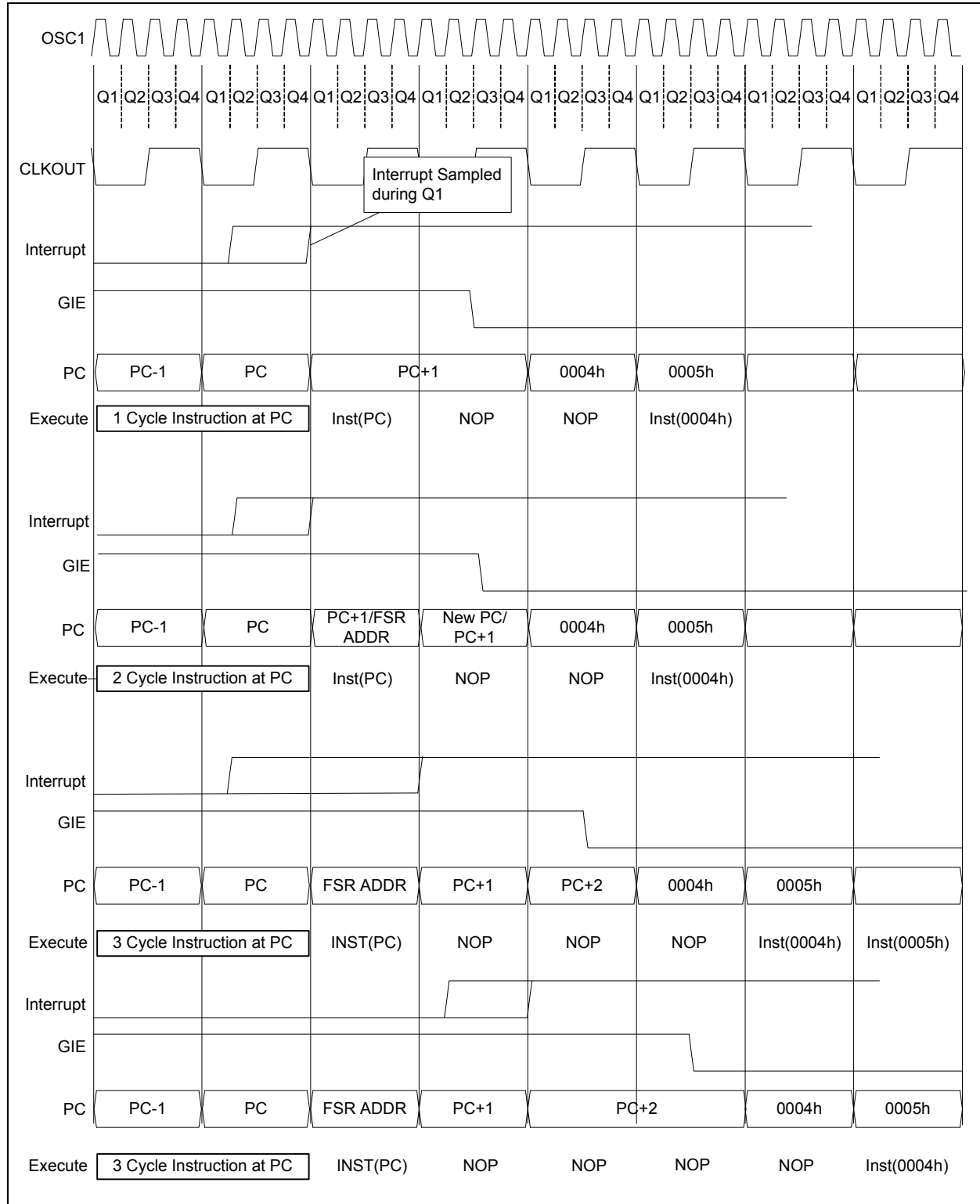
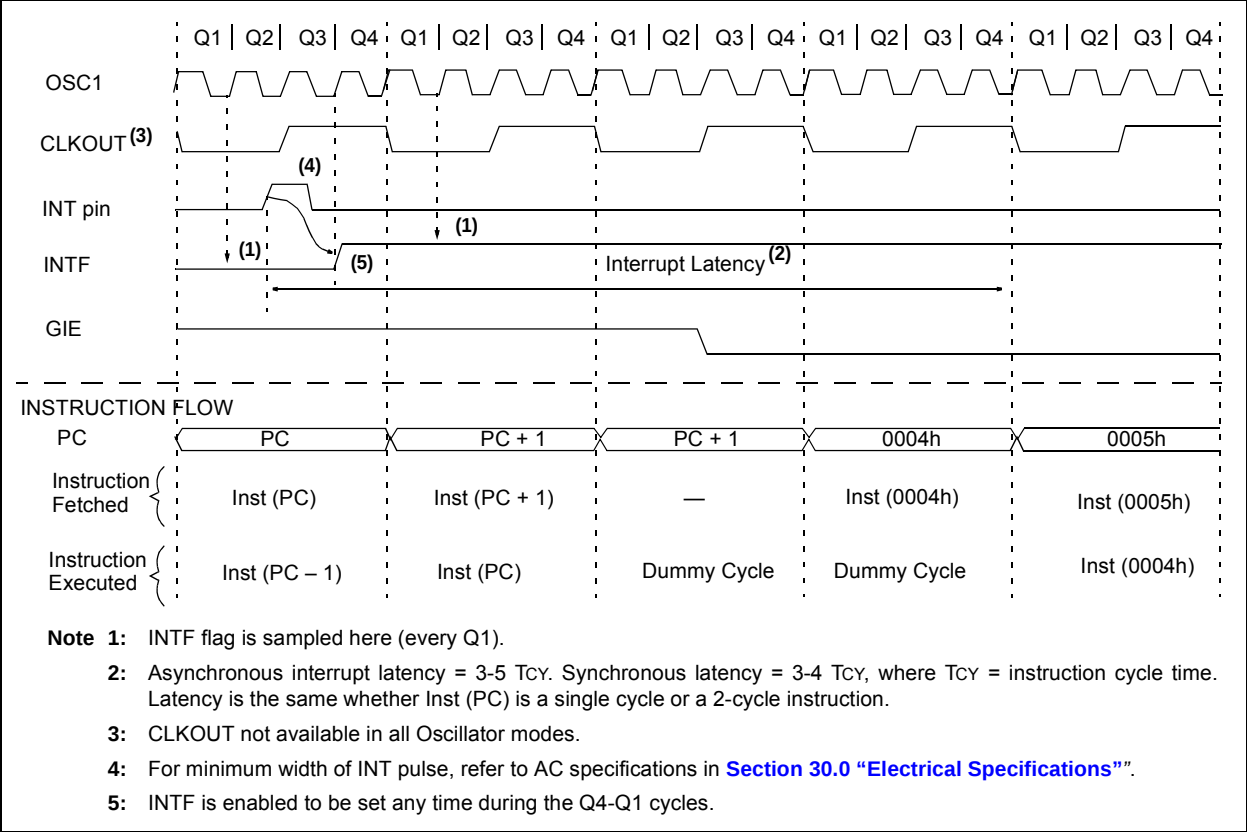


FIGURE 8-3: INT PIN INTERRUPT TIMING



8.3 Interrupts During Sleep

Some interrupts can be used to wake from Sleep. To wake from Sleep, the peripheral must be able to operate without the system clock. The interrupt source must have the appropriate Interrupt Enable bit(s) set prior to entering Sleep.

On waking from Sleep, if the GIE bit is also set, the processor will branch to the interrupt vector. Otherwise, the processor will continue executing instructions after the SLEEP instruction. The instruction directly after the SLEEP instruction will always be executed before branching to the ISR. Refer to [Section 9.0 “Power-Down Mode \(Sleep\)”](#) for more details.

8.4 INT Pin

The INT pin can be used to generate an asynchronous edge-triggered interrupt. This interrupt is enabled by setting the INTE bit of the INTCON register. The INTEDG bit of the OPTION_REG register determines on which edge the interrupt will occur. When the INTEDG bit is set, the rising edge will cause the interrupt. When the INTEDG bit is clear, the falling edge will cause the interrupt. The INTF bit of the INTCON register will be set when a valid edge appears on the INT pin. If the GIE and INTE bits are also set, the processor will redirect program execution to the interrupt vector.

8.5 Automatic Context Saving

Upon entering an interrupt, the return PC address is saved on the stack. Additionally, the following registers are automatically saved in the Shadow registers:

- W register
- STATUS register (except for $\overline{\text{TO}}$ and $\overline{\text{PD}}$)
- BSR register
- FSR registers
- PCLATH register

Upon exiting the Interrupt Service Routine, these registers are automatically restored. Any modifications to these registers during the ISR will be lost. If modifications to any of these registers are desired, the corresponding Shadow register should be modified and the value will be restored when exiting the ISR. The Shadow registers are available in Bank 31 and are readable and writable. Depending on the user's application, other registers may also need to be saved.

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8.6 Interrupt Control Registers

8.6.1 INTCON REGISTER

The INTCON register is a readable and writable register, that contains the various enable and flag bits for TMR0 register overflow, interrupt-on-change and external INT pin interrupts.

Note: Interrupt flag bits are set when an interrupt condition occurs, regardless of the state of its corresponding enable bit or the Global Enable bit, GIE, of the INTCON register. User software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

REGISTER 8-1: INTCON: INTERRUPT CONTROL REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R-0/0
GIE	PEIE	TMR0IE	INTE	IOCFIE	TMR0IF	INTF	IOCFIF ⁽¹⁾
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7 **GIE:** Global Interrupt Enable bit
1 = Enables all active interrupts
0 = Disables all interrupts
- bit 6 **PEIE:** Peripheral Interrupt Enable bit
1 = Enables all active peripheral interrupts
0 = Disables all peripheral interrupts
- bit 5 **TMR0IE:** Timer0 Overflow Interrupt Enable bit
1 = Enables the Timer0 interrupt
0 = Disables the Timer0 interrupt
- bit 4 **INTE:** INT External Interrupt Enable bit
1 = Enables the INT external interrupt
0 = Disables the INT external interrupt
- bit 3 **IOCFIE:** Interrupt-on-Change Enable bit
1 = Enables the interrupt-on-change
0 = Disables the interrupt-on-change
- bit 2 **TMR0IF:** Timer0 Overflow Interrupt Flag bit
1 = TMR0 register has overflowed
0 = TMR0 register did not overflow
- bit 1 **INTF:** INT External Interrupt Flag bit
1 = The INT external interrupt occurred
0 = The INT external interrupt did not occur
- bit 0 **IOCFIF:** Interrupt-on-Change Interrupt Flag bit⁽¹⁾
1 = When at least one of the interrupt-on-change pins changed state
0 = None of the interrupt-on-change pins have changed state

Note 1: The IOCFIF Flag bit is read-only and cleared when all the Interrupt-on-Change flags in the IOCBF register have been cleared by software.

8.6.2 PIE1 REGISTER

The PIE1 register contains the interrupt enable bits, as shown in [Register 8-2](#).

Note: Bit PEIE of the INTCON register must be set to enable any peripheral interrupt.

REGISTER 8-2: PIE1: PERIPHERAL INTERRUPT ENABLE REGISTER 1

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

- bit 7 **TMR1GIE:** Timer1 Gate Interrupt Enable bit
 1 = Enables the Timer1 Gate Acquisition interrupt
 0 = Disables the Timer1 Gate Acquisition interrupt
- bit 6 **ADIE:** A/D Converter (ADC) Interrupt Enable bit
 1 = Enables the ADC interrupt
 0 = Disables the ADC interrupt
- bit 5 **RCIE:** USART Receive Interrupt Enable bit
 1 = Enables the USART receive interrupt
 0 = Disables the USART receive interrupt
- bit 4 **TXIE:** USART Transmit Interrupt Enable bit
 1 = Enables the USART transmit interrupt
 0 = Disables the USART transmit interrupt
- bit 3 **SSP1IE:** Synchronous Serial Port 1 (MSSP1) Interrupt Enable bit
 1 = Enables the MSSP1 interrupt
 0 = Disables the MSSP1 interrupt
- 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 Timer2 to PR2 match interrupt
 0 = Disables the Timer2 to PR2 match interrupt
- bit 0 **TMR1IE:** Timer1 Overflow Interrupt Enable bit
 1 = Enables the Timer1 overflow interrupt
 0 = Disables the Timer1 overflow interrupt

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8.6.3 PIE2 REGISTER

The PIE2 register contains the interrupt enable bits, as shown in [Register 8-3](#).

Note: Bit PEIE of the INTCON register must be set to enable any peripheral interrupt.

REGISTER 8-3: PIE2: PERIPHERAL INTERRUPT ENABLE REGISTER 2

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	U-0	U-0	R/W-0/0
OSFIE	C2IE	C1IE	EEIE	BCL1IE	—	—	CCP2IE ⁽¹⁾
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7 **OSFIE:** Oscillator Fail Interrupt Enable bit
1 = Enables the Oscillator Fail interrupt
0 = Disables the Oscillator Fail interrupt
- bit 6 **C2IE:** Comparator C2 Interrupt Enable bit
1 = Enables the Comparator C2 interrupt
0 = Disables the Comparator C2 interrupt
- bit 5 **C1IE:** Comparator C1 Interrupt Enable bit
1 = Enables the Comparator C1 interrupt
0 = Disables the Comparator C1 interrupt
- bit 4 **EEIE:** EEPROM Write Completion Interrupt Enable bit
1 = Enables the EEPROM Write Completion interrupt
0 = Disables the EEPROM Write Completion interrupt
- bit 3 **BCL1IE:** MSSP1 Bus Collision Interrupt Enable bit
1 = Enables the MSSP1 Bus Collision Interrupt
0 = Disables the MSSP1 Bus Collision Interrupt
- bit 2-1 **Unimplemented:** Read as '0'
- bit 0 **CCP2IE:** CCP2 Interrupt Enable bit
1 = Enables the CCP2 interrupt
0 = Disables the CCP2 interrupt

Note 1: PIC16(L)F1827 only.

8.6.4 PIE3 REGISTER

The PIE3 register contains the interrupt enable bits, as shown in [Register 8-4](#).

Note: Bit PEIE of the INTCON register must be set to enable any peripheral interrupt.

REGISTER 8-4: PIE3: PERIPHERAL INTERRUPT ENABLE REGISTER 3⁽¹⁾

U-0	U-0	R/W-0/0	R/W-0/0	R/W-0/0	U-0	R/W-0/0	U-0
—	—	CCP4IE	CCP3IE	TMR6IE	—	TMR4IE	—
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7-6 **Unimplemented:** Read as '0'

bit 5 **CCP4IE:** CCP4 Interrupt Enable bit

1 = Enables the CCP4 interrupt

0 = Disables the CCP4 interrupt

bit 4 **CCP3IE:** CCP3 Interrupt Enable bit

1 = Enables the CCP3 interrupt

0 = Disables the CCP3 interrupt

bit 3 **TMR6IE:** TMR6 to PR6 Match Interrupt Enable bit

1 = Enables the TMR6 to PR6 Match interrupt

0 = Disables the TMR6 to PR6 Match interrupt

bit 2 **Unimplemented:** Read as '0'

bit 1 **TMR4IE:** TMR4 to PR4 Match Interrupt Enable bit

1 = Enables the TMR4 to PR4 Match interrupt

0 = Disables the TMR4 to PR4 Match interrupt

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

Note 1: This register is only available on PIC16(L)F1827.

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8.6.5 PIE4 REGISTER⁽¹⁾

The PIE4 register contains the interrupt enable bits, as shown in [Register 8-5](#).

Note 1: The PIE4 register is available only on the PIC16(L)F1827 device.

2: Bit PEIE of the INTCON register must be set to enable any peripheral interrupt.

REGISTER 8-5: PIE4: PERIPHERAL INTERRUPT ENABLE REGISTER 4⁽¹⁾

U-0	U-0	U-0	U-0	U-0	U-0	R/W-0/0	R/W-0/0
—	—	—	—	—	—	BCL2IE	SSP2IE
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7-2 **Unimplemented:** Read as '0'

bit 1 **BCL2IE:** MSSP2 Bus Collision Interrupt Enable bit

1 = Enables the MSSP2 Bus Collision Interrupt

0 = Disables the MSSP2 Bus Collision Interrupt

bit 0 **SSP2IE:** Master Synchronous Serial Port 2 (MSSP2) Interrupt Enable bit

1 = Enables the MSSP2 interrupt

0 = Disables the MSSP2 interrupt

Note 1: This register is only available on PIC16(L)F1827.

8.6.6 PIR1 REGISTER

The PIR1 register contains the interrupt flag bits, as shown in [Register 8-6](#).

Note: Interrupt flag bits are set when an interrupt condition occurs, regardless of the state of its corresponding enable bit or the Global Enable bit, GIE, of the INTCON register. User software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

REGISTER 8-6: PIR1: PERIPHERAL INTERRUPT REQUEST REGISTER 1

R/W-0/0	R/W-0/0	R-0/0	R-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7	TMR1GIF: Timer1 Gate Interrupt Flag bit 1 = Interrupt is pending 0 = Interrupt is not pending
bit 6	ADIF: A/D Converter Interrupt Flag bit 1 = Interrupt is pending 0 = Interrupt is not pending
bit 5	RCIF: USART Receive Interrupt Flag bit 1 = Interrupt is pending 0 = Interrupt is not pending
bit 4	TXIF: USART Transmit Interrupt Flag bit 1 = Interrupt is pending 0 = Interrupt is not pending
bit 3	SSP1IF: Synchronous Serial Port 1 (MSSP1) Interrupt Flag bit 1 = Interrupt is pending 0 = Interrupt is not pending
bit 2	CCP1IF: CCP1 Interrupt Flag bit 1 = Interrupt is pending 0 = Interrupt is not pending
bit 1	TMR2IF: Timer2 to PR2 Interrupt Flag bit 1 = Interrupt is pending 0 = Interrupt is not pending
bit 0	TMR1IF: Timer1 Overflow Interrupt Flag bit 1 = Interrupt is pending 0 = Interrupt is not pending

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8.6.7 PIR2 REGISTER

The PIR2 register contains the interrupt flag bits, as shown in [Register 8-7](#).

Note: Interrupt flag bits are set when an interrupt condition occurs, regardless of the state of its corresponding enable bit or the Global Enable bit, GIE, of the INTCON register. User software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

REGISTER 8-7: PIR2: PERIPHERAL INTERRUPT REQUEST REGISTER 2

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	U-0	U-0	R/W-0/0
OSFIF	C2IF	C1IF	EEIF	BCL1IF	—	—	CCP2IF ⁽¹⁾
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7 **OSFIF:** Oscillator Fail Interrupt Flag bit
1 = Interrupt is pending
0 = Interrupt is not pending
- bit 6 **C2IF:** Comparator C2 Interrupt Flag bit
1 = Interrupt is pending
0 = Interrupt is not pending
- bit 5 **C1IF:** Comparator C1 Interrupt Flag bit
1 = Interrupt is pending
0 = Interrupt is not pending
- bit 4 **EEIF:** EEPROM Write Completion Interrupt Flag bit
1 = Interrupt is pending
0 = Interrupt is not pending
- bit 3 **BCL1IF:** MSSP1 Bus Collision Interrupt Flag bit
1 = Interrupt is pending
0 = Interrupt is not pending
- bit 2-1 **Unimplemented:** Read as '0'
- bit 0 **CCP2IF:** CCP2 Interrupt Flag bit⁽¹⁾
1 = Interrupt is pending
0 = Interrupt is not pending

Note 1: PIC16(L)F1827 only.

8.6.8 PIR3 REGISTER

The PIR3 register contains the interrupt flag bits, as shown in [Register 8-8](#).

Note: Interrupt flag bits are set when an interrupt condition occurs, regardless of the state of its corresponding enable bit or the Global Enable bit, GIE, of the INTCON register. User software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

REGISTER 8-8: PIR3: PERIPHERAL INTERRUPT REQUEST REGISTER 3⁽¹⁾

U-0	U-0	R/W-0/0	R/W-0/0	R/W-0/0	U-0	R/W-0/0	U-0
—	—	CCP4IF	CCP3IF	TMR6IF	—	TMR4IF	—
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7-6 **Unimplemented:** Read as '0'
- bit 5 **CCP4IF:** CCP4 Interrupt Flag bit
1 = Interrupt is pending
0 = Interrupt is not pending
- bit 4 **CCP3IF:** CCP3 Interrupt Flag bit
1 = Interrupt is pending
0 = Interrupt is not pending
- bit 3 **TMR6IF:** TMR6 to PR6 Match Interrupt Flag bit
1 = Interrupt is pending
0 = Interrupt is not pending
- bit 2 **Unimplemented:** Read as '0'
- bit 1 **TMR4IF:** TMR4 to PR4 Match Interrupt Flag bit
1 = Interrupt is pending
0 = Interrupt is not pending
- bit 0 **Unimplemented:** Read as '0'

Note 1: This register is only available on PIC16(L)F1827.

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8.6.9 PIR4 REGISTER⁽¹⁾

The PIR4 register contains the interrupt flag bits, as shown in [Register 8-9](#).

Note 1: The PIR4 register is available only on the PIC16(L)F1827 device.

2: Interrupt flag bits are set when an interrupt condition occurs, regardless of the state of its corresponding enable bit or the Global Enable bit, GIE, of the INTCON register. User software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

REGISTER 8-9: PIR4: PERIPHERAL INTERRUPT REQUEST REGISTER 4⁽¹⁾

U-0	U-0	U-0	U-0	U-0	U-0	R/W/HS-0/0	R/W/HS-0/0
—	—	—	—	—	—	BCL2IF	SSP2IF
bit 7						bit 0	

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

HS = Bit is set by hardware

bit 7-2 **Unimplemented:** Read as '0'

bit 1 **BCL2IF:** MSSP2 Bus Collision Interrupt Flag bit

1 = A Bus Collision was detected (must be cleared in software)

0 = No Bus collision was detected

bit 0 **SSP2IF:** Master Synchronous Serial Port 2 (MSSP2) Interrupt Flag bit

1 = The Transmission/Reception/Bus Condition is complete (must be cleared in software)

0 = Waiting to Transmit/Receive/Bus Condition in progress

Note 1: This register is only available on PIC16(L)F1827.

TABLE 8-1: SUMMARY OF REGISTERS ASSOCIATED WITH INTERRUPTS

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
OPTION_REG	WPUEN	INTEDG	TMR0CS	TMR0SE	PSA	PS2	PS1	PS0	177
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE	87
PIE2	OSFIE	C2IE	C1IE	EEIE	BCL1IE	—	—	CCP2IE ⁽¹⁾	88
PIE3 ⁽¹⁾	—	—	CCP4IE	CCP3IE	TMR6IE	—	TMR4IE	—	89
PIE4 ⁽¹⁾	—	—	—	—	—	—	BCL2IE	SSP2IE	90
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF	91
PIR2	OSFIF	C2IF	C1IF	EEIF	BCL1IF	—	—	CCP2IF ⁽¹⁾	92
PIR3 ⁽¹⁾	—	—	CCP4IF	CCP3IF	TMR6IF	—	TMR4IF	—	93
PIR4 ⁽¹⁾	—	—	—	—	—	—	BCL2IF	SSP2IF	94

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

Note 1: PIC16(L)F1827 only.

9.0 POWER-DOWN MODE (SLEEP)

The Power-Down mode is entered by executing a SLEEP instruction.

Upon entering Sleep mode, the following conditions exist:

1. WDT will be cleared but keeps running, if enabled for operation during Sleep.
2. $\overline{\text{PD}}$ bit of the STATUS register is cleared.
3. $\overline{\text{TO}}$ bit of the STATUS register is set.
4. CPU clock is disabled.
5. 31 kHz LFINTOSC is unaffected and peripherals that operate from it may continue operation in Sleep.
6. Timer1 oscillator is unaffected and peripherals that operate from it may continue operation in Sleep.
7. ADC is unaffected, if the dedicated FRC clock is selected.
8. Capacitive Sensing oscillator is unaffected.
9. I/O ports maintain the status they had before SLEEP was executed (driving high, low or high-impedance).
10. Resets other than WDT are not affected by Sleep mode.

Refer to individual chapters for more details on peripheral operation during Sleep.

To minimize current consumption, the following conditions should be considered:

- I/O pins should not be floating
- External circuitry sinking current from I/O pins
- Internal circuitry sourcing current from I/O pins
- Current draw from pins with internal weak pull-ups
- Modules using 31 kHz LFINTOSC
- Modules using Timer1 oscillator

I/O pins that are high-impedance inputs should be pulled to VDD or VSS externally to avoid switching currents caused by floating inputs.

Examples of internal circuitry that might be sourcing current include modules such as the DAC and FVR modules. See [Section 17.0 “Digital-to-Analog Converter \(DAC\) Module”](#) and [Section 14.0 “Fixed Voltage Reference \(FVR\)”](#) for more information on these modules.

9.1 Wake-up from Sleep

The device can wake-up from Sleep through one of the following events:

1. External Reset input on $\overline{\text{MCLR}}$ pin, if enabled
2. BOR Reset, if enabled
3. POR Reset
4. Watchdog Timer, if enabled
5. Any external interrupt
6. Interrupts by peripherals capable of running during Sleep (see individual peripheral for more information)

The first three events will cause a device Reset. The last three events are considered a continuation of program execution. To determine whether a device Reset or wake-up event occurred, refer to [Section 7.10 “Determining the Cause of a Reset”](#).

When the SLEEP instruction is being executed, the next instruction (PC + 1) is prefetched. For the device to wake-up through an interrupt event, the corresponding interrupt enable bit must be enabled. Wake-up will occur regardless of the state of the GIE bit. If the GIE bit is disabled, the device continues execution at the instruction after the SLEEP instruction. If the GIE bit is enabled, the device executes the instruction after the SLEEP instruction, the device will then call the Interrupt Service Routine. In cases where the execution of the instruction following SLEEP is not desirable, the user should have a NOP after the SLEEP instruction.

The WDT is cleared when the device wakes up from Sleep, regardless of the source of wake-up.

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9.1.1 WAKE-UP USING INTERRUPTS

When global interrupts are disabled (GIE cleared) and any interrupt source has both its interrupt enable bit and interrupt flag bit set, one of the following will occur:

- If the interrupt occurs **before** the execution of a SLEEP instruction
 - SLEEP instruction will execute as a NOP.
 - WDT and WDT prescaler will not be cleared
 - $\overline{TO}$ bit of the STATUS register will not be set
 - $\overline{PD}$ bit of the STATUS register will not be cleared.

- If the interrupt occurs **during or after** the execution of a SLEEP instruction
 - SLEEP instruction will be completely executed
 - Device will immediately wake-up from Sleep
 - WDT and WDT prescaler will be cleared
 - $\overline{TO}$ bit of the STATUS register will be set
 - $\overline{PD}$ bit of the STATUS register will be cleared.

Even if the flag bits were checked before executing a SLEEP instruction, it may be possible for flag bits to become set before the SLEEP instruction completes. To determine whether a SLEEP instruction executed, test the $\overline{PD}$ bit. If the $\overline{PD}$ bit is set, the SLEEP instruction was executed as a NOP.

FIGURE 9-1: WAKE-UP FROM SLEEP THROUGH INTERRUPT

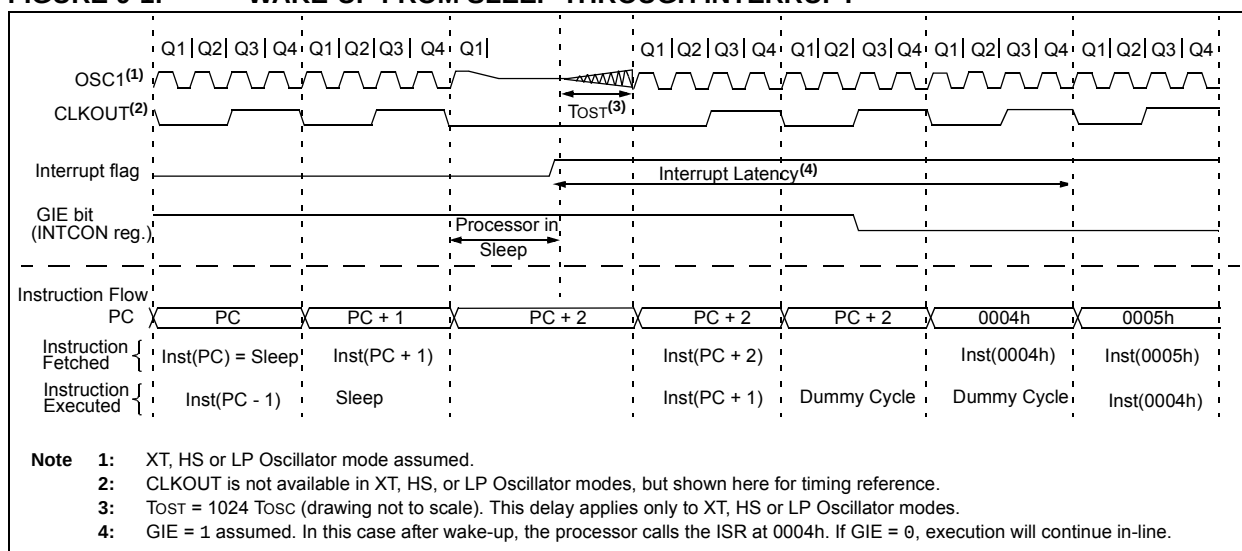


TABLE 9-1: SUMMARY OF REGISTERS ASSOCIATED WITH POWER-DOWN MODE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
INTCON	GIE	PEIE	TMR0IE	INTE	IOCFIE	TMR0IF	INTF	IOCFIF	91
IOCBF	IOCBF7	IOCBF6	IOCBF5	IOCBF4	IOCBF3	IOCBF2	IOCBF1	IOCBF0	134
IOCBN	IOCBN7	IOCBN6	IOCBN5	IOCBN4	IOCBN3	IOCBN2	IOCBN1	IOCBN0	134
IOCBP	IOCBP7	IOCBP6	IOCBP5	IOCBP4	IOCBP3	IOCBP2	IOCBP1	IOCBP0	134
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE	92
PIE2	OSFIE	C2IE	C1IE	EEIE	BCL1IE	—	—	CCP2IE ⁽¹⁾	93
PIE4 ⁽¹⁾	—	—	—	—	—	—	BCL2IE	SSP2IE	95
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF	96
PIR2	OSFIF	C2IF	C1IF	EEIF	BCL1IF	—	—	CCP2IF ⁽¹⁾	97
PIR4 ⁽¹⁾	—	—	—	—	—	—	BCL2IF	SSP2IF	99
STATUS	—	—	—	$\overline{TO}$	$\overline{PD}$	Z	DC	C	23
WDTCON	—	—	WDTPS4	WDTPS3	WDTPS2	WDTPS1	WDTPS0	SWDTEN	105

Legend: — = unimplemented, read as '0'. Shaded cells are not used in Power-down mode.

Note 1: PIC16(L)F1827 only.

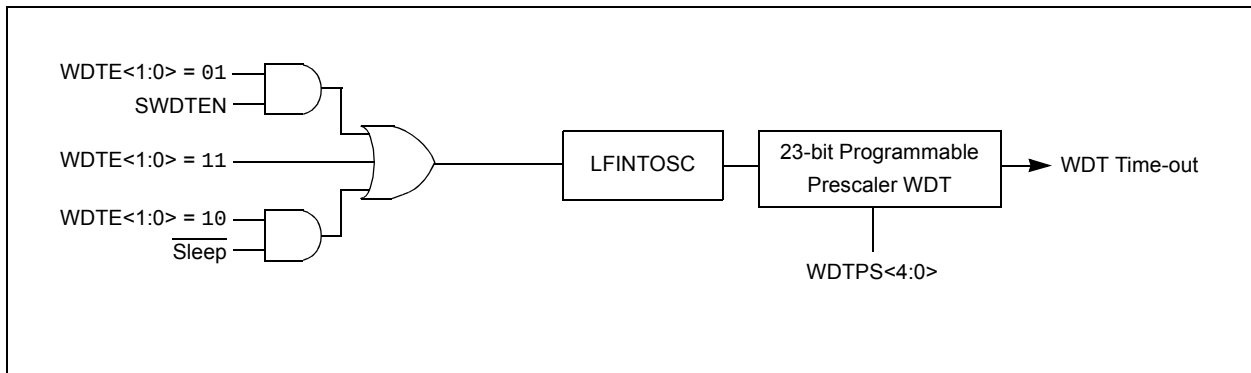
10.0 WATCHDOG TIMER

The Watchdog Timer is a system timer that generates a Reset if the firmware does not issue a CLRWDT instruction within the time-out period. The Watchdog Timer is typically used to recover the system from unexpected events.

The WDT has the following features:

- Independent clock source
- Multiple operating modes
 - WDT is always on
 - WDT is off when in Sleep
 - WDT is controlled by software
 - WDT is always off
- Configurable time-out period is from 1 ms to 256 seconds (typical)
- Multiple Reset conditions
- Operation during Sleep

FIGURE 10-1: WATCHDOG TIMER BLOCK DIAGRAM



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10.1 Independent Clock Source

The WDT derives its time base from the 31 kHz LFINTOSC internal oscillator. Time intervals in this chapter are based on a nominal interval of 1 ms. See [Section 30.0 “Electrical Specifications”](#) for the LFINTOSC tolerances.

10.2 WDT Operating Modes

The Watchdog Timer module has four operating modes controlled by the WDTE<1:0> bits in Configuration Word 1. See [Table 10-1](#).

10.2.1 WDT IS ALWAYS ON

When the WDTE bits of Configuration Word 1 are set to ‘11’, the WDT is always on.

WDT protection is active during Sleep.

10.2.2 WDT IS OFF IN SLEEP

When the WDTE bits of Configuration Word 1 are set to ‘10’, the WDT is on, except in Sleep.

WDT protection is not active during Sleep.

10.2.3 WDT CONTROLLED BY SOFTWARE

When the WDTE bits of Configuration Word 1 are set to ‘01’, the WDT is controlled by the SWDTEN bit of the WDTCON register.

WDT protection is unchanged by Sleep. See [Table 10-1](#) for more details.

TABLE 10-1: WDT OPERATING MODES

WDTE<1:0>	SWDTEN	Device Mode	WDT Mode
11	X	X	Active
10	X	Awake	Active
		Sleep	Disabled
01	1	X	Active
	0		Disabled
00	X	X	Disabled

TABLE 10-2: WDT CLEARING CONDITIONS

Conditions	WDT
WDTE<1:0> = 00	Cleared
WDTE<1:0> = 01 and SWDTEN = 0	
WDTE<1:0> = 10 and enter Sleep	
CLRWDT Command	
Oscillator Fail Detected	
Exit Sleep + System Clock = T1OSC, EXTRC, INTOSC, EXTCLK	
Exit Sleep + System Clock = XT, HS, LP	Cleared until the end of OST
Change INTOSC divider (IRCF bits)	Unaffected

10.3 Time-Out Period

The WDTPS bits of the WDTCON register set the time-out period from 1 ms to 256 seconds (nominal). After a Reset, the default time-out period is 2 seconds.

10.4 Clearing the WDT

The WDT is cleared when any of the following conditions occur:

- Any Reset
- CLRWDT instruction is executed
- Device enters Sleep
- Device wakes up from Sleep
- Oscillator fail event
- WDT is disabled
- Oscillator Start-up Timer (OST) is running

See [Table 10-2](#) for more information.

10.5 Operation During Sleep

When the device enters Sleep, the WDT is cleared. If the WDT is enabled during Sleep, the WDT resumes counting.

When the device exits Sleep, the WDT is cleared again. The WDT remains clear until the OST, if enabled, completes. See [Section 5.0 “Oscillator Module \(With Fail-Safe Clock Monitor\)”](#) for more information on the OST.

When a WDT time-out occurs while the device is in Sleep, no Reset is generated. Instead, the device wakes up and resumes operation. The TO and PD bits in the STATUS register are changed to indicate the event. See [Register 3-1](#) for more information.

10.6 Watchdog Control Register

REGISTER 10-1: WDTCON: WATCHDOG TIMER CONTROL REGISTER

U-0	U-0	R/W-0/0	R/W-1/1	R/W-0/0	R/W-1/1	R/W-1/1	R/W-0/0
—	—	WDTPS<4:0>					SWDTEN
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-m/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7-6 **Unimplemented:** Read as '0'

bit 5-1 **WDTPS<4:0>:** Watchdog Timer Period Select bits⁽¹⁾

Bit Value = Prescale Rate

00000 = 1:32 (Interval 1 ms nominal)
 00001 = 1:64 (Interval 2 ms nominal)
 00010 = 1:128 (Interval 4 ms nominal)
 00011 = 1:256 (Interval 8 ms nominal)
 00100 = 1:512 (Interval 16 ms nominal)
 00101 = 1:1024 (Interval 32 ms nominal)
 00110 = 1:2048 (Interval 64 ms nominal)
 00111 = 1:4096 (Interval 128 ms nominal)
 01000 = 1:8192 (Interval 256 ms nominal)
 01001 = 1:16384 (Interval 512 ms nominal)
 01010 = 1:32768 (Interval 1s nominal)
 01011 = 1:65536 (Interval 2s nominal) (Reset value)
 01100 = 1:131072 (2¹⁷) (Interval 4s nominal)
 01101 = 1:262144 (2¹⁸) (Interval 8s nominal)
 01110 = 1:524288 (2¹⁹) (Interval 16s nominal)
 01111 = 1:1048576 (2²⁰) (Interval 32s nominal)
 10000 = 1:2097152 (2²¹) (Interval 64s nominal)
 10001 = 1:4194304 (2²²) (Interval 128s nominal)
 10010 = 1:8388608 (2²³) (Interval 256s nominal)

10011 = Reserved. Results in minimum interval (1:32)

•
•
•

11111 = Reserved. Results in minimum interval (1:32)

bit 0 **SWDTEN:** Software Enable/Disable for Watchdog Timer bit

If WDTE<1:0> = 00:

This bit is ignored.

If WDTE<1:0> = 01:

1 = WDT is turned on

0 = WDT is turned off

If WDTE<1:0> = 1x:

This bit is ignored.

Note 1: Times are approximate. WDT time is based on 31 kHz LFINTOSC.

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TABLE 10-3: SUMMARY OF REGISTERS ASSOCIATED WITH WATCHDOG TIMER

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
OSCCON	—	IRCF<3:0>				—	SCS<1:0>		69
STATUS	—	—	—	$\overline{TO}$	$\overline{PD}$	Z	DC	C	21
WDTCON	—	—	WDTPS<4:0>					SWDTEN	99

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

TABLE 10-4: SUMMARY OF CONFIGURATION WORD WITH WATCHDOG TIMER

Name	Bits	Bit -/7	Bit -/6	Bit 13/5	Bit 12/4	Bit 11/3	Bit 10/2	Bit 9/1	Bit 8/0	Register on Page
CONFIG1	13:8	—	—	FCMEN	IESO	CLKOUTEN	BOREN<1:0>		CPD	44
	7:0	CP	MCLRE	PWRTRE	WDTE<1:0>		FOSC<2:0>			

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

11.0 DATA EEPROM AND FLASH PROGRAM MEMORY CONTROL

The Data EEPROM and Flash program memory are readable and writable during normal operation (full V_{DD} range). These memories are not directly mapped in the register file space. Instead, they are indirectly addressed through the Special Function Registers (SFRs). There are six SFRs used to access these memories:

- EECON1
- EECON2
- EEDATL
- EEDATH
- EEADRL
- EEADRH

When interfacing the data memory block, EEDATL holds the 8-bit data for read/write, and EEADRL holds the address of the EEDATL location being accessed. These devices have 256 bytes of data EEPROM with an address range from 0h to 0FFh.

When accessing the program memory block, the EEDATH:EEDATL register pair forms a 2-byte word that holds the 14-bit data for read/write, and the EEADRL and EEADRH registers form a 2-byte word that holds the 15-bit address of the program memory location being read.

The EEPROM data memory allows byte read and write. An EEPROM byte write automatically erases the location and writes the new data (erase before write).

The write time is controlled by an on-chip timer. The write/erase voltages are generated by an on-chip charge pump rated to operate over the voltage range of the device for byte or word operations.

Depending on the setting of the Flash Program Memory Self Write Enable bits $WRT<1:0>$ of the Configuration Word 2, the device may or may not be able to write certain blocks of the program memory. However, reads from the program memory are always allowed.

When the device is code-protected, the device programmer can no longer access data or program memory. When code-protected, the CPU may continue to read and write the data EEPROM memory and Flash program memory.

11.1 EEADRL and EEADRH Registers

The EEADRH:EEADRL register pair can address up to a maximum of 256 bytes of data EEPROM or up to a maximum of 32K words of program memory.

When selecting a program address value, the MSB of the address is written to the EEADRH register and the LSB is written to the EEADRL register. When selecting a EEPROM address value, only the LSB of the address is written to the EEADRL register.

11.1.1 EECON1 AND EECON2 REGISTERS

EECON1 is the control register for EE memory accesses.

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

Control bits RD and WR initiate read and write, respectively. These bits cannot be cleared, only set, in software. They are cleared in hardware at completion of the read or write operation. The inability to clear the WR bit in software prevents the accidental, premature termination of a write operation.

The WREN bit, when set, will allow a write operation to occur. On power-up, the WREN bit is clear. The WRERR bit is set when a write operation is interrupted by a Reset during normal operation. In these situations, following Reset, the user can check the WRERR bit and execute the appropriate error handling routine.

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

Reading EECON2 will read all '0's. The EECON2 register is used exclusively in the data EEPROM write sequence. To enable writes, a specific pattern must be written to EECON2.

11.2 Using the Data EEPROM

The data EEPROM is a high-endurance, byte addressable array that has been optimized for the storage of frequently changing information (e.g., program variables or other data that are updated often). When variables in one section change frequently, while variables in another section do not change, it is possible to exceed the total number of write cycles to the EEPROM without exceeding the total number of write cycles to a single byte. Refer to [Section 30.0 “Electrical Specifications”](#). If this is the case, then a refresh of the array must be performed. For this reason, variables that change infrequently (such as constants, IDs, calibration, etc.) should be stored in Flash program memory.

11.2.1 READING THE DATA EEPROM MEMORY

To read a data memory location, the user must write the address to the EEADRL register, clear the EEPGD and CFGS control bits of the EECON1 register, and then set control bit RD. The data is available at the very next cycle, in the EEDATL register; therefore, it can be read in the next instruction. EEDATL will hold this value until another read or until it is written to by the user (during a write operation).

EXAMPLE 11-1: DATA EEPROM READ

```
BANKSEL EEADRL      ;  
MOVLW  DATA_EE_ADDR ;  
MOVWF  EEADRL       ;Data Memory  
                        ;Address to read  
BCF    EECON1, CFGS ;Deselect Config space  
BCF    EECON1, EEPGD;Point to DATA memory  
BSF    EECON1, RD   ;EE Read  
MOVF   EEDATL, W    ;W = EEDATL
```

Note: Data EEPROM can be read regardless of the setting of the CPD bit.

11.2.2 WRITING TO THE DATA EEPROM MEMORY

To write an EEPROM data location, the user must first write the address to the EEADRL register and the data to the EEDATL register. Then the user must follow a specific sequence to initiate the write for each byte.

The write will not initiate if the above sequence is not followed exactly (write 55h to EECON2, write AAh to EECON2, then set the WR bit) for each byte. Interrupts should be disabled during this code segment.

Additionally, the WREN bit in EECON1 must be set to enable write. This mechanism prevents accidental writes to data EEPROM due to errant (unexpected) code execution (i.e., lost programs). The user should keep the WREN bit clear at all times, except when updating EEPROM. The WREN bit is not cleared by hardware.

After a write sequence has been initiated, clearing the WREN bit will not affect this write cycle. The WR bit will be inhibited from being set unless the WREN bit is set.

At the completion of the write cycle, the WR bit is cleared in hardware and the EE Write Complete Interrupt Flag bit (EEIF) is set. The user can either enable this interrupt or poll this bit. EEIF must be cleared by software.

11.2.3 PROTECTION AGAINST SPURIOUS WRITE

There are conditions when the user may not want to write to the data EEPROM memory. To protect against spurious EEPROM writes, various mechanisms have been built-in. On power-up, WREN is cleared. Also, the Power-up Timer (64 ms duration) prevents EEPROM write.

The write initiate sequence and the WREN bit together help prevent an accidental write during:

- Brown-out
- Power Glitch
- Software Malfunction

11.2.4 DATA EEPROM OPERATION DURING CODE-PROTECT

Data memory can be code-protected by programming the CPD bit in the Configuration Word 1 ([Register 4-1](#)) to '0'.

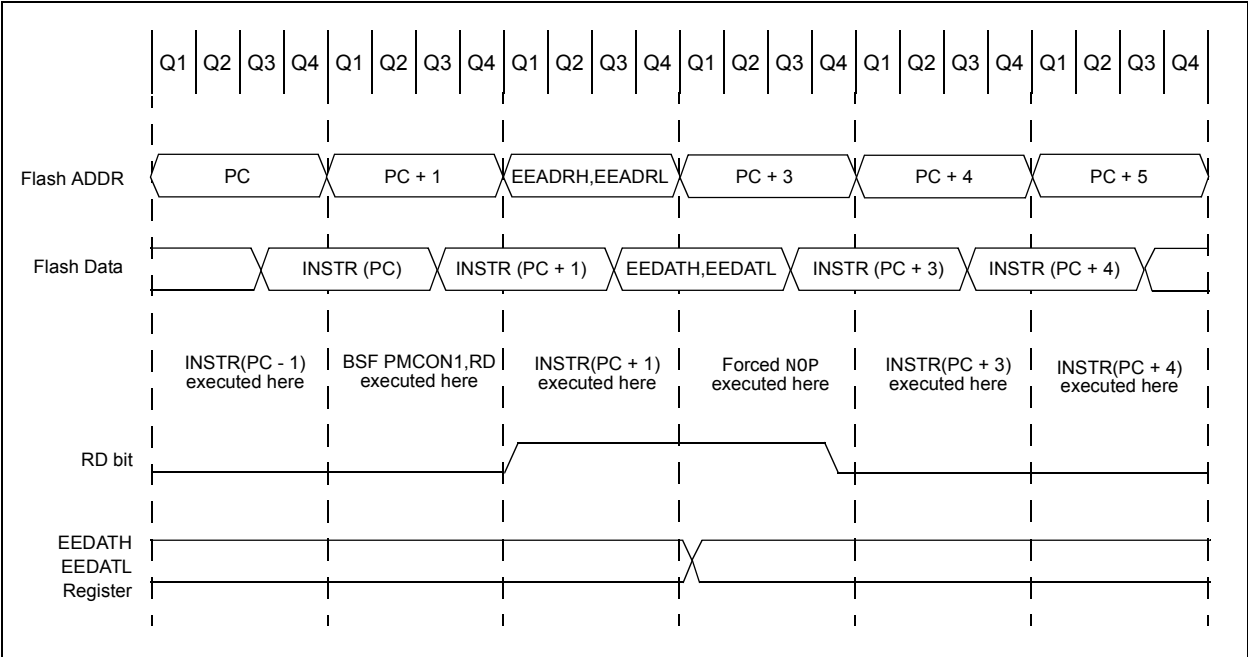
When the data memory is code-protected, only the CPU is able to read and write data to the data EEPROM. It is recommended to code-protect the program memory when code-protecting data memory. This prevents anyone from replacing your program with a program that will access the contents of the data EEPROM.

EXAMPLE 11-2: DATA EEPROM WRITE

Required Sequence	BANKSEL	EEADRL	;
	MOVLW	DATA_EE_ADDR	;
	MOVWF	EEADRL	;Data Memory Address to write
	MOVLW	DATA_EE_DATA	;
	MOVWF	EEDATL	;Data Memory Value to write
	BCF	EECON1, CFGS	;Deselect Configuration space
	BCF	EECON1, EEPGD	;Point to DATA memory
	BSF	EECON1, WREN	;Enable writes
	BCF	INTCON, GIE	;Disable INTs.
	MOVLW	55h	;
	MOVWF	EECON2	;Write 55h
	MOVLW	0AAh	;
	MOVWF	EECON2	;Write AAh
	BSF	EECON1, WR	;Set WR bit to begin write
	BSF	INTCON, GIE	;Enable Interrupts
	BCF	EECON1, WREN	;Disable writes
	BTFSC	EECON1, WR	;Wait for write to complete
GOTO	\$-2	;Done	

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FIGURE 11-1: FLASH PROGRAM MEMORY READ CYCLE EXECUTION



11.3 Flash Program Memory Overview

It is important to understand the Flash program memory structure for erase and programming operations. Flash Program memory is arranged in rows. A row consists of a fixed number of 14-bit program memory words. A row is the minimum block size that can be erased by user software.

Flash program memory may only be written or erased if the destination address is in a segment of memory that is not write-protected, as defined in bits WRT<1:0> of Configuration Word 2.

After a row has been erased, the user can reprogram all or a portion of this row. Data to be written into the program memory row is written to 14-bit wide data write latches. These write latches are not directly accessible to the user, but may be loaded via sequential writes to the EEDATH:EEDATL register pair.

Note: If the user wants to modify only a portion of a previously programmed row, then the contents of the entire row must be read and saved in RAM prior to the erase.

The number of data write latches may not be equivalent to the number of row locations. During programming, user software may need to fill the set of write latches and initiate a programming operation multiple times in order to fully reprogram an erased row. For example, a device with a row size of 32 words and eight write latches will need to load the write latches with data and initiate a programming operation four times.

The size of a program memory row and the number of program memory write latches may vary by device. See [Table 11-1](#) for details.

TABLE 11-1: FLASH MEMORY ORGANIZATION BY DEVICE

Device	Erase Block (Row) Size/ Boundary	Number of Write Latches/ Boundary
PIC16(L)F1826/27	32 words, EEADRL<4:0> = 00000	32 words, EEADRL<4:0> = 00000

11.3.1 READING THE FLASH PROGRAM MEMORY

To read a program memory location, the user must:

1. Write the Least and Most Significant address bits to the EEADRH:EEADRL register pair.
2. Clear the CFGS bit of the EECON1 register.
3. Set the EEPGD control bit of the EECON1 register.
4. Then, set control bit RD of the EECON1 register.

Once the read control bit is set, the program memory Flash controller will use the second instruction cycle to read the data. This causes the second instruction immediately following the "BSF EECON1, RD" instruction to be ignored. The data is available in the very next cycle, in the EEDATH:EEDATL register pair; therefore, it can be read as two bytes in the following instructions.

EEDATH:EEDATL register pair will hold this value until another read or until it is written to by the user.

Note 1: The two instructions following a program memory read are required to be NOPs. This prevents the user from executing a two-cycle instruction on the next instruction after the RD bit is set.

- 2: Flash program memory can be read regardless of the setting of the $\overline{CP}$ bit.

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EXAMPLE 11-3: FLASH PROGRAM MEMORY READ

```
* This code block will read 1 word of program
* memory at the memory address:
  PROG_ADDR_HI : PROG_ADDR_LO
* data will be returned in the variables;
* PROG_DATA_HI, PROG_DATA_LO

BANKSEL  EEADRL          ; Select Bank for EEPROM registers
MOVLW    PROG_ADDR_LO    ;
MOVWF    EEADRL          ; Store LSB of address
MOVLW    PROG_ADDR_HI    ;
MOVWL    EEADRH          ; Store MSB of address

BCF      EECON1,CFGSR    ; Do not select Configuration Space
BSF      EECON1,EEPGD     ; Select Program Memory
BCF      INTCON,GIE      ; Disable interrupts
BSF      EECON1,RD        ; Initiate read
NOP      ; Ignored (Figure 11-1)
NOP      ; Ignored (Figure 11-1)
BSF      INTCON,GIE      ; Restore interrupts

MOVF     EEDATL,W         ; Get LSB of word
MOVWF    PROG_DATA_LO     ; Store in user location
MOVF     EEDATH,W         ; Get MSB of word
MOVWF    PROG_DATA_HI     ; Store in user location
```

11.3.2 ERASING FLASH PROGRAM MEMORY

While executing code, program memory can only be erased by rows. To erase a row:

1. Load the EEADRH:EEADRL register pair with the address of new row to be erased.
2. Clear the CFGS bit of the EECON1 register.
3. Set the EEPGD, FREE, and WREN bits of the EECON1 register.
4. Write 55h, then AAh, to EECON2 (Flash programming unlock sequence).
5. Set control bit WR of the EECON1 register to begin the erase operation.
6. Poll the FREE bit in the EECON1 register to determine when the row erase has completed.

See [Example 11-4](#).

After the “BSF EECON1, WR” instruction, the processor requires two cycles to set up the erase operation. The user must place two NOP instructions after the WR bit is set. The processor will halt internal operations for the typical 2 ms erase time. This is not Sleep mode as the clocks and peripherals will continue to run. After the erase cycle, the processor will resume operation with the third instruction after the EECON1 write instruction.

11.3.3 WRITING TO FLASH PROGRAM MEMORY

Program memory is programmed using the following steps:

1. Load the starting address of the word(s) to be programmed.
2. Load the write latches with data.
3. Initiate a programming operation.
4. Repeat steps 1 through 3 until all data is written.

Before writing to program memory, the word(s) to be written must be erased or previously unwritten. Program memory can only be erased one row at a time. No automatic erase occurs upon the initiation of the write.

Program memory can be written one or more words at a time. The maximum number of words written at one time is equal to the number of write latches. See [Figure 11-2](#) (block writes to program memory with 32 write latches) for more details. The write latches are aligned to the address boundary defined by EEADRL as shown in [Table 11-1](#). Write operations do not cross these boundaries. At the completion of a program memory write operation, the write latches are reset to contain 0x3FFF.

The following steps should be completed to load the write latches and program a block of program memory. These steps are divided into two parts. First, all write latches are loaded with data except for the last program memory location. Then, the last write latch is loaded and the programming sequence is initiated. A special unlock sequence is required to load a write latch with data or initiate a Flash programming operation. This unlock sequence should not be interrupted.

1. Set the EEPGD and WREN bits of the EECON1 register.
2. Clear the CFGS bit of the EECON1 register.
3. Set the LWLO bit of the EECON1 register. When the LWLO bit of the EECON1 register is ‘1’, the write sequence will only load the write latches and will not initiate the write to Flash program memory.
4. Load the EEADRH:EEADRL register pair with the address of the location to be written.
5. Load the EEDATH:EEDATL register pair with the program memory data to be written.
6. Write 55h, then AAh, to EECON2, then set the WR bit of the EECON1 register (Flash programming unlock sequence). The write latch is now loaded.
7. Increment the EEADRH:EEADRL register pair to point to the next location.
8. Repeat steps 5 through 7 until all but the last write latch has been loaded.
9. Clear the LWLO bit of the EECON1 register. When the LWLO bit of the EECON1 register is ‘0’, the write sequence will initiate the write to Flash program memory.
10. Load the EEDATH:EEDATL register pair with the program memory data to be written.
11. Write 55h, then AAh, to EECON2, then set the WR bit of the EECON1 register (Flash programming unlock sequence). The entire latch block is now written to Flash program memory.

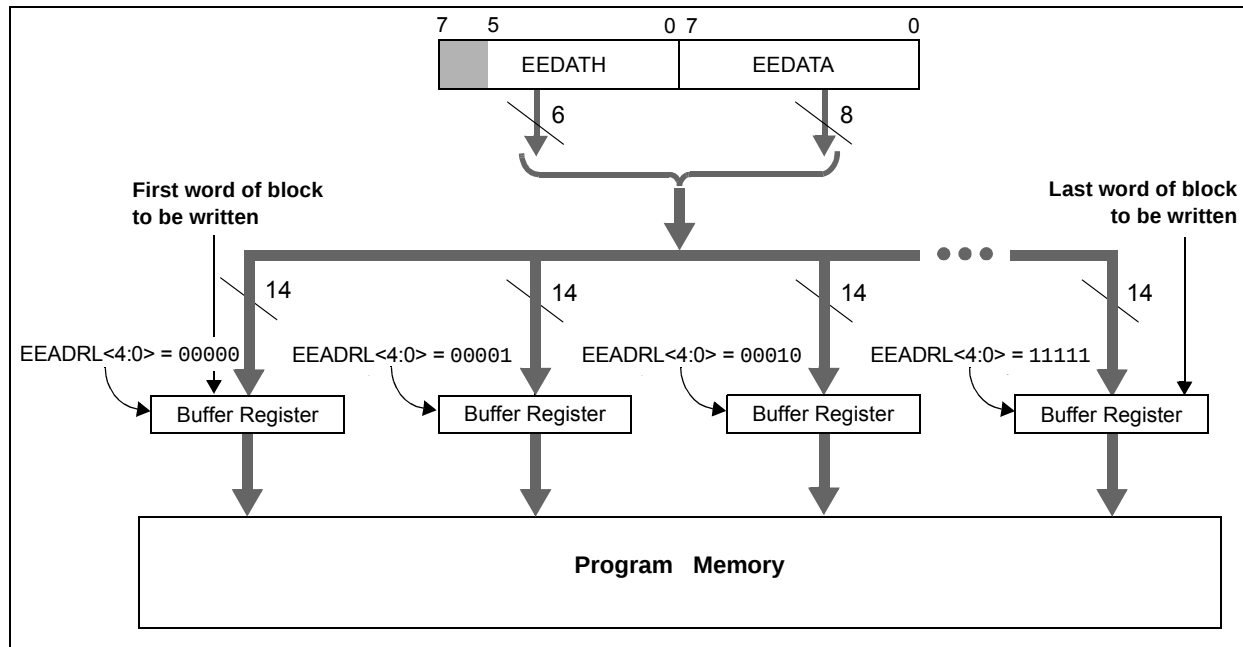
It is not necessary to load the entire write latch block with user program data. However, the entire write latch block will be written to program memory.

An example of the complete write sequence for eight words is shown in [Example 11-5](#). The initial address is loaded into the EEADRH:EEADRL register pair; the eight words of data are loaded using indirect addressing.

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After the “BSF EECON1, WR” instruction, the processor requires two cycles to set up the write operation. The user must place two NOP instructions after the WR bit is set. The processor will halt internal operations for the typical 2 ms, only during the cycle in which the write takes place (i.e., the last word of the block write). This is not Sleep mode as the clocks and peripherals will continue to run. The processor does not stall when LWLO = 1, loading the write latches. After the write cycle, the processor will resume operation with the third instruction after the EECON1 write instruction.

FIGURE 11-2: BLOCK WRITES TO FLASH PROGRAM MEMORY WITH 32 WRITE LATCHES



EXAMPLE 11-4: ERASING ONE ROW OF PROGRAM MEMORY -

```
; This row erase routine assumes the following:
; 1. A valid address within the erase block is loaded in ADDRH:ADDRL
; 2. ADDRH and ADDRL are located in shared data memory 0x70 - 0x7F (common RAM)

        BCF      INTCON,GIE      ; Disable ints so required sequences will execute properly
        BANKSEL  EEADRL
        MOVF     ADDRL,W          ; Load lower 8 bits of erase address boundary
        MOVWF    EEADRL
        MOVF     ADDRH,W         ; Load upper 6 bits of erase address boundary
        MOVWF    EEADRH
        BSF      EECON1,EEPGD     ; Point to program memory
        BCF      EECON1,CFGSR    ; Not configuration space
        BSF      EECON1,FREE      ; Specify an erase operation
        BSF      EECON1,WREN      ; Enable writes

        MOV LW   55h             ; Start of required sequence to initiate erase
        MOVWF    EECON2          ; Write 55h
        MOV LW   0AAh           ;
        MOVWF    EECON2          ; Write AAh
        BSF      EECON1,WR       ; Set WR bit to begin erase
        NOP      ; Any instructions here are ignored as processor
        NOP      ; halts to begin erase sequence
        NOP      ; Processor will stop here and wait for erase complete.

        ; after erase processor continues with 3rd instruction

        BCF      EECON1,WREN      ; Disable writes
        BSF      INTCON,GIE      ; Enable interrupts
```

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EXAMPLE 11-5: WRITING TO FLASH PROGRAM MEMORY

```

; This write routine assumes the following:
; 1. The 16 bytes of data are loaded, starting at the address in DATA_ADDR
; 2. Each word of data to be written is made up of two adjacent bytes in DATA_ADDR,
;    stored in little endian format
; 3. A valid starting address (the least significant bits = 000) is loaded in ADDRH:ADDRL
; 4. ADDRH and ADDRL are located in shared data memory 0x70 - 0x7F (common RAM)
;
BCF      INTCON,GIE      ; Disable ints so required sequences will execute properly
BANKSEL  EEADRH          ; Bank 3
MOVF     ADDRH,W         ; Load initial address
MOVWF    EEADRH          ;
MOVF     ADDRL,W         ;
MOVWF    EEADRL          ;
MOVLW    LOW DATA_ADDR  ; Load initial data address
MOVWF    FSR0L           ;
MOVLW    HIGH DATA_ADDR ; Load initial data address
MOVWF    FSR0H           ;
BSF      EECON1,EEPGD     ; Point to program memory
BCF      EECON1,CFGSR     ; Not configuration space
BSF      EECON1,WREN      ; Enable writes
BSF      EECON1,LWLO      ; Only Load Write Latches

LOOP
    MOVIW  FSR0++         ; Load first data byte into lower
    MOVWF  EEDATL         ;
    MOVIW  FSR0++         ; Load second data byte into upper
    MOVWF  EEDATH         ;

    MOVF   EEADRL,W       ; Check if lower bits of address are '000'
    XORLW  0x07           ; Check if we're on the last of 8 addresses
    ANDLW  0x07           ;
    BTFSC  STATUS,Z       ; Exit if last of eight words,
    GOTO   START_WRITE    ;

    Required Sequence
    MOVLW  55h            ; Start of required write sequence:
    MOVWF  EECON2          ; Write 55h
    MOVLW  0AAh           ;
    MOVWF  EECON2          ; Write AAh
    BSF    EECON1,WR       ; Set WR bit to begin write
    NOP    ; Any instructions here are ignored as processor
    NOP    ; halts to begin write sequence
    NOP    ; Processor will stop here and wait for write to complete.

    ; After write processor continues with 3rd instruction.

    INCF   EEADRL,F        ; Still loading latches Increment address
    GOTO   LOOP           ; Write next latches

START_WRITE
    BCF    EECON1,LWLO     ; No more loading latches - Actually start Flash program
    ; memory write

    Required Sequence
    MOVLW  55h            ; Start of required write sequence:
    MOVWF  EECON2          ; Write 55h
    MOVLW  0AAh           ;
    MOVWF  EECON2          ; Write AAh
    BSF    EECON1,WR       ; Set WR bit to begin write
    NOP    ; Any instructions here are ignored as processor
    NOP    ; halts to begin write sequence
    NOP    ; Processor will stop here and wait for write complete.

    ; after write processor continues with 3rd instruction

    BCF    EECON1,WREN     ; Disable writes
    BSF    INTCON,GIE      ; Enable interrupts

```

11.4 Modifying Flash Program Memory

When modifying existing data in a program memory row, and data within that row must be preserved, it must first be read and saved in a RAM image. Program memory is modified using the following steps:

1. Load the starting address of the row to be modified.
2. Read the existing data from the row into a RAM image.
3. Modify the RAM image to contain the new data to be written into program memory.
4. Load the starting address of the row to be rewritten.
5. Erase the program memory row.
6. Load the write latches with data from the RAM image.
7. Initiate a programming operation.
8. Repeat steps 6 and 7 as many times as required to reprogram the erased row.

11.5 User ID, Device ID and Configuration Word Access

Instead of accessing program memory or EEPROM data memory, the User ID's, Device ID/Revision ID and Configuration Words can be accessed when CFGS = 1 in the EECON1 register. This is the region that would be pointed to by PC<15> = 1, but not all addresses are accessible. Different access may exist for reads and writes. Refer to [Table 11-2](#).

When read access is initiated on an address outside the parameters listed in [Table 11-2](#), the EEDATH:EED-ATL register pair is cleared.

TABLE 11-2: USER ID, DEVICE ID AND CONFIGURATION WORD ACCESS (CFGS = 1)

Address	Function	Read Access	Write Access
8000h-8003h	User IDs	Yes	Yes
8006h	Device ID/Revision ID	Yes	No
8007h-8008h	Configuration Words 1 and 2	Yes	No

EXAMPLE 11-3: CONFIGURATION WORD AND DEVICE ID ACCESS

```
* This code block will read 1 word of program memory at the memory address:
*   PROG_ADDR_LO (must be 00h-08h) data will be returned in the variables;
*   PROG_DATA_HI, PROG_DATA_LO

BANKSEL  EEADRL      ; Select correct Bank
MOVLW    PROG_ADDR_LO
MOVWF    EEADRL      ; Store LSB of address
CLRF     EEADRH      ; Clear MSB of address

BSF      EECON1,CFGS ; Select Configuration Space
BCF      INTCON,GIE  ; Disable interrupts
BSF      EECON1,RD    ; Initiate read
NOP      ; Executed (See Figure 11-1)
NOP      ; Ignored (See Figure 11-1)
BSF      INTCON,GIE   ; Restore interrupts

MOVF     EEDATL,W     ; Get LSB of word
MOVWF    PROG_DATA_LO ; Store in user location
MOVF     EEDATH,W     ; Get MSB of word
MOVWF    PROG_DATA_HI ; Store in user location
```

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11.6 Write Verify

Depending on the application, good programming practice may dictate that the value written to the data EEPROM or program memory should be verified (see [Example 11-6](#)) to the desired value to be written. [Example 11-6](#) shows how to verify a write to EEPROM.

EXAMPLE 11-6: EEPROM WRITE VERIFY

```
BANKSEL EEDATL      ;  
MOVF    EEDATL, W    ;EEDATL not changed  
                ;from previous write  
BSF      EECON1, RD   ;YES, Read the  
                ;value written  
XORWF    EEDATL, W    ;  
BTFSS    STATUS, Z    ;Is data the same  
GOTO     WRITE_ERR    ;No, handle error  
:                ;Yes, continue
```

11.7 EEPROM and Flash Control Registers

REGISTER 11-1: EEDATL: EEPROM LOW BYTE DATA REGISTER

R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
EEDAT<7:0>							
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
 u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
 '1' = Bit is set '0' = Bit is cleared

bit 7-0 **EEDAT<7:0>**: Read/write value for EEPROM data byte or Least Significant bits of program memory

REGISTER 11-2: EEDATH: EEPROM DATA HIGH BYTE REGISTER

U-0	U-0	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
—	—	EEDAT<13:8>					
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
 u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
 '1' = Bit is set '0' = Bit is cleared

bit 7-6 **Unimplemented**: Read as '0'

bit 5-0 **EEDAT<13:8>**: Read/write value for Most Significant bits of program memory

REGISTER 11-3: EEADRL: EEPROM ADDRESS REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
EEADR<7:0>							
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
 u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
 '1' = Bit is set '0' = Bit is cleared

bit 7-0 **EEADR<7:0>**: Specifies the Least Significant bits for program memory address or EEPROM address

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REGISTER 11-4: EEADRH: EEPROM ADDRESS HIGH BYTE REGISTER

U-1	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	
—	EEADR<14:8>							
bit 7								bit 0

Legend:		
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7 **Unimplemented:** Read as '1'

bit 6-0 **EEADR<14:8>:** Specifies the Most Significant bits for program memory address or EEPROM address

REGISTER 11-5: EECN1: EEPROM CONTROL 1 REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W/HC-0/0	R/W-x/q	R/W-0/0	R/S/HC-0/0	R/S/HC-0/0
EEPGD	CFGS	LWLO	FREE	WRERR	WREN	WR	RD
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
S = Bit can only be set	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	HC = Bit is cleared by hardware

- bit 7 **EEPGD:** Flash Program/Data EEPROM Memory Select bit
1 = Accesses program space Flash memory
0 = Accesses data EEPROM memory
- bit 6 **CFGS:** Flash Program/Data EEPROM or Configuration Select bit
1 = Accesses Configuration, User ID and Device ID Registers
0 = Accesses Flash Program or data EEPROM Memory
- bit 5 **LWLO:** Load Write Latches Only bit
If CFGS = 1 (Configuration space) OR CFGS = 0 and EEGPD = 1 (program Flash):
1 = The next WR command does not initiate a write; only the program memory latches are updated.
0 = The next WR command writes a value from EEDATH:EEDATL into program memory latches and initiates a write of all the data stored in the program memory latches.
If CFGS = 0 and EEGPD = 0: (Accessing data EEPROM)
LWLO is ignored. The next WR command initiates a write to the data EEPROM.
- bit 4 **FREE:** Program Flash Erase Enable bit
If CFGS = 1 (Configuration space) OR CFGS = 0 and EEGPD = 1 (program Flash):
1 = Performs an erase operation on the next WR command (cleared by hardware after completion of erase).
0 = Performs a write operation on the next WR command.
If EEGPD = 0 and CFGS = 0: (Accessing data EEPROM)
FREE is ignored. The next WR command will initiate both a erase cycle and a write cycle.
- bit 3 **WRERR:** EEPROM Error Flag bit
1 = Condition indicates an improper program or erase sequence attempt or termination (bit is set automatically on any set attempt (write '1') of the WR bit).
0 = The program or erase operation completed normally.
- bit 2 **WREN:** Program/Erase Enable bit
1 = Allows program/erase cycles
0 = Inhibits programming/erasing of program Flash and data EEPROM
- bit 1 **WR:** Write Control bit
1 = Initiates a program Flash or data EEPROM program/erase operation.
The operation is self-timed and the bit is cleared by hardware once operation is complete.
The WR bit can only be set (not cleared) in software.
0 = Program/erase operation to the Flash or data EEPROM is complete and inactive.
- bit 0 **RD:** Read Control bit
1 = Initiates an program Flash or data EEPROM read. Read takes one cycle. RD is cleared in hardware. The RD bit can only be set (not cleared) in software.
0 = Does not initiate a program Flash or data EEPROM data read.

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REGISTER 11-6: EECON2: EEPROM CONTROL 2 REGISTER

W-0/0	W-0/0	W-0/0	W-0/0	W-0/0	W-0/0	W-0/0	W-0/0
EEPROM Control Register 2							
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
 S = Bit can only be set x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
 '1' = Bit is set '0' = Bit is cleared

bit 7-0

Data EEPROM Unlock Pattern bits

To unlock writes, a 55h must be written first, followed by an AAh, before setting the WR bit of the EECON1 register. The value written to this register is used to unlock the writes. There are specific timing requirements on these writes. Refer to [Section 11.2.2 "Writing to the Data EEPROM Memory"](#) for more information.

TABLE 11-3: SUMMARY OF REGISTERS ASSOCIATED WITH DATA EEPROM

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
EECON1	EEPGD	CFG5	LWLO	FREE	WRERR	WREN	WR	RD	115
EECON2	EEPROM Control Register 2 (not a physical register)								101 *
EEADRL	EEADRL7	EEADRL6	EEADRL5	EEADRL4	EEADRL3	EEADRL2	EEADRL1	EEADRL0	113
EEADRH	—	EEADRH6	EEADRH5	EEADRH4	EEADRH3	EEADRH2	EEADRH1	EEADRH0	114
EEDATL	EEDATL7	EEDATL6	EEDATL5	EEDATL4	EEDATL3	EEDATL2	EEDATL1	EEDATL0	113
EEDATH	—	—	EEDATH5	EEDATH4	EEDATH3	EEDATH2	EEDATH1	EEDATH0	113
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCF	91
PIE2	OSFIE	C2IE	C1IE	EEIE	BCL1IE	—	—	CCP2IE	93
PIR2	OSFIF	C2IF	C1IF	EEIF	BCL1IF	—	—	CCP2IF	97

Legend: — = unimplemented read as '0'. Shaded cells are not used by data EEPROM module.

* Page provides register information.

12.1 Alternate Pin Function

The Alternate Pin Function Control (APFCON0 and APFCON1) registers are used to steer specific peripheral input and output functions between different pins. The APFCON0 and APFCON1 registers are shown in [Register 12-1](#) and [Register 12-2](#). For this device family, the following functions can be moved between different pins.

- RX/DT
- SDO1
- $\overline{SS1}$ (Slave Select 1)
- P2B
- CCP2/P2A
- P1D
- P1C
- CCP1/P1A
- TX/CK

These bits have no effect on the values of any TRIS register. PORT and TRIS overrides will be routed to the correct pin. The unselected pin will be unaffected.

REGISTER 12-1: APFCON0: ALTERNATE PIN FUNCTION CONTROL REGISTER 0

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
RXDTSEL	SDO1SEL	SS1SEL	P2BSEL ⁽¹⁾	CCP2SEL ⁽¹⁾	P1DSEL	P1CSEL	CCP1SEL
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7	RXDTSEL: Pin Selection bit 0 = RX/DT function is on RB1 1 = RX/DT function is on RB2
bit 6	SDO1SEL: Pin Selection bit 0 = SDO1 function is on RB2 1 = SDO1 function is on RA6
bit 5	SS1SEL: Pin Selection bit 0 = SS1 function is on RB5 1 = SS1 function is on RA5
bit 4	P2BSEL: Pin Selection bit 0 = P2B function is on RB7 1 = P2B function is on RA6
bit 3	CCP2SEL: Pin Selection bit 0 = CCP2/P2A function is on RB6 1 = CCP2/P2A function is on RA7
bit 2	P1DSEL: Pin Selection bit 0 = P1D function is on RB7 1 = P1D function is on RA6
bit 1	P1CSEL: Pin Selection bit 0 = P1C function is on RB6 1 = P1C function is on RA7
bit 0	CCP1SEL: Pin Selection bit 0 = CCP1/P1A function is on RB3 1 = CCP1/P1A function is on RB0

Note 1: PIC16(L)F1827 only.

REGISTER 12-2: APFCON1: ALTERNATE PIN FUNCTION CONTROL REGISTER 1

U-0	U-0	U-0	U-0	U-0	U-0	U-0	R/W-0/0
—	—	—	—	—	—	—	TXCKSEL
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7-1	Unimplemented: Read as '0'
bit 0	TXCKSEL: Pin Selection bit 0 = TX/CK function is on RB2 1 = TX/CK function is on RB5

12.2 PORTA Registers

PORTA is a 8-bit wide, bidirectional port. The corresponding data direction register is TRISA ([Register 12-4](#)). Setting a TRISA bit (= 1) will make the corresponding PORTA pin an input (i.e., disable the output driver). Clearing a TRISA bit (= 0) will make the corresponding PORTA pin an output (i.e., enables output driver and puts the contents of the output latch on the selected pin). The exception is RA5, which is input only and its TRIS bit will always read as '1'. [Example 12-1](#) shows how to initialize an I/O port.

Reading the PORTA register ([Register 12-3](#)) reads the status of the pins, whereas writing to it will write to the PORT latch. All write operations are read-modify-write operations. Therefore, a write to a port implies that the port pins are read, this value is modified and then written to the PORT data latch (LATA).

The TRISA register ([Register 12-4](#)) controls the PORTA pin output drivers, even when they are being used as analog inputs. The user should ensure the bits in the TRISA register are maintained set when using them as analog inputs. I/O pins configured as analog input always read '0'.

12.2.1 WEAK PULL-UPS

Each of the PORTA pins has an individually configurable internal weak pull-up. Control bit WPUA<5> enables or disables the pull-up (see [Register 12-6](#)). The weak pull-up is automatically turned off when the port pin is configured as an output. The pull-up is disabled on a Power-on Reset by the WPUEN bit of the OPTION register.

12.2.2 ANSELA REGISTER

The ANSELA register ([Register 12-7](#)) is used to configure the Input mode of an I/O pin to analog. Setting the appropriate ANSELA bit high will cause all digital reads on the pin to be read as '0' and allow analog functions on the pin to operate correctly.

The state of the ANSELA bits has no effect on digital output functions. A pin with TRIS clear and ANSEL set will still operate as a digital output, but the Input mode will be analog. This can cause unexpected behavior when executing read-modify-write instructions on the affected port.

Note: The ANSELA bits default to the Analog mode after Reset. To use any pins as digital general purpose or peripheral inputs, the corresponding ANSEL bits must be initialized to '0' by user software.

12.2.3 PORTA FUNCTIONS AND OUTPUT PRIORITIES

Each PORTA pin is multiplexed with other functions. The pins, their combined functions and their output priorities are shown in [Table 12-2](#).

When multiple outputs are enabled, the actual pin control goes to the peripheral with the highest priority.

Analog input functions, such as ADC, comparator and CapSense inputs, are not shown in the priority lists. These inputs are active when the I/O pin is set for Analog mode using the ANSELx registers. Digital output functions may control the pin when it is in Analog mode with the priority shown in [Table 12-2](#).

TABLE 12-2: PORTA OUTPUT PRIORITY

Pin Name	Function Priority ⁽¹⁾
RA0	SDO2 (PIC16(L)F1827 only) RA0
RA1	SS2 (PIC16(L)F1827 only) RA1
RA2	DACOUT (DAC) RA2
RA3	SRQ (SR latch) CCP3 (PIC16(L)F1827 only) C1OUT (Comparator) RA3
RA4	SRNQ (SR latch) CCP4 (PIC16(L)F1827 only) T0CKI C2OUT (Comparator) RA4
RA5	Input only pin
RA6	OSC2 (enabled by Configuration Word) CLKOUT CLKR SDO1 P1D P2B (PIC16(L)F1827 only) RA6
RA7	OSC1/CLKIN (enabled by Configuration Word) P1C CCP2 (PIC16(L)F1827 only) P2A (PIC16(L)F1827 only) RA7

Note 1: Priority listed from highest to lowest.

Each PORTA pin is multiplexed with other functions. The pins, their combined functions and their output priorities are briefly described here. For additional information, refer to the appropriate section in this data sheet.

When multiple outputs are enabled, the actual pin control goes to the peripheral with the lowest number in the following lists.

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REGISTER 12-3: PORTA: PORTA REGISTER

R/W-x/x	R/W-x/x	R-x/x	R/W-x/x	R/W-x/x	R/W-x/x	R/W-x/x	R/W-x/x
RA7	RA6	RA5	RA4	RA3	RA2	RA1	RA0
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set '0' = Bit is cleared

bit 7-0 **RA<7:0>**: PORTA I/O Value bits⁽¹⁾
1 = Port pin is > V_{IH}
0 = Port pin is < V_{IL}

Note 1: Writes to PORTA are actually written to corresponding LATA register. Reads from PORTA register is return of actual I/O pin values.

REGISTER 12-4: TRISA: PORTA TRI-STATE REGISTER

R/W-1/1	R/W-1/1	R-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1
TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set '0' = Bit is cleared

bit 7-6 **TRISA<7:6>**: PORTA Tri-State Control bit
1 = PORTA pin configured as an input (tri-stated)
0 = PORTA pin configured as an output

bit 5 **TRISA5**: RA5 Port Tri-State Control bit
This bit is always '1' as RA5 is an input only

bit 4-0 **TRISA<4:0>**: PORTA Tri-State Control bit
1 = PORTA pin configured as an input (tri-stated)
0 = PORTA pin configured as an output

REGISTER 12-5: LATA: PORTA DATA LATCH REGISTER

R/W-x/u	R/W-x/u	U-0	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
LATA7	LATA6	—	LATA4	LATA3	LATA2	LATA1	LATA0
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set '0' = Bit is cleared

bit 7-6 **LATA<7:6>**: RA<7:6> Output Latch Value bits⁽¹⁾

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

bit 4-0 **LATA<4:0>**: RA<4:0> Output Latch Value bits⁽¹⁾

Note 1: Writes to PORTA are actually written to corresponding LATA register. Reads from PORTA register is return of actual I/O pin values.

REGISTER 12-6: WPUA: WEAK PULL-UP PORTA REGISTER

U-0	U-0	R/W-1/1	U-0	U-0	U-0	U-0	U-0
—	—	WPUA5	—	—	—	—	—
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7-6 **Unimplemented:** Read as '0'

bit 5 **WPUA5:** Weak Pull-up RA5 Control bit

If $\overline{\text{MCLR}}$ in Configuration Word 1 = 0, $\overline{\text{MCLR}}$ is disabled):

1 = Weak Pull-up enabled⁽¹⁾

0 = Weak Pull-up disabled

If $\overline{\text{MCLR}}$ in Configuration Word 1 = 1, $\overline{\text{MCLR}}$ is enabled):

Weak Pull-up is always enabled.

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

Note 1: Global $\overline{\text{WPUEN}}$ bit of the OPTION register must be cleared for individual pull-ups to be enabled.

2: The weak pull-up device is automatically disabled if the pin is configured as an output.

REGISTER 12-7: ANSALA: PORTA ANALOG SELECT REGISTER

U-0	U-0	U-0	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1
—	—	—	ANSA4	ANSA3	ANSA2	ANSA1	ANSA0
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7-5 **Unimplemented:** Read as '0'

bit 4-0 **ANSA<4:0>:** Analog Select between Analog or Digital Function on pins RA<4:0>, respectively

0 = Digital I/O. Pin is assigned to port or digital special function.

1 = Analog input. Pin is assigned as analog input⁽¹⁾. Digital input buffer disabled.

Note 1: When setting a pin to an analog input, the corresponding TRIS bit must be set to Input mode in order to allow external control of the voltage on the pin.

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TABLE 12-3: SUMMARY OF REGISTERS ASSOCIATED WITH PORTA

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
ANSELA	—	—	—	ANSA4	ANSA3	ANSA2	ANSA1	ANSA0	123
LATA	LATA7	LATA6	—	LATA4	LATA3	LATA2	LATA1	LATA0	122
OPTION_REG	WPUEN	INTEDG	TMR0CS	TMR0SE	PSA	PS2	PS1	PS0	176
PORTA	RA7	RA6	RA5	RA4	RA3	RA2	RA1	RA0	122
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122
WPUA	—	—	WPUA5	—	—	—	—	—	123

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

TABLE 12-4: SUMMARY OF CONFIGURATION WORD ASSOCIATED WITH PORTA

Name	Bits	Bit -/7	Bit -/6	Bit 13/5	Bit 12/4	Bit 11/3	Bit 10/2	Bit 9/1	Bit 8/0	Register on Page
CONFIG1	13:8	—	—	FCMEN	IESO	CLKOUTEN	BOREN1	BOREN0	CPD	44
	7:0	CP	MCLRE	PWRTE	WDTE1	WDTE0	FOSC2	FOSC1	FOSC0	

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

12.3 PORTB and TRISB Registers

PORTB is an 8-bit wide, bidirectional port. The corresponding data direction register is TRISB (Register 12-9). 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., enable the output driver and put the contents of the output latch on the selected pin). Example 12-1 shows how to initialize an I/O port.

Reading the PORTB register (Register 12-8) reads the status of the pins, whereas writing to it will write to the PORT latch. All write operations are read-modify-write operations. Therefore, a write to a port implies that the port pins are read, this value is modified and then written to the PORT data latch.

The TRISB register (Register 12-9) controls the PORTB pin output drivers, even when they are being used as analog inputs. The user should ensure the bits in the TRISB register are maintained set when using them as analog inputs. I/O pins configured as analog input always read '0'.

12.3.1 INTERRUPT-ON-CHANGE

All of the PORTB pins are individually configurable as an interrupt-on-change pin. Control bits IOCB<7:0> enable or disable the interrupt function for each pin. The interrupt-on-change feature is disabled on a Power-on Reset. Reference Section 13.0 "Interrupt-On-Change" for more information.

12.3.2 WEAK PULL-UPS

Each of the PORTB pins has an individually configurable internal weak pull-up. Control bits WPUB<7:0> enable or disable each pull-up (see Register 12-11). Each weak pull-up is automatically turned off when the port pin is configured as an output. All pull-ups are disabled on a Power-on Reset by the $\overline{\text{WPUEN}}$ bit of the OPTION register.

12.3.3 ANSELB REGISTER

The ANSELB register (Register 12-12) is used to configure the Input mode of an I/O pin to analog. Setting the appropriate ANSELB bit high will cause all digital reads on the pin to be read as '0' and allow analog functions on the pin to operate correctly.

The state of the ANSELB bits has no effect on digital output functions. A pin with TRIS clear and ANSELB set will still operate as a digital output, but the Input mode will be analog. This can cause unexpected behavior when executing read-modify-write instructions on the affected port.

The TRISB register (Register 12-9) controls the PORTB pin output drivers, even when they are being used as analog inputs. The user should ensure the bits in the TRISB register are maintained set when using them as analog inputs. I/O pins configured as analog input always read '0'.

Note: The ANSELB register must be initialized to configure an analog channel as a digital input. Pins configured as analog inputs will read '0'.

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12.3.4 PORTB FUNCTIONS AND OUTPUT PRIORITIES

Each PORTB pin is multiplexed with other functions. The pins, their combined functions and their output priorities are shown in [Table 12-5](#).

When multiple outputs are enabled, the actual pin control goes to the peripheral with the highest priority.

Analog input and some digital input functions are not included in the list below. These input functions can remain active when the pin is configured as an output. Certain digital input functions, such as the EUSART RX signal, override other port functions and are included in the priority list.

TABLE 12-5: PORTB OUTPUT PRIORITY

Pin Name	Function Priority ⁽¹⁾
RB0	P1A RB0
RB1	SDA1 RX/DT RB1
RB2	SDA2 (PIC16(L)F1827 only) TX/CK RX/DT SDO1 RB2
RB3	MDOUT CCP1/P1A RB3
RB4	SCL1 SCK1 RB4
RB5	SCL2 (PIC16(L)F1827 only) TX/CK SCK2 (PIC16(L)F1827 only) P1B RB5
RB6	ICSPCLK (Programming) T1OSI P1C CCP2 (PIC16(L)F1827 only) P2A (PIC16(L)F1827 only) RB6
RB7	ICSPDAT (Programming) T1OSO P1D P2B (PIC16(L)F1827 only) RB7

Note 1: Priority listed from highest to lowest.

REGISTER 12-8: PORTB: PORTB REGISTER

R/W-x/x	R/W-x/x	R/W-x/x	R/W-x/x	R/W-x/x	R/W-x/x	R/W-x/x	R/W-x/x
RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
 u = bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
 '1' = Bit is set '0' = Bit is cleared

bit 7-0 **RB<7:0>**: PORTB I/O Pin bit
 1 = Port pin is > V_{IH}
 0 = Port pin is < V_{IL}

REGISTER 12-9: TRISB: PORTB TRI-STATE REGISTER

R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1
TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
 u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
 '1' = Bit is set '0' = Bit is cleared

bit 7-0 **TRISB<7:0>**: PORTB Tri-State Control bit
 1 = PORTB pin configured as an input (tri-stated)
 0 = PORTB pin configured as an output

REGISTER 12-10: LATB: PORTB DATA LATCH REGISTER

R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
LATB7	LATB6	LATB5	LATB4	LATB3	LATB2	LATB1	LATB0
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
 u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
 '1' = Bit is set '0' = Bit is cleared

bit 7-0 **LATB<7:0>**: PORTB Output Latch Value bits⁽¹⁾

Note 1: Writes to PORTB are actually written to corresponding LATB register. Reads from PORTB register is return of actual I/O pin values.

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REGISTER 12-11: WPUB: WEAK PULL-UP PORTB REGISTER

R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1
WPUB7	WPUB6	WPUB5	WPUB4	WPUB3	WPUB2	WPUB1	WPUB0
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set '0' = Bit is cleared

bit 7-0 **WPUB<7:0>**: Weak Pull-up Register bits
 1 = Pull-up enabled
 0 = Pull-up disabled

- Note 1:** Global $\overline{\text{WPUEN}}$ bit of the OPTION register must be cleared for individual pull-ups to be enabled.
2: The weak pull-up device is automatically disabled if the pin is in configured as an output.

REGISTER 12-12: ANSELB: PORTB ANALOG SELECT REGISTER

R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	U-0
ANSB7	ANSB6	ANSB5	ANSB4	ANSB3	ANSB2	ANSB1	—
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set '0' = Bit is cleared

bit 7-1 **ANSB<7:1>**: Analog Select between Analog or Digital Function on Pins RB<7:1>, respectively
 0 = Digital I/O. Pin is assigned to port or digital special function.
 1 = Analog input. Pin is assigned as analog input⁽¹⁾. Digital input buffer disabled.

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

- Note 1:** When setting a pin to an analog input, the corresponding TRIS bit must be set to Input mode in order to allow external control of the voltage on the pin.

TABLE 12-6: SUMMARY OF REGISTERS ASSOCIATED WITH PORTB

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
ANSELB	ANSB7	ANSB6	ANSB5	ANSB4	ANSB3	ANSB2	ANSB1	—	128
LATB	LATB7	LATB6	LATB5	LATB4	LATB3	LATB2	LATB1	LATB0	127
OPTION_REG	WPUEN	INTEDG	TMR0CS	TMR0SE	PSA	PS2	PS1	PS0	176
PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0	127
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127
WPUB	WPUB7	WPUB6	WPUB5	WPUB4	WPUB3	WPUB2	WPUB1	WPUB0	128

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

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NOTES:

13.0 INTERRUPT-ON-CHANGE

The PORTB pins can be configured to operate as Interrupt-On-Change (IOC) pins. An interrupt can be generated by detecting a signal that has either a rising edge or a falling edge. Any individual PORTB pin can be configured to generate an interrupt. The interrupt-on-change module has the following features:

- Interrupt-on-Change enable (Master Switch)
- Individual pin configuration
- Rising and falling edge detection
- Individual pin interrupt flags

Figure 13-1 is a block diagram of the IOC module.

13.1 Enabling the Module

To allow individual port pins to generate an interrupt, the IOCIE bit of the INTCON register must be set. If the IOCIE bit is disabled, the edge detection on the pin will still occur, but an interrupt will not be generated.

13.2 Individual Pin Configuration

For each port pin, a rising edge detector and a falling edge detector are present. To enable a pin to detect a rising edge, the associated IOCBP_x bit of the IOCBP register is set. To enable a pin to detect a falling edge, the associated IOCBN_x bit of the IOCBN register is set.

A pin can be configured to detect rising and falling edges simultaneously by setting both the IOCBP_x bit and the IOCBN_x bit of the IOCBP and IOCBN registers, respectively.

13.3 Interrupt Flags

The IOCBF_x bits located in the IOCBF register are status flags that correspond to the Interrupt-on-change pins of the port. If an expected edge is detected on an appropriately enabled pin, then the status flag for that pin will be set, and an interrupt will be generated if the IOCIE bit is set. The IOCIF bit of the INTCON register reflects the status of all IOCBF_x bits.

13.4 Clearing Interrupt Flags

The individual status flags, (IOCBF_x bits), can be cleared by resetting them to zero. If another edge is detected during this clearing operation, the associated status flag will be set at the end of the sequence, regardless of the value actually being written.

In order to ensure that no detected edge is lost while clearing flags, only AND operations masking out known changed bits should be performed. The following sequence is an example of what should be performed.

EXAMPLE 13-1:

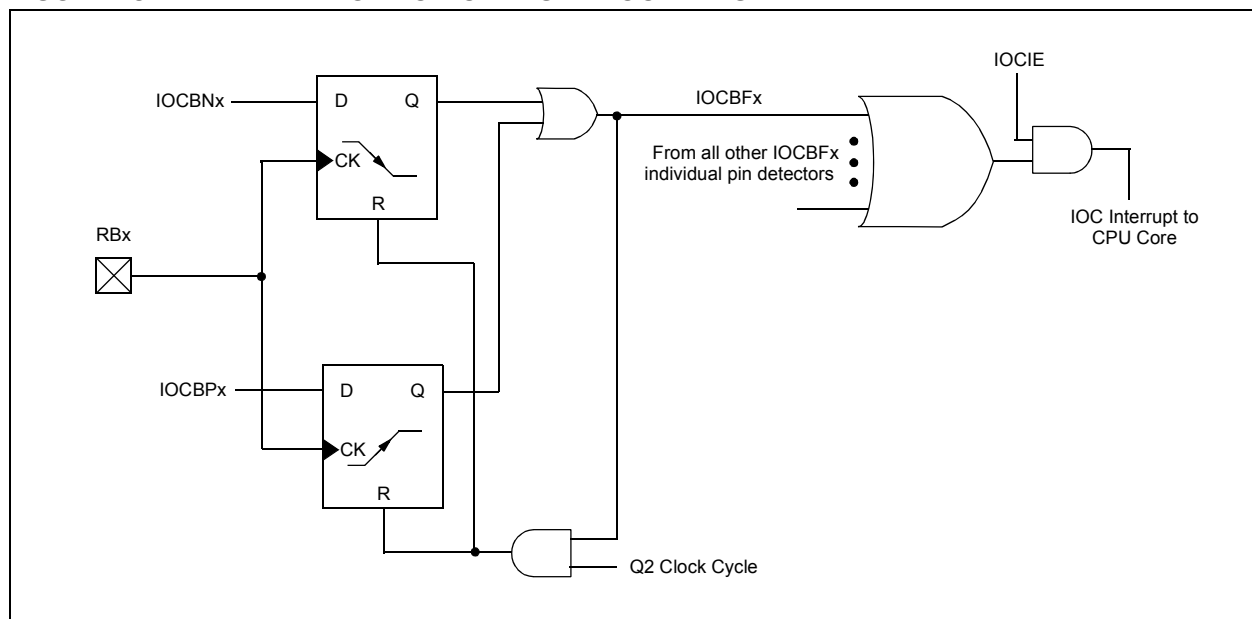
```
MOVLW 0xff
XORWF IOCBF, W
ANDWF IOCBF, F
```

13.5 Operation in Sleep

The interrupt-on-change interrupt sequence will wake the device from Sleep mode, if the IOCIE bit is set.

If an edge is detected while in Sleep mode, the IOCBF register will be updated prior to the first instruction executed out of Sleep.

FIGURE 13-1: INTERRUPT-ON-CHANGE BLOCK DIAGRAM



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13.6 Interrupt-On-Change Registers

REGISTER 13-1: IOCBP: INTERRUPT-ON-CHANGE POSITIVE EDGE REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
IOCBP7	IOCBP6	IOCBP5	IOCBP4	IOCBP3	IOCBP2	IOCBP1	IOCBP0
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7-0

IOCBP<7:0>: Interrupt-on-Change Positive Edge Enable bits

1 = Interrupt-on-change enabled on the pin for a positive going edge. Associated Status bit and interrupt flag will be set upon detecting an edge.

0 = Interrupt-on-change disabled for the associated pin.

REGISTER 13-2: IOCBN: INTERRUPT-ON-CHANGE NEGATIVE EDGE REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
IOCBN7	IOCBN6	IOCBN5	IOCBN4	IOCBN3	IOCBN2	IOCBN1	IOCBN0
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7-0

IOCBN<7:0>: Interrupt-on-Change Negative Edge Enable bits

1 = Interrupt-on-change enabled on the pin for a negative going edge. Associated Status bit and interrupt flag will be set upon detecting an edge.

0 = Interrupt-on-change disabled for the associated pin.

REGISTER 13-3: IOCBF: INTERRUPT-ON-CHANGE FLAG REGISTER

R/W/HS-0/0	R/W/HS-0/0	R/W/HS-0/0	R/W/HS-0/0	R/W/HS-0/0	R/W/HS-0/0	R/W/HS-0/0	R/W/HS-0/0
IOCBF7	IOCBF6	IOCBF5	IOCBF4	IOCBF3	IOCBF2	IOCBF1	IOCBF0
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

HS - Bit is set in hardware

bit 7-0

IOCBF<7:0>: Interrupt-on-Change Flag bits

1 = An enabled change was detected on the associated pin.

Set when IOCBPx = 1 and a rising edge was detected on RBx, or when IOCBNx = 1 and a falling edge was detected on RBx.

0 = No change was detected, or the user cleared the detected change.

TABLE 13-1: SUMMARY OF REGISTERS ASSOCIATED WITH INTERRUPT-ON-CHANGE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
ANSELB	ANSB7	ANSB6	ANSB5	ANSB4	ANSB3	ANSB2	ANSB1	—	128
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
IOCBF	IOCBF7	IOCBF6	IOCBF5	IOCBF4	IOCBF3	IOCBF2	IOCBF1	IOCBF0	132
IOCBN	IOCBN7	IOCBN6	IOCBN5	IOCBN4	IOCBN3	IOCBN2	IOCBN1	IOCBN0	132
IOCBP	IOCBP7	IOCBP6	IOCBP5	IOCBP4	IOCBP3	IOCBP2	IOCBP1	IOCBP0	132
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127

Legend: — = unimplemented locations read as '0'. Shaded cells are not used by interrupt-on-change.

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NOTES:

14.0 FIXED VOLTAGE REFERENCE (FVR)

The Fixed Voltage Reference, or FVR, is a stable voltage reference, independent of V_{DD} , with 1.024V, 2.048V or 4.096V selectable output levels. The output of the FVR can be configured to supply a reference voltage to the following:

- ADC input channel
- ADC positive reference
- Comparator positive input
- Digital-to-Analog Converter (DAC)
- Capacitive Sensing (CPS) module

The FVR can be enabled by setting the FVREN bit of the FVRCON register.

14.1 Independent Gain Amplifiers

The output of the FVR supplied to the ADC, Comparators, and DAC and CPS is routed through two independent programmable gain amplifiers. Each amplifier can be configured to amplify the reference voltage by 1x, 2x or 4x, to produce the three possible voltage levels.

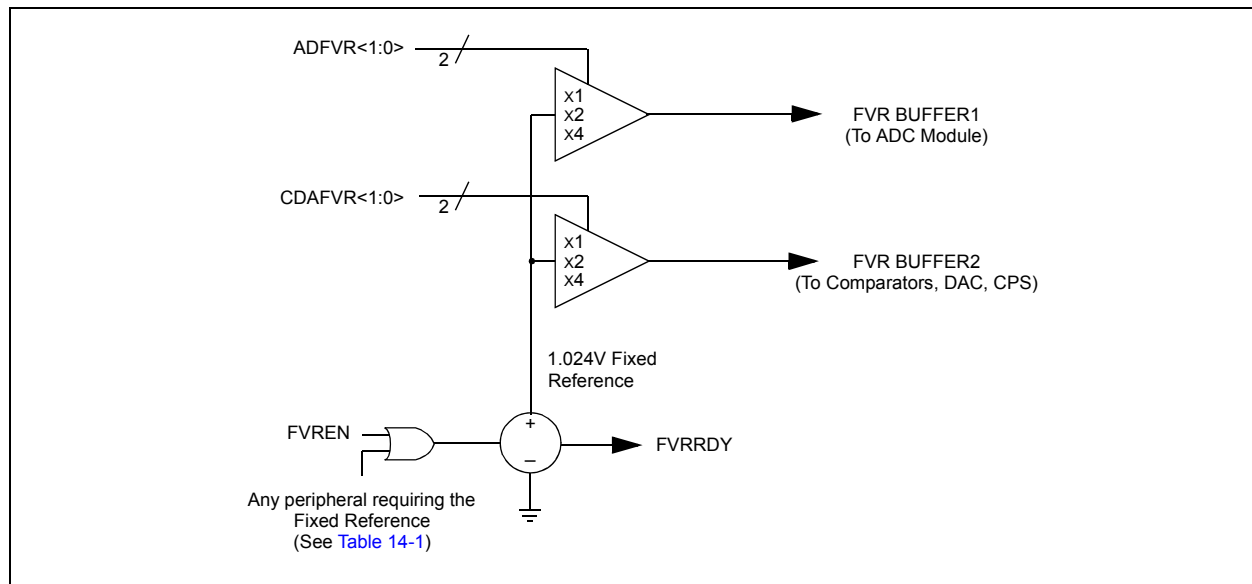
The ADFVR<1:0> bits of the FVRCON register are used to enable and configure the gain amplifier settings for the reference supplied to the ADC module. Reference [Section 16.0 “Analog-to-Digital Converter \(ADC\) Module”](#) for additional information.

The CDAFVR<1:0> bits of the FVRCON register are used to enable and configure the gain amplifier settings for the reference supplied to the DAC and comparator module. Reference [Section 16.0 “Digital-to-Analog Converter \(DAC\) Module”](#) and [Section 18.0 “Comparator Module”](#) and [Section 27.0 “Capacitive Sensing Module”](#) for additional information.

14.2 FVR Stabilization Period

When the Fixed Voltage Reference module is enabled, it requires time for the reference and amplifier circuits to stabilize. Once the circuits stabilize and are ready for use, the FVRRDY bit of the FVRCON register will be set. See [Section 30.0 “Electrical Specifications”](#) for the minimum delay requirement.

FIGURE 14-1: VOLTAGE REFERENCE BLOCK DIAGRAM



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14.3 FVR Control Registers

REGISTER 14-1: FVRCON: FIXED VOLTAGE REFERENCE CONTROL REGISTER

R/W-0/0	R-q/q	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
FVREN	FVRRDY ⁽¹⁾	Reserved	Reserved	CDAFVR<1:0>	ADFVR<1:0>		
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	q = Value depends on condition

bit 7	FVREN: Fixed Voltage Reference Enable bit 0 = Fixed Voltage Reference is disabled 1 = Fixed Voltage Reference is enabled
bit 6	FVRRDY: Fixed Voltage Reference Ready Flag bit ⁽¹⁾ 0 = Fixed Voltage Reference output is not ready or not enabled 1 = Fixed Voltage Reference output is ready for use
bit 5-4	Reserved: Read as '0'. Maintain these bits clear.
bit 3-2	CDAFVR<1:0>: Comparator and DAC Fixed Voltage Reference Selection bit 00 = Comparator and DAC Fixed Voltage Reference Peripheral output is off. 01 = Comparator and DAC Fixed Voltage Reference Peripheral output is 1x (1.024V) 10 = Comparator and DAC Fixed Voltage Reference Peripheral output is 2x (2.048V) ⁽²⁾ 11 = Comparator and DAC Fixed Voltage Reference Peripheral output is 4x (4.096V) ⁽²⁾
bit 1-0	ADFVR<1:0>: ADC Fixed Voltage Reference Selection bit 00 = ADC Fixed Voltage Reference Peripheral output is off. 01 = ADC Fixed Voltage Reference Peripheral output is 1x (1.024V) 10 = ADC Fixed Voltage Reference Peripheral output is 2x (2.048V) ⁽²⁾ 11 = ADC Fixed Voltage Reference Peripheral output is 4x (4.096V) ⁽²⁾

Note 1: FVRRDY is always '1' on devices with LDO (PIC16F1826/27).

2: Fixed Voltage Reference output cannot exceed VDD.

TABLE 14-1: SUMMARY OF REGISTERS ASSOCIATED WITH THE FVR MODULE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on page
FVRCON	FVREN	FVRRDY	Reserved	Reserved	CDAFVR1	CDAFVR0	ADFVR1	ADFVR0	136

Legend: Shaded cells are unused by the FVR module.

15.0 TEMPERATURE INDICATOR MODULE

This family of devices is equipped with a temperature circuit designed to measure the operating temperature of the silicon die. The circuit's range of operating temperature falls between of -40°C and +85°C. The output is a voltage that is proportional to the device temperature. The output of the temperature indicator is internally connected to the device ADC.

The circuit may be used as a temperature threshold detector or a more accurate temperature indicator, depending on the level of calibration performed. A one-point calibration allows the circuit to indicate a temperature closely surrounding that point. A two-point calibration allows the circuit to sense the entire range of temperature more accurately. Reference Application Note AN1333, "Use and Calibration of the Internal Temperature Indicator" (DS01333) for more details regarding the calibration process.

15.1 Circuit Operation

Figure 15-1 shows a simplified block diagram of the temperature circuit. The proportional voltage output is achieved by measuring the forward voltage drop across multiple silicon junctions.

Equation 15-1 describes the output characteristics of the temperature indicator.

EQUATION 15-1: V_{OUT} RANGES

High Range: $V_{OUT} = V_{DD} - 4V_T$

Low Range: $V_{OUT} = V_{DD} - 2V_T$

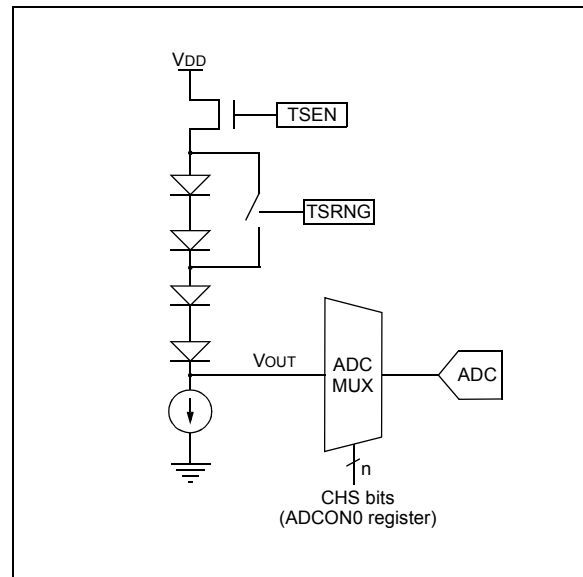
The temperature sense circuit is integrated with the Fixed Voltage Reference (FVR) module. See Section 14.0 "Fixed Voltage Reference (FVR)" for more information.

The circuit is enabled by setting the TSEN bit of the FVRCON register. When disabled, the circuit draws no current.

The circuit operates in either high or low range. The high range, selected by setting the TSRNG bit of the FVRCON register, provides a wider output voltage. This provides more resolution over the temperature range, but may be less consistent from part to part. This range requires a higher bias voltage to operate and thus, a higher V_{DD} is needed.

The low range is selected by clearing the TSRNG bit of the FVRCON register. The low range generates a lower voltage drop and thus, a lower bias voltage is needed to operate the circuit. The low range is provided for low voltage operation.

FIGURE 15-1: TEMPERATURE CIRCUIT DIAGRAM



15.2 Minimum Operating V_{DD} vs. Minimum Sensing Temperature

When the temperature circuit is operated in low range, the device may be operated at any operating voltage that is within specifications.

When the temperature circuit is operated in high range, the device operating voltage, V_{DD} , must be high enough to ensure that the temperature circuit is correctly biased.

Table 15-1 shows the recommended minimum V_{DD} vs. range setting.

TABLE 15-1: RECOMMENDED V_{DD} VS. RANGE

Min. V_{DD} , TSRNG = 1	Min. V_{DD} , TSRNG = 0
3.6V	1.8V

15.3 Temperature Output

The output of the circuit is measured using the internal analog to digital converter. Channel 29 is reserved for the temperature circuit output. Refer to Section 16.0 "Analog-to-Digital Converter (ADC) Module" for detailed information.

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NOTES:

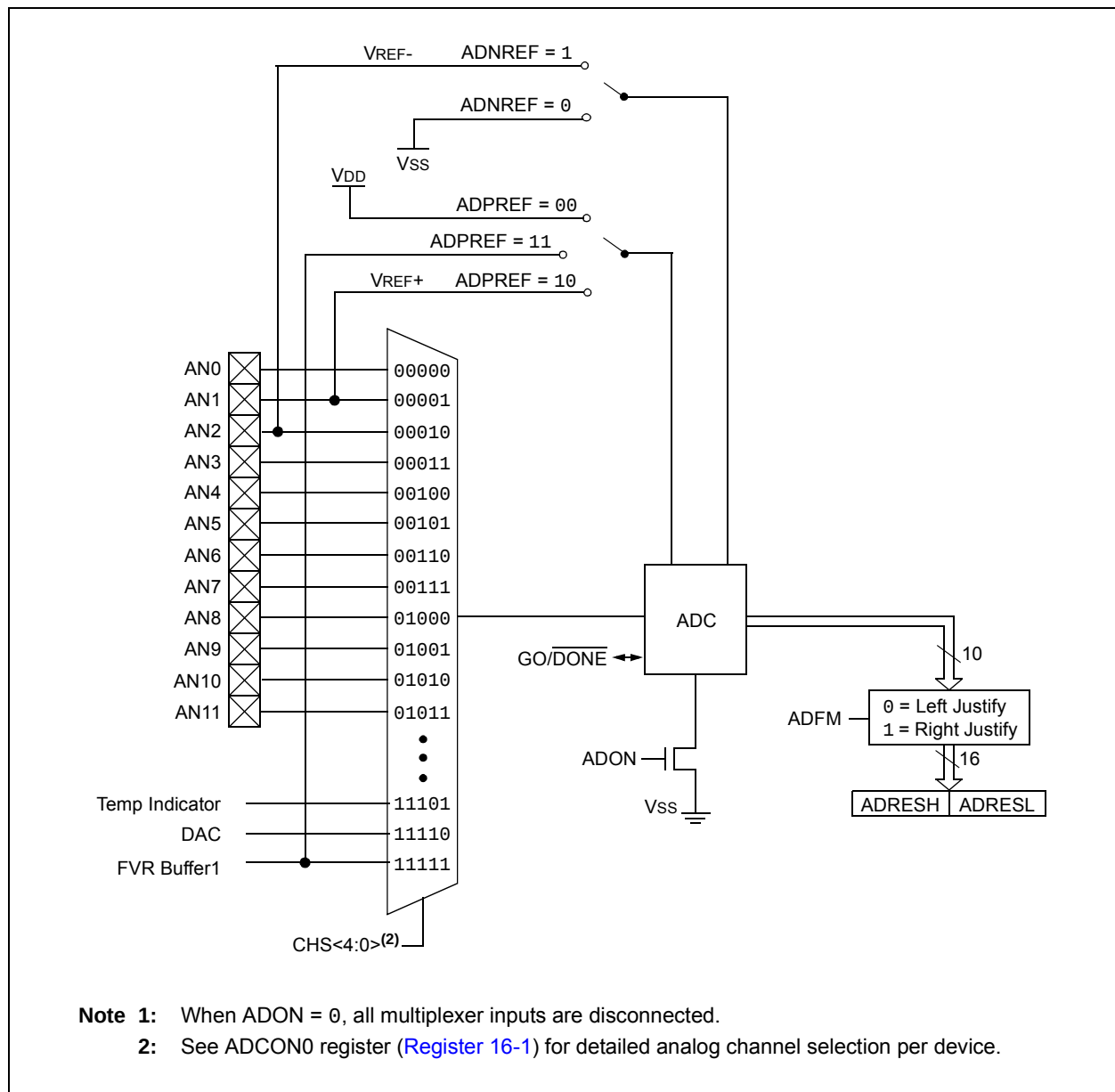
16.0 ANALOG-TO-DIGITAL CONVERTER (ADC) MODULE

The Analog-to-Digital Converter (ADC) allows conversion of an analog input signal to a 10-bit binary representation of that signal. This device uses analog inputs, which are multiplexed into a single sample and hold circuit. The output of the sample and hold is connected to the input of the converter. The converter generates a 10-bit binary result via successive approximation and stores the conversion result into the ADC result registers (ADRESH:ADRESL register pair). [Figure 16-1](#) shows the block diagram of the ADC.

The ADC voltage reference is software selectable to be either internally generated or externally supplied.

The ADC can generate an interrupt upon completion of a conversion. This interrupt can be used to wake-up the device from Sleep.

FIGURE 16-1: ADC BLOCK DIAGRAM



16.1 ADC Configuration

When configuring and using the ADC the following functions must be considered:

- Port configuration
- Channel selection
- ADC voltage reference selection
- ADC conversion clock source
- Interrupt control
- Result formatting

16.1.1 PORT CONFIGURATION

The ADC can be used to convert both analog and digital signals. When converting analog signals, the I/O pin should be configured for analog by setting the associated TRIS and ANSEL bits. Refer to [Section 12.0 “I/O Ports”](#) for more information.

Note: Analog voltages on any pin that is defined as a digital input may cause the input buffer to conduct excess current.

16.1.2 CHANNEL SELECTION

There are up to 15 channel selections available:

- AN<11:0> pins
- Temperature Indicator
- DAC Output
- FVR (Fixed Voltage Reference) Output

Refer to [Section 14.0 “Fixed Voltage Reference \(FVR\)”](#) and [Section 15.0 “Temperature Indicator Module”](#) for more information on these channel selections.

The CHS bits of the ADCON0 register determine which channel is connected to the sample and hold circuit.

When changing channels, a delay is required before starting the next conversion. Refer to [Section 16.2 “ADC Operation”](#) for more information.

16.1.3 ADC VOLTAGE REFERENCE

The ADPREF bits of the ADCON1 register provides control of the positive voltage reference. The positive voltage reference can be:

- VREF+ pin
- VDD
- FVR 2.048V
- FVR 4.096V (Not available on LF devices)

The ADNREF bits of the ADCON1 register provides control of the negative voltage reference. The negative voltage reference can be:

- VREF- pin
- VSS

See [Section 14.0 “Fixed Voltage Reference \(FVR\)”](#) for more details on the fixed voltage reference.

16.1.4 CONVERSION CLOCK

The source of the conversion clock is software selectable via the ADCS bits of the ADCON1 register. There are seven possible clock options:

- Fosc/2
- Fosc/4
- Fosc/8
- Fosc/16
- Fosc/32
- Fosc/64
- FRC (dedicated internal oscillator)

The time to complete one bit conversion is defined as TAD. One full 10-bit conversion requires 11.5 TAD periods as shown in [Figure 16-2](#).

For correct conversion, the appropriate TAD specification must be met. Refer to the A/D conversion requirements in [Section 30.0 “Electrical Specifications”](#) for more information. [Table 16-1](#) gives examples of appropriate ADC clock selections.

Note: Unless using the FRC, any changes in the system clock frequency will change the ADC clock frequency, which may adversely affect the ADC result.

TABLE 16-1: ADC CLOCK PERIOD (T_{AD}) Vs. DEVICE OPERATING FREQUENCIES

ADC Clock Period (T _{AD})		Device Frequency (F _{osc})					
ADC Clock Source	ADCS<2:0>	32 MHz	20 MHz	16 MHz	8 MHz	4 MHz	1 MHz
Fosc/2	000	62.5ns ⁽²⁾	100 ns ⁽²⁾	125 ns ⁽²⁾	250 ns ⁽²⁾	500 ns ⁽²⁾	2.0 μs
Fosc/4	100	125 ns ⁽²⁾	200 ns ⁽²⁾	250 ns ⁽²⁾	500 ns ⁽²⁾	1.0 μs	4.0 μs
Fosc/8	001	0.5 μs ⁽²⁾	400 ns ⁽²⁾	0.5 μs ⁽²⁾	1.0 μs	2.0 μs	8.0 μs ⁽³⁾
Fosc/16	101	800 ns	800 ns	1.0 μs	2.0 μs	4.0 μs	16.0 μs ⁽³⁾
Fosc/32	010	1.0 μs	1.6 μs	2.0 μs	4.0 μs	8.0 μs ⁽³⁾	32.0 μs ⁽³⁾
Fosc/64	110	2.0 μs	3.2 μs	4.0 μs	8.0 μs ⁽³⁾	16.0 μs ⁽³⁾	64.0 μs ⁽³⁾
FRC	x11	1.0-6.0 μs ^(1,4)	1.0-6.0 μs ^(1,4)	1.0-6.0 μs ^(1,4)	1.0-6.0 μs ^(1,4)	1.0-6.0 μs ^(1,4)	1.0-6.0 μs ^(1,4)

Legend: Shaded cells are outside of recommended range.

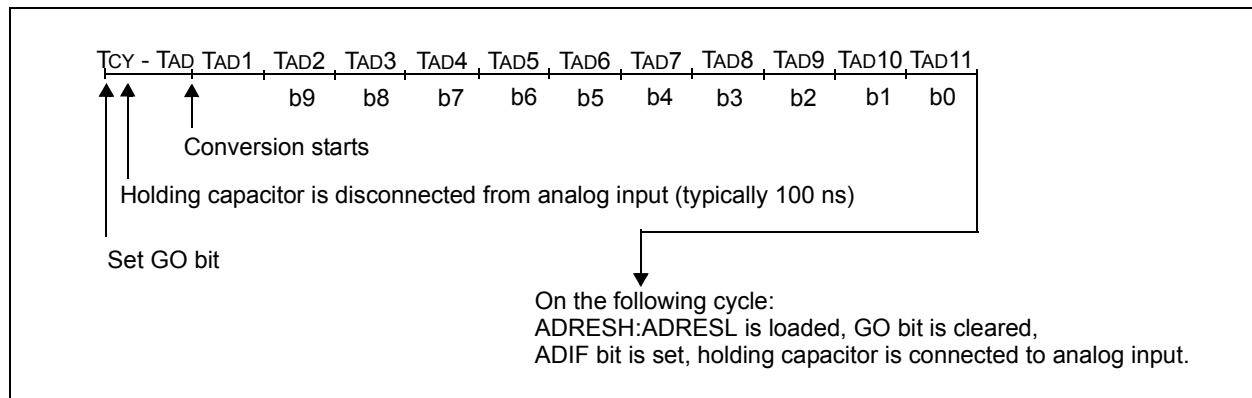
Note 1: The FRC source has a typical T_{AD} time of 1.6 μs for V_{DD}.

2: These values violate the minimum required T_{AD} time.

3: For faster conversion times, the selection of another clock source is recommended.

4: The ADC clock period (T_{AD}) and total ADC conversion time can be minimized when the ADC clock is derived from the system clock Fosc. However, the FRC clock source must be used when conversions are to be performed with the device in Sleep mode.

FIGURE 16-2: ANALOG-TO-DIGITAL CONVERSION T_{AD} CYCLES



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16.1.5 INTERRUPTS

The ADC module allows for the ability to generate an interrupt upon completion of an Analog-to-Digital conversion. The ADC Interrupt Flag is the ADIF bit in the PIR1 register. The ADC Interrupt Enable is the ADIE bit in the PIE1 register. The ADIF bit must be cleared in software.

- Note 1:** The ADIF bit is set at the completion of every conversion, regardless of whether or not the ADC interrupt is enabled.

2: The ADC operates during Sleep only when the FRC oscillator is selected.

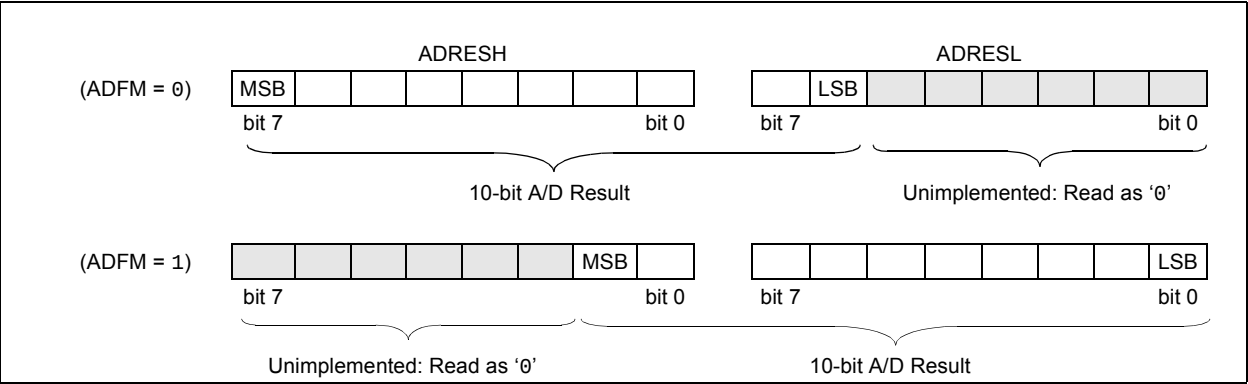
This interrupt can be generated while the device is operating or while in Sleep. If the device is in Sleep, the interrupt will wake-up the device. Upon waking from Sleep, the next instruction following the SLEEP instruction is always executed. If the user is attempting to wake-up from Sleep and resume in-line code execution, the GIE and PEIE bits of the INTCON register must be disabled. If the GIE and PEIE bits of the INTCON register are enabled, execution will switch to the Interrupt Service Routine.

16.1.6 RESULT FORMATTING

The 10-bit A/D conversion result can be supplied in two formats, left justified or right justified. The ADFM bit of the ADCON1 register controls the output format.

Figure 16-3 shows the two output formats.

FIGURE 16-3: 10-BIT A/D CONVERSION RESULT FORMAT



16.2 ADC Operation

16.2.1 STARTING A CONVERSION

To enable the ADC module, the ADON bit of the ADCON0 register must be set to a '1'. Setting the GO/DONE bit of the ADCON0 register to a '1' will start the Analog-to-Digital conversion.

Note: The GO/DONE bit should not be set in the same instruction that turns on the ADC. Refer to [Section 16.2.6 “A/D Conversion Procedure”](#).

16.2.2 COMPLETION OF A CONVERSION

When the conversion is complete, the ADC module will:

- Clear the GO/DONE bit
- Set the ADIF Interrupt Flag bit
- Update the ADRESH and ADRESL registers with new conversion result

16.2.3 TERMINATING A CONVERSION

If a conversion must be terminated before completion, the GO/DONE bit can be cleared in software. The ADRESH and ADRESL registers will be updated with the partially complete Analog-to-Digital conversion sample. Incomplete bits will match the last bit converted.

Note: A device Reset forces all registers to their Reset state. Thus, the ADC module is turned off and any pending conversion is terminated.

16.2.4 ADC OPERATION DURING SLEEP

The ADC module can operate during Sleep. This requires the ADC clock source to be set to the FRC option. When the FRC clock source is selected, the ADC waits one additional instruction before starting the conversion. This allows the SLEEP instruction to be executed, which can reduce system noise during the conversion. If the ADC interrupt is enabled, the device will wake-up from Sleep when the conversion completes. If the ADC interrupt is disabled, the ADC module is turned off after the conversion completes, although the ADON bit remains set.

When the ADC clock source is something other than FRC, a SLEEP instruction causes the present conversion to be aborted and the ADC module is turned off, although the ADON bit remains set.

16.2.5 SPECIAL EVENT TRIGGER

The Special Event Trigger of the CCPx/ECCPx module allows periodic ADC measurements without software intervention. When this trigger occurs, the GO/DONE bit is set by hardware and the Timer1 counter resets to zero.

TABLE 16-2: SPECIAL EVENT TRIGGER

Device	CCPx/ECCPx
PIC16(L)F1826	ECCP1
PIC16(L)F1827	CCP4

Using the Special Event Trigger does not assure proper ADC timing. It is the user's responsibility to ensure that the ADC timing requirements are met.

Refer to [Section 24.0 “Capture/Compare/PWM Modules”](#) for more information.

16.2.6 A/D CONVERSION PROCEDURE

This is an example procedure for using the ADC to perform an Analog-to-Digital conversion:

1. Configure Port:
 - Disable pin output driver (Refer to the TRIS register)
 - Configure pin as analog (Refer to the ANSEL register)
2. Configure the ADC module:
 - Select ADC conversion clock
 - Configure voltage reference
 - Select ADC input channel
 - Turn on ADC module
3. Configure ADC interrupt (optional):
 - Clear ADC interrupt flag
 - Enable ADC interrupt
 - Enable peripheral interrupt
 - Enable global interrupt⁽¹⁾
4. Wait the required acquisition time⁽²⁾.
5. Start conversion by setting the GO/DONE bit.
6. Wait for ADC conversion to complete by one of the following:
 - Polling the GO/DONE bit
 - Waiting for the ADC interrupt (interrupts enabled)
7. Read ADC Result.
8. Clear the ADC interrupt flag (required if interrupt is enabled).

Note 1: The global interrupt can be disabled if the user is attempting to wake-up from Sleep and resume in-line code execution.

2: Refer to [Section 16.4 “A/D Acquisition Requirements”](#).

EXAMPLE 16-1: A/D CONVERSION

```
;This code block configures the ADC
;for polling, Vdd and Vss references, Frc
;clock and AN0 input.
;
;Conversion start & polling for completion
; are included.
;
BANKSEL    ADCON1    ;
MOVLW      B'11110000' ;Right justify, Frc
                        ;clock
MOVWF      ADCON1    ;Vdd and Vss Vref
BANKSEL    TRISA     ;
BSF        TRISA,0    ;Set RA0 to input
BANKSEL    ANSEL     ;
BSF        ANSEL,0    ;Set RA0 to analog
BANKSEL    ADCON0    ;
MOVLW      B'00000001' ;Select channel AN0
MOVWF      ADCON0    ;Turn ADC On
CALL       SampleTime ;Acquisition delay
BSF        ADCON0,ADGO ;Start conversion
BTFSC      ADCON0,ADGO ;Is conversion done?
GOTO       $-1        ;No, test again
BANKSEL    ADRESH     ;
MOVF       ADRESH,W   ;Read upper 2 bits
MOVWF      RESULTHI   ;store in GPR space
BANKSEL    ADRESL     ;
MOVF       ADRESL,W   ;Read lower 8 bits
MOVWF      RESULTLO   ;Store in GPR space
```

16.3 ADC Register Definitions

The following registers are used to control the operation of the ADC.

REGISTER 16-1: ADCON0: A/D CONTROL REGISTER 0

U-0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
—	CHS<4:0>					GO/DONE	ADON
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

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

bit 6-2 **CHS<4:0>:** Analog Channel Select bits

00000 = AN0

00001 = AN1

00010 = AN2

00011 = AN3

00100 = AN4

00101 = AN5

00110 = AN6

00111 = AN7

01000 = AN8

01001 = AN9

01010 = AN10

01011 = AN11

01100 = Reserved. No channel connected.

•

•

•

11101 = Temperature Indicator⁽³⁾

11110 = DAC output⁽¹⁾

11111 = FVR (Fixed Voltage Reference) Buffer 1 Output⁽²⁾

bit 1 **GO/DONE:** A/D Conversion Status bit

1 = A/D conversion cycle in progress. Setting this bit starts an A/D conversion cycle.

This bit is automatically cleared by hardware when the A/D conversion has completed.

0 = A/D conversion completed/not in progress

bit 0 **ADON:** ADC Enable bit

1 = ADC is enabled

0 = ADC is disabled and consumes no operating current

Note 1: See [Section 17.0 “Digital-to-Analog Converter \(DAC\) Module”](#) for more information.

2: See [Section 14.0 “Fixed Voltage Reference \(FVR\)”](#) for more information.

3: See [Section 15.0 “Temperature Indicator Module”](#) for more information.

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REGISTER 16-2: ADCON1: A/D CONTROL REGISTER 1

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	U-0	R/W-0/0	R/W-0/0	R/W-0/0
ADFM	ADCS<2:0>			—	ADNREF	ADPREF<1:0>	
bit 7				bit 0			

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7 **ADFM:** A/D Result Format Select bit
1 = Right justified. Six Most Significant bits of ADRESH are set to '0' when the conversion result is loaded.
0 = Left justified. Six Least Significant bits of ADRESL are set to '0' when the conversion result is loaded.
- bit 6-4 **ADCS<2:0>:** A/D Conversion Clock Select bits
000 = FOSC/2
001 = FOSC/8
010 = FOSC/32
011 = FRC (clock supplied from a dedicated RC oscillator)
100 = FOSC/4
101 = FOSC/16
110 = FOSC/64
111 = FRC (clock supplied from a dedicated RC oscillator)
- bit 3 **Unimplemented:** Read as '0'
- bit 2 **ADNREF:** A/D Negative Voltage Reference Configuration bit
0 = VREF- is connected to VSS
1 = VREF- is connected to external VREF- pin⁽¹⁾
- bit 1-0 **ADPREF<1:0>:** A/D Positive Voltage Reference Configuration bits
00 = VREF+ is connected to VDD
01 = Reserved
10 = VREF+ is connected to external VREF+ pin⁽¹⁾
11 = VREF+ is connected to internal Fixed Voltage Reference (FVR) module⁽¹⁾

Note 1: When selecting the FVR or the VREF+ pin as the source of the positive reference, be aware that a minimum voltage specification exists. See [Section 30.0 "Electrical Specifications"](#) for details.

REGISTER 16-3: ADRESH: ADC RESULT REGISTER HIGH (ADRESH) ADFM = 0

R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
ADRES<9:2>							
bit 7 bit 0							

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7-0 **ADRES<9:2>**: ADC Result Register bits
Upper 8 bits of 10-bit conversion result

REGISTER 16-4: ADRESL: ADC RESULT REGISTER LOW (ADRESL) ADFM = 0

R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
ADRES<1:0>		—	—	—	—	—	—
bit 7 bit 0							

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7-6 **ADRES<1:0>**: ADC Result Register bits
Lower 2 bits of 10-bit conversion result

bit 5-0 **Reserved**: Do not use.

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REGISTER 16-5: ADRESH: ADC RESULT REGISTER HIGH (ADRESH) ADFM = 1

R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
—	—	—	—	—	—	ADRES<9:8>	
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7-2

Reserved: Do not use.

bit 1-0

ADRES<9:8>: ADC Result Register bits
Upper 2 bits of 10-bit conversion result

REGISTER 16-6: ADRESL: ADC RESULT REGISTER LOW (ADRESL) ADFM = 1

R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
ADRES<7:0>							
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7-0

ADRES<7:0>: ADC Result Register bits
Lower 8 bits of 10-bit conversion result

16.4 A/D Acquisition Requirements

For the ADC to meet its specified accuracy, the charge holding capacitor (CHOLD) must be allowed to fully charge to the input channel voltage level. The Analog Input model is shown in Figure 16-4. The source impedance (Rs) and the internal sampling switch (RSS) impedance directly affect the time required to charge the capacitor CHOLD. The sampling switch (RSS) impedance varies over the device voltage (VDD), refer to Figure 16-4. **The maximum recommended impedance for analog sources is 10 kΩ.** As the

source impedance is decreased, the acquisition time may be decreased. After the analog input channel is selected (or changed), an A/D acquisition must be done before the conversion can be started. To calculate the minimum acquisition time, Equation 16-1 may be used. This equation assumes that 1/2 LSB error is used (1,024 steps for the ADC). The 1/2 LSB error is the maximum error allowed for the ADC to meet its specified resolution.

EQUATION 16-1: ACQUISITION TIME EXAMPLE

Assumptions: Temperature = 50°C and external impedance of 10kΩ 5.0V VDD

$$\begin{aligned} T_{ACQ} &= \text{Amplifier Settling Time} + \text{Hold Capacitor Charging Time} + \text{Temperature Coefficient} \\ &= T_{AMP} + T_C + T_{COFF} \\ &= 2\mu s + T_C + [(Temperature - 25^\circ C)(0.05\mu s/^\circ C)] \end{aligned}$$

The value for TC can be approximated with the following equations:

$$V_{APPLIED} \left(1 - \frac{1}{(2^{n+1}) - 1} \right) = V_{CHOLD} \quad ;[1] \text{ } V_{CHOLD} \text{ charged to within } 1/2 \text{ lsb}$$

$$V_{APPLIED} \left(1 - e^{\frac{-T_C}{RC}} \right) = V_{CHOLD} \quad ;[2] \text{ } V_{CHOLD} \text{ charge response to } V_{APPLIED}$$

$$V_{APPLIED} \left(1 - e^{\frac{-T_C}{RC}} \right) = V_{APPLIED} \left(1 - \frac{1}{(2^{n+1}) - 1} \right) \quad ;\text{combining [1] and [2]}$$

Note: Where n = number of bits of the ADC.

Solving for TC:

$$\begin{aligned} T_C &= -CHOLD(RIC + RSS + Rs) \ln(1/511) \\ &= -10pF(1k\Omega + 7k\Omega + 10k\Omega) \ln(0.001957) \\ &= 1.12\mu s \end{aligned}$$

Therefore:

$$\begin{aligned} T_{ACQ} &= 2\mu s + 1.12\mu s + [(50^\circ C - 25^\circ C)(0.05\mu s/^\circ C)] \\ &= 4.42\mu s \end{aligned}$$

Note 1: The reference voltage (VREF) has no effect on the equation, since it cancels itself out.

2: The charge holding capacitor (CHOLD) is not discharged after each conversion.

3: The maximum recommended impedance for analog sources is 10 kΩ. This is required to meet the pin leakage specification.

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FIGURE 16-4: ANALOG INPUT MODEL

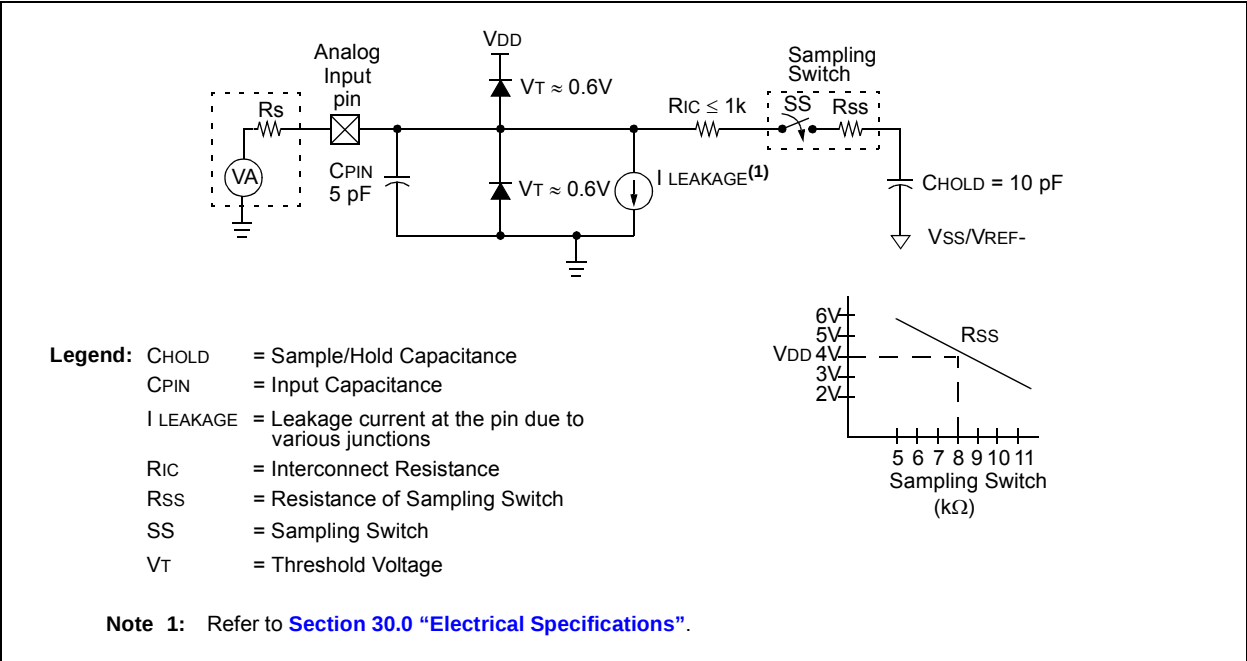


FIGURE 16-5: ADC TRANSFER FUNCTION

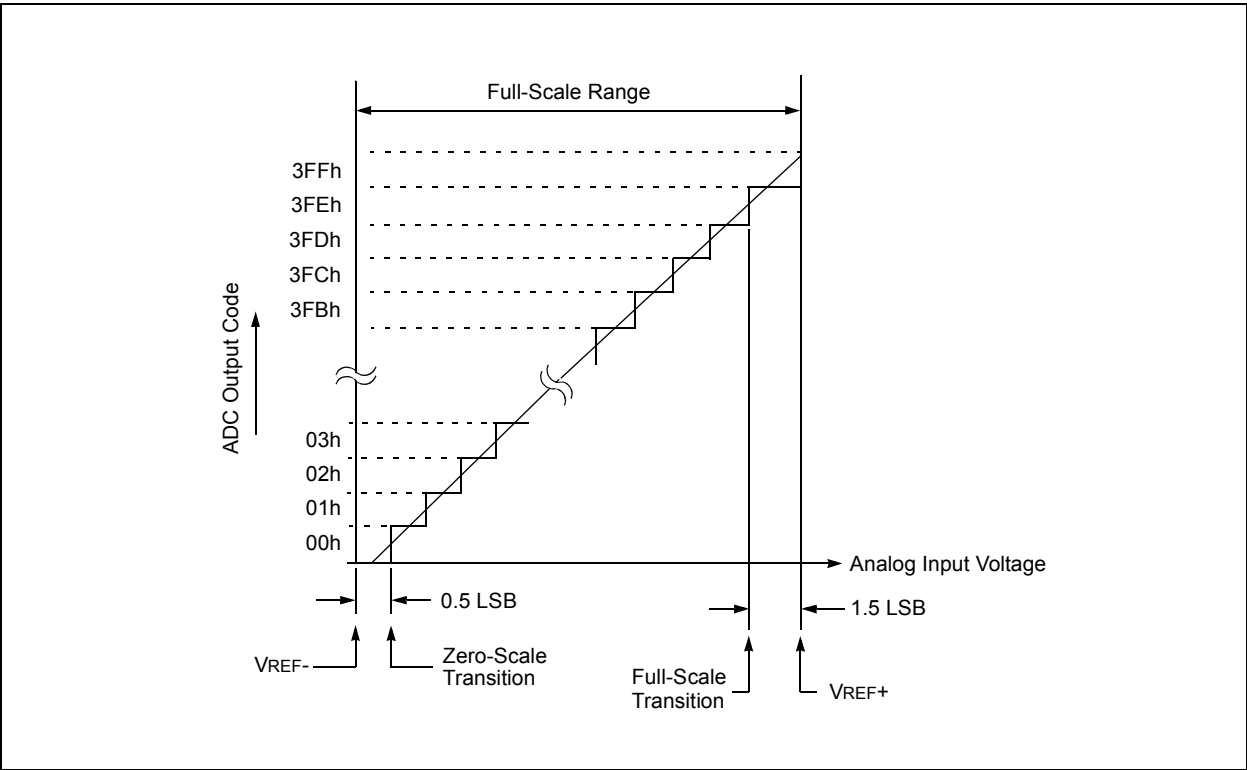


TABLE 16-3: SUMMARY OF REGISTERS ASSOCIATED WITH ADC

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
ADCON0	—	CHS4	CHS3	CHS2	CHS1	CHS0	GO/DONE	ADON	145
ADCON1	ADFM	ADCS2	ADCS1	ADCS0	—	ADNREF	ADPREF1	ADPREF0	146
ADRESH	A/D Result Register High								147, 148
ADRESL	A/D Result Register Low								147, 148
ANSELA	—	—	—	ANSA4	ANSA3	ANSA2	ANSA1	ANSA0	123
ANSELB	ANSB7	ANSB6	ANSB5	ANSB4	ANSB3	ANSB2	ANSB1	—	123
CCPxCON	PxM1	PxM0	DCxB1	DCxB0	CCPxM3	CCPxM2	CCPxM1	CCPxM0	226
INTCON	GIE	PEIE	TMR0IE	INTE	IOCE	TMR0IF	INTF	IOCF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF	91
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	123
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	123
FVRCON	FVREN	FVRRDY	Reserved	Reserved	CDAFVR1	CDAFVR0	ADFVR1	ADFVR0	136
DACCON0	DACEN	DACLPS	DACOE	—	DACPSS1	DACPSS0	—	DACNSS	156
DACCON1	—	—	—	DACR4	DACR3	DACR2	DACR1	DACR0	156

Legend: — = unimplemented read as '0'. Shaded cells are not used for ADC module.

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NOTES:

17.0 DIGITAL-TO-ANALOG CONVERTER (DAC) MODULE

The Digital-to-Analog Converter supplies a variable voltage reference, ratiometric with the input source, with 32 selectable output levels.

The input of the DAC can be connected to:

- External VREF pins
- VDD supply voltage
- FVR (Fixed Voltage Reference)

The output of the DAC can be configured to supply a reference voltage to the following:

- Comparator positive input
- ADC input channel
- DACOUT pin
- Capacitive Sensing module (CSM)

The Digital-to-Analog Converter (DAC) can be enabled by setting the DACEN bit of the DACCON0 register.

17.1 Output Voltage Selection

The DAC has 32 voltage level ranges. The 32 levels are set with the DACR<4:0> bits of the DACCON1 register.

The DAC output voltage is determined by the equations in [Equation 17-1](#).

EQUATION 17-1: DAC OUTPUT VOLTAGE

IF DACEN = 1

$$V_{OUT} = \left((V_{SOURCE+} - V_{SOURCE-}) \times \frac{DACR[4:0]}{2^5} \right) + V_{SOURCE-}$$

IF DACEN = 0 and DACLPS = 1 and DACR[4:0] = 11111

$$V_{OUT} = V_{SOURCE+}$$

IF DACEN = 0 and DACLPS = 0 and DACR[4:0] = 00000

$$V_{OUT} = V_{SOURCE-}$$

$V_{SOURCE+} = V_{DD}, V_{REF}, \text{ or } FVR \text{ BUFFER } 2$

$V_{SOURCE-} = V_{SS}$

17.2 Ratiometric Output Level

The DAC output value is derived using a resistor ladder with each end of the ladder tied to a positive and negative voltage reference input source. If the voltage of either input source fluctuates, a similar fluctuation will result in the DAC output value.

The value of the individual resistors within the ladder can be found in [Section 29.0 “Electrical Specifications”](#).

17.3 DAC Voltage Reference Output

The DAC can be output to the DACOUT pin by setting the DACOE bit of the DACCON0 register to ‘1’. Selecting the DAC reference voltage for output on the DACOUT pin automatically overrides the digital output buffer and digital input threshold detector functions of that pin. Reading the DACOUT pin when it has been configured for DAC reference voltage output will always return a ‘0’.

Due to the limited current drive capability, a buffer must be used on the DAC voltage reference output for external connections to DACOUT. [Figure 17-2](#) shows an example buffering technique.

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FIGURE 17-1: DIGITAL-TO-ANALOG CONVERTER BLOCK DIAGRAM

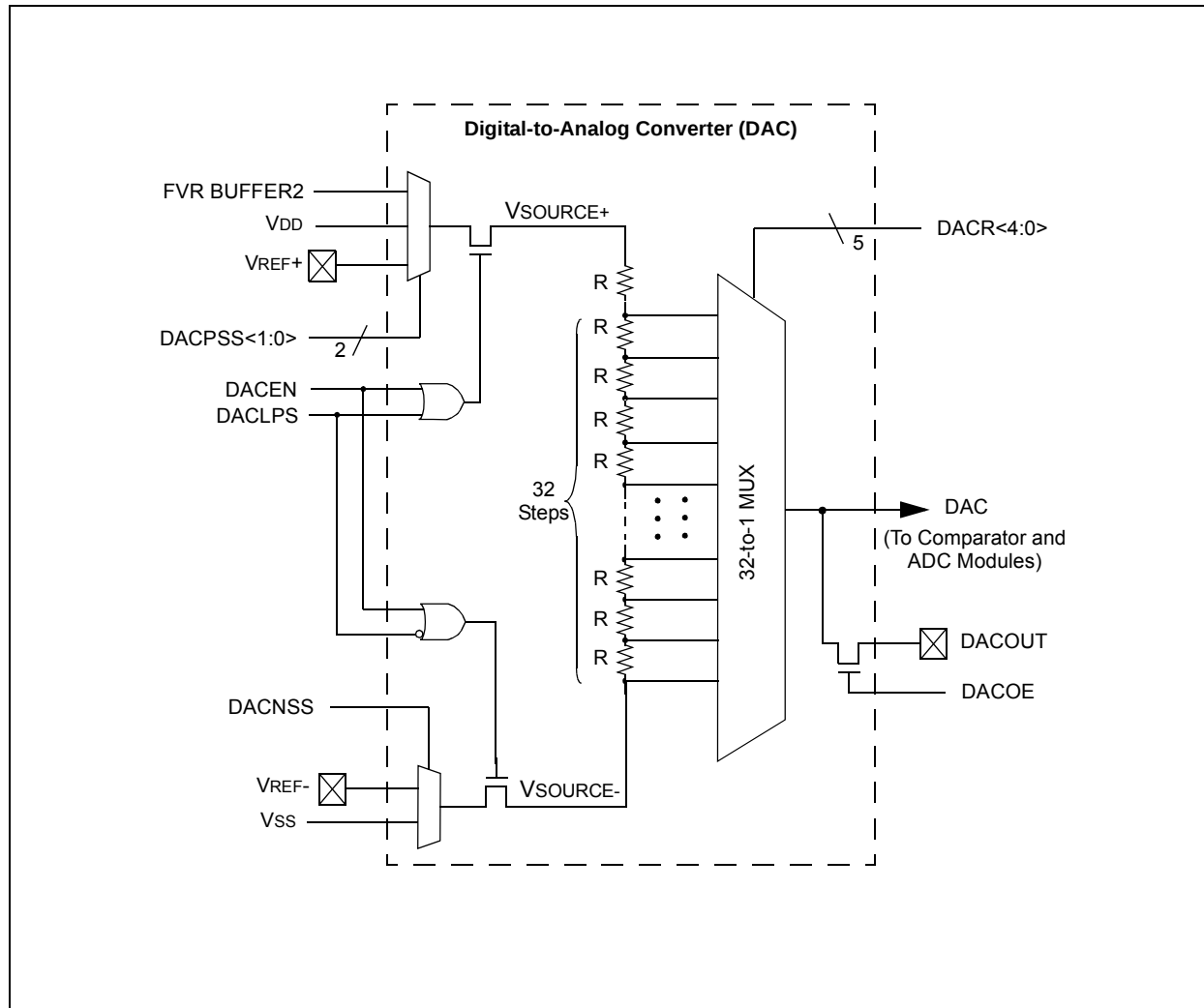
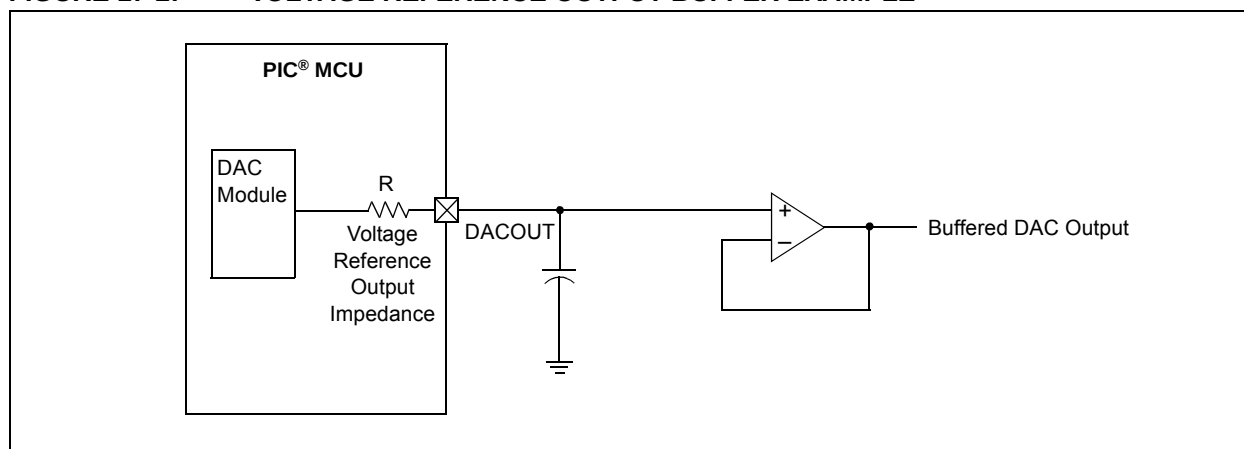


FIGURE 17-2: VOLTAGE REFERENCE OUTPUT BUFFER EXAMPLE



17.4 Low-Power Voltage State

In order for the DAC module to consume the least amount of power, one of the two voltage reference input sources to the resistor ladder must be disconnected. Either the positive voltage source, (VSOURCE+), or the negative voltage source, (VSOURCE-) can be disabled.

The negative voltage source is disabled by setting the DACLPS bit in the DACCON0 register. Clearing the DACLPS bit in the DACCON0 register disables the positive voltage source.

17.4.1 OUTPUT CLAMPED TO POSITIVE VOLTAGE SOURCE

The DAC output voltage can be set to VSOURCE+ with the least amount of power consumption by performing the following:

- Clearing the DACEN bit in the DACCON0 register.
- Setting the DACLPS bit in the DACCON0 register.
- Configuring the DACPSS bits to the proper positive source.
- Configuring the DACR<4:0> bits to '11111' in the DACCON1 register.

This is also the method used to output the voltage level from the FVR to an output pin. See [Section 17.5 "Operation During Sleep"](#) for more information.

Reference [Figure 17-3](#) for output clamping examples.

17.4.2 OUTPUT CLAMPED TO NEGATIVE VOLTAGE SOURCE

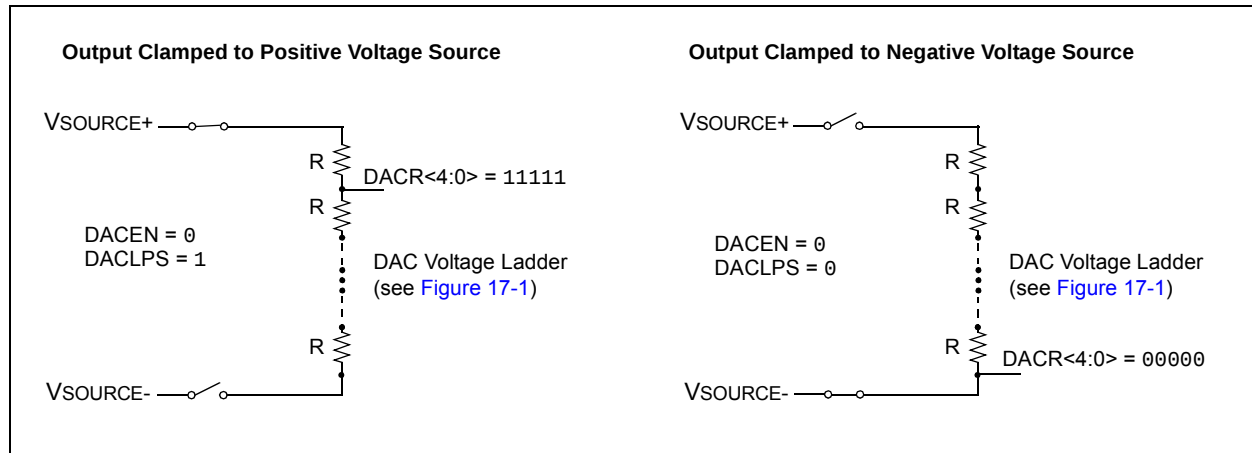
The DAC output voltage can be set to VSOURCE- with the least amount of power consumption by performing the following:

- Clearing the DACEN bit in the DACCON0 register.
- Clearing the DACLPS bit in the DACCON0 register.
- Configuring the DACNSS bits to the proper negative source.
- Configuring the DACR<4:0> bits to '00000' in the DACCON1 register.

This allows the comparator to detect a zero-crossing while not consuming additional current through the DAC module.

Reference [Figure 17-3](#) for output clamping examples.

FIGURE 17-3: OUTPUT VOLTAGE CLAMPING EXAMPLES



17.5 Operation During Sleep

When the device wakes up from Sleep through an interrupt or a Watchdog Timer time-out, the contents of the DACCON0 register are not affected. To minimize current consumption in Sleep mode, the voltage reference should be disabled.

17.6 Effects of a Reset

A device Reset affects the following:

- DAC is disabled.
- DAC output voltage is removed from the DACOUT pin.
- The DACR<4:0> range select bits are cleared.

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17.7 DAC Control Registers

REGISTER 17-1: DACCON0: VOLTAGE REFERENCE CONTROL REGISTER 0

R/W-0/0	R/W-0/0	R/W-0/0	U-0	R/W-0/0	R/W-0/0	U-0	R/W-0/0
DACEN	DACLPS	DACOE	—	DACPSS<1:0>	—	—	DACNSS
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set '0' = Bit is cleared

bit 7 **DACEN:** DAC Enable bit
1 = DAC is enabled
0 = DAC is disabled

bit 6 **DACLPS:** DAC Low-Power Voltage State Select bit
1 = DAC Positive reference source selected
0 = DAC Negative reference source selected

bit 5 **DACOE:** DAC Voltage Output Enable bit
1 = DAC voltage level is also an output on the DACOUT pin
0 = DAC voltage level is disconnected from the DACOUT pin

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

bit 3-2 **DACPSS<1:0>:** DAC Positive Source Select bits
00 = VDD
01 = VREF+ pin
10 = FVR Buffer2 output
11 = Reserved, do not use

bit 1 **Unimplemented:** Read as '0'

bit 0 **DACNSS:** DAC Negative Source Select bits
1 = VREF-
0 = VSS

REGISTER 17-2: DACCON1: VOLTAGE REFERENCE CONTROL REGISTER 1

U-0	U-0	U-0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
—	—	—	DACR<4:0>				
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set '0' = Bit is cleared

bit 7-5 **Unimplemented:** Read as '0'

bit 4-0 **DACR<4:0>:** DAC Voltage Output Select bits

TABLE 17-1: SUMMARY OF REGISTERS ASSOCIATED WITH THE DAC MODULE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on page
FVRCON	FVREN	FVRRDY	Reserved	Reserved	CDAFVR1	CDAFVR0	ADFVR1	ADFVR0	138
DACCON0	DACEN	DACLPS	DACOE	—	DACPSS1	DACPSS0	—	DACNSS	156
DACCON1	—	—	—	DACR4	DACR3	DACR2	DACR1	DACR0	156

Legend: — = unimplemented, read as '0'. Shaded cells are unused with the DAC module.

18.0 SR LATCH

The module consists of a single SR Latch with multiple Set and Reset inputs as well as separate latch outputs. The SR Latch module includes the following features:

- Programmable input selection
- SR Latch output is available externally
- Separate Q and $\bar{Q}$ outputs
- Firmware Set and Reset

The SR Latch can be used in a variety of analog applications, including oscillator circuits, one-shot circuit, hysteretic controllers, and analog timing applications.

18.1 Latch Operation

The latch is a Set-Reset Latch that does not depend on a clock source. Each of the Set and Reset inputs are active-high. The latch can be Set or Reset by:

- Software control (SRPS and SRPR bits)
- Comparator C1 output (SYNCC1OUT)
- Comparator C2 output (SYNCC2OUT)
- SRI pin
- Programmable clock (SRCLK)

The SRPS and the SRPR bits of the SRCON0 register may be used to set or reset the SR Latch, respectively. The latch is Reset-dominant. Therefore, if both Set and Reset inputs are high, the latch will go to the Reset state. Both the SRPS and SRPR bits are self resetting which means that a single write to either of the bits is all that is necessary to complete a latch Set or Reset operation.

The output from Comparator C1 or C2 can be used as the Set or Reset inputs of the SR Latch. The output of either comparator can be synchronized to the Timer1 clock source. See [Section 19.0 “Comparator Module”](#) and [Section 21.0 “Timer1 Module with Gate Control”](#) for more information.

An external source on the SRI pin can be used as the Set or Reset inputs of the SR Latch.

An internal clock source is available that can periodically set or reset the SR Latch. The SRCLK<2:0> bits in the SRCON0 register are used to select the clock source period. The SRSCKE and SRRCKE bits of the SRCON1 register enable the clock source to set or reset the SR Latch, respectively.

Note: Enabling both the Set and Reset inputs from any one source at the same time may result in indeterminate operation, as the Reset dominance cannot be assured.

18.2 Latch Output

The SRQEN and SRNQEN bits of the SRCON0 register control the Q and $\bar{Q}$ latch outputs. Both of the SR Latch outputs may be directly output to an I/O pin at the same time.

The applicable TRIS bit of the corresponding port must be cleared to enable the port pin output driver.

18.3 Effects of a Reset

Upon any device Reset, the SR Latch output is not initialized to a known state. The user's firmware is responsible for initializing the latch output before enabling the output pins.

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FIGURE 18-1: SR LATCH SIMPLIFIED BLOCK DIAGRAM

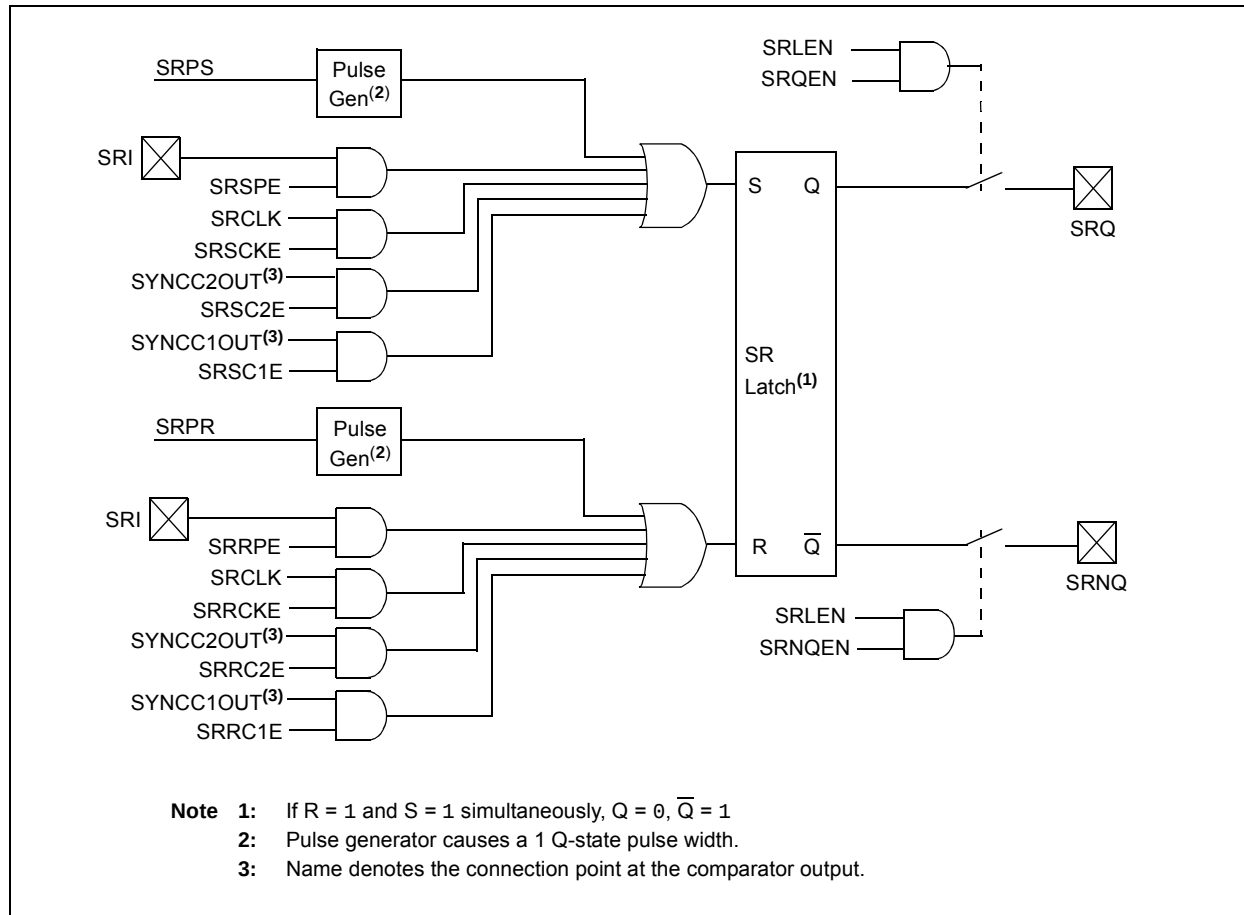


TABLE 18-1: SRCLK FREQUENCY TABLE

SRCLK	Divider	Fosc = 32 MHz	Fosc = 20 MHz	Fosc = 16 MHz	Fosc = 4 MHz	Fosc = 1 MHz
111	512	62.5 kHz	39.0 kHz	31.3 kHz	7.81 kHz	1.95 kHz
110	256	125 kHz	78.1 kHz	62.5 kHz	15.6 kHz	3.90 kHz
101	128	250 kHz	156 kHz	125 kHz	31.25 kHz	7.81 kHz
100	64	500 kHz	313 kHz	250 kHz	62.5 kHz	15.6 kHz
011	32	1 MHz	625 kHz	500 kHz	125 kHz	31.3 kHz
010	16	2 MHz	1.25 MHz	1 MHz	250 kHz	62.5 kHz
001	8	4 MHz	2.5 MHz	2 MHz	500 kHz	125 kHz
000	4	8 MHz	5 MHz	4 MHz	1 MHz	250 kHz

REGISTER 18-1: SRCON0: SR LATCH CONTROL 0 REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/S-0/0	R/S-0/0
SRLEN	SRCLK<2:0>			SRQEN	SRNQEN	SRPS	SRPR
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	S = Bit is set only

bit 7	SRLEN: SR Latch Enable bit 1 = SR Latch is enabled 0 = SR Latch is disabled
bit 6-4	SRCLK<2:0>: SR Latch Clock Divider bits 000 = Generates a 1 Fosc wide pulse every 4th Fosc cycle clock 001 = Generates a 1 Fosc wide pulse every 8th Fosc cycle clock 010 = Generates a 1 Fosc wide pulse every 16th Fosc cycle clock 011 = Generates a 1 Fosc wide pulse every 32nd Fosc cycle clock 100 = Generates a 1 Fosc wide pulse every 64th Fosc cycle clock 101 = Generates a 1 Fosc wide pulse every 128th Fosc cycle clock 110 = Generates a 1 Fosc wide pulse every 256th Fosc cycle clock 111 = Generates a 1 Fosc wide pulse every 512th Fosc cycle clock
bit 3	SRQEN: SR Latch Q Output Enable bit <u>If SRLEN = 1:</u> 1 = Q is present on the SRQ pin 0 = External Q output is disabled <u>If SRLEN = 0:</u> SR Latch is disabled
bit 2	SRNQEN: SR Latch $\bar{Q}$ Output Enable bit <u>If SRLEN = 1:</u> 1 = $\bar{Q}$ is present on the SRnQ pin 0 = External $\bar{Q}$ output is disabled <u>If SRLEN = 0:</u> SR Latch is disabled
bit 1	SRPS: Pulse Set Input of the SR Latch bit ⁽¹⁾ 1 = Pulse set input for 1 Q-clock period 0 = No effect on set input.
bit 0	SRPR: Pulse Reset Input of the SR Latch bit ⁽¹⁾ 1 = Pulse reset input for 1 Q-clock period 0 = No effect on reset input.

Note 1: Set only, always reads back '0'.

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REGISTER 18-2: SRCON1: SR LATCH CONTROL 1 REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
SRSPE	SRSCKE	SRSC2E	SRSC1E	SRRPE	SRRCKE	SRRC2E	SRRC1E
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7	SRSPE: SR Latch Peripheral Set Enable bit 1 = SR Latch is set when the SRI pin is high. 0 = SRI pin has no effect on the set input of the SR Latch
bit 6	SRSCKE: SR Latch Set Clock Enable bit 1 = Set input of SR Latch is pulsed with SRCLK 0 = SRCLK has no effect on the set input of the SR Latch
bit 5	SRSC2E: SR Latch C2 Set Enable bit 1 = SR Latch is set when the C2 Comparator output is high 0 = C2 Comparator output has no effect on the set input of the SR Latch
bit 4	SRSC1E: SR Latch C1 Set Enable bit 1 = SR Latch is set when the C1 Comparator output is high 0 = C1 Comparator output has no effect on the set input of the SR Latch
bit 3	SRRPE: SR Latch Peripheral Reset Enable bit 1 = SR Latch is reset when the SRI pin is high. 0 = SRI pin has no effect on the reset input of the SR Latch
bit 2	SRRCKE: SR Latch Reset Clock Enable bit 1 = Reset input of SR Latch is pulsed with SRCLK 0 = SRCLK has no effect on the reset input of the SR Latch
bit 1	SRRC2E: SR Latch C2 Reset Enable bit 1 = SR Latch is reset when the C2 Comparator output is high 0 = C2 Comparator output has no effect on the reset input of the SR Latch
bit 0	SRRC1E: SR Latch C1 Reset Enable bit 1 = SR Latch is reset when the C1 Comparator output is high 0 = C1 Comparator output has no effect on the reset input of the SR Latch

TABLE 18-2: SUMMARY OF REGISTERS ASSOCIATED WITH SR LATCH MODULE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
ANSELA	—	—	—	ANSA4	ANSA3	ANSA2	ANSA1	ANSA0	123
SRCON0	SRLEN	SRCLK2	SRCLK1	SRCLK0	SRQEN	SRNQEN	SRPS	SRPR	159
SRCON1	SRSPE	SRSCKE	SRSC2E	SRSC1E	SRRPE	SRRCKE	SRRC2E	SRRC1E	160
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122

Legend: — = unimplemented, read as '0'. Shaded cells are unused by the SR latch module.

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NOTES:

19.0 COMPARATOR MODULE

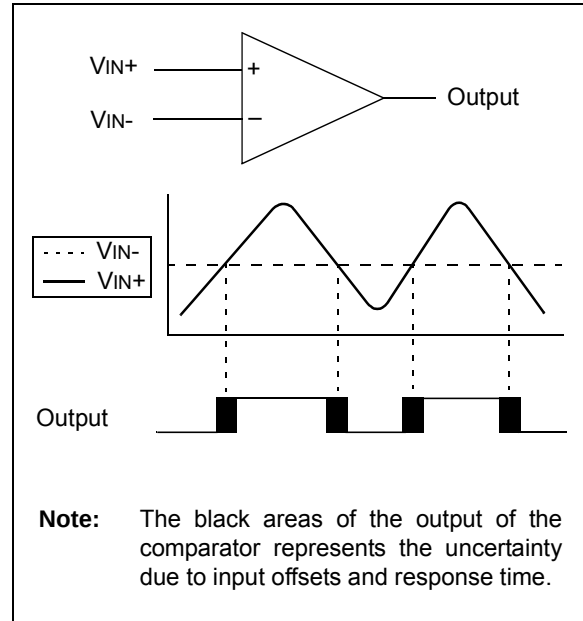
Comparators are used to interface analog circuits to a digital circuit by comparing two analog voltages and providing a digital indication of their relative magnitudes. Comparators are very useful mixed signal building blocks because they provide analog functionality independent of program execution. The analog comparator module includes the following features:

- Independent comparator control
- Programmable input selection
- Comparator output is available internally/externally
- Programmable output polarity
- Interrupt-on-change
- Wake-up from Sleep
- Programmable Speed/Power optimization
- PWM shutdown
- Programmable and fixed voltage reference

19.1 Comparator Overview

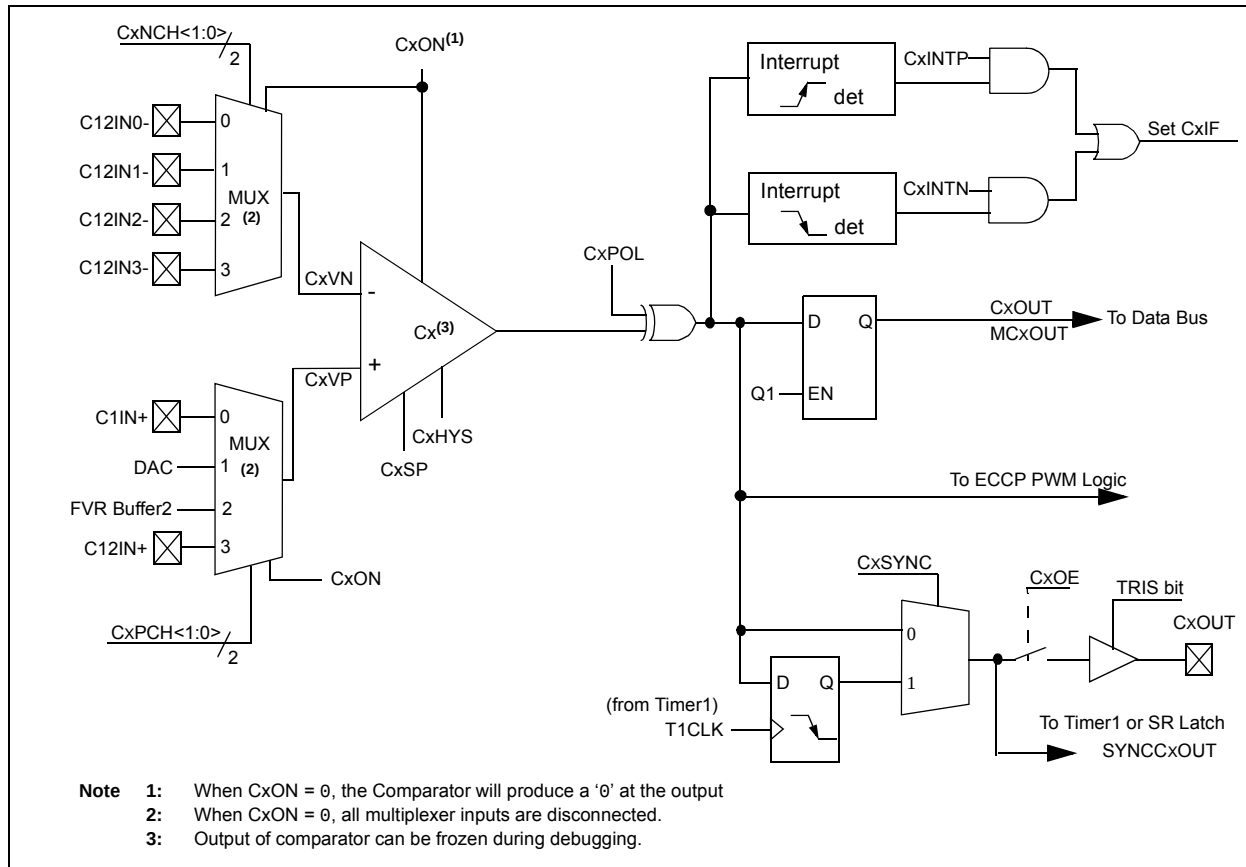
A single comparator is shown in [Figure 19-1](#) along with the relationship between the analog input levels and the digital output. When the analog voltage at V_{IN+} is less than the analog voltage at V_{IN-} , the output of the comparator is a digital low level. When the analog voltage at V_{IN+} is greater than the analog voltage at V_{IN-} , the output of the comparator is a digital high level.

FIGURE 19-1: SINGLE COMPARATOR



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FIGURE 19-2: COMPARATOR 1 MODULE SIMPLIFIED BLOCK DIAGRAM



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19.2 Comparator Control

Each comparator has 2 control registers: CMxCON0 and CMxCON1.

The CMxCON0 registers (see [Register 19-1](#)) contain Control and Status bits for the following:

- Enable
- Output selection
- Output polarity
- Speed/Power selection
- Hysteresis enable
- Output synchronization

The CMxCON1 registers (see [Register 19-2](#)) contain Control bits for the following:

- Interrupt enable
- Interrupt edge polarity
- Positive input channel selection
- Negative input channel selection

19.2.1 COMPARATOR ENABLE

Setting the CxON bit of the CMxCON0 register enables the comparator for operation. Clearing the CxON bit disables the comparator resulting in minimum current consumption.

19.2.2 COMPARATOR OUTPUT SELECTION

The output of the comparator can be monitored by reading either the CxOUT bit of the CMxCON0 register or the MCxOUT bit of the CMOUT register. In order to make the output available for an external connection, the following conditions must be true:

- CxOE bit of the CMxCON0 register must be set
- Corresponding TRIS bit must be cleared
- CxON bit of the CMxCON0 register must be set

Note 1: The CxOE bit of the CMxCON0 register overrides the PORT data latch. Setting the CxON bit of the CMxCON0 register has no impact on the port override.

2: The internal output of the comparator is latched with each instruction cycle. Unless otherwise specified, external outputs are not latched.

19.2.3 COMPARATOR OUTPUT POLARITY

Inverting the output of the comparator is functionally equivalent to swapping the comparator inputs. The polarity of the comparator output can be inverted by setting the CxPOL bit of the CMxCON0 register. Clearing the CxPOL bit results in a non-inverted output.

[Table 19-1](#) shows the output state versus input conditions, including polarity control.

TABLE 19-1: COMPARATOR OUTPUT STATE VS. INPUT CONDITIONS

Input Condition	CxPOL	CxOUT
$CxVN > CxVP$	0	0
$CxVN < CxVP$	0	1
$CxVN > CxVP$	1	1
$CxVN < CxVP$	1	0

19.2.4 COMPARATOR SPEED/POWER SELECTION

The trade-off between speed or power can be optimized during program execution with the CxSP control bit. The default state for this bit is '1' which selects the normal speed mode. Device power consumption can be optimized at the cost of slower comparator propagation delay by clearing the CxSP bit to '0'.

19.3 Comparator Hysteresis

A selectable amount of separation voltage can be added to the input pins of each comparator to provide a hysteresis function to the overall operation. Hysteresis is enabled by setting the CxHYS bit of the CMxCON0 register.

See [Section 29.0 “Electrical Specifications”](#) for more information.

19.4 Timer1 Gate Operation

The output resulting from a comparator operation can be used as a source for gate control of Timer1. See [Section 21.6 “Timer1 Gate”](#) for more information. This feature is useful for timing the duration or interval of an analog event.

It is recommended that the comparator output be synchronized to Timer1. This ensures that Timer1 does not increment while a change in the comparator is occurring.

19.4.1 COMPARATOR OUTPUT SYNCHRONIZATION

The output from either comparator, C1 or C2, can be synchronized with Timer1 by setting the CxSYNC bit of the CMxCON0 register.

Once enabled, the comparator output is latched on the falling edge of the Timer1 source clock. If a prescaler is used with Timer1, the comparator output is latched after the prescaling function. To prevent a race condition, the comparator output is latched on the falling edge of the Timer1 clock source and Timer1 increments on the rising edge of its clock source. See the Comparator Block Diagrams ([Figure 19-2](#) and [Figure 19-3](#)) and the Timer1 Block Diagram ([Figure 21-1](#)) for more information.

19.5 Comparator Interrupt

An interrupt can be generated upon a change in the output value of the comparator for each comparator, a rising edge detector and a Falling edge detector are present.

When either edge detector is triggered and its associated enable bit is set (CxINTP and/or CxINTN bits of the CMxCON1 register), the Corresponding Interrupt Flag bit (CxIF bit of the PIR2 register) will be set.

To enable the interrupt, you must set the following bits:

- CxON, CxPOL and CxSP bits of the CMxCON0 register
- CxIE bit of the PIE2 register
- CxINTP bit of the CMxCON1 register (for a rising edge detection)
- CxINTN bit of the CMxCON1 register (for a falling edge detection)
- PEIE and GIE bits of the INTCON register

The associated interrupt flag bit, CxIF bit of the PIR2 register, must be cleared in software. If another edge is detected while this flag is being cleared, the flag will still be set at the end of the sequence.

Note: Although a comparator is disabled, an interrupt can be generated by changing the output polarity with the CxPOL bit of the CMxCON0 register, or by switching the comparator on or off with the CxON bit of the CMxCON0 register.

19.6 Comparator Positive Input Selection

Configuring the CxPCH<1:0> bits of the CMxCON1 register directs an internal voltage reference or an analog pin to the non-inverting input of the comparator:

- C1IN+ or C2IN+ analog pin
- DAC
- FVR (Fixed Voltage Reference)
- Vss (Ground)

See [Section 14.0 “Fixed Voltage Reference \(FVR\)”](#) for more information on the Fixed Voltage Reference module.

See [Section 17.0 “Digital-to-Analog Converter \(DAC\) Module”](#) for more information on the DAC input signal.

Any time the comparator is disabled (CxON = 0), all comparator inputs are disabled.

19.7 Comparator Negative Input Selection

The CxNCH<1:0> bits of the CMxCON0 register direct one of four analog pins to the comparator inverting input.

Note: To use CxIN+ and CxINx- pins as analog input, the appropriate bits must be set in the ANSEL register and the corresponding TRIS bits must also be set to disable the output drivers.

19.8 Comparator Response Time

The comparator output is indeterminate for a period of time after the change of an input source or the selection of a new reference voltage. This period is referred to as the response time. The response time of the comparator differs from the settling time of the voltage reference. Therefore, both of these times must be considered when determining the total response time to a comparator input change. See the Comparator and Voltage Reference Specifications in [Section 29.0 “Electrical Specifications”](#) for more details.

19.9 Interaction with ECCP Logic

The C1 and C2 comparators can be used as general purpose comparators. Their outputs can be brought out to the C1OUT and C2OUT pins. When the ECCP Auto-Shutdown is active it can use one or both comparator signals. If auto-restart is also enabled, the comparators can be configured as a closed loop analog feedback to the ECCP, thereby, creating an analog controlled PWM.

Note: When the comparator module is first initialized the output state is unknown. Upon initialization, the user should verify the output state of the comparator prior to relying on the result, primarily when using the result in connection with other peripheral features, such as the ECCP Auto-Shutdown mode.

19.10 Analog Input Connection Considerations

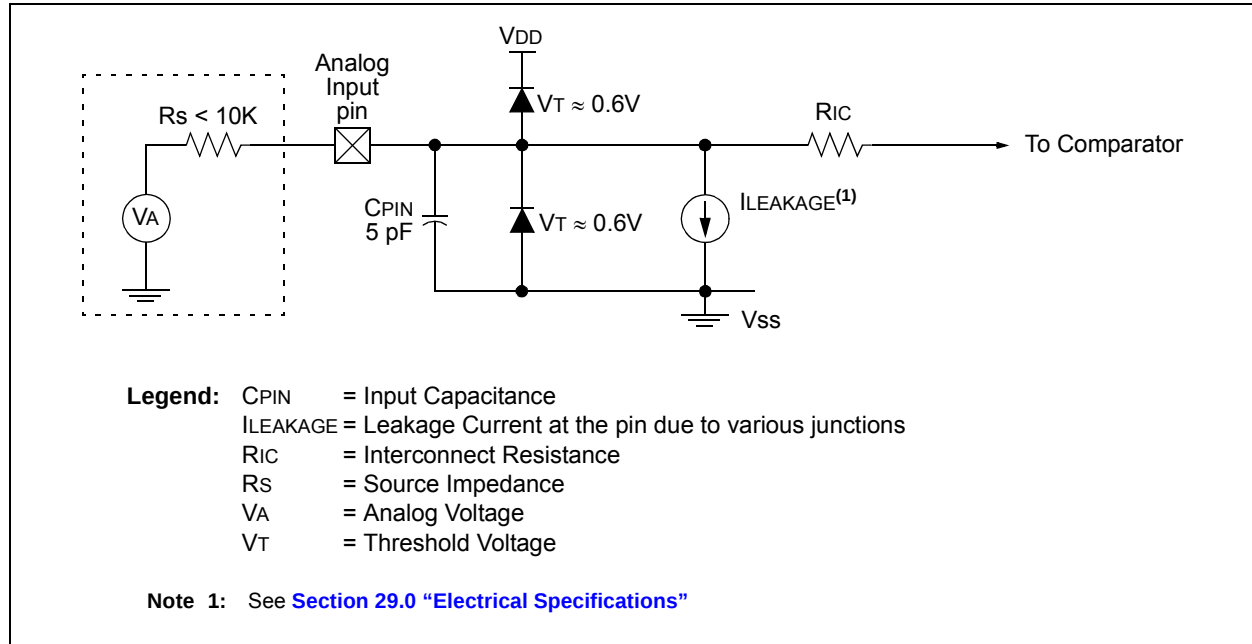
A simplified circuit for an analog input is shown in [Figure 19-4](#). Since the analog input pins share their connection with a digital input, they have reverse biased ESD protection diodes to VDD and VSS. The analog input, therefore, must be between VSS and VDD. If the input voltage deviates from this range by more than 0.6V in either direction, one of the diodes is forward biased and a latch-up may occur.

A maximum source impedance of 10 k Ω is recommended for the analog sources. Also, any external component connected to an analog input pin, such as a capacitor or a Zener diode, should have very little leakage current to minimize inaccuracies introduced.

Note 1: When reading a PORT register, all pins configured as analog inputs will read as a '0'. Pins configured as digital inputs will convert as an analog input, according to the input specification.

2: Analog levels on any pin defined as a digital input, may cause the input buffer to consume more current than is specified.

FIGURE 19-4: ANALOG INPUT MODEL



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REGISTER 19-1: CMxCON0: COMPARATOR Cx CONTROL REGISTER 0

R/W-0/0	R-0/0	R/W-0/0	R/W-0/0	U-0	R/W-1/1	R/W-0/0	R/W-0/0
CxON	CxOUT	CxOE	CxPOL	—	CxSP	CxHYS	CxSYNC
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7 **CxON:** Comparator Enable bit
1 = Comparator is enabled and consumes no active power
0 = Comparator is disabled
- bit 6 **CxOUT:** Comparator Output bit
If CxPOL = 1 (inverted polarity):
1 = CxVP < CxVN
0 = CxVP > CxVN
If CxPOL = 0 (non-inverted polarity):
1 = CxVP > CxVN
0 = CxVP < CxVN
- bit 5 **CxOE:** Comparator Output Enable bit
1 = CxOUT is present on the CxOUT pin. Requires that the associated TRIS bit be cleared to actually drive the pin. Not affected by CxON.
0 = CxOUT is internal only
- bit 4 **CxPOL:** Comparator Output Polarity Select bit
1 = Comparator output is inverted
0 = Comparator output is not inverted
- bit 3 **Unimplemented:** Read as '0'
- bit 2 **CxSP:** Comparator Speed/Power Select bit
1 = Comparator operates in normal power, higher speed mode
0 = Comparator operates in low-power, low-speed mode
- bit 1 **CxHYS:** Comparator Hysteresis Enable bit
1 = Comparator hysteresis enabled
0 = Comparator hysteresis disabled
- bit 0 **CxSYNC:** Comparator Output Synchronous Mode bit
1 = Comparator output to Timer1 and I/O pin is synchronous to changes on Timer1 clock source. Output updated on the falling edge of Timer1 clock source.
0 = Comparator output to Timer1 and I/O pin is asynchronous.

REGISTER 19-2: CMxCON1: COMPARATOR Cx CONTROL REGISTER 1

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	U-0	U-0	R/W-0/0	R/W-0/0
CxINTP	CxINTN	CxPCH<1:0>	—	—	—	CxNCH<1:0>	—
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

- bit 7 **CxINTP:** Comparator Interrupt on Positive Going Edge Enable bits
 1 = The CxIF interrupt flag will be set upon a positive going edge of the CxOUT bit
 0 = No interrupt flag will be set on a positive going edge of the CxOUT bit
- bit 6 **CxINTN:** Comparator Interrupt on Negative Going Edge Enable bits
 1 = The CxIF interrupt flag will be set upon a negative going edge of the CxOUT bit
 0 = No interrupt flag will be set on a negative going edge of the CxOUT bit
- bit 5-4 **CxPCH<1:0>:** Comparator Positive Input Channel Select bits
 00 = CxVP connects to CxIN+ pin
 01 = CxVP connects to DAC Voltage Reference
 10 = CxVP connects to FVR Voltage Reference
For C1:
 11 = CxVP connects to C12IN+ pin
For C2:
 11 = CxVP connects to Vss
- bit 3-2 **Unimplemented:** Read as '0'
- bit 1-0 **CxNCH<1:0>:** Comparator Negative Input Channel Select bits
 00 = CxVN connects to C12IN0- pin
 01 = CxVN connects to C12IN1- pin
 10 = CxVN connects to C12IN2- pin
 11 = CxVN connects to C12IN3- pin

REGISTER 19-3: CMOUT: COMPARATOR OUTPUT REGISTER

U-0	U-0	U-0	U-0	U-0	U-0	R-0/0	R-0/0
—	—	—	—	—	—	MC2OUT	MC1OUT
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

- bit 7-2 **Unimplemented:** Read as '0'
- bit 1 **MC2OUT:** Mirror Copy of C2OUT bit
- bit 0 **MC1OUT:** Mirror Copy of C1OUT bit

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TABLE 19-2: SUMMARY OF REGISTERS ASSOCIATED WITH COMPARATOR MODULE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
ANSELA	—	—	—	ANSA4	ANSA3	ANSA2	ANSA1	ANSA0	123
CMxCON0	CxON	CxOUT	CxOE	CxPOL	—	CxSP	CxHYS	CxSYNC	170
CMxCON1	CxNTP	CxINTN	CxPCH1	CxPCH0	—	—	CxNCH1	CxNCH0	171
CMOUT	—	—	—	—	—	—	MC2OUT	MC1OUT	171
DACCON0	DACEN	DACLPS	DACOE	—	DACPSS1	DACPSS0	—	DACNSS	156
DACCON1	—	—	—	DACR4	DACR3	DACR2	DACR1	DACR0	156
FVRCON	FVREN	FVRRDY	Reserved	Reserved	CDAFVR1	CDAFVR0	ADFVR1	ADFVR0	136
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
LATA	LATA7	LATA6	—	LATA4	LATA3	LATA2	LATA1	LATA0	122
PIE2	OSFIE	C2IE	C1IE	EEIE	BCL1IE	—	—	CCP2IE ⁽¹⁾	88
PIR2	OSFIF	C2IF	C1IF	EEIF	BCL1IF	—	—	CCP2IF ⁽¹⁾	92
PORTA	RA7	RA6	RA5	RA4	RA3	RA2	RA1	RA0	122
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122

Legend: — = unimplemented, read as '0'. Shaded cells are unused by the comparator module.

Note 1: PIC16(L)F1827 only.

20.0 TIMER0 MODULE

The Timer0 module is an 8-bit timer/counter with the following features:

- 8-bit timer/counter register (TMR0)
- 8-bit prescaler (independent of Watchdog Timer)
- Programmable internal or external clock source
- Programmable external clock edge selection
- Interrupt on overflow
- TMR0 can be used to gate Timer1

Figure 20-1 is a block diagram of the Timer0 module.

20.1 Timer0 Operation

The Timer0 module can be used as either an 8-bit timer or an 8-bit counter.

20.1.1 8-BIT TIMER MODE

The Timer0 module will increment every instruction cycle, if used without a prescaler. 8-Bit Timer mode is selected by clearing the TMR0CS bit of the OPTION_REG register.

When TMR0 is written, the increment is inhibited for two instruction cycles immediately following the write.

Note: The value written to the TMR0 register can be adjusted, in order to account for the two instruction cycle delay when TMR0 is written.

20.1.2 8-BIT COUNTER MODE

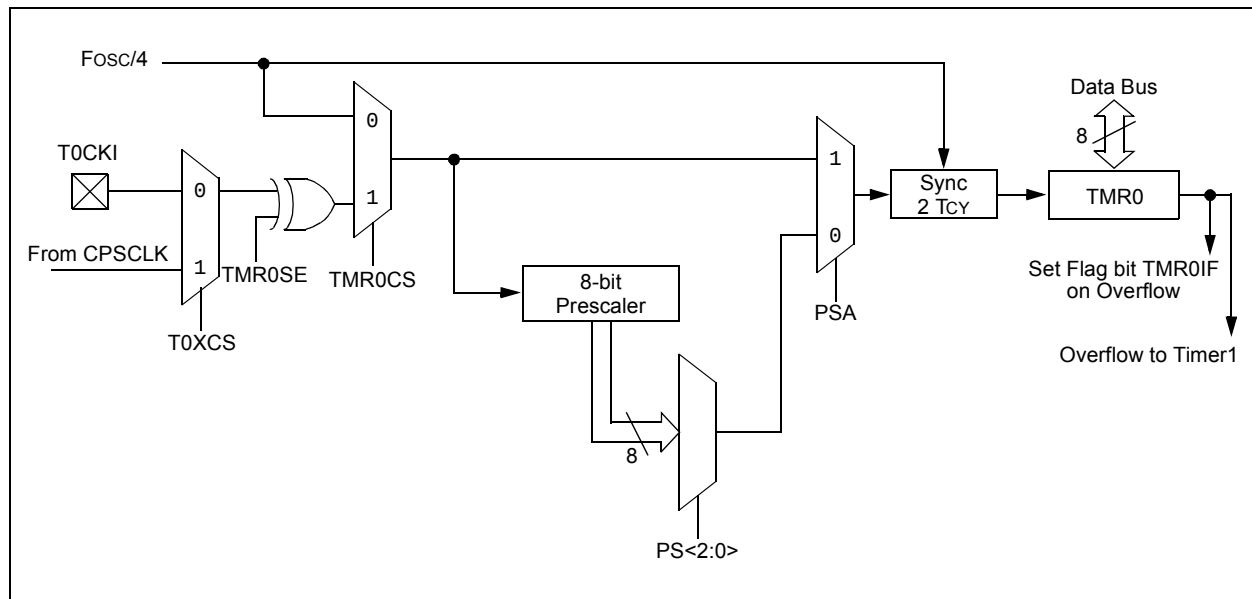
In 8-Bit Counter mode, the Timer0 module will increment on every rising or falling edge of the T0CKI pin or the Capacitive Sensing Oscillator (CPSClk) signal.

8-Bit Counter mode using the T0CKI pin is selected by setting the TMR0CS bit in the OPTION_REG register to '1' and resetting the T0XCS bit in the CPSCON0 register to '0'.

8-Bit Counter mode using the Capacitive Sensing Oscillator (CPSClk) signal is selected by setting the TMR0CS bit in the OPTION_REG register to '1' and setting the T0XCS bit in the CPSCON0 register to '1'.

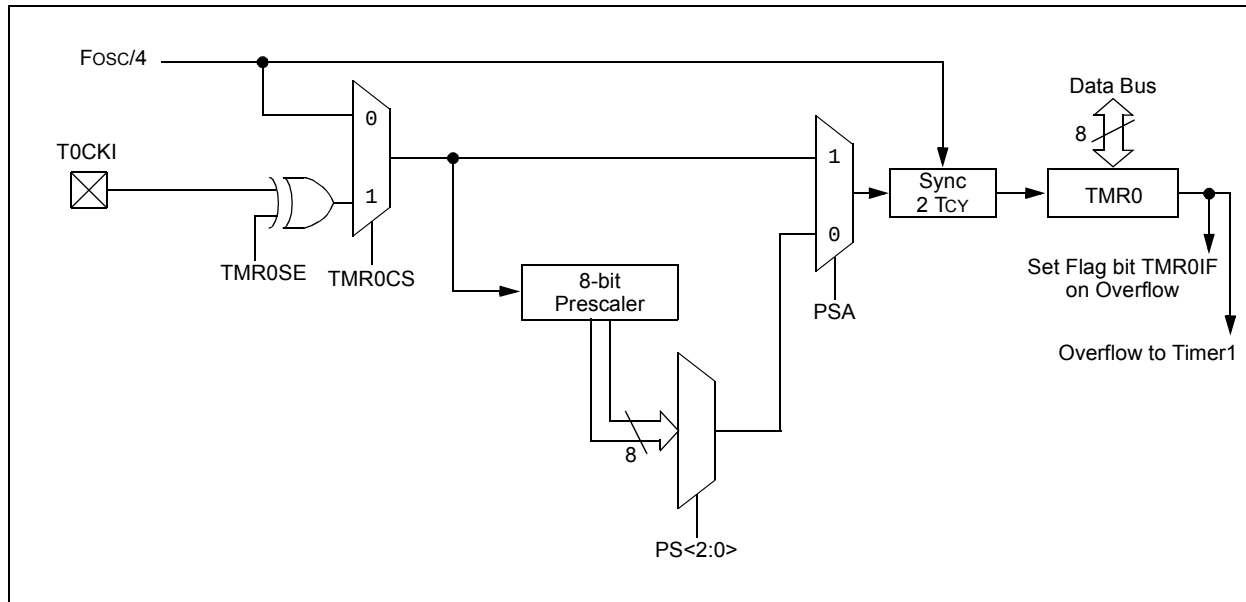
The rising or falling transition of the incrementing edge for either input source is determined by the TMR0SE bit in the OPTION_REG register.

FIGURE 20-1: BLOCK DIAGRAM OF THE TIMER0



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FIGURE 20-2: BLOCK DIAGRAM OF THE TMR0



20.1.3 SOFTWARE PROGRAMMABLE PRESCALER

A software programmable prescaler is available for exclusive use with Timer0. The prescaler is enabled by clearing the PSA bit of the OPTION_REG register.

Note: The Watchdog Timer (WDT) uses its own independent prescaler.

There are 8 prescaler options for the Timer0 module ranging from 1:2 to 1:256. The prescale values are selectable via the PS<2:0> bits of the OPTION_REG register. In order to have a 1:1 prescaler value for the Timer0 module, the prescaler must be disabled by setting the PSA bit of the OPTION_REG register.

The prescaler is not readable or writable. All instructions writing to the TMR0 register will clear the prescaler.

20.1.4 TIMER0 INTERRUPT

Timer0 will generate an interrupt when the TMR0 register overflows from FFh to 00h. The TMR0IF interrupt flag bit of the INTCON register is set every time the TMR0 register overflows, regardless of whether or not the Timer0 interrupt is enabled. The TMR0IF bit can only be cleared in software. The Timer0 interrupt enable is the TMR0IE bit of the INTCON register.

Note: The Timer0 interrupt cannot wake the processor from Sleep since the timer is frozen during Sleep.

20.1.5 8-BIT COUNTER MODE SYNCHRONIZATION

When in 8-Bit Counter mode, the incrementing edge on the T0CKI pin must be synchronized to the instruction clock. Synchronization can be accomplished by sampling the prescaler output on the Q2 and Q4 cycles of the instruction clock. The high and low periods of the external clocking source must meet the timing requirements as shown in [Section 29.0 “Electrical Specifications”](#).

20.1.6 OPERATION DURING SLEEP

Timer0 cannot operate while the processor is in Sleep mode. The contents of the TMR0 register will remain unchanged while the processor is in Sleep mode.

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20.2 Option and Timer0 Control Register

REGISTER 20-1: OPTION_REG: OPTION REGISTER

R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1
WPUEN	INTEDG	TMR0CS	TMR0SE	PSA	PS<2:0>		
bit 7							bit 0

Legend:

R = Readable bit W = Writable bit U = Unimplemented bit, read as '0'
u = Bit is unchanged x = Bit is unknown -n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set '0' = Bit is cleared

- bit 7 **WPUEN:** Weak Pull-up Enable bit
1 = All weak pull-ups are disabled (except MCLR, if it is enabled)
0 = Weak pull-ups are enabled by individual WPUx latch values
- bit 6 **INTEDG:** Interrupt Edge Select bit
1 = Interrupt on rising edge of INT pin
0 = Interrupt on falling edge of INT pin
- bit 5 **TMR0CS:** Timer0 Clock Source Select bit
1 = Transition on T0CKI pin
0 = Internal instruction cycle clock (Fosc/4)
- bit 4 **TMR0SE:** 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:** Prescaler Assignment bit
1 = Prescaler is not assigned to the Timer0 module
0 = Prescaler is assigned to the Timer0 module
- bit 2-0 **PS<2:0>:** Prescaler Rate Select bits

Bit Value	Timer0 Rate
000	1 : 2
001	1 : 4
010	1 : 8
011	1 : 16
100	1 : 32
101	1 : 64
110	1 : 128
111	1 : 256

TABLE 20-1: SUMMARY OF REGISTERS ASSOCIATED WITH TIMER0

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
CPSCON0	CPSON	—	—	—	CPSRNG1	CPSRNG0	CPSOUT	T0XCS	318
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
OPTION_REG	WPUEN	INTEDG	TMR0CS	TMR0SE	PSA	PS2	PS1	PS0	177
TMR0	Timer0 Module Register								173*
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122

Legend: — = Unimplemented locations, read as '0'. Shaded cells are not used by the Timer0 module.

* Page provides register information.

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21.1 Timer1 Operation

The Timer1 module is a 16-bit incrementing counter which is accessed through the TMR1H:TMR1L register pair. Writes to TMR1H or TMR1L directly update the counter.

When used with an internal clock source, the module is a timer and increments on every instruction cycle. When used with an external clock source, the module can be used as either a timer or counter and increments on every selected edge of the external source.

Timer1 is enabled by configuring the TMR1ON and TMR1GE bits in the T1CON and T1GCON registers, respectively. Table 21-1 displays the Timer1 enable selections.

TABLE 21-1: TIMER1 ENABLE SELECTIONS

TMR1ON	TMR1GE	Timer1 Operation
0	0	Off
0	1	Off
1	0	Always On
1	1	Count Enabled

21.2 Clock Source Selection

The TMR1CS<1:0> and T1OSCEN bits of the T1CON register are used to select the clock source for Timer1. Table 21-2 displays the clock source selections.

21.2.1 INTERNAL CLOCK SOURCE

When the internal clock source is selected the TMR1H:TMR1L register pair will increment on multiples of Fosc as determined by the Timer1 prescaler.

When the Fosc internal clock source is selected, the Timer1 register value will increment by four counts every instruction clock cycle. Due to this condition, a 2 LSB error in resolution will occur when reading the Timer1 value. To utilize the full resolution of Timer1, an asynchronous input signal must be used to gate the Timer1 clock input.

The following asynchronous sources may be used:

- Asynchronous event on the T1G pin to Timer1 gate
- C1 or C2 comparator input to Timer1 gate

21.2.2 EXTERNAL CLOCK SOURCE

When the external clock source is selected, the Timer1 module may work as a timer or a counter.

When enabled to count, Timer1 is incremented on the rising edge of the external clock input T1CKI or the capacitive sensing oscillator signal. Either of these external clock sources can be synchronized to the microcontroller system clock or they can run asynchronously.

When used as a timer with a clock oscillator, an external 32.768 kHz crystal can be used in conjunction with the dedicated internal oscillator circuit.

Note: In Counter mode, a falling edge must be registered by the counter prior to the first incrementing rising edge after any one or more of the following conditions:

- Timer1 enabled after POR
- Write to TMR1H or TMR1L
- Timer1 is disabled
- Timer1 is disabled (TMR1ON = 0) when T1CKI is high then Timer1 is enabled (TMR1ON=1) when T1CKI is low.

TABLE 21-2: CLOCK SOURCE SELECTIONS

TMR1CS1	TMR1CS0	T1OSCEN	Clock Source
0	0	x	Instruction Clock (Fosc/4)
0	1	x	System Clock (Fosc)
1	0	0	External Clocking on T1CKI Pin
1	0	0	External Clocking on T1CKI Pin
1	1	x	Capacitive Sensing Oscillator

21.3 Timer1 Prescaler

Timer1 has four prescaler options allowing 1, 2, 4 or 8 divisions of the clock input. The T1CKPS bits of the T1CON register control the prescale counter. The prescale counter is not directly readable or writable; however, the prescaler counter is cleared upon a write to TMR1H or TMR1L.

21.4 Timer1 Oscillator

A dedicated low-power 32.768 kHz oscillator circuit is built-in between pins T1OSI (input) and T1OSO (amplifier output). This internal circuit is to be used in conjunction with an external 32.768 kHz crystal.

The oscillator circuit is enabled by setting the T1OSCEN bit of the T1CON register. The oscillator will continue to run during Sleep.

Note: The oscillator requires a start-up and stabilization time before use. Thus, T1OSCEN should be set and a suitable delay observed prior to using Timer1. A suitable delay similar to the OST delay can be implemented in software by clearing the TMR1IF bit then presetting the TMR1H:TMR1L register pair to FC00h. The TMR1IF flag will be set when 1024 clock cycles have elapsed, thereby indicating that the oscillator is running and reasonably stable.

21.5 Timer1 Operation in Asynchronous Counter Mode

If control bit T1SYNC of the T1CON register is set, the external clock input is not synchronized. The timer increments asynchronously to the internal phase clocks. If the external clock source is selected then the timer will continue to run during Sleep and can generate an interrupt on overflow, which will wake-up the processor. However, special precautions in software are needed to read/write the timer (see [Section 21.5.1 “Reading and Writing Timer1 in Asynchronous Counter Mode”](#)).

Note: When switching from synchronous to asynchronous operation, it is possible to skip an increment. When switching from asynchronous to synchronous operation, it is possible to produce an additional increment.

21.5.1 READING AND WRITING TIMER1 IN ASYNCHRONOUS COUNTER MODE

Reading TMR1H or TMR1L while the timer is running from an external asynchronous clock will ensure a valid read (taken care of in hardware). However, the user should keep in mind that reading the 16-bit timer in two 8-bit values itself, poses certain problems, since the timer may overflow between the reads.

For writes, it is recommended that the user simply stop the timer and write the desired values. A write contention may occur by writing to the timer registers, while the register is incrementing. This may produce an unpredictable value in the TMR1H:TMR1L register pair.

21.6 Timer1 Gate

Timer1 can be configured to count freely or the count can be enabled and disabled using Timer1 gate circuitry. This is also referred to as Timer1 gate enable.

Timer1 gate can also be driven by multiple selectable sources.

21.6.1 TIMER1 GATE ENABLE

The Timer1 Gate Enable mode is enabled by setting the TMR1GE bit of the T1GCON register. The polarity of the Timer1 Gate Enable mode is configured using the T1GPOL bit of the T1GCON register.

When Timer1 Gate Enable mode is enabled, Timer1 will increment on the rising edge of the Timer1 clock source. When Timer1 Gate Enable mode is disabled, no incrementing will occur and Timer1 will hold the current count. See [Figure 21-3](#) for timing details.

TABLE 21-3: TIMER1 GATE ENABLE SELECTIONS

T1CLK	T1GPOL	T1G	Timer1 Operation
↑	0	0	Counts
↑	0	1	Holds Count
↑	1	0	Holds Count
↑	1	1	Counts

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21.6.2 TIMER1 GATE SOURCE SELECTION

The Timer1 gate source can be selected from one of four different sources. Source selection is controlled by the T1GSS bits of the T1GCON register. The polarity for each available source is also selectable. Polarity selection is controlled by the T1GPOL bit of the T1GCON register.

TABLE 21-4: TIMER1 GATE SOURCES

T1GSS	Timer1 Gate Source
00	Timer1 Gate Pin
01	Overflow of Timer0 (TMR0 increments from FFh to 00h)
10	Comparator 1 Output SYNCC1OUT (optionally Timer1 synchronized output)
11	Comparator 2 Output SYNCC2OUT (optionally Timer1 synchronized output)

21.6.2.1 T1G Pin Gate Operation

The T1G pin is one source for Timer1 gate control. It can be used to supply an external source to the Timer1 gate circuitry.

21.6.2.2 Timer0 Overflow Gate Operation

When Timer0 increments from FFh to 00h, a low-to-high pulse will automatically be generated and internally supplied to the Timer1 gate circuitry.

21.6.2.3 Comparator C1 Gate Operation

The output resulting from a Comparator 1 operation can be selected as a source for Timer1 gate control. The Comparator 1 output (SYNCC1OUT) can be synchronized to the Timer1 clock or left asynchronous. For more information see [Section 19.4.1 “Comparator Output Synchronization”](#).

21.6.2.4 Comparator C2 Gate Operation

The output resulting from a Comparator 2 operation can be selected as a source for Timer1 gate control. The Comparator 2 output (SYNCC2OUT) can be synchronized to the Timer1 clock or left asynchronous. For more information see [Section 19.4.1 “Comparator Output Synchronization”](#).

21.6.3 TIMER1 GATE TOGGLE MODE

When Timer1 Gate Toggle mode is enabled, it is possible to measure the full-cycle length of a Timer1 gate signal, as opposed to the duration of a single level pulse.

The Timer1 gate source is routed through a flip-flop that changes state on every incrementing edge of the signal. See [Figure 21-4](#) for timing details.

Timer1 Gate Toggle mode is enabled by setting the T1GTM bit of the T1GCON register. When the T1GTM bit is cleared, the flip-flop is cleared and held clear. This is necessary in order to control which edge is measured.

Note: Enabling Toggle mode at the same time as changing the gate polarity may result in indeterminate operation.

21.6.4 TIMER1 GATE SINGLE-PULSE MODE

When Timer1 Gate Single-Pulse mode is enabled, it is possible to capture a single pulse gate event. Timer1 Gate Single-Pulse mode is first enabled by setting the T1GSPM bit in the T1GCON register. Next, the T1GGO/DONE bit in the T1GCON register must be set. The Timer1 will be fully enabled on the next incrementing edge. On the next trailing edge of the pulse, the T1GGO/DONE bit will automatically be cleared. No other gate events will be allowed to increment Timer1 until the T1GGO/DONE bit is once again set in software. See [Figure 21-5](#) for timing details.

If the Single Pulse Gate mode is disabled by clearing the T1GSPM bit in the T1GCON register, the T1GGO/DONE bit should also be cleared.

Enabling the Toggle mode and the Single-Pulse mode simultaneously will permit both sections to work together. This allows the cycle times on the Timer1 gate source to be measured. See [Figure 21-6](#) for timing details.

21.6.5 TIMER1 GATE VALUE STATUS

When Timer1 Gate Value Status is utilized, it is possible to read the most current level of the gate control value. The value is stored in the T1GVAL bit in the T1GCON register. The T1GVAL bit is valid even when the Timer1 gate is not enabled (TMR1GE bit is cleared).

21.6.6 TIMER1 GATE EVENT INTERRUPT

When Timer1 Gate Event Interrupt is enabled, it is possible to generate an interrupt upon the completion of a gate event. When the falling edge of T1GVAL occurs, the TMR1GIF flag bit in the PIR1 register will be set. If the TMR1GIE bit in the PIE1 register is set, then an interrupt will be recognized.

The TMR1GIF flag bit operates even when the Timer1 gate is not enabled (TMR1GE bit is cleared).

21.7 Timer1 Interrupt

The Timer1 register pair (TMR1H:TMR1L) increments to FFFFh and rolls over to 0000h. When Timer1 rolls over, the Timer1 interrupt flag bit of the PIR1 register is set. To enable the interrupt on rollover, you must set these bits:

- TMR1ON bit of the T1CON register
- TMR1IE bit of the PIE1 register
- PEIE bit of the INTCON register
- GIE bit of the INTCON register

The interrupt is cleared by clearing the TMR1IF bit in the Interrupt Service Routine.

Note: The TMR1H:TMR1L register pair and the TMR1IF bit should be cleared before enabling interrupts.

21.8 Timer1 Operation During Sleep

Timer1 can only operate during Sleep when setup in Asynchronous Counter mode. In this mode, an external crystal or clock source can be used to increment the counter. To set up the timer to wake the device:

- TMR1ON bit of the T1CON register must be set
- TMR1IE bit of the PIE1 register must be set
- PEIE bit of the INTCON register must be set
- T1SYNC bit of the T1CON register must be set
- TMR1CS bits of the T1CON register must be configured
- T1OSCEN bit of the T1CON register must be configured

The device will wake-up on an overflow and execute the next instructions. If the GIE bit of the INTCON register is set, the device will call the Interrupt Service Routine.

Timer1 oscillator will continue to operate in Sleep regardless of the T1SYNC bit setting.

21.9 ECCP/CCP Capture/Compare Time Base

The CCP modules use the TMR1H:TMR1L register pair as the time base when operating in Capture or Compare mode.

In Capture mode, the value in the TMR1H:TMR1L register pair is copied into the CCPR1H:CCPR1L register pair on a configured event.

In Compare mode, an event is triggered when the value CCPR1H:CCPR1L register pair matches the value in the TMR1H:TMR1L register pair. This event can be a Special Event Trigger.

For more information, see [Section 24.0 "Capture/Compare/PWM Modules"](#).

21.10 ECCP/CCP Special Event Trigger

When any of the CCP's are configured to trigger a special event, the trigger will clear the TMR1H:TMR1L register pair. This special event does not cause a Timer1 interrupt. The CCP module may still be configured to generate a CCP interrupt.

In this mode of operation, the CCPR1H:CCPR1L register pair becomes the period register for Timer1.

Timer1 should be synchronized and Fosc/4 should be selected as the clock source in order to utilize the Special Event Trigger. Asynchronous operation of Timer1 can cause a Special Event Trigger to be missed.

In the event that a write to TMR1H or TMR1L coincides with a Special Event Trigger from the CCP, the write will take precedence.

For more information, see [Section 16.2.5 "Special Event Trigger"](#).

FIGURE 21-2: TIMER1 INCREMENTING EDGE

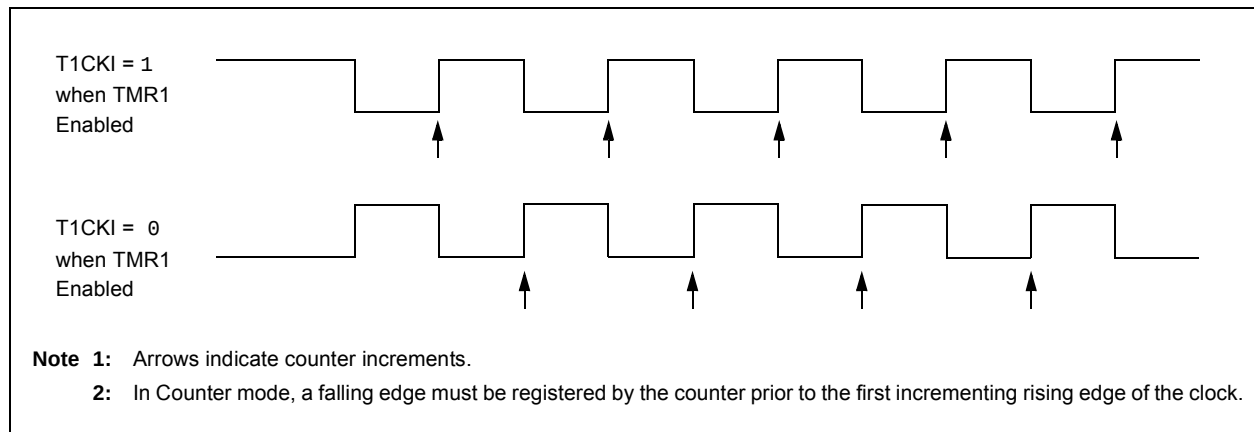


FIGURE 21-3: TIMER1 GATE ENABLE MODE

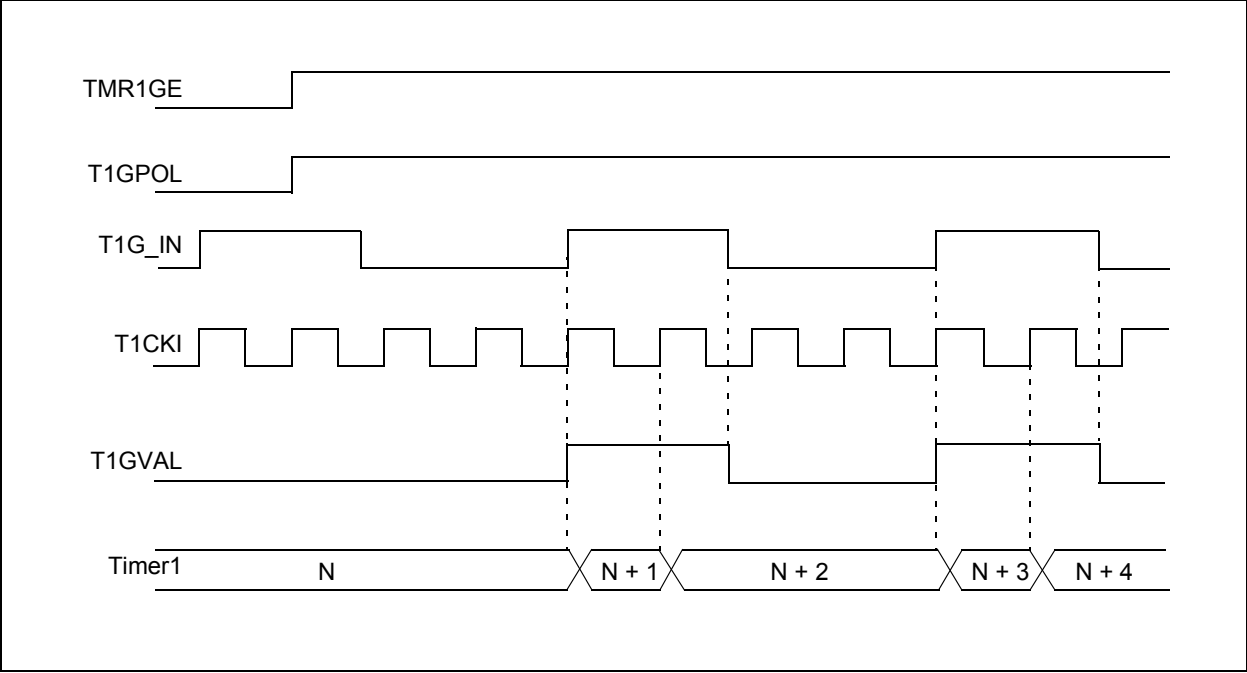


FIGURE 21-4: TIMER1 GATE TOGGLE MODE

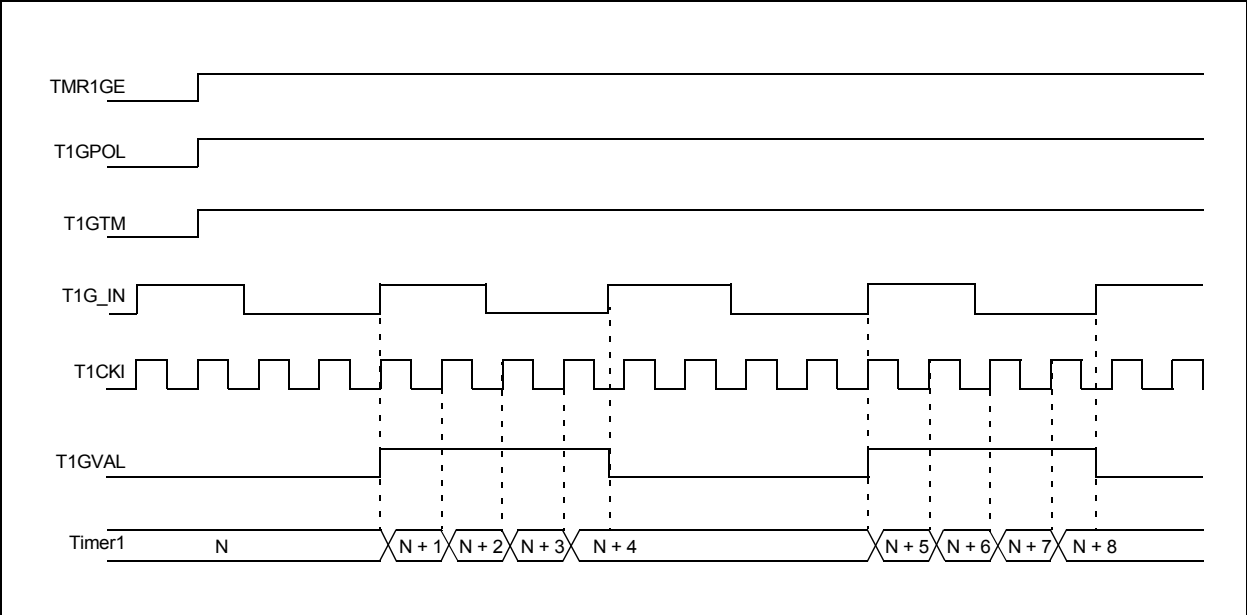
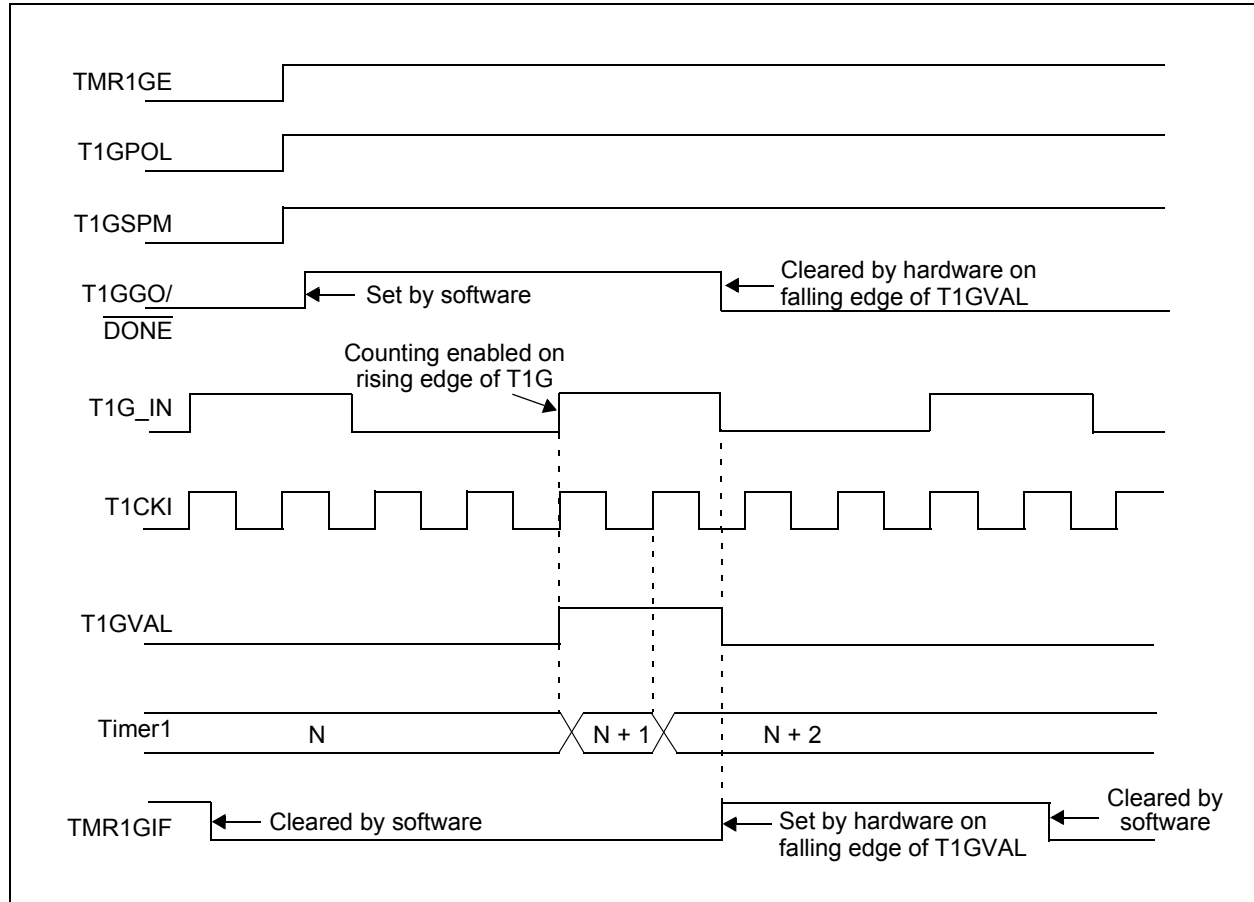
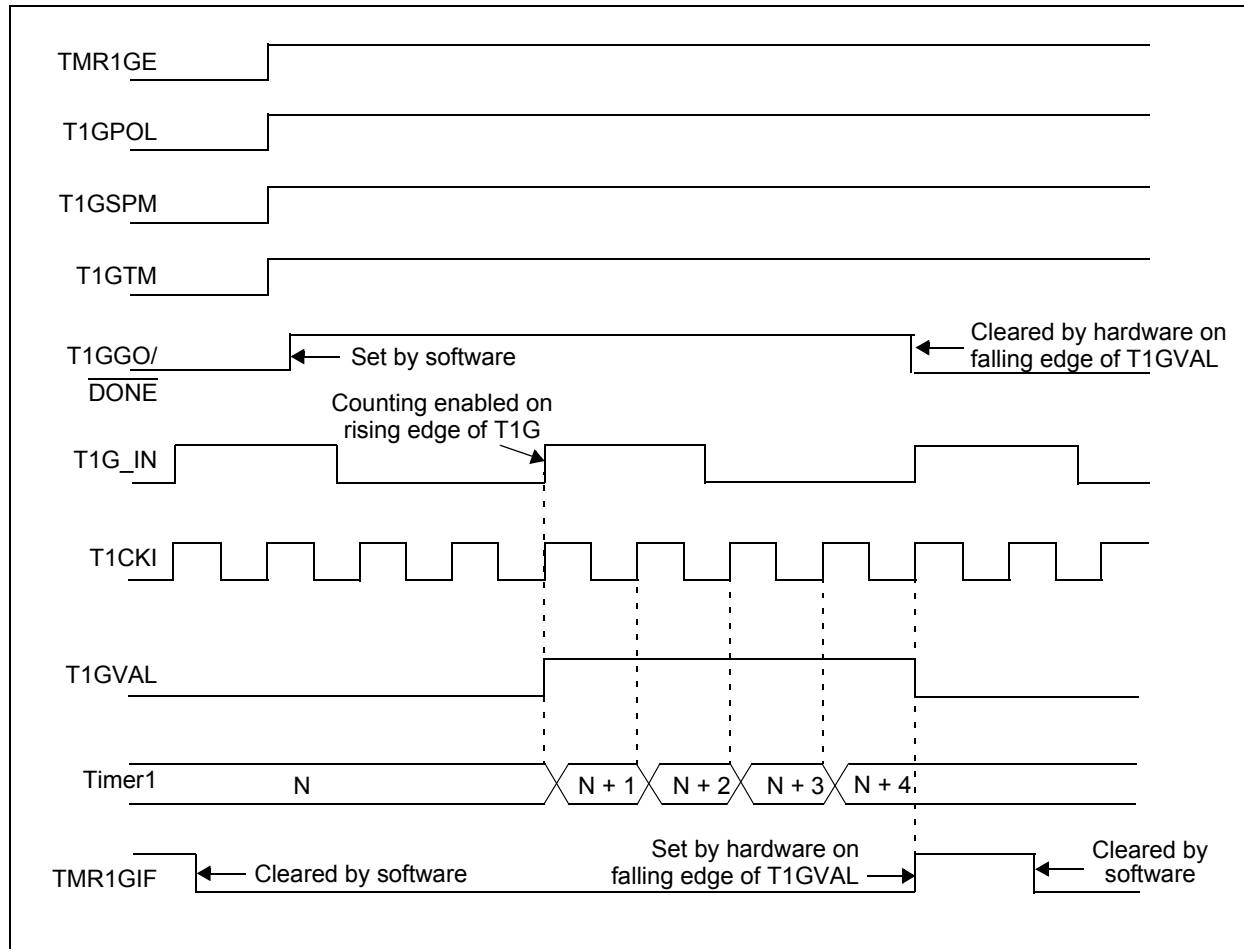


FIGURE 21-5: TIMER1 GATE SINGLE-PULSE MODE



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FIGURE 21-6: TIMER1 GATE SINGLE-PULSE AND TOGGLE COMBINED MODE



21.11 Timer1 Control Register

The Timer1 Control register (T1CON), shown in [Register 21-1](#), is used to control Timer1 and select the various features of the Timer1 module.

REGISTER 21-1: T1CON: TIMER1 CONTROL REGISTER

R/W-0/u	R/W-0/u	R/W-0/u	R/W-0/u	R/W-0/u	R/W-0/u	U-0	R/W-0/u
TMR1CS<1:0>		T1CKPS<1:0>		T1OSCEN	T1SYNĈ	—	TMR1ON
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7-6 **TMR1CS<1:0>**: Timer1 Clock Source Select bits
11 = Timer1 clock source is Capacitive Sensing Oscillator (CAPOSC)
10 = Timer1 clock source is pin or oscillator:
 If T1OSCEN = 0:
 External clock from T1CKI pin (on the rising edge)
 If T1OSCEN = 1:
 Crystal oscillator on T1OSI/T1OSO pins
01 = Timer1 clock source is system clock (Fosc)
00 = Timer1 clock source is instruction clock (Fosc/4)
- bit 5-4 **T1CKPS<1:0>**: 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**: LP Oscillator Enable Control bit
1 = Dedicated Timer1 oscillator circuit enabled
0 = Dedicated Timer1 oscillator circuit disabled
- bit 2 **T1SYNC**: Timer1 External Clock Input Synchronization Control bit
TMR1CS<1:0> = 1X:
1 = Do not synchronize external clock input
0 = Synchronize external clock input with system clock (Fosc)

TMR1CS<1:0> = 0X:
This bit is ignored.
- bit 1 **Unimplemented**: Read as '0'
- bit 0 **TMR1ON**: Timer1 On bit
1 = Enables Timer1
0 = Stops Timer1
 Clears Timer1 gate flip-flop

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21.12 Timer1 Gate Control Register

The Timer1 Gate Control register (T1GCON), shown in [Register 21-2](#), is used to control Timer1 gate.

REGISTER 21-2: T1GCON: TIMER1 GATE CONTROL REGISTER

R/W-0/u	R/W-0/u	R/W-0/u	R/W-0/u	R/W/HC-0/u	R-x/x	R/W-0/u	R/W-0/u
TMR1GE	T1GPOL	T1GTM	T1GSPM	T1GGO/ DONE	T1GVAL	T1GSS<1:0>	
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

HC = Bit is cleared by hardware

bit 7 **TMR1GE:** Timer1 Gate Enable bit

If TMR1ON = 0:

This bit is ignored

If TMR1ON = 1:

1 = Timer1 counting is controlled by the Timer1 gate function

0 = Timer1 counts regardless of Timer1 gate function

bit 6 **T1GPOL:** Timer1 Gate Polarity bit

1 = Timer1 gate is active-high (Timer1 counts when gate is high)

0 = Timer1 gate is active-low (Timer1 counts when gate is low)

bit 5 **T1GTM:** Timer1 Gate Toggle Mode bit

1 = Timer1 Gate Toggle mode is enabled

0 = Timer1 Gate Toggle mode is disabled and toggle flip-flop is cleared

Timer1 gate flip-flop toggles on every rising edge.

bit 4 **T1GSPM:** Timer1 Gate Single-Pulse Mode bit

1 = Timer1 gate Single-Pulse mode is enabled and is controlling Timer1 gate

0 = Timer1 gate Single-Pulse mode is disabled

bit 3 **T1GGO/DONE:** Timer1 Gate Single-Pulse Acquisition Status bit

1 = Timer1 gate single-pulse acquisition is ready, waiting for an edge

0 = Timer1 gate single-pulse acquisition has completed or has not been started

bit 2 **T1GVAL:** Timer1 Gate Current State bit

Indicates the current state of the Timer1 gate that could be provided to TMR1H:TMR1L.

Unaffected by Timer1 Gate Enable (TMR1GE).

bit 1-0 **T1GSS<1:0>:** Timer1 Gate Source Select bits

00 = Timer1 gate pin

01 = Timer0 overflow output

10 = Comparator 1 optionally synchronized output (SYNCC1OUT)

11 = Comparator 2 optionally synchronized output (SYNCC2OUT)

TABLE 21-5: SUMMARY OF REGISTERS ASSOCIATED WITH TIMER1

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
ANSELB	ANSB7	ANSB6	ANSB5	ANSB4	ANSB3	ANSB2	ANSB1	—	128
CCP1CON	PxM1	PxM0	DCxB1	DCxB0	CCPxM3	CCPxM2	CCPxM1	CCPxM0	226
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF	91
PORTB	RB7	RB6	RB5	RB4	RB3	RB2	RB1	RB0	127
TMR1H	Holding Register for the Most Significant Byte of the 16-bit TMR1 Register								177 *
TMR1L	Holding Register for the Least Significant Byte of the 16-bit TMR1 Register								177 *
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127
T1CON	TMR1CS1	TMR1CS0	T1CKPS1	T1CKPS0	T1OSCEN	T1SYNC	—	TMR1ON	185
T1GCON	TMR1GE	T1GPOL	T1GTM	T1GSPM	T1GGO/ DONE	T1GVAL	T1GSS1	T1GSS0	186

Legend: — = unimplemented, read as '0'. Shaded cells are not used by the Timer1 module.

* Page provides register information.

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NOTES:

22.0 TIMER2/4/6 MODULES

There are up to three identical Timer2-type modules available. To maintain pre-existing naming conventions, the Timers are called Timer2, Timer4 and Timer6 (also Timer2/4/6).

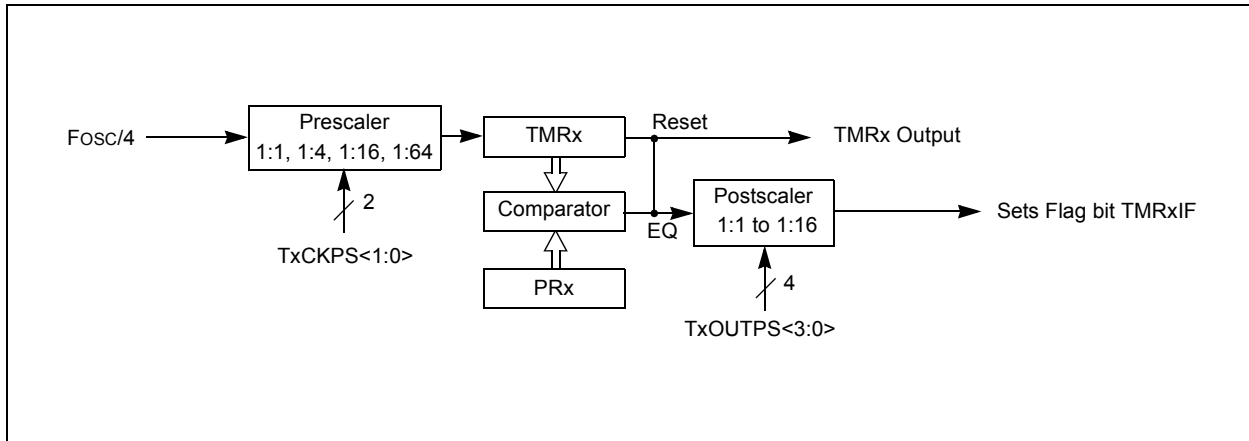
Note: The 'x' variable used in this section is used to designate Timer2, Timer4, or Timer6. For example, TxCON references T2CON, T4CON, or T6CON. PRx references PR2, PR4, or PR6.

The Timer2/4/6 modules incorporate the following features:

- 8-bit Timer and Period registers (TMRx and PRx, respectively)
- Readable and writable (both registers)
- Software programmable prescaler (1:1, 1:4, 1:16, and 1:64)
- Software programmable postscaler (1:1 to 1:16)
- Interrupt on TMRx match with PRx, respectively
- Optional use as the shift clock for the MSSPx modules (Timer2 only)

See [Figure 22-1](#) for a block diagram of Timer2/4/6.

FIGURE 22-1: TIMER2/4/6 BLOCK DIAGRAM



22.1 Timer2/4/6 Operation

The clock input to the Timer2/4/6 modules is the system instruction clock ($F_{osc}/4$).

TMRx increments from 00h on each clock edge.

A 4-bit counter/prescaler on the clock input allows direct input, divide-by-4 and divide-by-16 prescale options. These options are selected by the prescaler control bits, TxCKPS<1:0> of the TxCON register. The value of TMRx is compared to that of the Period register, PRx, 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 TMRx to 00h on the next cycle and drives the output counter/postscaler (see [Section 22.2 “Timer2/4/6 Interrupt”](#)).

The TMRx and PRx registers are both directly readable and writable. The TMRx register is cleared on any device Reset, whereas the PRx register initializes to FFh. Both the prescaler and postscaler counters are cleared on the following events:

- a write to the TMRx register
- a write to the TxCON register
- Power-on Reset (POR)
- Brown-out Reset (BOR)
- MCLR Reset
- Watchdog Timer (WDT) Reset
- Stack Overflow Reset
- Stack Underflow Reset
- RESET Instruction

Note: TMRx is not cleared when TxCON is written.

22.2 Timer2/4/6 Interrupt

Timer2/4/6 can also generate an optional device interrupt. The Timer2/4/6 output signal (TMRx-to-PRx match) provides the input for the 4-bit counter/postscaler. This counter generates the TMRx match interrupt flag which is latched in TMRxIF of the PIRx register. The interrupt is enabled by setting the TMRx Match Interrupt Enable bit, TMRxIE of the PIRx register.

A range of 16 postscale options (from 1:1 through 1:16 inclusive) can be selected with the postscaler control bits, TxOUTPS<3:0>, of the TxCON register.

22.3 Timer2/4/6 Output

The unscaled output of TMRx is available primarily to the CCP modules, where it is used as a time base for operations in PWM mode.

Timer2 can be optionally used as the shift clock source for the MSSPx modules operating in SPI mode. Additional information is provided in [Section 25.1 “Master SSPx \(MSSPx\) Module Overview”](#)
Timer2/4/6 Operation During Sleep

The Timer2/4/6 timers cannot be operated while the processor is in Sleep mode. The contents of the TMRx and PRx registers will remain unchanged while the processor is in Sleep mode.

22.4 Timer2 Control Register

REGISTER 22-1: TXCON: TIMER2/TIMER4/TIMER6 CONTROL REGISTER

U-0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
—	TxOUTPS<3:0>				TMRxON	TxCKPS<1:0>	
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

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

bit 6-3 **TxOUTPS<3:0>:** Timerx Output Postscaler Select bits

0000 = 1:1 Postscaler

0001 = 1:2 Postscaler

0010 = 1:3 Postscaler

0011 = 1:4 Postscaler

0100 = 1:5 Postscaler

0101 = 1:6 Postscaler

0110 = 1:7 Postscaler

0111 = 1:8 Postscaler

1000 = 1:9 Postscaler

1001 = 1:10 Postscaler

1010 = 1:11 Postscaler

1011 = 1:12 Postscaler

1100 = 1:13 Postscaler

1101 = 1:14 Postscaler

1110 = 1:15 Postscaler

1111 = 1:16 Postscaler

bit 2 **TMRxON:** Timerx On bit

1 = Timerx is on

0 = Timerx is off

bit 1-0 **TxCKPS<1:0>:** Timer2-type Clock Prescale Select bits

00 = Prescaler is 1

01 = Prescaler is 4

10 = Prescaler is 16

11 = Prescaler is 64

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TABLE 22-1: SUMMARY OF REGISTERS ASSOCIATED WITH TIMER2/4/6

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	91
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE	92
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF	96
PIE3 ⁽¹⁾	—	—	CCP4IE	CCP3IE	TMR6IE	—	TMR4IE	—	94
PIR3 ⁽¹⁾	—	—	CCP4IF	CCP3IF	TMR6IF	—	TMR4IF	—	98
PR2	Timer2 Module Period Register								189*
PR4	Timer4 Module Period Register								189*
PR6	Timer6 Module Period Register								189*
T2CON	—	T2OUTPS3	T2OUTPS2	T2OUTPS1	T2OUTPS0	TMR2ON	T2CKPS1	T2CKPS0	191
T4CON	—	T4OUTPS3	T4OUTPS2	T4OUTPS1	T4OUTPS0	TMR4ON	T4CKPS1	T4CKPS0	191
T6CON	—	T6OUTPS3	T6OUTPS2	T6OUTPS1	T6OUTPS0	TMR6ON	T6CKPS1	T6CKPS0	191
TMR2	Holding Register for the 8-bit TMR2 Time Base								189*
TMR4	Holding Register for the 8-bit TMR4 Time Base ⁽¹⁾								189*
TMR6	Holding Register for the 8-bit TMR6 Time Base ⁽¹⁾								189*

Legend: — = unimplemented read as '0'. Shaded cells are not used for Timer2 module.

* Page provides register information.

Note 1: PIC16(L)F1827 only.

23.0 DATA SIGNAL MODULATOR

The Data Signal Modulator (DSM) is a peripheral which allows the user to mix a data stream, also known as a modulator signal, with a carrier signal to produce a modulated output.

Both the carrier and the modulator signals are supplied to the DSM module either internally, from the output of a peripheral, or externally through an input pin.

The modulated output signal is generated by performing a logical “AND” operation of both the carrier and modulator signals and then provided to the MDOUT pin.

The carrier signal is comprised of two distinct and separate signals. A carrier high (CARH) signal and a carrier low (CARL) signal. During the time in which the modulator (MOD) signal is in a logic high state, the DSM mixes the carrier high signal with the modulator signal. When the modulator signal is in a logic low state, the DSM mixes the carrier low signal with the modulator signal.

Using this method, the DSM can generate the following types of Key Modulation schemes:

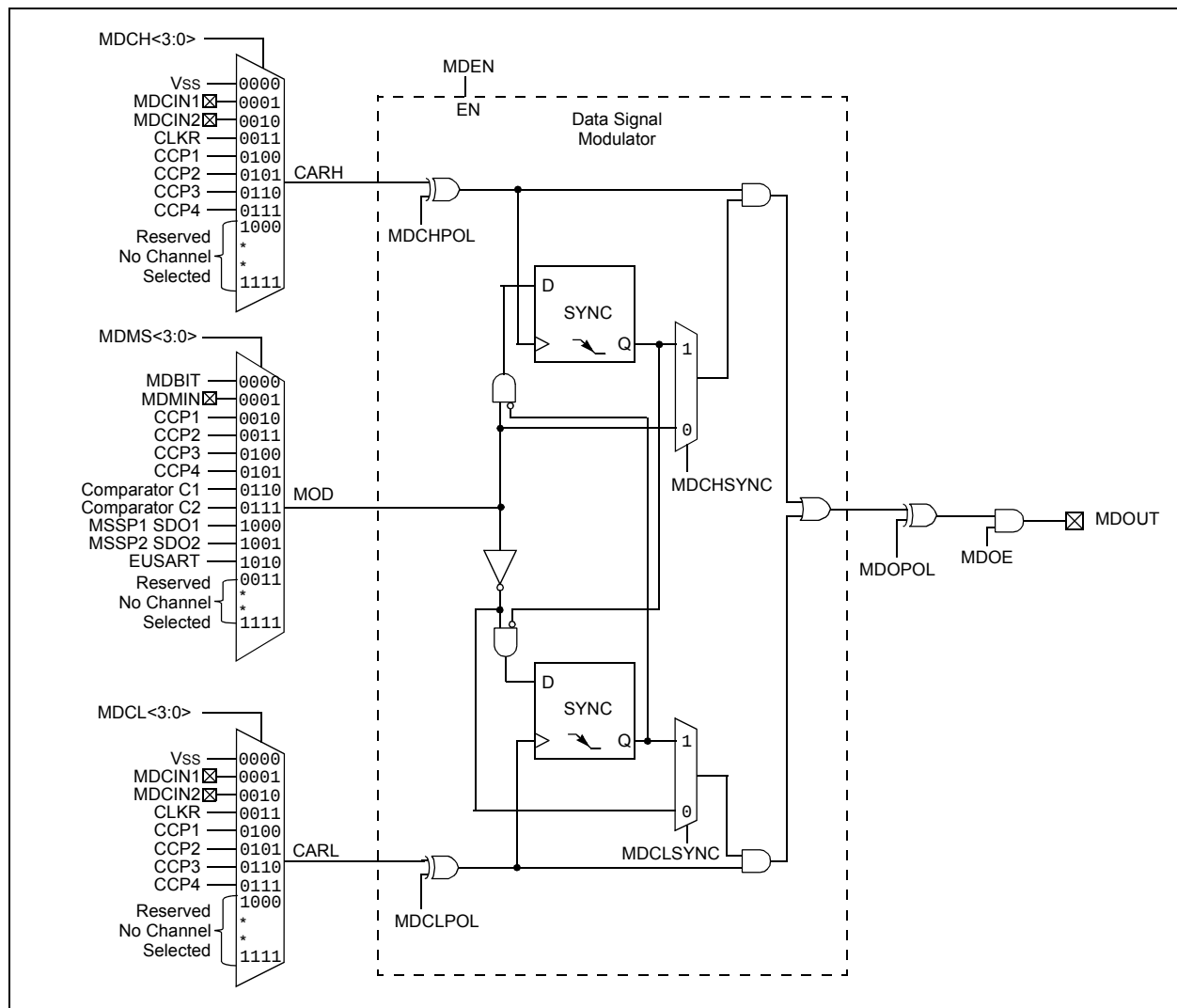
- Frequency-Shift Keying (FSK)
- Phase-Shift Keying (PSK)
- On-Off Keying (OOK)

Additionally, the following features are provided within the DSM module:

- Carrier Synchronization
- Carrier Source Polarity Select
- Carrier Source Pin Disable
- Programmable Modulator Data
- Modulator Source Pin Disable
- Modulated Output Polarity Select
- Slew Rate Control

Figure 23-1 shows a Simplified Block Diagram of the Data Signal Modulator peripheral.

FIGURE 23-1: SIMPLIFIED BLOCK DIAGRAM OF THE DATA SIGNAL MODULATOR



23.1 DSM Operation

The DSM module can be enabled by setting the MDEN bit in the MDCON register. Clearing the MDEN bit in the MDCON register, disables the DSM module by automatically switching the carrier high and carrier low signals to the Vss signal source. The modulator signal source is also switched to the MDBIT in the MDCON register. This not only assures that the DSM module is inactive, but that it is also consuming the least amount of current.

The values used to select the carrier high, carrier low, and modulator sources held by the Modulation Source, Modulation High Carrier, and Modulation Low Carrier control registers are not affected when the MDEN bit is cleared and the DSM module is disabled. The values inside these registers remain unchanged while the DSM is inactive. The sources for the carrier high, carrier low and modulator signals will once again be selected when the MDEN bit is set and the DSM module is again enabled and active.

The modulated output signal can be disabled without shutting down the DSM module. The DSM module will remain active and continue to mix signals, but the output value will not be sent to the MDOUT pin. During the time that the output is disabled, the MDOUT pin will remain low. The modulated output can be disabled by clearing the MDOE bit in the MDCON register.

23.2 Modulator Signal Sources

The modulator signal can be supplied from the following sources:

- CCP1 Signal
- CCP2 Signal
- CCP3 Signal
- CCP4 Signal
- MSSP1 SDO1 Signal (SPI Mode Only)
- MSSP2 SDO2 Signal (SPI Mode Only)
- Comparator C1 Signal
- Comparator C2 Signal
- EUSART TX Signal
- External Signal on MDMIN1 pin
- MDBIT bit in the MDCON register

The modulator signal is selected by configuring the MDMS <3:0> bits in the MDSRC register.

23.3 Carrier Signal Sources

The carrier high signal and carrier low signal can be supplied from the following sources:

- CCP1 Signal
- CCP2 Signal
- CCP3 Signal
- CCP4 Signal
- Reference Clock Module Signal
- External Signal on MDCIN1 pin
- External Signal on MDCIN2 pin
- Vss

The carrier high signal is selected by configuring the MDCH <3:0> bits in the MDCARH register. The carrier low signal is selected by configuring the MDCL <3:0> bits in the MDCARL register.

23.4 Carrier Synchronization

During the time when the DSM switches between carrier high and carrier low signal sources, the carrier data in the modulated output signal can become truncated. To prevent this, the carrier signal can be synchronized to the modulator signal. When synchronization is enabled, the carrier pulse that is being mixed at the time of the transition is allowed to transition low before the DSM switches over to the next carrier source.

Synchronization is enabled separately for the carrier high and carrier low signal sources. Synchronization for the carrier high signal can be enabled by setting the MDCHSYNC bit in the MDCARH register. Synchronization for the carrier low signal can be enabled by setting the MDCLSYNC bit in the MDCARL register.

[Figure 23-1](#) through [Figure 23-5](#) show timing diagrams of using various synchronization methods.

FIGURE 23-2: ON OFF KEYING (OOK) SYNCHRONIZATION



EXAMPLE 23-1: NO SYNCHRONIZATION (MDSHSYNC = 0, MDCLSYNC = 0)

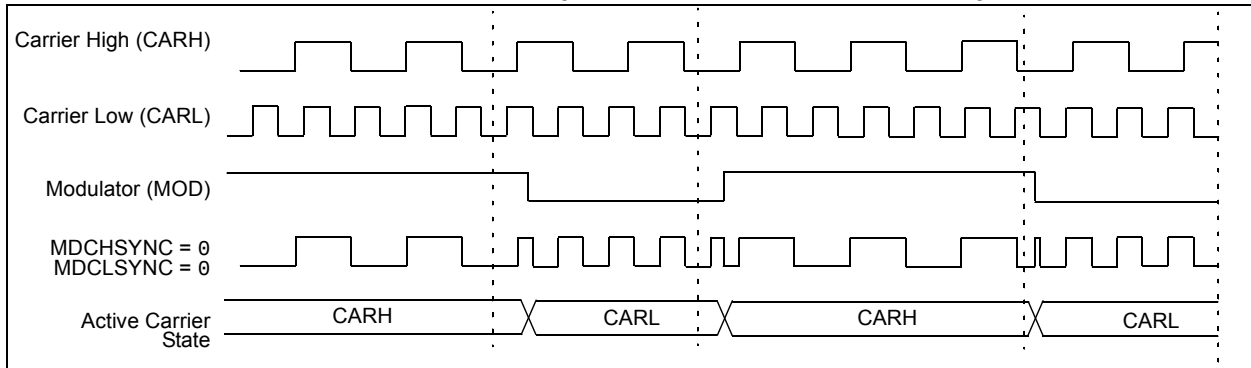


FIGURE 23-3: CARRIER HIGH SYNCHRONIZATION (MDSHSYNC = 1, MDCLSYNC = 0)

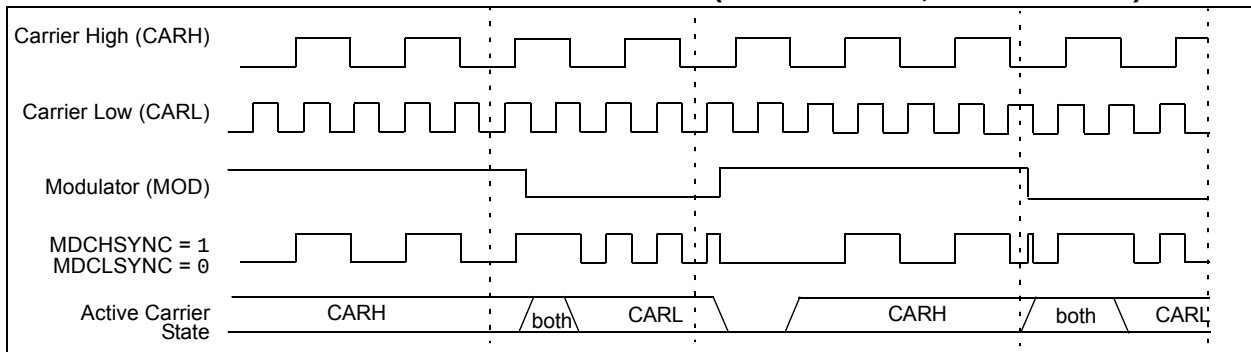


FIGURE 23-4: CARRIER LOW SYNCHRONIZATION (MDSHSYNC = 0, MDCLSYNC = 1)



FIGURE 23-5: FULL SYNCHRONIZATION (MDSHSYNC = 1, MDCLSYNC = 1)



23.5 Carrier Source Polarity Select

The signal provided from any selected input source for the carrier high and carrier low signals can be inverted. Inverting the signal for the carrier high source is enabled by setting the MDCHPOL bit of the MDCARH register. Inverting the signal for the carrier low source is enabled by setting the MDCLPOL bit of the MDCARL register.

23.6 Carrier Source Pin Disable

Some peripherals assert control over their corresponding output pin when they are enabled. For example, when the CCP1 module is enabled, the output of CCP1 is connected to the CCP1 pin.

This default connection to a pin can be disabled by setting the MDCHODIS bit in the MDCARH register for the carrier high source and the MDCLDIS bit in the MDCARL register for the carrier low source.

23.7 Programmable Modulator Data

The MDBIT of the MDCON register can be selected as the source for the modulator signal. This gives the user the ability to program the value used for modulation.

23.8 Modulator Source Pin Disable

The modulator source default connection to a pin can be disabled by setting the MDMSODIS bit in the MDSRC register.

23.9 Modulated Output Polarity

The modulated output signal provided on the MDOUT pin can also be inverted. Inverting the modulated output signal is enabled by setting the MDOPOL bit of the MDCON register.

23.10 Slew Rate Control

The slew rate limitation on the output port pin can be disabled. The slew rate limitation can be removed by clearing the MDSLRL bit in the MDCON register.

23.11 Operation in Sleep Mode

The DSM module is not affected by Sleep mode. The DSM can still operate during Sleep, if the Carrier and Modulator input sources are also still operable during Sleep.

23.12 Effects of a Reset

Upon any device Reset, the data signal modulator module is disabled. The user's firmware is responsible for initializing the module before enabling the output. The registers are reset to their default values.

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REGISTER 23-1: MDCON: MODULATION CONTROL REGISTER

R/W-0/0	R/W-0/0	R/W-1/1	R/W-0/0	R-0/0	U-0	U-0	R/W-0/0
MDEN	MDOE	MDSLR	MDOPOL	MDOUT	—	—	MDBIT
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7 **MDEN:** Modulator Module Enable bit
1 = Modulator module is enabled and mixing input signals
0 = Modulator module is disabled and has no output
- bit 6 **MDOE:** Modulator Module Pin Output Enable bit
1 = Modulator pin output enabled
0 = Modulator pin output disabled
- bit 5 **MDSLR:** MDOUT Pin Slew Rate Limiting bit
1 = MDOUT pin slew rate limiting enabled
0 = MDOUT pin slew rate limiting disabled
- bit 4 **MDOPOL:** Modulator Output Polarity Select bit
1 = Modulator output signal is inverted
0 = Modulator output signal is not inverted
- bit 3 **MDOUT:** Modulator Output bit
Displays the current output value of the modulator module.⁽¹⁾
- bit 2-1 **Unimplemented:** Read as '0'
- bit 0 **MDBIT:** Allows software to manually set modulation source input to module⁽²⁾
1 = Modulator uses High Carrier source
0 = Modulator uses Low Carrier source

Note 1: The modulated output frequency can be greater and asynchronous from the clock that updates this register bit, the bit value may not be valid for higher speed modulator or carrier signals.

2: MDBIT must be selected as the modulation source in the MDSRC register for this operation.

REGISTER 23-2: MDSRC: MODULATION SOURCE CONTROL REGISTER

R/W-x/u	U-0	U-0	U-0	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
MDMSODIS	—	—	—	MDMS<3:0>			
bit 7				bit 0			

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

- bit 7 **MDMSODIS:** Modulation Source Output Disable bit
1 = Output signal driving the peripheral output pin (selected by MDMS<3:0>) is disabled
0 = Output signal driving the peripheral output pin (selected by MDMS<3:0>) is enabled
- bit 6-4 **Unimplemented:** Read as '0'
- bit 3-0 **MDMS<3:0>** Modulation Source Selection bits
1111 = Reserved. No channel connected.
1110 = Reserved. No channel connected.
1101 = Reserved. No channel connected.
1100 = Reserved. No channel connected.
1011 = Reserved. No channel connected.
1010 = EUSART TX output
1001 = MSSP2 SDOx output
1000 = MSSP1 SDOx output
0111 = Comparator2 output
0110 = Comparator1 output
0101 = CCP4 output (PWM Output mode only)
0100 = CCP3 output (PWM Output mode only)
0011 = CCP2 output (PWM Output mode only)
0010 = CCP1 output (PWM Output mode only)
0001 = MDMIN port pin
0000 = MDBIT bit of MDCON register is modulation source

Note 1: Narrowed carrier pulse widths or spurs may occur in the signal stream if the carrier is not synchronized.

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REGISTER 23-3: MDCARH: MODULATION HIGH CARRIER CONTROL REGISTER

R/W-x/u	R/W-x/u	R/W-x/u	U-0	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
MDCHODIS	MDCHPOL	MDCHSYNC	—	MDCH<3:0>			
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

- bit 7 **MDCHODIS:** Modulator High Carrier Output Disable bit
1 = Output signal driving the peripheral output pin (selected by MDCH<3:0>) is disabled
0 = Output signal driving the peripheral output pin (selected by MDCH<3:0>) is enabled
- bit 6 **MDCHPOL:** Modulator High Carrier Polarity Select bit
1 = Selected high carrier signal is inverted
0 = Selected high carrier signal is not inverted
- bit 5 **MDCHSYNC:** Modulator High Carrier Synchronization Enable bit
1 = Modulator waits for a falling edge on the high time carrier signal before allowing a switch to the low time carrier
0 = Modulator Output is not synchronized to the high time carrier signal⁽¹⁾
- bit 4 **Unimplemented:** Read as '0'
- bit 3-0 **MDCH<3:0>** Modulator Data High Carrier Selection bits ⁽¹⁾
1111 = Reserved. No channel connected.
•
•
•
1000 = Reserved. No channel connected.
0111 = CCP4 output (PWM Output mode only)
0110 = CCP3 output (PWM Output mode only)
0101 = CCP2 output (PWM Output mode only)
0100 = CCP1 output (PWM Output mode only)
0011 = Reference Clock module signal
0010 = MDCIN2 port pin
0001 = MDCIN1 port pin
0000 = Vss

Note 1: Narrowed carrier pulse widths or spurs may occur in the signal stream if the carrier is not synchronized.

REGISTER 23-4: MDCARL: MODULATION LOW CARRIER CONTROL REGISTER

R/W-x/u	R/W-x/u	R/W-x/u	U-0	R/W-x/u	R/W-x/u	R/W-x/u	R/W-x/u
MDCLDIS	MDCLPOL	MDCLSYNC	—	MDCL<3:0>			
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7	MDCLDIS: Modulator Low Carrier Output Disable bit 1 = Output signal driving the peripheral output pin (selected by MDCL<3:0> of the MDCARL register) is disabled 0 = Output signal driving the peripheral output pin (selected by MDCL<3:0> of the MDCARL register) is enabled
bit 6	MDCLPOL: Modulator Low Carrier Polarity Select bit 1 = Selected low carrier signal is inverted 0 = Selected low carrier signal is not inverted
bit 5	MDCLSYNC: Modulator Low Carrier Synchronization Enable bit 1 = Modulator waits for a falling edge on the low time carrier signal before allowing a switch to the high time carrier 0 = Modulator Output is not synchronized to the low time carrier signal ⁽¹⁾
bit 4	Unimplemented: Read as '0'
bit 3-0	MDCL<3:0> Modulator Data High Carrier Selection bits ⁽¹⁾ 1111 = Reserved. No channel connected. • • • 1000 = Reserved. No channel connected. 0111 = CCP4 output (PWM Output mode only) 0110 = CCP3 output (PWM Output mode only) 0101 = CCP2 output (PWM Output mode only) 0100 = CCP1 output (PWM Output mode only) 0011 = Reference Clock module signal 0010 = MDCIN2 port pin 0001 = MDCIN1 port pin 0000 = Vss

Note 1: Narrowed carrier pulse widths or spurs may occur in the signal stream if the carrier is not synchronized.

TABLE 23-1: SUMMARY OF REGISTERS ASSOCIATED WITH DATA SIGNAL MODULATOR MODE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
MDCARH	MDCHDIS	MDCHPOL	MDCHSYNC	—	MDCH<3:0>				200
MDCARL	MDCLDIS	MDCLPOL	MDCLSYNC	—	MDCL<3:0>				201
MDCON	MDEN	MDOE	MDSLRL	MDOPOL	MDOUT	—	—	MDBIT	198
MDSRC	MDMSODIS	—	—	—	MDMS<3:0>				199

Legend: — = unimplemented, read as '0'. Shaded cells are not used in the Data Signal Modulator mode.

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NOTES:

24.0 CAPTURE/COMPARE/PWM MODULES

The Capture/Compare/PWM module is a peripheral which allows the user to time and control different events, and to generate Pulse-Width Modulation (PWM) signals. In Capture mode, the peripheral allows the timing of the duration of an event. The Compare mode allows the user to trigger an external event when a predetermined amount of time has expired. The PWM mode can generate Pulse-Width Modulated signals of varying frequency and duty cycle.

This family of devices contains two Enhanced Capture/Compare/PWM modules (ECCP1 and ECCP2) and two standard Capture/Compare/PWM modules (CCP3 and CCP4).

The Capture and Compare functions are identical for all four CCP modules (ECCP1, ECCP2, CCP3 and CCP4). The only differences between CCP modules are in the Pulse-Width Modulation (PWM) function. The standard PWM function is identical in modules, CCP3 and CCP4. In CCP modules ECCP1 and ECCP2, the Enhanced PWM function has slight variations from one another. Full-Bridge ECCP modules have four available I/O pins while Half-Bridge ECCP modules only have two available I/O pins. See [Table 24-1](#) for more information.

Note 1: In devices with more than one CCP module, it is very important to pay close attention to the register names used. A number placed after the module acronym is used to distinguish between separate modules. For example, the CCP1CON and CCP2CON control the same operational aspects of two completely different CCP modules.

2: Throughout this section, generic references to a CCP module in any of its operating modes may be interpreted as being equally applicable to ECCP1, ECCP2, CCP3 and CCP4. Register names, module signals, I/O pins, and bit names may use the generic designator 'x' to indicate the use of a numeral to distinguish a particular module, when required.

TABLE 24-1: PWM RESOURCES

Device Name	ECCP1	ECCP2	CCP3	CCP4
PIC16(L)F1826	Enhanced PWM Full-Bridge	Not Available	Not Available	Not Available
PIC16(L)F1827	Enhanced PWM Full-Bridge	Enhanced PWM Half-Bridge	Standard PWM	Standard PWM

24.1 Capture Mode

The Capture mode function described in this section is available and identical for CCP modules ECCP1, ECCP2, CCP3 and CCP4.

Capture mode makes use of the 16-bit Timer1 resource. When an event occurs on the CCPx pin, the 16-bit CCPRxH:CCPRxL register pair captures and stores the 16-bit value of the TMR1H:TMR1L register pair, respectively. An event is defined as one of the following and is configured by the CCPxM<3:0> bits of the CCPxCON register:

- Every falling edge
- Every rising edge
- Every 4th rising edge
- Every 16th rising edge

When a capture is made, the Interrupt Request Flag bit CCPxIF of the PIRx register is set. The interrupt flag must be cleared in software. If another capture occurs before the value in the CCPRxH, CCPRxL register pair is read, the old captured value is overwritten by the new captured value.

Figure 24-1 shows a simplified diagram of the Capture operation.

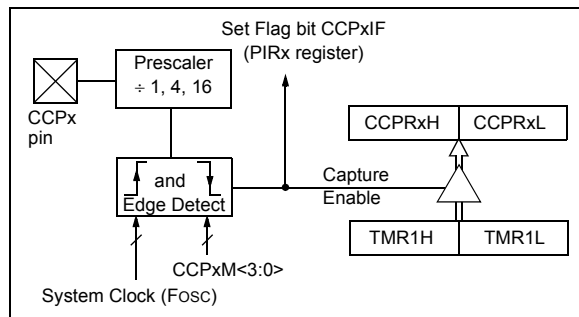
24.1.1 CCP PIN CONFIGURATION

In Capture mode, the CCPx pin should be configured as an input by setting the associated TRIS control bit.

Also, the CCPx pin function can be moved to alternative pins using the APFCON0 register. Refer to Section 12.1 “Alternate Pin Function” for more details.

Note: If the CCPx pin is configured as an output, a write to the port can cause a capture condition.

FIGURE 24-1: CAPTURE MODE OPERATION BLOCK DIAGRAM



24.1.2 TIMER1 MODE RESOURCE

Timer1 must be running in Timer mode or Synchronized Counter mode for the CCP module to use the capture feature. In Asynchronous Counter mode, the capture operation may not work.

See Section 21.0 “Timer1 Module with Gate Control” for more information on configuring Timer1.

24.1.3 SOFTWARE INTERRUPT MODE

When the Capture mode is changed, a false capture interrupt may be generated. The user should keep the CCPxIE interrupt enable bit of the PIRx register clear to avoid false interrupts. Additionally, the user should clear the CCPxIF interrupt flag bit of the PIRx register following any change in Operating mode.

24.1.4 CCP PRESCALER

There are four prescaler settings specified by the CCPxM<3:0> bits of the CCPxCON register. Whenever the CCP module is turned off, or the CCP module is not in Capture mode, the prescaler counter is cleared. Any Reset will clear the prescaler counter.

Switching from one capture prescaler to another does not clear the prescaler and may generate a false interrupt. To avoid this unexpected operation, turn the module off by clearing the CCPxCON register before changing the prescaler. Equation 24-1 demonstrates the code to perform this function.

EXAMPLE 24-1: CHANGING BETWEEN CAPTURE PRESCALERS

```
BANKSEL CCPxCON    ;Set Bank bits to point
                    ;to CCPxCON
CLRf    CCPxCON    ;Turn CCP module off
MOVLW   NEW_CAPT_PS;Load the W reg with
                    ;the new prescaler
                    ;move value and CCP ON
MOVWF   CCPxCON    ;Load CCPxCON with this
                    ;value
```

24.1.5 CAPTURE DURING SLEEP

Capture mode depends upon the Timer1 module for proper operation. There are two options for driving the Timer1 module in Capture mode. It can be driven by the instruction clock (Fosc/4), or by an external clock source.

When Timer1 is clocked by Fosc/4, Timer1 will not increment during Sleep. When the device wakes from Sleep, Timer1 will continue from its previous state.

Capture mode will operate during Sleep when Timer1 is clocked by an external clock source.

24.1.6 ALTERNATE PIN LOCATIONS

This module incorporates I/O pins that can be moved to other locations with the use of the alternate pin function registers, APFCON0 and APFCON1. To determine which pins can be moved and what their default locations are upon a reset, see [Section 12.1 “Alternate Pin Function”](#) for more information.

TABLE 24-2: SUMMARY OF REGISTERS ASSOCIATED WITH CAPTURE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSEL	SDO1SEL	SS1SEL	P2BSEL ⁽²⁾	CCP2SEL ⁽²⁾	P1DSEL	P1CSEL	CCP1SEL	119
CCPxCON	PxM1 ⁽¹⁾	PxM0 ⁽¹⁾	DCxB1	DCxB0	CCPxM3	CCPxM2	CCPxM1	CCPxM0	226
CCPRxL	Capture/Compare/PWM Register x Low Byte (LSB)								204*
CCPRxH	Capture/Compare/PWM Register x High Byte (MSB)								204*
CM1CON0	C1ON	C1OUT	C1OE	C1POL	—	C1SP	C1HYS	C1SYNC	170
CM1CON1	C1INTP	C1INTN	C1PCH1	C1PCH0	—	—	C1NCH1	C1NCH0	171
CM2CON0	C2ON	C2OUT	C2OE	C2POL	—	C2SP	C2HYS	C2SYNC	170
CM2CON1	C2INTP	C2INTN	C2PCH1	C2PCH0	—	—	C2NCH1	C2NCH0	171
INTCON	GIE	PEIE	TMR0IE	INTE	IOCF	TMR0IF	INTF	IOCF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE	87
PIE2	OSFIE	C2IE	C1IE	EEIE	BCL1IE	—	—	CCP2IE ⁽²⁾	88
PIE3 ⁽²⁾	—	—	CCP4IE	CCP3IE	TMR6IE	—	TMR4IE	—	89
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF	91
PIR2	OSFIF	C2IF	C1IF	EEIF	BCL1IF	—	—	CCP2IF ⁽²⁾	92
PIR3 ⁽²⁾	—	—	CCP4IF	CCP3IF	TMR6IF	—	TMR4IF	—	93
T1CON	TMR1CS1	TMR1CS0	T1CKPS1	T1CKPS0	T1OSCEN	T1SYN $\bar{C}$	—	TMR1ON	185
T1GCON	TMR1GE	T1GPOL	T1GTM	T1GSPM	T1GGO/DONE	T1GVAL	T1GSS1	T1GSS0	186
TMR1L	Holding Register for the Least Significant Byte of the 16-bit TMR1 Register								177*
TMR1H	Holding Register for the Most Significant Byte of the 16-bit TMR1 Register								177*
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127

Legend: — = Unimplemented locations, read as '0'. Shaded cells are not used by Capture mode.

* Page provides register information.

Note 1: Applies to ECCP modules only.

2: PIC16(L)F1827 only.

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24.2 Compare Mode

The Compare mode function described in this section is available and identical for CCP modules ECCP1, ECCP2, CCP3 and CCP4.

Compare mode makes use of the 16-bit Timer1 resource. The 16-bit value of the CCPRxH:CCPRxL register pair is constantly compared against the 16-bit value of the TMR1H:TMR1L register pair. When a match occurs, one of the following events can occur:

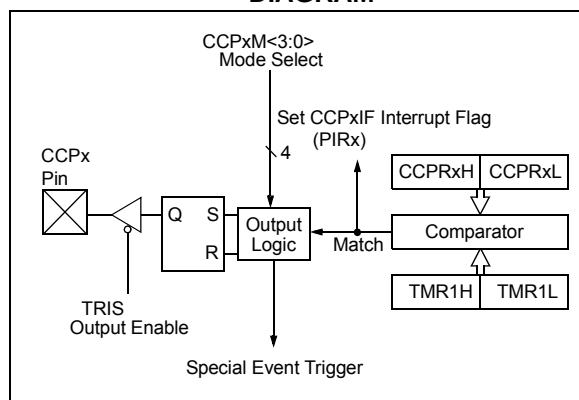
- Toggle the CCPx output
- Set the CCPx output
- Clear the CCPx output
- Generate a Special Event Trigger
- Generate a Software Interrupt

The action on the pin is based on the value of the CCPxM<3:0> control bits of the CCPxCON register. At the same time, the interrupt flag CCPxIF bit is set.

All Compare modes can generate an interrupt.

Figure 24-2 shows a simplified diagram of the Compare operation.

FIGURE 24-2: COMPARE MODE OPERATION BLOCK DIAGRAM



24.2.1 CCP PIN CONFIGURATION

The user must configure the CCPx pin as an output by clearing the associated TRIS bit.

Also, the CCPx pin function can be moved to alternative pins using the APFCON0 register. Refer to Section 12.1 “Alternate Pin Function” for more details.

Note: Clearing the CCPxCON register will force the CCPx compare output latch to the default low level. This is not the PORT I/O data latch.

24.2.2 TIMER1 MODE RESOURCE

In Compare mode, Timer1 must be running in either Timer mode or Synchronized Counter mode. The compare operation may not work in Asynchronous Counter mode.

See Section 21.0 “Timer1 Module with Gate Control” for more information on configuring Timer1.

Note: Clocking Timer1 from the system clock (Fosc) should not be used in Compare mode. In order for Compare mode to recognize the trigger event on the CCPx pin, Timer1 must be clocked from the instruction clock (Fosc/4) or from an external clock source.

24.2.3 SOFTWARE INTERRUPT MODE

When Generate Software Interrupt mode is chosen (CCPxM<3:0> = 1010), the CCPx module does not assert control of the CCPx pin (see the CCPxCON register).

24.2.4 SPECIAL EVENT TRIGGER

When Special Event Trigger mode is chosen (CCPxM<3:0> = 1011), the CCPx module does the following:

- Resets Timer1
- Starts an ADC conversion if ADC is enabled

The CCPx module does not assert control of the CCPx pin in this mode.

The Special Event Trigger output of the CCP occurs immediately upon a match between the TMR1H, TMR1L register pair and the CCPRxH, CCPRxL register pair. The TMR1H, TMR1L register pair is not reset until the next rising edge of the Timer1 clock. The Special Event Trigger output starts an A/D conversion (if the A/D module is enabled). This allows the CCPRxH, CCPRxL register pair to effectively provide a 16-bit programmable period register for Timer1.

TABLE 24-3: SPECIAL EVENT TRIGGER

Device	CCPx/ECCPx
PIC16(L)F1826	ECCP1
PIC16(L)F1827	CCP4

Refer to Section 16.2.5 “Special Event Trigger” for more information.

- Note 1:** The Special Event Trigger from the CCP module does not set interrupt flag bit TMR1IF of the PIR1 register.
- 2:** Removing the match condition by changing the contents of the CCPRxH and CCPRxL register pair, between the clock edge that generates the Special Event Trigger and the clock edge that generates the Timer1 Reset, will preclude the Reset from occurring.

24.2.5 COMPARE DURING SLEEP

The Compare mode is dependent upon the system clock (Fosc) for proper operation. Since Fosc is shut down during Sleep mode, the Compare mode will not function properly during Sleep.

24.2.6 ALTERNATE PIN LOCATIONS

This module incorporates I/O pins that can be moved to other locations with the use of the alternate pin function registers, APFCON0 and APFCON1. To determine which pins can be moved and what their default locations are upon a reset, see [Section 12.1 “Alternate Pin Function”](#) for more information.

TABLE 24-4: SUMMARY OF REGISTERS ASSOCIATED WITH COMPARE

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSEL	SDO1SEL	SS1SEL	P2BSEL ⁽²⁾	CCP2SEL ⁽²⁾	P1DSEL	P1CSEL	CCP1SEL	119
CCPxCON	PxM1 ⁽¹⁾	PxM0 ⁽¹⁾	DCxB1	DCxB0	CCPxM3	CCPxM2	CCPxM1	CCPxM0	226
CCPRxL	Capture/Compare/PWM Register x Low Byte (LSB)								204*
CCPRxH	Capture/Compare/PWM Register x High Byte (MSB)								204*
CM1CON0	C1ON	C1OUT	C1OE	C1POL	—	C1SP	C1HYS	C1SYNC	170
CM1CON1	C1INTP	C1INTN	C1PCH1	C1PCH0	—	—	C1NCH1	C1NCH0	171
CM2CON0	C2ON	C2OUT	C2OE	C2POL	—	C2SP	C2HYS	C2SYNC	170
CM2CON1	C2INTP	C2INTN	C2PCH1	C2PCH0	—	—	C2NCH1	C2NCH0	171
INTCON	GIE	PEIE	TMR0IE	INTE	IOCF	TMR0IF	INTF	IOCF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSPIE	CCP1IE	TMR2IE	TMR1IE	87
PIE2	OSFIE	C2IE	C1IE	EEIE	BCL1IE	—	—	CCP2IE ⁽²⁾	88
PIE3 ⁽²⁾	—	—	CCP4IE	CCP3IE	TMR6IE	—	TMR4IE	—	89
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSPIF	CCP1IF	TMR2IF	TMR1IF	91
PIR2	OSFIF	C2IF	C1IF	EEIF	BCLIF	—	—	CCP2IF ⁽²⁾	92
PIR3 ⁽²⁾	—	—	CCP4IF	CCP3IF	TMR6IF	—	TMR4IF	—	93
T1CON	TMR1CS1	TMR1CS0	T1CKPS1	T1CKPS0	T1OSCEN	T1SYN $\bar{C}$	—	TMR1ON	185
T1GCON	TMR1GE	T1GPOL	T1GTM	T1GSPM	T1GGO/DONE	T1GVAL	T1GSS1	T1GSS0	186
TMR1L	Holding Register for the Least Significant Byte of the 16-bit TMR1 Register								177*
TMR1H	Holding Register for the Most Significant Byte of the 16-bit TMR1 Register								177*
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127

Legend: — = Unimplemented locations, read as '0'. Shaded cells are not used by Compare mode.

* Page provides register information.

Note 1: Applies to ECCP modules only.

2: PIC16(L)F1827 only.

24.3 PWM Overview

Pulse-Width Modulation (PWM) is a scheme that provides power to a load by switching quickly between fully on and fully off states. The PWM signal resembles a square wave where the high portion of the signal is considered the on state and the low portion of the signal is considered the off state. The high portion, also known as the pulse width, can vary in time and is defined in steps. A larger number of steps applied, which lengthens the pulse width, also supplies more power to the load. Lowering the number of steps applied, which shortens the pulse width, supplies less power. The PWM period is defined as the duration of one complete cycle or the total amount of on and off time combined.

PWM resolution defines the maximum number of steps that can be present in a single PWM period. A higher resolution allows for more precise control of the pulse width time and in turn the power that is applied to the load.

The term duty cycle describes the proportion of the on time to the off time and is expressed in percentages, where 0% is fully off and 100% is fully on. A lower duty cycle corresponds to less power applied and a higher duty cycle corresponds to more power applied.

Figure 24-3 shows a typical waveform of the PWM signal.

24.3.1 STANDARD PWM OPERATION

The standard PWM function described in this section is available and identical for CCP modules ECCP1, ECCP2, CCP3 and CCP4.

The standard PWM mode generates a Pulse-Width Modulation (PWM) signal on the CCPx pin with up to 10 bits of resolution. The period, duty cycle, and resolution are controlled by the following registers:

- PRx registers
- TxCON registers
- CCPRxL registers
- CCPxCON registers

Figure 24-4 shows a simplified block diagram of PWM operation.

Note 1: The corresponding TRIS bit must be cleared to enable the PWM output on the CCPx pin.

2: Clearing the CCPxCON register will relinquish control of the CCPx pin.

FIGURE 24-3: CCP PWM OUTPUT SIGNAL

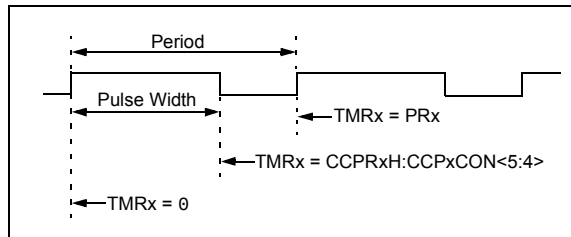
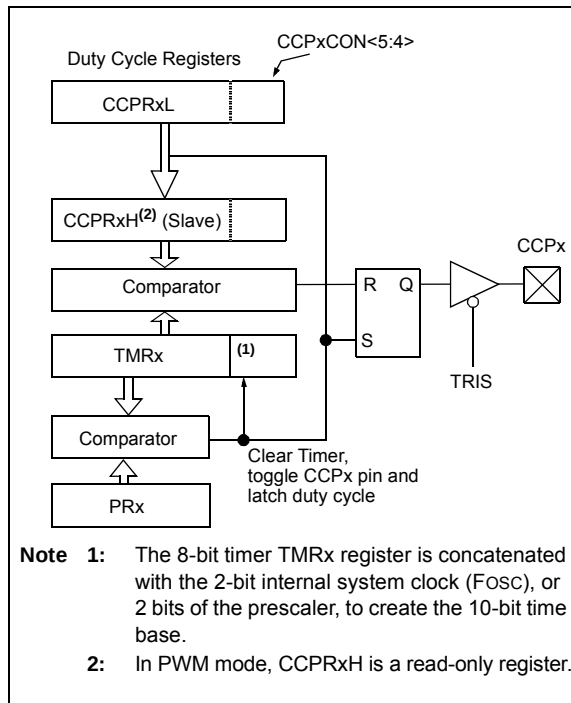


FIGURE 24-4: SIMPLIFIED PWM BLOCK DIAGRAM



24.3.2 SETUP FOR PWM OPERATION

The following steps should be taken when configuring the CCP module for standard PWM operation:

1. Disable the CCPx pin output driver by setting the associated TRIS bit.
2. Load the PRx register with the PWM period value.
3. Configure the CCP module for the PWM mode by loading the CCPxCON register with the appropriate values.
4. Load the CCPRxL register and the DCxBx bits of the CCPxCON register, with the PWM duty cycle value.
5. Configure and start Timer2/4/6:
 - Select the Timer2/4/6 resource to be used for PWM generation by setting the CxTSEL<1:0> bits in the CCPTMRS register.
 - Clear the TMRxIF interrupt flag bit of the PIRx register. See Note below.
 - Configure the TxCKPS bits of the TxCON register with the Timer prescale value.
 - Enable the Timer by setting the TMRxON bit of the TxCON register.
6. Enable PWM output pin:
 - Wait until the Timer overflows and the TMRxIF bit of the PIRx register is set. See Note below.
 - Enable the CCPx pin output driver by clearing the associated TRIS bit.

Note: In order to send a complete duty cycle and period on the first PWM output, the above steps must be included in the setup sequence. If it is not critical to start with a complete PWM signal on the first output, then step 6 may be ignored.

24.3.3 TIMER2/4/6 TIMER RESOURCE

The PWM standard mode makes use of one of the 8-bit Timer2/4/6 timer resources to specify the PWM period.

Configuring the CxTSEL<1:0> bits in the CCPTMRS register selects which Timer2/4/6 timer is used.

24.3.4 PWM PERIOD

The PWM period is specified by the PRx register of Timer2/4/6. The PWM period can be calculated using the formula of [Equation 24-1](#).

EQUATION 24-1: PWM PERIOD

$$PWM\ Period = [(PRx) + 1] \cdot 4 \cdot TOSC \cdot (TMRx\ Prescale\ Value)$$

Note 1: $TOSC = 1/FOSC$

When TMRx is equal to PRx, the following three events occur on the next increment cycle:

- TMRx is cleared
- The CCPx pin is set. (Exception: If the PWM duty cycle = 0%, the pin will not be set.)
- The PWM duty cycle is latched from CCPRxL into CCPRxH.

Note: The Timer postscaler (see [Section 22.1 "Timer2/4/6 Operation"](#)) is not used in the determination of the PWM frequency.

24.3.5 PWM DUTY CYCLE

The PWM duty cycle is specified by writing a 10-bit value to multiple registers: CCPRxL register and DCxB<1:0> bits of the CCPxCON register. The CCPRxL contains the eight MSBs and the DCxB<1:0> bits of the CCPxCON register contain the two LSBs. CCPRxL and DCxB<1:0> bits of the CCPxCON register can be written to at any time. The duty cycle value is not latched into CCPRxH until after the period completes (i.e., a match between PRx and TMRx registers occurs). While using the PWM, the CCPRxH register is read-only.

[Equation 24-2](#) is used to calculate the PWM pulse width.

[Equation 24-3](#) is used to calculate the PWM duty cycle ratio.

EQUATION 24-2: PULSE WIDTH

$$Pulse\ Width = (CCPRxL:CCPxCON<5:4>) \cdot TOSC \cdot (TMRx\ Prescale\ Value)$$

EQUATION 24-3: DUTY CYCLE RATIO

$$Duty\ Cycle\ Ratio = \frac{(CCPRxL:CCPxCON<5:4>)}{4(PRx + 1)}$$

The CCPRxH 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.

The 8-bit timer TMRx register is concatenated with either the 2-bit internal system clock (FOSC), or 2 bits of the prescaler, to create the 10-bit time base. The system clock is used if the Timer2/4/6 prescaler is set to 1:1.

When the 10-bit time base matches the CCPRxH and 2-bit latch, then the CCPx pin is cleared (see [Figure 24-4](#)).

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24.3.6 PWM RESOLUTION

The resolution determines the number of available duty cycles for a given period. For example, a 10-bit resolution will result in 1024 discrete duty cycles, whereas an 8-bit resolution will result in 256 discrete duty cycles.

The maximum PWM resolution is 10 bits when PRx is 255. The resolution is a function of the PRx register value as shown by [Equation 24-4](#).

EQUATION 24-4: PWM RESOLUTION

$$Resolution = \frac{\log[4(PRx + 1)]}{\log(2)} \text{ bits}$$

Note: If the pulse width value is greater than the period the assigned PWM pin(s) will remain unchanged.

TABLE 24-5: EXAMPLE PWM FREQUENCIES AND RESOLUTIONS (Fosc = 32 MHz)

PWM Frequency	1.95 kHz	7.81 kHz	31.25 kHz	125 kHz	250 kHz	333.3 kHz
Timer Prescale (1, 4, 16)	16	4	1	1	1	1
PRx Value	0xFF	0xFF	0xFF	0x3F	0x1F	0x17
Maximum Resolution (bits)	10	10	10	8	7	6.6

TABLE 24-6: EXAMPLE PWM FREQUENCIES AND RESOLUTIONS (Fosc = 20 MHz)

PWM Frequency	1.22 kHz	4.88 kHz	19.53 kHz	78.12 kHz	156.3 kHz	208.3 kHz
Timer Prescale (1, 4, 16)	16	4	1	1	1	1
PRx Value	0xFF	0xFF	0xFF	0x3F	0x1F	0x17
Maximum Resolution (bits)	10	10	10	8	7	6.6

TABLE 24-7: EXAMPLE PWM FREQUENCIES AND RESOLUTIONS (Fosc = 8 MHz)

PWM Frequency	1.22 kHz	4.90 kHz	19.61 kHz	76.92 kHz	153.85 kHz	200.0 kHz
Timer Prescale (1, 4, 16)	16	4	1	1	1	1
PRx Value	0x65	0x65	0x65	0x19	0x0C	0x09
Maximum Resolution (bits)	8	8	8	6	5	5

24.3.7 OPERATION IN SLEEP MODE

In Sleep mode, the TMRx register will not increment and the state of the module will not change. If the CCPx pin is driving a value, it will continue to drive that value. When the device wakes up, TMRx will continue from its previous state.

24.3.8 CHANGES IN SYSTEM CLOCK FREQUENCY

The PWM frequency is derived from the system clock frequency. Any changes in the system clock frequency will result in changes to the PWM frequency. See [Section 5.0 “Oscillator Module \(With Fail-Safe Clock Monitor\)”](#) for additional details.

24.3.9 EFFECTS OF RESET

Any Reset will force all ports to Input mode and the CCP registers to their Reset states.

24.3.10 ALTERNATE PIN LOCATIONS

This module incorporates I/O pins that can be moved to other locations with the use of the alternate pin function registers, APFCON0 and APFCON1. To determine which pins can be moved and what their default locations are upon a reset, see [Section 12.1 “Alternate Pin Function”](#) for more information.

TABLE 24-8: SUMMARY OF REGISTERS ASSOCIATED WITH STANDARD PWM

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSEL	SDO1SEL	SS1SEL	P2BSEL ⁽²⁾	CCP2SEL ⁽²⁾	P1DSEL	P1CSEL	CCP1SEL	119
CCPxCON	PxM1 ⁽¹⁾	PxM0 ⁽¹⁾	DCxB1	DCxB0	CCPxM3	CCPxM2	CCPxM1	CCPxM0	226
CCPxAS	CCPxASE	CCPxAS2	CCPxAS1	CCPxAS0	PSSxAC1	PSSxAC0	PSSxBD1	PSSxBD0	228
CCPTMRS	C4TSEL1	C4TSEL0	C3TSEL1	C3TSEL0	C2TSEL1	C2TSEL0	C1TSEL1	C1TSEL0	227
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
PR2	Timer2 Period Register								189 *
PR4	Timer4 Module Period Register								189 *
PR6	Timer6 Module Period Register								189 *
PSTRxCON	—	—	—	STRxSYNC	STRxD	STRxC	STRxB	STRxA	230
PWMxCON	PxRSEN	PxDC6	PxDC5	PxDC4	PxDC3	PxDC2	PxDC1	PxDC0	229
T2CON	—	T2OUTPS3	T2OUTPS2	T2OUTPS1	T2OUTPS0	TMR2ON	T2CKPS1	T2CKPS0	191
T4CON	—	T4OUTPS3	T4OUTPS2	T4OUTPS1	T4OUTPS0	TMR4ON	T4CKPS1	T4CKPS0	191
T6CON	—	T6OUTPS3	T6OUTPS2	T6OUTPS1	T6OUTPS0	TMR6ON	T6CKPS1	T6CKPS0	191
TMR2	Holding Register for the 8-bit TMR2 Time Base								189 *
TMR4	Holding Register for the 8-bit TMR4 Time Base ⁽¹⁾								189 *
TMR6	Holding Register for the 8-bit TMR6 Time Base ⁽¹⁾								189 *
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127

Legend: — = Unimplemented locations, read as ‘0’. Shaded cells are not used by the PWM.

* Page provides register information.

Note 1: Applies to ECCP modules only.

2: PIC16(L)F1827 only.

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24.4 PWM (Enhanced Mode)

The enhanced PWM function described in this section is available for CCP modules ECCP1 and ECCP2, with any differences between modules noted.

The enhanced PWM mode generates a Pulse-Width Modulation (PWM) signal on up to four different output pins with up to 10 bits of resolution. The period, duty cycle, and resolution are controlled by the following registers:

- PRx registers
- TxCON registers
- CCPRxL registers
- CCPxCON registers

The ECCP modules have the following additional PWM registers which control Auto-shutdown, Auto-restart, Dead-band Delay and PWM Steering modes:

- CCPxAS registers
- PSTRxCON registers
- PWMxCON registers

The enhanced PWM module can generate the following five PWM Output modes:

- Single PWM
- Half-Bridge PWM
- Full-Bridge PWM, Forward Mode
- Full-Bridge PWM, Reverse Mode
- Single PWM with PWM Steering Mode

To select an Enhanced PWM Output mode, the PxM bits of the CCPxCON register must be configured appropriately.

The PWM outputs are multiplexed with I/O pins and are designated PxA, PxB, PxC and PxD. The polarity of the PWM pins is configurable and is selected by setting the CCPxM bits in the CCPxCON register appropriately.

Figure 24-5 shows an example of a simplified block diagram of the Enhanced PWM module.

Figure 24-9 shows the pin assignments for various Enhanced PWM modes.

- Note 1:** The corresponding TRIS bit must be cleared to enable the PWM output on the CCPx pin.
- 2:** Clearing the CCPxCON register will relinquish control of the CCPx pin.
- 3:** Any pin not used in the enhanced PWM mode is available for alternate pin functions, if applicable.
- 4:** To prevent the generation of an incomplete waveform when the PWM is first enabled, the ECCP module waits until the start of a new PWM period before generating a PWM signal.

FIGURE 24-5: EXAMPLE SIMPLIFIED BLOCK DIAGRAM OF THE ENHANCED PWM MODE

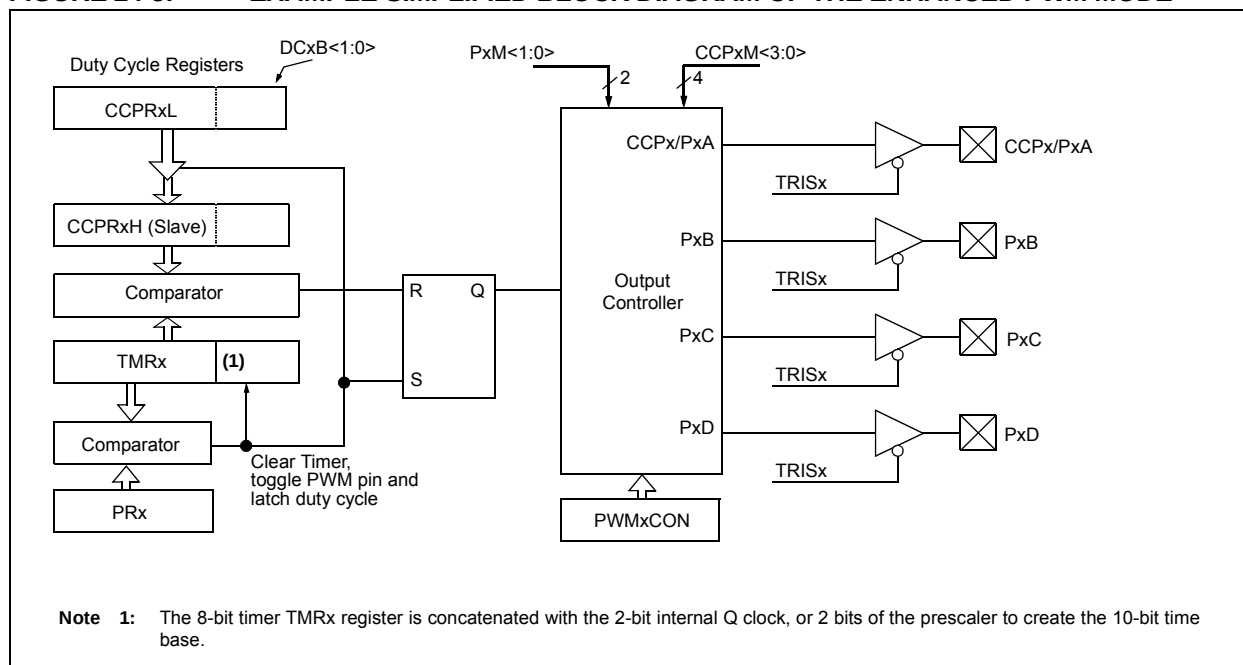
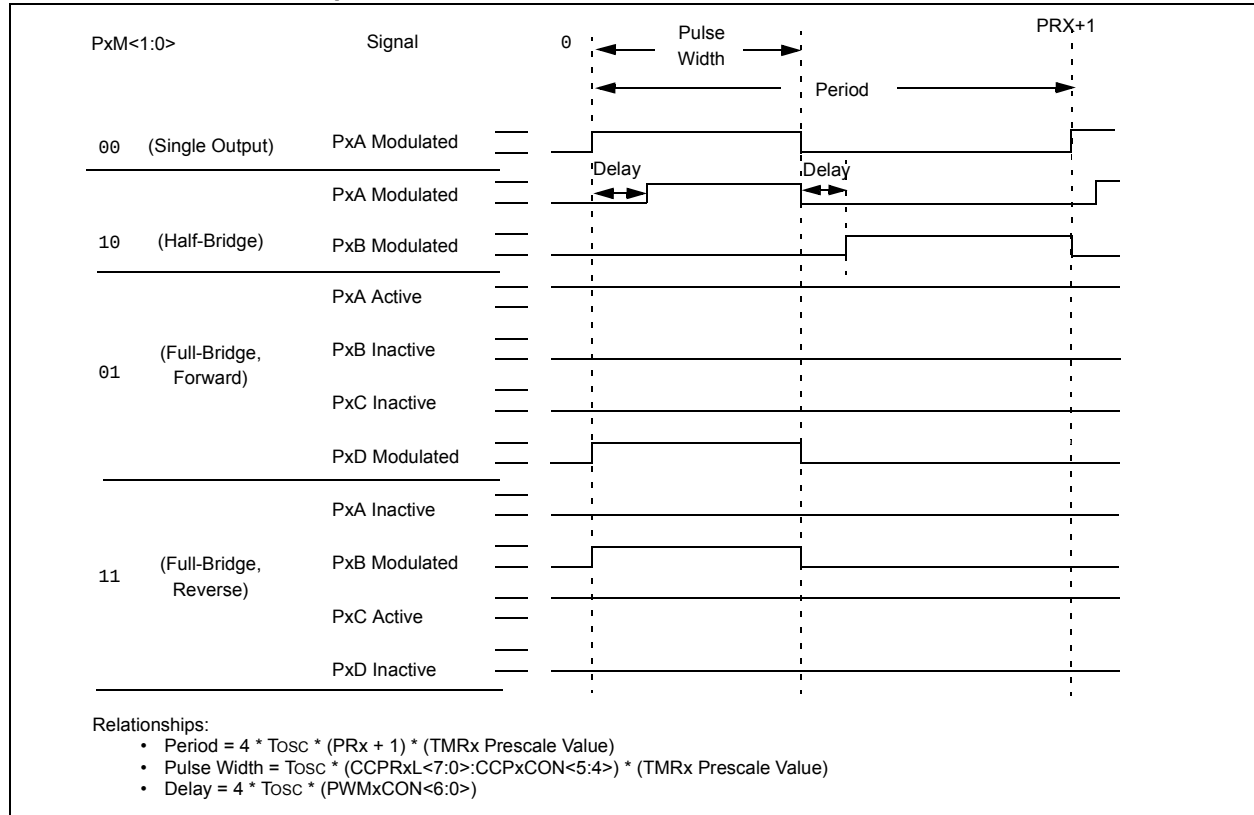


TABLE 24-9: EXAMPLE PIN ASSIGNMENTS FOR VARIOUS PWM ENHANCED MODES

ECCP Mode	PxM<1:0>	CCPx/PxA	PxB	PxC	PxD
Single	00	Yes ⁽¹⁾	Yes ⁽¹⁾	Yes ⁽¹⁾	Yes ⁽¹⁾
Half-Bridge	10	Yes	Yes	No	No
Full-Bridge, Forward	01	Yes	Yes	Yes	Yes
Full-Bridge, Reverse	11	Yes	Yes	Yes	Yes

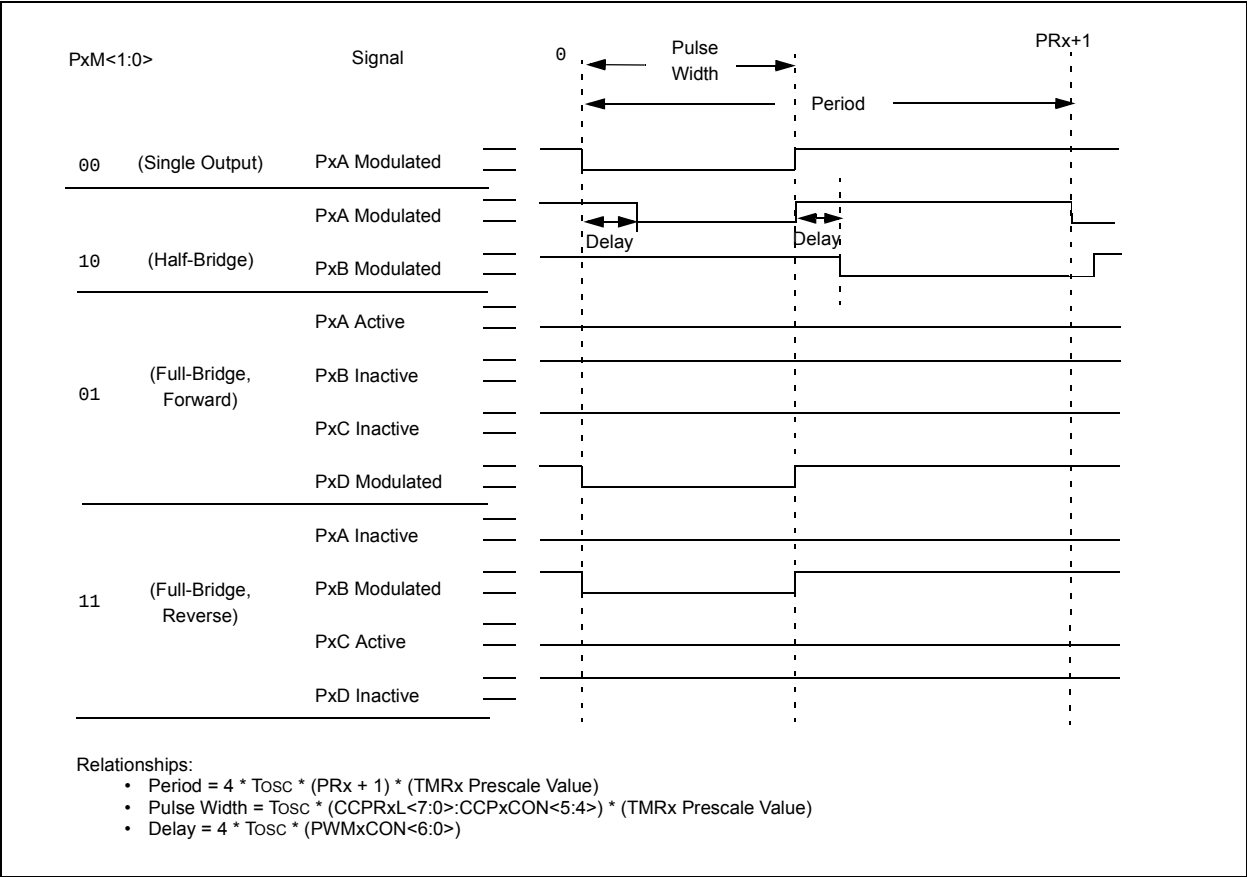
Note 1: PWM Steering enables outputs in Single mode.

FIGURE 24-6: EXAMPLE PWM (ENHANCED MODE) OUTPUT RELATIONSHIPS (ACTIVE-HIGH STATE)



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FIGURE 24-7: EXAMPLE ENHANCED PWM OUTPUT RELATIONSHIPS (ACTIVE-LOW STATE)



24.4.1 HALF-BRIDGE MODE

In Half-Bridge mode, two pins are used as outputs to drive push-pull loads. The PWM output signal is output on the CCPx/PxA pin, while the complementary PWM output signal is output on the PxB pin (see Figure 24-9). This mode can be used for Half-Bridge applications, as shown in Figure 24-9, or for Full-Bridge applications, where four power switches are being modulated with two PWM signals.

In Half-Bridge mode, the programmable dead-band delay can be used to prevent shoot-through current in Half-Bridge power devices. The value of the PDC<6:0> bits of the PWMxCON register sets the number of instruction cycles before the output is driven active. If the value is greater than the duty cycle, the corresponding output remains inactive during the entire cycle. See Section 24.4.5 “Programmable Dead-Band Delay Mode” for more details of the dead-band delay operations.

Since the PxA and PxB outputs are multiplexed with the PORT data latches, the associated TRIS bits must be cleared to configure PxA and PxB as outputs.

FIGURE 24-8: EXAMPLE OF HALF-BRIDGE PWM OUTPUT

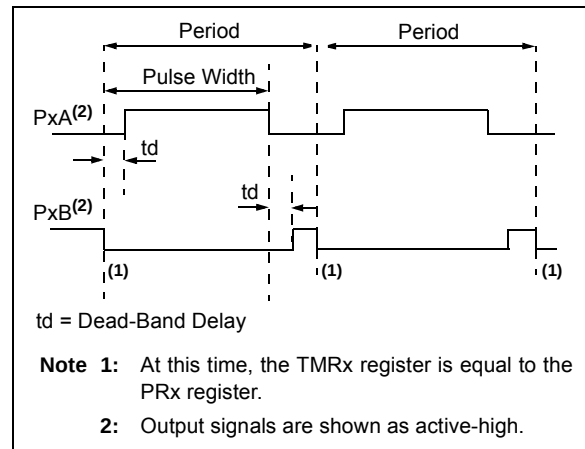
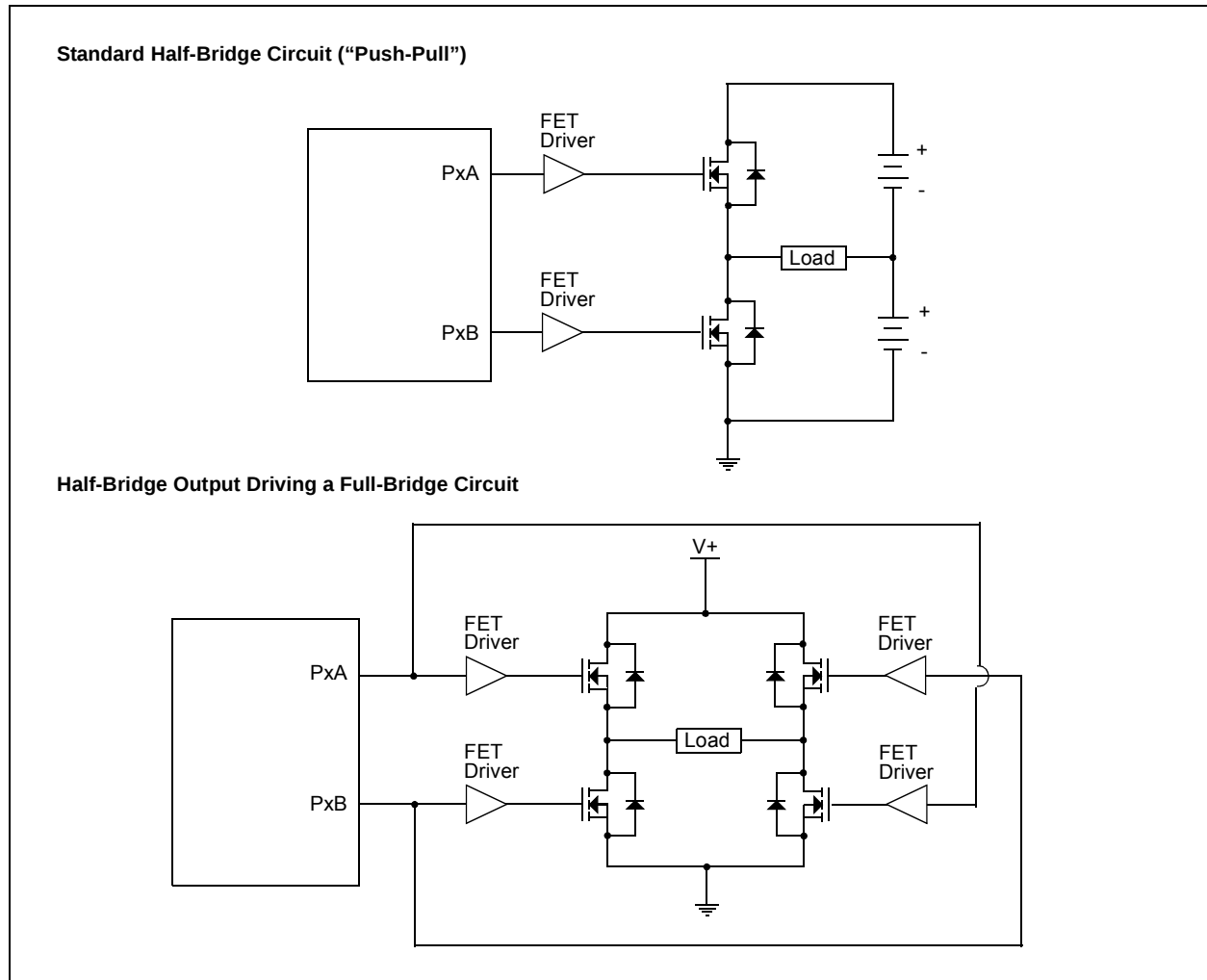


FIGURE 24-9: EXAMPLE OF HALF-BRIDGE APPLICATIONS



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24.4.2 FULL-BRIDGE MODE

In Full-Bridge mode, all four pins are used as outputs. An example of Full-Bridge application is shown in [Figure 24-10](#).

In the Forward mode, pin CCPx/PxA is driven to its active state, pin PxD is modulated, while PxB and PxC will be driven to their inactive state as shown in [Figure 24-11](#).

In the Reverse mode, PxC is driven to its active state, pin PxB is modulated, while PxA and PxD will be driven to their inactive state as shown [Figure 24-11](#).

PxA, PxB, PxC and PxD outputs are multiplexed with the PORT data latches. The associated TRIS bits must be cleared to configure the PxA, PxB, PxC and PxD pins as outputs.

FIGURE 24-10: EXAMPLE OF FULL-BRIDGE APPLICATION

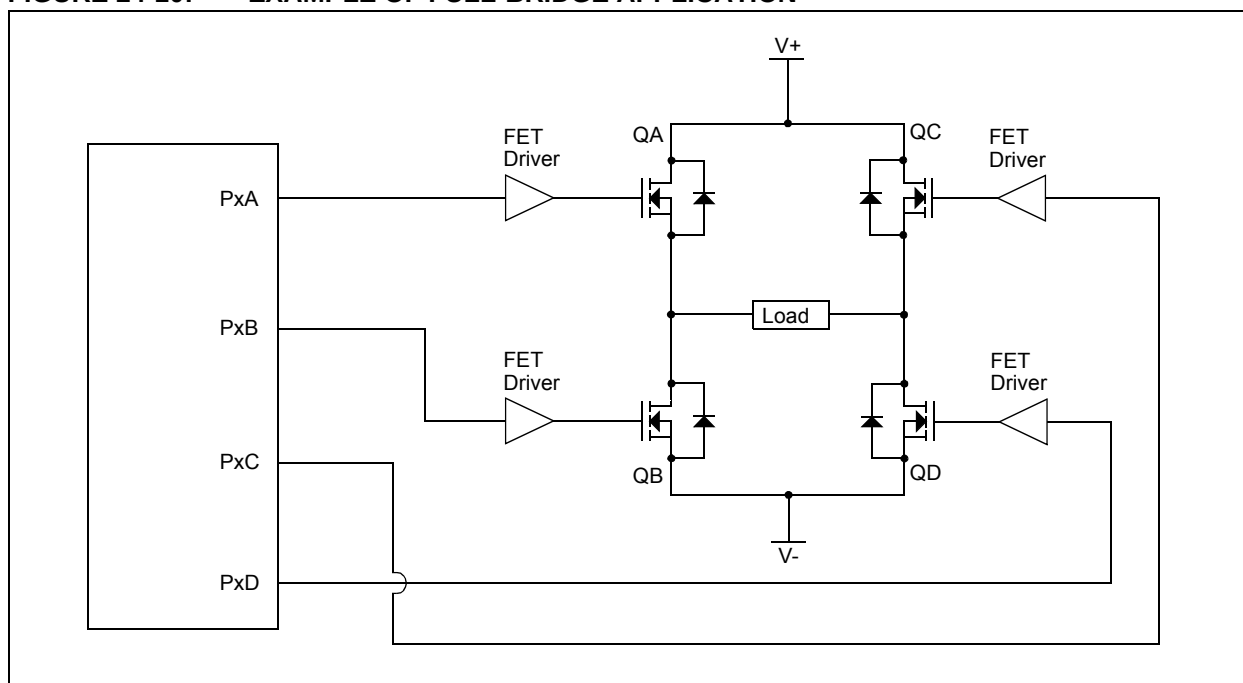
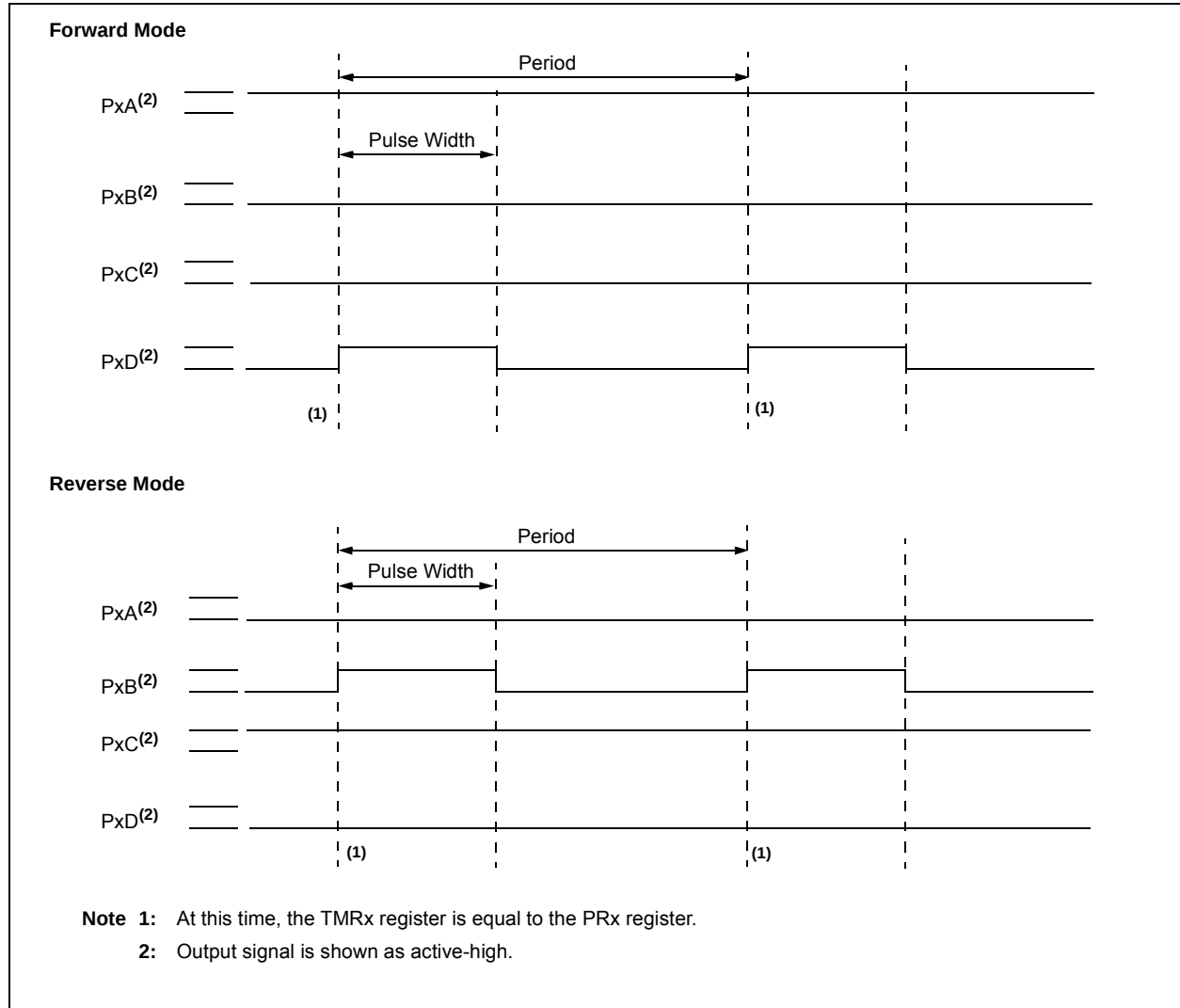


FIGURE 24-11: EXAMPLE OF FULL-BRIDGE PWM OUTPUT



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24.4.2.1 Direction Change in Full-Bridge Mode

In the Full-Bridge mode, the PxM1 bit in the CCPxCON register allows users to control the forward/reverse direction. When the application firmware changes this direction control bit, the module will change to the new direction on the next PWM cycle.

A direction change is initiated in software by changing the PxM1 bit of the CCPxCON register. The following sequence occurs four Timer cycles prior to the end of the current PWM period:

- The modulated outputs (PxB and PxD) are placed in their inactive state.
- The associated unmodulated outputs (PxA and PxC) are switched to drive in the opposite direction.
- PWM modulation resumes at the beginning of the next period.

See Figure 24-12 for an illustration of this sequence.

The Full-Bridge mode does not provide dead-band delay. As one output is modulated at a time, dead-band delay is generally not required. There is a situation where dead-band delay is required. This situation occurs when both of the following conditions are true:

1. The direction of the PWM output changes when the duty cycle of the output is at or near 100%.
2. The turn off time of the power switch, including the power device and driver circuit, is greater than the turn on time.

Figure 24-13 shows an example of the PWM direction changing from forward to reverse, at a near 100% duty cycle. In this example, at time t1, the output PxA and PxD become inactive, while output PxC becomes active. Since the turn off time of the power devices is longer than the turn on time, a shoot-through current will flow through power devices QC and QD (see Figure 24-10) for the duration of 't'. The same phenomenon will occur to power devices QA and QB for PWM direction change from reverse to forward.

If changing PWM direction at high duty cycle is required for an application, two possible solutions for eliminating the shoot-through current are:

1. Reduce PWM duty cycle for one PWM period before changing directions.
2. Use switch drivers that can drive the switches off faster than they can drive them on.

Other options to prevent shoot-through current may exist.

FIGURE 24-12: EXAMPLE OF PWM DIRECTION CHANGE

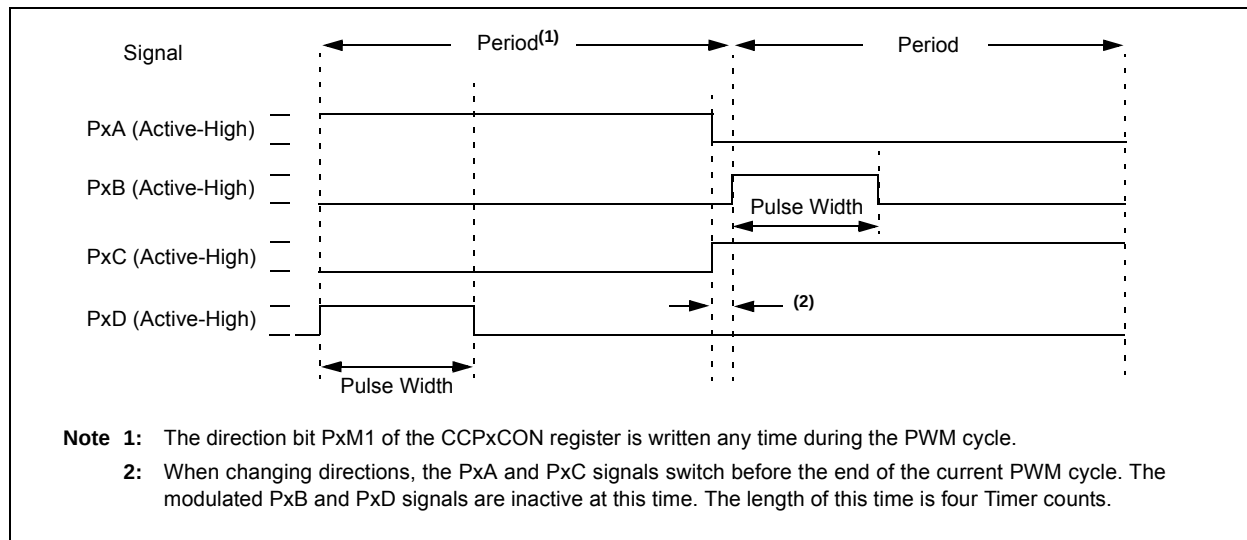
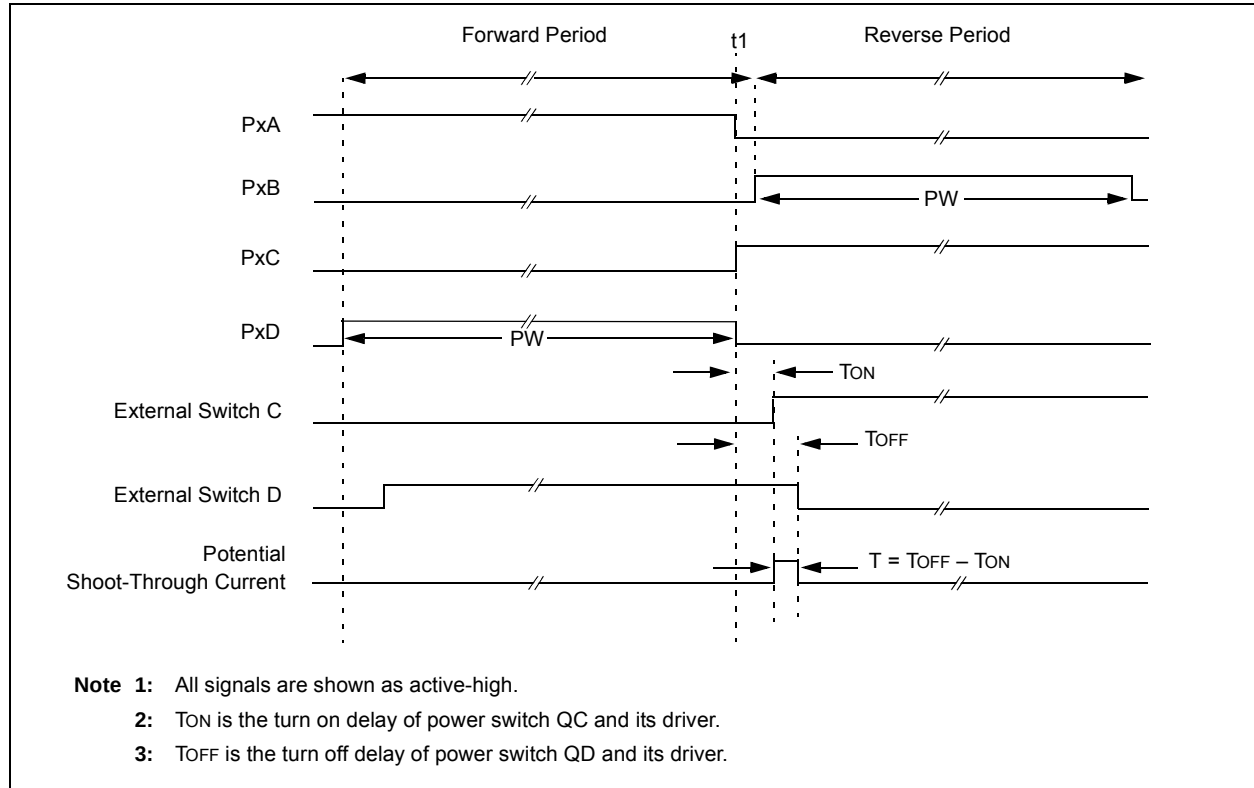


FIGURE 24-13: EXAMPLE OF PWM DIRECTION CHANGE AT NEAR 100% DUTY CYCLE



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24.4.3 ENHANCED PWM AUTO-SHUTDOWN MODE

The PWM mode supports an Auto-Shutdown mode that will disable the PWM outputs when an external shutdown event occurs. Auto-Shutdown mode places the PWM output pins into a predetermined state. This mode is used to help prevent the PWM from damaging the application.

The auto-shutdown sources are selected using the CCPxAS<2:0> bits of the CCPxAS register. A shutdown event may be generated by:

- A logic '0' on the INT pin
- A logic '1' on a Comparator (Cx) output

A shutdown condition is indicated by the CCPxASE (Auto-Shutdown Event Status) bit of the CCPxAS register. If the bit is a '0', the PWM pins are operating normally. If the bit is a '1', the PWM outputs are in the shutdown state.

When a shutdown event occurs, two things happen:

The CCPxASE bit is set to '1'. The CCPxASE will remain set until cleared in firmware or an auto-restart occurs (see [Section 24.4.4 "Auto-Restart Mode"](#)).

The enabled PWM pins are asynchronously placed in their shutdown states. The PWM output pins are grouped into pairs [PxA/PxC] and [PxB/PxD]. The state of each pin pair is determined by the PSSxAC and PSSxBD bits of the CCPxAS register. Each pin pair may be placed into one of three states:

- Drive logic '1'
- Drive logic '0'
- Tri-state (high-impedance)

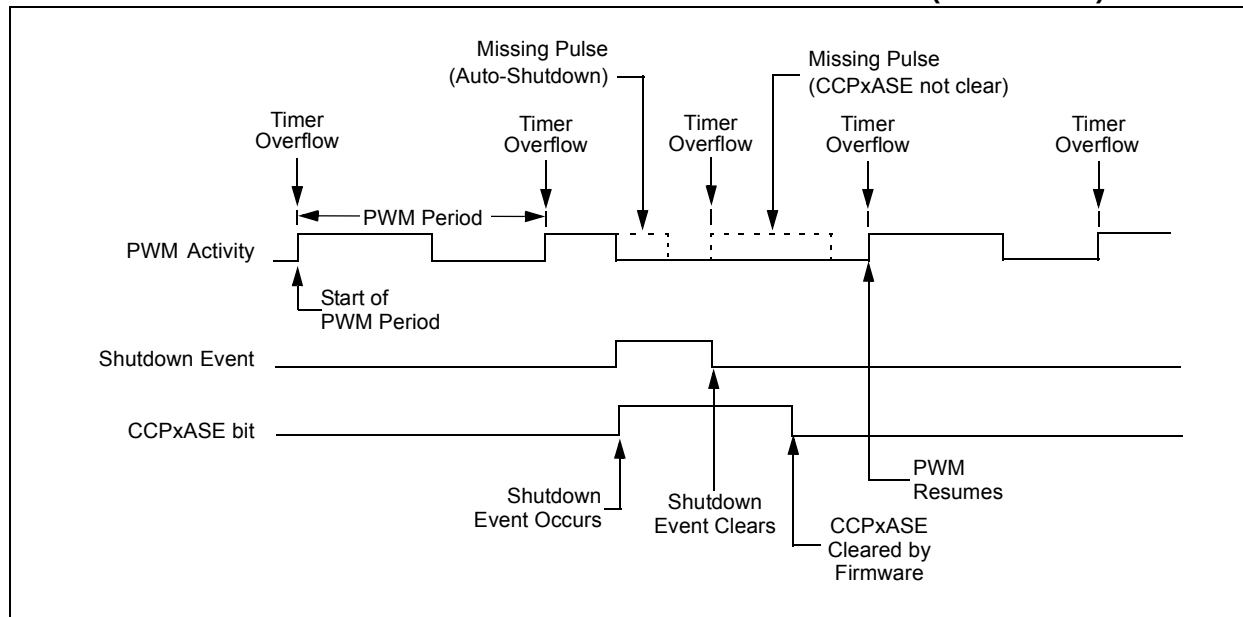
Note 1: The auto-shutdown condition is a level-based signal, not an edge-based signal. As long as the level is present, the auto-shutdown will persist.

2: Writing to the CCPxASE bit of the CCPxAS register is disabled while an auto-shutdown condition persists.

3: Once the auto-shutdown condition has been removed and the PWM restarted (either through firmware or auto-restart) the PWM signal will always restart at the beginning of the next PWM period.

4: Prior to an auto-shutdown event caused by a comparator output or INT pin event, a software shutdown can be triggered in firmware by setting the CCPxASE bit of the CCPxAS register to '1'. The Auto-Restart feature tracks the active status of a shutdown caused by a comparator output or INT pin event only. If it is enabled at this time, it will immediately clear this bit and restart the ECCP module at the beginning of the next PWM period.

FIGURE 24-14: PWM AUTO-SHUTDOWN WITH FIRMWARE RESTART (PXRSEN = 0)

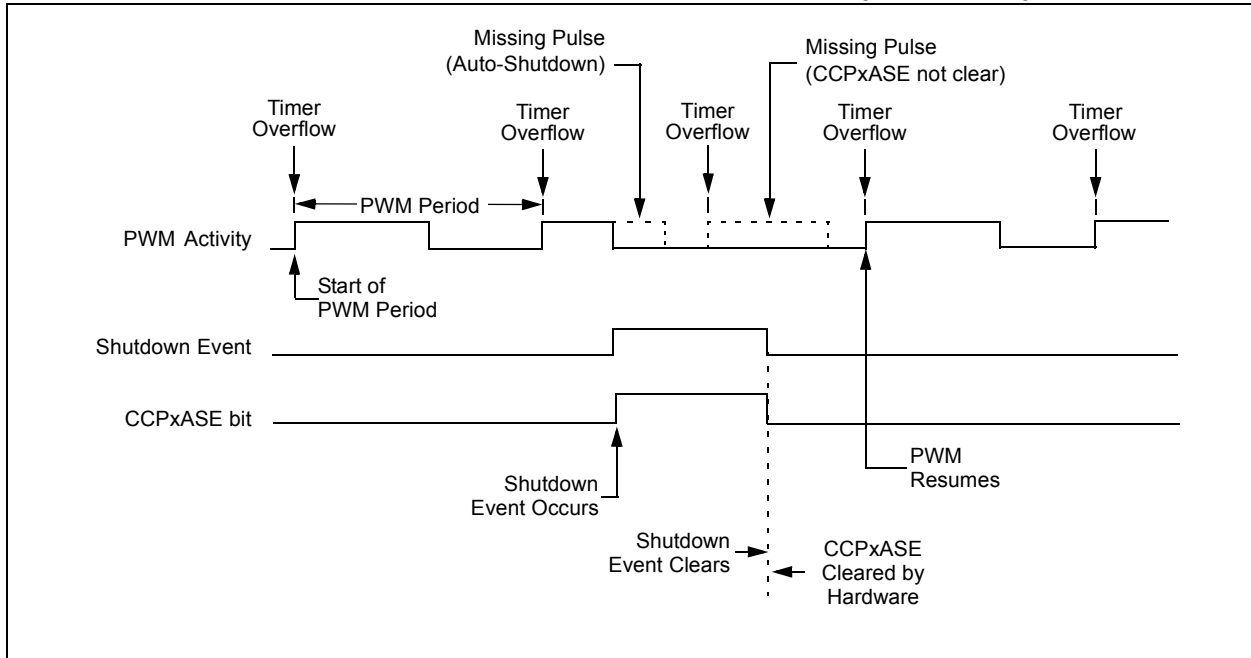


24.4.4 AUTO-RESTART MODE

The Enhanced PWM can be configured to automatically restart the PWM signal once the auto-shutdown condition has been removed. Auto-restart is enabled by setting the PxRSEN bit in the PWMxCON register.

If auto-restart is enabled, the CCPxASE bit will remain set as long as the auto-shutdown condition is active. When the auto-shutdown condition is removed, the CCPxASE bit will be cleared via hardware and normal operation will resume.

FIGURE 24-15: PWM AUTO-SHUTDOWN WITH AUTO-RESTART (PxRSEN = 1)



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24.4.5 PROGRAMMABLE DEAD-BAND DELAY MODE

In Half-Bridge applications where all power switches are modulated at the PWM frequency, the power switches normally require more time to turn off than to turn on. If both the upper and lower power switches are switched at the same time (one turned on, and the other turned off), both switches may be on for a short period of time until one switch completely turns off. During this brief interval, a very high current (*shoot-through current*) will flow through both power switches, shorting the bridge supply. To avoid this potentially destructive shoot-through current from flowing during switching, turning on either of the power switches is normally delayed to allow the other switch to completely turn off.

In Half-Bridge mode, a digitally programmable dead-band delay is available to avoid shoot-through current from destroying the bridge power switches. The delay occurs at the signal transition from the non-active state to the active state. See [Figure 24-16](#) for illustration. The lower seven bits of the associated PWMxCON register ([Register 24-4](#)) sets the delay period in terms of microcontroller instruction cycles (T_{CY} or $4 T_{OSC}$).

FIGURE 24-16: EXAMPLE OF HALF-BRIDGE PWM OUTPUT

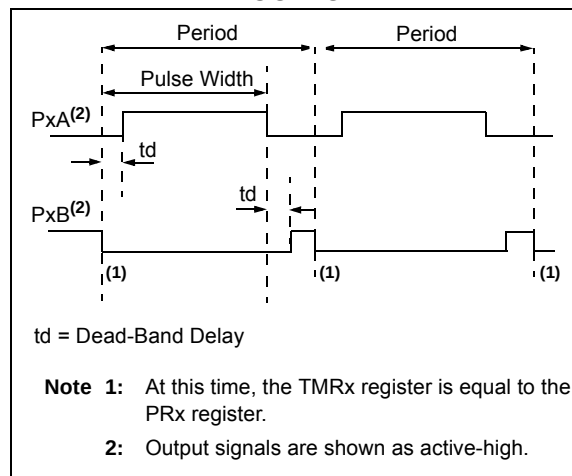
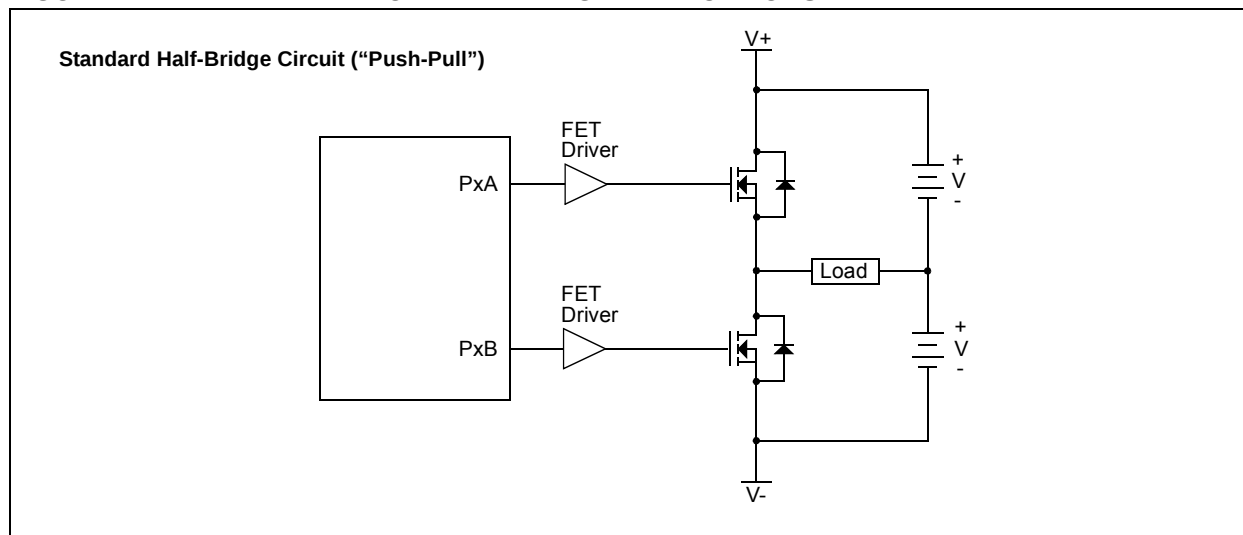


FIGURE 24-17: EXAMPLE OF HALF-BRIDGE APPLICATIONS



24.4.6 PWM STEERING MODE

In Single Output mode, PWM steering allows any of the PWM pins to be the modulated signal. Additionally, the same PWM signal can be simultaneously available on multiple pins.

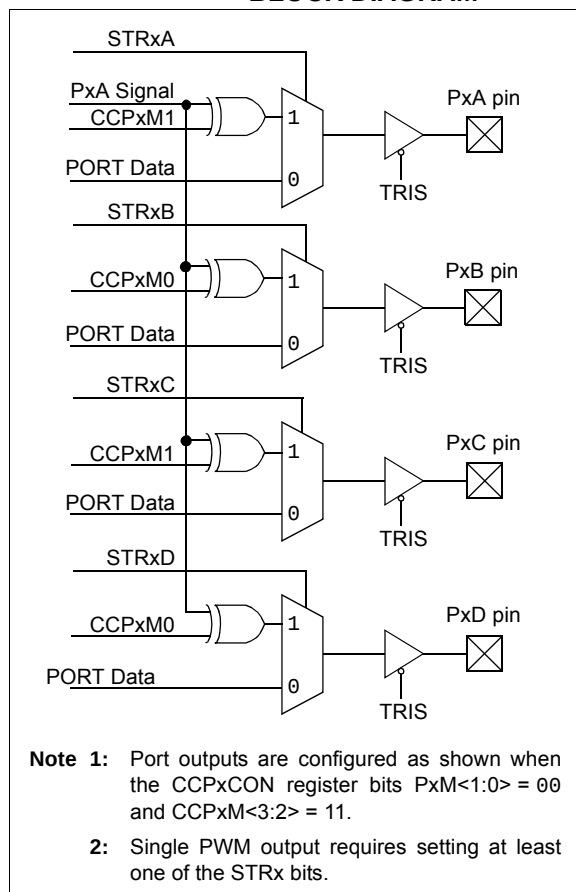
Once the Single Output mode is selected ($CCPxM<3:2> = 11$ and $PxM<1:0> = 00$ of the $CCPxCON$ register), the user firmware can bring out the same PWM signal to one, two, three or four output pins by setting the appropriate $STRx<D:A>$ bits of the $PSTRxCON$ register, as shown in [Register 24-5](#).

Note: The associated TRIS bits must be set to output ('0') to enable the pin output driver in order to see the PWM signal on the pin.

While the PWM Steering mode is active, $CCPxM<1:0>$ bits of the $CCPxCON$ register select the PWM output polarity for the $Px<D:A>$ pins.

The PWM auto-shutdown operation also applies to PWM Steering mode as described in [Section 24.4.3 “Enhanced PWM Auto-shutdown mode”](#). An auto-shutdown event will only affect pins that have PWM outputs enabled.

FIGURE 24-18: SIMPLIFIED STEERING BLOCK DIAGRAM



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24.4.6.1 Steering Synchronization

The STRxSYNC bit of the PSTRxCON register gives the user two selections of when the steering event will happen. When the STRxSYNC bit is '0', the steering event will happen at the end of the instruction that writes to the PSTRxCON register. In this case, the output signal at the Px<D:A> pins may be an incomplete PWM waveform. This operation is useful when the user firmware needs to immediately remove a PWM signal from the pin.

When the STRxSYNC bit is '1', the effective steering update will happen at the beginning of the next PWM period. In this case, steering on/off the PWM output will always produce a complete PWM waveform.

Figures 24-19 and 24-20 illustrate the timing diagrams of the PWM steering depending on the STRxSYNC setting.

24.4.7 START-UP CONSIDERATIONS

When any PWM mode is used, the application hardware must use the proper external pull-up and/or pull-down resistors on the PWM output pins.

The CCPxM<1:0> bits of the CCPxCON register allow the user to choose whether the PWM output signals are active-high or active-low for each pair of PWM output pins (Px<A>/Px<C> and Px/Px<D>). The PWM output polarities must be selected before the PWM pin output drivers are enabled. Changing the polarity

configuration while the PWM pin output drivers are enable is not recommended since it may result in damage to the application circuits.

The Px<A>, Px, Px<C> and Px<D> output latches may not be in the proper states when the PWM module is initialized. Enabling the PWM pin output drivers at the same time as the Enhanced PWM modes may cause damage to the application circuit. The Enhanced PWM modes must be enabled in the proper Output mode and complete a full PWM cycle before enabling the PWM pin output drivers. The completion of a full PWM cycle is indicated by the TMRxIF bit of the PIRx register being set as the second PWM period begins.

Note: When the microcontroller is released from Reset, all of the I/O pins are in the high-impedance state. The external circuits must keep the power switch devices in the Off state until the microcontroller drives the I/O pins with the proper signal levels or activates the PWM output(s).

24.4.8 ALTERNATE PIN LOCATIONS

This module incorporates I/O pins that can be moved to other locations with the use of the alternate pin function registers, APFCON0 and APFCON1. To determine which pins can be moved and what their default locations are upon a reset, see [Section 12.1 "Alternate Pin Function"](#) for more information.

FIGURE 24-19: EXAMPLE OF STEERING EVENT AT END OF INSTRUCTION (STRxSYNC = 0)

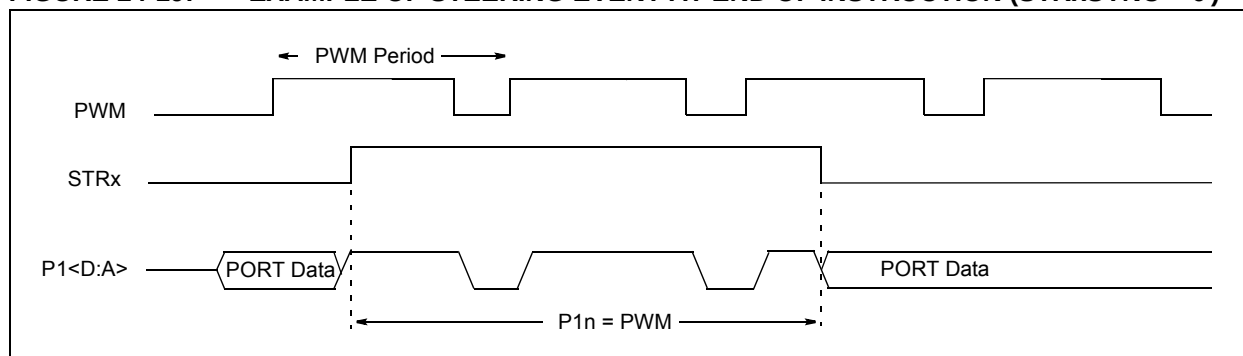


FIGURE 24-20: EXAMPLE OF STEERING EVENT AT BEGINNING OF INSTRUCTION (STRxSYNC = 1)

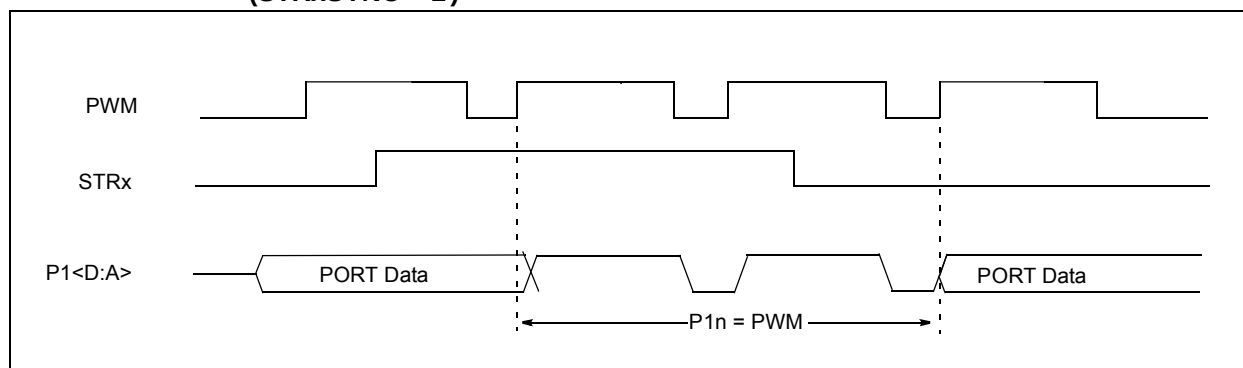


TABLE 24-10: SUMMARY OF REGISTERS ASSOCIATED WITH ENHANCED PWM

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSEL	SDO1SEL	SS1SEL	P2BSEL ⁽²⁾	CCP2SEL ⁽²⁾	P1DSEL	P1CSEL	CCP1SEL	119
CCPxCON	PxM<1:0> ⁽¹⁾		DCxB<1:0>		CCPxM<3:0>				226
CCPxAS	CCPxASE	CCPxAS<2:0>			PSSxAC<1:0>		PSSxBD<1:0>		228
CCPTMRS	C4TSEL<1:0>		C3TSEL<1:0>		C2TSEL<1:0>		C1TSEL<1:0>		227
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSPIE	CCP1IE	TMR2IE	TMR1IE	87
PIE2	OSFIE	C2IE	C1IE	EEIE	BCLIE	—	—	CCP2IE	88
PIE3 ⁽²⁾	—	—	CCP4IE	CCP3IE	TMR6IE	—	TMR4IE	—	89
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSPIF	CCP1IF	TMR2IF	TMR1IF	91
PIR2	OSFIF	C2IF	C1IF	EEIF	BCLIF	—	—	CCP2IF	92
PIR3 ⁽²⁾	—	—	CCP4IF	CCP3IF	TMR6IF	—	TMR4IF	—	93
PR2	Timer2 Period Register								189*
PR4	Timer4 Module Period Register								189*
PR6	Timer6 Module Period Register								189*
PSTRxCON	—	—	—	STRxSYNC	STRxD	STRxC	STRxB	STRxA	230
PWMxCON	PxRSEN	PxDC<6:0>							229
T2CON	—	T2OUTPS3	T2OUTPS2	T2OUTPS1	T2OUTPS0	TMR2ON	T2CKPS1	T2CKPS0	191
T4CON	—	T4OUTPS3	T4OUTPS2	T4OUTPS1	T4OUTPS0	TMR4ON	T4CKPS1	T4CKPS0	191
T6CON	—	T6OUTPS3	T6OUTPS2	T6OUTPS1	T6OUTPS0	TMR6ON	T6CKPS1	T6CKPS0	191
TMR2	Holding Register for the 8-bit TMR2 Time Base								189*
TMR4	Holding Register for the 8-bit TMR4 Time Base ⁽¹⁾								189*
TMR6	Holding Register for the 8-bit TMR6 Time Base ⁽¹⁾								189*
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127

Legend: — = Unimplemented location, read as '0'. Shaded cells are not used by the PWM.

* Page provides register information.

Note 1: Applies to ECCP modules only.

2: PIC16(L)F1827 only.

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24.5 CCP Control Registers

REGISTER 24-1: CCPxCON: CCPx CONTROL REGISTER

R/W-00	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
PxM<1:0> ⁽¹⁾		DCxB<1:0>		CCPxM<3:0>			
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Reset

'1' = Bit is set

'0' = Bit is cleared

bit 7-6 **PxM<1:0>**: Enhanced PWM Output Configuration bits⁽¹⁾

Capture mode:

Unused

Compare mode:

Unused

If CCPxM<3:2> = 00, 01, 10:

xx = PxA assigned as Capture/Compare input; PxB, PxC, PxD assigned as port pins

If CCPxM<3:2> = 11:

00 = Single output; PxA modulated; PxB, PxC, PxD assigned as port pins

01 = Full-Bridge output forward; PxD modulated; PxA active; PxB, PxC inactive

10 = Half-Bridge output; PxA, PxB modulated with dead-band control; PxC, PxD assigned as port pins

11 = Full-Bridge output reverse; PxB modulated; PxC active; PxA, PxD inactive

bit 5-4 **DCxB<1:0>**: PWM Duty Cycle Least Significant bits

Capture mode:

Unused

Compare mode:

Unused

PWM mode:

These bits are the two LSBs of the PWM duty cycle. The eight MSBs are found in CCPRxL.

bit 3-0 **CCPxM<3:0>**: ECCPx Mode Select bits

0000 =Capture/Compare/PWM off (resets ECCPx module)

0001 =Reserved

0010 =Compare mode: toggle output on match

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 ECCPx pin low; set output on compare match (set CCPxIF)

1001 =Compare mode: initialize ECCPx pin high; clear output on compare match (set CCPxIF)

1010 =Compare mode: generate software interrupt only; ECCPx pin reverts to I/O state

1011 =Compare mode: Special Event Trigger (ECCPx resets Timer, sets CCPxIF bit, starts A/D conversion if A/D module is enabled)⁽¹⁾

CCP Modules only:

11xx =PWM mode

ECCP Modules only:

1100 =PWM mode: PxA, PxC active-high; PxB, PxD active-high

1101 =PWM mode: PxA, PxC active-high; PxB, PxD active-low

1110 =PWM mode: PxA, PxC active-low; PxB, PxD active-high

1111 =PWM mode: PxA, PxC active-low; PxB, PxD active-low

Note 1: These bits are not implemented on CCP<4:3>.

REGISTER 24-2: CCPTMRS: PWM TIMER SELECTION CONTROL REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
C4TSEL<1:0>		C3TSEL<1:0>		C2TSEL<1:0>		C1TSEL<1:0>	
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7-6 **C4TSEL<1:0>**: CCP4 Timer Selection
00 =CCP4 is based off Timer 2 in PWM Mode
01 =CCP4 is based off Timer 4 in PWM Mode
10 =CCP4 is based off Timer 6 in PWM Mode
11 =Reserved
- bit 5-4 **C3TSEL<1:0>**: CCP3 Timer Selection
00 =CCP3 is based off Timer 2 in PWM Mode
01 =CCP3 is based off Timer 4 in PWM Mode
10 =CCP3 is based off Timer 6 in PWM Mode
11 =Reserved
- bit 3-2 **C2TSEL<1:0>**: CCP2 Timer Selection
00 =CCP2 is based off Timer 2 in PWM Mode
01 =CCP2 is based off Timer 4 in PWM Mode
10 =CCP2 is based off Timer 6 in PWM Mode
11 =Reserved
- bit 1-0 **C1TSEL<1:0>**: CCP1 Timer Selection
00 =CCP1 is based off Timer 2 in PWM Mode
01 =CCP1 is based off Timer 4 in PWM Mode
10 =CCP1 is based off Timer 6 in PWM Mode
11 =Reserved

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REGISTER 24-3: CCPxAS: CCPx AUTO-SHUTDOWN CONTROL REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
CCPxASE	CCPxAS<2:0>			PSSxAC<1:0>		PSSxBD<1:0>	
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- bit 7 **CCPxASE:** CCPx Auto-Shutdown Event Status bit
1 = A shutdown event has occurred; CCPx outputs are in shutdown state
0 = CCPx outputs are operating
- bit 6-4 **CCxPAS<2:0>:** CCPx Auto-Shutdown Source Select bits
000 = Auto-shutdown is disabled
001 = Comparator C1 output high⁽¹⁾
010 = Comparator C2 output high⁽¹⁾
011 = Either Comparator C1 or C2 high⁽¹⁾
100 = VIL on INT pin
101 = VIL on INT pin or Comparator C1 high⁽¹⁾
110 = VIL on INT pin or Comparator C2 high⁽¹⁾
111 = VIL on INT pin or Comparator C1 or Comparator C2 high⁽¹⁾
- bit 3-2 **PSSxAC<1:0>:** Pins PxA and PxC Shutdown State Control bits
00 = Drive pins PxA and PxC to '0'
01 = Drive pins PxA and PxC to '1'
1x = Pins PxA and PxC tri-state
- bit 1-0 **PSSxBD<1:0>:** Pins PxB and PxD Shutdown State Control bits
00 = Drive pins PxB and PxD to '0'
01 = Drive pins PxB and PxD to '1'
1x = Pins PxB and PxD tri-state

Note 1: If CxSYNC is enabled, the shutdown will be delayed by Timer1.

REGISTER 24-4: PWMxCON: ENHANCED PWM CONTROL REGISTER

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
PxRSEN	PxDC<6:0>						
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

- bit 7 **PxRSEN:** PWM Restart Enable bit
 1 = Upon auto-shutdown, the CCPxASE bit clears automatically once the shutdown event goes away; the PWM restarts automatically
 0 = Upon auto-shutdown, CCPxASE must be cleared in software to restart the PWM
- bit 6-0 **PxDC<6:0>:** PWM Delay Count bits
 PxDCx = Number of Fosc/4 (4 * TOSC) cycles between the scheduled time when a PWM signal **should** transition active and the **actual** time it transitions active

Note 1: Bit resets to '0' with Two-Speed Start-up and LP, XT or HS selected as the Oscillator mode or Fail-Safe mode is enabled.

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REGISTER 24-5: PSTRxCON: PWM STEERING CONTROL REGISTER⁽¹⁾

U-0	U-0	U-0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-1/1
—	—	—	STRxSYNC	STRxD	STRxC	STRxB	STRxA
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7-5 **Unimplemented:** Read as '0'

bit 4 **STRxSYNC:** Steering Sync bit

1 = Output steering update occurs on next PWM period

0 = Output steering update occurs at the beginning of the instruction cycle boundary

bit 3 **STRxD:** Steering Enable bit D

1 = PxD pin has the PWM waveform with polarity control from CCPxM<1:0>

0 = PxD pin is assigned to port pin

bit 2 **STRxC:** Steering Enable bit C

1 = PxC pin has the PWM waveform with polarity control from CCPxM<1:0>

0 = PxC pin is assigned to port pin

bit 1 **STRxB:** Steering Enable bit B

1 = PxB pin has the PWM waveform with polarity control from CCPxM<1:0>

0 = PxB pin is assigned to port pin

bit 0 **STRxA:** Steering Enable bit A

1 = PxA pin has the PWM waveform with polarity control from CCPxM<1:0>

0 = PxA pin is assigned to port pin

Note 1: The PWM Steering mode is available only when the CCPxCON register bits CCPxM<3:2> = 11 and PxM<1:0> = 00.

25.0 MASTER SYNCHRONOUS SERIAL PORT (MSSP1 AND MSSP2) MODULE

25.1 Master SSPx (MSSPx) Module Overview

The Master Synchronous Serial Port (MSSPx) module is a serial interface useful for communicating with other peripheral or microcontroller devices. These peripheral devices may be Serial EEPROMs, shift registers, display drivers, A/D converters, etc. The MSSPx module can operate in one of two modes:

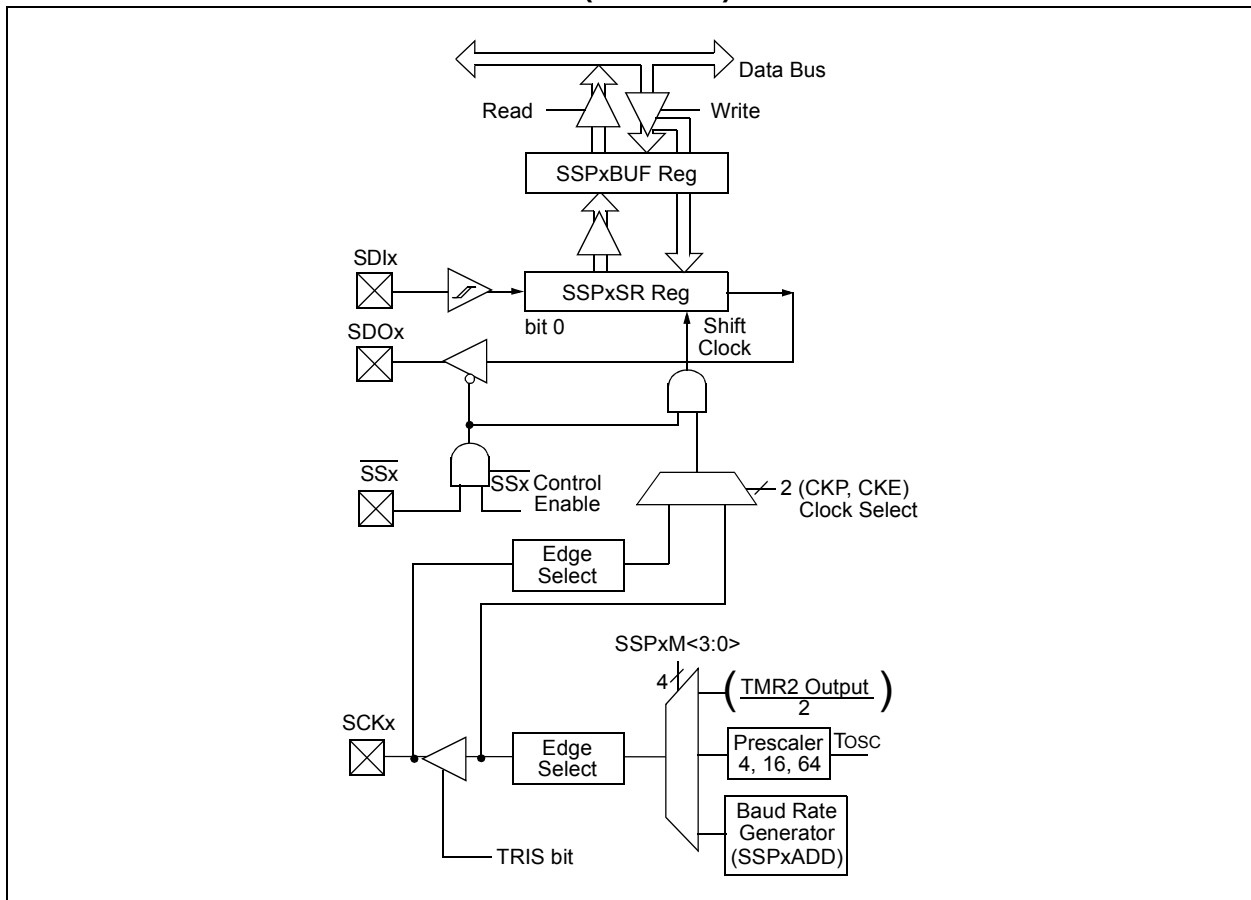
- Serial Peripheral Interface (SPI)
- Inter-Integrated Circuit (I²C™)

The SPI interface supports the following modes and features:

- Master mode
- Slave mode
- Clock Parity
- Slave Select Synchronization (Slave mode only)
- Daisy-chain connection of slave devices

Figure 25-1 is a block diagram of the SPI interface module.

FIGURE 25-1: MSSPX BLOCK DIAGRAM (SPI MODE)



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The I²C interface supports the following modes and features:

- Master mode
- Slave mode
- Byte NACKing (Slave mode)
- Limited Multi-master support
- 7-bit and 10-bit addressing
- Start and Stop interrupts
- Interrupt masking
- Clock stretching
- Bus collision detection
- General call address matching
- Address masking
- Address Hold and Data Hold modes
- Selectable SDAx hold times

Figure 25-2 is a block diagram of the I²C interface module in Master mode. Figure 25-3 is a diagram of the I²C interface module in Slave mode.

The PIC16F1827 has two MSSP modules, MSSP1 and MSSP2, each module operating independently from the other.

Note 1: In devices with more than one MSSP module, it is very important to pay close attention to SSPxCONx register names. SSP1CON1 and SSP1CON2 registers control different operational aspects of the same module, while SSP1CON1 and SSP2CON1 control the same features for two different modules.

2: Throughout this section, generic references to an MSSP module in any of its operating modes may be interpreted as being equally applicable to MSSP1 or MSSP2. Register names, module I/O signals, and bit names may use the generic designator 'x' to indicate the use of a numeral to distinguish a particular module when required.

FIGURE 25-2: MSSPX BLOCK DIAGRAM (I²C™ MASTER MODE)

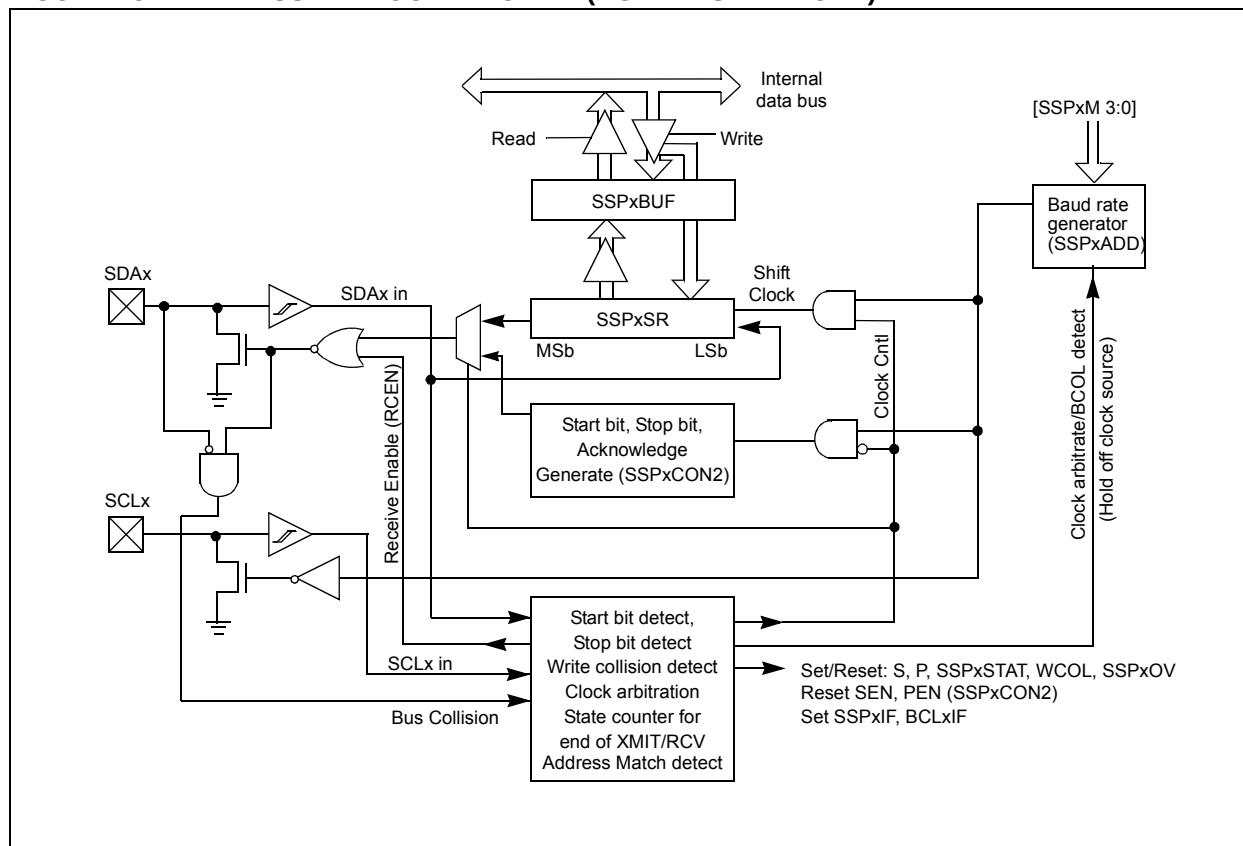
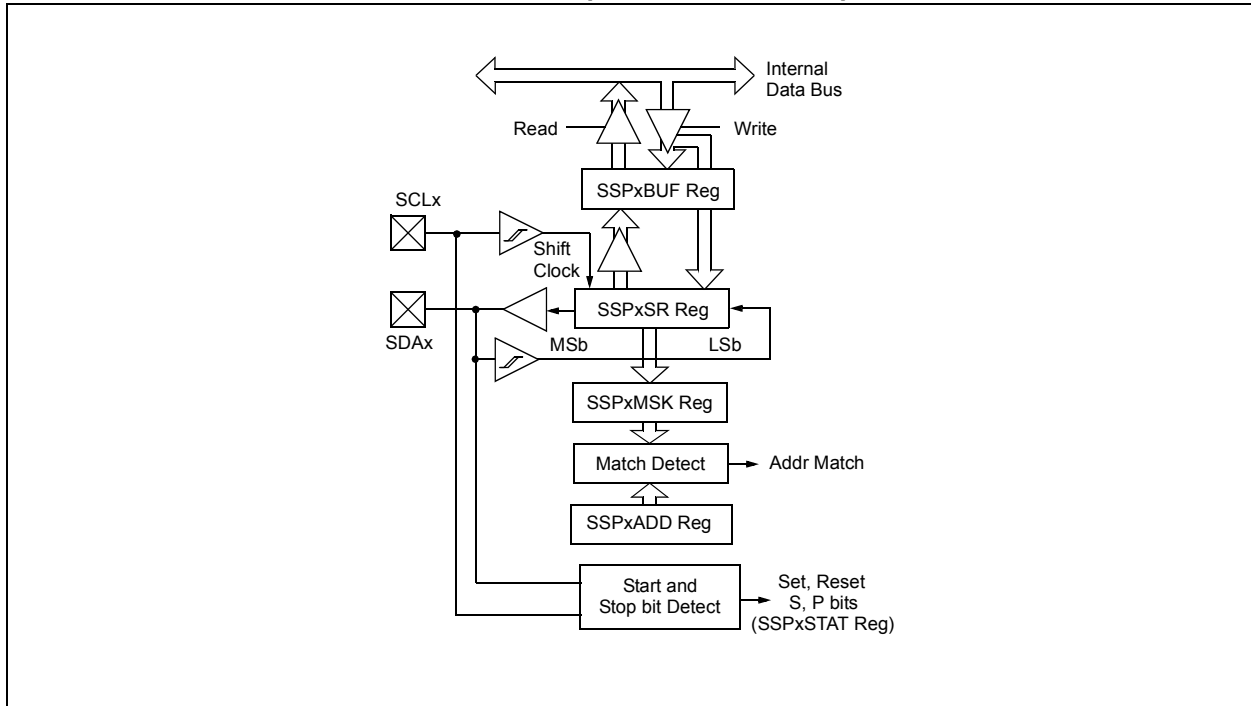


FIGURE 25-3: MSSPX BLOCK DIAGRAM (I²C™ SLAVE MODE)



25.2 SPI Mode Overview

The Serial Peripheral Interface (SPI) bus is a synchronous serial data communication bus that operates in Full-Duplex mode. Devices communicate in a master/slave environment where the master device initiates the communication. A slave device is controlled through a Chip Select known as Slave Select.

The SPI bus specifies four signal connections:

- Serial Clock (SCKx)
- Serial Data Out (SDOx)
- Serial Data In (SDIx)
- Slave Select ($\overline{SSx}$)

Figure 25-1 shows the block diagram of the MSSPx module when operating in SPI Mode.

The SPI bus operates with a single master device and one or more slave devices. When multiple slave devices are used, an independent Slave Select connection is required from the master device to each slave device.

Figure 25-4 shows a typical connection between a master device and multiple slave devices.

The master selects only one slave at a time. Most slave devices have tri-state outputs so their output signal appears disconnected from the bus when they are not selected.

Transmissions involve two shift registers, eight bits in size, one in the master and one in the slave. With either the master or the slave device, data is always shifted out one bit at a time, with the Most Significant bit (MSb) shifted out first. At the same time, a new Least Significant bit (LSb) is shifted into the same register.

Figure 25-5 shows a typical connection between two processors configured as master and slave devices.

Data is shifted out of both shift registers on the programmed clock edge and latched on the opposite edge of the clock.

The master device transmits information out on its SDOx output pin which is connected to, and received by, the slave's SDIx input pin. The slave device transmits information out on its SDOx output pin, which is connected to, and received by, the master's SDIx input pin.

To begin communication, the master device first sends out the clock signal. Both the master and the slave devices should be configured for the same clock polarity.

The master device starts a transmission by sending out the MSb from its shift register. The slave device reads this bit from that same line and saves it into the LSb position of its shift register.

During each SPI clock cycle, a full-duplex data transmission occurs. This means that while the master device is sending out the MSb from its shift register (on its SDOx pin) and the slave device is reading this bit and saving it as the LSb of its shift register, that the slave device is also sending out the MSb from its shift register (on its SDOx pin) and the master device is reading this bit and saving it as the LSb of its shift register.

After 8 bits have been shifted out, the master and slave have exchanged register values.

If there is more data to exchange, the shift registers are loaded with new data and the process repeats itself.

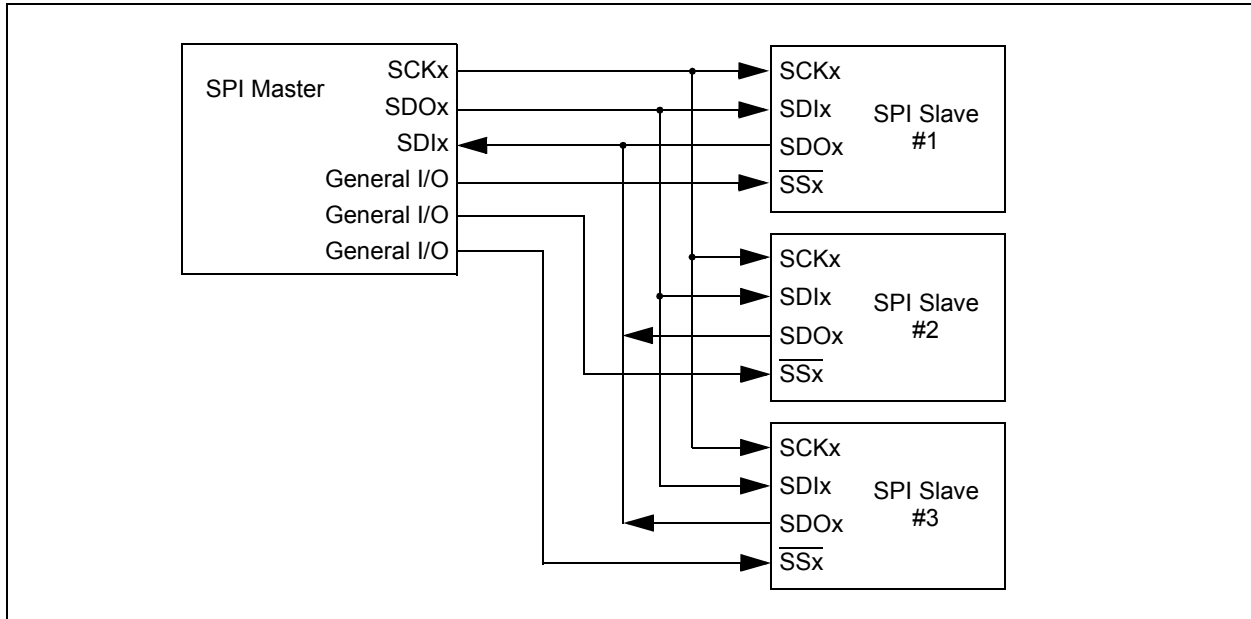
Whether the data is meaningful or not (dummy data), depends on the application software. This leads to three scenarios for data transmission:

- Master sends useful data and slave sends dummy data.
- Master sends useful data and slave sends useful data.
- Master sends dummy data and slave sends useful data.

Transmissions may involve any number of clock cycles. When there is no more data to be transmitted, the master stops sending the clock signal and it deselects the slave.

Every slave device connected to the bus that has not been selected through its slave select line must disregard the clock and transmission signals and must not transmit out any data of its own.

FIGURE 25-4: SPI MASTER AND MULTIPLE SLAVE CONNECTION



25.2.1 SPI MODE REGISTERS

The MSSPx module has five registers for SPI mode operation. These are:

- MSSPx STATUS register (SSPxSTAT)
- MSSPx Control Register 1 (SSPxCON1)
- MSSPx Control Register 3 (SSPxCON3)
- MSSPx Data Buffer register (SSPxBUF)
- MSSPx Address register (SSPxADD)
- MSSPx Shift register (SSPxSR)
(Not directly accessible)

SSPxCON1 and SSPxSTAT are the control and STATUS registers in SPI mode operation. The SSPxCON1 register is readable and writable. The lower 6 bits of the SSPxSTAT are read-only. The upper two bits of the SSPxSTAT are read/write.

In one SPI master mode, SSPxADD can be loaded with a value used in the Baud Rate Generator. More information on the Baud Rate Generator is available in [Section 25.7 "Baud Rate Generator"](#).

SSPxSR is the shift register used for shifting data in and out. SSPxBUF provides indirect access to the SSPxSR register. SSPxBUF is the buffer register to which data bytes are written, and from which data bytes are read.

In receive operations, SSPxSR and SSPxBUF together create a buffered receiver. When SSPxSR receives a complete byte, it is transferred to SSPxBUF and the SSPxIF interrupt is set.

During transmission, the SSPxBUF is not buffered. A write to SSPxBUF will write to both SSPxBUF and SSPxSR.

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25.2.2 SPI MODE OPERATION

When initializing the SPI, several options need to be specified. This is done by programming the appropriate control bits (SSPxCON1<5:0> and SSPxSTAT<7:6>). These control bits allow the following to be specified:

- Master mode (SCKx is the clock output)
- Slave mode (SCKx is the clock input)
- Clock Polarity (Idle state of SCKx)
- Data Input Sample Phase (middle or end of data output time)
- Clock Edge (output data on rising/falling edge of SCKx)
- Clock Rate (Master mode only)
- Slave Select mode (Slave mode only)

To enable the serial port, SSPx Enable bit, SSPxEN of the SSPxCON1 register, must be set. To reset or reconfigure SPI mode, clear the SSPxEN bit, re-initialize the SSPxCONx registers and then set the SSPxEN bit. This configures the SDIx, SDOx, SCKx and $\overline{\text{SSx}}$ pins as serial port pins. For the pins to behave as the serial port function, some must have their data direction bits (in the TRIS register) appropriately programmed as follows:

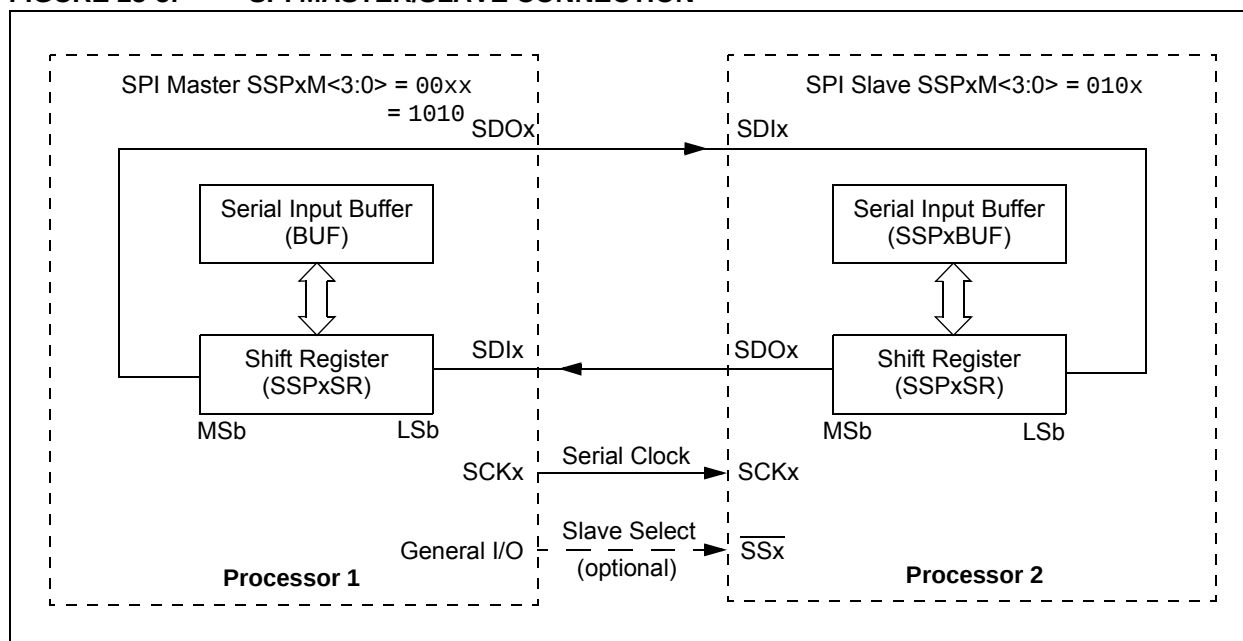
- SDIx must have corresponding TRIS bit set
- SDOx must have corresponding TRIS bit cleared
- SCKx (Master mode) must have corresponding TRIS bit cleared
- SCKx (Slave mode) must have corresponding TRIS bit set
- $\overline{\text{SSx}}$ must have corresponding TRIS bit set

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

The MSSPx consists of a transmit/receive shift register (SSPxSR) and a buffer register (SSPxBUF). The SSPxSR shifts the data in and out of the device, MSb first. The SSPxBUF holds the data that was written to the SSPxSR until the received data is ready. Once the 8 bits of data have been received, that byte is moved to the SSPxBUF register. Then, the Buffer Full Detect bit, BF of the SSPxSTAT register, and the interrupt flag bit, SSPxIF, are set. This double-buffering of the received data (SSPxBUF) allows the next byte to start reception before reading the data that was just received. Any write to the SSPxBUF register during transmission/reception of data will be ignored and the write collision detect bit WCOL of the SSPxCON1 register, will be set. User software must clear the WCOL bit to allow the following write(s) to the SSPxBUF register to complete successfully.

When the application software is expecting to receive valid data, the SSPxBUF should be read before the next byte of data to transfer is written to the SSPxBUF. The Buffer Full bit, BF of the SSPxSTAT register, indicates when SSPxBUF has been loaded with the received data (transmission is complete). When the SSPxBUF is read, the BF bit is cleared. This data may be irrelevant if the SPI is only a transmitter. Generally, the MSSPx interrupt is used to determine when the transmission/reception has completed. If the interrupt method is not going to be used, then software polling can be done to ensure that a write collision does not occur.

FIGURE 25-5: SPI MASTER/SLAVE CONNECTION



25.2.3 SPI MASTER MODE

The master can initiate the data transfer at any time because it controls the SCKx line. The master determines when the slave (Processor 2, [Figure 25-5](#)) is to broadcast data by the software protocol.

In Master mode, the data is transmitted/received as soon as the SSPxBUF register is written to. If the SPI is only going to receive, the SDOx output could be disabled (programmed as an input). The SSPxSR register will continue to shift in the signal present on the SDIx pin at the programmed clock rate. As each byte is received, it will be loaded into the SSPxBUF register as if a normal received byte (interrupts and Status bits appropriately set).

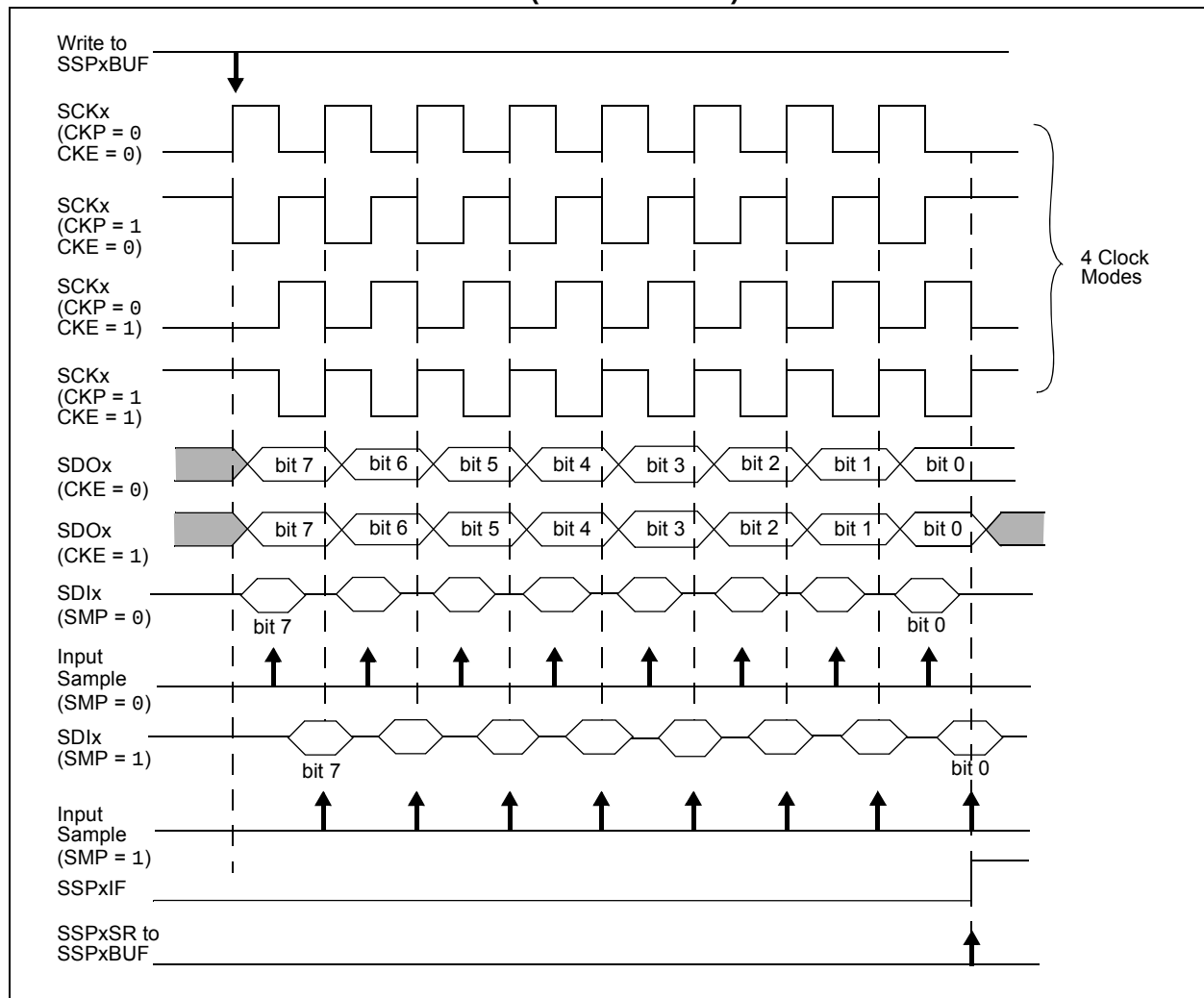
The clock polarity is selected by appropriately programming the CKP bit of the SSPxCON1 register and the CKE bit of the SSPxSTAT register. This then, would give waveforms for SPI communication as shown in [Figure 25-6](#), [Figure 25-8](#) and [Figure 25-9](#), where the MSB is transmitted first. In Master mode, the SPI clock rate (bit rate) is user programmable to be one of the following:

- $F_{osc}/4$ (or T_{CY})
- $F_{osc}/16$ (or $4 * T_{CY}$)
- $F_{osc}/64$ (or $16 * T_{CY}$)
- Timer2 output/2
- $F_{osc}/(4 * (SSPxADD + 1))$

[Figure 25-6](#) shows the waveforms for Master mode.

When the CKE bit is set, the SDOx data is valid before there is a clock edge on SCKx. The change of the input sample is shown based on the state of the SMP bit. The time when the SSPxBUF is loaded with the received data is shown.

FIGURE 25-6: SPI MODE WAVEFORM (MASTER MODE)



25.2.4 SPI SLAVE MODE

In Slave mode, the data is transmitted and received as external clock pulses appear on SCKx. When the last bit is latched, the SSPxIF interrupt flag bit is set.

Before enabling the module in SPI Slave mode, the clock line must match the proper Idle state. The clock line can be observed by reading the SCKx pin. The Idle state is determined by the CKP bit of the SSPxCON1 register.

While in Slave mode, the external clock is supplied by the external clock source on the SCKx pin. This external clock must meet the minimum high and low times as specified in the electrical specifications.

While in Sleep mode, the slave can transmit/receive data. The shift register is clocked from the SCKx pin input and when a byte is received, the device will generate an interrupt. If enabled, the device will wake-up from Sleep.

25.2.4.1 Daisy-Chain Configuration

The SPI bus can sometimes be connected in a daisy-chain configuration. The first slave output is connected to the second slave input, the second slave output is connected to the third slave input, and so on. The final slave output is connected to the master input. Each slave sends out, during a second group of clock pulses, an exact copy of what was received during the first group of clock pulses. The whole chain acts as one large communication shift register. The daisy-chain feature only requires a single Slave Select line from the master device.

Figure 25-7 shows the block diagram of a typical daisy-chain connection when operating in SPI Mode.

In a daisy-chain configuration, only the most recent byte on the bus is required by the slave. Setting the BOEN bit of the SSPxCON3 register will enable writes to the SSPxBUF register, even if the previous byte has not been read. This allows the software to ignore data that may not apply to it.

25.2.5 SLAVE SELECT SYNCHRONIZATION

The Slave Select can also be used to synchronize communication. The Slave Select line is held high until the master device is ready to communicate. When the Slave Select line is pulled low, the slave knows that a new transmission is starting.

If the slave fails to receive the communication properly, it will be reset at the end of the transmission, when the Slave Select line returns to a high state. The slave is then ready to receive a new transmission when the Slave Select line is pulled low again. If the Slave Select line is not used, there is a risk that the slave will eventually become out of sync with the master. If the slave misses a bit, it will always be one bit off in future transmissions. Use of the Slave Select line allows the slave and master to align themselves at the beginning of each transmission.

The $\overline{\text{SSx}}$ pin allows a Synchronous Slave mode. The SPI must be in Slave mode with $\overline{\text{SSx}}$ pin control enabled (SSPxCON1<3:0> = 0100).

When the $\overline{\text{SSx}}$ pin is low, transmission and reception are enabled and the SDOx pin is driven.

When the $\overline{\text{SSx}}$ pin goes high, the SDOx pin is no longer driven, even if in the middle of a transmitted byte and becomes a floating output. External pull-up/pull-down resistors may be desirable depending on the application.

- Note 1:** When the SPI is in Slave mode with $\overline{\text{SSx}}$ pin control enabled (SSPxCON1<3:0> = 0100), the SPI module will reset if the $\overline{\text{SSx}}$ pin is set to VDD.

2: When the SPI is used in Slave mode with CKE set; the user must enable $\overline{\text{SSx}}$ pin control.

3: While operated in SPI Slave mode the SMP bit of the SSPxSTAT register must remain clear.

When the SPI module resets, the bit counter is forced to '0'. This can be done by either forcing the $\overline{\text{SSx}}$ pin to a high level or clearing the SSPxEN bit.

FIGURE 25-7: SPI DAISY-CHAIN CONNECTION

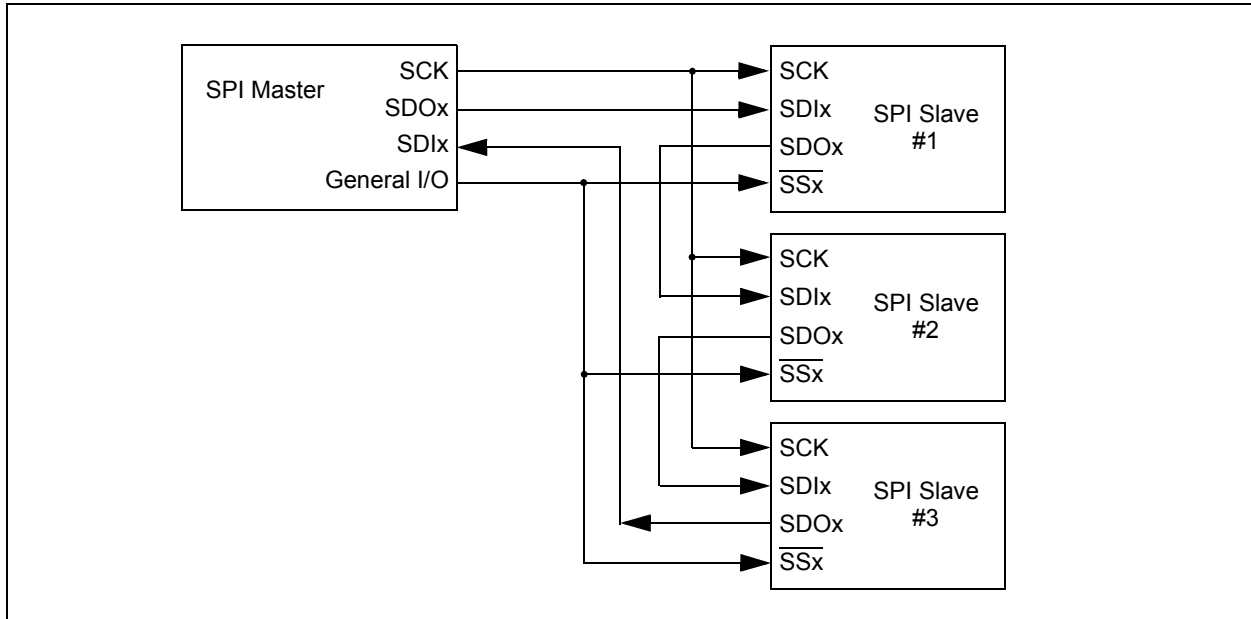
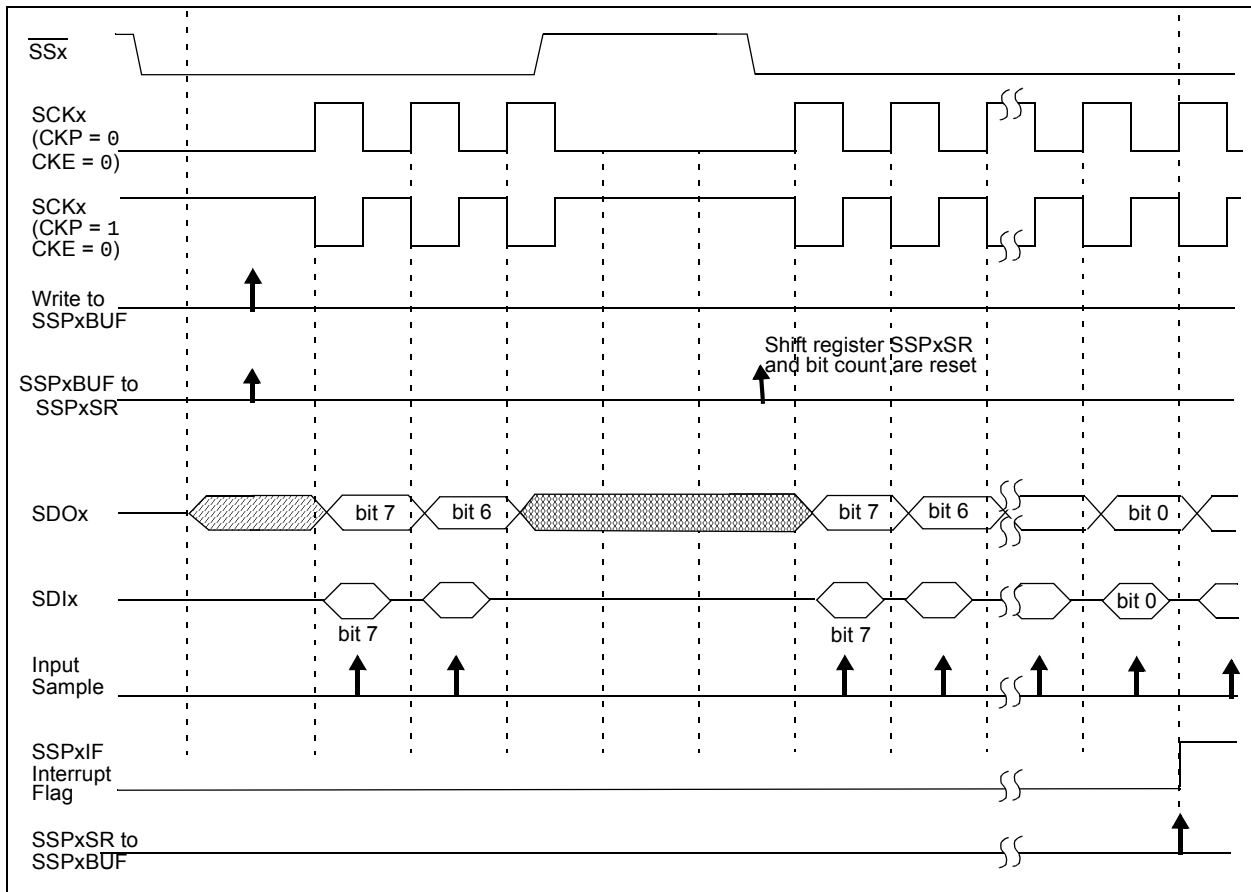


FIGURE 25-8: SLAVE SELECT SYNCHRONOUS WAVEFORM



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FIGURE 25-9: SPI MODE WAVEFORM (SLAVE MODE WITH CKE = 0)

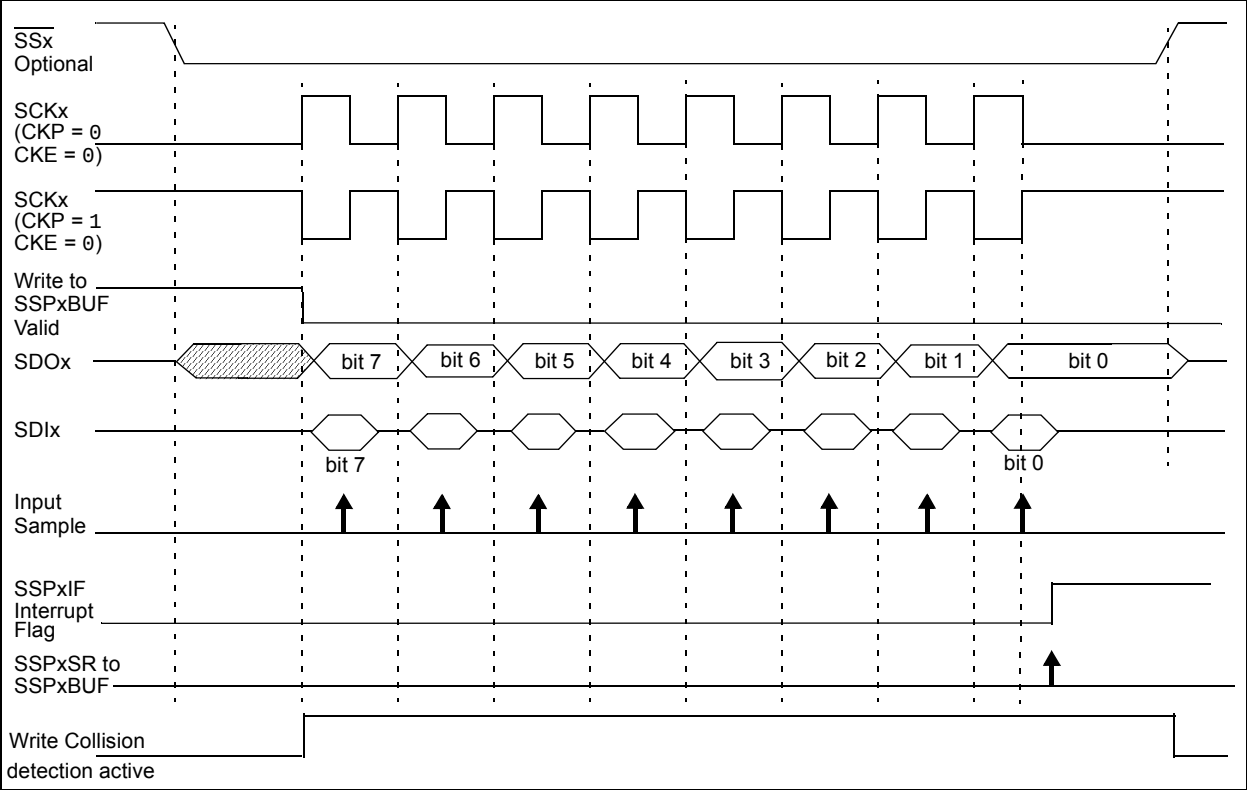
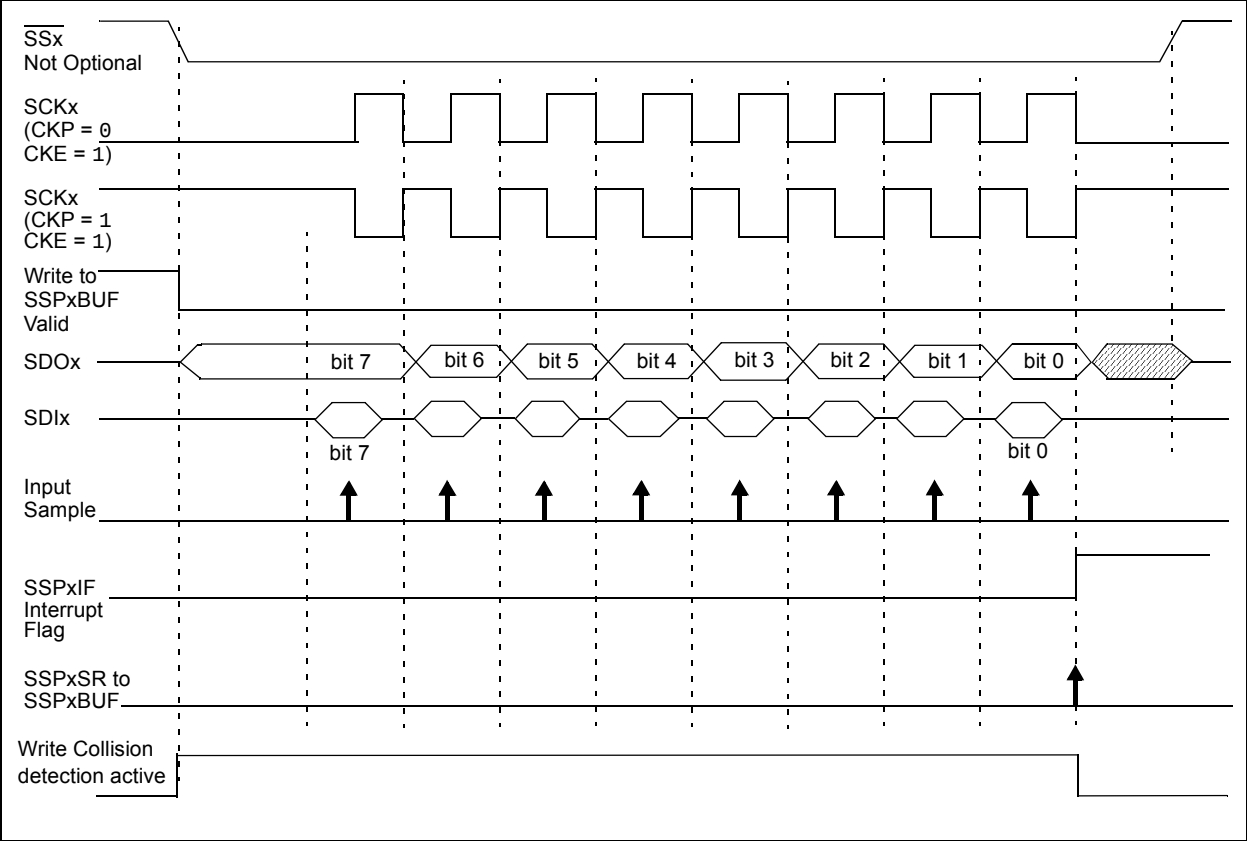


FIGURE 25-10: SPI MODE WAVEFORM (SLAVE MODE WITH CKE = 1)



25.2.6 SPI OPERATION IN SLEEP MODE

In SPI Master mode, module clocks may be operating at a different speed than when in full power mode; in the case of the Sleep mode, all clocks are halted.

Special care must be taken by the user when the MSSPx clock is much faster than the system clock.

In Slave mode, when MSSPx interrupts are enabled, after the master completes sending data, an MSSPx interrupt will wake the controller from Sleep.

If an exit from Sleep mode is not desired, MSSPx interrupts should be disabled.

In SPI Master mode, when the Sleep mode is selected, all module clocks are halted and the transmission/reception will remain in that state until the device wakes. After the device returns to Run mode, the module will resume transmitting and receiving data.

In SPI Slave mode, the SPI Transmit/Receive Shift register operates asynchronously to the device. This allows the device to be placed in Sleep mode and data to be shifted into the SPI Transmit/Receive Shift register. When all 8 bits have been received, the MSSPx interrupt flag bit will be set and if enabled, will wake the device.

TABLE 25-1: SUMMARY OF REGISTERS ASSOCIATED WITH SPI OPERATION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSEL	SDO1SEL	SS1SEL	P2BSEL ⁽¹⁾	CCP2SEL ⁽¹⁾	P1DSEL	P1CSEL	CCP1SEL	119
ANSELA	—	—	—	ANSA4	ANSA3	ANSA2	ANSA1	ANSA0	123
ANSELB	ANSB7	ANSB6	ANSB5	ANSB4	ANSB3	ANSB2	ANSB1	—	128
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF	91
SSPxBUF	Synchronous Serial Port Receive Buffer/Transmit Register								235*
SSPxCON1	WCOL	SSPxOV	SSPxEN	CKP	SSPxM3	SSPxM2	SSPxM1	SSPxM0	280
SSPxCON3	ACKTIM	PCIE	SCIE	BOEN	SDAHT	SBCDE	AHEN	DHEN	282
SSPxSTAT	SMP	CKE	D/ $\bar{A}$	P	S	R/ $\bar{W}$	UA	BF	279
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127

Legend: — = Unimplemented location, read as '0'. Shaded cells are not used by the MSSPx in SPI mode.

* Page provides register information.

Note 1: PIC16(L)F1827 only.

25.3 I²C MODE OVERVIEW

The Inter-Integrated Circuit Bus (I²C) is a multi-master serial data communication bus. Devices communicate in a master/slave environment where the master devices initiate the communication. A Slave device is controlled through addressing.

The I²C bus specifies two signal connections:

- Serial Clock (SCLx)
- Serial Data (SDAx)

Figure 25-11 shows the block diagram of the MSSPx module when operating in I²C Mode.

Both the SCLx and SDAx connections are bidirectional open-drain lines, each requiring pull-up resistors for the supply voltage. Pulling the line to ground is considered a logical zero and letting the line float is considered a logical one.

Figure 25-11 shows a typical connection between two processors configured as master and slave devices.

The I²C bus can operate with one or more master devices and one or more slave devices.

There are four potential modes of operation for a given device:

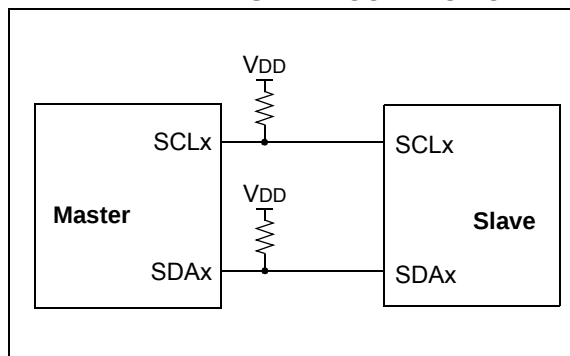
- Master Transmit mode
(master is transmitting data to a slave)
- Master Receive mode
(master is receiving data from a slave)
- Slave Transmit mode
(slave is transmitting data to a master)
- Slave Receive mode
(slave is receiving data from the master)

To begin communication, a master device starts out in Master Transmit mode. The master device sends out a Start bit followed by the address byte of the slave it intends to communicate with. This is followed by a single Read/Write bit, which determines whether the master intends to transmit to or receive data from the slave device.

If the requested slave exists on the bus, it will respond with an Acknowledge bit, otherwise known as an ACK. The master then continues in either Transmit mode or Receive mode and the slave continues in the complement, either in Receive mode or Transmit mode, respectively.

A Start bit is indicated by a high-to-low transition of the SDAx line while the SCLx line is held high. Address and data bytes are sent out, Most Significant bit (MSb) first. The Read/Write bit is sent out as a logical one when the master intends to read data from the slave, and is sent out as a logical zero when it intends to write data to the slave.

FIGURE 25-11: I²C MASTER/SLAVE CONNECTION



The Acknowledge bit ($\overline{\text{ACK}}$) is an active-low signal, which holds the SDAx line low to indicate to the transmitter that the slave device has received the transmitted data and is ready to receive more.

The transition of a data bit is always performed while the SCLx line is held low. Transitions that occur while the SCLx line is held high are used to indicate Start and Stop bits.

If the master intends to write to the slave, then it repeatedly sends out a byte of data, with the slave responding after each byte with an $\overline{\text{ACK}}$ bit. In this example, the master device is in Master Transmit mode and the slave is in Slave Receive mode.

If the master intends to read from the slave, then it repeatedly receives a byte of data from the slave, and responds after each byte with an $\overline{\text{ACK}}$ bit. In this example, the master device is in Master Receive mode and the slave is Slave Transmit mode.

On the last byte of data communicated, the master device may end the transmission by sending a Stop bit. If the master device is in Receive mode, it sends the Stop bit in place of the last ACK bit. A Stop bit is indicated by a low-to-high transition of the SDAx line while the SCLx line is held high.

In some cases, the master may want to maintain control of the bus and re-initiate another transmission. If so, the master device may send another Start bit in place of the Stop bit or last $\overline{\text{ACK}}$ bit when it is in receive mode.

The I²C bus specifies three message protocols;

- Single message where a master writes data to a slave.
- Single message where a master reads data from a slave.
- Combined message where a master initiates a minimum of two writes, or two reads, or a combination of writes and reads, to one or more slaves.

When one device is transmitting a logical one, or letting the line float, and a second device is transmitting a logical zero, or holding the line low, the first device can detect that the line is not a logical one. This detection, when used on the SCLx line, is called clock stretching. Clock stretching gives slave devices a mechanism to control the flow of data. When this detection is used on the SDAx line, it is called arbitration. Arbitration ensures that there is only one master device communicating at any single time.

25.3.1 CLOCK STRETCHING

When a slave device has not completed processing data, it can delay the transfer of more data through the process of Clock Stretching. An addressed slave device may hold the SCLx clock line low after receiving or sending a bit, indicating that it is not yet ready to continue. The master that is communicating with the slave will attempt to raise the SCLx line in order to transfer the next bit, but will detect that the clock line has not yet been released. Because the SCLx connection is open-drain, the slave has the ability to hold that line low until it is ready to continue communicating.

Clock stretching allows receivers that cannot keep up with a transmitter to control the flow of incoming data.

25.3.2 ARBITRATION

Each master device must monitor the bus for Start and Stop bits. If the device detects that the bus is busy, it cannot begin a new message until the bus returns to an Idle state.

However, two master devices may try to initiate a transmission on or about the same time. When this occurs, the process of arbitration begins. Each transmitter checks the level of the SDAx data line and compares it to the level that it expects to find. The first transmitter to observe that the two levels don't match, loses arbitration, and must stop transmitting on the SDAx line.

For example, if one transmitter holds the SDAx line to a logical one (lets it float) and a second transmitter holds it to a logical zero (pulls it low), the result is that the SDAx line will be low. The first transmitter then observes that the level of the line is different than expected and concludes that another transmitter is communicating.

The first transmitter to notice this difference is the one that loses arbitration and must stop driving the SDAx line. If this transmitter is also a master device, it also must stop driving the SCLx line. It then can monitor the lines for a Stop condition before trying to reissue its transmission. In the meantime, the other device that has not noticed any difference between the expected and actual levels on the SDAx line continues with its original transmission. It can do so without any complications, because so far, the transmission appears exactly as expected with no other transmitter disturbing the message.

Slave Transmit mode can also be arbitrated, when a master addresses multiple slaves, but this is less common.

If two master devices are sending a message to two different slave devices at the address stage, the master sending the lower slave address always wins arbitration. When two master devices send messages to the same slave address, and addresses can sometimes refer to multiple slaves, the arbitration process must continue into the data stage.

Arbitration usually occurs very rarely, but it is a necessary process for proper multi-master support.

25.4 I²C MODE OPERATION

All MSSPx I²C communication is byte oriented and shifted out MSb first. Six SFR registers and 2 interrupt flags interface the module with the PIC[®] microcontroller and user software. Two pins, SDAx and SCLx, are exercised by the module to communicate with other external I²C devices.

25.4.1 BYTE FORMAT

All communication in I²C is done in 9-bit segments. A byte is sent from a Master to a Slave or vice-versa, followed by an Acknowledge bit sent back. After the 8th falling edge of the SCLx line, the device outputting data on the SDAx changes that pin to an input and reads in an acknowledge value on the next clock pulse.

The clock signal, SCLx, is provided by the master. Data is valid to change while the SCLx signal is low, and sampled on the rising edge of the clock. Changes on the SDAx line while the SCLx line is high define special conditions on the bus, explained below.

25.4.2 DEFINITION OF I²C TERMINOLOGY

There is language and terminology in the description of I²C communication that have definitions specific to I²C. That word usage is defined below and may be used in the rest of this document without explanation. This table was adapted from the Philips I²C specification.

25.4.3 SDAX AND SCLX PINS

Selection of any I²C mode with the SSPxEN bit set, forces the SCLx and SDAx pins to be open-drain. These pins should be set by the user to inputs by setting the appropriate TRIS bits.

Note: Data is tied to output zero when an I²C mode is enabled.

25.4.4 SDAX HOLD TIME

The hold time of the SDAx pin is selected by the SDAHT bit of the SSPxCON3 register. Hold time is the time SDAx is held valid after the falling edge of SCLx. Setting the SDAHT bit selects a longer 300 ns minimum hold time and may help on buses with large capacitance.

TABLE 25-2: I²C BUS TERMS

TERM	Description
Transmitter	The device which shifts data out onto the bus.
Receiver	The device which shifts data in from the bus.
Master	The device that initiates a transfer, generates clock signals and terminates a transfer.
Slave	The device addressed by the master.
Multi-master	A bus with more than one device that can initiate data transfers.
Arbitration	Procedure to ensure that only one master at a time controls the bus. Winning arbitration ensures that the message is not corrupted.
Synchronization	Procedure to synchronize the clocks of two or more devices on the bus.
Idle	No master is controlling the bus, and both SDAx and SCLx lines are high.
Active	Any time one or more master devices are controlling the bus.
Addressed Slave	Slave device that has received a matching address and is actively being clocked by a master.
Matching Address	Address byte that is clocked into a slave that matches the value stored in SSPxADD.
Write Request	Slave receives a matching address with R/W bit clear, and is ready to clock in data.
Read Request	Master sends an address byte with the R/W bit set, indicating that it wishes to clock data out of the Slave. This data is the next and all following bytes until a Restart or Stop.
Clock Stretching	When a device on the bus hold SCLx low to stall communication.
Bus Collision	Any time the SDAx line is sampled low by the module while it is outputting and expected high state.

25.4.5 START CONDITION

The I²C specification defines a Start condition as a transition of SDAx from a high to a low state while SCLx line is high. A Start condition is always generated by the master and signifies the transition of the bus from an Idle to an Active state. Figure 25-10 shows wave forms for Start and Stop conditions.

A bus collision can occur on a Start condition if the module samples the SDAx line low before asserting it low. This does not conform to the I²C Specification that states no bus collision can occur on a Start.

25.4.6 STOP CONDITION

A Stop condition is a transition of the SDAx line from low-to-high state while the SCLx line is high.

Note: At least one SCLx low time must appear before a Stop is valid, therefore, if the SDAx line goes low then high again while the SCLx line stays high, only the Start condition is detected.

25.4.7 RESTART CONDITION

A Restart is valid any time that a Stop would be valid. A master can issue a Restart if it wishes to hold the bus after terminating the current transfer. A Restart has the same effect on the slave that a Start would, resetting all slave logic and preparing it to clock in an address. The master may want to address the same or another slave.

In 10-bit Addressing Slave mode a Restart is required for the master to clock data out of the addressed slave. Once a slave has been fully addressed, matching both high and low address bytes, the master can issue a Restart and the high address byte with the R/W bit set. The slave logic will then hold the clock and prepare to clock out data.

After a full match with R/W clear in 10-bit mode, a prior match flag is set and maintained. Until a Stop condition, a high address with R/W clear, or high address match fails.

25.4.8 START/STOP CONDITION INTERRUPT MASKING

The SCIE and PCIE bits of the SSPxCON3 register can enable the generation of an interrupt in Slave modes that do not typically support this function. Slave modes where interrupt on Start and Stop detect are already enabled, these bits will have no effect.

FIGURE 25-12: I²C START AND STOP CONDITIONS

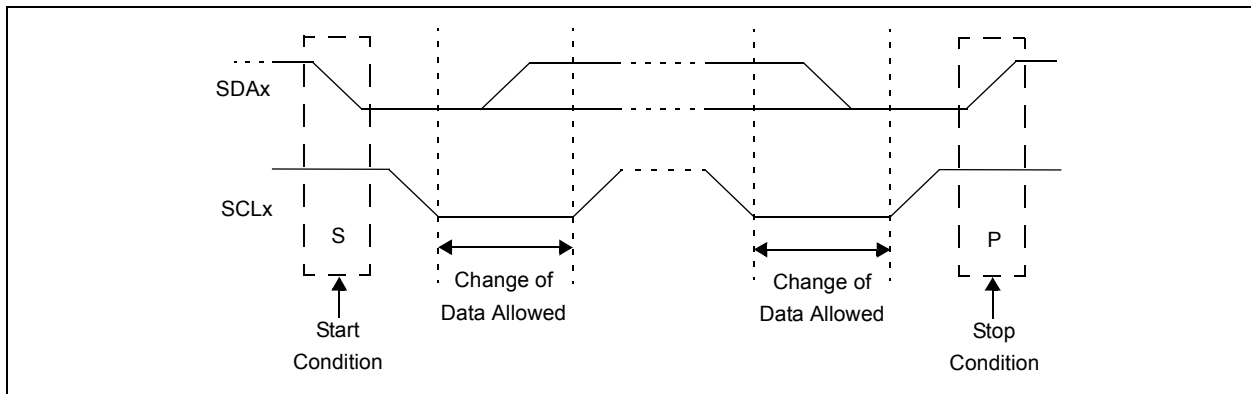
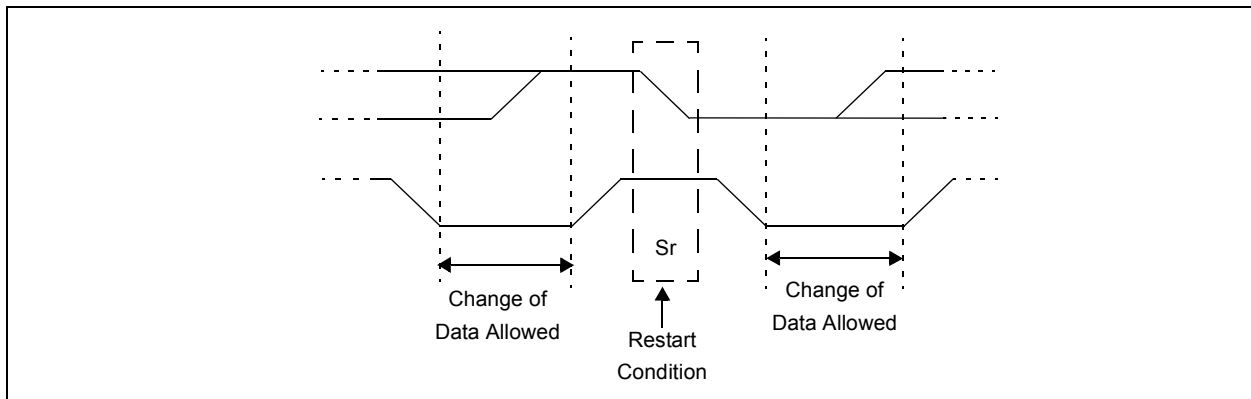


FIGURE 25-13: I²C RESTART CONDITION



25.4.9 ACKNOWLEDGE SEQUENCE

The 9th SCLx pulse for any transferred byte in I²C is dedicated as an Acknowledge. It allows receiving devices to respond back to the transmitter by pulling the SDAx line low. The transmitter must release control of the line during this time to shift in the response. The Acknowledge (ACK) is an active-low signal, pulling the SDAx line low indicated to the transmitter that the device has received the transmitted data and is ready to receive more.

The result of an $\overline{\text{ACK}}$ is placed in the ACKSTAT bit of the SSPxCON2 register.

Slave software, when the AHEN and DHEN bits are set, allow the user to set the $\overline{\text{ACK}}$ value sent back to the transmitter. The ACKDT bit of the SSPxCON2 register is set/cleared to determine the response.

Slave hardware will generate an $\overline{\text{ACK}}$ response if the AHEN and DHEN bits of the SSPxCON3 register are clear.

There are certain conditions where an $\overline{\text{ACK}}$ will not be sent by the slave. If the BF bit of the SSPxSTAT register or the SSPxOV bit of the SSPxCON1 register are set when a byte is received.

When the module is addressed, after the 8th falling edge of SCLx on the bus, the ACKTIM bit of the SSPxCON3 register is set. The ACKTIM bit indicates the acknowledge time of the active bus. The ACKTIM Status bit is only active when the AHEN bit or DHEN bit is enabled.

25.5 I²C SLAVE MODE OPERATION

The MSSPx Slave mode operates in one of four modes selected in the SSPxM bits of SSPxCON1 register. The modes can be divided into 7-bit and 10-bit Addressing mode. 10-bit Addressing modes operate the same as 7-bit with some additional overhead for handling the larger addresses.

Modes with Start and Stop bit interrupts operated the same as the other modes with SSPxIF additionally getting set upon detection of a Start, Restart, or Stop condition.

25.5.1 SLAVE MODE ADDRESSES

The SSPxADD register ([Register 25-6](#)) contains the Slave mode address. The first byte received after a Start or Restart condition is compared against the value stored in this register. If the byte matches, the value is loaded into the SSPxBUF register and an interrupt is generated. If the value does not match, the module goes Idle and no indication is given to the software that anything happened.

The SSPx Mask register ([Register 25-5](#)) affects the address matching process. See [Section 25.5.9 "SSPx Mask Register"](#) for more information.

25.5.1.1 I²C Slave 7-bit Addressing Mode

In 7-bit Addressing mode, the LSb of the received data byte is ignored when determining if there is an address match.

25.5.1.2 I²C Slave 10-bit Addressing Mode

In 10-bit Addressing mode, the first received byte is compared to the binary value of '1 1 1 1 0 A9 A8 0'. A9 and A8 are the two MSb of the 10-bit address and stored in bits 2 and 1 of the SSPxADD register.

After the acknowledge of the high byte the UA bit is set and SCLx is held low until the user updates SSPxADD with the low address. The low address byte is clocked in and all 8 bits are compared to the low address value in SSPxADD. Even if there is not an address match; SSPxIF and UA are set, and SCLx is held low until SSPxADD is updated to receive a high byte again. When SSPxADD is updated the UA bit is cleared. This ensures the module is ready to receive the high address byte on the next communication.

A high and low address match as a write request is required at the start of all 10-bit addressing communication. A transmission can be initiated by issuing a Restart once the slave is addressed, and clocking in the high address with the R/W bit set. The slave hardware will then acknowledge the read request and prepare to clock out data. This is only valid for a slave after it has received a complete high and low address byte match.

25.5.2 SLAVE RECEPTION

When the $\overline{R/\overline{W}}$ bit of a matching received address byte is clear, the $\overline{R/\overline{W}}$ bit of the SSPxSTAT register is cleared. The received address is loaded into the SSPx-BUF register and acknowledged.

When the overflow condition exists for a received address, then not Acknowledge is given. An overflow condition is defined as either bit BF of the SSPxSTAT register is set, or bit SSPxOV of the SSPxCON1 register is set. The BOEN bit of the SSPxCON3 register modifies this operation. For more information see [Register 25-4](#).

An MSSPx interrupt is generated for each transferred data byte. Flag bit, SSPxIF, must be cleared by software.

When the SEN bit of the SSPxCON2 register is set, SCLx will be held low (clock stretch) following each received byte. The clock must be released by setting the CKP bit of the SSPxCON1 register, except sometimes in 10-bit mode. See [Section 25.2.3 "SPI Master Mode"](#) for more detail.

25.5.2.1 7-bit Addressing Reception

This section describes a standard sequence of events for the MSSPx module configured as an I²C Slave in 7-bit Addressing mode. All decisions made by hardware or software and their effect on reception. [Figure 25-13](#) and [Figure 25-14](#) is used as a visual reference for this description.

This is a step by step process of what typically must be done to accomplish I²C communication.

1. Start bit detected.
2. S bit of SSPxSTAT is set; SSPxIF is set if interrupt on Start detect is enabled.
3. Matching address with $\overline{R/\overline{W}}$ bit clear is received.
4. The slave pulls SDAx low sending an $\overline{ACK}$ to the master, and sets SSPxIF bit.
5. Software clears the SSPxIF bit.
6. Software reads received address from SSPx-BUF clearing the BF flag.
7. If SEN = 1; Slave software sets CKP bit to release the SCLx line.
8. The master clocks out a data byte.
9. Slave drives SDAx low sending an $\overline{ACK}$ to the master, and sets SSPxIF bit.
10. Software clears SSPxIF.
11. Software reads the received byte from SSPx-BUF clearing BF.
12. Steps 8-12 are repeated for all received bytes from the Master.
13. Master sends Stop condition, setting P bit of SSPxSTAT, and the bus goes Idle.

25.5.2.2 7-bit Reception with AHEN and DHEN

Slave device reception with AHEN and DHEN set operate the same as without these options with extra interrupts and clock stretching added after the 8th falling edge of SCLx. These additional interrupts allow the slave software to decide whether it wants to ACK the receive address or data byte, rather than the hardware. This functionality adds support for PMBus™ that was not present on previous versions of this module.

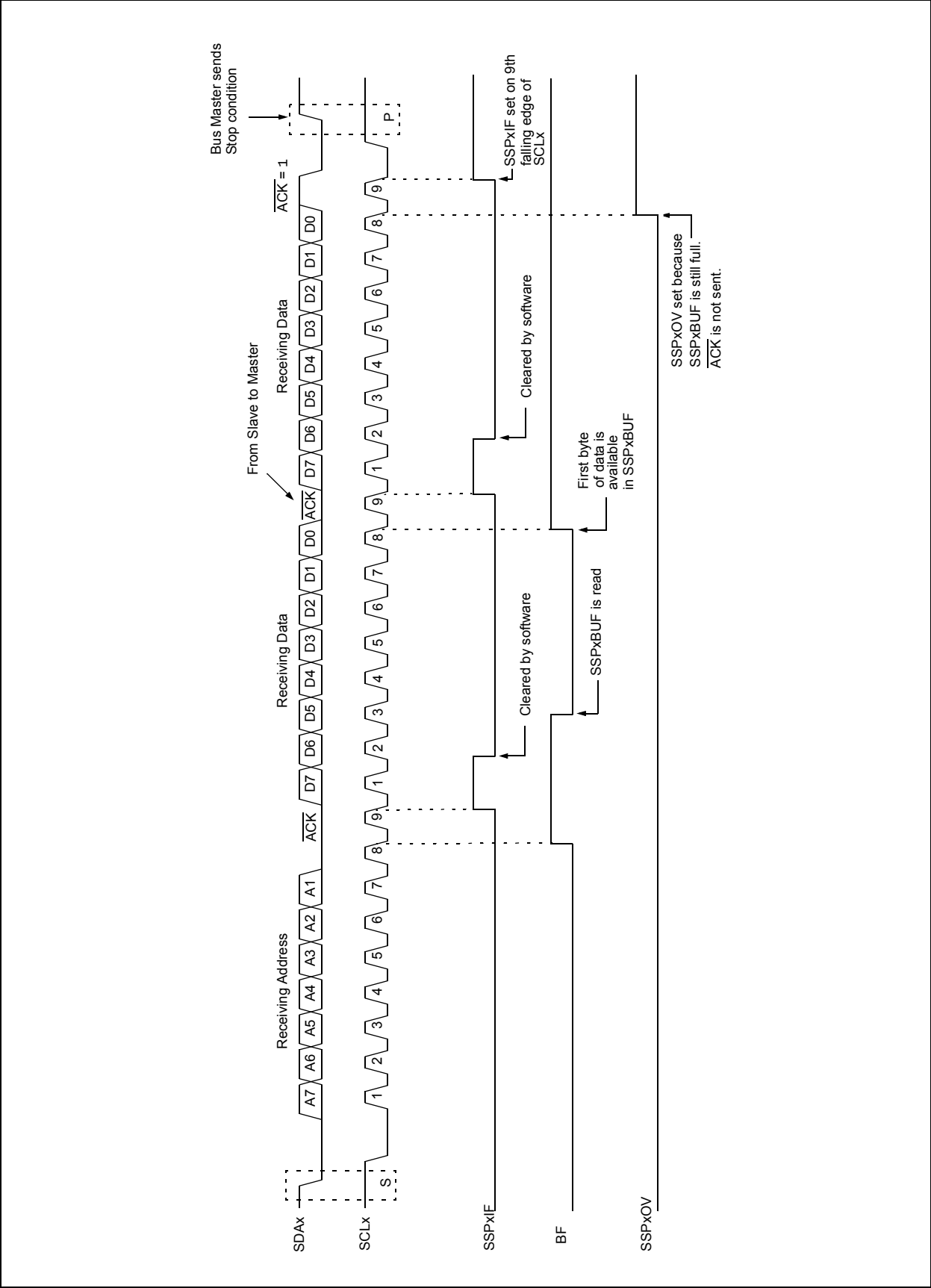
This list describes the steps that need to be taken by slave software to use these options for I²C communication. [Figure 25-15](#) displays a module using both address and data holding. [Figure 25-16](#) includes the operation with the SEN bit of the SSPxCON2 register set.

1. S bit of SSPxSTAT is set; SSPxIF is set if interrupt on Start detect is enabled.
2. Matching address with $\overline{R/\overline{W}}$ bit clear is clocked in. SSPxIF is set and CKP cleared after the 8th falling edge of SCLx.
3. Slave clears the SSPxIF.
4. Slave can look at the ACKTIM bit of the SSPxCON3 register to determine if the SSPxIF was after or before the $\overline{ACK}$.
5. Slave reads the address value from SSPxBUF, clearing the BF flag.
6. Slave sets $\overline{ACK}$ value clocked out to the master by setting ACKDT.
7. Slave releases the clock by setting CKP.
8. SSPxIF is set after an $\overline{ACK}$, not after a NACK.
9. If SEN = 1 the slave hardware will stretch the clock after the $\overline{ACK}$.
10. Slave clears SSPxIF.

Note: SSPxIF is still set after the 9th falling edge of SCLx even if there is no clock stretching and BF has been cleared. Only if NACK is sent to Master is SSPxIF not set

11. SSPxIF set and CKP cleared after 8th falling edge of SCLx for a received data byte.
12. Slave looks at ACKTIM bit of SSPxCON3 to determine the source of the interrupt.
13. Slave reads the received data from SSPxBUF clearing BF.
14. Steps 7-14 are the same for each received data byte.
15. Communication is ended by either the slave sending an $\overline{ACK} = 1$, or the master sending a Stop condition. If a Stop is sent and Interrupt on Stop Detect is disabled, the slave will only know by polling the P bit of the SSTSTAT register.

FIGURE 25-14: I²C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 0, AHEN = 0, DHEN = 0)



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FIGURE 25-16: I²C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 0, AHEN = 1, DHEN = 1)

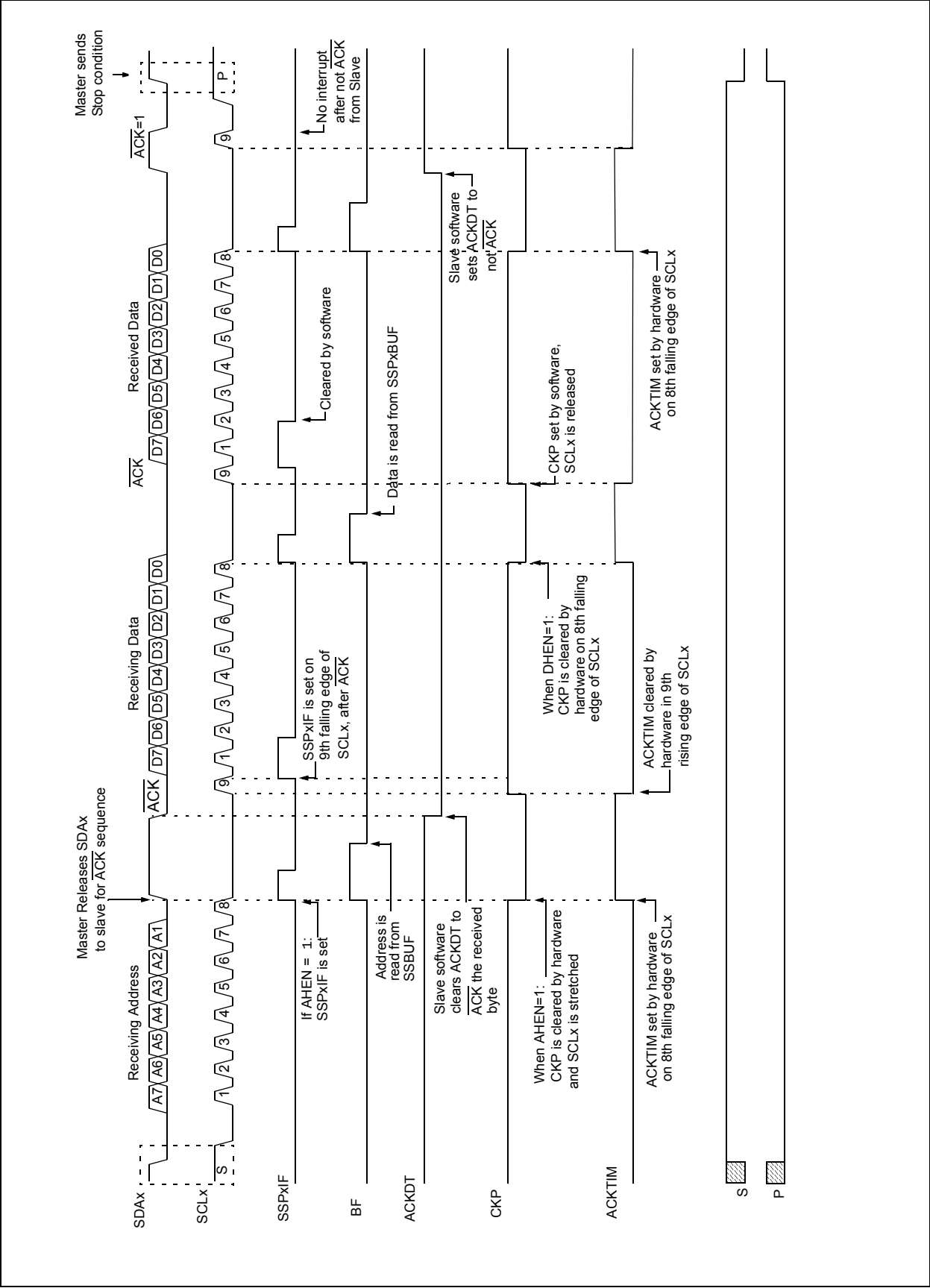
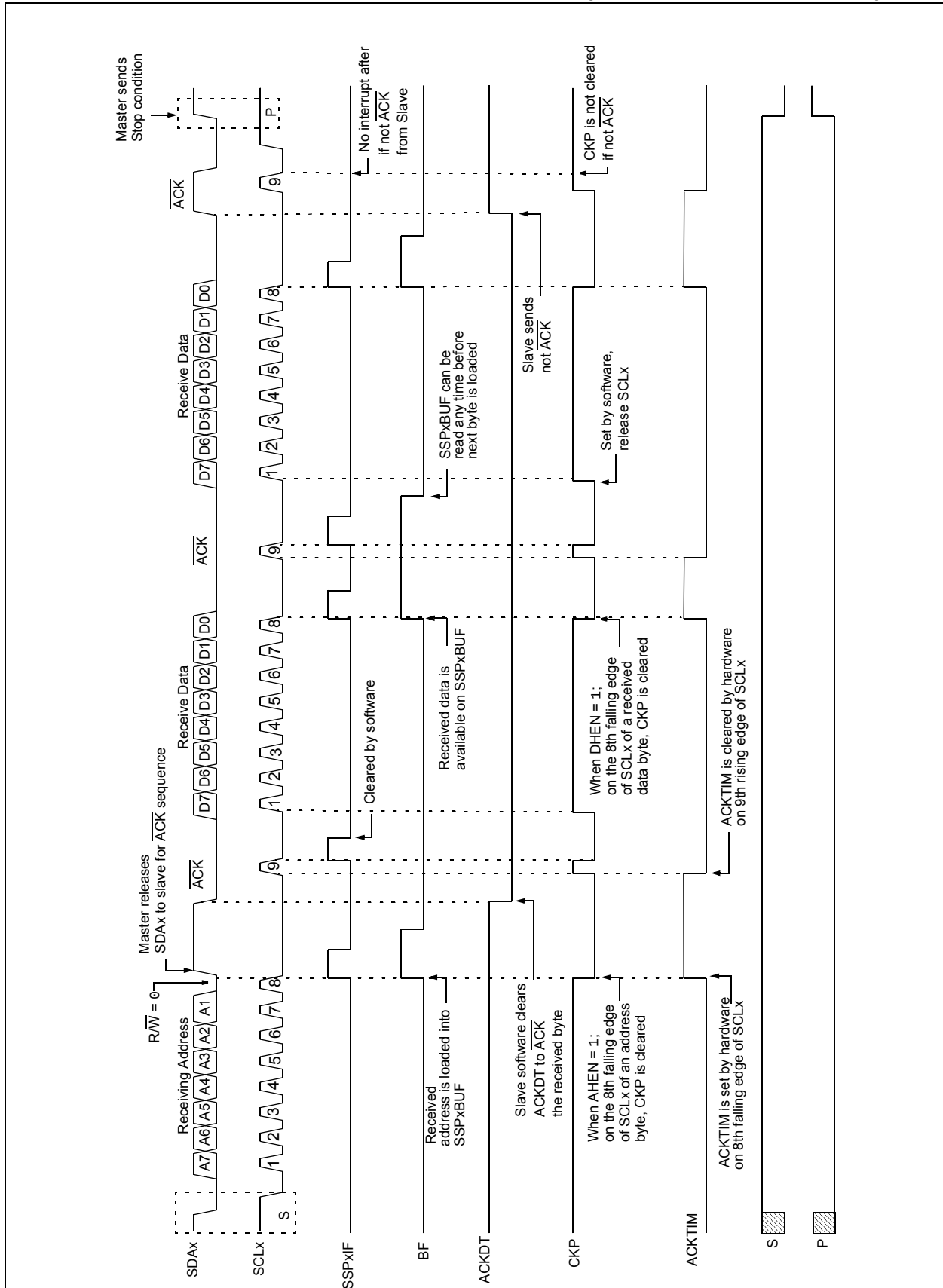


FIGURE 25-17: I²C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 1, AHEN = 1, DHEN = 1)



25.5.3 SLAVE TRANSMISSION

When the $\overline{R/W}$ bit of the incoming address byte is set and an address match occurs, the $\overline{R/W}$ bit of the SSPxSTAT register is set. The received address is loaded into the SSPxBUF register, and an $\overline{ACK}$ pulse is sent by the slave on the ninth bit.

Following the $\overline{ACK}$, slave hardware clears the CKP bit and the SCLx pin is held low (see [Section 25.5.6 "Clock Stretching"](#) for more detail). By stretching the clock, the master will be unable to assert another clock pulse until the slave is done preparing the transmit data.

The transmit data must be loaded into the SSPxBUF register which also loads the SSPxSR register. Then the SCLx pin should be released by setting the CKP bit of the SSPxCON1 register. The eight data bits are shifted out on the falling edge of the SCLx input. This ensures that the SDAx signal is valid during the SCLx high time.

The $\overline{ACK}$ pulse from the master-receiver is latched on the rising edge of the ninth SCLx input pulse. This $\overline{ACK}$ value is copied to the ACKSTAT bit of the SSPxCON2 register. If ACKSTAT is set (not $\overline{ACK}$), then the data transfer is complete. In this case, when the not $\overline{ACK}$ is latched by the slave, the slave goes Idle and waits for another occurrence of the Start bit. If the SDAx line was low ($\overline{ACK}$), the next transmit data must be loaded into the SSPxBUF register. Again, the SCLx pin must be released by setting bit CKP.

An MSSPx interrupt is generated for each data transfer byte. The SSPxIF bit must be cleared by software and the SSPxSTAT register is used to determine the status of the byte. The SSPxIF bit is set on the falling edge of the ninth clock pulse.

25.5.3.1 Slave Mode Bus Collision

A slave receives a Read request and begins shifting data out on the SDAx line. If a bus collision is detected and the SBCDE bit of the SSPxCON3 register is set, the BCLxIF bit of the PIRx register is set. Once a bus collision is detected, the slave goes Idle and waits to be addressed again. User software can use the BCLxIF bit to handle a slave bus collision.

25.5.3.2 7-bit Transmission

A master device can transmit a read request to a slave, and then clock data out of the slave. The list below outlines what software for a slave will need to do to accomplish a standard transmission. [Figure 25-17](#) can be used as a reference to this list.

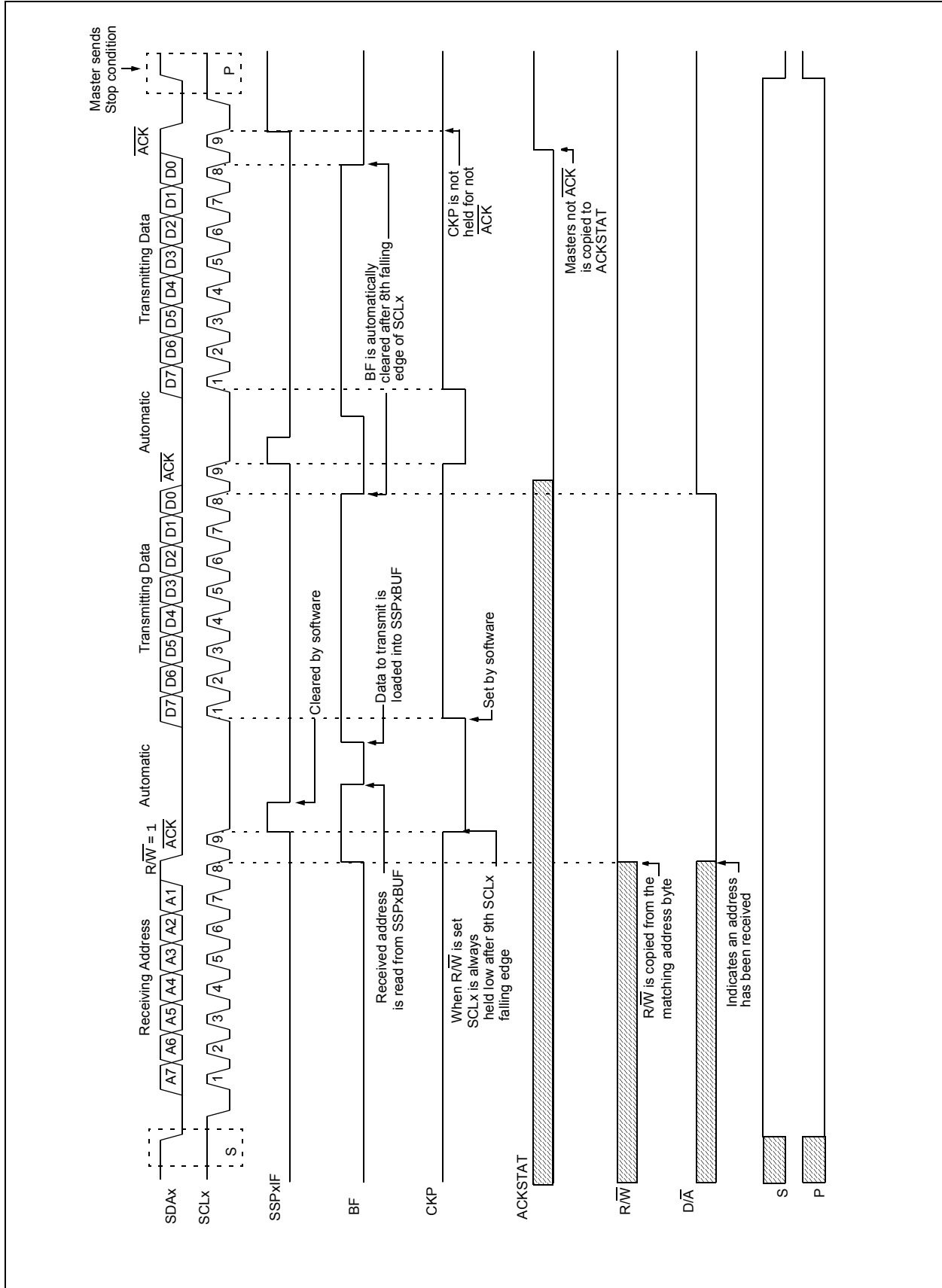
1. Master sends a Start condition on SDAx and SCLx.
2. S bit of SSPxSTAT is set; SSPxIF is set if interrupt on Start detect is enabled.
3. Matching address with $\overline{R/W}$ bit set is received by the Slave setting SSPxIF bit.
4. Slave hardware generates an $\overline{ACK}$ and sets SSPxIF.
5. SSPxIF bit is cleared by user.
6. Software reads the received address from SSPxBUF, clearing BF.
7. $\overline{R/W}$ is set so CKP was automatically cleared after the $\overline{ACK}$.
8. The slave software loads the transmit data into SSPxBUF.
9. CKP bit is set releasing SCLx, allowing the master to clock the data out of the slave.
10. SSPxIF is set after the $\overline{ACK}$ response from the master is loaded into the ACKSTAT register.
11. SSPxIF bit is cleared.
12. The slave software checks the ACKSTAT bit to see if the master wants to clock out more data.

Note 1: If the master $\overline{ACK}$ s the clock will be stretched.

2: ACKSTAT is the only bit updated on the rising edge of SCLx (9th) rather than the falling.

13. Steps 9-13 are repeated for each transmitted byte.
14. If the master sends a not $\overline{ACK}$; the clock is not held, but SSPxIF is still set.
15. The master sends a Restart condition or a Stop.
16. The slave is no longer addressed.

FIGURE 25-18: I²C SLAVE, 7-BIT ADDRESS, TRANSMISSION (AHEN = 0)



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25.5.3.3 7-bit Transmission with Address Hold Enabled

Setting the AHEN bit of the SSPxCON3 register enables additional clock stretching and interrupt generation after the 8th falling edge of a received matching address. Once a matching address has been clocked in, CKP is cleared and the SSPxIF interrupt is set.

Figure 25-18 displays a standard waveform of a 7-bit Address Slave Transmission with AHEN enabled.

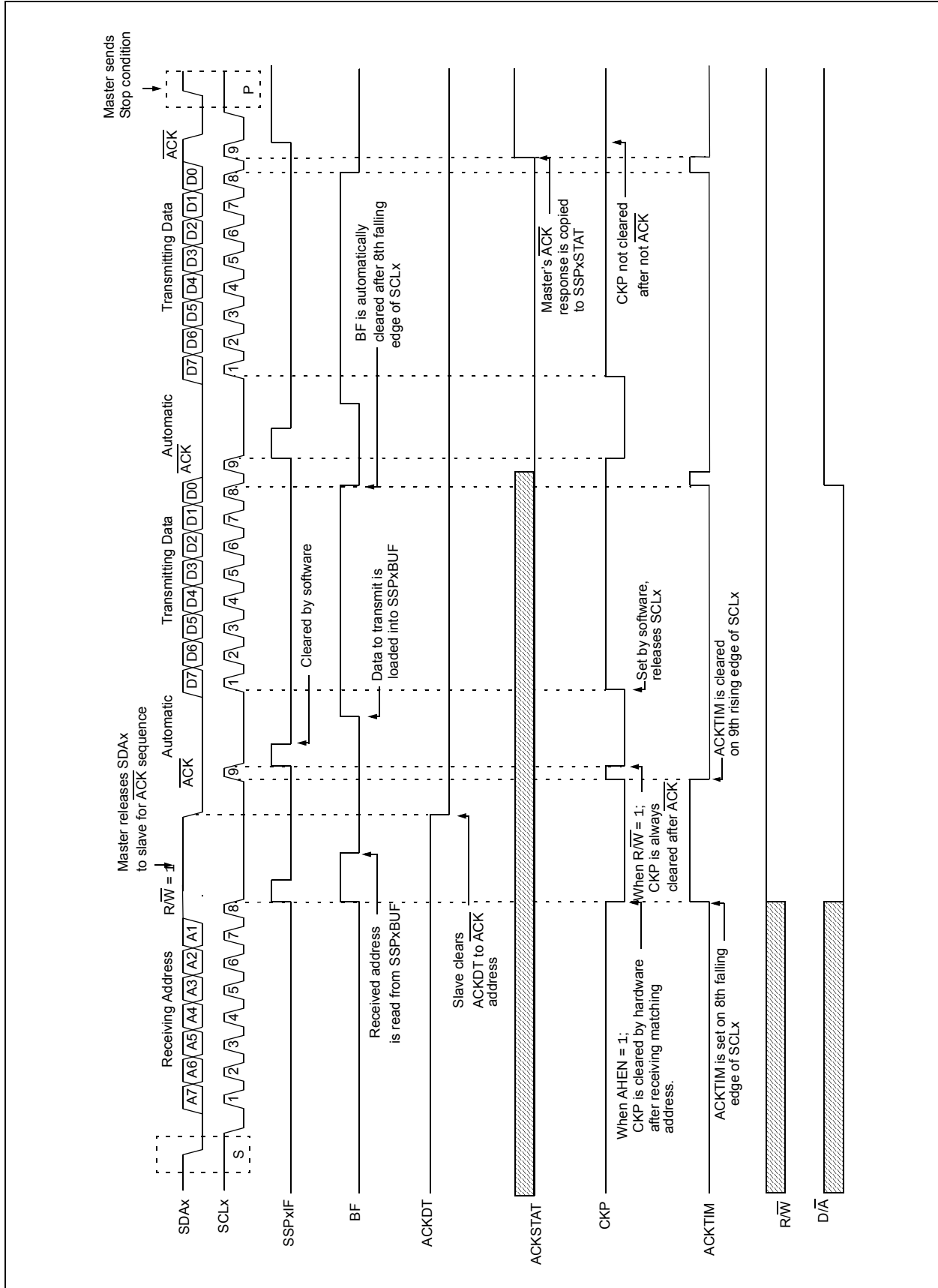
1. Bus starts Idle.
2. Master sends Start condition; the S bit of SSPxSTAT is set; SSPxIF is set if interrupt on Start detect is enabled.
3. Master sends matching address with $\overline{R/W}$ bit set. After the 8th falling edge of the SCLx line the CKP bit is cleared and SSPxIF interrupt is generated.
4. Slave software clears SSPxIF.
5. Slave software reads ACKTIM bit of SSPxCON3 register, and $\overline{R/W}$ and D/A of the SSPxSTAT register to determine the source of the interrupt.
6. Slave reads the address value from the SSPxBUF register clearing the BF bit.
7. Slave software decides from this information if it wishes to ACK or not ACK and sets ACKDT bit of the SSPxCON2 register accordingly.
8. Slave sets the CKP bit releasing SCLx.
9. Master clocks in the $\overline{ACK}$ value from the slave.
10. Slave hardware automatically clears the CKP bit and sets SSPxIF after the $\overline{ACK}$ if the $\overline{R/W}$ bit is set.
11. Slave software clears SSPxIF.
12. Slave loads value to transmit to the master into SSPxBUF setting the BF bit.

Note: SSPxBUF cannot be loaded until after the $\overline{ACK}$.

13. Slave sets CKP bit releasing the clock.
14. Master clocks out the data from the slave and sends an $\overline{ACK}$ value on the 9th SCLx pulse.
15. Slave hardware copies the $\overline{ACK}$ value into the ACKSTAT bit of the SSPxCON2 register.
16. Steps 10-15 are repeated for each byte transmitted to the master from the slave.
17. If the master sends a not $\overline{ACK}$ the slave releases the bus allowing the master to send a Stop and end the communication.

Note: Master must send a not $\overline{ACK}$ on the last byte to ensure that the slave releases the SCLx line to receive a Stop.

FIGURE 25-19: I²C SLAVE, 7-BIT ADDRESS, TRANSMISSION (AHEN = 1)



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25.5.4 SLAVE MODE 10-BIT ADDRESS RECEPTION

This section describes a standard sequence of events for the MSSPx module configured as an I²C Slave in 10-bit Addressing mode.

Figure 25-19 is used as a visual reference for this description.

This is a step by step process of what must be done by slave software to accomplish I²C communication.

1. Bus starts Idle.
2. Master sends Start condition; S bit of SSPxSTAT is set; SSPxIF is set if interrupt on Start detect is enabled.
3. Master sends matching high address with R/W bit clear; UA bit of the SSPxSTAT register is set.
4. Slave sends $\overline{\text{ACK}}$ and SSPxIF is set.
5. Software clears the SSPxIF bit.
6. Software reads received address from SSPxBUF clearing the BF flag.
7. Slave loads low address into SSPxADD, releasing SCLx.
8. Master sends matching low address byte to the Slave; UA bit is set.

Note: Updates to the SSPxADD register are not allowed until after the $\overline{\text{ACK}}$ sequence.

9. Slave sends $\overline{\text{ACK}}$ and SSPxIF is set.

Note: If the low address does not match, SSPxIF and UA are still set so that the slave software can set SSPxADD back to the high address. BF is not set because there is no match. CKP is unaffected.

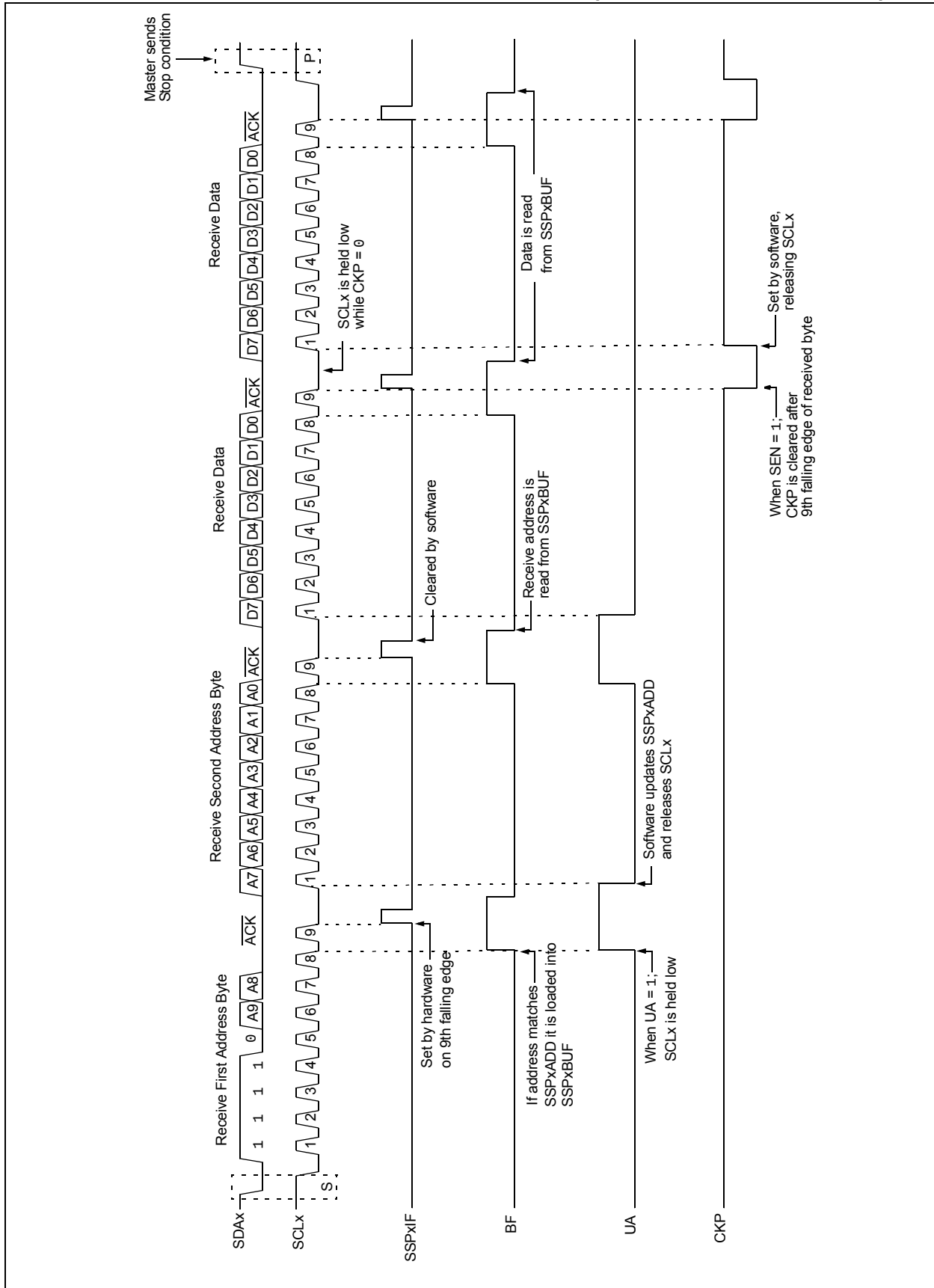
10. Slave clears SSPxIF.
11. Slave reads the received matching address from SSPxBUF clearing BF.
12. Slave loads high address into SSPxADD.
13. Master clocks a data byte to the slave and clocks out the slaves $\overline{\text{ACK}}$ on the 9th SCLx pulse; SSPxIF is set.
14. If SEN bit of SSPxCON2 is set, CKP is cleared by hardware and the clock is stretched.
15. Slave clears SSPxIF.
16. Slave reads the received byte from SSPxBUF clearing BF.
17. If SEN is set the slave sets CKP to release the SCLx.
18. Steps 13-17 repeat for each received byte.
19. Master sends Stop to end the transmission.

25.5.5 10-BIT ADDRESSING WITH ADDRESS OR DATA HOLD

Reception using 10-bit addressing with AHEN or DHEN set is the same as with 7-bit modes. The only difference is the need to update the SSPxADD register using the UA bit. All functionality, specifically when the CKP bit is cleared and SCLx line is held low are the same. Figure 25-20 can be used as a reference of a slave in 10-bit addressing with AHEN set.

Figure 25-21 shows a standard waveform for a slave transmitter in 10-bit Addressing mode.

FIGURE 25-20: I²C SLAVE, 10-BIT ADDRESS, RECEPTION (SEN = 1, AHEN = 0, DHEN = 0)



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FIGURE 25-21: I²C SLAVE, 10-BIT ADDRESS, RECEPTION (SEN = 0, AHEN = 1, DHEN = 0)

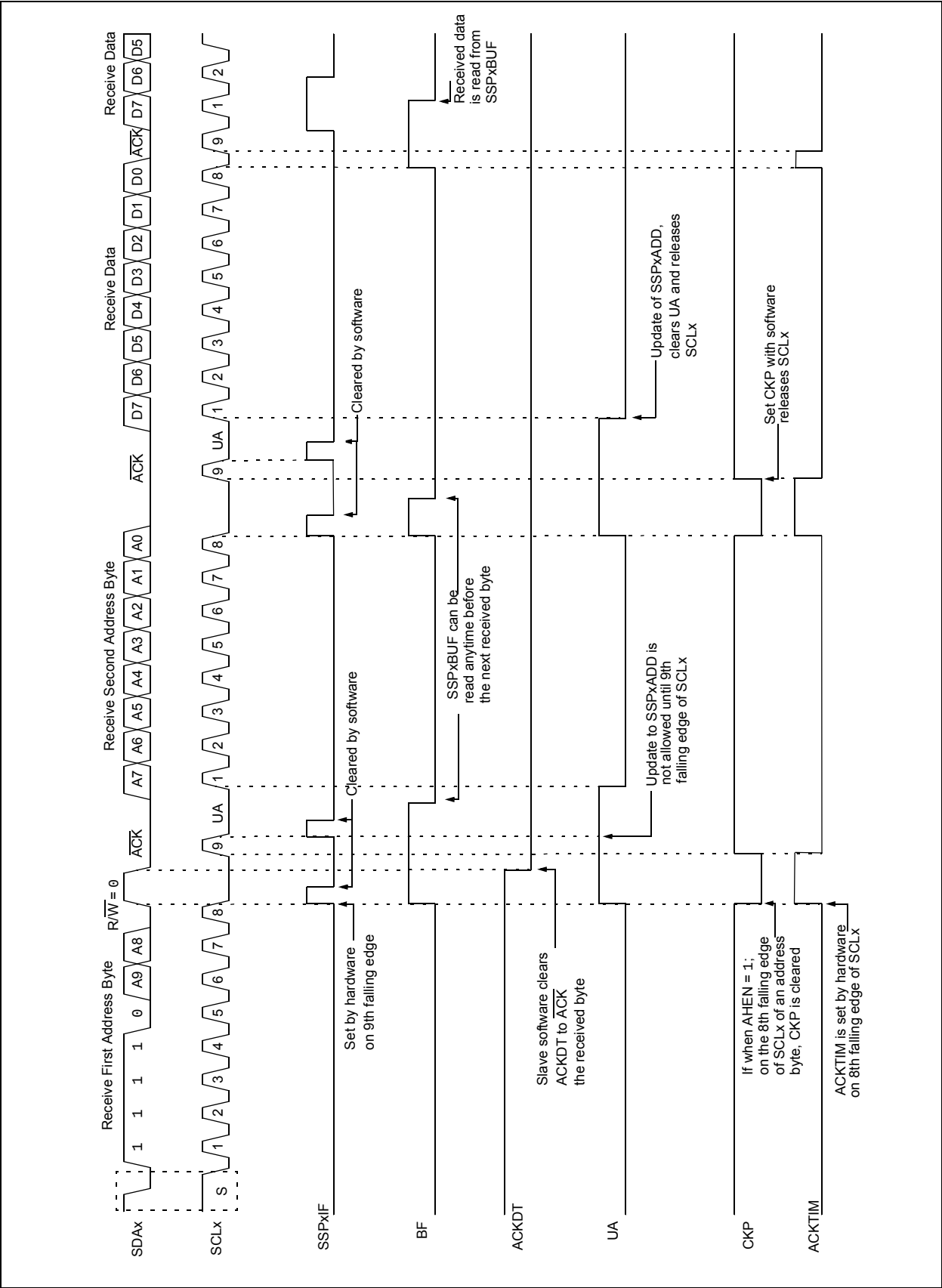
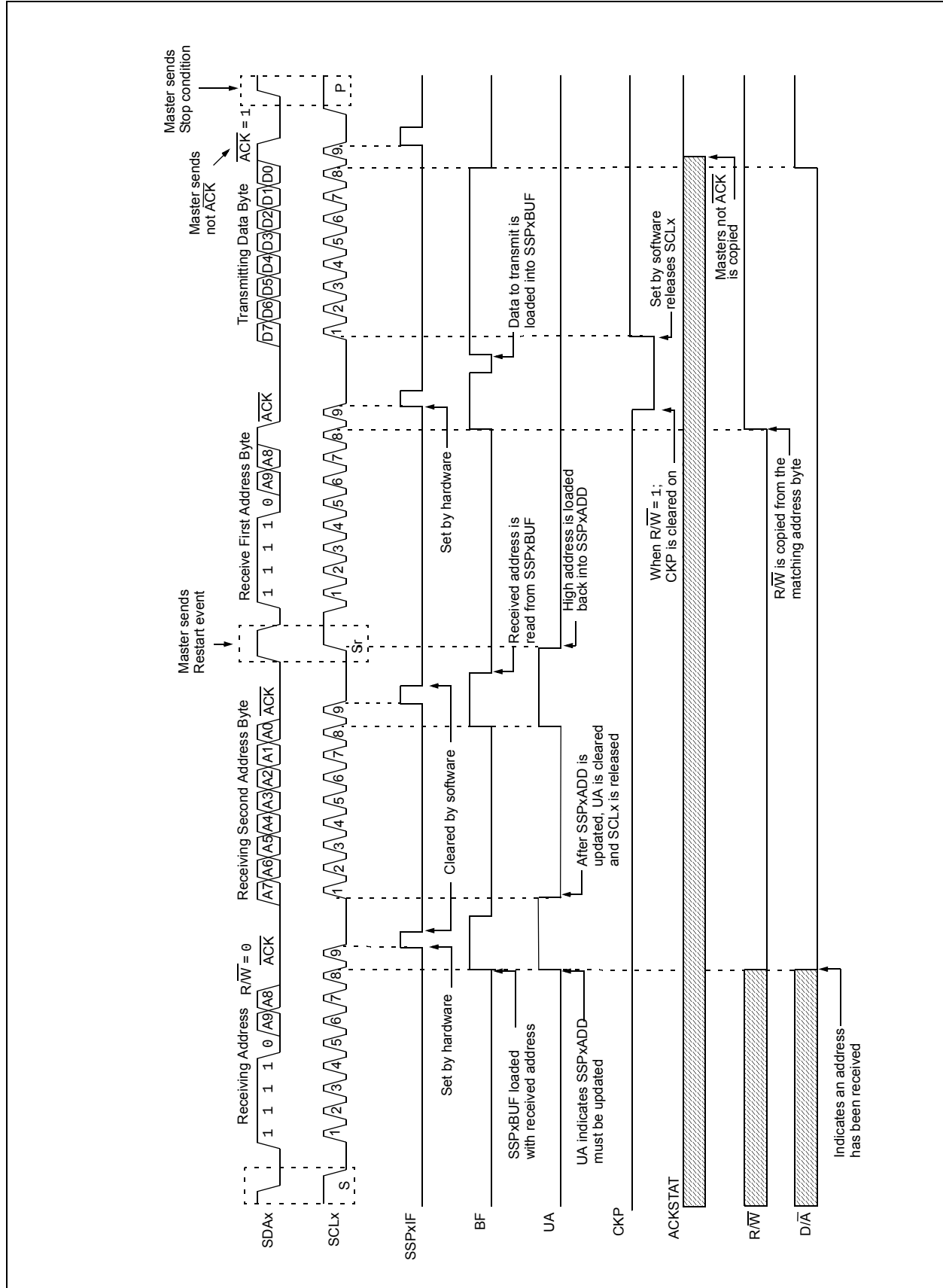


FIGURE 25-22: I²C SLAVE, 10-BIT ADDRESS, TRANSMISSION (SEN = 0, AHEN = 0, DHEN = 0)



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25.5.6 CLOCK STRETCHING

Clock stretching occurs when a device on the bus holds the SCLx line low effectively pausing communication. The slave may stretch the clock to allow more time to handle data or prepare a response for the master device. A master device is not concerned with stretching as anytime it is active on the bus and not transferring data it is stretching. Any stretching done by a slave is invisible to the master software and handled by the hardware that generates SCLx.

The CKP bit of the SSPxCON1 register is used to control stretching in software. Any time the CKP bit is cleared, the module will wait for the SCLx line to go low and then hold it. Setting CKP will release SCLx and allow more communication.

25.5.6.1 Normal Clock Stretching

Following an $\overline{\text{ACK}}$ if the R/W bit of SSPxSTAT is set, a read request, the slave hardware will clear CKP. This allows the slave time to update SSPxBUF with data to transfer to the master. If the SEN bit of SSPxCON2 is set, the slave hardware will always stretch the clock after the $\overline{\text{ACK}}$ sequence. Once the slave is ready; CKP is set by software and communication resumes.

Note 1: The BF bit has no effect on if the clock will be stretched or not. This is different than previous versions of the module that would not stretch the clock, clear CKP, if SSPxBUF was read before the 9th falling edge of SCLx.

2: Previous versions of the module did not stretch the clock for a transmission if SSPxBUF was loaded before the 9th falling edge of SCLx. It is now always cleared for read requests.

25.5.6.2 10-bit Addressing Mode

In 10-bit Addressing mode, when the UA bit is set, the clock is always stretched. This is the only time the SCLx is stretched without CKP being cleared. SCLx is released immediately after a write to SSPxADD.

Note: Previous versions of the module did not stretch the clock if the second address byte did not match.

25.5.6.3 Byte NACKing

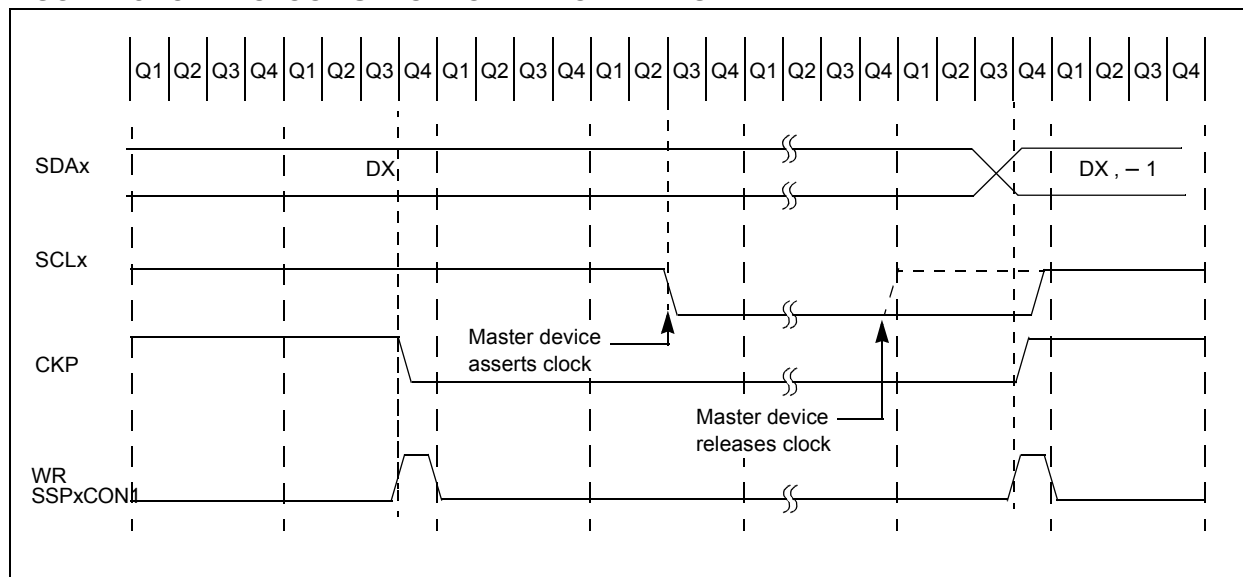
When AHEN bit of SSPxCON3 is set; CKP is cleared by hardware after the 8th falling edge of SCLx for a received matching address byte. When DHEN bit of SSPxCON3 is set; CKP is cleared after the 8th falling edge of SCLx for received data.

Stretching after the 8th falling edge of SCLx allows the slave to look at the received address or data and decide if it wants to ACK the received data.

25.5.7 CLOCK SYNCHRONIZATION AND THE CKP BIT

Any time the CKP bit is cleared, the module will wait for the SCLx line to go low and then hold it. However, clearing the CKP bit will not assert the SCLx output low until the SCLx output is already sampled low. Therefore, the CKP bit will not assert the SCLx line until an external I²C master device has already asserted the SCLx line. The SCLx output will remain low until the CKP bit is set and all other devices on the I²C bus have released SCLx. This ensures that a write to the CKP bit will not violate the minimum high time requirement for SCLx (see Figure 25-22).

FIGURE 25-23: CLOCK SYNCHRONIZATION TIMING



25.5.8 GENERAL CALL ADDRESS SUPPORT

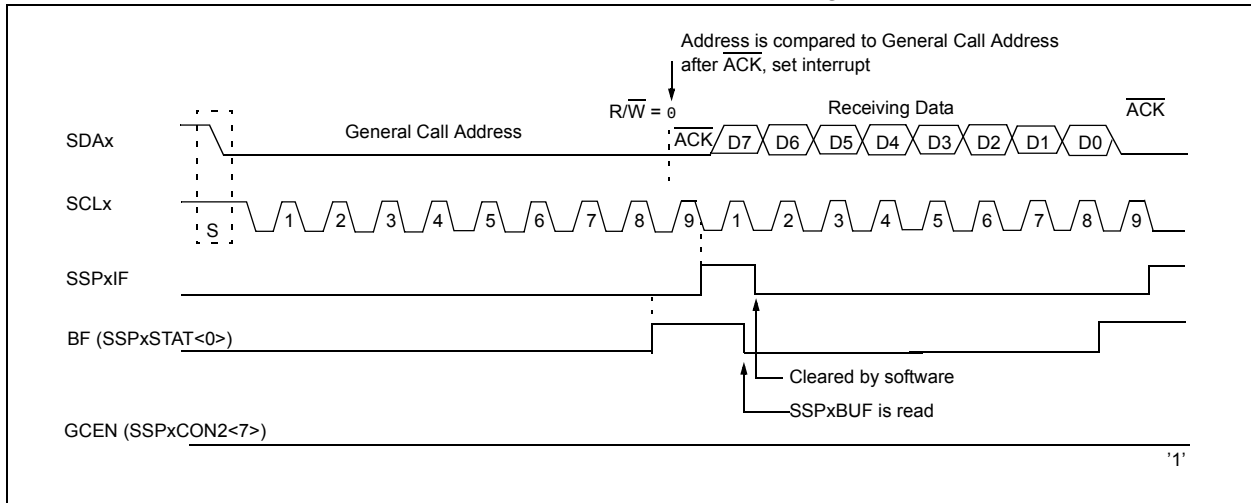
The addressing procedure for the I²C bus is such that the first byte after the Start condition usually determines which device will be the slave addressed by the master device. The exception is the general call address which can address all devices. When this address is used, all devices should, in theory, respond with an acknowledge.

The general call address is a reserved address in the I²C protocol, defined as address 0x00. When the GCEN bit of the SSPxCON2 register is set, the slave module will automatically ACK the reception of this address regardless of the value stored in SSPxADD. After the slave clocks in an address of all zeros with the R/W bit clear, an interrupt is generated and slave software can read SSPxBUF and respond. Figure 25-23 shows a general call reception sequence.

In 10-bit Address mode, the UA bit will not be set on the reception of the general call address. The slave will prepare to receive the second byte as data, just as it would in 7-bit mode.

If the AHEN bit of the SSPxCON3 register is set, just as with any other address reception, the slave hardware will stretch the clock after the 8th falling edge of SCLx. The slave must then set its ACKDT value and release the clock with communication progressing as it would normally.

FIGURE 25-24: SLAVE MODE GENERAL CALL ADDRESS SEQUENCE



25.5.9 SSPX MASK REGISTER

An SSPx Mask (SSPxMSK) register (Register 25-5) is available in I²C Slave mode as a mask for the value held in the SSPxSR register during an address comparison operation. A zero ('0') bit in the SSPxMSK register has the effect of making the corresponding bit of the received address a "don't care".

This register is reset to all '1's upon any Reset condition and, therefore, has no effect on standard SSPx operation until written with a mask value.

The SSPx Mask register is active during:

- 7-bit Address mode: address compare of A<7:1>.
- 10-bit Address mode: address compare of A<7:0> only. The SSPx mask has no effect during the reception of the first (high) byte of the address.

25.6 I²C MASTER MODE

Master mode is enabled by setting and clearing the appropriate SSPxM bits in the SSPxCON1 register and by setting the SSPxEN bit. In Master mode, the SDAx and SCKx pins must be configured as inputs. The MSSP peripheral hardware will override the output driver TRIS controls when necessary to drive the pins low.

Master mode of operation is supported by interrupt generation on the detection of the Start and Stop conditions. The Stop (P) and Start (S) bits are cleared from a Reset or when the MSSPx module is disabled. Control of the I²C bus may be taken when the P bit is set, or the bus is Idle.

In Firmware Controlled Master mode, user code conducts all I²C bus operations based on Start and Stop bit condition detection. Start and Stop condition detection is the only active circuitry in this mode. All other communication is done by the user software directly manipulating the SDAx and SCLx lines.

The following events will cause the SSPx Interrupt Flag bit, SSPxIF, to be set (SSPx interrupt, if enabled):

- Start condition detected
- Stop condition detected
- Data transfer byte transmitted/received
- Acknowledge transmitted/received
- Repeated Start generated

Note 1: The MSSPx module, when configured in I²C Master mode, does not allow queueing of events. For instance, the user is not allowed to initiate a Start condition and immediately write the SSPxBUF register to initiate transmission before the Start condition is complete. In this case, the SSPxBUF will not be written to and the WCOL bit will be set, indicating that a write to the SSPxBUF did not occur

2: When in Master mode, Start/Stop detection is masked and an interrupt is generated when the SEN/PEN bit is cleared and the generation is complete.

25.6.1 I²C MASTER MODE OPERATION

The master device generates all of the serial clock pulses and the Start and Stop conditions. A transfer is ended with a Stop condition or with a Repeated Start condition. Since the Repeated Start condition is also the beginning of the next serial transfer, the I²C bus will not be released.

In Master Transmitter mode, serial data is output through SDAx, while SCLx outputs the serial clock. The first byte transmitted contains the slave address of the receiving device (7 bits) and the Read/Write (R/W) bit. In this case, the R/W bit will be logic '0'. Serial data is transmitted 8 bits at a time. After each byte is transmitted, an Acknowledge bit is received. Start and Stop conditions are output to indicate the beginning and the end of a serial transfer.

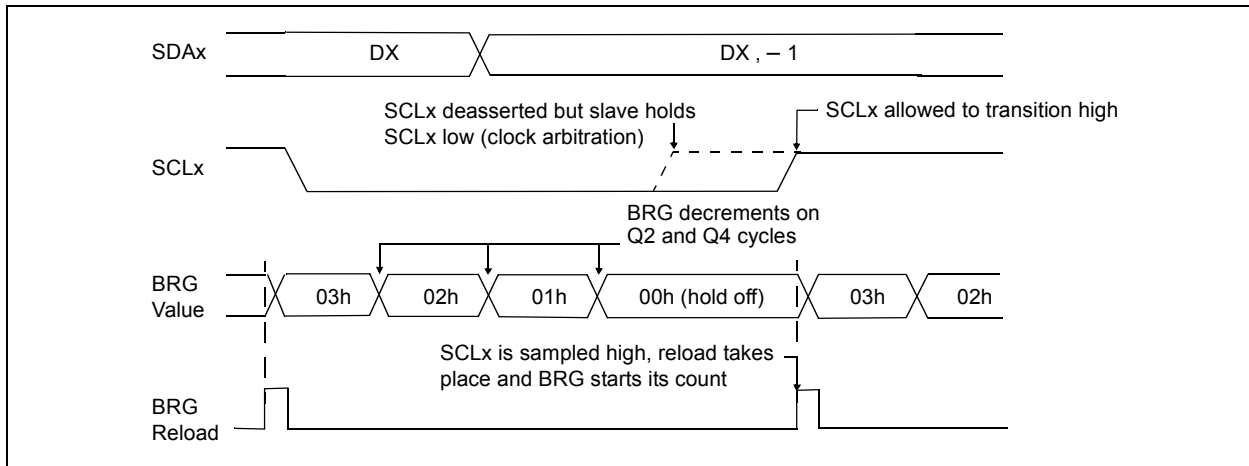
In Master Receive mode, the first byte transmitted contains the slave address of the transmitting device (7 bits) and the R/W bit. In this case, the R/W bit will be logic '1'. Thus, the first byte transmitted is a 7-bit slave address followed by a '1' to indicate the receive bit. Serial data is received via SDAx, while SCLx outputs the serial clock. Serial data is received 8 bits at a time. After each byte is received, an Acknowledge bit is transmitted. Start and Stop conditions indicate the beginning and end of transmission.

A Baud Rate Generator is used to set the clock frequency output on SCLx. See [Section 25.7 "Baud Rate Generator"](#) for more detail.

25.6.2 CLOCK ARBITRATION

Clock arbitration occurs when the master, during any receive, transmit or Repeated Start/Stop condition, releases the SCLx pin (SCLx allowed to float high). When the SCLx pin is allowed to float high, the Baud Rate Generator (BRG) is suspended from counting until the SCLx pin is actually sampled high. When the SCLx pin is sampled high, the Baud Rate Generator is reloaded with the contents of SSPxADD<7:0> and begins counting. This ensures that the SCLx high time will always be at least one BRG rollover count in the event that the clock is held low by an external device (Figure 25-25).

FIGURE 25-25: BAUD RATE GENERATOR TIMING WITH CLOCK ARBITRATION



25.6.3 WCOL STATUS FLAG

If the user writes the SSPxBUF when a Start, Restart, Stop, Receive or Transmit sequence is in progress, the WCOL is set and the contents of the buffer are unchanged (the write does not occur). Any time the WCOL bit is set it indicates that an action on SSPxBUF was attempted while the module was not Idle.

Note: Because queueing of events is not allowed, writing to the lower 5 bits of SSPxCON2 is disabled until the Start condition is complete.

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25.6.4 I²C MASTER MODE START CONDITION TIMING

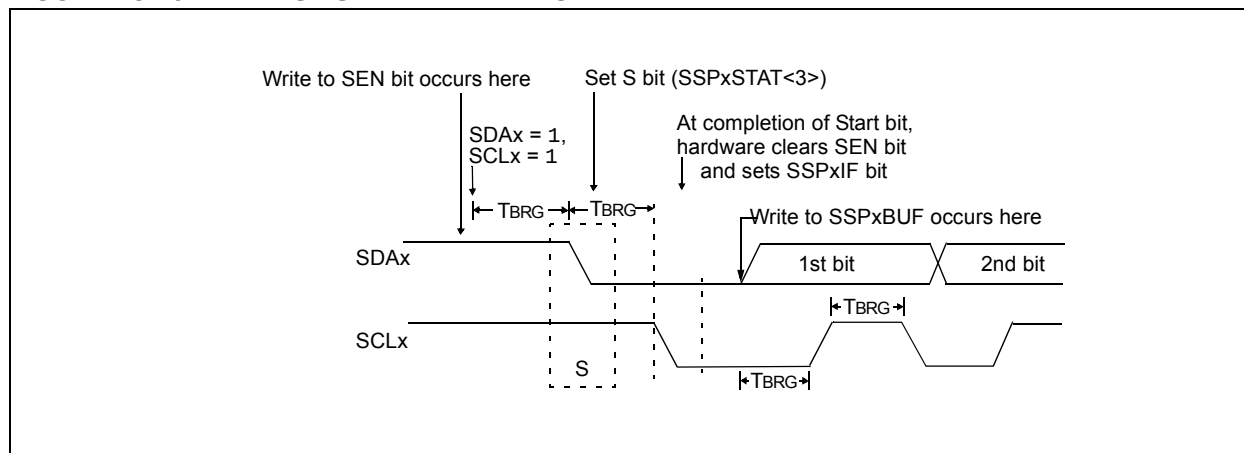
To initiate a Start condition, the user sets the Start Enable bit, SEN bit of the SSPxCON2 register. If the SDAx and SCLx pins are sampled high, the Baud Rate Generator is reloaded with the contents of SSPxADD<7:0> and starts its count. If SCLx and SDAx are both sampled high when the Baud Rate Generator times out (TBRG), the SDAx pin is driven low. The action of the SDAx being driven low while SCLx is high is the Start condition and causes the S bit of the SSPxSTAT1 register to be set. Following this, the Baud Rate Generator is reloaded with the contents of SSPxADD<7:0> and resumes its count. When the Baud Rate Generator times out (TBRG), the SEN bit of the SSPxCON2 register will be automatically cleared

by hardware; the Baud Rate Generator is suspended, leaving the SDAx line held low and the Start condition is complete.

Note 1: If at the beginning of the Start condition, the SDAx and SCLx pins are already sampled low, or if during the Start condition, the SCLx line is sampled low before the SDAx line is driven low, a bus collision occurs, the Bus Collision Interrupt Flag, BCLxIF, is set, the Start condition is aborted and the I²C module is reset into its Idle state.

2: The Philips I²C Specification states that a bus collision cannot occur on a Start.

FIGURE 25-26: FIRST START BIT TIMING



25.6.5 I²C MASTER MODE REPEATED START CONDITION TIMING

A Repeated Start condition occurs when the RSEN bit of the SSPxCON2 register is programmed high and the Master state machine is no longer active. When the RSEN bit is set, the SCLx pin is asserted low. When the SCLx pin is sampled low, the Baud Rate Generator is loaded and begins counting. The SDAx pin is released (brought high) for one Baud Rate Generator count (TBRG). When the Baud Rate Generator times out, if SDAx is sampled high, the SCLx pin will be deasserted (brought high). When SCLx is sampled high, the Baud Rate Generator is reloaded and begins counting. SDAx and SCLx must be sampled high for one TBRG. This action is then followed by assertion of the SDAx pin (SDAx = 0) for one TBRG while SCLx is high. SCLx is asserted low. Following this, the RSEN bit of the

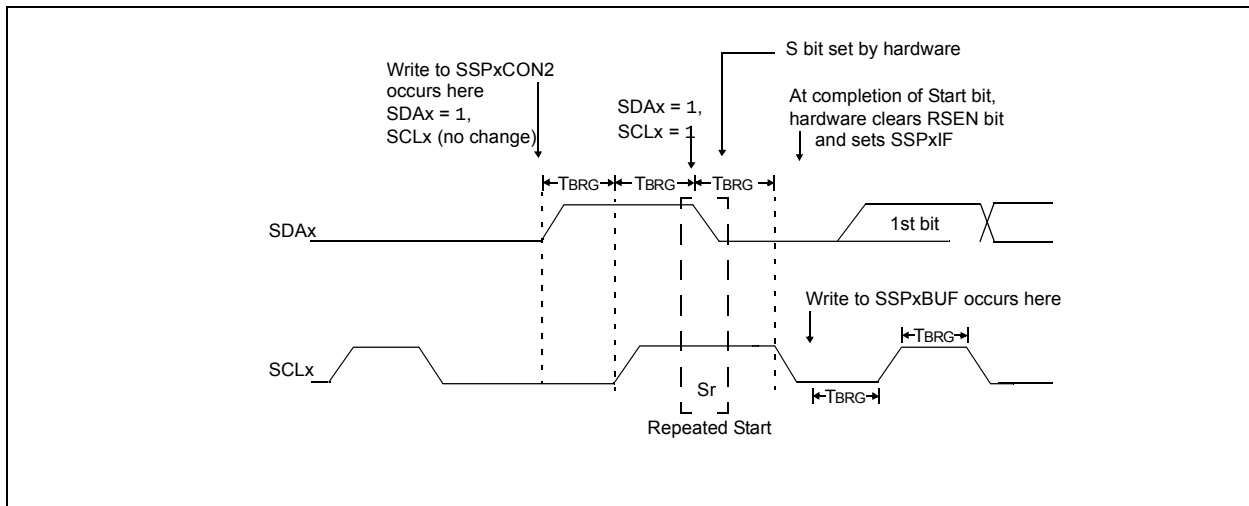
SSPxCON2 register will be automatically cleared and the Baud Rate Generator will not be reloaded, leaving the SDAx pin held low. As soon as a Start condition is detected on the SDAx and SCLx pins, the S bit of the SSPxSTAT register will be set. The SSPxIF bit will not be set until the Baud Rate Generator has timed out.

Note 1: If RSEN is programmed while any other event is in progress, it will not take effect.

2: A bus collision during the Repeated Start condition occurs if:

- SDAx is sampled low when SCLx goes from low-to-high.
- SCLx goes low before SDAx is asserted low. This may indicate that another master is attempting to transmit a data '1'.

FIGURE 25-27: REPEAT START CONDITION WAVEFORM



25.6.6 I²C MASTER MODE TRANSMISSION

Transmission of a data byte, a 7-bit address or the other half of a 10-bit address is accomplished by simply writing a value to the SSPxBUF register. This action will set the Buffer Full flag bit, BF and allow the Baud Rate Generator to begin counting and start the next transmission. Each bit of address/data will be shifted out onto the SDAx pin after the falling edge of SCLx is asserted. SCLx is held low for one Baud Rate Generator rollover count (TBRG). Data should be valid before SCLx is released high. When the SCLx pin is released high, it is held that way for TBRG. The data on the SDAx pin must remain stable for that duration and some hold time after the next falling edge of SCLx. After the eighth bit is shifted out (the falling edge of the eighth clock), the BF flag is cleared and the master releases SDAx. This allows the slave device being addressed to respond with an ACK bit during the ninth bit time if an address match occurred, or if data was received properly. The status of $\overline{\text{ACK}}$ is written into the ACKSTAT bit on the rising edge of the ninth clock. If the master receives an Acknowledge, the Acknowledge Status bit, ACKSTAT, is cleared. If not, the bit is set. After the ninth clock, the SSPxIF bit is set and the master clock (Baud Rate Generator) is suspended until the next data byte is loaded into the SSPxBUF, leaving SCLx low and SDAx unchanged (Figure 25-27).

After the write to the SSPxBUF, each bit of the address will be shifted out on the falling edge of SCLx until all seven address bits and the R/W bit are completed. On the falling edge of the eighth clock, the master will release the SDAx pin, allowing the slave to respond with an Acknowledge. On the falling edge of the ninth clock, the master will sample the SDAx pin to see if the address was recognized by a slave. The status of the $\overline{\text{ACK}}$ bit is loaded into the ACKSTAT Status bit of the SSPxCON2 register. Following the falling edge of the ninth clock transmission of the address, the SSPxIF is set, the BF flag is cleared and the Baud Rate Generator is turned off until another write to the SSPxBUF takes place, holding SCLx low and allowing SDAx to float.

25.6.6.1 BF Status Flag

In Transmit mode, the BF bit of the SSPxSTAT register is set when the CPU writes to SSPxBUF and is cleared when all 8 bits are shifted out.

25.6.6.2 WCOL Status Flag

If the user writes the SSPxBUF when a transmit is already in progress (i.e., SSPxSR is still shifting out a data byte), the WCOL is set and the contents of the buffer are unchanged (the write does not occur).

WCOL must be cleared by software before the next transmission.

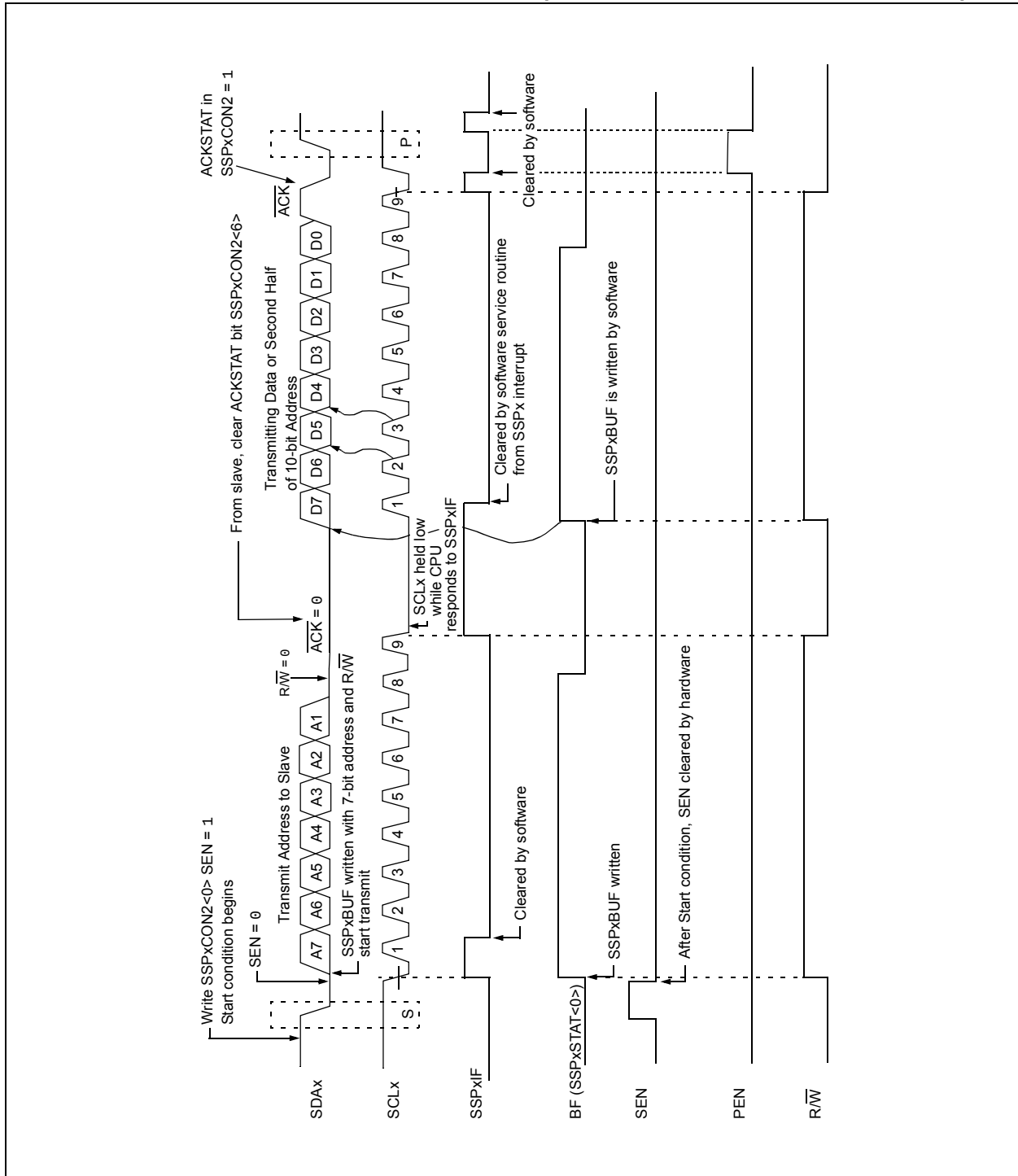
25.6.6.3 ACKSTAT Status Flag

In Transmit mode, the ACKSTAT bit of the SSPxCON2 register is cleared when the slave has sent an Acknowledge ($\text{ACK} = 0$) and is set when the slave does not Acknowledge ($\text{ACK} = 1$). A slave sends an Acknowledge when it has recognized its address (including a general call), or when the slave has properly received its data.

25.6.6.4 Typical transmit sequence:

1. The user generates a Start condition by setting the SEN bit of the SSPxCON2 register.
2. SSPxIF is set by hardware on completion of the Start.
3. SSPxIF is cleared by software.
4. The MSSPx module will wait the required start time before any other operation takes place.
5. The user loads the SSPxBUF with the slave address to transmit.
6. Address is shifted out the SDAx pin until all 8 bits are transmitted. Transmission begins as soon as SSPxBUF is written to.
7. The MSSPx module shifts in the $\overline{\text{ACK}}$ bit from the slave device and writes its value into the ACKSTAT bit of the SSPxCON2 register.
8. The MSSPx module generates an interrupt at the end of the ninth clock cycle by setting the SSPxIF bit.
9. The user loads the SSPxBUF with eight bits of data.
10. Data is shifted out the SDAx pin until all 8 bits are transmitted.
11. The MSSPx module shifts in the $\overline{\text{ACK}}$ bit from the slave device and writes its value into the ACKSTAT bit of the SSPxCON2 register.
12. Steps 8-11 are repeated for all transmitted data bytes.
13. The user generates a Stop or Restart condition by setting the PEN or RSEN bits of the SSPxCON2 register. Interrupt is generated once the Stop/Restart condition is complete.

FIGURE 25-28: I²C MASTER MODE WAVEFORM (TRANSMISSION, 7 OR 10-BIT ADDRESS)



25.6.7 I²C MASTER MODE RECEPTION

Master mode reception is enabled by programming the Receive Enable bit, RCEN bit of the SSPxCON2 register.

Note: The MSSPx module must be in an Idle state before the RCEN bit is set or the RCEN bit will be disregarded.

The Baud Rate Generator begins counting and on each rollover, the state of the SCLx pin changes (high-to-low/low-to-high) and data is shifted into the SSPxSR. After the falling edge of the eighth clock, the receive enable flag is automatically cleared, the contents of the SSPxSR are loaded into the SSPxBUF, the BF flag bit is set, the SSPxIF flag bit is set and the Baud Rate Generator is suspended from counting, holding SCLx low. The MSSPx is now in Idle state awaiting the next command. When the buffer is read by the CPU, the BF flag bit is automatically cleared. The user can then send an Acknowledge bit at the end of reception by setting the Acknowledge Sequence Enable, ACKEN bit of the SSPxCON2 register.

25.6.7.1 BF Status Flag

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

25.6.7.2 SSPxOV Status Flag

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

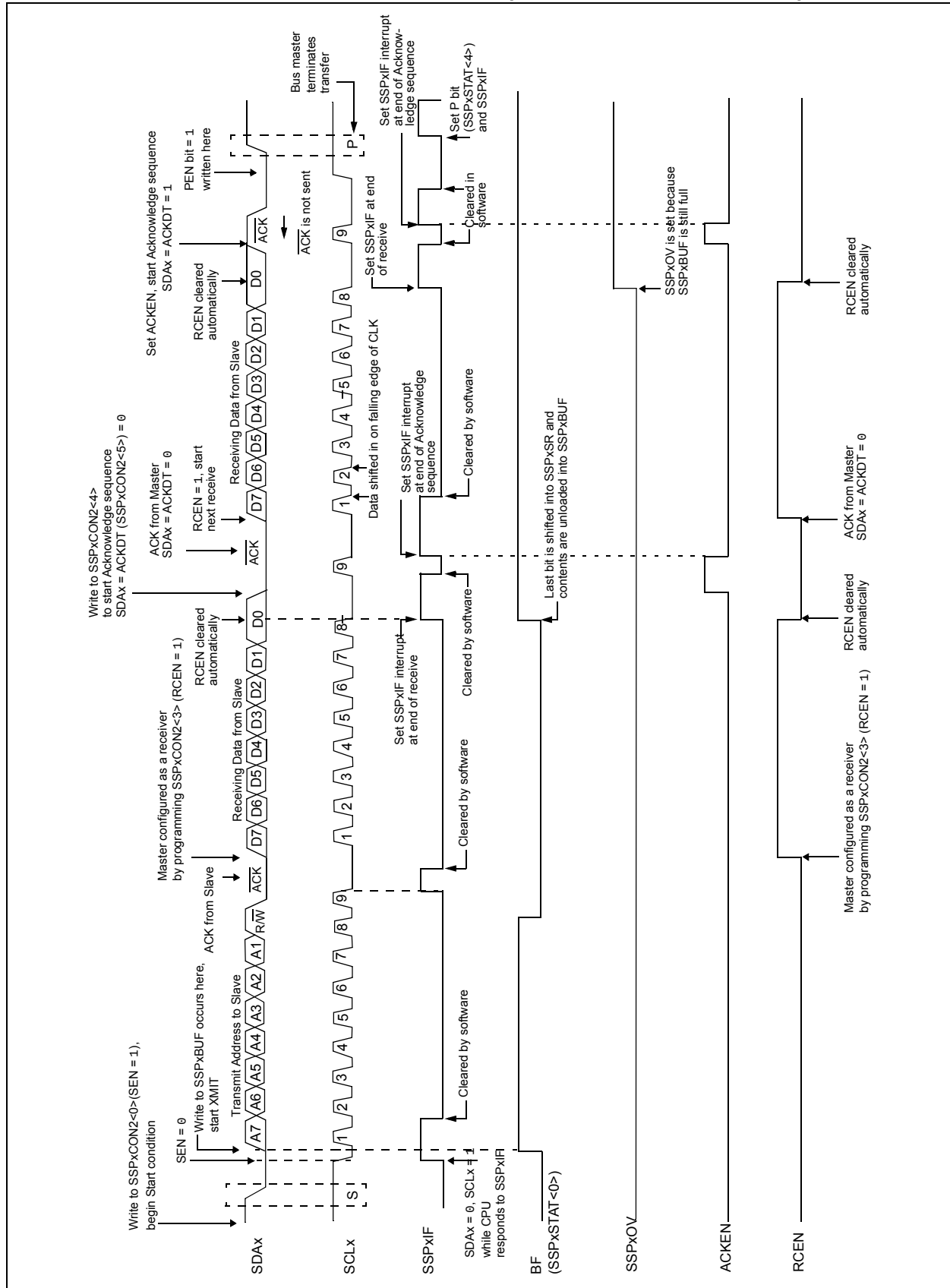
25.6.7.3 WCOL Status Flag

If the user writes the SSPxBUF when a receive is already in progress (i.e., SSPxSR is still shifting in a data byte), the WCOL bit is set and the contents of the buffer are unchanged (the write does not occur).

25.6.7.4 Typical Receive Sequence:

1. The user generates a Start condition by setting the SEN bit of the SSPxCON2 register.
2. SSPxIF is set by hardware on completion of the Start.
3. SSPxIF is cleared by software.
4. User writes SSPxBUF with the slave address to transmit and the R/W bit set.
5. Address is shifted out the SDAx pin until all 8 bits are transmitted. Transmission begins as soon as SSPxBUF is written to.
6. The MSSPx module shifts in the $\overline{\text{ACK}}$ bit from the slave device and writes its value into the ACKSTAT bit of the SSPxCON2 register.
7. The MSSPx module generates an interrupt at the end of the ninth clock cycle by setting the SSPxIF bit.
8. User sets the RCEN bit of the SSPxCON2 register and the Master clocks in a byte from the slave.
9. After the 8th falling edge of SCLx, SSPxIF and BF are set.
10. Master clears SSPxIF and reads the received byte from SSPxUF, clears BF.
11. Master sets $\overline{\text{ACK}}$ value sent to slave in ACKDT bit of the SSPxCON2 register and initiates the ACK by setting the ACKEN bit.
12. Masters $\overline{\text{ACK}}$ is clocked out to the Slave and SSPxIF is set.
13. User clears SSPxIF.
14. Steps 8-13 are repeated for each received byte from the slave.
15. Master sends a not $\overline{\text{ACK}}$ or Stop to end communication.

FIGURE 25-29: I²C MASTER MODE WAVEFORM (RECEPTION, 7-BIT ADDRESS)



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25.6.8 ACKNOWLEDGE SEQUENCE TIMING

An Acknowledge sequence is enabled by setting the Acknowledge Sequence Enable bit, ACKEN bit of the SSPxCON2 register. When this bit is set, the SCLx pin is pulled low and the contents of the Acknowledge data bit are presented on the SDAx pin. If the user wishes to generate an Acknowledge, then the ACKDT bit should be cleared. If not, the user should set the ACKDT bit before starting an Acknowledge sequence. The Baud Rate Generator then counts for one rollover period (TBRG) and the SCLx pin is deasserted (pulled high). When the SCLx pin is sampled high (clock arbitration), the Baud Rate Generator counts for TBRG. The SCLx pin is then pulled low. Following this, the ACKEN bit is automatically cleared, the Baud Rate Generator is turned off and the MSSPx module then goes into Idle mode (Figure 25-29).

25.6.8.1 WCOL Status Flag

If the user writes the SSPxBUF when an Acknowledge sequence is in progress, then WCOL is set and the contents of the buffer are unchanged (the write does not occur).

25.6.9 STOP CONDITION TIMING

A Stop bit is asserted on the SDAx pin at the end of a receive/transmit by setting the Stop Sequence Enable bit, PEN bit of the SSPxCON2 register. At the end of a receive/transmit, the SCLx line is held low after the falling edge of the ninth clock. When the PEN bit is set, the master will assert the SDAx line low. When the SDAx line is sampled low, the Baud Rate Generator is reloaded and counts down to '0'. When the Baud Rate Generator times out, the SCLx pin will be brought high and one TBRG (Baud Rate Generator rollover count) later, the SDAx pin will be deasserted. When the SDAx pin is sampled high while SCLx is high, the P bit of the SSPxSTAT register is set. A TBRG later, the PEN bit is cleared and the SSPxIF bit is set (Figure 25-30).

25.6.9.1 WCOL Status Flag

If the user writes the SSPxBUF when a Stop sequence is in progress, then the WCOL bit is set and the contents of the buffer are unchanged (the write does not occur).

FIGURE 25-30: ACKNOWLEDGE SEQUENCE WAVEFORM

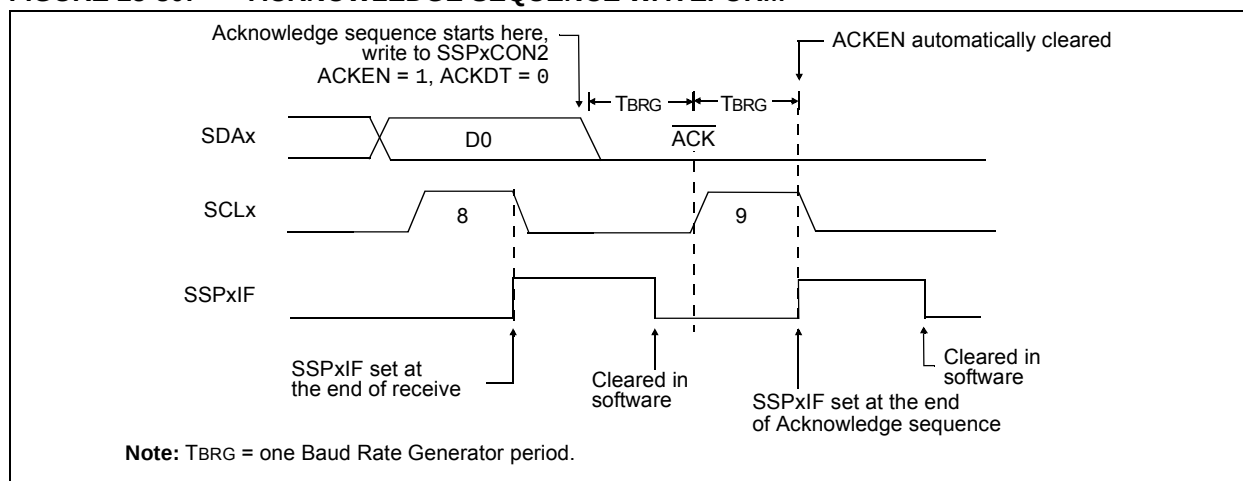
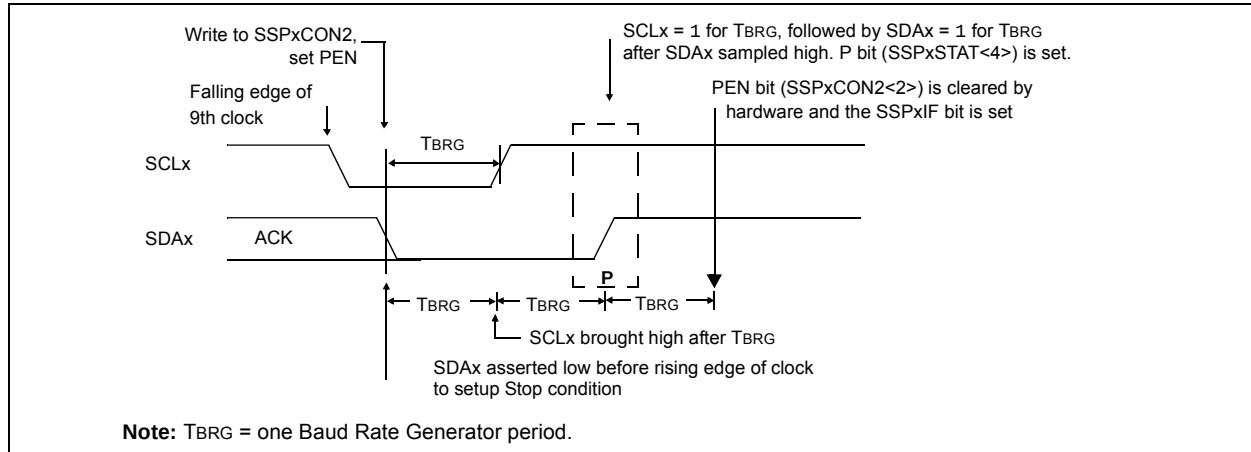


FIGURE 25-31: STOP CONDITION RECEIVE OR TRANSMIT MODE



25.6.10 SLEEP OPERATION

While in Sleep mode, the I²C slave module can receive addresses or data and when an address match or complete byte transfer occurs, wake the processor from Sleep (if the MSSPx interrupt is enabled).

25.6.11 EFFECTS OF A RESET

A Reset disables the MSSPx module and terminates the current transfer.

25.6.12 MULTI-MASTER MODE

In Multi-Master mode, the interrupt generation on the detection of the Start and Stop conditions allows the determination of when the bus is free. The Stop (P) and Start (S) bits are cleared from a Reset or when the MSSPx module is disabled. Control of the I²C bus may be taken when the P bit of the SSPxSTAT register is set, or the bus is Idle, with both the S and P bits clear. When the bus is busy, enabling the SSPx interrupt will generate the interrupt when the Stop condition occurs.

In multi-master operation, the SDAx line must be monitored for arbitration to see if the signal level is the expected output level. This check is performed by hardware with the result placed in the BCLxIF bit.

The states where arbitration can be lost are:

- Address Transfer
- Data Transfer
- A Start Condition
- A Repeated Start Condition
- An Acknowledge Condition

25.6.13 MULTI-MASTER COMMUNICATION, BUS COLLISION AND BUS ARBITRATION

Multi-Master mode support is achieved by bus arbitration. When the master outputs address/data bits onto the SDAx pin, arbitration takes place when the master outputs a '1' on SDAx, by letting SDAx float high and another master asserts a '0'. When the SCLx pin floats high, data should be stable. If the expected data on SDAx is a '1' and the data sampled on the SDAx pin is '0', then a bus collision has taken place. The master will set the Bus Collision Interrupt Flag, BCLxIF and reset the I²C port to its Idle state (Figure 25-31).

If a transmit was in progress when the bus collision occurred, the transmission is halted, the BF flag is cleared, the SDAx and SCLx lines are deasserted and the SSPxBUF can be written to. When the user services the bus collision Interrupt Service Routine and if the I²C bus is free, the user can resume communication by asserting a Start condition.

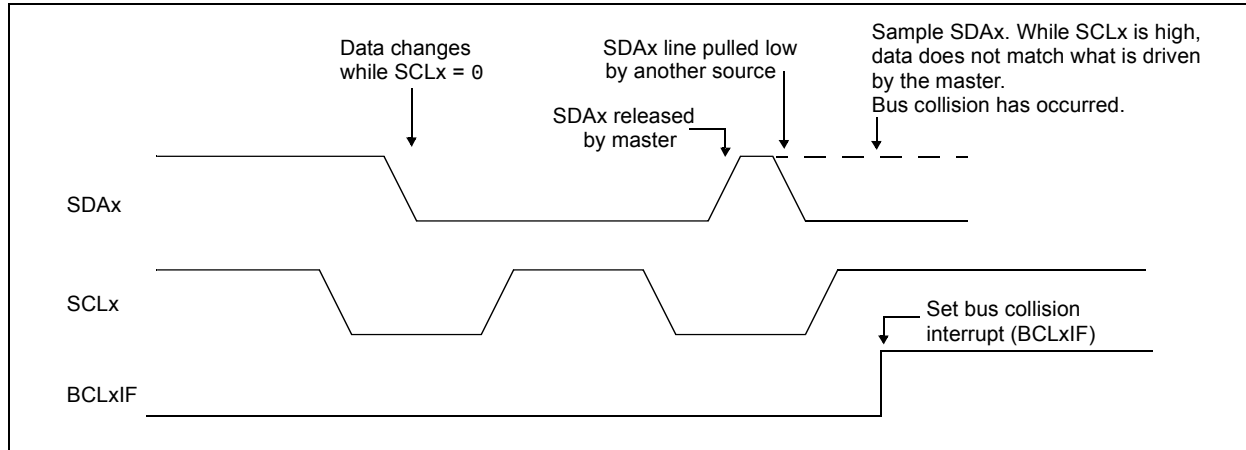
If a Start, Repeated Start, Stop or Acknowledge condition was in progress when the bus collision occurred, the condition is aborted, the SDAx and SCLx lines are deasserted and the respective control bits in the SSPxCON2 register are cleared. When the user services the bus collision Interrupt Service Routine and if the I²C bus is free, the user can resume communication by asserting a Start condition.

The master will continue to monitor the SDAx and SCLx pins. If a Stop condition occurs, the SSPxIF bit will be set.

A write to the SSPxBUF will start the transmission of data at the first data bit, regardless of where the transmitter left off when the bus collision occurred.

In Multi-Master mode, the interrupt generation on the detection of Start and Stop conditions allows the determination of when the bus is free. Control of the I²C bus can be taken when the P bit is set in the SSPxSTAT register, or the bus is Idle and the S and P bits are cleared.

FIGURE 25-32: BUS COLLISION TIMING FOR TRANSMIT AND ACKNOWLEDGE



25.6.13.1 Bus Collision During a Start Condition

During a Start condition, a bus collision occurs if:

- SDAx or SCLx are sampled low at the beginning of the Start condition (Figure 25-32).
- SCLx is sampled low before SDAx is asserted low (Figure 25-33).

During a Start condition, both the SDAx and the SCLx pins are monitored.

If the SDAx pin is already low, or the SCLx pin is already low, then all of the following occur:

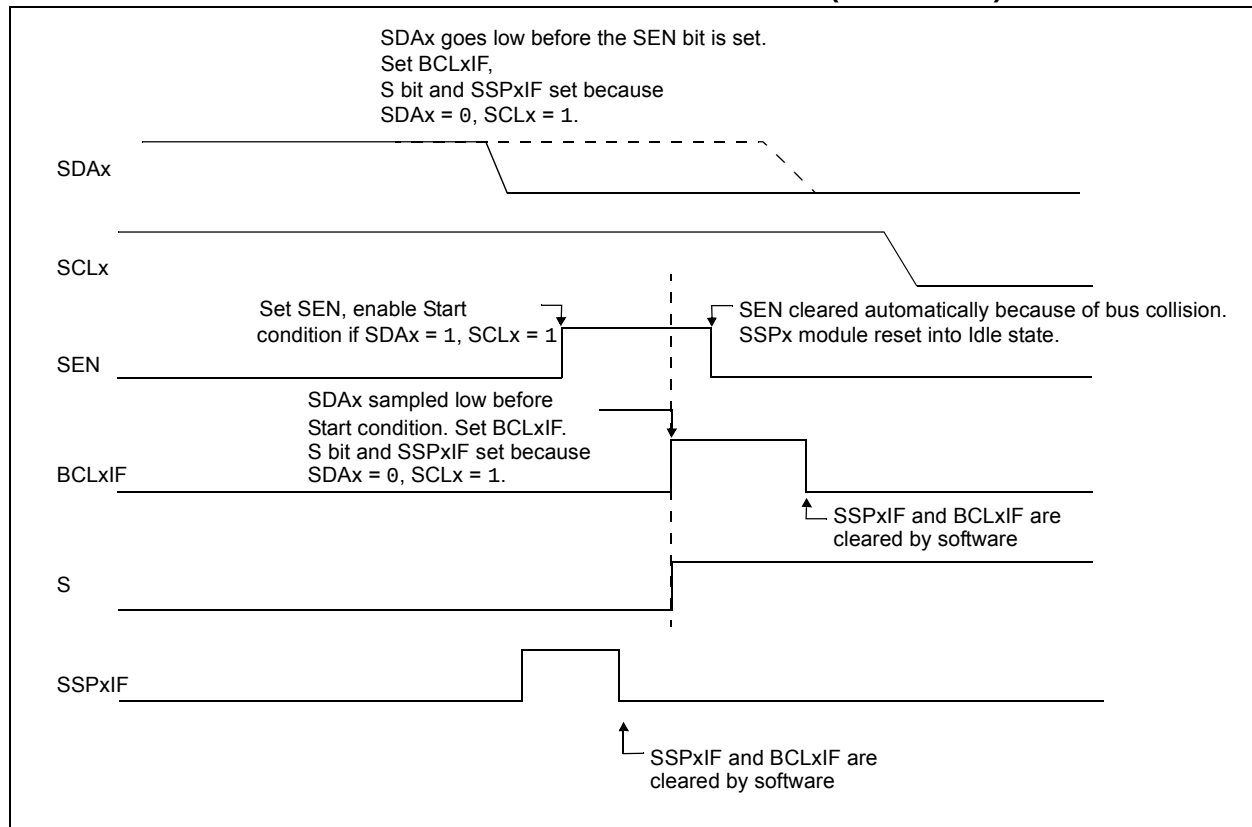
- the Start condition is aborted,
- the BCLxIF flag is set and
- the MSSPx module is reset to its Idle state (Figure 25-32).

The Start condition begins with the SDAx and SCLx pins deasserted. When the SDAx pin is sampled high, the Baud Rate Generator is loaded and counts down. If the SCLx pin is sampled low while SDAx is high, a bus collision occurs because it is assumed that another master is attempting to drive a data '1' during the Start condition.

If the SDAx pin is sampled low during this count, the BRG is reset and the SDAx line is asserted early (Figure 25-34). If, however, a '1' is sampled on the SDAx pin, the SDAx pin is asserted low at the end of the BRG count. The Baud Rate Generator is then reloaded and counts down to zero; if the SCLx pin is sampled as '0' during this time, a bus collision does not occur. At the end of the BRG count, the SCLx pin is asserted low.

Note: The reason that bus collision is not a factor during a Start condition is that no two bus masters can assert a Start condition at the exact same time. Therefore, one master will always assert SDAx before the other. This condition does not cause a bus collision because the two masters must be allowed to arbitrate the first address following the Start condition. If the address is the same, arbitration must be allowed to continue into the data portion, Repeated Start or Stop conditions.

FIGURE 25-33: BUS COLLISION DURING START CONDITION (SDAx ONLY)



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FIGURE 25-34: BUS COLLISION DURING START CONDITION (SCLX = 0)

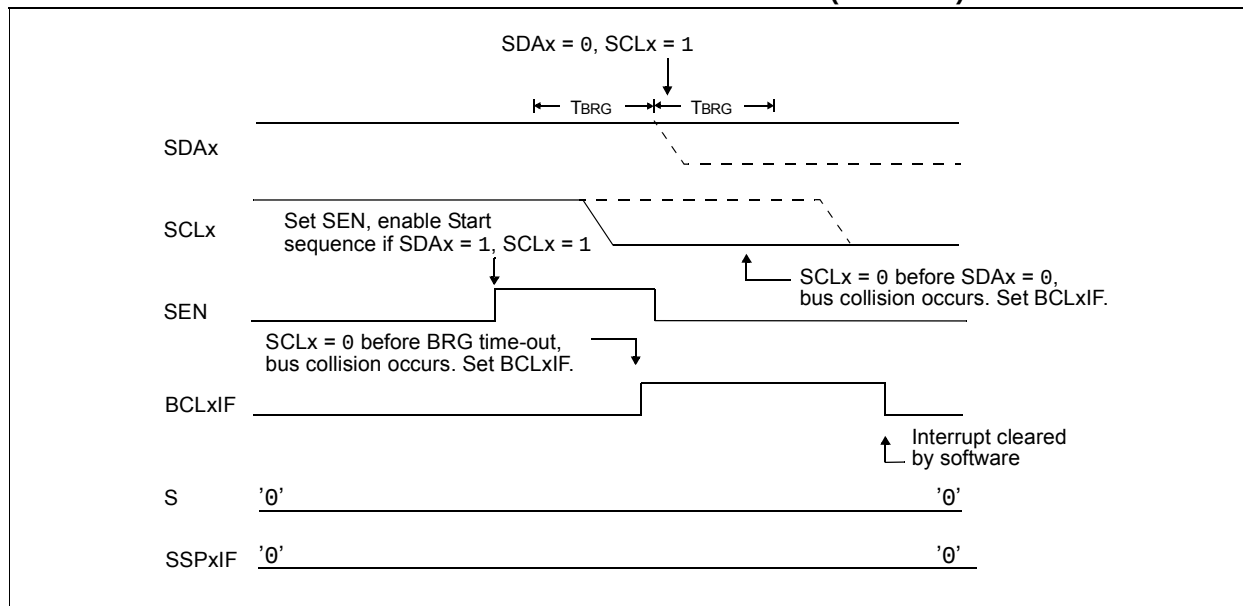
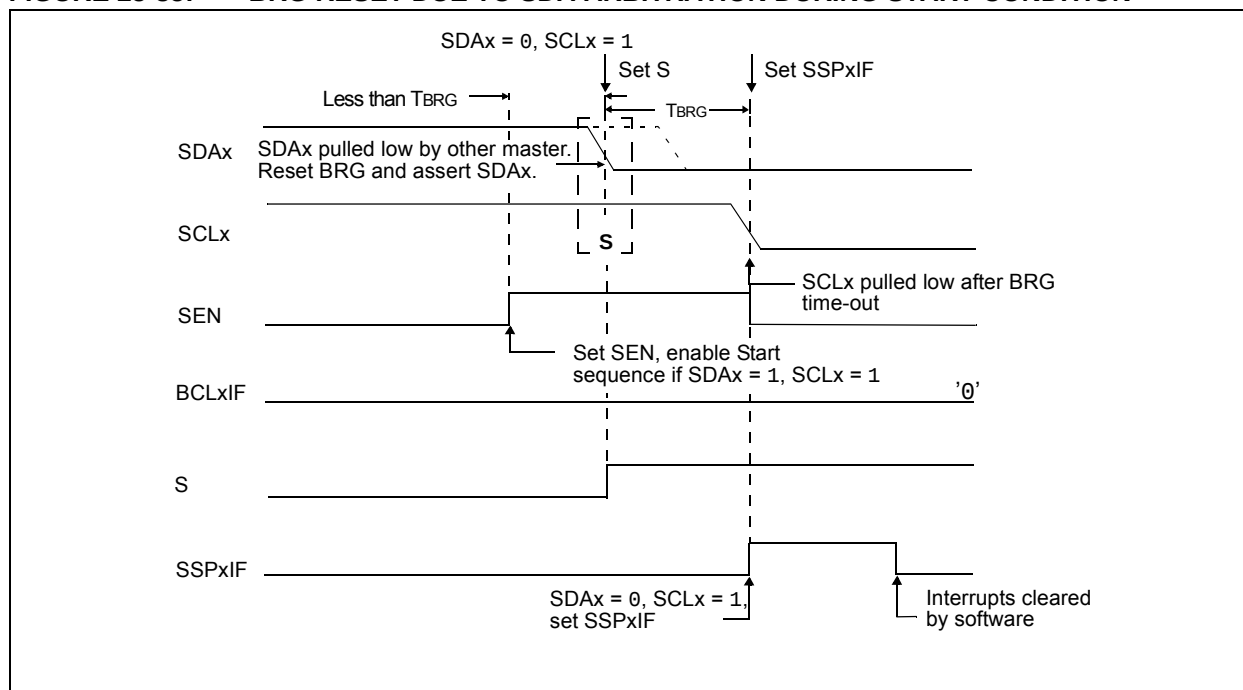


FIGURE 25-35: BRG RESET DUE TO SDA ARBITRATION DURING START CONDITION



25.6.13.2 Bus Collision During a Repeated Start Condition

During a Repeated Start condition, a bus collision occurs if:

- A low level is sampled on SDAx when SCLx goes from low level to high level.
- SCLx goes low before SDAx is asserted low, indicating that another master is attempting to transmit a data '1'.

When the user releases SDAx and the pin is allowed to float high, the BRG is loaded with SSPxADD and counts down to zero. The SCLx pin is then deasserted and when sampled high, the SDAx pin is sampled.

If SDAx is low, a bus collision has occurred (i.e., another master is attempting to transmit a data '0', [Figure 25-35](#)). If SDAx is sampled high, the BRG is reloaded and begins counting. If SDAx goes from high-to-low before the BRG times out, no bus collision occurs because no two masters can assert SDAx at exactly the same time.

If SCLx goes from high-to-low before the BRG times out and SDAx has not already been asserted, a bus collision occurs. In this case, another master is attempting to transmit a data '1' during the Repeated Start condition, see [Figure 25-36](#).

If, at the end of the BRG time-out, both SCLx and SDAx are still high, the SDAx pin is driven low and the BRG is reloaded and begins counting. At the end of the count, regardless of the status of the SCLx pin, the SCLx pin is driven low and the Repeated Start condition is complete.

FIGURE 25-36: BUS COLLISION DURING A REPEATED START CONDITION (CASE 1)

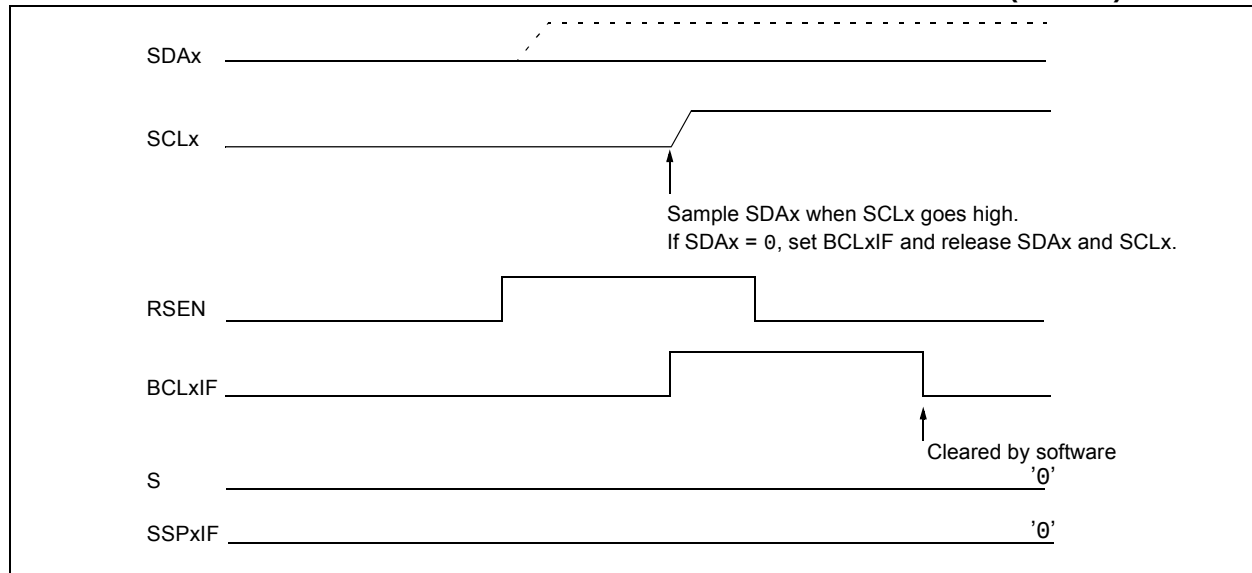
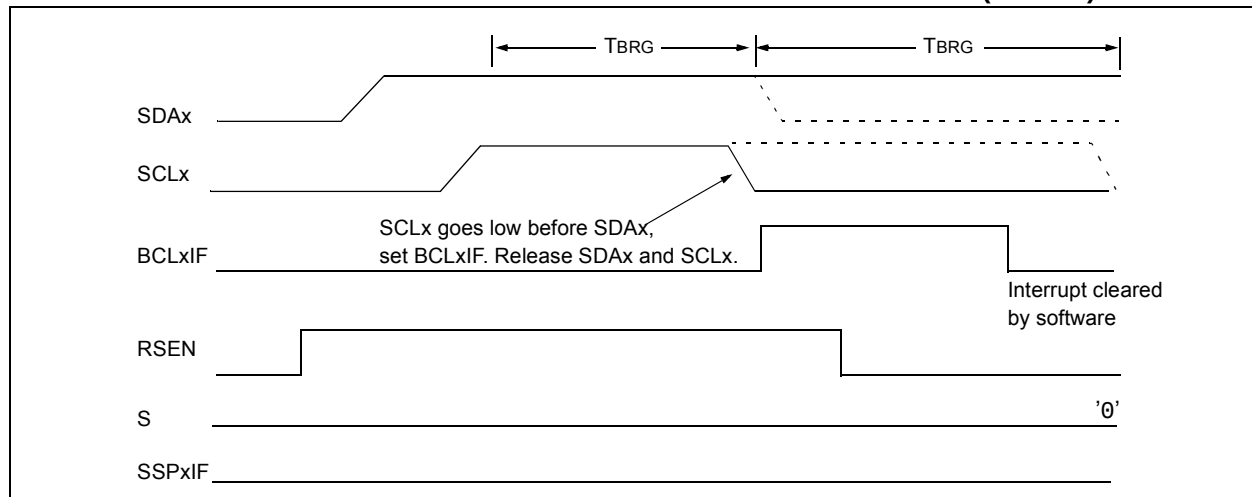


FIGURE 25-37: BUS COLLISION DURING REPEATED START CONDITION (CASE 2)



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25.6.13.3 Bus Collision During a Stop Condition

Bus collision occurs during a Stop condition if:

- After the SDAx pin has been deasserted and allowed to float high, SDAx is sampled low after the BRG has timed out.
- After the SCLx pin is deasserted, SCLx is sampled low before SDAx goes high.

The Stop condition begins with SDAx asserted low. When SDAx is sampled low, the SCLx pin is allowed to float. When the pin is sampled high (clock arbitration), the Baud Rate Generator is loaded with SSPxADD and counts down to 0. After the BRG times out, SDAx is sampled. If SDAx is sampled low, a bus collision has occurred. This is due to another master attempting to drive a data '0' (Figure 25-37). If the SCLx pin is sampled low before SDAx is allowed to float high, a bus collision occurs. This is another case of another master attempting to drive a data '0' (Figure 25-38).

FIGURE 25-38: BUS COLLISION DURING A STOP CONDITION (CASE 1)

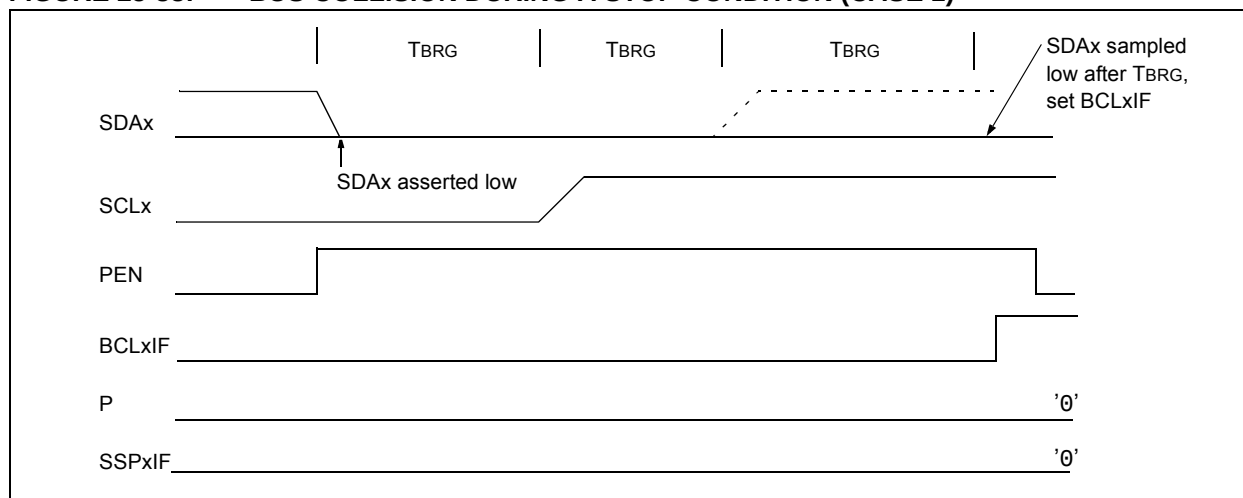


FIGURE 25-39: BUS COLLISION DURING A STOP CONDITION (CASE 2)

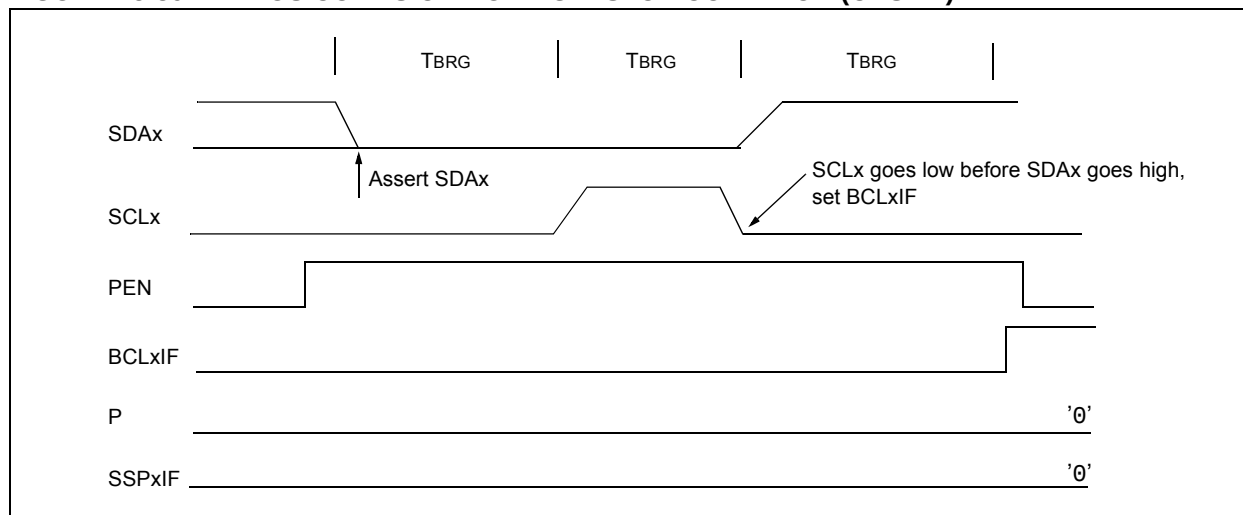


TABLE 25-3: SUMMARY OF REGISTERS ASSOCIATED WITH I²C™ OPERATION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Reset Values on Page:
INTCON	GIE	PEIE	TMR0IE	INTE	IOCFIE	TMR0IF	INTF	IOCF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE	87
PIE2	OSFIE	C2IE	C1IE	EEIE	BCL1IE	—	—	CCP2IE ⁽¹⁾	88
PIE4 ⁽¹⁾	—	—	—	—	—	—	BCL2IE	SSP2IE	90
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF	91
PIR2	OSFIF	C2IF	C1IF	EEIF	BCL1IF	—	—	CCP2IF ⁽¹⁾	92
PIR4 ⁽¹⁾	—	—	—	—	—	—	BCL2IF	SSP2IF	94
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127
SSPxADD	ADD7	ADD6	ADD5	ADD4	ADD3	ADD2	ADD1	ADD0	283
SSPxBUF	MSSPx Receive Buffer/Transmit Register								235*
SSPxCON1	WCOL	SSPOV	SSPEN	CKP	SSPM3	SSPM2	SSPM1	SSPM0	280
SSPxCON2	GCEN	ACKSTAT	ACKDT	ACKEN	RCEN	PEN	RSEN	SEN	281
SSPxCON3	ACKTIM	PCIE	SCIE	BOEN	SDAHT	SBCDE	AHEN	DHEN	282
SSPxMSK	MSK7	MSK6	MSK5	MSK4	MSK3	MSK2	MSK1	MSK0	283
SSPxSTAT	SMP	CKE	D/Ā	P	S	R/W	UA	BF	279

Legend: — = unimplemented, read as '0'. Shaded cells are not used by the MSSP module in I²C™ mode.

* Page provides register information.

Note 1: PIC16(L)F1827 only.

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25.7 BAUD RATE GENERATOR

The MSSPx module has a Baud Rate Generator available for clock generation in both I²C and SPI Master modes. The Baud Rate Generator (BRG) reload value is placed in the SSPxADD register (Register 25-6). When a write occurs to SSPxBUF, the Baud Rate Generator will automatically begin counting down.

Once the given operation is complete, the internal clock will automatically stop counting and the clock pin will remain in its last state.

An internal signal “Reload” in Figure 25-39 triggers the value from SSPxADD to be loaded into the BRG counter. This occurs twice for each oscillation of the

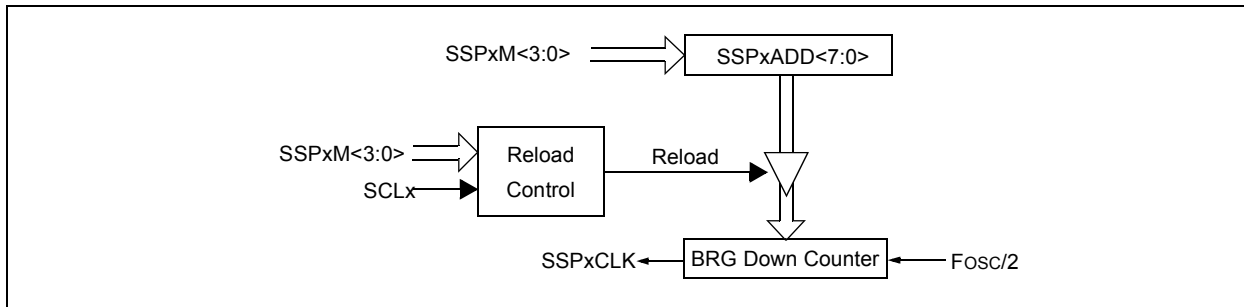
module clock line. The logic dictating when the reload signal is asserted depends on the mode the MSSPx is being operated in.

Table 25-4 demonstrates clock rates based on instruction cycles and the BRG value loaded into SSPxADD.

EQUATION 25-1:

$$F_{CLOCK} = \frac{F_{OSC}}{(SSPxADD + 1)(4)}$$

FIGURE 25-40: BAUD RATE GENERATOR BLOCK DIAGRAM



Note: Values of 0x00, 0x01 and 0x02 are not valid for SSPxADD when used as a Baud Rate Generator for I²C. This is an implementation limitation.

TABLE 25-4: MSSPX CLOCK RATE W/BRG

Fosc	Fcy	BRG Value	FCLOCK (2 Rollovers of BRG)
32 MHz	8 MHz	13h	400 kHz ⁽¹⁾
32 MHz	8 MHz	19h	308 kHz
32 MHz	8 MHz	4Fh	100 kHz
16 MHz	4 MHz	09h	400 kHz ⁽¹⁾
16 MHz	4 MHz	0Ch	308 kHz
16 MHz	4 MHz	27h	100 kHz
4 MHz	1 MHz	09h	100 kHz

Note 1: The I²C interface does not conform to the 400 kHz I²C specification (which applies to rates greater than 100 kHz) in all details, but may be used with care where higher rates are required by the application.

REGISTER 25-1: SSPxSTAT: SSPx STATUS REGISTER

R/W-0/0	R/W-0/0	R-0/0	R-0/0	R-0/0	R-0/0	R-0/0	R-0/0
SMP	CKE	D/A	P	S	R/W	UA	BF
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

bit 7	SMP: SPI Data Input Sample bit <u>SPI Master mode:</u> 1 = Input data sampled at end of data output time 0 = Input data sampled at middle of data output time <u>SPI Slave mode:</u> SMP must be cleared when SPI is used in Slave mode <u>In I²C Master or Slave mode:</u> 1 = Slew rate control disabled for standard speed mode (100 kHz and 1 MHz) 0 = Slew rate control enabled for high speed mode (400 kHz)
bit 6	CKE: SPI Clock Edge Select bit (SPI mode only) <u>In SPI Master or Slave mode:</u> 1 = Transmit occurs on transition from active to Idle clock state 0 = Transmit occurs on transition from Idle to active clock state <u>In I²C™ mode only:</u> 1 = Enable input logic so that thresholds are compliant with SM bus™ specification 0 = Disable SM bus™ specific inputs
bit 5	D/A: Data/Address bit (I ² C mode only) 1 = Indicates that the last byte received or transmitted was data 0 = Indicates that the last byte received or transmitted was address
bit 4	P: Stop bit (I ² C mode only. This bit is cleared when the MSSPx module is disabled, SSPxEN is cleared.) 1 = Indicates that a Stop bit has been detected last (this bit is '0' on Reset) 0 = Stop bit was not detected last
bit 3	S: Start bit (I ² C mode only. This bit is cleared when the MSSPx module is disabled, SSPxEN is cleared.) 1 = Indicates that a Start bit has been detected last (this bit is '0' on Reset) 0 = Start bit was not detected last
bit 2	R/W: Read/Write bit information (I ² C mode only) This bit holds the R/W bit information following the last address match. This bit is only valid from the address match to the next Start bit, Stop bit, or not ACK bit. <u>In I²C Slave mode:</u> 1 = Read 0 = Write <u>In I²C Master mode:</u> 1 = Transmit is in progress 0 = Transmit is not in progress OR-ing this bit with SEN, RSEN, PEN, RCEN or ACKEN will indicate if the MSSPx is in Idle mode.
bit 1	UA: Update Address bit (10-bit I ² C mode only) 1 = Indicates that the user needs to update the address in the SSPxADD register 0 = Address does not need to be updated
bit 0	BF: Buffer Full Status bit <u>Receive (SPI and I²C modes):</u> 1 = Receive complete, SSPxBUF is full 0 = Receive not complete, SSPxBUF is empty <u>Transmit (I²C mode only):</u> 1 = Data transmit in progress (does not include the ACK and Stop bits), SSPxBUF is full 0 = Data transmit complete (does not include the ACK and Stop bits), SSPxBUF is empty

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REGISTER 25-2: SSPxCON1: SSPx CONTROL REGISTER 1

R/C/HS-0/0	R/C/HS-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
WCOL	SSPxOV	SSPxEN	CKP	SSPxM<3:0>			
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	HS = Bit is set by hardware
		C = User cleared

bit 7	WCOL: Write Collision Detect bit Master mode: 1 = A write to the SSPxBUF register was attempted while the I ² C conditions were not valid for a transmission to be started 0 = No collision Slave mode: 1 = The SSPxBUF register is written while it is still transmitting the previous word (must be cleared in software) 0 = No collision
bit 6	SSPxOV: Receive Overflow Indicator bit ⁽¹⁾ In SPI mode: 1 = A new byte is received while the SSPxBUF register is still holding the previous data. In case of overflow, the data in SSPxSR is lost. Overflow can only occur in Slave mode. In Slave mode, the user must read the SSPxBUF, even if only transmitting data, to avoid setting overflow. In Master mode, the overflow bit is not set since each new reception (and transmission) is initiated by writing to the SSPxBUF register (must be cleared in software). 0 = No overflow In I²C mode: 1 = A byte is received while the SSPxBUF register is still holding the previous byte. SSPxOV is a "don't care" in Transmit mode (must be cleared in software). 0 = No overflow
bit 5	SSPxEN: Synchronous Serial Port Enable bit In both modes, when enabled, these pins must be properly configured as input or output In SPI mode: 1 = Enables serial port and configures SCKx, SDOx, SDIx and SSx as the source of the serial port pins ⁽²⁾ 0 = Disables serial port and configures these pins as I/O port pins In I²C mode: 1 = Enables the serial port and configures the SDAx and SCLx pins as the source of the serial port pins ⁽³⁾ 0 = Disables serial port and configures these pins as I/O port pins
bit 4	CKP: Clock Polarity Select bit In SPI mode: 1 = Idle state for clock is a high level 0 = Idle state for clock is a low level In I²C Slave mode: SCLx release control 1 = Enable clock 0 = Holds clock low (clock stretch). (Used to ensure data setup time.) In I²C Master mode: Unused in this mode
bit 3-0	SSPxM<3:0>: Synchronous Serial Port Mode Select bits 0000 = SPI Master mode, clock = Fosc/4 0001 = SPI Master mode, clock = Fosc/16 0010 = SPI Master mode, clock = Fosc/64 0011 = SPI Master mode, clock = TMR2 output/2 0100 = SPI Slave mode, clock = SCKx pin, SSx pin control enabled 0101 = SPI Slave mode, clock = SCKx pin, SSx pin control disabled, SSx can be used as I/O pin 0110 = I ² C Slave mode, 7-bit address 0111 = I ² C Slave mode, 10-bit address 1000 = I ² C Master mode, clock = Fosc/(4 * (SSPxADD+1)) ⁽⁴⁾ 1001 = Reserved 1010 = SPI Master mode, clock = Fosc/(4 * (SSPxADD+1)) ⁽⁵⁾ 1011 = I ² C firmware controlled Master mode (Slave idle) 1100 = Reserved 1101 = Reserved 1110 = I ² C Slave mode, 7-bit address with Start and Stop bit interrupts enabled 1111 = I ² C Slave mode, 10-bit address with Start and Stop bit interrupts enabled

- Note**
- 1: In Master mode, the overflow bit is not set since each new reception (and transmission) is initiated by writing to the SSPxBUF register.
 - 2: When enabled, these pins must be properly configured as input or output.
 - 3: When enabled, the SDAx and SCLx pins must be configured as inputs.
 - 4: SSPxADD values of 0, 1 or 2 are not supported for I²C Mode.
 - 5: SSPxADD value of '0' is not supported. Use SSPxM = 0000 instead.

REGISTER 25-3: SSPxCON2: SSPx CONTROL REGISTER 2

R/W-0/0	R-0/0	R/W-0/0	R/S/HS-0/0	R/S/HS-0/0	R/S/HS-0/0	R/S/HS-0/0	R/W/HS-0/0
GCEN	ACKSTAT	ACKDT	ACKEN	RCEN	PEN	RSEN	SEN
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	HC = Cleared by hardware S = User set

- bit 7 **GCEN:** General Call Enable bit (in I²C Slave mode only)
1 = Enable interrupt when a general call address (0x00 or 00h) is received in the SSPxSR
0 = General call address disabled
- bit 6 **ACKSTAT:** Acknowledge Status bit (in I²C mode only)
1 = Acknowledge was not received
0 = Acknowledge was received
- bit 5 **ACKDT:** Acknowledge Data bit (in I²C mode only)
In Receive mode:
Value transmitted when the user initiates an Acknowledge sequence at the end of a receive
1 = Not Acknowledge
0 = Acknowledge
- bit 4 **ACKEN:** Acknowledge Sequence Enable bit (in I²C Master mode only)
In Master Receive mode:
1 = Initiate Acknowledge sequence on SDAx and SCLx pins, and transmit ACKDT data bit.
Automatically cleared by hardware.
0 = Acknowledge sequence Idle
- bit 3 **RCEN:** Receive Enable bit (in I²C Master mode only)
1 = Enables Receive mode for I²C
0 = Receive Idle
- bit 2 **PEN:** Stop Condition Enable bit (in I²C Master mode only)
SCKx Release Control:
1 = Initiate Stop condition on SDAx and SCLx pins. Automatically cleared by hardware.
0 = Stop condition Idle
- bit 1 **RSEN:** Repeated Start Condition Enabled bit (in I²C Master mode only)
1 = Initiate Repeated Start condition on SDAx and SCLx pins. Automatically cleared by hardware.
0 = Repeated Start condition Idle
- bit 0 **SEN:** Start Condition Enabled bit (in I²C Master mode only)
In Master mode:
1 = Initiate Start condition on SDAx and SCLx pins. Automatically cleared by hardware.
0 = Start condition Idle
In Slave mode:
1 = Clock stretching is enabled for both slave transmit and slave receive (stretch enabled)
0 = Clock stretching is disabled

Note 1: For bits ACKEN, RCEN, PEN, RSEN, SEN: If the I²C module is not in the Idle mode, this bit may not be set (no spooling) and the SSPxBUF may not be written (or writes to the SSPxBUF are disabled).

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REGISTER 25-4: SSPxCON3: SSPx CONTROL REGISTER 3

R-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
ACKTIM	PCIE	SCIE	BOEN	SDAHT	SBCDE	AHEN	DHEN
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

- bit 7 **ACKTIM:** Acknowledge Time Status bit (I²C mode only)⁽³⁾
1 = Indicates the I²C bus is in an Acknowledge sequence, set on 8TH falling edge of SCLx clock
0 = Not an Acknowledge sequence, cleared on 9TH rising edge of SCLx clock
- bit 6 **PCIE:** Stop Condition Interrupt Enable bit (I²C mode only)
1 = Enable interrupt on detection of Stop condition
0 = Stop detection interrupts are disabled⁽²⁾
- bit 5 **SCIE:** Start Condition Interrupt Enable bit (I²C mode only)
1 = Enable interrupt on detection of Start or Restart conditions
0 = Start detection interrupts are disabled⁽²⁾
- bit 4 **BOEN:** Buffer Overwrite Enable bit
In SPI Slave mode:⁽¹⁾
1 = SSPxBUF updates every time that a new data byte is shifted in ignoring the BF bit
0 = If new byte is received with BF bit of the SSPxSTAT register already set, SSPxOV bit of the SSPxCON1 register is set, and the buffer is not updated
In I²C Master mode and SPI Master mode:
This bit is ignored.
In I²C Slave mode:
1 = SSPxBUF is updated and $\overline{\text{ACK}}$ is generated for a received address/data byte, ignoring the state of the SSPxOV bit only if the BF bit = 0.
0 = SSPxBUF is only updated when SSPxOV is clear
- bit 3 **SDAHT:** SDAx Hold Time Selection bit (I²C mode only)
1 = Minimum of 300 ns hold time on SDAx after the falling edge of SCLx
0 = Minimum of 100 ns hold time on SDAx after the falling edge of SCLx
- bit 2 **SBCDE:** Slave Mode Bus Collision Detect Enable bit (I²C Slave mode only)
If on the rising edge of SCLx, SDAx is sampled low when the module is outputting a high state, the BCLxIF bit of the PIR2 register is set, and bus goes Idle
1 = Enable slave bus collision interrupts
0 = Slave bus collision interrupts are disabled
- bit 1 **AHEN:** Address Hold Enable bit (I²C Slave mode only)
1 = Following the 8th falling edge of SCLx for a matching received address byte; CKP bit of the SSPxCON1 register will be cleared and the SCLx will be held low.
0 = Address holding is disabled
- bit 0 **DHEN:** Data Hold Enable bit (I²C Slave mode only)
1 = Following the 8th falling edge of SCLx for a received data byte; slave hardware clears the CKP bit of the SSPxCON1 register and SCLx is held low.
0 = Data holding is disabled

- Note 1:** For daisy-chained SPI operation; allows the user to ignore all but the last received byte. SSPxOV is still set when a new byte is received and BF = 1, but hardware continues to write the most recent byte to SSPxBUF.
- 2:** This bit has no effect in Slave modes that Start and Stop condition detection is explicitly listed as enabled.
- 3:** The ACKTIM Status bit is only active when the AHEN bit or DHEN bit is set.

REGISTER 25-5: SSPxMSK: SSPx MASK REGISTER

R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1	R/W-1/1
MSK<7:0>							
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

- bit 7-1 **MSK<7:1>**: Mask bits
 1 = The received address bit n is compared to SSPxADD<n> to detect I²C address match
 0 = The received address bit n is not used to detect I²C address match
- bit 0 **MSK<0>**: Mask bit for I²C Slave mode, 10-bit Address
 I²C Slave mode, 10-bit address (SSPxM<3:0> = 0111 or 1111):
 1 = The received address bit 0 is compared to SSPxADD<0> to detect I²C address match
 0 = The received address bit 0 is not used to detect I²C address match
 I²C Slave mode, 7-bit address, the bit is ignored

REGISTER 25-6: SSPxADD: MSSPx ADDRESS AND BAUD RATE REGISTER (I²C MODE)

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
ADD<7:0>							
bit 7							bit 0

Legend:

R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'
u = Bit is unchanged	x = Bit is unknown	-n/n = Value at POR and BOR/Value at all other Resets
'1' = Bit is set	'0' = Bit is cleared	

Master mode:

- bit 7-0 **ADD<7:0>**: Baud Rate Clock Divider bits
 $SCLx \text{ pin clock period} = ((ADD<7:0> + 1) * 4) / F_{osc}$

10-Bit Slave mode — Most Significant Address byte:

- bit 7-3 **Not used**: Unused for Most Significant Address byte. Bit state of this register is a "don't care". Bit pattern sent by master is fixed by I²C specification and must be equal to '11110'. However, those bits are compared by hardware and are not affected by the value in this register.
- bit 2-1 **ADD<2:1>**: Two Most Significant bits of 10-bit address
- bit 0 **Not used**: Unused in this mode. Bit state is a "don't care".

10-Bit Slave mode — Least Significant Address byte:

- bit 7-0 **ADD<7:0>**: Eight Least Significant bits of 10-bit address

7-Bit Slave mode:

- bit 7-1 **ADD<7:1>**: 7-bit address
- bit 0 **Not used**: Unused in this mode. Bit state is a "don't care".

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NOTES:

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FIGURE 26-2: EUSART RECEIVE BLOCK DIAGRAM



The operation of the EUSART module is controlled through three registers:

- Transmit Status and Control (TXSTA)
- Receive Status and Control (RCSTA)
- Baud Rate Control (BAUDCON)

These registers are detailed in [Register 26-1](#), [Register 26-2](#) and [Register 26-3](#), respectively.

When the receiver or transmitter section is not enabled then the corresponding RX or TX pin may be used for general purpose input and output.

26.1 EUSART Asynchronous Mode

The EUSART transmits and receives data using the standard non-return-to-zero (NRZ) format. NRZ is implemented with two levels: a V_{OH} mark state which represents a '1' data bit, and a V_{OL} space state which represents a '0' data bit. NRZ refers to the fact that consecutively transmitted data bits of the same value stay at the output level of that bit without returning to a neutral level between each bit transmission. An NRZ transmission port idles in the mark state. Each character transmission consists of one Start bit followed by eight or nine data bits and is always terminated by one or more Stop bits. The Start bit is always a space and the Stop bits are always marks. The most common data format is 8 bits. Each transmitted bit persists for a period of 1/(Baud Rate). An on-chip dedicated 8-bit/16-bit Baud Rate Generator is used to derive standard baud rate frequencies from the system oscillator. See [Table 26-5](#) for examples of baud rate configurations.

The EUSART transmits and receives the LSb first. The EUSART's transmitter and receiver are functionally independent, but share the same data format and baud rate. Parity is not supported by the hardware, but can be implemented in software and stored as the ninth data bit.

26.1.1 EUSART ASYNCHRONOUS TRANSMITTER

The EUSART transmitter block diagram is shown in [Figure 26-1](#). The heart of the transmitter is the serial Transmit Shift Register (TSR), which is not directly accessible by software. The TSR obtains its data from the transmit buffer, which is the TXREG register.

26.1.1.1 Enabling the Transmitter

The EUSART transmitter is enabled for asynchronous operations by configuring the following three control bits:

- TXEN = 1
- SYNC = 0
- SPEN = 1

All other EUSART control bits are assumed to be in their default state.

Setting the TXEN bit of the TXSTA register enables the transmitter circuitry of the EUSART. Clearing the SYNC bit of the TXSTA register configures the EUSART for asynchronous operation. Setting the SPEN bit of the RCSTA register enables the EUSART and automatically configures the TX/CK I/O pin as an output. If the TX/CK pin is shared with an analog peripheral, the analog I/O function must be disabled by clearing the corresponding ANSEL bit.

Note: The TXIF Transmitter Interrupt flag is set when the TXEN enable bit is set.

26.1.1.2 Transmitting Data

A transmission is initiated by writing a character to the TXREG register. If this is the first character, or the previous character has been completely flushed from the TSR, the data in the TXREG is immediately transferred to the TSR register. If the TSR still contains all or part of a previous character, the new character data is held in the TXREG until the Stop bit of the previous character has been transmitted. The pending character in the TXREG is then transferred to the TSR in one T_{cy} immediately following the Stop bit transmission. The transmission of the Start bit, data bits and Stop bit sequence commences immediately following the transfer of the data to the TSR from the TXREG.

26.1.1.3 Transmit Data Polarity

The polarity of the transmit data can be controlled with the SCKP bit of the BAUDCON register. The default state of this bit is '0' which selects high true transmit idle and data bits. Setting the SCKP bit to '1' will invert the transmit data resulting in low true idle and data bits. The SCKP bit controls transmit data polarity in Asynchronous mode only. In Synchronous mode, the SCKP bit has a different function. See [Section 26.4.1.2 "Clock Polarity"](#).

26.1.1.4 Transmit Interrupt Flag

The TXIF interrupt flag bit of the PIR1 register is set whenever the EUSART transmitter is enabled and no character is being held for transmission in the TXREG. In other words, the TXIF bit is only clear when the TSR is busy with a character and a new character has been queued for transmission in the TXREG. The TXIF flag bit is not cleared immediately upon writing TXREG. TXIF becomes valid in the second instruction cycle following the write execution. Polling TXIF immediately following the TXREG write will return invalid results. The TXIF bit is read-only, it cannot be set or cleared by software.

The TXIF interrupt can be enabled by setting the TXIE interrupt enable bit of the PIE1 register. However, the TXIF flag bit will be set whenever the TXREG is empty, regardless of the state of TXIE enable bit.

To use interrupts when transmitting data, set the TXIE bit only when there is more data to send. Clear the TXIE interrupt enable bit upon writing the last character of the transmission to the TXREG.

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26.1.1.5 TSR Status

The TRMT bit of the TXSTA register indicates the status of the TSR register. This is a read-only bit. The TRMT bit is set when the TSR register is empty and is cleared when a character is transferred to the TSR register from the TXREG. The TRMT bit remains clear until all bits have been shifted out of the TSR register. No interrupt logic is tied to this bit, so the user has to poll this bit to determine the TSR status.

Note: The TSR register is not mapped in data memory, so it is not available to the user.

26.1.1.6 Transmitting 9-Bit Characters

The EUSART supports 9-bit character transmissions. When the TX9 bit of the TXSTA register is set, the EUSART will shift 9 bits out for each character transmitted. The TX9D bit of the TXSTA register is the ninth, and Most Significant, data bit. When transmitting 9-bit data, the TX9D data bit must be written before writing the 8 Least Significant bits into the TXREG. All nine bits of data will be transferred to the TSR shift register immediately after the TXREG is written.

A special 9-bit Address mode is available for use with multiple receivers. See [Section 26.1.2.7 “Address Detection”](#) for more information on the address mode.

26.1.1.7 Asynchronous Transmission Set-up:

1. Initialize the SPBRGH, SPBRGL register pair and the BRGH and BRG16 bits to achieve the desired baud rate (see [Section 26.3 “EUSART Baud Rate Generator \(BRG\)”](#)).
2. Enable the asynchronous serial port by clearing the SYNC bit and setting the SPEN bit.
3. If 9-bit transmission is desired, set the TX9 control bit. A set ninth data bit will indicate that the 8 Least Significant data bits are an address when the receiver is set for address detection.
4. Set SCKP bit if inverted transmit is desired.
5. Enable the transmission by setting the TXEN control bit. This will cause the TXIF interrupt bit to be set.
6. If interrupts are desired, set the TXIE interrupt enable bit of the PIE1 register. An interrupt will occur immediately provided that the GIE and PEIE bits of the INTCON register are also set.
7. If 9-bit transmission is selected, the ninth bit should be loaded into the TX9D data bit.
8. Load 8-bit data into the TXREG register. This will start the transmission.

FIGURE 26-3: ASYNCHRONOUS TRANSMISSION

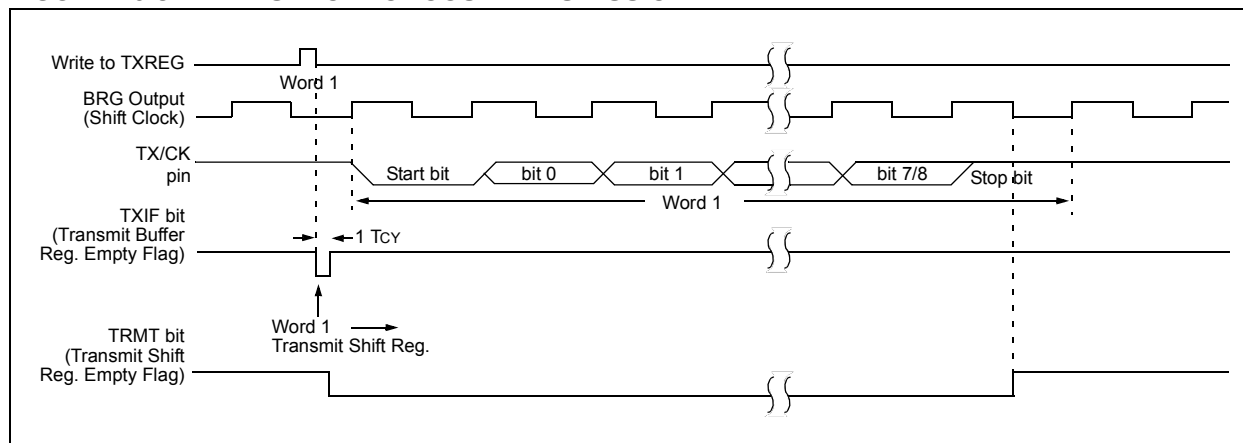


FIGURE 26-4: ASYNCHRONOUS TRANSMISSION (BACK-TO-BACK)

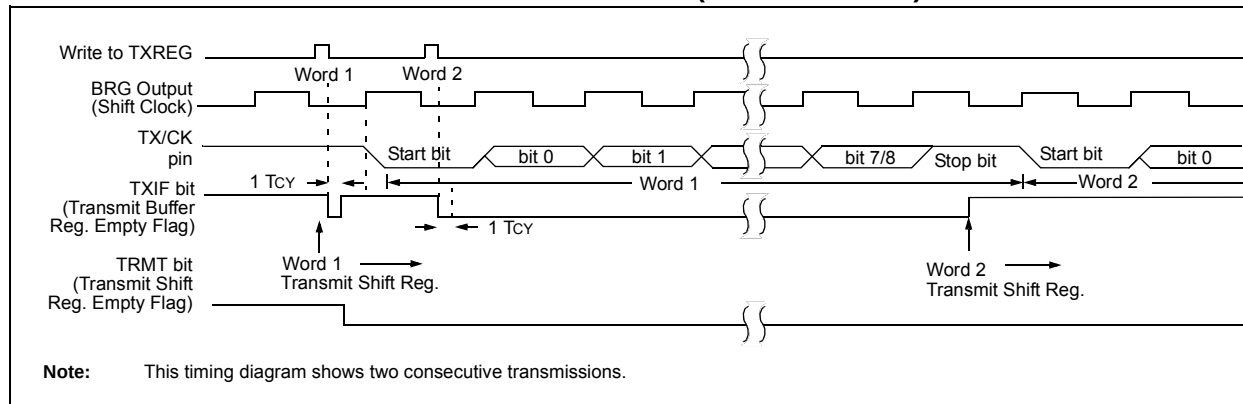


TABLE 26-1: SUMMARY OF REGISTERS ASSOCIATED WITH ASYNCHRONOUS TRANSMISSION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSEL	SDO1SEL	SS1SEL	P2BSEL ⁽¹⁾	CCP2SEL ⁽¹⁾	P1DSEL	P1CSEL	CCP1SEL	119
APFCON1	—	—	—	—	—	—	—	TXCKSEL	119
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	296
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSPIE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSPIF	CCP1IF	TMR2IF	TMR1IF	91
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	295
SPBRGL	BRG<7:0>								297*
SPBRGH	BRG<15:8>								297*
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127
TXREG	EUSART Transmit Data Register								287*
TXSTA	CSRC	TX9	TXEN	SYNC	SEnDB	BRGH	TRMT	TX9D	294

Legend: — = unimplemented location, read as '0'. Shaded cells are not used for Asynchronous Transmission.

* Page provides register information.

Note 1: PIC16(L)F1827 only.

26.1.2 EUSART ASYNCHRONOUS RECEIVER

The Asynchronous mode is typically used in RS-232 systems. The receiver block diagram is shown in [Figure 26-2](#). The data is received on the RX/DT pin and drives the data recovery block. The data recovery block is actually a high-speed shifter operating at 16 times the baud rate, whereas the serial Receive Shift Register (RSR) operates at the bit rate. When all 8 or 9 bits of the character have been shifted in, they are immediately transferred to a two character First-In-First-Out (FIFO) memory. The FIFO buffering allows reception of two complete characters and the start of a third character before software must start servicing the EUSART receiver. The FIFO and RSR registers are not directly accessible by software. Access to the received data is via the RCREG register.

26.1.2.1 Enabling the Receiver

The EUSART receiver is enabled for asynchronous operation by configuring the following three control bits:

- CREN = 1
- SYNC = 0
- SPEN = 1

All other EUSART control bits are assumed to be in their default state.

Setting the CREN bit of the RCSTA register enables the receiver circuitry of the EUSART. Clearing the SYNC bit of the TXSTA register configures the EUSART for asynchronous operation. Setting the SPEN bit of the RCSTA register enables the EUSART. The programmer must set the corresponding TRIS bit to configure the RX/DT I/O pin as an input.

Note: If the RX/DT function is on an analog pin, the corresponding ANSEL bit must be cleared for the receiver to function.

26.1.2.2 Receiving Data

The receiver data recovery circuit initiates character reception on the falling edge of the first bit. The first bit, also known as the Start bit, is always a zero. The data recovery circuit counts one-half bit time to the center of the Start bit and verifies that the bit is still a zero. If it is not a zero then the data recovery circuit aborts character reception, without generating an error, and resumes looking for the falling edge of the Start bit. If the Start bit zero verification succeeds then the data recovery circuit counts a full bit time to the center of the next bit. The bit is then sampled by a majority detect circuit and the resulting '0' or '1' is shifted into the RSR. This repeats until all data bits have been sampled and shifted into the RSR. One final bit time is measured and the level sampled. This is the Stop bit, which is always a '1'. If the data recovery circuit samples a '0' in the Stop bit position then a framing error is set for this character, otherwise the framing error is cleared for this character. See [Section 26.1.2.4 "Receive Framing Error"](#) for more information on framing errors.

Immediately after all data bits and the Stop bit have been received, the character in the RSR is transferred to the EUSART receive FIFO and the RCIF interrupt flag bit of the PIR1 register is set. The top character in the FIFO is transferred out of the FIFO by reading the RCREG register.

Note: If the receive FIFO is overrun, no additional characters will be received until the overrun condition is cleared. See [Section 26.1.2.5 "Receive Overrun Error"](#) for more information on overrun errors.

26.1.2.3 Receive Interrupts

The RCIF interrupt flag bit of the PIR1 register is set whenever the EUSART receiver is enabled and there is an unread character in the receive FIFO. The RCIF interrupt flag bit is read-only, it cannot be set or cleared by software.

RCIF interrupts are enabled by setting all of the following bits:

- RCIE interrupt enable bit of the PIE1 register
- PEIE peripheral interrupt enable bit of the INTCON register
- GIE global interrupt enable bit of the INTCON register

The RCIF interrupt flag bit will be set when there is an unread character in the FIFO, regardless of the state of interrupt enable bits.

26.1.2.4 Receive Framing Error

Each character in the receive FIFO buffer has a corresponding framing error Status bit. A framing error indicates that a Stop bit was not seen at the expected time. The framing error status is accessed via the FERR bit of the RCSTA register. The FERR bit represents the status of the top unread character in the receive FIFO. Therefore, the FERR bit must be read before reading the RCREG.

The FERR bit is read-only and only applies to the top unread character in the receive FIFO. A framing error (FERR = 1) does not preclude reception of additional characters. It is not necessary to clear the FERR bit. Reading the next character from the FIFO buffer will advance the FIFO to the next character and the next corresponding framing error.

The FERR bit can be forced clear by clearing the SPEN bit of the RCSTA register which resets the EUSART. Clearing the CREN bit of the RCSTA register does not affect the FERR bit. A framing error by itself does not generate an interrupt.

Note: If all receive characters in the receive FIFO have framing errors, repeated reads of the RCREG will not clear the FERR bit.

26.1.2.5 Receive Overrun Error

The receive FIFO buffer can hold two characters. An overrun error will be generated if a third character, in its entirety, is received before the FIFO is accessed. When this happens the OERR bit of the RCSTA register is set. The characters already in the FIFO buffer can be read but no additional characters will be received until the error is cleared. The error must be cleared by either clearing the CREN bit of the RCSTA register or by resetting the EUSART by clearing the SPEN bit of the RCSTA register.

26.1.2.6 Receiving 9-bit Characters

The EUSART supports 9-bit character reception. When the RX9 bit of the RCSTA register is set the EUSART will shift 9 bits into the RSR for each character received. The RX9D bit of the RCSTA register is the ninth and Most Significant data bit of the top unread character in the receive FIFO. When reading 9-bit data from the receive FIFO buffer, the RX9D data bit must be read before reading the 8 Least Significant bits from the RCREG.

26.1.2.7 Address Detection

A special Address Detection mode is available for use when multiple receivers share the same transmission line, such as in RS-485 systems. Address detection is enabled by setting the ADDEN bit of the RCSTA register.

Address detection requires 9-bit character reception. When address detection is enabled, only characters with the ninth data bit set will be transferred to the receive FIFO buffer, thereby setting the RCIF interrupt bit. All other characters will be ignored.

Upon receiving an address character, user software determines if the address matches its own. Upon address match, user software must disable address detection by clearing the ADDEN bit before the next Stop bit occurs. When user software detects the end of the message, determined by the message protocol used, software places the receiver back into the Address Detection mode by setting the ADDEN bit.

26.1.2.8 Asynchronous Reception Set-up:

1. Initialize the SPBRGH, SPBRGL register pair and the BRGH and BRG16 bits to achieve the desired baud rate (see [Section 26.3 “EUSART Baud Rate Generator \(BRG\)”](#)).
2. Clear the ANSEL bit for the RX pin (if applicable).
3. Enable the serial port by setting the SPEN bit. The SYNC bit must be clear for asynchronous operation.
4. If interrupts are desired, set the RCIE bit of the PIE1 register and the GIE and PEIE bits of the INTCON register.
5. If 9-bit reception is desired, set the RX9 bit.
6. Enable reception by setting the CREN bit.
7. The RCIF interrupt flag bit will be set when a character is transferred from the RSR to the receive buffer. An interrupt will be generated if the RCIE interrupt enable bit was also set.
8. Read the RCSTA register to get the error flags and, if 9-bit data reception is enabled, the ninth data bit.
9. Get the received 8 Least Significant data bits from the receive buffer by reading the RCREG register.
10. If an overrun occurred, clear the OERR flag by clearing the CREN receiver enable bit.

26.1.2.9 9-bit Address Detection Mode Set-up

This mode would typically be used in RS-485 systems. To set up an Asynchronous Reception with Address Detect Enable:

1. Initialize the SPBRGH, SPBRGL register pair and the BRGH and BRG16 bits to achieve the desired baud rate (see [Section 26.3 “EUSART Baud Rate Generator \(BRG\)”](#)).
2. Clear the ANSEL bit for the RX pin (if applicable).
3. Enable the serial port by setting the SPEN bit. The SYNC bit must be clear for asynchronous operation.
4. If interrupts are desired, set the RCIE bit of the PIE1 register and the GIE and PEIE bits of the INTCON register.
5. Enable 9-bit reception by setting the RX9 bit.
6. Enable address detection by setting the ADDEN bit.
7. Enable reception by setting the CREN bit.
8. The RCIF interrupt flag bit will be set when a character with the ninth bit set is transferred from the RSR to the receive buffer. An interrupt will be generated if the RCIE interrupt enable bit was also set.
9. Read the RCSTA register to get the error flags. The ninth data bit will always be set.
10. Get the received 8 Least Significant data bits from the receive buffer by reading the RCREG register. Software determines if this is the device's address.
11. If an overrun occurred, clear the OERR flag by clearing the CREN receiver enable bit.
12. If the device has been addressed, clear the ADDEN bit to allow all received data into the receive buffer and generate interrupts.

FIGURE 26-5: ASYNCHRONOUS RECEPTION

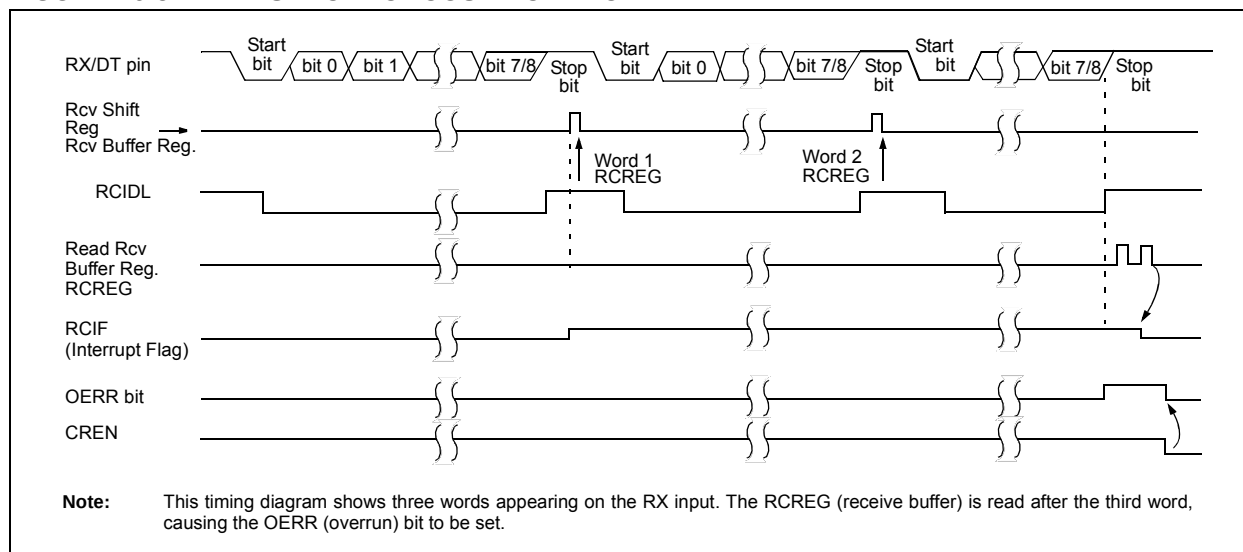


TABLE 26-2: SUMMARY OF REGISTERS ASSOCIATED WITH ASYNCHRONOUS RECEPTION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSSEL	SDO1SEL	SS1SEL	P2BSEL ⁽¹⁾	CCP2SEL ⁽¹⁾	P1DSEL	P1CSEL	CCP1SEL	119
APFCON1	—	—	—	—	—	—	—	TXCKSEL	119
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	296
INTCON	GIE	PEIE	TMR0IE	INTE	IOCFIE	TMR0IF	INTF	IOCFIF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSPIE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSPIF	CCP1IF	TMR2IF	TMR1IF	91
RCREG	EUSART Receive Data Register								290*
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	295
SPBRGL	BRG<7:0>								297*
SPBRGH	BRG<15:8>								297*
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127
TXSTA	CSRC	TX9	TXEN	SYNC	SEnDB	BRGH	TRMT	TX9D	294

Legend: — = unimplemented location, read as '0'. Shaded cells are not used for Asynchronous Reception.

* Page provides register information.

Note 1: PIC16(L)F1827 only.

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26.2 Clock Accuracy with Asynchronous Operation

The factory calibrates the internal oscillator block output (INTOSC). However, the INTOSC frequency may drift as VDD or temperature changes, and this directly affects the asynchronous baud rate. Two methods may be used to adjust the baud rate clock, but both require a reference clock source of some kind.

The first (preferred) method uses the OSCTUNE register to adjust the INTOSC output. Adjusting the value in the OSCTUNE register allows for fine resolution changes to the system clock source. See [Section 5.2.2 “Internal Clock Sources”](#) for more information.

The other method adjusts the value in the Baud Rate Generator. This can be done automatically with the Auto-Baud Detect feature (see [Section 26.3.1 “Auto-Baud Detect”](#)). There may not be fine enough resolution when adjusting the Baud Rate Generator to compensate for a gradual change in the peripheral clock frequency.

REGISTER 26-1: TXSTA: TRANSMIT STATUS AND CONTROL REGISTER

R/W-0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R-1/1	R/W-0/0
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'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7	CSRC: Clock Source Select bit <u>Asynchronous mode:</u> Don't care <u>Synchronous mode:</u> 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 <u>Asynchronous mode:</u> 1 = Send Sync Break on next transmission (cleared by hardware upon completion) 0 = Sync Break transmission completed <u>Synchronous mode:</u> Don't care
bit 2	BRGH: High Baud Rate Select bit <u>Asynchronous mode:</u> 1 = High speed 0 = Low speed <u>Synchronous mode:</u> Unused in this mode
bit 1	TRMT: Transmit Shift Register Status bit 1 = TSR empty 0 = TSR full
bit 0	TX9D: Ninth bit of Transmit Data Can be address/data bit or a parity bit.

Note 1: SREN/CREN overrides TXEN in Sync mode.

REGISTER 26-2: RCSTA: RECEIVE STATUS AND CONTROL REGISTER⁽¹⁾

R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	R-0/0	R-0/0	R-0/0
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'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

- 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, enable interrupt and load 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 receive 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:** Ninth bit of Received Data
This can be address/data bit or a parity bit and must be calculated by user firmware.

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REGISTER 26-3: BAUDCON: BAUD RATE CONTROL REGISTER

R-0/0	R-1/1	U-0	R/W-0/0	R/W-0/0	U-0	R/W-0/0	R/W-0/0
ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7 **ABDOVF:** Auto-Baud Detect Overflow bit

Asynchronous mode:

1 = Auto-baud timer overflowed

0 = Auto-baud timer did not overflow

Synchronous mode:

Don't care

bit 6 **RCIDL:** Receive Idle Flag bit

Asynchronous mode:

1 = Receiver is Idle

0 = Start bit has been received and the receiver is receiving

Synchronous mode:

Don't care

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

bit 4 **SCKP:** Synchronous Clock Polarity Select bit

Asynchronous mode:

1 = Transmit inverted data to the TX/CK pin

0 = Transmit non-inverted data to the TX/CK pin

Synchronous mode:

1 = Data is clocked on rising edge of the clock

0 = Data is clocked on falling edge of the clock

bit 3 **BRG16:** 16-bit Baud Rate Generator bit

1 = 16-bit Baud Rate Generator is used

0 = 8-bit Baud Rate Generator is used

bit 2 **Unimplemented:** Read as '0'

bit 1 **WUE:** Wake-up Enable bit

Asynchronous mode:

1 = Receiver is waiting for a falling edge. No character will be received, byte RCIF will be set. WUE will automatically clear after RCIF is set.

0 = Receiver is operating normally

Synchronous mode:

Don't care

bit 0 **ABDEN:** Auto-Baud Detect Enable bit

Asynchronous mode:

1 = Auto-Baud Detect mode is enabled (clears when auto-baud is complete)

0 = Auto-Baud Detect mode is disabled

Synchronous mode:

Don't care

26.3 EUSART Baud Rate Generator (BRG)

The Baud Rate Generator (BRG) is an 8-bit or 16-bit timer that is dedicated to the support of both the asynchronous and synchronous EUSART operation. By default, the BRG operates in 8-bit mode. Setting the BRG16 bit of the BAUDCON register selects 16-bit mode.

The SPBRGH, SPBRGL register pair determines the period of the free running baud rate timer. In Asynchronous mode the multiplier of the baud rate period is determined by both the BRGH bit of the TXSTA register and the BRG16 bit of the BAUDCON register. In Synchronous mode, the BRGH bit is ignored.

Table 26-3 contains the formulas for determining the baud rate. Example 26-1 provides a sample calculation for determining the baud rate and baud rate error.

Typical baud rates and error values for various asynchronous modes have been computed for your convenience and are shown in Table 26-3. It may be advantageous to use the high baud rate (BRGH = 1), or the 16-bit BRG (BRG16 = 1) to reduce the baud rate error. The 16-bit BRG mode is used to achieve slow baud rates for fast oscillator frequencies.

Writing a new value to the SPBRGH, SPBRGL register pair causes the BRG timer to be reset (or cleared). This ensures that the BRG does not wait for a timer overflow before outputting the new baud rate.

If the system clock is changed during an active receive operation, a receive error or data loss may result. To avoid this problem, check the status of the RCIDL bit to make sure that the receive operation is Idle before changing the system clock.

EXAMPLE 26-1: CALCULATING BAUD RATE ERROR

For a device with FOSC of 16 MHz, desired baud rate of 9600, Asynchronous mode, 8-bit BRG:

$$\text{Desired Baud Rate} = \frac{F_{OSC}}{64(SPBRGH:SPBRGL) + 1}$$

Solving for SPBRGH:SPBRGL:

$$X = \frac{\frac{F_{OSC}}{\text{Desired Baud Rate}}}{64} - 1$$

$$= \frac{\frac{16000000}{9600}}{64} - 1$$

$$= [25.042] = 25$$

$$\text{Calculated Baud Rate} = \frac{16000000}{64(25 + 1)}$$

$$= 9615$$

$$\text{Error} = \frac{\text{Calc. Baud Rate} - \text{Desired Baud Rate}}{\text{Desired Baud Rate}}$$

$$= \frac{(9615 - 9600)}{9600} = 0.16\%$$

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TABLE 26-3: BAUD RATE FORMULAS

Configuration Bits			BRG/EUSART Mode	Baud Rate Formula
SYNC	BRG16	BRGH		
0	0	0	8-bit/Asynchronous	$F_{osc}/[64 (n+1)]$
0	0	1	8-bit/Asynchronous	$F_{osc}/[16 (n+1)]$
0	1	0	16-bit/Asynchronous	
0	1	1	16-bit/Asynchronous	$F_{osc}/[4 (n+1)]$
1	0	x	8-bit/Synchronous	
1	1	x	16-bit/Synchronous	

Legend: x = Don't care, n = value of SPBRGH, SPBRGL register pair

TABLE 26-4: SUMMARY OF REGISTERS ASSOCIATED WITH THE BAUD RATE GENERATOR

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	296
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	295
SPBRGL	BRG<7:0>								297*
SPBRGH	BRG<15:8>								297*
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	294

Legend: — = unimplemented location, read as '0'. Shaded cells are not used for the Baud Rate Generator.

* Page provides register information.

TABLE 26-5: BAUD RATES FOR ASYNCHRONOUS MODES

BAUD RATE	SYNC = 0, BRGH = 0, BRG16 = 0											
	Fosc = 32.000 MHz			Fosc = 20.000 MHz			Fosc = 18.432 MHz			Fosc = 11.0592 MHz		
	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)
300	—	—	—	—	—	—	—	—	—	—	—	—
1200	—	—	—	1221	1.73	255	1200	0.00	239	1200	0.00	143
2400	2404	0.16	207	2404	0.16	129	2400	0.00	119	2400	0.00	71
9600	9615	0.16	51	9470	-1.36	32	9600	0.00	29	9600	0.00	17
10417	10417	0.00	47	10417	0.00	29	10286	-1.26	27	10165	-2.42	16
19.2k	19.23k	0.16	25	19.53k	1.73	15	19.20k	0.00	14	19.20k	0.00	8
57.6k	55.55k	-3.55	3	—	—	—	57.60k	0.00	7	57.60k	0.00	2
115.2k	—	—	—	—	—	—	—	—	—	—	—	—

BAUD RATE	SYNC = 0, BRGH = 0, BRG16 = 0											
	Fosc = 8.000 MHz			Fosc = 4.000 MHz			Fosc = 3.6864 MHz			Fosc = 1.000 MHz		
	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)
300	—	—	—	300	0.16	207	300	0.00	191	300	0.16	51
1200	1202	0.16	103	1202	0.16	51	1200	0.00	47	1202	0.16	12
2400	2404	0.16	51	2404	0.16	25	2400	0.00	23	—	—	—
9600	9615	0.16	12	—	—	—	9600	0.00	5	—	—	—
10417	10417	0.00	11	10417	0.00	5	—	—	—	—	—	—
19.2k	—	—	—	—	—	—	19.20k	0.00	2	—	—	—
57.6k	—	—	—	—	—	—	57.60k	0.00	0	—	—	—
115.2k	—	—	—	—	—	—	—	—	—	—	—	—

BAUD RATE	SYNC = 0, BRGH = 1, BRG16 = 0											
	Fosc = 32.000 MHz			Fosc = 20.000 MHz			Fosc = 18.432 MHz			Fosc = 11.0592 MHz		
	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)
300	—	—	—	—	—	—	—	—	—	—	—	—
1200	—	—	—	—	—	—	—	—	—	—	—	—
2400	—	—	—	—	—	—	—	—	—	—	—	—
9600	9615	0.16	207	9615	0.16	129	9600	0.00	119	9600	0.00	71
10417	10417	0.00	191	10417	0.00	119	10378	-0.37	110	10473	0.53	65
19.2k	19.23k	0.16	103	19.23k	0.16	64	19.20k	0.00	59	19.20k	0.00	35
57.6k	57.14k	-0.79	34	56.82k	-1.36	21	57.60k	0.00	19	57.60k	0.00	11
115.2k	117.64k	2.12	16	113.64k	-1.36	10	115.2k	0.00	9	115.2k	0.00	5

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TABLE 26-5: BAUD RATES FOR ASYNCHRONOUS MODES (CONTINUED)

BAUD RATE	SYNC = 0, BRGH = 1, BRG16 = 0											
	Fosc = 8.000 MHz			Fosc = 4.000 MHz			Fosc = 3.6864 MHz			Fosc = 1.000 MHz		
	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)
300	—	—	—	—	—	—	—	—	—	300	0.16	207
1200	—	—	—	1202	0.16	207	1200	0.00	191	1202	0.16	51
2400	2404	0.16	207	2404	0.16	103	2400	0.00	95	2404	0.16	25
9600	9615	0.16	51	9615	0.16	25	9600	0.00	23	—	—	—
10417	10417	0.00	47	10417	0.00	23	10473	0.53	21	10417	0.00	5
19.2k	19231	0.16	25	19.23k	0.16	12	19.2k	0.00	11	—	—	—
57.6k	55556	-3.55	8	—	—	—	57.60k	0.00	3	—	—	—
115.2k	—	—	—	—	—	—	115.2k	0.00	1	—	—	—

BAUD RATE	SYNC = 0, BRGH = 0, BRG16 = 1											
	Fosc = 32.000 MHz			Fosc = 20.000 MHz			Fosc = 18.432 MHz			Fosc = 11.0592 MHz		
	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)
300	300.0	0.00	6666	300.0	-0.01	4166	300.0	0.00	3839	300.0	0.00	2303
1200	1200	-0.02	3332	1200	-0.03	1041	1200	0.00	959	1200	0.00	575
2400	2401	-0.04	832	2399	-0.03	520	2400	0.00	479	2400	0.00	287
9600	9615	0.16	207	9615	0.16	129	9600	0.00	119	9600	0.00	71
10417	10417	0.00	191	10417	0.00	119	10378	-0.37	110	10473	0.53	65
19.2k	19.23k	0.16	103	19.23k	0.16	64	19.20k	0.00	59	19.20k	0.00	35
57.6k	57.14k	-0.79	34	56.818	-1.36	21	57.60k	0.00	19	57.60k	0.00	11
115.2k	117.6k	2.12	16	113.636	-1.36	10	115.2k	0.00	9	115.2k	0.00	5

BAUD RATE	SYNC = 0, BRGH = 0, BRG16 = 1											
	Fosc = 8.000 MHz			Fosc = 4.000 MHz			Fosc = 3.6864 MHz			Fosc = 1.000 MHz		
	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)
300	299.9	-0.02	1666	300.1	0.04	832	300.0	0.00	767	300.5	0.16	207
1200	1199	-0.08	416	1202	0.16	207	1200	0.00	191	1202	0.16	51
2400	2404	0.16	207	2404	0.16	103	2400	0.00	95	2404	0.16	25
9600	9615	0.16	51	9615	0.16	25	9600	0.00	23	—	—	—
10417	10417	0.00	47	10417	0.00	23	10473	0.53	21	10417	0.00	5
19.2k	19.23k	0.16	25	19.23k	0.16	12	19.20k	0.00	11	—	—	—
57.6k	55556	-3.55	8	—	—	—	57.60k	0.00	3	—	—	—
115.2k	—	—	—	—	—	—	115.2k	0.00	1	—	—	—

TABLE 26-5: BAUD RATES FOR ASYNCHRONOUS MODES (CONTINUED)

BAUD RATE	SYNC = 0, BRGH = 1, BRG16 = 1 or SYNC = 1, BRG16 = 1											
	Fosc = 32.000 MHz			Fosc = 20.000 MHz			Fosc = 18.432 MHz			Fosc = 11.0592 MHz		
	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)
300	300.0	0.00	26666	300.0	0.00	16665	300.0	0.00	15359	300.0	0.00	9215
1200	1200	0.00	6666	1200	-0.01	4166	1200	0.00	3839	1200	0.00	2303
2400	2400	0.01	3332	2400	0.02	2082	2400	0.00	1919	2400	0.00	1151
9600	9604	0.04	832	9597	-0.03	520	9600	0.00	479	9600	0.00	287
10417	10417	0.00	767	10417	0.00	479	10425	0.08	441	10433	0.16	264
19.2k	19.18k	-0.08	416	19.23k	0.16	259	19.20k	0.00	239	19.20k	0.00	143
57.6k	57.55k	-0.08	138	57.47k	-0.22	86	57.60k	0.00	79	57.60k	0.00	47
115.2k	115.9k	0.64	68	116.3k	0.94	42	115.2k	0.00	39	115.2k	0.00	23

BAUD RATE	SYNC = 0, BRGH = 1, BRG16 = 1 or SYNC = 1, BRG16 = 1											
	Fosc = 8.000 MHz			Fosc = 4.000 MHz			Fosc = 3.6864 MHz			Fosc = 1.000 MHz		
	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)	Actual Rate	% Error	SPBRG value (decimal)
300	300.0	0.00	6666	300.0	0.01	3332	300.0	0.00	3071	300.1	0.04	832
1200	1200	-0.02	1666	1200	0.04	832	1200	0.00	767	1202	0.16	207
2400	2401	0.04	832	2398	0.08	416	2400	0.00	383	2404	0.16	103
9600	9615	0.16	207	9615	0.16	103	9600	0.00	95	9615	0.16	25
10417	10417	0	191	10417	0.00	95	10473	0.53	87	10417	0.00	23
19.2k	19.23k	0.16	103	19.23k	0.16	51	19.20k	0.00	47	19.23k	0.16	12
57.6k	57.14k	-0.79	34	58.82k	2.12	16	57.60k	0.00	15	—	—	—
115.2k	117.6k	2.12	16	111.1k	-3.55	8	115.2k	0.00	7	—	—	—

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26.3.1 AUTO-BAUD DETECT

The EUSART module supports automatic detection and calibration of the baud rate.

In the Auto-Baud 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. The Baud Rate Generator is used to time the period of a received 55h (ASCII “U”) which is the Sync character for the LIN bus. The unique feature of this character is that it has five rising edges including the Stop bit edge.

Setting the ABDEN bit of the BAUDCON register starts the auto-baud calibration sequence (Figure 26-6). While the ABD sequence takes place, the EUSART state machine is held in Idle. On the first rising edge of the receive line, after the Start bit, the SPBRG begins counting up using the BRG counter clock as shown in Table 26-6. The fifth rising edge will occur on the RX pin at the end of the eighth bit period. At that time, an accumulated value totaling the proper BRG period is left in the SPBRGH, SPBRGL register pair, the ABDEN bit is automatically cleared and the RCIF interrupt flag is set. The value in the RCREG needs to be read to clear the RCIF interrupt. RCREG content should be discarded. When calibrating for modes that do not use the SPBRGH register the user can verify that the SPBRGL register did not overflow by checking for 00h in the SPBRGH register.

The BRG auto-baud clock is determined by the BRG16 and BRGH bits as shown in Table 26-6. During ABD, both the SPBRGH and SPBRGL registers are used as a 16-bit counter, independent of the BRG16 bit setting. While calibrating the baud rate period, the SPBRGH

and SPBRGL registers are clocked at 1/8th the BRG base clock rate. The resulting byte measurement is the average bit time when clocked at full speed.

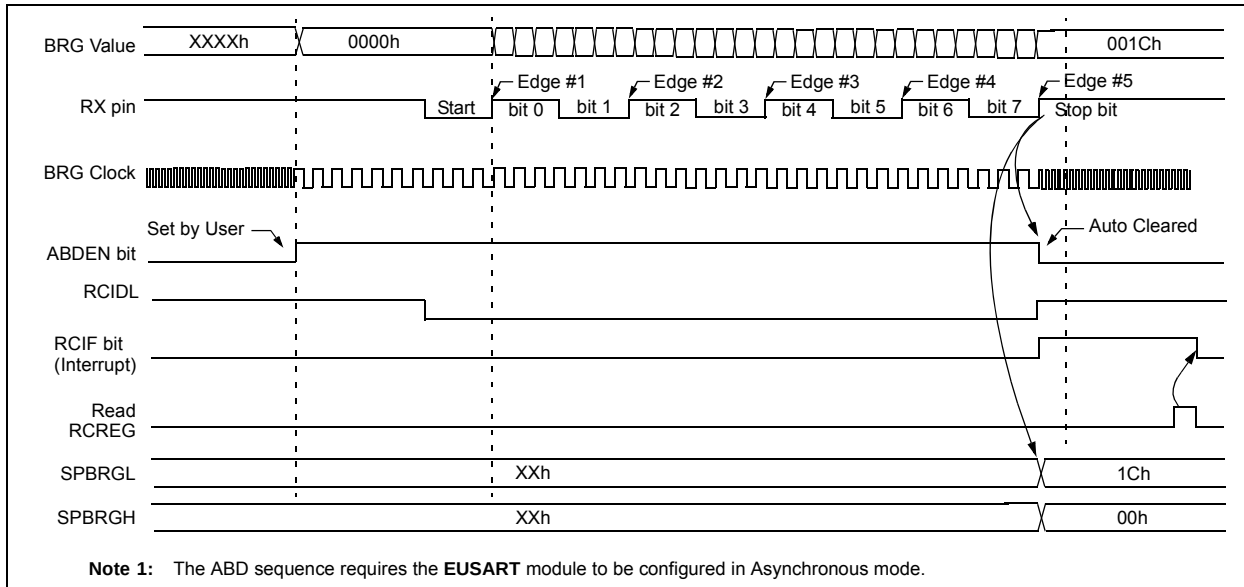
- Note 1:** If the WUE bit is set with the ABDEN bit, auto-baud detection will occur on the byte following the Break character (see Section 26.3.3 “Auto-Wake-up on Break”).
- 2:** It is up to the user to determine that the incoming character baud rate is within the range of the selected BRG clock source. Some combinations of oscillator frequency and EUSART baud rates are not possible.
- 3:** During the auto-baud process, the auto-baud counter starts counting at 1. Upon completion of the auto-baud sequence, to achieve maximum accuracy, subtract 1 from the SPBRGH:SPBRGL register pair.

TABLE 26-6: BRG COUNTER CLOCK RATES

BRG16	BRGH	BRG Base Clock	BRG ABD Clock
0	0	Fosc/64	Fosc/512
0	1	Fosc/16	Fosc/128
1	0	Fosc/16	Fosc/128
1	1	Fosc/4	Fosc/32

Note: During the ABD sequence, SPBRGL and SPBRGH registers are both used as a 16-bit counter, independent of BRG16 setting.

FIGURE 26-6: AUTOMATIC BAUD RATE CALIBRATION



26.3.2 AUTO-BAUD OVERFLOW

During the course of automatic baud detection, the ABDOVF bit of the BAUDCON register will be set if the baud rate counter overflows before the fifth rising edge is detected on the RX pin. The ABDOVF bit indicates that the counter has exceeded the maximum count that can fit in the 16 bits of the SPBRGH:SPBRGL register pair. After the ABDOVF has been set, the counter continues to count until the fifth rising edge is detected on the RX pin. Upon detecting the fifth RX edge, the hardware will set the RCIF interrupt flag and clear the ABDEN bit of the BAUDCON register. The RCIF flag can be subsequently cleared by reading the RCREG register. The ABDOVF flag of the BAUDCON register can be cleared by software directly.

To terminate the auto-baud process before the RCIF flag is set, clear the ABDEN bit then clear the ABDOVF bit of the BAUDCON register. The ABDOVF bit will remain set if the ABDEN bit is not cleared first.

26.3.3 AUTO-WAKE-UP ON BREAK

During Sleep mode, all clocks to the EUSART are suspended. Because of this, the Baud Rate Generator is inactive and a proper character reception cannot be performed. The Auto-Wake-up feature allows the controller to wake-up due to activity on the RX/DT line. This feature is available only in Asynchronous mode.

The Auto-Wake-up feature is enabled by setting the WUE bit of the BAUDCON register. Once set, the normal 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.)

The EUSART module generates an RCIF interrupt coincident with the wake-up event. The interrupt is generated synchronously to the Q clocks in normal CPU operating modes (Figure 26-7), and asynchronously if the device is in Sleep mode (Figure 26-8). The interrupt condition is cleared by reading the RCREG register.

The WUE bit is automatically cleared by the low-to-high transition on the RX line at the end of the Break. This signals to the user that the Break event is over. At this point, the EUSART module is in Idle mode waiting to receive the next character.

26.3.3.1 Special Considerations

Break Character

To avoid character errors or character fragments during a wake-up event, the wake-up character must be all zeros.

When the wake-up is enabled the function works independent of the low time on the data stream. If the WUE bit is set and a valid non-zero character is received, the low time from the Start bit to the first rising edge will be interpreted as the wake-up event. The remaining bits in the character will be received as a fragmented character and subsequent characters can result in framing or overrun errors.

Therefore, the initial character in the transmission must be all '0's. This must be 10 or more bit times, 13-bit times recommended for LIN bus, or any number of bit times for standard RS-232 devices.

Oscillator Start-up Time

Oscillator start-up time must be considered, especially in applications using oscillators with longer start-up intervals (i.e., LP, XT or HS/PLL 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.

WUE Bit

The wake-up event causes a receive interrupt by setting the RCIF bit. The WUE bit is cleared in hardware by a rising edge on RX/DT. The interrupt condition is then cleared in software by reading the RCREG register and discarding its contents.

To ensure that no actual data is lost, check the RCIDL bit to verify that a receive operation is not in process before setting the WUE bit. If a receive operation is not occurring, the WUE bit may then be set just prior to entering the Sleep mode.

FIGURE 26-7: AUTO-WAKE-UP BIT (WUE) TIMING DURING NORMAL OPERATION



FIGURE 26-8: AUTO-WAKE-UP BIT (WUE) TIMINGS DURING SLEEP



26.3.4 BREAK CHARACTER SEQUENCE

The EUSART module has the capability of sending the special Break character sequences that are required by the LIN bus standard. A Break character consists of a Start bit, followed by 12 '0' bits and a Stop bit.

To send a Break character, set the SENDB and TXEN bits of the TXSTA register. The Break character transmission is then initiated by a write to the TXREG. 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).

The TRMT bit of the TXSTA register indicates when the transmit operation is active or Idle, just as it does during normal transmission. See [Figure 26-9](#) for the timing of the Break character sequence.

26.3.4.1 Break and Sync Transmit Sequence

The following sequence will start 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 enable the Break sequence.
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 and the Sync character is then transmitted.

When the TXREG becomes empty, as indicated by the TXIF, the next data byte can be written to TXREG.

26.3.5 RECEIVING A BREAK CHARACTER

The Enhanced EUSART module can receive a Break character in two ways.

The first method to detect a Break character uses the FERR bit of the RCSTA register and the Received data as indicated by RCREG. The Baud Rate Generator is assumed to have been initialized to the expected baud rate.

A Break character has been received when;

- RCIF bit is set
- FERR bit is set
- RCREG = 00h

The second method uses the Auto-Wake-up feature described in [Section 26.3.3 "Auto-Wake-up on Break"](#). 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 Detect feature. For both methods, the user can set the ABDEN bit of the BAUDCON register before placing the EUSART in Sleep mode.

FIGURE 26-9: SEND BREAK CHARACTER SEQUENCE



26.4 EUSART Synchronous Mode

Synchronous serial communications are typically used in systems with a single master and one or more slaves. The master device contains the necessary circuitry for baud rate generation and supplies the clock for all devices in the system. Slave devices can take advantage of the master clock by eliminating the internal clock generation circuitry.

There are two signal lines in Synchronous mode: a bidirectional data line and a clock line. Slaves use the external clock supplied by the master to shift the serial data into and out of their respective receive and transmit shift registers. Since the data line is bidirectional, synchronous operation is half-duplex only. Half-duplex refers to the fact that master and slave devices can receive and transmit data but not both simultaneously. The EUSART can operate as either a master or slave device.

Start and Stop bits are not used in synchronous transmissions.

26.4.1 SYNCHRONOUS MASTER MODE

The following bits are used to configure the EUSART for Synchronous Master operation:

- SYNC = 1
- CSRC = 1
- SREN = 0 (for transmit); SREN = 1 (for receive)
- CREN = 0 (for transmit); CREN = 1 (for receive)
- SPEN = 1

Setting the SYNC bit of the TXSTA register configures the device for synchronous operation. Setting the CSRC bit of the TXSTA register configures the device as a master. Clearing the SREN and CREN bits of the RCSTA register ensures that the device is in the Transmit mode, otherwise the device will be configured to receive. Setting the SPEN bit of the RCSTA register enables the EUSART.

26.4.1.1 Master Clock

Synchronous data transfers use a separate clock line, which is synchronous with the data. A device configured as a master transmits the clock on the TX/CK line. The TX/CK pin output driver is automatically enabled when the EUSART is configured for synchronous transmit or receive operation. Serial data bits change on the leading edge to ensure they are valid at the trailing edge of each clock. One clock cycle is generated for each data bit. Only as many clock cycles are generated as there are data bits.

26.4.1.2 Clock Polarity

A clock polarity option is provided for Microwire compatibility. Clock polarity is selected with the SCKP bit of the BAUDCON register. Setting the SCKP bit sets the clock Idle state as high. When the SCKP bit is set, the data changes on the falling edge of each clock.

Clearing the SCKP bit sets the Idle state as low. When the SCKP bit is cleared, the data changes on the rising edge of each clock.

26.4.1.3 Synchronous Master Transmission

Data is transferred out of the device on the RX/DT pin. The RX/DT and TX/CK pin output drivers are automatically enabled when the EUSART is configured for synchronous master transmit operation.

A transmission is initiated by writing a character to the TXREG register. If the TSR still contains all or part of a previous character the new character data is held in the TXREG until the last bit of the previous character has been transmitted. If this is the first character, or the previous character has been completely flushed from the TSR, the data in the TXREG is immediately transferred to the TSR. The transmission of the character commences immediately following the transfer of the data to the TSR from the TXREG.

Each data bit changes on the leading edge of the master clock and remains valid until the subsequent leading clock edge.

Note: The TSR register is not mapped in data memory, so it is not available to the user.

26.4.1.4 Synchronous Master Transmission Set-up:

1. Initialize the SPBRGH, SPBRGL register pair and the BRGH and BRG16 bits to achieve the desired baud rate (see [Section 26.3 “EUSART Baud Rate Generator \(BRG\)”](#)).
2. Enable the synchronous master serial port by setting bits SYNC, SPEN and CSRC.
3. Disable Receive mode by clearing bits SREN and CREN.
4. Enable Transmit mode by setting the TXEN bit.
5. If 9-bit transmission is desired, set the TX9 bit.
6. If interrupts are desired, set the TXIE bit of the PIE1 register and the GIE and PEIE bits of the INTCON register.
7. If 9-bit transmission is selected, the ninth bit should be loaded in the TX9D bit.
8. Start transmission by loading data to the TXREG register.

FIGURE 26-10: SYNCHRONOUS TRANSMISSION

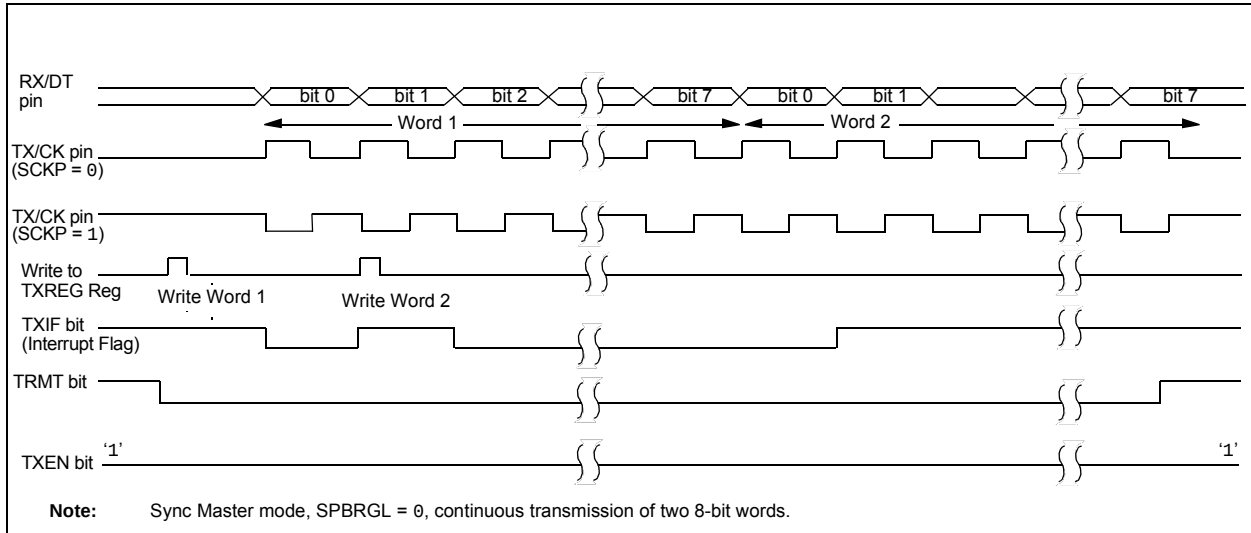
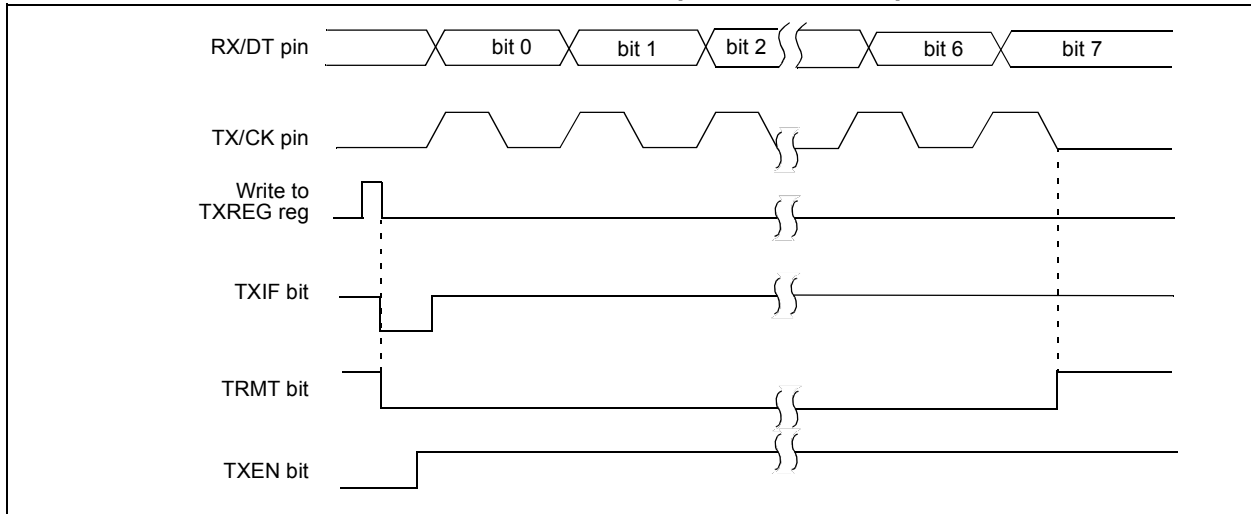


FIGURE 26-11: SYNCHRONOUS TRANSMISSION (THROUGH TXEN)



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TABLE 26-7: SUMMARY OF REGISTERS ASSOCIATED WITH SYNCHRONOUS MASTER TRANSMISSION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSEL	SDO1SEL	SS1SEL	P2BSEL ⁽¹⁾	CCP2SEL ⁽¹⁾	P1DSEL	P1CSEL	CCP1SEL	119
APFCON1	—	—	—	—	—	—	—	TXCKSEL	119
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	296
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSPIE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSPIF	CCP1IF	TMR2IF	TMR1IF	91
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	295
SPBRGL	BRG<7:0>								297*
SPBRGH	BRG<15:8>								297*
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127
TXREG	EUSART Transmit Data Register								287*
TXSTA	CSRC	TX9	TXEN	SYNC	SENDER	BRGH	TRMT	TX9D	294

Legend: — = unimplemented location, read as '0'. Shaded cells are not used for Synchronous Master Transmission.

* Page provides register information.

Note 1: PIC16(L)F1827 only.

26.4.1.5 Synchronous Master Reception

Data is received at the RX/DT pin. The RX/DT pin output driver is automatically disabled when the EUSART is configured for synchronous master receive operation.

In Synchronous mode, reception is enabled by setting either the Single Receive Enable bit (SREN of the RCSTA register) or the Continuous Receive Enable bit (CREN of the RCSTA register).

When SREN is set and CREN is clear, only as many clock cycles are generated as there are data bits in a single character. The SREN bit is automatically cleared at the completion of one character. When CREN is set, clocks are continuously generated until CREN is cleared. If CREN is cleared in the middle of a character the CK clock stops immediately and the partial character is discarded. If SREN and CREN are both set, then SREN is cleared at the completion of the first character and CREN takes precedence.

To initiate reception, set either SREN or CREN. Data is sampled at the RX/DT pin on the trailing edge of the TX/CK clock pin and is shifted into the Receive Shift Register (RSR). When a complete character is received into the RSR, the RCIF bit is set and the character is automatically transferred to the two character receive FIFO. The Least Significant eight bits of the top character in the receive FIFO are available in RCREG. The RCIF bit remains set as long as there are unread characters in the receive FIFO.

Note: If the RX/DT function is on an analog pin, the corresponding ANSEL bit must be cleared for the receiver to function.

26.4.1.6 Slave Clock

Synchronous data transfers use a separate clock line, which is synchronous with the data. A device configured as a slave receives the clock on the TX/CK line. The TX/CK pin output driver is automatically disabled when the device is configured for synchronous slave transmit or receive operation. Serial data bits change on the leading edge to ensure they are valid at the trailing edge of each clock. One data bit is transferred for each clock cycle. Only as many clock cycles should be received as there are data bits.

Note: If the device is configured as a slave and the TX/CK function is on an analog pin, the corresponding ANSEL bit must be cleared.
--

26.4.1.7 Receive Overrun Error

The receive FIFO buffer can hold two characters. An overrun error will be generated if a third character, in its entirety, is received before RCREG is read to access the FIFO. When this happens the OERR bit of the RCSTA register is set. Previous data in the FIFO will not be overwritten. The two characters in the FIFO

buffer can be read, however, no additional characters will be received until the error is cleared. The OERR bit can only be cleared by clearing the overrun condition. If the overrun error occurred when the SREN bit is set and CREN is clear then the error is cleared by reading RCREG. If the overrun occurred when the CREN bit is set then the error condition is cleared by either clearing the CREN bit of the RCSTA register or by clearing the SPEN bit which resets the EUSART.

26.4.1.8 Receiving 9-bit Characters

The EUSART supports 9-bit character reception. When the RX9 bit of the RCSTA register is set the EUSART will shift 9-bits into the RSR for each character received. The RX9D bit of the RCSTA register is the ninth, and Most Significant, data bit of the top unread character in the receive FIFO. When reading 9-bit data from the receive FIFO buffer, the RX9D data bit must be read before reading the 8 Least Significant bits from the RCREG.

26.4.1.9 Synchronous Master Reception Set-up:

1. Initialize the SPBRGH, SPBRGL register pair for the appropriate baud rate. Set or clear the BRGH and BRG16 bits, as required, to achieve the desired baud rate.
2. Clear the ANSEL bit for the RX pin (if applicable).
3. Enable the synchronous master serial port by setting bits SYNC, SPEN and CSRC.
4. Ensure bits CREN and SREN are clear.
5. If interrupts are desired, set the RCIE bit of the PIE1 register and the GIE and PEIE bits of the INTCON register.
6. If 9-bit reception is desired, set bit RX9.
7. Start reception by setting the SREN bit or for continuous reception, set the CREN bit.
8. Interrupt flag bit RCIF will be set when reception of a character is complete. An interrupt will be generated if the enable bit RCIE was set.
9. Read the RCSTA register to get the ninth bit (if enabled) and determine if any error occurred during reception.
10. Read the 8-bit received data by reading the RCREG register.
11. If an overrun error occurs, clear the error by either clearing the CREN bit of the RCSTA register or by clearing the SPEN bit which resets the EUSART.

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FIGURE 26-12: SYNCHRONOUS RECEPTION (MASTER MODE, SREN)

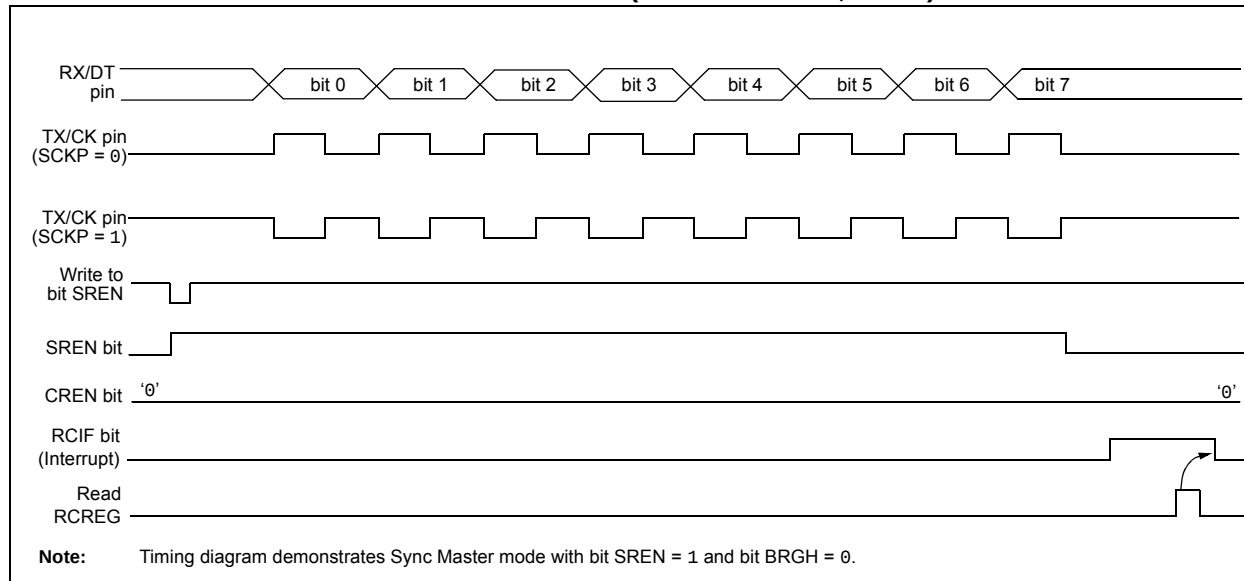


TABLE 26-8: SUMMARY OF REGISTERS ASSOCIATED WITH SYNCHRONOUS MASTER RECEPTION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSEL	SDO1SEL	SS1SEL	P2BSEL ⁽¹⁾	CCP2SEL ⁽¹⁾	P1DSEL	P1CSEL	CCP1SEL	119
APFCON1	—	—	—	—	—	—	—	TXCKSEL	119
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	296
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSPIE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSPIF	CCP1IF	TMR2IF	TMR1IF	91
RCREG	EUSART Receive Data Register								290*
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	295
SPBRGL	BRG<7:0>								297*
SPBRGH	BRG<15:8>								297*
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127
TXSTA	CSRC	TX9	TXEN	SYNC	SENDER	BRGH	TRMT	TX9D	294

Legend: — = unimplemented location, read as '0'. Shaded cells are not used for Synchronous Master Reception.

* Page provides register information.

Note 1: PIC16(L)F1827 only.

26.4.2 SYNCHRONOUS SLAVE MODE

The following bits are used to configure the EUSART for Synchronous slave operation:

- SYNC = 1
- CSRC = 0
- SREN = 0 (for transmit); SREN = 1 (for receive)
- CREN = 0 (for transmit); CREN = 1 (for receive)
- SPEN = 1

Setting the SYNC bit of the TXSTA register configures the device for synchronous operation. Clearing the CSRC bit of the TXSTA register configures the device as a slave. Clearing the SREN and CREN bits of the RCSTA register ensures that the device is in the Transmit mode, otherwise the device will be configured to receive. Setting the SPEN bit of the RCSTA register enables the EUSART.

26.4.2.1 EUSART Synchronous Slave Transmit

The operation of the Synchronous Master and Slave modes are identical (see [Section 26.4.1.3 “Synchronous Master Transmission”](#)), except in the case of the Sleep mode.

If two words are written to the TXREG and then the SLEEP instruction is executed, the following will occur:

1. The first character will immediately transfer to the TSR register and transmit.
2. The second word will remain in TXREG register.
3. The TXIF bit will not be set.
4. After the first character has been shifted out of TSR, the TXREG register will transfer the second character to the TSR and the TXIF bit will now be set.
5. If the PEIE and TXIE bits are set, the interrupt will wake the device from Sleep and execute the next instruction. If the GIE bit is also set, the program will call the Interrupt Service Routine.

26.4.2.2 Synchronous Slave Transmission Set-up:

1. Set the SYNC and SPEN bits and clear the CSRC bit.
2. Clear the ANSEL bit for the CK pin (if applicable).
3. Clear the CREN and SREN bits.
4. If interrupts are desired, set the TXIE bit of the PIE1 register and the GIE and PEIE bits of the INTCON register.
5. If 9-bit transmission is desired, set the TX9 bit.
6. Enable transmission by setting the TXEN bit.
7. If 9-bit transmission is selected, insert the Most Significant bit into the TX9D bit.
8. Start transmission by writing the Least Significant 8 bits to the TXREG register.

TABLE 26-9: SUMMARY OF REGISTERS ASSOCIATED WITH SYNCHRONOUS SLAVE TRANSMISSION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSSEL	SDO1SEL	SS1SEL	P2BSEL ⁽¹⁾	CCP2SEL ⁽¹⁾	P1DSEL	P1CSEL	CCP1SEL	119
APFCON1	—	—	—	—	—	—	—	TXCKSEL	119
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	296
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSPIE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSPIF	CCP1IF	TMR2IF	TMR1IF	91
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	295
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127
TXREG	EUSART Transmit Data Register								287*
TXSTA	CSRC	TX9	TXEN	SYNC	SENDB	BRGH	TRMT	TX9D	294

Legend: — = unimplemented location, read as ‘0’. Shaded cells are not used for Synchronous Slave Transmission.

* Page provides register information.

Note 1: PIC16(L)F1827 only.

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26.4.2.3 EUSART Synchronous Slave Reception

The operation of the Synchronous Master and Slave modes is identical ([Section 26.4.1.5 “Synchronous Master Reception”](#)), with the following exceptions:

- Sleep
- CREN bit is always set, therefore the receiver is never Idle
- SREN bit, which is a “don’t care” in Slave mode

A character may be received while in Sleep mode by setting the CREN bit prior to entering Sleep. 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 device from Sleep and execute the next instruction. If the GIE bit is also set, the program will branch to the interrupt vector.

26.4.2.4 Synchronous Slave Reception Set-up:

1. Set the SYNC and SPEN bits and clear the CSRC bit.
2. Clear the ANSEL bit for both the CK and DT pins (if applicable).
3. If interrupts are desired, set the RCIE bit of the PIE1 register and the GIE and PEIE bits of the INTCON register.
4. If 9-bit reception is desired, set the RX9 bit.
5. Set the CREN bit to enable reception.
6. The RCIF bit will be set when reception is complete. An interrupt will be generated if the RCIE bit was set.
7. If 9-bit mode is enabled, retrieve the Most Significant bit from the RX9D bit of the RCSTA register.
8. Retrieve the 8 Least Significant bits from the receive FIFO by reading the RCREG register.
9. If an overrun error occurs, clear the error by either clearing the CREN bit of the RCSTA register or by clearing the SPEN bit which resets the EUSART.

TABLE 26-10: SUMMARY OF REGISTERS ASSOCIATED WITH SYNCHRONOUS SLAVE RECEPTION

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
APFCON0	RXDTSSEL	SDO1SEL	SS1SEL	P2BSEL ⁽¹⁾	CCP2SEL ⁽¹⁾	P1DSEL	P1CSEL	CCP1SEL	119
APFCON1	—	—	—	—	—	—	—	TXCKSEL	119
BAUDCON	ABDOVF	RCIDL	—	SCKP	BRG16	—	WUE	ABDEN	296
INTCON	GIE	PEIE	TMR0IE	INTE	IOIE	TMR0IF	INTF	IOCIF	86
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSPIE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSPIF	CCP1IF	TMR2IF	TMR1IF	91
RCREG	EUSART Receive Data Register								290 *
RCSTA	SPEN	RX9	SREN	CREN	ADDEN	FERR	OERR	RX9D	295
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127
TXSTA	CSRC	TX9	TXEN	SYNC	SEnDB	BRGH	TRMT	TX9D	294

Legend: — = unimplemented location, read as ‘0’. Shaded cells are not used for Synchronous Slave Reception.

* Page provides register information.

Note 1: PIC16(L)F1827 only.

26.5 EUSART Operation During Sleep

The EUSART will remain active during Sleep only in the Synchronous Slave mode. All other modes require the system clock and therefore cannot generate the necessary signals to run the Transmit or Receive Shift registers during Sleep.

Synchronous Slave mode uses an externally generated clock to run the Transmit and Receive Shift registers.

26.5.1 SYNCHRONOUS RECEIVE DURING SLEEP

To receive during Sleep, all the following conditions must be met before entering Sleep mode:

- RCSTA and TXSTA Control registers must be configured for Synchronous Slave Reception (see [Section 26.4.2.4 “Synchronous Slave Reception Set-up:”](#)).
- If interrupts are desired, set the RCIE bit of the PIE1 register and the GIE and PEIE bits of the INTCON register.
- The RCIF interrupt flag must be cleared by reading RCREG to unload any pending characters in the receive buffer.

Upon entering Sleep mode, the device will be ready to accept data and clocks on the RX/DT and TX/CK pins, respectively. When the data word has been completely clocked in by the external device, the RCIF interrupt flag bit of the PIR1 register will be set. Thereby, waking the processor from Sleep.

Upon waking from Sleep, the instruction following the SLEEP instruction will be executed. If the GIE global interrupt enable bit of the INTCON register is also set, then the Interrupt Service Routine at address 004h will be called.

26.5.2 SYNCHRONOUS TRANSMIT DURING SLEEP

To transmit during Sleep, all the following conditions must be met before entering Sleep mode:

- RCSTA and TXSTA Control registers must be configured for Synchronous Slave Transmission (see [Section 26.4.2.2 “Synchronous Slave Transmission Set-up:”](#)).
- The TXIF interrupt flag must be cleared by writing the output data to the TXREG, thereby filling the TSR and transmit buffer.
- If interrupts are desired, set the TXIE bit of the PIE1 register and the PEIE bit of the INTCON register.
- Interrupt enable bits TXIE of the PIE1 register and PEIE of the INTCON register must set.

Upon entering Sleep mode, the device will be ready to accept clocks on TX/CK pin and transmit data on the RX/DT pin. When the data word in the TSR has been completely clocked out by the external device, the pending byte in the TXREG will transfer to the TSR and the TXIF flag will be set. Thereby, waking the processor from Sleep. At this point, the TXREG is available to accept another character for transmission, which will clear the TXIF flag.

Upon waking from Sleep, the instruction following the SLEEP instruction will be executed. If the Global Interrupt Enable (GIE) bit is also set then the Interrupt Service Routine at address 0004h will be called.

26.5.3 ALTERNATE PIN LOCATIONS

This module incorporates I/O pins that can be moved to other locations with the use of the alternate pin function registers, APFCON0 and APFCON1. To determine which pins can be moved and what their default locations are upon a reset, see [Section 12.1 “Alternate Pin Function”](#) for more information.

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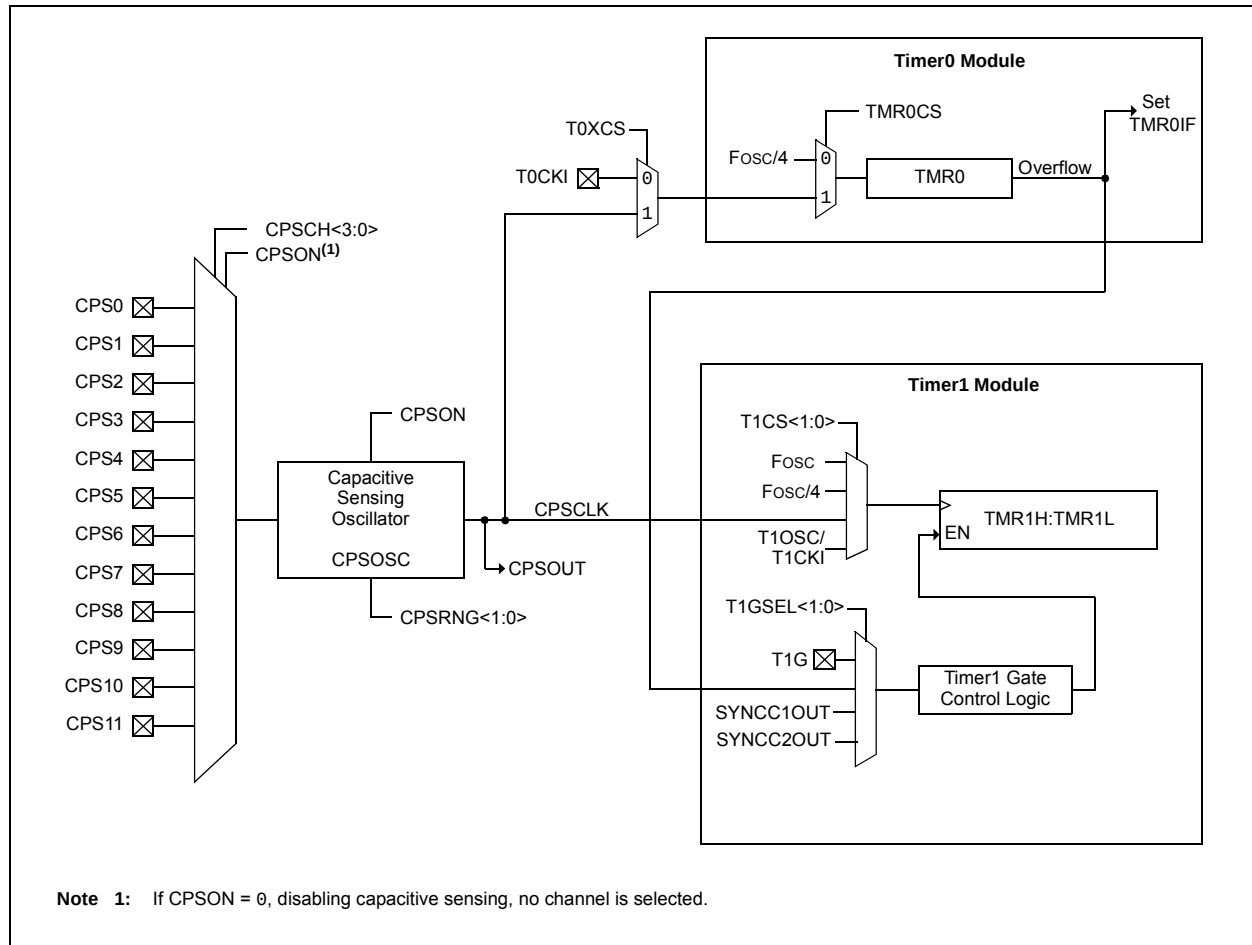
NOTES:

27.0 CAPACITIVE SENSING MODULE

The capacitive sensing module allows for an interaction with an end user without a mechanical interface. In a typical application, the capacitive sensing module is attached to a pad on a Printed Circuit Board (PCB), which is electrically isolated from the end user. When the end user places their finger over the PCB pad, a capacitive load is added, causing a frequency shift in the capacitive sensing module. The capacitive sensing module requires software and at least one timer resource to determine the change in frequency. Key features of this module include:

- Analog MUX for monitoring multiple inputs
- Capacitive sensing oscillator
- Multiple timer resources
- Software control
- Operation during Sleep

FIGURE 27-1: CAPACITIVE SENSING BLOCK DIAGRAM



27.1 Analog MUX

The capacitive sensing module can monitor up to 12 inputs. The capacitive sensing inputs are defined as CPS<11:0>. To determine if a frequency change has occurred the user must:

- Select the appropriate CPS pin by setting the CPSCH<3:0> bits of the CPSCON1 register
- Set the corresponding ANSEL bit
- Set the corresponding TRIS bit
- Run the software algorithm

Selection of the CPSx pin while the module is enabled will cause the capacitive sensing oscillator to be on the CPSx pin. Failure to set the corresponding ANSEL and TRIS bits can cause the capacitive sensing oscillator to stop, leading to false frequency readings.

27.2 Capacitive Sensing Oscillator

The capacitive sensing oscillator consists of a constant current source and a constant current sink, to produce a triangle waveform. The CPSOUT bit of the CPSCON0 register shows the status of the capacitive sensing oscillator, whether it is a sinking or sourcing current. The oscillator is designed to drive a capacitive load (single PCB pad) and at the same time, be a clock source to either Timer0 or Timer1. The oscillator has three different current settings as defined by CPSRNG<1:0> of the CPSCON0 register. The different current settings for the oscillator serve two purposes:

- Maximize the number of counts in a timer for a fixed time base
- Maximize the count differential in the timer during a change in frequency

27.3 Timer resources

To measure the change in frequency of the capacitive sensing oscillator, a fixed time base is required. For the period of the fixed time base, the capacitive sensing oscillator is used to clock either Timer0 or Timer1. The frequency of the capacitive sensing oscillator is equal to the number of counts in the timer divided by the period of the fixed time base.

27.4 Fixed Time Base

To measure the frequency of the capacitive sensing oscillator, a fixed time base is required. Any timer resource or software loop can be used to establish the fixed time base. It is up to the end user to determine the method in which the fixed time base is generated.

Note: The fixed time base can not be generated by the timer resource that the capacitive sensing oscillator is clocking.

27.4.1 TIMER0

To select Timer0 as the timer resource for the capacitive sensing module:

- Set the T0XCS bit of the CPSCON0 register
- Clear the TMR0CS bit of the OPTION register

When Timer0 is chosen as the timer resource, the capacitive sensing oscillator will be the clock source for Timer0. Refer to [Section 20.0 “Timer0 Module”](#) for additional information.

27.4.2 TIMER1

To select Timer1 as the timer resource for the capacitive sensing module, set the TMR1CS<1:0> of the T1CON register to ‘11’. When Timer1 is chosen as the timer resource, the capacitive sensing oscillator will be the clock source for Timer1. Because the Timer1 module has a gate control, developing a time base for the frequency measurement can be simplified by using the Timer0 overflow flag.

It is recommend that the Timer0 overflow flag, in conjunction with the Toggle mode of the Timer1 gate, be used to develop the fixed time base required by the software portion of the capacitive sensing module. Refer to [Section 21.6.3 “Timer1 Gate Toggle Mode”](#) for additional information.

TABLE 27-1: TIMER1 ENABLE FUNCTION

TMR1ON	TMR1GE	Timer1 Operation
0	0	Off
0	1	Off
1	0	On
1	1	Count Enabled by input

27.5 Software Control

The software portion of the capacitive sensing module is required to determine the change in frequency of the capacitive sensing oscillator. This is accomplished by the following:

- Setting a fixed time base to acquire counts on Timer0 or Timer1
- Establishing the nominal frequency for the capacitive sensing oscillator
- Establishing the reduced frequency for the capacitive sensing oscillator due to an additional capacitive load
- Set the frequency threshold

27.5.1 NOMINAL FREQUENCY (NO CAPACITIVE LOAD)

To determine the nominal frequency of the capacitive sensing oscillator:

- Remove any extra capacitive load on the selected CPSx pin
- At the start of the fixed time base, clear the timer resource
- At the end of the fixed time base save the value in the timer resource

The value of the timer resource is the number of oscillations of the capacitive sensing oscillator for the given time base. The frequency of the capacitive sensing oscillator is equal to the number of counts on in the timer divided by the period of the fixed time base.

27.5.2 REDUCED FREQUENCY (ADDITIONAL CAPACITIVE LOAD)

The extra capacitive load will cause the frequency of the capacitive sensing oscillator to decrease. To determine the reduced frequency of the capacitive sensing oscillator:

- Add a typical capacitive load on the selected CPSx pin
- Use the same fixed time base as the nominal frequency measurement
- At the start of the fixed time base, clear the timer resource
- At the end of the fixed time base save the value in the timer resource

The value of the timer resource is the number of oscillations of the capacitive sensing oscillator with an additional capacitive load. The frequency of the capacitive sensing oscillator is equal to the number of counts on in the timer divided by the period of the fixed time base. This frequency should be less than the value obtained during the nominal frequency measurement.

27.5.3 FREQUENCY THRESHOLD

The frequency threshold should be placed midway between the value of nominal frequency and the reduced frequency of the capacitive sensing oscillator. Refer to Application Note AN1103, “*Software Handling for Capacitive Sensing*” (DS01103) for more detailed information on the software required for capacitive sensing module.

Note: For more information on general capacitive sensing refer to Application Notes:

- AN1101, “*Introduction to Capacitive Sensing*” (DS01101)
- AN1102, “*Layout and Physical Design Guidelines for Capacitive Sensing*” (DS01102)

27.6 Operation during Sleep

The capacitive sensing oscillator will continue to run as long as the module is enabled, independent of the part being in Sleep. In order for the software to determine if a frequency change has occurred, the part must be awake. However, the part does not have to be awake when the timer resource is acquiring counts.

Note: Timer0 does not operate when in Sleep, and therefore cannot be used for capacitive sense measurements in Sleep.

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REGISTER 27-1: CPSCON0: CAPACITIVE SENSING CONTROL REGISTER 0

R/W-0/0	U-0	U-0	U-0	R/W-0/0	R/W-0/0	R-0/0	R/W-0/0
CPSON	—	—	—	CPSRNG1	CPSRNG0	CPSOUT	T0XCS
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

bit 7 **CPSON:** Capacitive Sensing Module Enable bit

1 = Capacitive sensing module is enabled

0 = Capacitive sensing module is disabled

bit 6-4 **Unimplemented:** Read as '0'

bit 3-2 **CPSRNG<1:0>:** Capacitive Sensing Oscillator Range bits

00 = Oscillator is off

01 = Oscillator is in low range. Charge/discharge current is nominally 0.1 μ A.

10 = Oscillator is in medium range. Charge/discharge current is nominally 1.2 μ A.

11 = Oscillator is in high range. Charge/discharge current is nominally 18 μ A.

bit 1 **CPSOUT:** Capacitive Sensing Oscillator Status bit

1 = Oscillator is sourcing current (Current flowing out the pin)

0 = Oscillator is sinking current (Current flowing into the pin)

bit 0 **T0XCS:** Timer0 External Clock Source Select bit

If TMR0CS = 1

The T0XCS bit controls which clock external to the core/Timer0 module supplies Timer0:

1 = Timer0 clock source is the capacitive sensing oscillator

0 = Timer0 clock source is the T0CKI pin

If TMR0CS = 0

Timer0 clock source is controlled by the core/Timer0 module and is $F_{osc}/4$

REGISTER 27-2: CPSCON1: CAPACITIVE SENSING CONTROL REGISTER 1

U-0	U-0	U-0	U-0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0
—	—	—	—	CPSCH3	CPSCH2	CPSCH1	CPSCH0
bit 7							bit 0

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

u = Bit is unchanged

x = Bit is unknown

-n/n = Value at POR and BOR/Value at all other Resets

'1' = Bit is set

'0' = Bit is cleared

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

bit 3-0 **CPSCH<3:0>:** Capacitive Sensing Channel Select bits

If CPSON = 0:

These bits are ignored. No channel is selected.

If CPSON = 1:

0000 = channel 0, (CPS0)
 0001 = channel 1, (CPS1)
 0010 = channel 2, (CPS2)
 0011 = channel 3, (CPS3)
 0100 = channel 4, (CPS4)
 0101 = channel 5, (CPS5)
 0110 = channel 6, (CPS6)
 0111 = channel 7, (CPS7)
 1000 = channel 8, (CPS8)
 1001 = channel 9, (CPS9)
 1010 = channel 10, (CPS10)
 1011 = channel 11, (CPS11)
 1100 = Reserved. Do not use.
 1101 = Reserved. Do not use.
 1110 = Reserved. Do not use.
 1111 = Reserved. Do not use.

TABLE 27-2: SUMMARY OF REGISTERS ASSOCIATED WITH CAPACITIVE SENSING

Name	Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Register on Page
ANSELA	—	—	—	ANSA4	ANSA3	ANSA2	ANSA1	ANSA0	123
ANSELB	ANSB7	ANSB6	ANSB5	ANSB4	ANSB3	ANSB2	ANSB1	—	128
CPSCON0	CPSON	—	—	—	CPSRNG1	CPSRNG0	CPSOUT	T0XCS	318
CPSCON1	—	—	—	—	CPSCH3	CPSCH2	CPSCH1	CPSCH0	319
INTCON	GIE	PEIE	TMR0IE	INTE	IOCIE	TMR0IF	INTF	IOCIF	86
OPTION_REG	WPUEN	INTEDG	TMR0CS	TMR0SE	PSA	PS2	PS1	PS0	176
PIE1	TMR1GIE	ADIE	RCIE	TXIE	SSP1IE	CCP1IE	TMR2IE	TMR1IE	87
PIR1	TMR1GIF	ADIF	RCIF	TXIF	SSP1IF	CCP1IF	TMR2IF	TMR1IF	91
T1CON	TMR1CS1	TMR1CS0	T1CKPS1	T1CKPS0	T1OSCEN	T1SYNC	—	TMR1ON	185
TxCON	—	TxOUTPS3	TxOUTPS2	TxOUTPS1	TxOUTPS0	TMRxON	TxCKPS1	TxCKPS0	185
TRISA	TRISA7	TRISA6	TRISA5	TRISA4	TRISA3	TRISA2	TRISA1	TRISA0	122
TRISB	TRISB7	TRISB6	TRISB5	TRISB4	TRISB3	TRISB2	TRISB1	TRISB0	127

Legend: — = Unimplemented locations, read as '0'. Shaded cells are not used by the capacitive sensing module.

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NOTES:

28.0 IN-CIRCUIT SERIAL PROGRAMMING™ (ICSP™)

ICSP™ programming allows customers to manufacture circuit boards with unprogrammed devices. Programming can be done after the assembly process allowing the device to be programmed with the most recent firmware or a custom firmware. Five pins are needed for ICSP™ programming:

- ICSPCLK
- ICSPDAT
- MCLR/VPP
- VDD
- VSS

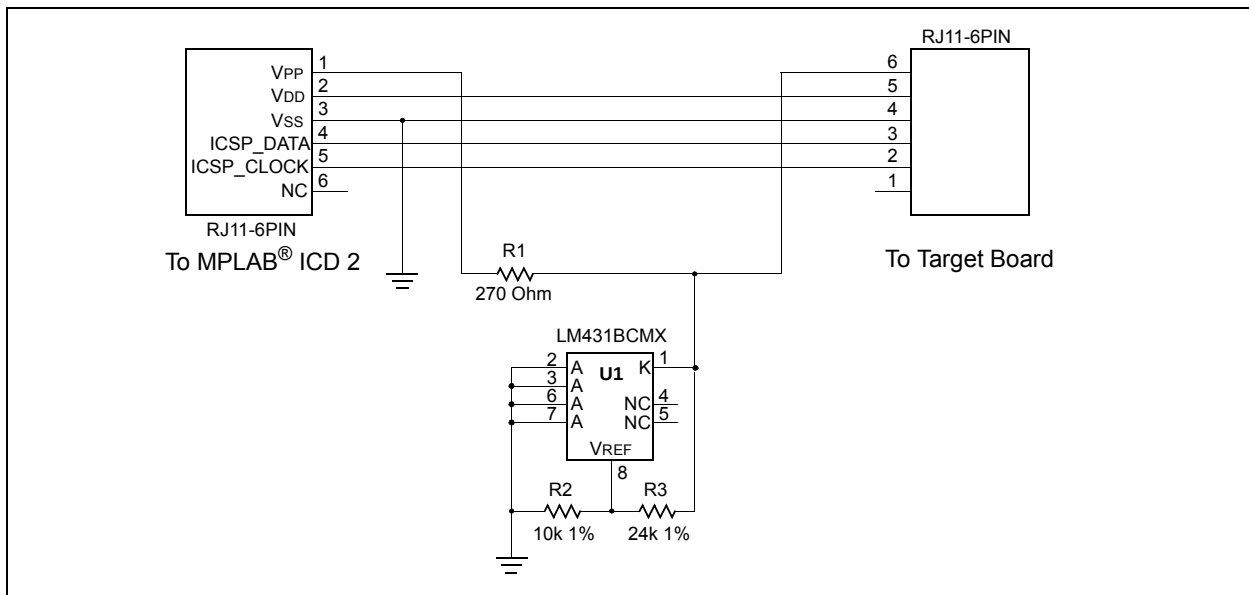
In Program/Verify mode the Program Memory, User IDs and the Configuration Words are programmed through serial communications. The ICSPDAT pin is a bidirectional I/O used for transferring the serial data and the ICSPCLK pin is the clock input. For more information on ICSP™ refer to the “PIC16(L)F182X/PIC12(L)F1822 Memory Programming Specification” (DS41390).

28.1 High-Voltage Programming Entry Mode

The device is placed into High-Voltage Programming Entry mode by holding the ICSPCLK and ICSPDAT pins low then raising the voltage on MCLR/VPP to VIH.

Some programmers produce VPP greater than VIH (9.0V), an external circuit is required to limit the VPP voltage. See Figure 28-1 for example circuit.

FIGURE 28-1: VPP LIMITER EXAMPLE CIRCUIT



Note: The ICD 2 produces a VPP voltage greater than the maximum VPP specification of the PIC16(L)F1826/27.

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28.2 Low-Voltage Programming Entry Mode

The Low-Voltage Programming Entry mode allows the PIC16(L)F1826/27 devices to be programmed using VDD only, without high voltage. When the LVP bit of Configuration Word 2 is set to '1', the low-voltage ICSP programming entry is enabled. To disable the Low-Voltage ICSP mode, the LVP bit must be programmed to '0'.

Entry into the Low-Voltage Programming Entry mode requires the following steps:

1. $\overline{\text{MCLR}}$ is brought to VIL.
2. A 32-bit key sequence is presented on ICSPDAT, while clocking ICSPCLK.

Once the key sequence is complete, $\overline{\text{MCLR}}$ must be held at VIL for as long as Program/Verify mode is to be maintained.

If low-voltage programming is enabled (LVP = 1), the $\overline{\text{MCLR}}$ Reset function is automatically enabled and cannot be disabled. See [Section 7.3 "MCLR"](#) for more information.

The LVP bit can only be reprogrammed to '0' by using the High-Voltage Programming mode.

28.3 Common Programming Interfaces

Connection to a target device is typically done through an ICSP™ header. A commonly found connector on development tools is the RJ-11 in the 6P6C (6 pin, 6 connector) configuration. See [Figure 28-2](#).

FIGURE 28-2: ICD RJ-11 STYLE CONNECTOR INTERFACE



Another connector often found in use with the PICKIT™ programmers is a standard 6-pin header with 0.1 inch spacing. Refer to [Figure 28-3](#).

FIGURE 28-3: PICKIT™ STYLE CONNECTOR INTERFACE



For additional interface recommendations, refer to your specific device programmer manual prior to PCB design.

It is recommended that isolation devices be used to separate the programming pins from other circuitry. The type of isolation is highly dependent on the specific application and may include devices such as resistors, diodes, or even jumpers. See [Figure 28-4](#) for more information.

FIGURE 28-4: TYPICAL CONNECTION FOR ICSP™ PROGRAMMING



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NOTES:

29.0 INSTRUCTION SET SUMMARY

Each PIC16 instruction is a 14-bit word containing the operation code (opcode) and all required operands. The op codes are broken into three broad categories.

- Byte Oriented
- Bit Oriented
- Literal and Control

The literal and control category contains the most varied instruction word format.

Table 29-3 lists the instructions recognized by the MPASM™ assembler.

All instructions are executed within a single instruction cycle, with the following exceptions, which may take two or three cycles:

- Subroutine takes two cycles (CALL, CALLW)
- Returns from interrupts or subroutines take two cycles (RETURN, RETLW, RETFIE)
- Program branching takes two cycles (GOTO, BRA, BRW, BTFSS, BTFSC, DECFSZ, INCSFZ)
- One additional instruction cycle will be used when any instruction references an indirect file register and the file select register is pointing to program memory.

One instruction cycle consists of 4 oscillator cycles; for an oscillator frequency of 4 MHz, this gives a nominal instruction execution rate of 1 MHz.

All instruction examples use the format '0xhh' to represent a hexadecimal number, where 'h' signifies a hexadecimal digit.

29.1 Read-Modify-Write Operations

Any instruction that specifies a file register as part of the instruction performs a Read-Modify-Write (R-M-W) operation. The register is read, the data is modified, and the result is stored according to either the instruction, or the destination designator 'd'. A read operation is performed on a register even if the instruction writes to that register.

TABLE 29-1: OPCODE FIELD DESCRIPTIONS

Field	Description
f	Register file address (0x00 to 0x7F)
W	Working register (accumulator)
b	Bit address within an 8-bit file register
k	Literal field, constant data or label
x	Don't care location (= 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.
d	Destination select; d = 0: store result in W, d = 1: store result in file register f. Default is d = 1.
n	FSR or INDF number. (0-1)
mm	Pre-post increment-decrement mode selection

TABLE 29-2: ABBREVIATION DESCRIPTIONS

Field	Description
PC	Program Counter
$\overline{TO}$	Time-out bit
C	Carry bit
DC	Digit carry bit
Z	Zero bit
$\overline{PD}$	Power-down bit

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FIGURE 29-1: GENERAL FORMAT FOR INSTRUCTIONS

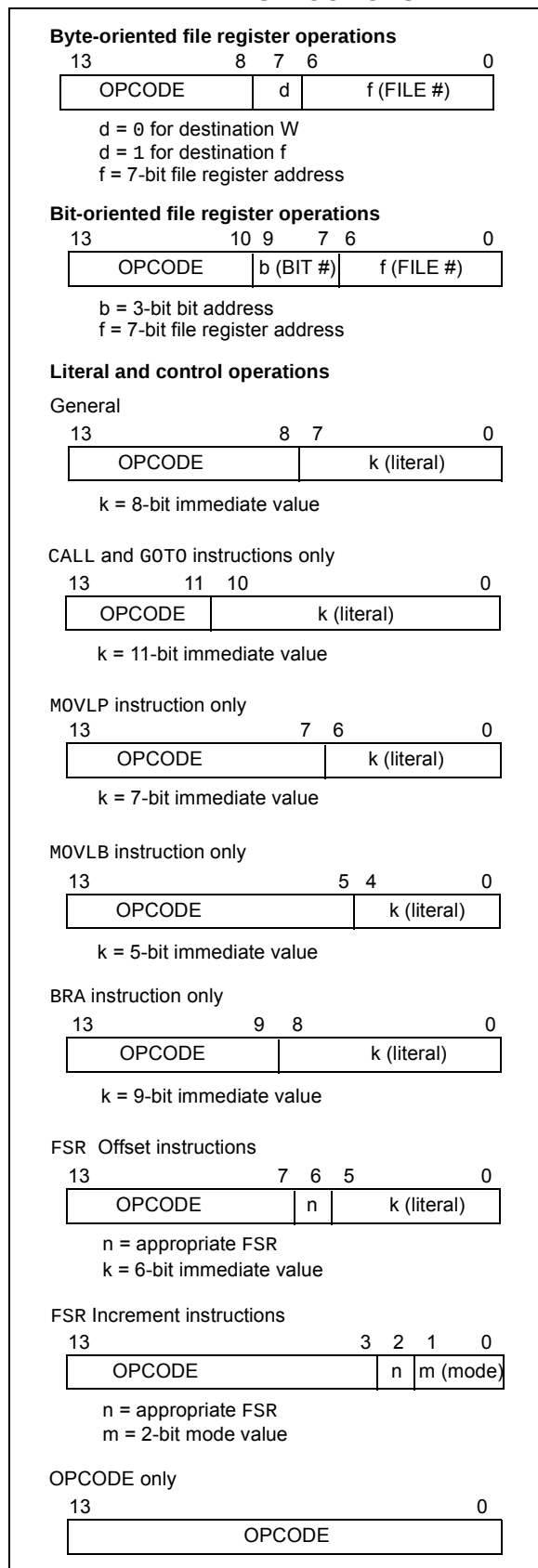


TABLE 29-3: PIC16(L)F1826/27 ENHANCED INSTRUCTION SET

Mnemonic, Operands		Description	Cycles	14-Bit Opcode				Status Affected	Notes
				MSb		LSb			
BYTE-ORIENTED FILE REGISTER OPERATIONS									
ADDWF	f, d	Add W and f	1	00	0111	dfff	ffff	C, DC, Z	2
ADDWFC	f, d	Add with Carry W and f	1	11	1101	dfff	ffff	C, DC, Z	2
ANDWF	f, d	AND W with f	1	00	0101	dfff	ffff	Z	2
ASRF	f, d	Arithmetic Right Shift	1	11	0111	dfff	ffff	C, Z	2
LSLF	f, d	Logical Left Shift	1	11	0101	dfff	ffff	C, Z	2
LSRF	f, d	Logical Right Shift	1	11	0110	dfff	ffff	C, Z	2
CLRF	f	Clear f	1	00	0001	1fff	ffff	Z	2
CLRW	—	Clear W	1	00	0001	0000	00xx	Z	
COMF	f, d	Complement f	1	00	1001	dfff	ffff	Z	2
DECF	f, d	Decrement f	1	00	0011	dfff	ffff	Z	2
INCF	f, d	Increment f	1	00	1010	dfff	ffff	Z	2
IORWF	f, d	Inclusive OR W with f	1	00	0100	dfff	ffff	Z	2
MOVF	f, d	Move f	1	00	1000	dfff	ffff	Z	2
MOVWF	f	Move W to f	1	00	0000	1fff	ffff		2
RLF	f, d	Rotate Left f through Carry	1	00	1101	dfff	ffff	C	2
RRF	f, d	Rotate Right f through Carry	1	00	1100	dfff	ffff	C	2
SUBWF	f, d	Subtract W from f	1	00	0010	dfff	ffff	C, DC, Z	2
SUBWFB	f, d	Subtract with Borrow W from f	1	11	1011	dfff	ffff	C, DC, Z	2
SWAPF	f, d	Swap nibbles in f	1	00	1110	dfff	ffff		2
XORWF	f, d	Exclusive OR W with f	1	00	0110	dfff	ffff	Z	2
BYTE ORIENTED SKIP OPERATIONS									
DECFSZ	f, d	Decrement f, Skip if 0	1(2)	00	1011	dfff	ffff		1, 2
INCFSZ	f, d	Increment f, Skip if 0	1(2)	00	1111	dfff	ffff		1, 2
BIT-ORIENTED FILE REGISTER OPERATIONS									
BCF	f, b	Bit Clear f	1	01	00bb	bfff	ffff		2
BSF	f, b	Bit Set f	1	01	01bb	bfff	ffff		2
BIT-ORIENTED SKIP OPERATIONS									
BTFSC	f, b	Bit Test f, Skip if Clear	1 (2)	01	10bb	bfff	ffff		1, 2
BTFSS	f, b	Bit Test f, Skip if Set	1 (2)	01	11bb	bfff	ffff		1, 2
LITERAL OPERATIONS									
ADDLW	k	Add literal and W	1	11	1110	kkkk	kkkk	C, DC, Z	
ANDLW	k	AND literal with W	1	11	1001	kkkk	kkkk	Z	
IORLW	k	Inclusive OR literal with W	1	11	1000	kkkk	kkkk	Z	
MOVLB	k	Move literal to BSR	1	00	0000	001k	kkkk		
MOVLP	k	Move literal to PCLATH	1	11	0001	1kkk	kkkk		
MOVLW	k	Move literal to W	1	11	0000	kkkk	kkkk		
SUBLW	k	Subtract W from literal	1	11	1100	kkkk	kkkk	C, DC, Z	
XORLW	k	Exclusive OR literal with W	1	11	1010	kkkk	kkkk	Z	

Note 1: 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.

2: If this instruction addresses an INDF register and the MSb of the corresponding FSR is set, this instruction will require one additional instruction cycle.

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TABLE 29-3: PIC16(L)F1826/27 ENHANCED INSTRUCTION SET (CONTINUED)

Mnemonic, Operands		Description	Cycles	14-Bit Opcode				Status Affected	Notes
				MSb		LSb			
CONTROL OPERATIONS									
BRA	k	Relative Branch	2	11	001k	kkkk	kkkk		
BRW	—	Relative Branch with W	2	00	0000	0000	1011		
CALL	k	Call Subroutine	2	10	0kkk	kkkk	kkkk		
CALLW	—	Call Subroutine with W	2	00	0000	0000	1010		
GOTO	k	Go to address	2	10	1kkk	kkkk	kkkk		
RETFIE	k	Return from interrupt	2	00	0000	0000	1001		
RETLW	k	Return with literal in W	2	11	0100	kkkk	kkkk		
RETURN	—	Return from Subroutine	2	00	0000	0000	1000		
INHERENT OPERATIONS									
CLRWDT	—	Clear Watchdog Timer	1	00	0000	0110	0100	$\overline{TO}$, $\overline{PD}$	
NOP	—	No Operation	1	00	0000	0000	0000		
OPTION	—	Load OPTION_REG register with W	1	00	0000	0110	0010		
RESET	—	Software device Reset	1	00	0000	0000	0001	$\overline{TO}$, $\overline{PD}$	
SLEEP	—	Go into Standby mode	1	00	0000	0110	0011		
TRIS	f	Load TRIS register with W	1	00	0000	0110	0fff		
C-COMPILER OPTIMIZED									
ADDFSR	n, k	Add Literal k to FSRn	1	11	0001	0nkk	kkkk	Z	2, 3
MOVIW	n mm	Move Indirect FSRn to W with pre/post inc/dec modifier, mm	1	00	0000	0001	0nmm		
MOVWI	k[n]	Move INDFn to W, Indexed Indirect.	1	11	1111	0nkk	kkkk	Z	2
	n mm	Move W to Indirect FSRn with pre/post inc/dec modifier, mm	1	00	0000	0001	1nmm		
	k[n]	Move W to INDFn, Indexed Indirect.	1	11	1111	1nkk	kkkk		2

Note 1: 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.

2: If this instruction addresses an INDF register and the MSb of the corresponding FSR is set, this instruction will require one additional instruction cycle.

3: See Table in the MOVIW and MOVWI instruction descriptions.

29.2 Instruction Descriptions

ADDFSR Add Literal to FSRn

Syntax:	[<i>label</i>] ADDFSR FSRn, k
Operands:	$-32 \leq k \leq 31$ $n \in [0, 1]$
Operation:	$FSR(n) + k \rightarrow FSR(n)$
Status Affected:	None
Description:	The signed 6-bit literal 'k' is added to the contents of the FSRnH:FSRnL register pair. FSRn is limited to the range 0000h - FFFFh. Moving beyond these bounds will cause the FSR to wrap around.

ANDLW AND literal with W

Syntax:	[<i>label</i>] ANDLW k
Operands:	$0 \leq k \leq 255$
Operation:	$(W) .AND. (k) \rightarrow (W)$
Status Affected:	Z
Description:	The contents of W register are AND'ed with the eight-bit literal 'k'. The result is placed in the W register.

ADDLW Add literal and W

Syntax:	[<i>label</i>] ADDLW k
Operands:	$0 \leq k \leq 255$
Operation:	$(W) + k \rightarrow (W)$
Status Affected:	C, DC, Z
Description:	The contents of the W register are added to the eight-bit literal 'k' and the result is placed in the W register.

ANDWF AND W with f

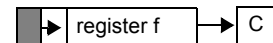
Syntax:	[<i>label</i>] ANDWF f,d
Operands:	$0 \leq f \leq 127$ $d \in [0, 1]$
Operation:	$(W) .AND. (f) \rightarrow (\text{destination})$
Status Affected:	Z
Description:	AND the W register with register 'f'. If 'd' is '0', the result is stored in the W register. If 'd' is '1', the result is stored back in register 'f'.

ADDWF Add W and f

Syntax:	[<i>label</i>] ADDWF f,d
Operands:	$0 \leq f \leq 127$ $d \in [0, 1]$
Operation:	$(W) + (f) \rightarrow (\text{destination})$
Status Affected:	C, DC, Z
Description:	Add the contents of the W register with register 'f'. If 'd' is '0', the result is stored in the W register. If 'd' is '1', the result is stored back in register 'f'.

ASRF Arithmetic Right Shift

Syntax:	[<i>label</i>] ASRF f {,d}
Operands:	$0 \leq f \leq 127$ $d \in [0, 1]$
Operation:	$(f<7>) \rightarrow \text{dest}<7>$ $(f<7:1>) \rightarrow \text{dest}<6:0>$, $(f<0>) \rightarrow C$,
Status Affected:	C, Z
Description:	The contents of register 'f' are shifted one bit to the right through the Carry flag. The MSb remains unchanged. If 'd' is '0', the result is placed in W. If 'd' is '1', the result is stored back in register 'f'.



ADDWFC ADD W and CARRY bit to f

Syntax:	[<i>label</i>] ADDWFC f {,d}
Operands:	$0 \leq f \leq 127$ $d \in [0, 1]$
Operation:	$(W) + (f) + (C) \rightarrow \text{dest}$
Status Affected:	C, DC, Z
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'.

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BCF Bit Clear f

Syntax: [*label*] BCF f,b
Operands: $0 \leq f \leq 127$
 $0 \leq b \leq 7$
Operation: $0 \rightarrow (f < b >)$
Status Affected: None
Description: Bit 'b' in register 'f' is cleared.

BTFSC Bit Test f, Skip if Clear

Syntax: [*label*] BTFSC f,b
Operands: $0 \leq f \leq 127$
 $0 \leq b \leq 7$
Operation: skip if $(f < b >) = 0$
Status Affected: None
Description: If bit 'b' in register 'f' is '1', the next instruction is executed.
If bit 'b', in register 'f', is '0', the next instruction is discarded, and a NOP is executed instead, making this a 2-cycle instruction.

BRA Relative Branch

Syntax: [*label*] BRA label
[*label*] BRA \$+k
Operands: $-256 \leq \text{label} - \text{PC} + 1 \leq 255$
 $-256 \leq k \leq 255$
Operation: $(\text{PC}) + 1 + k \rightarrow \text{PC}$
Status Affected: None
Description: Add the signed 9-bit literal 'k' to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be $\text{PC} + 1 + k$. This instruction is a two-cycle instruction. This branch has a limited range.

BTFSS Bit Test f, Skip if Set

Syntax: [*label*] BTFSS f,b
Operands: $0 \leq f \leq 127$
 $0 \leq b < 7$
Operation: skip if $(f < b >) = 1$
Status Affected: None
Description: If bit 'b' in register 'f' is '0', the next instruction is executed.
If bit 'b' is '1', then the next instruction is discarded and a NOP is executed instead, making this a 2-cycle instruction.

BRW Relative Branch with W

Syntax: [*label*] BRW
Operands: None
Operation: $(\text{PC}) + (W) \rightarrow \text{PC}$
Status Affected: None
Description: Add the contents of W (unsigned) to the PC. Since the PC will have incremented to fetch the next instruction, the new address will be $\text{PC} + 1 + (W)$. This instruction is a two-cycle instruction.

BSF Bit Set f

Syntax: [*label*] BSF f,b
Operands: $0 \leq f \leq 127$
 $0 \leq b \leq 7$
Operation: $1 \rightarrow (f < b >)$
Status Affected: None
Description: Bit 'b' in register 'f' is set.

CALL Call Subroutine

Syntax: [*label*] CALL *k*

Operands: $0 \leq k \leq 2047$

Operation: (PC)+ 1 → TOS,
 $k \rightarrow PC<10:0>$,
(PCLATH<6:3>) → PC<14:11>

Status Affected: None

Description: Call Subroutine. First, return address (PC + 1) is pushed onto the stack. The eleven-bit immediate address is loaded into PC bits <10:0>. The upper bits of the PC are loaded from PCLATH. CALL is a two-cycle instruction.

CLRWDTClear Watchdog Timer

Syntax: [*label*] CLRWDTClear Watchdog Timer

Operands: None

Operation: 00h → WDT
0 → WDT prescaler,
1 → $\overline{TO}$
1 → $\overline{PD}$

Status Affected: $\overline{TO}$, $\overline{PD}$

Description: CLRWDTClear Watchdog Timer. It also resets the prescaler of the WDT. Status bits $\overline{TO}$ and $\overline{PD}$ are set.

CALLW Subroutine Call With W

Syntax: [*label*] CALLW

Operands: None

Operation: (PC) + 1 → TOS,
(W) → PC<7:0>,
(PCLATH<6:0>) → PC<14:8>

Status Affected: None

Description: Subroutine call with W. First, the return address (PC + 1) is pushed onto the return stack. Then, the contents of W is loaded into PC<7:0>, and the contents of PCLATH into PC<14:8>. CALLW is a two-cycle instruction.

COMF Complement f

Syntax: [*label*] COMF *f*,*d*

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: ($\bar{f}$) → (destination)

Status Affected: Z

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'.

CLRF Clear f

Syntax: [*label*] CLRF *f*

Operands: $0 \leq f \leq 127$

Operation: 00h → (f)
1 → Z

Status Affected: Z

Description: The contents of register 'f' are cleared and the Z bit is set.

DECF Decrement f

Syntax: [*label*] DECF *f*,*d*

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: (f) - 1 → (destination)

Status Affected: Z

Description: Decrement register 'f'. If 'd' is '0', the result is stored in the W register. If 'd' is '1', the result is stored back in register 'f'.

CLRWClear W

Syntax: [*label*] CLRWClear W

Operands: None

Operation: 00h → (W)
1 → Z

Status Affected: Z

Description: W register is cleared. Zero bit (Z) is set.

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DECFSZ Decrement f, Skip if 0

Syntax:	[<i>label</i>] DECFSZ f,d
Operands:	$0 \leq f \leq 127$ $d \in [0,1]$
Operation:	$(f) - 1 \rightarrow (\text{destination})$; skip if result = 0
Status Affected:	None
Description:	The contents of register 'f' are decremented. If 'd' is '0', the result is placed in the W register. If 'd' is '1', the result is placed back in register 'f'. If the result is '1', the next instruction is executed. If the result is '0', then a NOP is executed instead, making it a 2-cycle instruction.

INCFSZ Increment f, Skip if 0

Syntax:	[<i>label</i>] INCFSZ f,d
Operands:	$0 \leq f \leq 127$ $d \in [0,1]$
Operation:	$(f) + 1 \rightarrow (\text{destination})$; skip if result = 0
Status Affected:	None
Description:	The contents of register 'f' are incremented. If 'd' is '0', the result is placed in the W register. If 'd' is '1', the result is placed back in register 'f'. If the result is '1', the next instruction is executed. If the result is '0', a NOP is executed instead, making it a 2-cycle instruction.

GOTO Unconditional Branch

Syntax:	[<i>label</i>] GOTO k
Operands:	$0 \leq k \leq 2047$
Operation:	$k \rightarrow PC<10:0>$ $PCLATH<6:3> \rightarrow PC<14:11>$
Status Affected:	None
Description:	GOTO is an unconditional branch. The eleven-bit immediate value is loaded into PC bits <10:0>. The upper bits of PC are loaded from PCLATH<4:3>. GOTO is a two-cycle instruction.

IORLW Inclusive OR literal with W

Syntax:	[<i>label</i>] IORLW k
Operands:	$0 \leq k \leq 255$
Operation:	$(W) .OR. k \rightarrow (W)$
Status Affected:	Z
Description:	The contents of the W register are OR'ed with the eight-bit literal 'k'. The result is placed in the W register.

INCF Increment f

Syntax:	[<i>label</i>] INCF f,d
Operands:	$0 \leq f \leq 127$ $d \in [0,1]$
Operation:	$(f) + 1 \rightarrow (\text{destination})$
Status Affected:	Z
Description:	The contents of register 'f' are incremented. If 'd' is '0', the result is placed in the W register. If 'd' is '1', the result is placed back in register 'f'.

IORWF Inclusive OR W with f

Syntax:	[<i>label</i>] IORWF f,d
Operands:	$0 \leq f \leq 127$ $d \in [0,1]$
Operation:	$(W) .OR. (f) \rightarrow (\text{destination})$
Status Affected:	Z
Description:	Inclusive OR the W register with register 'f'. If 'd' is '0', the result is placed in the W register. If 'd' is '1', the result is placed back in register 'f'.

LSLF Logical Left Shift

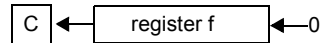
Syntax: `[label] LSLF f{,d}`

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: $(f<7>) \rightarrow C$
 $(f<6:0>) \rightarrow \text{dest}<7:1>$
 $0 \rightarrow \text{dest}<0>$

Status Affected: C, Z

Description: The contents of register 'f' are shifted one bit to the left through the Carry flag. A '0' is shifted into the LSb. If 'd' is '0', the result is placed in W. If 'd' is '1', the result is stored back in register 'f'.



LSRF Logical Right Shift

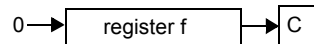
Syntax: `[label] LSRF f{,d}`

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: $0 \rightarrow \text{dest}<7>$
 $(f<7:1>) \rightarrow \text{dest}<6:0>$,
 $(f<0>) \rightarrow C$,

Status Affected: C, Z

Description: The contents of register 'f' are shifted one bit to the right through the Carry flag. A '0' is shifted into the MSb. If 'd' is '0', the result is placed in W. If 'd' is '1', the result is stored back in register 'f'.



MOVF Move f

Syntax: `[label] MOVF f,d`

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: $(f) \rightarrow (\text{dest})$

Status Affected: Z

Description: The contents of register f is moved to a destination dependent upon the status of d. If d = 0, destination is W register. If d = 1, the destination is file register f itself. d = 1 is useful to test a file register since status flag Z is affected.

Words: 1

Cycles: 1

Example: `MOVF FSR, 0`

After Instruction
W = value in FSR register
Z = 1

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MOVIW Move INDFn to W

Syntax: [*label*] MOVIW ++FSRn
[*label*] MOVIW --FSRn
[*label*] MOVIW FSRn++
[*label*] MOVIW FSRn--
[*label*] MOVIW k[FSRn]

Operands: $n \in [0,1]$
 $mm \in [00,01, 10, 11]$
 $-32 \leq k \leq 31$

Operation: INDFn $\rightarrow$ W
Effective address is determined by

- FSR + 1 (preincrement)
- FSR - 1 (predecrement)
- FSR + k (relative offset)

After the Move, the FSR value will be either:

- FSR + 1 (all increments)
- FSR - 1 (all decrements)
- Unchanged

Status Affected: Z

Mode	Syntax	mm
Preincrement	++FSRn	00
Predecrement	--FSRn	01
Postincrement	FSRn++	10
Postdecrement	FSRn--	11

Description: This instruction is used to move data between W and one of the indirect registers (INDFn). Before/after this move, the pointer (FSRn) is updated by pre/post incrementing/decrementing it.

Note: The INDFn registers are not physical registers. Any instruction that accesses an INDFn register actually accesses the register at the address specified by the FSRn.

FSRn is limited to the range 0000h - FFFFh. Incrementing/decrementing it beyond these bounds will cause it to wrap around.

MOVLB Move literal to BSR

Syntax: [*label*] MOVLB k

Operands: $0 \leq k \leq 15$

Operation: $k \rightarrow$ BSR

Status Affected: None

Description: The five-bit literal 'k' is loaded into the Bank Select Register (BSR).

MOVL P Move literal to PCLATH

Syntax: [*label*] MOVL P k

Operands: $0 \leq k \leq 127$

Operation: $k \rightarrow$ PCLATH

Status Affected: None

Description: The seven-bit literal 'k' is loaded into the PCLATH register.

MOVLW Move literal to W

Syntax: [*label*] MOVLW k

Operands: $0 \leq k \leq 255$

Operation: $k \rightarrow$ (W)

Status Affected: None

Description: The eight-bit literal 'k' is loaded into W register. The "don't cares" will assemble as '0's'.

Words: 1

Cycles: 1

Example: MOVLW 0x5A
After Instruction
W = 0x5A

MOVWF Move W to f

Syntax: [*label*] MOVWF f

Operands: $0 \leq f \leq 127$

Operation: (W) $\rightarrow$ (f)

Status Affected: None

Description: Move data from W register to register 'f'.

Words: 1

Cycles: 1

Example: MOVWF OPTION_REG
Before Instruction
OPTION_REG = 0xFF
W = 0x4F
After Instruction
OPTION_REG = 0x4F
W = 0x4F

MOVWI Move W to INDFn

Syntax: [*label*] MOVWI ++FSRn
[*label*] MOVWI --FSRn
[*label*] MOVWI FSRn++
[*label*] MOVWI FSRn--
[*label*] MOVWI k[FSRn]

Operands: n ∈ [0,1]
mm ∈ [00,01, 10, 11]
-32 ≤ k ≤ 31

Operation: W → INDFn
Effective address is determined by

- FSR + 1 (preincrement)
- FSR - 1 (predecrement)
- FSR + k (relative offset)

After the Move, the FSR value will be either:

- FSR + 1 (all increments)
- FSR - 1 (all decrements)

Unchanged

Status Affected: None

Mode	Syntax	mm
Preincrement	++FSRn	00
Predecrement	--FSRn	01
Postincrement	FSRn++	10
Postdecrement	FSRn--	11

Description: This instruction is used to move data between W and one of the indirect registers (INDFn). Before/after this move, the pointer (FSRn) is updated by pre/post incrementing/decrementing it.

Note: The INDFn registers are not physical registers. Any instruction that accesses an INDFn register actually accesses the register at the address specified by the FSRn.

FSRn is limited to the range 0000h - FFFFh. Incrementing/decrementing it beyond these bounds will cause it to wrap around.

The increment/decrement operation on FSRn WILL NOT affect any Status bits.

NOP No Operation

Syntax: [*label*] NOP

Operands: None

Operation: No operation

Status Affected: None

Description: No operation.

Words: 1

Cycles: 1

Example: NOP

OPTION Load OPTION_REG Register with W

Syntax: [*label*] OPTION

Operands: None

Operation: (W) → OPTION_REG

Status Affected: None

Description: Move data from W register to OPTION_REG register.

Words: 1

Cycles: 1

Example: OPTION

Before Instruction
OPTION_REG = 0xFF
W = 0x4F

After Instruction
OPTION_REG = 0x4F
W = 0x4F

RESET Software Reset

Syntax: [*label*] RESET

Operands: None

Operation: Execute a device Reset. Resets the nRI flag of the PCON register.

Status Affected: None

Description: This instruction provides a way to execute a hardware Reset by software.

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RETFIE Return from Interrupt

Syntax: [*label*] RETFIE

Operands: None

Operation: TOS → PC,
1 → GIE

Status Affected: None

Description: Return from Interrupt. Stack is POPed and Top-of-Stack (TOS) is loaded in the PC. Interrupts are enabled by setting Global Interrupt Enable bit, GIE (INTCON<7>). This is a two-cycle instruction.

Words: 1

Cycles: 2

Example: RETFIE

After Interrupt

PC	=	TOS
GIE	=	1

RETLW Return with literal in W

Syntax: [*label*] RETLW *k*

Operands: $0 \leq k \leq 255$

Operation: *k* → (W);
TOS → PC

Status Affected: None

Description: The W register is loaded with the eight bit literal '*k*'. The program counter is loaded from the top of the stack (the return address). This is a two-cycle instruction.

Words: 1

Cycles: 2

Example: CALL TABLE;W contains table
;offset value
• ;W now has table value
•
•
ADDWF PC ;W = offset
RETLW *k*1 ;Begin table
RETLW *k*2 ;
•
•
•
RETLW *k*n ; End of table

TABLE

Before Instruction
W = 0x07

After Instruction
W = value of *k*8

RETURN Return from Subroutine

Syntax: [*label*] RETURN

Operands: None

Operation: TOS → PC

Status Affected: None

Description: Return from subroutine. The stack is POPed and the top of the stack (TOS) is loaded into the program counter. This is a two-cycle instruction.

RLF Rotate Left f through Carry

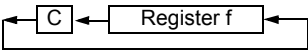
Syntax: [*label*] RLF *f*,*d*

Operands: $0 \leq f \leq 127$
d ∈ [0,1]

Operation: See description below

Status Affected: C

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 the W register. If '*d*' is '1', the result is stored back in register '*f*'.



Words: 1

Cycles: 1

Example: RLF REG1,0

Before Instruction

REG1	=	1110 0110
C	=	0

After Instruction

REG1	=	1110 0110
W	=	1100 1100
C	=	1

RRF Rotate Right f through Carry

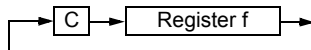
Syntax: [*label*] RRF f,d

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: See description below

Status Affected: C

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 the W register. If 'd' is '1', the result is placed back in register 'f'.



SUBLW Subtract W from literal

Syntax: [*label*] SUBLW k

Operands: $0 \leq k \leq 255$

Operation: $k - (W) \rightarrow (W)$

Status Affected: C, DC, Z

Description: The W register is subtracted (2's complement method) from the eight-bit literal 'k'. The result is placed in the W register.

C = 0	$W > k$
C = 1	$W \leq k$
DC = 0	$W<3:0> > k<3:0>$
DC = 1	$W<3:0> \leq k<3:0>$

SLEEP Enter Sleep mode

Syntax: [*label*] SLEEP

Operands: None

Operation: 00h $\rightarrow$ WDT,
0 $\rightarrow$ WDT prescaler,
1 $\rightarrow$ $\overline{TO}$,
0 $\rightarrow$ $\overline{PD}$

Status Affected: $\overline{TO}$, $\overline{PD}$

Description: The power-down Status bit, $\overline{PD}$ is cleared. Time-out Status bit, $\overline{TO}$ is set. Watchdog Timer and its prescaler are cleared.
The processor is put into Sleep mode with the oscillator stopped.

SUBWF Subtract W from f

Syntax: [*label*] SUBWF f,d

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: $(f) - (W) \rightarrow (\text{destination})$

Status Affected: C, DC, Z

Description: Subtract (2's complement method) W register from register 'f'. If 'd' is '0', the result is stored in the W register. If 'd' is '1', the result is stored back in register 'f'.

C = 0	$W > f$
C = 1	$W \leq f$
DC = 0	$W<3:0> > f<3:0>$
DC = 1	$W<3:0> \leq f<3:0>$

SUBWFB Subtract W from f with Borrow

Syntax: SUBWFB f{,d}

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: $(f) - (W) - (\overline{B}) \rightarrow \text{dest}$

Status Affected: C, DC, Z

Description: Subtract W and the BORROW flag (CARRY) 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'.

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SWAPF **Swap Nibbles in f**

Syntax: [*label*] SWAPF f,d

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: $(f<3:0>) \rightarrow (\text{destination}<7:4>)$,
 $(f<7:4>) \rightarrow (\text{destination}<3:0>)$

Status Affected: None

Description: The upper and lower nibbles of register 'f' are exchanged. If 'd' is '0', the result is placed in the W register. If 'd' is '1', the result is placed in register 'f'.

XORLW **Exclusive OR literal with W**

Syntax: [*label*] XORLW k

Operands: $0 \leq k \leq 255$

Operation: $(W) .XOR. k \rightarrow (W)$

Status Affected: Z

Description: The contents of the W register are XOR'ed with the eight-bit literal 'k'. The result is placed in the W register.

TRIS **Load TRIS Register with W**

Syntax: [*label*] TRIS f

Operands: $5 \leq f \leq 7$

Operation: $(W) \rightarrow \text{TRIS register 'f'}$

Status Affected: None

Description: Move data from W register to TRIS register.
 When 'f' = 5, TRISA is loaded.
 When 'f' = 6, TRISB is loaded.
 When 'f' = 7, TRISC is loaded.

XORWF **Exclusive OR W with f**

Syntax: [*label*] XORWF f,d

Operands: $0 \leq f \leq 127$
 $d \in [0,1]$

Operation: $(W) .XOR. (f) \rightarrow (\text{destination})$

Status Affected: Z

Description: Exclusive OR the contents of the W register with register 'f'. If 'd' is '0', the result is stored in the W register. If 'd' is '1', the result is stored back in register 'f'.

30.0 ELECTRICAL SPECIFICATIONS

Absolute Maximum Ratings^(†)

Ambient temperature under bias	-40°C to +125°C
Storage temperature	-65°C to +150°C
Voltage on VDD with respect to VSS, PIC16F1826/27	-0.3V to +6.5V
Voltage on VDD with respect to VSS, PIC16LF1826/27	-0.3V to +4.0V
Voltage on MCLR with respect to VSS	-0.3V to +9.0V
Voltage on all other pins with respect to VSS	-0.3V to (VDD + 0.3V)
Total power dissipation ⁽¹⁾	800 mW
Maximum current out of VSS pin, -40°C ≤ TA ≤ +85°C for industrial.....	396 mA
Maximum current out of VSS pin, -40°C ≤ TA ≤ +125°C for extended	114 mA
Maximum current into VDD pin, -40°C ≤ TA ≤ +85°C for industrial.....	292 mA
Maximum current into VDD pin, -40°C ≤ TA ≤ +125°C for extended	107 mA
Clamp current, IK (VPIN < 0 or VPIN > VDD).....	20 mA
Maximum output current sunk by any I/O pin.....	25 mA
Maximum output current sourced by any I/O pin	25 mA

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

† 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 above maximum rating conditions for extended periods may affect device reliability.

PIC16(L)F1826/27

FIGURE 30-1: PIC16F1826/27 VOLTAGE FREQUENCY GRAPH, $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$

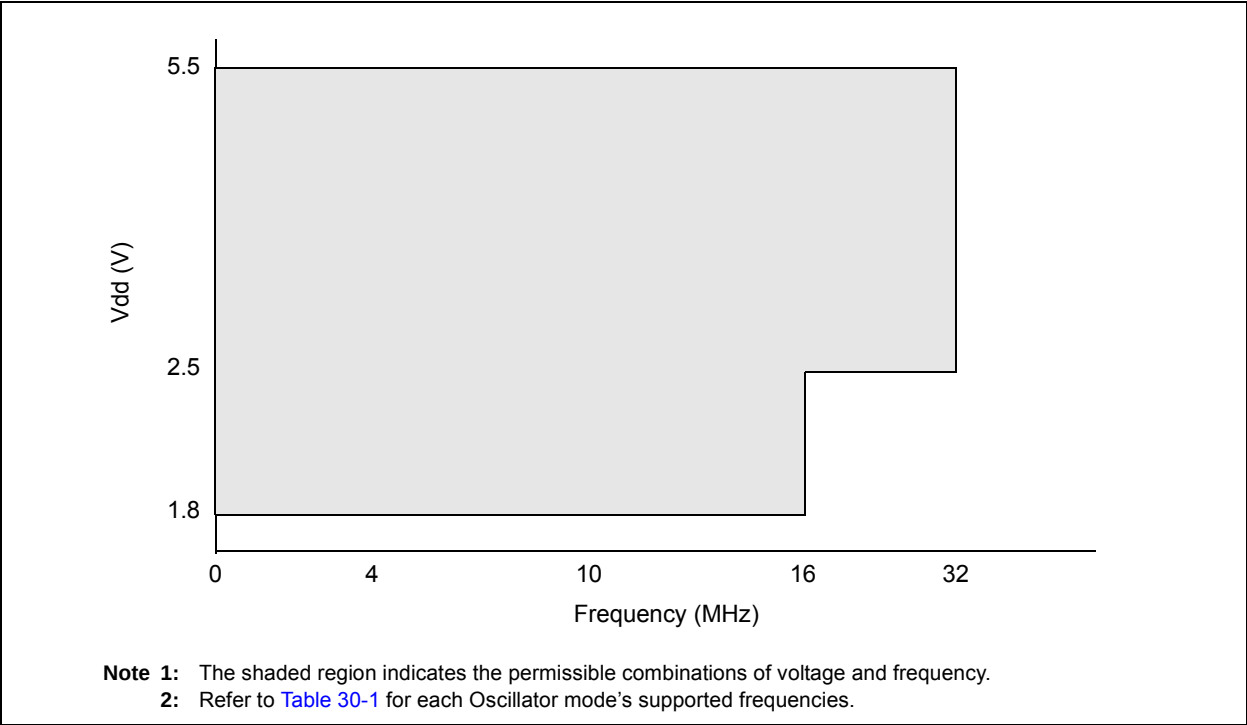


FIGURE 30-2: PIC16LF1826/27 VOLTAGE FREQUENCY GRAPH, $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$

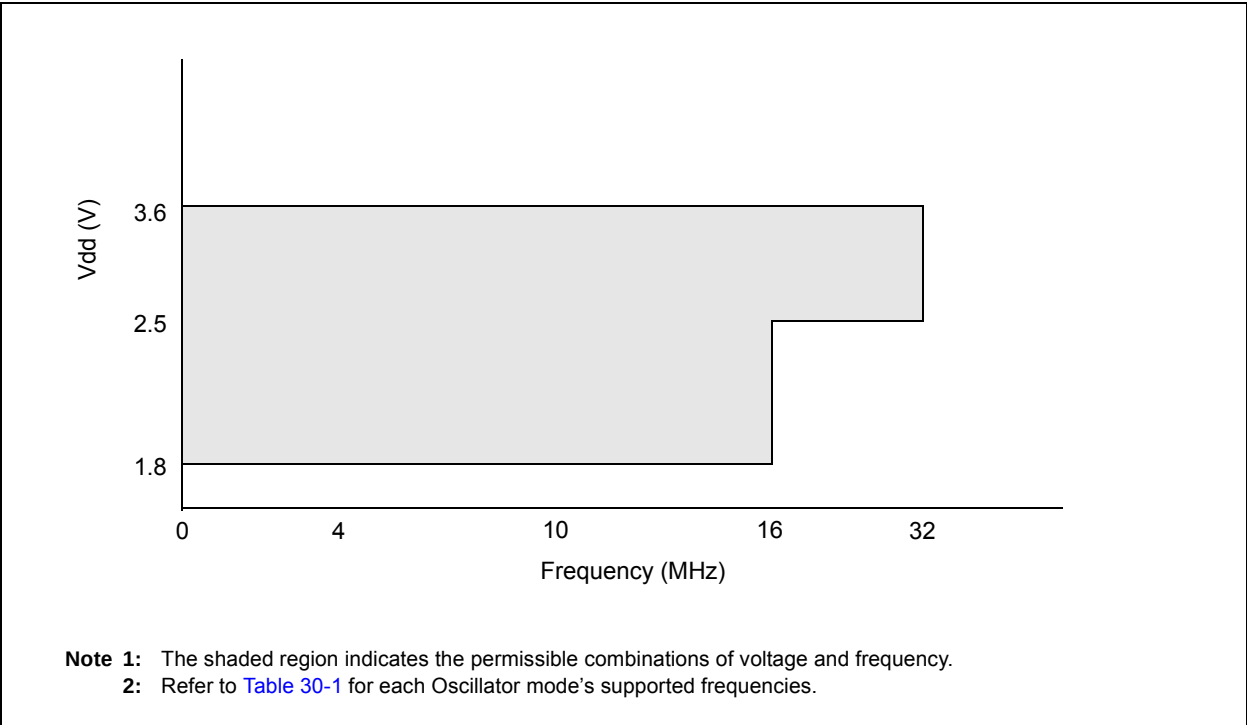
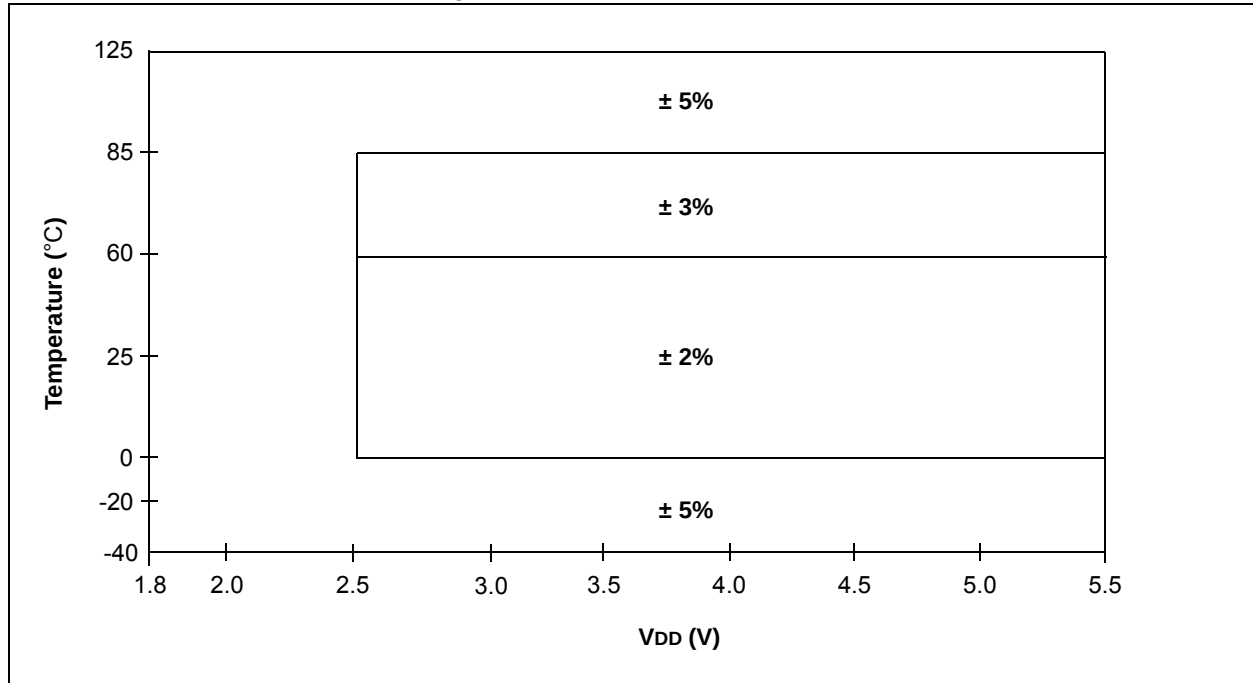


FIGURE 30-3: HFINTOSC FREQUENCY ACCURACY OVER DEVICE V_{DD} AND TEMPERATURE



PIC16(L)F1826/27

30.1 DC Characteristics: PIC16(L)F1826/27-I/E (Industrial, Extended)

PIC16LF1826/27		Standard Operating Conditions (unless otherwise stated) Operating temperature $-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$ for industrial $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$ for extended					
PIC16F1826/27		Standard Operating Conditions (unless otherwise stated) Operating temperature $-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$ for industrial $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$ for extended					
Param. No.	Sym.	Characteristic	Min.	Typ†	Max.	Units	Conditions
D001	VDD	Supply Voltage					
		PIC16LF1826/27	1.8 2.5	— —	3.6 3.6	V V	Fosc ≤ 16 MHz: Fosc ≤ 32 MHz (NOTE 2)
D001		PIC16F1826/27	1.8 2.5	— —	5.5 5.5	V V	Fosc ≤ 16 MHz: Fosc ≤ 32 MHz (NOTE 2)
D002*	VDR	RAM Data Retention Voltage ⁽¹⁾					
		PIC16LF1826/27	1.5	—	—	V	Device in Sleep mode
D002*		PIC16F1826/27	1.7	—	—	V	Device in Sleep mode
	VPOR*	Power-on Reset Release Voltage	—	1.6	—	V	
	VPORR*	Power-on Reset Rearm Voltage					
		PIC16LF1826/27	—	0.8	—	V	Device in Sleep mode
		PIC16F1826/27	—	1.7	—	V	Device in Sleep mode
D003	VADFVR	Fixed Voltage Reference Voltage for ADC	-8	—	6	%	1.024V, VDD ≥ 2.5V
			-8	—	6		2.048V, VDD ≥ 2.5V
			-8	—	6		4.096V, VDD ≥ 4.75
D003A	VCDAFVR	Fixed Voltage Reference Voltage for Comparator and DAC	-11	—	7	%	1.024V, VDD ≥ 2.5V
			-11	—	7		2.048V, VDD ≥ 2.5V
			-11	—	7		4.096V, VDD ≥ 4.75
D004*	SVDD	VDD Rise Rate to ensure internal Power-on Reset signal	0.05	—	—	V/ms	See Section 7.1 "Power-on Reset (POR)" for details.

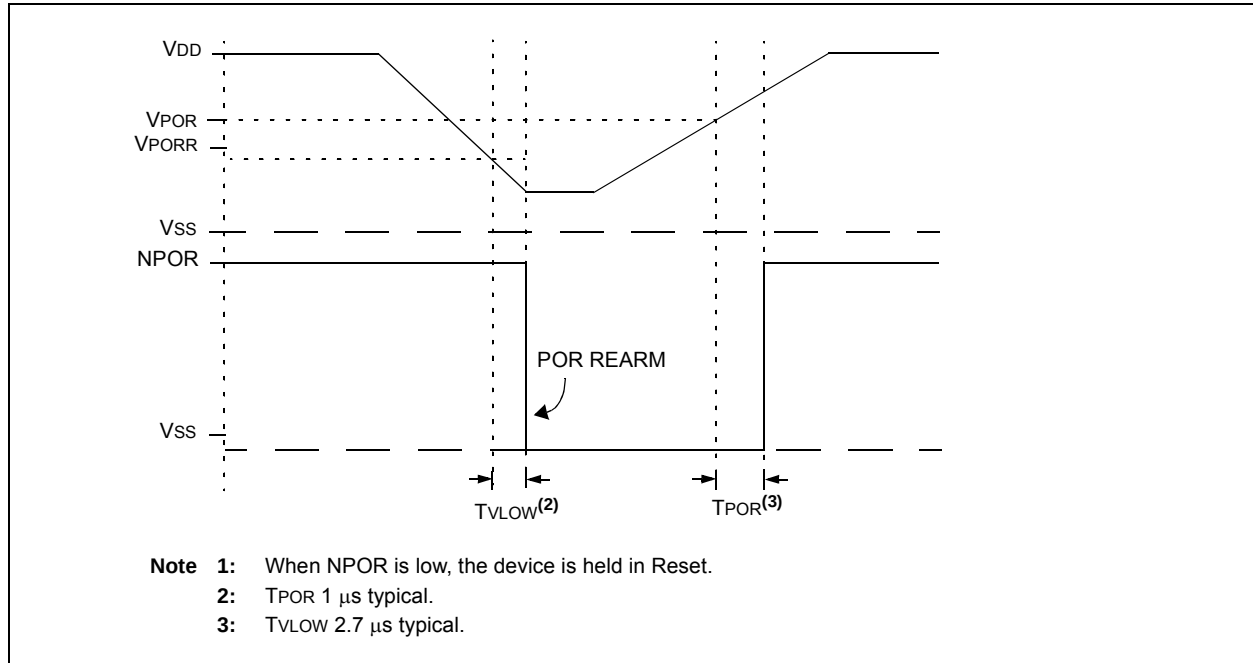
* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

Note 1: This is the limit to which VDD can be lowered in Sleep mode without losing RAM data.

Note 2: PLL required for 32 MHz operation.

FIGURE 30-4: POR AND POR REARM WITH SLOW RISING V_{DD}



PIC16(L)F1826/27

30.2 DC Characteristics: PIC16(L)F1826/27-I/E (Industrial, Extended)

PIC16LF1826/27			Standard Operating Conditions (unless otherwise stated)				
			Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended				
PIC16F1826/27			Standard Operating Conditions (unless otherwise stated)				
			Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended				
Param No.	Device Characteristics	Min.	Typ†	Max.	Units	Conditions	
						VDD	Note
D010	Supply Current (IDD) ^(1, 2)						
		—	7.0	13	μA	1.8	Fosc = 32 kHz
		—	9.0	16	μA	3.0	LP Oscillator mode, -40°C ≤ TA ≤ +85°C
		—	7.0	17	μA	1.8	Fosc = 32 kHz
		—	9.0	18	μA	3.0	LP Oscillator mode, -40°C ≤ TA ≤ +125°C
D010		—	24	40	μA	1.8	Fosc = 32 kHz
		—	30	48	μA	3.0	LP Oscillator mode
		—	32	55	μA	5.0	-40°C ≤ TA ≤ +85°C
		—	24	43	μA	1.8	Fosc = 32 kHz
		—	30	50	μA	3.0	LP Oscillator mode
		—	32	60	μA	5.0	-40°C ≤ TA ≤ +125°C
D011		—	110	200	μA	1.8	Fosc = 1 MHz
		—	200	400	μA	3.0	XT Oscillator mode
D011		—	160	210	μA	1.8	Fosc = 1 MHz
		—	210	400	μA	3.0	XT Oscillator mode
		—	250	450	μA	5.0	
D012		—	290	475	μA	1.8	Fosc = 4 MHz
		—	600	900	μA	3.0	XT Oscillator mode
D012		—	380	570	μA	1.8	Fosc = 4 MHz
		—	650	880	μA	3.0	XT Oscillator mode
		—	680	1100	μA	5.0	
D013		—	40	80	μA	1.8	Fosc = 500 kHz
		—	70	120	μA	3.0	EC Oscillator mode, Low-power mode
D013		—	60	120	μA	1.8	Fosc = 500 kHz
		—	80	180	μA	3.0	EC Oscillator mode
		—	93	200	μA	5.0	Low-power mode

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

- Note**
- 1: The test conditions for all IDD measurements in active operation mode are: OSC1 = external square wave, from rail-to-rail; all I/O pins as inputs, pulled to VDD; MCLR = VDD; WDT disabled.
 - 2: The supply current is mainly a function of the operating voltage and frequency. Other factors, such as I/O pin loading and switching rate, oscillator type, internal code execution pattern and temperature, also have an impact on the current consumption.
 - 3: 8 MHz internal RC oscillator with 4x PLL enabled.
 - 4: 8 MHz crystal oscillator with 4x PLL enabled.
 - 5: For RC oscillator configurations, current through REXT is not included. The current through the resistor can be extended by the formula $I_R = V_{DD}/2R_{EXT}$ (mA) with REXT in kΩ.

30.2 DC Characteristics: PIC16(L)F1826/27-I/E (Industrial, Extended) (Continued)

PIC16LF1826/27			Standard Operating Conditions (unless otherwise stated)				
			Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended				
PIC16F1826/27			Standard Operating Conditions (unless otherwise stated)				
			Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended				
Param No.	Device Characteristics	Min.	Typ†	Max.	Units	Conditions	
						VDD	Note
	Supply Current (IDD) ^(1, 2)						
D014		—	260	475	μA	1.8	Fosc = 4 MHz
		—	550	800	μA	3.0	EC Oscillator mode, Medium-power mode
D014		—	375	655	μA	1.8	Fosc = 4 MHz
		—	600	800	μA	3.0	EC Oscillator mode
		—	650	930	μA	5.0	Medium-power mode
D015		—	3.6	10	μA	1.8	Fosc = 31 kHz
		—	7.0	15	μA	3.0	LFINTOSC mode
D015		—	21	42	μA	1.8	Fosc = 31 kHz
		—	27	55	μA	3.0	LFINTOSC mode
		—	28	60	μA	5.0	
D016		—	110	210	μA	1.8	Fosc = 500 kHz
		—	150	250	μA	3.0	MFINTOSC mode
D016		—	150	250	μA	1.8	Fosc = 500 kHz
		—	210	345	μA	3.0	MFINTOSC mode
		—	270	425	μA	5.0	
D017*		—	0.8	1.5	mA	1.8	Fosc = 8 MHz
		—	1.3	2.4	mA	3.0	HFINTOSC mode
D017*		—	1.0	2.0	mA	1.8	Fosc = 8 MHz
		—	1.5	2.6	mA	3.0	HFINTOSC mode
		—	1.7	2.8	mA	5.0	
D018		—	1.2	2.5	mA	1.8	Fosc = 16 MHz
		—	2.5	3.75	mA	3.0	HFINTOSC mode
D018		—	1.7	2.23	mA	1.8	Fosc = 16 MHz
		—	2.7	4.3	mA	3.0	HFINTOSC mode
		—	3.0	4.6	mA	5.0	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

- Note 1:** 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 as inputs, pulled to V_{DD}; MCLR = V_{DD}; WDT disabled.
- Note 2:** The supply current is mainly a function of the operating voltage and frequency. Other factors, such as I/O pin loading and switching rate, oscillator type, internal code execution pattern and temperature, also have an impact on the current consumption.
- Note 3:** 8 MHz internal RC oscillator with 4x PLL enabled.
- Note 4:** 8 MHz crystal oscillator with 4x PLL enabled.
- Note 5:** For RC oscillator configurations, current through R_{EXT} is not included. The current through the resistor can be extended by the formula $I_R = V_{DD}/2R_{EXT}$ (mA) with R_{EXT} in kΩ.

PIC16(L)F1826/27

30.2 DC Characteristics: PIC16(L)F1826/27-I/E (Industrial, Extended) (Continued)

PIC16LF1826/27			Standard Operating Conditions (unless otherwise stated)				
			Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended				
PIC16F1826/27			Standard Operating Conditions (unless otherwise stated)				
			Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended				
Param No.	Device Characteristics	Min.	Typ†	Max.	Units	Conditions	
						VDD	Note
	Supply Current (IDD) ^(1, 2)						
D019		—	4.0	7.3	mA	3.0	Fosc = 32 MHz
		—	4.4	7.5	mA	3.6	HFINTOSC mode (Note 3)
D019		—	4.2	7.3	mA	3.0	Fosc = 32 MHz
		—	4.6	7.5	mA	5.0	HFINTOSC mode (Note 3)
D020		—	4.0	6.0	mA	3.0	Fosc = 32 MHz
		—	4.7	7.0	mA	3.6	HS Oscillator mode (Note 4)
D020		—	4.2	6.8	mA	3.0	Fosc = 32 MHz
		—	4.9	7.6	mA	5.0	HS Oscillator mode (Note 4)
D021		—	410	0.65	mA	1.8	Fosc = 4 MHz
		—	710	1.25	mA	3.0	EXTRC mode (Note 5)
D021		—	430	0.695	mA	1.8	Fosc = 4 MHz
		—	730	1.3	mA	3.0	EXTRC mode (Note 5)
		—	860	1.35	mA	5.0	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

- Note 1:** The test conditions for all IDD measurements in active operation mode are: OSC1 = external square wave, from rail-to-rail; all I/O pins as inputs, pulled to VDD; MCLR = VDD; WDT disabled.
- Note 2:** The supply current is mainly a function of the operating voltage and frequency. Other factors, such as I/O pin loading and switching rate, oscillator type, internal code execution pattern and temperature, also have an impact on the current consumption.
- Note 3:** 8 MHz internal RC oscillator with 4x PLL enabled.
- Note 4:** 8 MHz crystal oscillator with 4x PLL enabled.
- Note 5:** For RC oscillator configurations, current through REXT is not included. The current through the resistor can be extended by the formula $I_R = V_{DD}/2R_{EXT}$ (mA) with REXT in kΩ.

30.3 DC Characteristics: PIC16(L)F1826/27-I/E (Power-Down)

PIC16LF1826/27			Standard Operating Conditions (unless otherwise stated)					
			Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended					
PIC16F1826/27			Standard Operating Conditions (unless otherwise stated)					
			Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended					
Param No.	Device Characteristics	Min.	Typ†	Max. +85°C	Max. +125°C	Units	Conditions	
							VDD	Note
D022		Power-down Base Current (IPD) ⁽²⁾						
		—	0.02	1.0	4.0	μA	1.8	WDT, BOR, FVR, and T1OSC disabled, all Peripherals Inactive
		—	0.03	1.1	7.0	μA	3.0	
D022		—	15	35	50	μA	1.8	WDT, BOR, FVR, and T1OSC disabled, all Peripherals Inactive
		—	18	40	60	μA	3.0	
		—	19	45	70	μA	5.0	
D023		—	0.5	1.1	5.0	μA	1.8	LPWDT Current (Note 1)
		—	0.8	2.0	8.0	μA	3.0	
D023		—	16	35	50	μA	1.8	LPWDT Current (Note 1)
		—	19	40	60	μA	3.0	
		—	20	45	70	μA	5.0	
D023A		—	8.5	23	32	μA	1.8	FVR current (Note 1)
		—	8.5	26	40	μA	3.0	
D023A		—	32	62	66	μA	1.8	FVR current (Note 1)
		—	39	70	80	μA	3.0	
		—	70	110	120	μA	5.0	
D024		—	8.1	14	20	μA	3.0	BOR Current (Note 1)
D024		—	34	57	70	μA	3.0	BOR Current (Note 1)
		—	67	100	115	μA	5.0	
D025		—	0.6	1.5	5.0	μA	1.8	T1OSC Current (Note 1)
		—	0.8	2.5	8.0	μA	3.0	
D025		—	16	35	50	μA	1.8	T1OSC Current (Note 1)
		—	21	40	60	μA	3.0	
		—	25	45	70	μA	5.0	
D026		—	0.1	1.1	5.0	μA	1.8	A/D Current (Note 1, Note 3), no conversion in progress
		—	0.1	2.0	8.0	μA	3.0	
D026		—	16	35	50	μA	1.8	A/D Current (Note 1, Note 3), no conversion in progress
		—	21	40	60	μA	3.0	
		—	25	45	70	μA	5.0	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

- Note 1:** The peripheral current is the sum of the base IDD or IPD and the additional current consumed when this peripheral is enabled. The peripheral Δ current can be determined by subtracting the base IDD or IPD current from this limit. Max values should be used when calculating total current consumption.
- 2:** 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 set to inputs state and tied to VDD.
- 3:** A/D oscillator source is FRC.

PIC16(L)F1826/27

30.3 DC Characteristics: PIC16(L)F1826/27-I/E (Power-Down) (Continued)

PIC16LF1826/27			Standard Operating Conditions (unless otherwise stated)					
			Operating temperature $-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$ for industrial $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$ for extended					
PIC16F1826/27			Standard Operating Conditions (unless otherwise stated)					
			Operating temperature $-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$ for industrial $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$ for extended					
Param No.	Device Characteristics	Min.	Typ†	Max. +85°C	Max. +125°C	Units	Conditions	
							VDD	Note
D026A*	Power-down Base Current (IPD) ⁽²⁾	—	250	—	—	μA	1.8	A/D Current (Note 1 , Note 3), conversion in progress
		—	250	—	—	μA	3.0	
D026A*		—	280	—	—	μA	1.8	A/D Current (Note 1 , Note 3), conversion in progress
		—	280	—	—	μA	3.0	
		—	280	—	—	μA	5.0	
D027		—	3.5	6	8	μA	1.8	Cap Sense Low Power Oscillator mode (Note 1)
		—	7	10	14	μA	3.0	
D027		—	4.3	36	38	μA	1.8	Cap Sense Low Power Oscillator mode (Note 1)
		—	5.8	39	42	μA	3.0	
		—	6.3	42	45	μA	5.0	
D027A		—	4.2	8	10	μA	1.8	Cap Sense Medium Power Oscillator mode (Note 1)
		—	6	12	15	μA	3.0	
D027A		—	7.4	38	40	μA	1.8	Cap Sense Medium Power Oscillator mode (Note 1)
		—	9.7	42	43	μA	3.0	
		—	10.4	46	48	μA	5.0	
D027B		—	6	10	15	μA	1.8	Cap Sense High Power Oscillator mode (Note 1)
		—	10	14	20	μA	3.0	
D027B		—	17	44	50	μA	1.8	Cap Sense High Power Oscillator mode (Note 1)
		—	41	68	80	μA	3.0	
		—	50	78	90	μA	5.0	
D028		—	6.9	11	15	μA	1.8	Comparator Current, Low Power mode, one comparator enabled (Note 1)
		—	7.0	13	16	μA	3.0	
D028		—	24	45	60	μA	1.8	Comparator Current, Low Power mode, one comparator enabled (Note 1)
		—	24.5	60	70	μA	3.0	
		—	25	65	75	μA	5.0	
D028A		—	7.0	12	16	μA	1.8	Comparator Current, Low Power mode, two comparators enabled (Note 1)
		—	7.2	14	17	μA	3.0	
D028A		—	24	45	60	μA	1.8	Comparator Current, Low Power mode, two comparators enabled (Note 1)
		—	24.5	60	70	μA	3.0	
		—	25	65	75	μA	5.0	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

- Note 1:** The peripheral current is the sum of the base IDD or IPD and the additional current consumed when this peripheral is enabled. The peripheral Δ current can be determined by subtracting the base IDD or IPD current from this limit. Max values should be used when calculating total current consumption.
- 2:** 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 set to inputs state and tied to VDD.
- 3:** A/D oscillator source is FRC.

30.3 DC Characteristics: PIC16(L)F1826/27-I/E (Power-Down) (Continued)

PIC16LF1826/27			Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended					
PIC16F1826/27			Standard Operating Conditions (unless otherwise stated) Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended					
Param No.	Device Characteristics	Min.	Typ†	Max. +85°C	Max. +125°C	Units	Conditions	
							VDD	Note
D028B	Power-down Base Current (IPD) ⁽²⁾							
		—	24	32	40	μA	1.8	Comparator Current, High Power mode, one comparator enabled (Note 1)
		—	25	35	45	μA	3.0	
D028B		—	36	60	80	μA	1.8	Comparator Current, High Power mode, one comparator enabled (Note 1)
		—	37	63	87	μA	3.0	
		—	38	65	90	μA	5.0	
D028C		—	40	80	90	μA	1.8	Comparator Current, High Power mode, two comparators enabled
		—	41	83	95	μA	3.0	
D028C		—	43	86	100	μA	1.8	Comparator Current, High Power mode, two comparators enabled (Note 1)
		—	44	90	105	μA	3.0	
		—	45	95	110	μA	5.0	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

- Note 1:** The peripheral current is the sum of the base IDD or IPD and the additional current consumed when this peripheral is enabled. The peripheral Δ current can be determined by subtracting the base IDD or IPD current from this limit. Max values should be used when calculating total current consumption.
- 2:** 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 set to inputs state and tied to VDD.
- 3:** A/D oscillator source is FRC.

PIC16(L)F1826/27

30.4 DC Characteristics: PIC16(L)F1826/27-I/E

DC CHARACTERISTICS			Standard Operating Conditions (unless otherwise stated)				
			Operating temperature -40°C ≤ TA ≤ +85°C for industrial -40°C ≤ TA ≤ +125°C for extended				
Param No.	Sym.	Characteristic	Min.	Typ†	Max.	Units	Conditions
D030 D030A D031 D032 D033	VIL	Input Low Voltage					
		I/O PORT:					
		with TTL buffer	—	—	0.8	V	4.5V ≤ VDD ≤ 5.5V
			—	—	0.15 VDD	V	1.8V ≤ VDD ≤ 4.5V
		with Schmitt Trigger buffer	—	—	0.2 VDD	V	2.0V ≤ VDD ≤ 5.5V
		with I ² C™ levels	—	—	0.3 VDD	V	
		with SMBus™ levels	—	—	0.8	V	2.7V ≤ VDD ≤ 5.5V
D032		MCLR, OSC1 (RC mode) ⁽¹⁾	—	—	0.2 VDD	V	
D033		OSC1 (HS mode)	—	—	0.3 VDD	V	
D040 D040A D041 D042 D043A D043B	VIH	Input High Voltage					
		I/O ports:		—	—		
		with TTL buffer	2.0	—	—	V	4.5V ≤ VDD ≤ 5.5V
			0.25 VDD + 0.8	—	—	V	1.8V ≤ VDD ≤ 4.5V
		with Schmitt Trigger buffer	0.8 VDD	—	—	V	2.0V ≤ VDD ≤ 5.5V
		with I ² C™ levels	0.7 VDD	—	—	V	
		with SMBus™ levels	2.1	—	—	V	2.7V ≤ VDD ≤ 5.5V
		MCLR	0.8 VDD	—	—	V	
D042		OSC1 (HS mode)	0.7 VDD	—	—	V	
D043B		OSC1 (RC mode)	0.9 VDD	—	—	V	(Note 1)
D060 D061	IIL	Input Leakage Current⁽²⁾					
		I/O ports	—	± 5	± 100	nA	VSS ≤ VPIN ≤ VDD, Pin at high-impedance at 85°C
				± 5	± 1000	nA	125°C
D061		MCLR ⁽³⁾	—	± 50	± 200	nA	VSS ≤ VPIN ≤ VDD at 85°C
D070*	IPUR	Weak Pull-up Current					
			25 25	100 140	200 300	μA	VDD = 3.3V, VPIN = VSS VDD = 5.0V, VPIN = VSS
D080	VOL	Output Low Voltage⁽⁴⁾					
		I/O ports	—	—	0.6	V	IOL = 8mA, VDD = 5V IOL = 6mA, VDD = 3.3V IOL = 1.8mA, VDD = 1.8V
D090	VOH	Output High Voltage⁽⁴⁾					
		I/O ports	VDD - 0.7	—	—	V	IOH = 3.5mA, VDD = 5V IOH = 3mA, VDD = 3.3V IOH = 1mA, VDD = 1.8V
D101* D101A*	COSC2 Cio	Capacitive Loading Specs on Output Pins					
		OSC2 pin	—	—	15	pF	In XT, HS and LP modes when external clock is used to drive OSC1
D101A*	Cio	All I/O pins	—	—	50	pF	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

Note 1: In RC oscillator configuration, the OSC1/CLKIN pin is a Schmitt Trigger input. It is not recommended to use an external clock in RC mode.

2: Negative current is defined as current sourced by the pin.

3: The leakage current on the 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.

4: Including OSC2 in CLKOUT mode.

30.5 Memory Programming Requirements

DC CHARACTERISTICS			Standard Operating Conditions (unless otherwise stated) Operating temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$				
Param No.	Sym.	Characteristic	Min.	Typ†	Max.	Units	Conditions
Program Memory Programming Specifications							
D110	VIHH	Voltage on $\overline{\text{MCLR}}/\text{VPP}/\text{RA5}$ pin	8.0	—	9.0	V	(Note 3, Note 4)
D111	IDDP	Supply Current during Programming	—	—	10	mA	
D112		VDD for Bulk Erase	2.7	—	VDD max.	V	
D113	VPEW	VDD for Write or Row Erase	VDD min.	—	VDD max.	V	
D114	IPPPGM	Current on $\overline{\text{MCLR}}/\text{VPP}$ during Erase/Write	—	—	1.0	mA	
D115	IDDPGM	Current on VDD during Erase/Write	—	—	5.0	mA	
Data EEPROM Memory							
D116	ED	Byte Endurance	100K	—	—	E/W	-40°C to +85°C
D117	VDRW	VDD for Read/Write	VDD min.	—	VDD max.	V	
D118	TDEW	Erase/Write Cycle Time	—	4.0	5.0	ms	Provided no other specifications are violated
D119	TRETD	Characteristic Retention	—	40	—	Year	
D120	TREF	Number of Total Erase/Write Cycles before Refresh ⁽²⁾	1M	10M	—	E/W	
Program Flash Memory							
D121	EP	Cell Endurance	10K	—	—	E/W	-40°C to +85°C (Note 1)
D122	VPR	VDD for Read	VDD min.	—	VDD max.	V	
D123	TIW	Self-timed Write Cycle Time	—	2	2.5	ms	Provided no other specifications are violated
D124	TRETD	Characteristic Retention	—	40	—	Year	

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

Note 1: Self-write and Block Erase.

2: Refer to [Section 11.2 "Using the Data EEPROM"](#) for a more detailed discussion on data EEPROM endurance.

3: Required only if single-supply programming is disabled.

4: The MPLAB ICD 2 does not support variable VPP output. Circuitry to limit the ICD 2 VPP voltage must be placed between the ICD 2 and target system when programming or debugging with the ICD 2.

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30.6 Thermal Considerations

Standard Operating Conditions (unless otherwise stated)					
Operating temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$					
Param No.	Sym.	Characteristic	Typ.	Units	Conditions
TH01	θ_{JA}	Thermal Resistance Junction to Ambient	65.5	$^{\circ}\text{C}/\text{W}$	18-pin PDIP package
			76	$^{\circ}\text{C}/\text{W}$	18-pin SOIC package
			89.3	$^{\circ}\text{C}/\text{W}$	20-pin SSOP package
			TBD	$^{\circ}\text{C}/\text{W}$	28-pin UQFN 4x4mm package
			31.1	$^{\circ}\text{C}/\text{W}$	28-pin QFN 6x6mm package
TH02	θ_{JC}	Thermal Resistance Junction to Case	29.5	$^{\circ}\text{C}/\text{W}$	18-pin PDIP package
			23.5	$^{\circ}\text{C}/\text{W}$	18-pin SOIC package
			31.1	$^{\circ}\text{C}/\text{W}$	20-pin SSOP package
			TBD	$^{\circ}\text{C}/\text{W}$	28-pin UQFN 4x4mm package
			5	$^{\circ}\text{C}/\text{W}$	28-pin QFN 6x6mm package
TH03	T_{JMAX}	Maximum Junction Temperature	150	$^{\circ}\text{C}$	
TH04	PD	Power Dissipation	—	W	$PD = P_{INTERNAL} + P_{I/O}$
TH05	$P_{INTERNAL}$	Internal Power Dissipation	—	W	$P_{INTERNAL} = I_{DD} \times V_{DD}^{(1)}$
TH06	$P_{I/O}$	I/O Power Dissipation	—	W	$P_{I/O} = \sum (I_{OL} \times V_{OL}) + \sum (I_{OH} \times (V_{DD} - V_{OH}))$
TH07	P_{DER}	Derated Power	—	W	$P_{DER} = P_{DMAX} (T_J - T_A) / \theta_{JA}^{(2)}$

Legend: TBD = To Be Determined

Note 1: I_{DD} is current to run the chip alone without driving any load on the output pins.

2: T_A = Ambient Temperature

3: T_J = Junction Temperature

30.7 Timing Parameter Symbolology

The timing parameter symbols have been created with one of the following formats:

1. TppS2ppS
2. TppS

T			
F	Frequency	T	Time

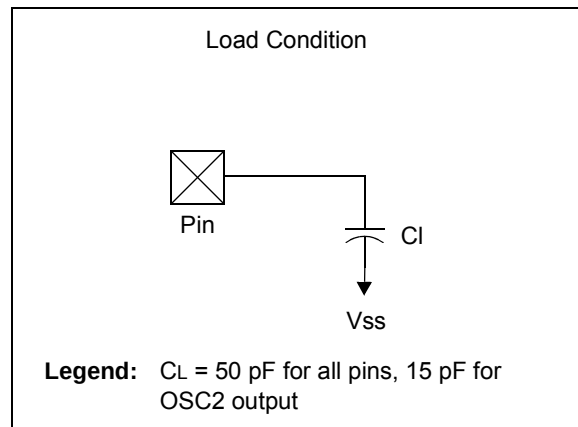
Lowercase letters (pp) and their meanings:

pp			
cc	CCP1	osc	OSC1
ck	CLKOUT	rd	$\overline{RD}$
cs	$\overline{CS}$	rw	$\overline{RD}$ or $\overline{WR}$
di	SDIx	sc	SCKx
do	SDO	ss	$\overline{SS}$
dt	Data in	t0	T0CKI
io	I/O PORT	t1	T1CKI
mc	MCLR	wr	$\overline{WR}$

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

FIGURE 30-5: LOAD CONDITIONS



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30.8 AC Characteristics: PIC16(L)F1826/27-I/E

FIGURE 30-6: CLOCK TIMING

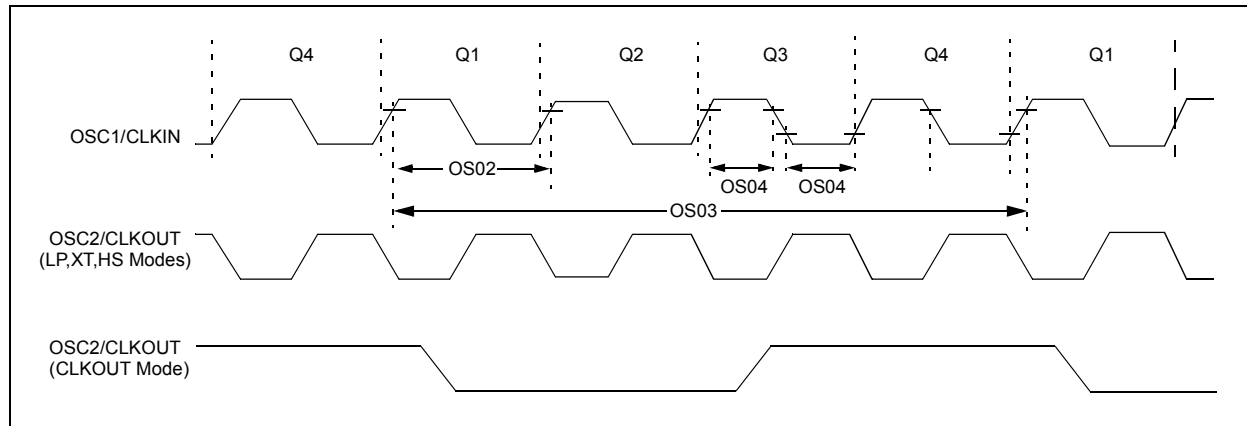


TABLE 30-1: CLOCK OSCILLATOR TIMING REQUIREMENTS

Standard Operating Conditions (unless otherwise stated)							
Operating temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$							
Param No.	Sym.	Characteristic	Min.	Typ†	Max.	Units	Conditions
OS01	Fosc	External CLKIN Frequency ⁽¹⁾	DC	—	0.5	MHz	EC Oscillator mode (low)
			DC	—	4	MHz	EC Oscillator mode (medium)
			DC	—	20	MHz	EC Oscillator mode (high)
		Oscillator Frequency ⁽¹⁾	—	32.768	—	kHz	LP Oscillator mode
			0.1	—	4	MHz	XT Oscillator mode
			1	—	4	MHz	HS Oscillator mode
OS02	Tosc	External CLKIN Period ⁽¹⁾	1	—	20	MHz	HS Oscillator mode, $V_{DD} > 2.7\text{V}$
			DC	—	4	MHz	RC Oscillator mode, $V_{DD} > 2.0\text{V}$
		Oscillator Period ⁽¹⁾	27	—	∞	μs	LP Oscillator mode
			250	—	∞	ns	XT Oscillator mode
			50	—	∞	ns	HS Oscillator mode
			50	—	∞	ns	EC Oscillator mode
OS03	Tcy	Instruction Cycle Time ⁽¹⁾	—	30.5	—	μs	LP Oscillator mode
			250	—	10,000	ns	XT Oscillator mode
			50	—	1,000	ns	HS Oscillator mode
			250	—	—	ns	RC Oscillator mode
OS04*	TosH, TosL	External CLKIN High, External CLKIN Low	200 Tcy	—	DC	ns	$T_{cy} = F_{osc}/4$
			2	—	—	μs	LP oscillator
			100	—	—	ns	XT oscillator
OS05*	TosR, TosF	External CLKIN Rise, External CLKIN Fall	20	—	—	ns	HS oscillator
			0	—	∞	ns	LP oscillator
			0	—	∞	ns	XT oscillator
OS05*	TosR, TosF	External CLKIN Rise, External CLKIN Fall	0	—	∞	ns	HS oscillator
			0	—	∞	ns	XT oscillator

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

Note 1: Instruction cycle period (Tcy) equals four times the input oscillator time base period. 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 OSC1 pin. When an external clock input is used, the "max" cycle time limit is "DC" (no clock) for all devices.

TABLE 30-2: OSCILLATOR PARAMETERS

Standard Operating Conditions (unless otherwise stated) Operating Temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$								
Param No.	Sym.	Characteristic	Freq. Tolerance	Min.	Typ†	Max.	Units	Conditions
OS08	HFosc	Internal Calibrated HFINTOSC Frequency ⁽²⁾	$\pm 2\%$	—	16.0	—	MHz	$0^{\circ}\text{C} \leq T_A \leq +60^{\circ}\text{C}$, $V_{DD} \geq 2.5\text{V}$
			$\pm 3\%$	—	16.0	—	MHz	$60^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$, $V_{DD} \geq 2.5\text{V}$
			$\pm 5\%$	—	16.0	—	MHz	$-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$
OS08A	MFosc	Internal Calibrated MFINTOSC Frequency ⁽²⁾	$\pm 2\%$	—	500	—	kHz	$0^{\circ}\text{C} \leq T_A \leq +60^{\circ}\text{C}$, $V_{DD} \geq 2.5\text{V}$
			$\pm 3\%$	—	500	—	kHz	$60^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$, $V_{DD} \geq 2.5\text{V}$
			$\pm 5\%$	—	500	—	kHz	$-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$
OS09	LFosc	Internal LFINTOSC Frequency	—	—	31	—	kHz	$-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$
OS10*	Tiosc ST	HFINTOSC Wake-up from Sleep Start-up Time	—	—	3.2	8	μs	
		MFINTOSC Wake-up from Sleep Start-up Time	—	—	24	35	μs	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

Note 1: Instruction cycle period (Tcy) equals four times the input oscillator time base period. 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 pin. When an external clock input is used, the "max" cycle time limit is "DC" (no clock) for all devices.

2: To ensure these oscillator frequency tolerances, VDD and VSS must be capacitively decoupled as close to the device as possible. 0.1 μF and 0.01 μF values in parallel are recommended.

3: By design.

TABLE 30-3: PLL CLOCK TIMING SPECIFICATIONS (VDD = 2.7V TO 5.5V)

Param No.	Sym.	Characteristic	Min.	Typ†	Max.	Units	Conditions
F10	FOSC	Oscillator Frequency Range	4	—	8	MHz	
F11	FSYS	On-Chip VCO System Frequency	16	—	32	MHz	
F12	TRC	PLL Start-up Time (Lock Time)	—	—	2	ms	
F13*	ΔCLK	CLKOUT Stability (Jitter)	-0.25%	—	+0.25%	%	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

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FIGURE 30-7: CLKOUT AND I/O TIMING

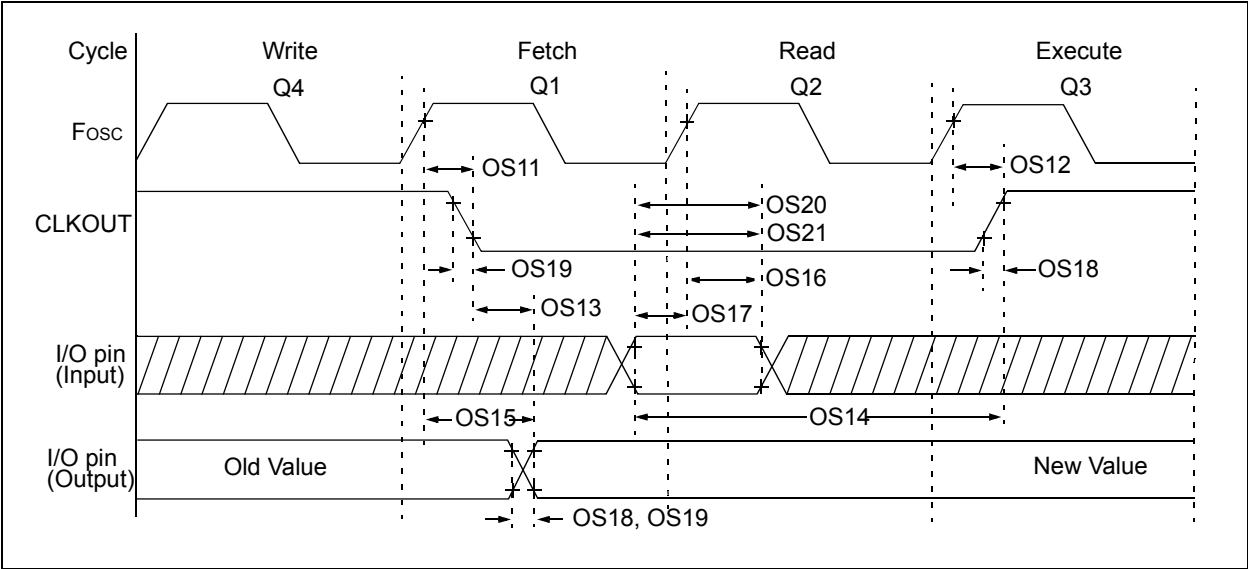


TABLE 30-4: CLKOUT AND I/O TIMING PARAMETERS

Standard Operating Conditions (unless otherwise stated) Operating Temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$							
Param No.	Sym.	Characteristic	Min.	Typ†	Max.	Units	Conditions
OS11	TosH2ckL	Fosc↑ to CLKOUT↓ ⁽¹⁾	—	—	70	ns	VDD = 3.3-5.0V
OS12	TosH2ckH	Fosc↑ to CLKOUT↑ ⁽¹⁾	—	—	72	ns	VDD = 3.3-5.0V
OS13	TckL2ioV	CLKOUT↓ to Port out valid ⁽¹⁾	—	—	20	ns	
OS14	TioV2ckH	Port input valid before CLKOUT↑ ⁽¹⁾	Tosc + 200 ns	—	—	ns	
OS15	TosH2ioV	Fosc↑ (Q1 cycle) to Port out valid	—	50	70*	ns	VDD = 3.3-5.0V
OS16	TosH2ioI	Fosc↑ (Q2 cycle) to Port input invalid (I/O in hold time)	50	—	—	ns	VDD = 3.3-5.0V
OS17	TioV2osH	Port input valid to Fosc↑ (Q2 cycle) (I/O in setup time)	20	—	—	ns	
OS18	TioR	Port output rise time ⁽²⁾	—	40 15	72 32	ns	VDD = 1.8V VDD = 3.3-5.0V
OS19	TioF	Port output fall time ⁽²⁾	—	28 15	55 30	ns	VDD = 1.8V VDD = 3.3-5.0V
OS20*	Tinp	INT pin input high or low time	25	—	—	ns	
OS21*	Tioc	Interrupt-on-change new input level time	25	—	—	ns	

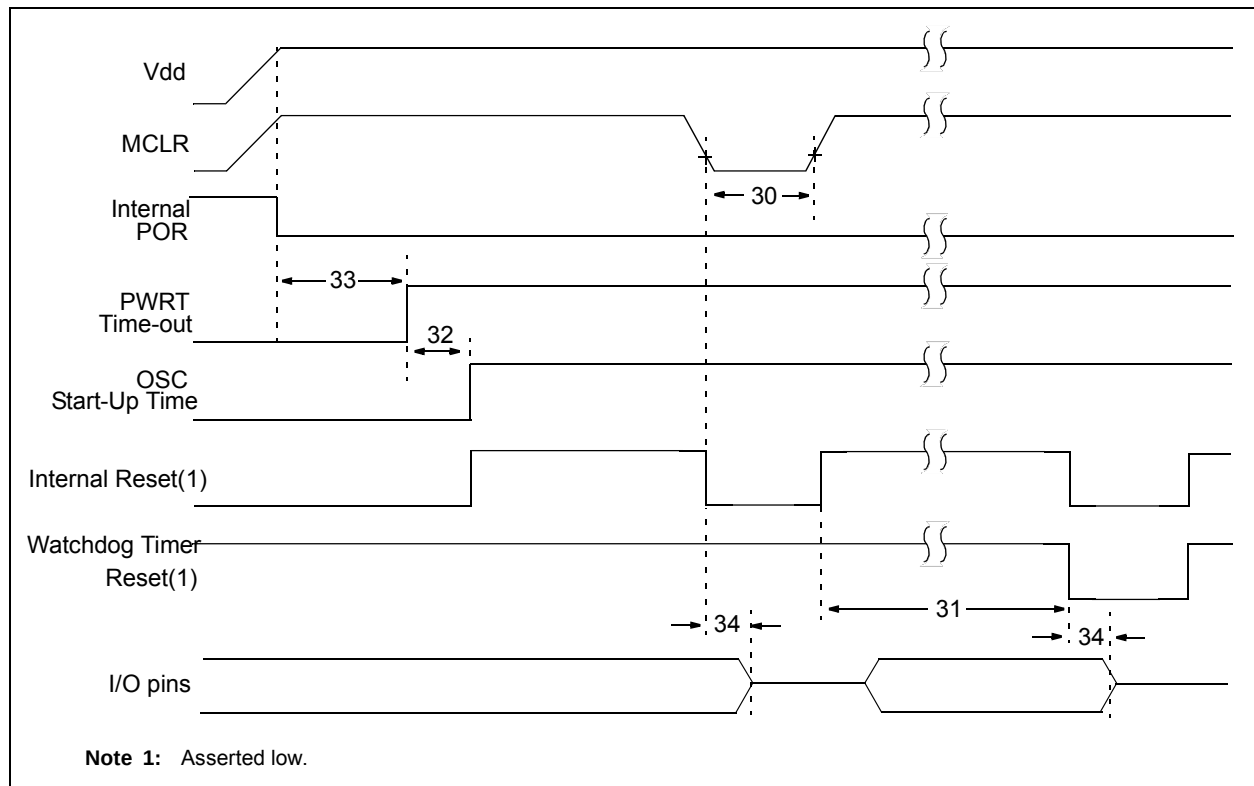
* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated.

Note 1: Measurements are taken in RC mode where CLKOUT output is 4 x Tosc.

2: Includes OSC2 in CLKOUT mode.

FIGURE 30-8: RESET, WATCHDOG TIMER, OSCILLATOR START-UP TIMER AND POWER-UP TIMER TIMING



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FIGURE 30-9: BROWN-OUT RESET TIMING AND CHARACTERISTICS

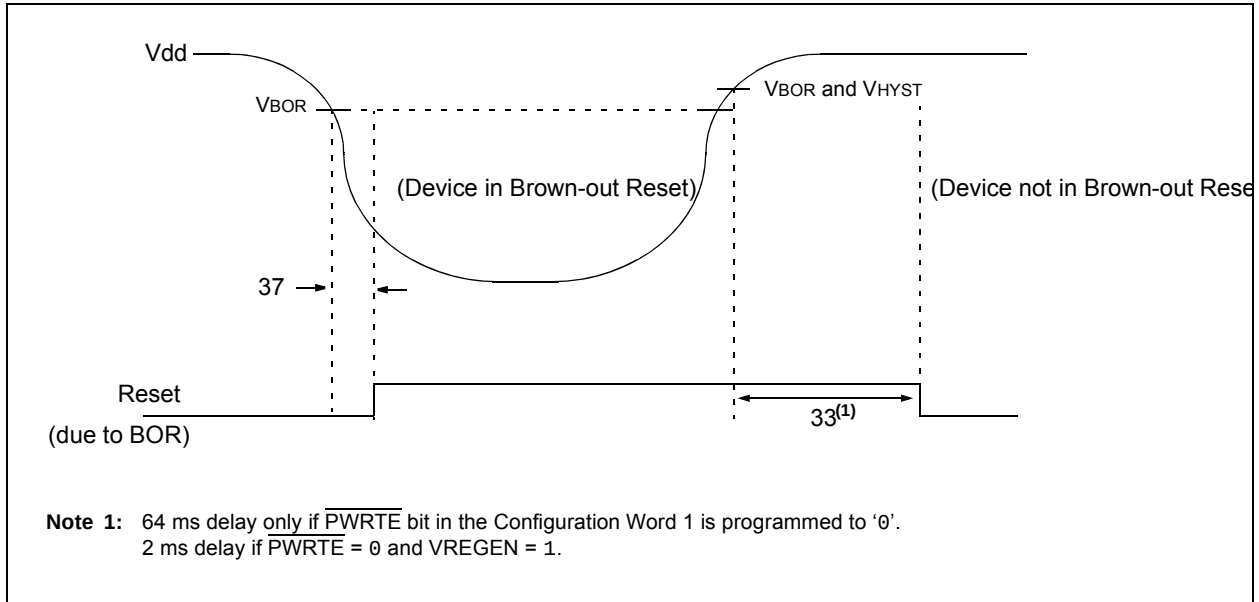


TABLE 30-5: RESET, WATCHDOG TIMER, OSCILLATOR START-UP TIMER, POWER-UP TIMER AND BROWN-OUT RESET PARAMETERS

Standard Operating Conditions (unless otherwise stated) Operating Temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$							
Param No.	Sym.	Characteristic	Min.	Typ†	Max.	Units	Conditions
30	TMCL	MCLR Pulse Width (low)	2	—	—	μs	
31	TWDTLP	Low-Power Watchdog Timer Time-out Period (No Prescaler)	10	16	27	ms	$V_{DD} = 3.3\text{V}-5\text{V}$ 1:16 Prescaler used
32	TOST	Oscillator Start-up Timer Period ^{(1), (2)}	—	1024	—	T_{osc}	(Note 3)
33*	TPWRT	Power-up Timer Period, $\overline{\text{PWRTE}} = 0$	40	65	140	ms	
34*	TIOZ	I/O high-impedance from MCLR Low or Watchdog Timer Reset	—	—	2.0	μs	
35	VBOR	Brown-out Reset Voltage	2.38 1.80	2.5 1.9	2.73 2.11	V	BORV=2.5V BORV=1.9V
36*	VHYST	Brown-out Reset Hysteresis	0	25	50	mV	-40°C to $+85^{\circ}\text{C}$
37*	TBORDC	Brown-out Reset DC Response Time	0	3	35	μs	$V_{DD} \leq V_{BOR}$

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

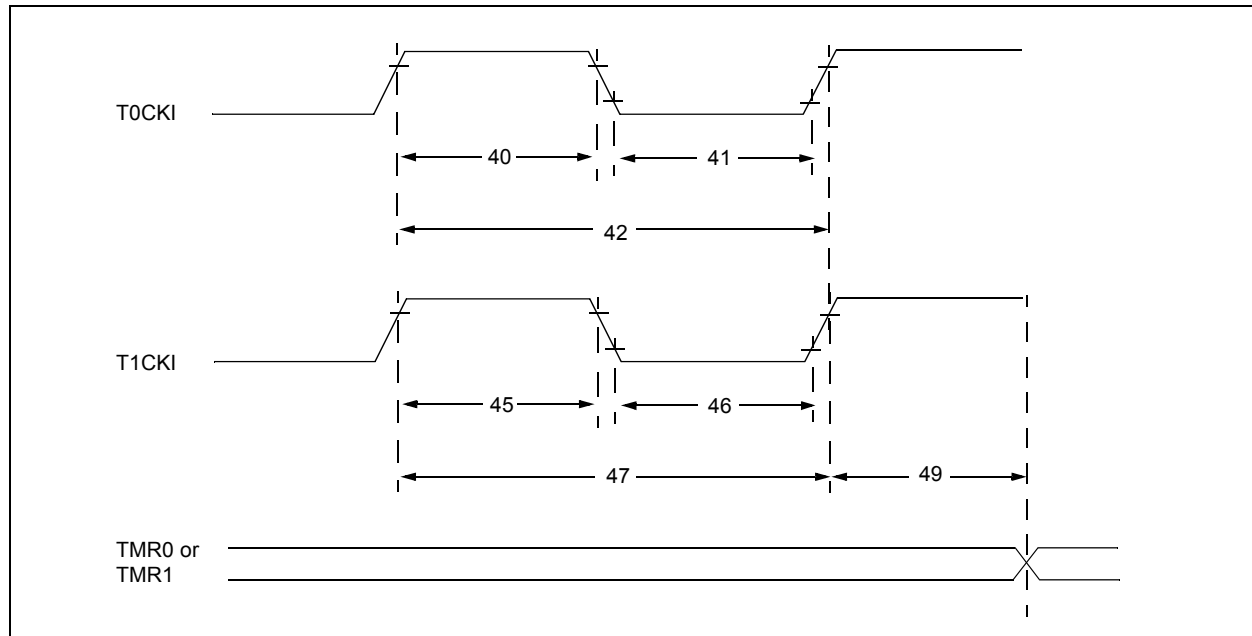
Note 1: Instruction cycle period (T_{CY}) equals four times the input oscillator time base period. All specified values are based on characterization data for that particular oscillator type under standard operating conditions with the device executing code. Exceeding these specified limits may result 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 pin. When an external clock input is used, the "max" cycle time limit is "DC" (no clock) for all devices.

2: By design.

3: Period of the slower clock.

4: To ensure these voltage tolerances, V_{DD} and V_{SS} must be capacitively decoupled as close to the device as possible. 0.1 μF and 0.01 μF values in parallel are recommended.

FIGURE 30-10: TIMER0 AND TIMER1 EXTERNAL CLOCK TIMINGS



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TABLE 30-6: TIMER0 AND TIMER1 EXTERNAL CLOCK REQUIREMENTS

Standard Operating Conditions (unless otherwise stated)								
Operating Temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$								
Param No.	Sym.	Characteristic		Min.	Typ†	Max.	Units	Conditions
40*	Tt0H	T0CKI High Pulse Width	No Prescaler	$0.5 T_{CY} + 20$	—	—	ns	
			With Prescaler	10	—	—	ns	
41*	Tt0L	T0CKI Low Pulse Width	No Prescaler	$0.5 T_{CY} + 20$	—	—	ns	
			With Prescaler	10	—	—	ns	
42*	Tt0P	T0CKI Period		Greater of: 20 or $\frac{T_{CY} + 40}{N}$	—	—	ns	N = prescale value (2, 4, ..., 256)
45*	Tt1H	T1CKI High Time	Synchronous, No Prescaler	$0.5 T_{CY} + 20$	—	—	ns	
			Synchronous, with Prescaler	15	—	—	ns	
			Asynchronous	30	—	—	ns	
46*	Tt1L	T1CKI Low Time	Synchronous, No Prescaler	$0.5 T_{CY} + 20$	—	—	ns	
			Synchronous, with Prescaler	15	—	—	ns	
			Asynchronous	30	—	—	ns	
47*	Tt1P	T1CKI Input Period	Synchronous	Greater of: 30 or $\frac{T_{CY} + 40}{N}$	—	—	ns	
			Asynchronous	60	—	—	ns	
48	Ft1	Timer1 Oscillator Input Frequency Range (oscillator enabled by setting bit T1OSCEN)		32.4	32.768	33.1	kHz	
49*	TCKEZ _{TMR1}	Delay from External Clock Edge to Timer Increment		2 TOSC	—	7 TOSC	—	Timers in Sync mode

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

FIGURE 30-11: CAPTURE/COMPARE/PWM TIMINGS (CCP)

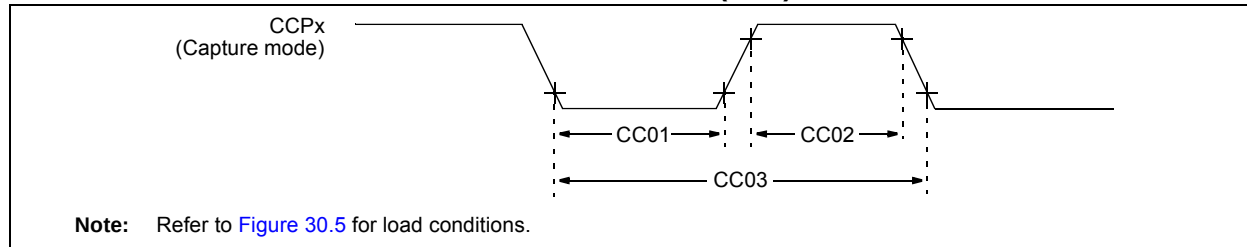


TABLE 30-7: CAPTURE/COMPARE/PWM REQUIREMENTS (CCP)

Standard Operating Conditions (unless otherwise stated) Operating Temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$							
Param No.	Sym.	Characteristic		Min.	Typ†	Max.	Units
CC01*	TccL	CCPx Input Low Time	No Prescaler	$0.5 T_{CY} + 20$	—	—	ns
			With Prescaler	20	—	—	ns
CC02*	TccH	CCPx Input High Time	No Prescaler	$0.5 T_{CY} + 20$	—	—	ns
			With Prescaler	20	—	—	ns
CC03*	TccP	CCPx Input Period		$\frac{3 T_{CY} + 40}{N}$	—	—	ns
N = prescale value (1, 4 or 16)							

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

TABLE 30-8: PIC16(L)F1826/27 A/D CONVERTER (ADC) CHARACTERISTICS:

Standard Operating Conditions (unless otherwise stated)							
Operating temperature Tested at +25°C							
Param No.	Sym.	Characteristic	Min.	Typ†	Max.	Units	Conditions
AD01	NR	Resolution	—	—	10	bit	
AD02	EIL	Integral Error	—	—	±1.7	LSb	VREF = 3.0V
AD03	EDL	Differential Error	—	—	±1	LSb	No missing codes VREF = 3.0V
AD04	EOFF	Offset Error	—	—	±2.5	LSb	VREF = 3.0V
AD05	EGN	Gain Error	—	—	±2.0	LSb	VREF = 3.0V
AD06	VREF	Reference Voltage ⁽³⁾	—	—	VDD	V	VREF = (VREF+ minus VREF-) (NOTE 5)
AD07	VAIN	Full-Scale Range	—	—	VREF	V	
AD08	ZAIN	Recommended Impedance of Analog Voltage Source	—	—	10	kΩ	Can go higher if external 0.01μF capacitor is present on input pin.

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

Note 1: Total Absolute Error includes integral, differential, offset and gain errors.

2: The A/D conversion result never decreases with an increase in the input voltage and has no missing codes.

3: ADC VREF is from external VREF, VDD pin or FVR, whichever is selected as reference input.

4: When ADC is off, it will not consume any current other than leakage current. The power-down current specification includes any such leakage from the ADC module.

5: FVR voltage selected must be 2.048V or 4.096V.

TABLE 30-9: PIC16(L)F1826/27 A/D CONVERSION REQUIREMENTS

Standard Operating Conditions (unless otherwise stated)							
Operating temperature -40°C ≤ TA ≤ +125°C							
Param No.	Sym.	Characteristic	Min.	Typ†	Max.	Units	Conditions
AD130*	TAD	A/D Clock Period	1.0	—	9.0	μs	TOSC-based
		A/D Internal RC Oscillator Period	1.0	2.5	6.0	μs	ADCS<1:0> = 11 (ADRC mode)
AD131	TCNV	Conversion Time (not including Acquisition Time) ⁽¹⁾	—	11	—	TAD	Set GO/DONE bit to conversion complete
AD132*	TACQ	Acquisition Time	—	5.0	—	μs	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

Note 1: The ADRES register may be read on the following Tcy cycle.

PIC16(L)F1826/27

FIGURE 30-12: PIC16(L)F1826/27 A/D CONVERSION TIMING (NORMAL MODE)

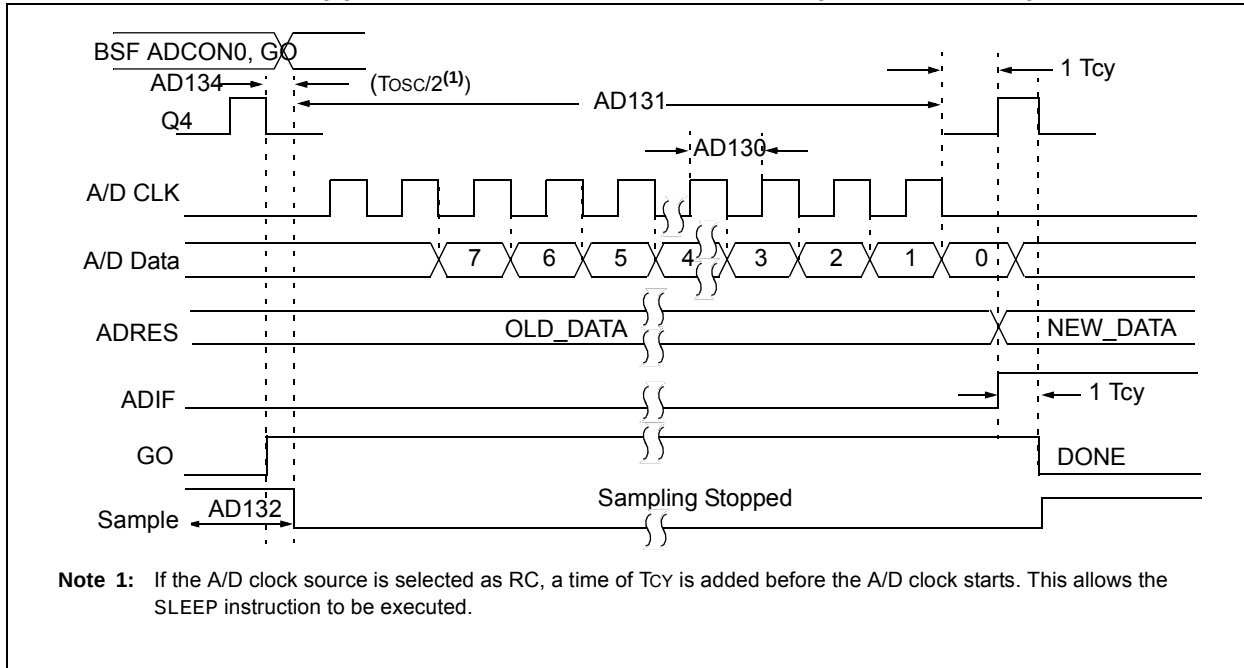


FIGURE 30-13: PIC16(L)F1826/27 A/D CONVERSION TIMING (SLEEP MODE)

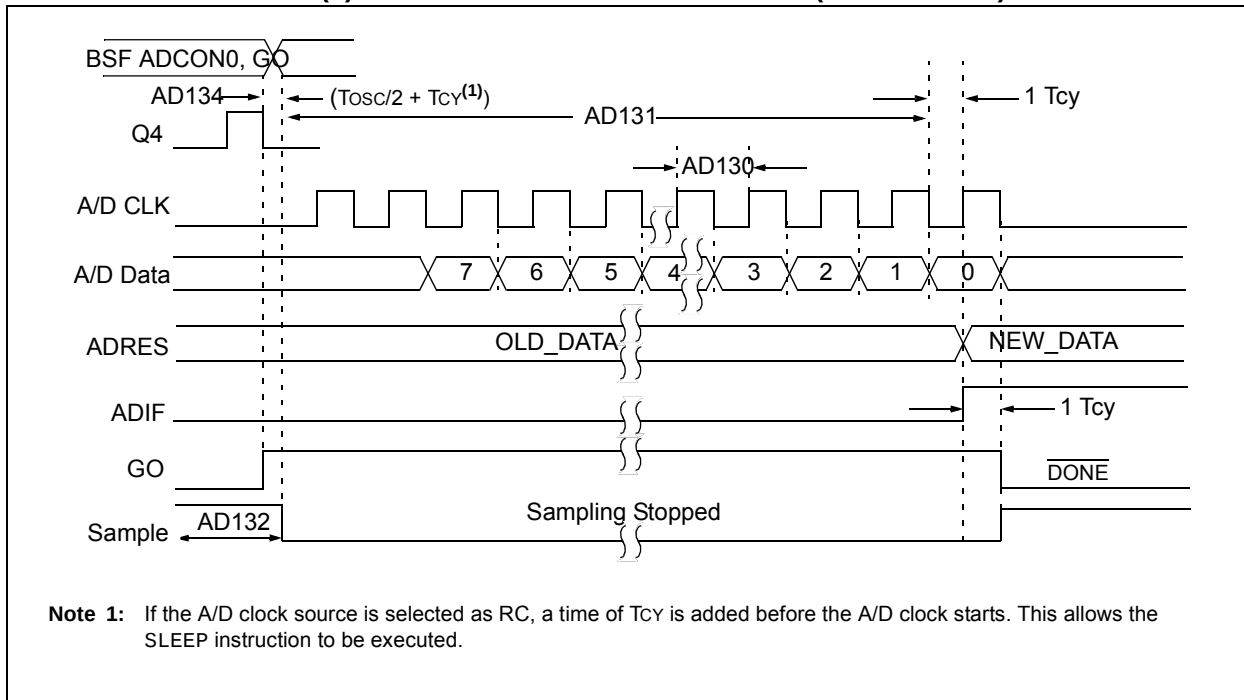


TABLE 30-10: COMPARATOR SPECIFICATIONS

Operating Conditions: 1.8V < VDD < 5.5V, -40°C < TA < +125°C (unless otherwise stated).							
Param No.	Sym.	Characteristics	Min.	Typ.	Max.	Units	Comments
CM01	Vioff	Input Offset Voltage	—	±7.5	±60	mV	High Power Mode
CM02	Vicm	Input Common Mode Voltage	0	—	VDD	V	
CM03*	CMRR	Common Mode Rejection Ratio	—	50	—	dB	
CM04A	Tresp	Response Time Rising Edge	—	400	800	ns	High Power Mode
CM04B		Response Time Falling Edge	—	200	400	ns	High Power Mode
CM04C		Response Time Rising Edge	—	1200	—	ns	Low Power Mode
CM04D		Response Time Falling Edge	—	550	—	ns	
CM05*	Tmc2ov	Comparator Mode Change to Output Valid	—	—	10	µs	
CM06	Chyster	Comparator Hysteresis	—	65	—	mV	Hysteresis ON

* These parameters are characterized but not tested.

TABLE 30-11: DIGITAL-TO-ANALOG CONVERTER (DAC) SPECIFICATIONS

Operating Conditions: 1.8V < VDD < 5.5V, -40°C < TA < +125°C (unless otherwise stated).							
Param No.	Sym.	Characteristics	Min.	Typ.	Max.	Units	Comments
DAC01*	CLSB	Step Size	—	VDD/32	—	V	
DAC02*	CACC	Absolute Accuracy	—	—	± 1/2	LSb	
DAC03*	CR	Unit Resistor Value (R)	—	5000	—	Ω	
DAC04*	CST	Settling Time ⁽¹⁾	—	—	10	µs	

* These parameters are characterized but not tested.

Note 1: Settling time measured while DACR<4:0> transitions from '0000' to '1111'.

PIC16(L)F1826/27

FIGURE 30-14: USART SYNCHRONOUS TRANSMISSION (MASTER/SLAVE) TIMING

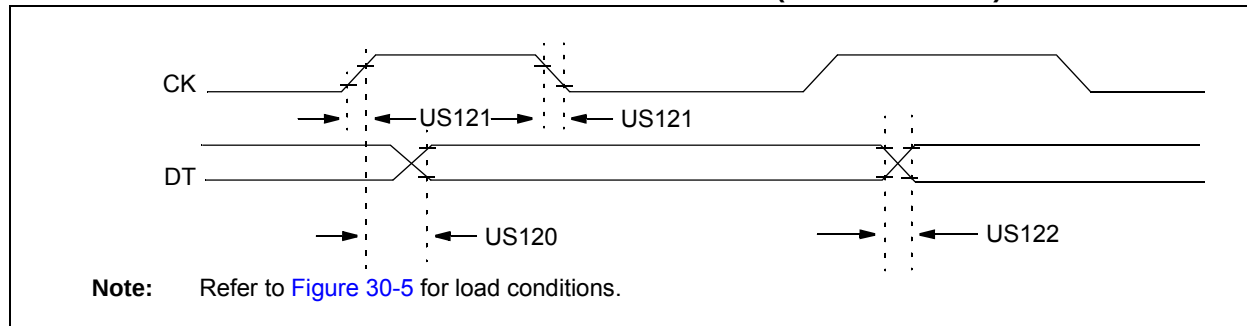


TABLE 30-12: USART SYNCHRONOUS TRANSMISSION REQUIREMENTS

Standard Operating Conditions (unless otherwise stated)							
Operating Temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$							
Param. No.	Symbol	Characteristic		Min.	Max.	Units	Conditions
US120	TCKH2DTV	SYNC XMIT (Master and Slave) Clock high to data-out valid	3.0-5.5V	—	80	ns	
			1.8-5.5V	—	100	ns	
US121	TCKRF	Clock out rise time and fall time (Master mode)	3.0-5.5V	—	45	ns	
			1.8-5.5V	—	50	ns	
US122	TDTRF	Data-out rise time and fall time	3.0-5.5V	—	45	ns	
			1.8-5.5V	—	50	ns	

FIGURE 30-15: USART SYNCHRONOUS RECEIVE (MASTER/SLAVE) TIMING

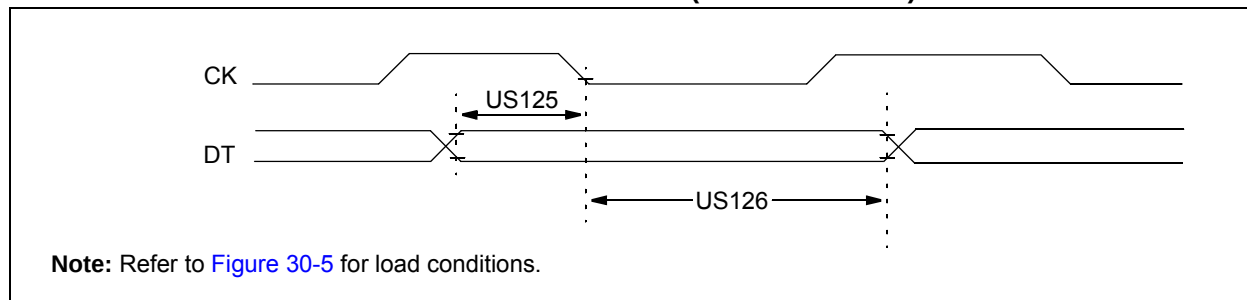


TABLE 30-13: USART SYNCHRONOUS RECEIVE REQUIREMENTS

Standard Operating Conditions (unless otherwise stated)						
Operating Temperature $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$						
Param. No.	Symbol	Characteristic	Min.	Max.	Units	Conditions
US125	TDTV2CKL	SYNC RCV (Master and Slave) Data-hold before CK $\downarrow$ (DT hold time)	10	—	ns	
US126	TCKL2DTL	Data-hold after CK $\downarrow$ (DT hold time)	15	—	ns	

FIGURE 30-16: SPI MASTER MODE TIMING (CKE = 0, SMP = 0)

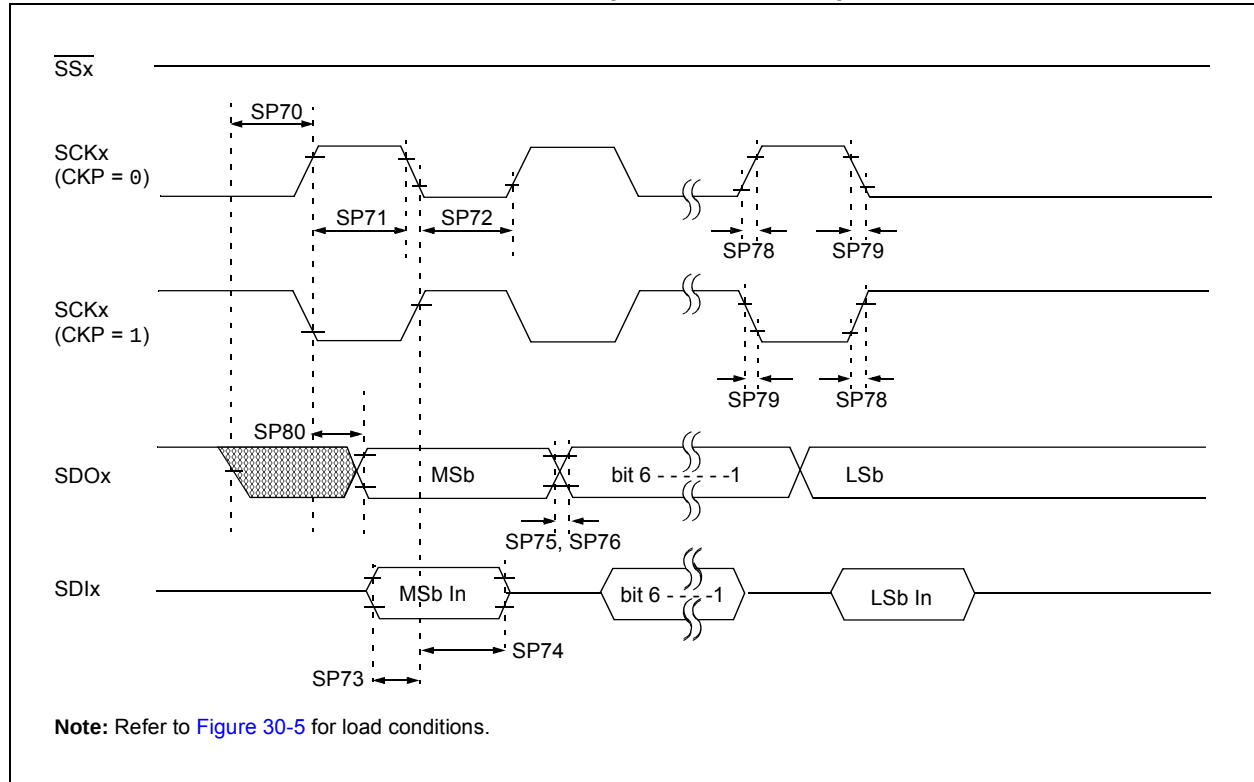
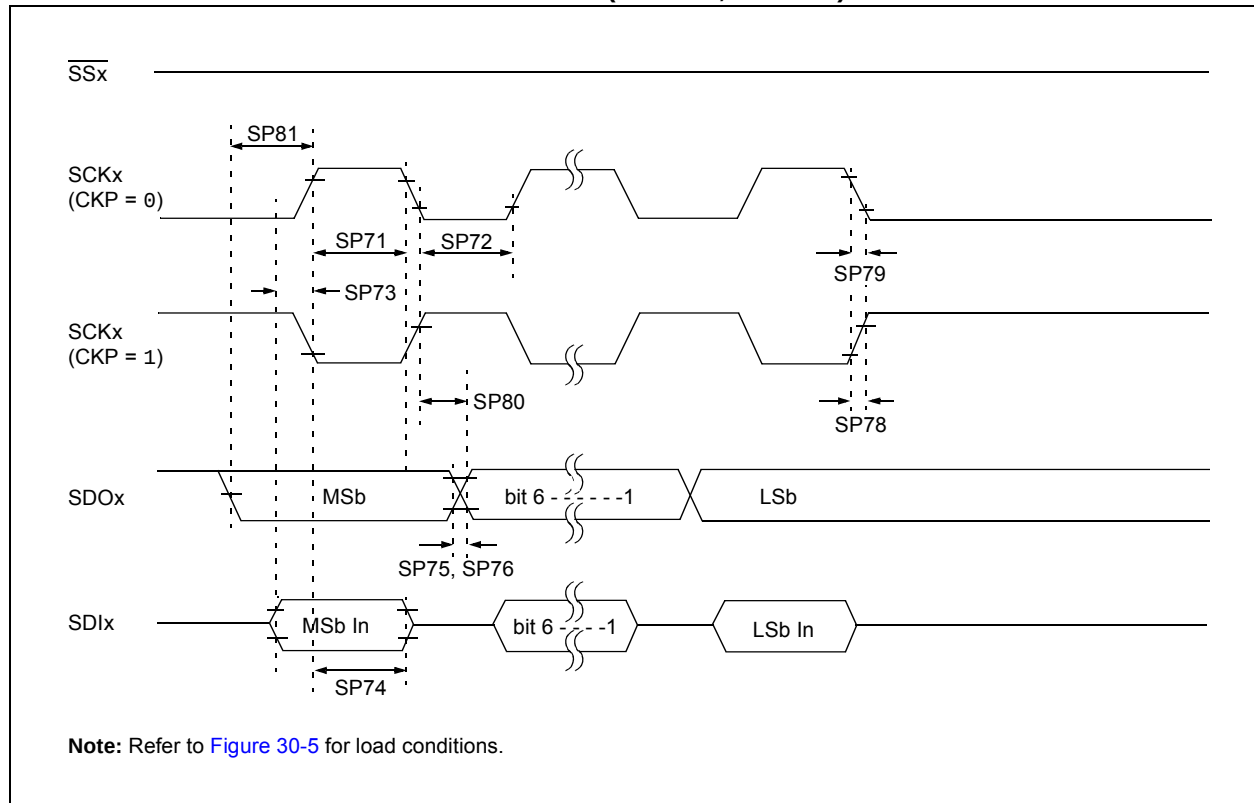


FIGURE 30-17: SPI MASTER MODE TIMING (CKE = 1, SMP = 1)



PIC16(L)F1826/27

FIGURE 30-18: SPI SLAVE MODE TIMING (CKE = 0)

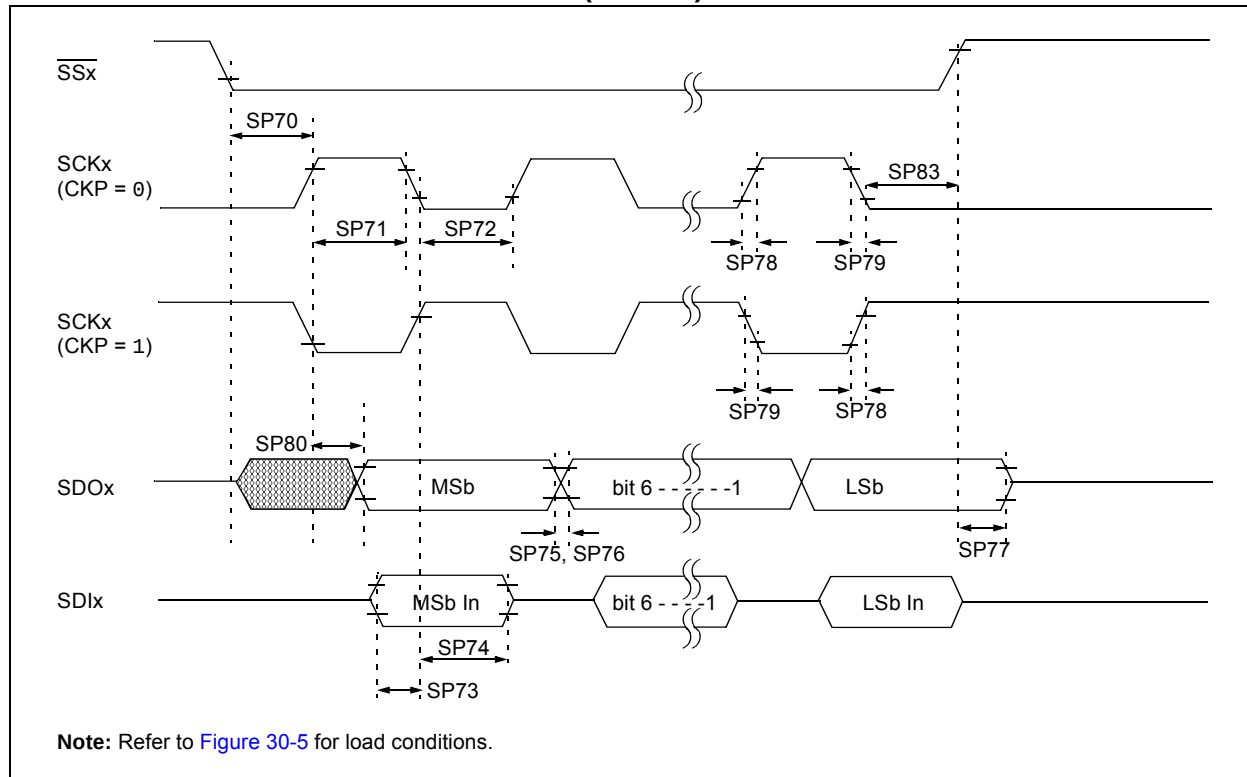


FIGURE 30-19: SPI SLAVE MODE TIMING (CKE = 1)

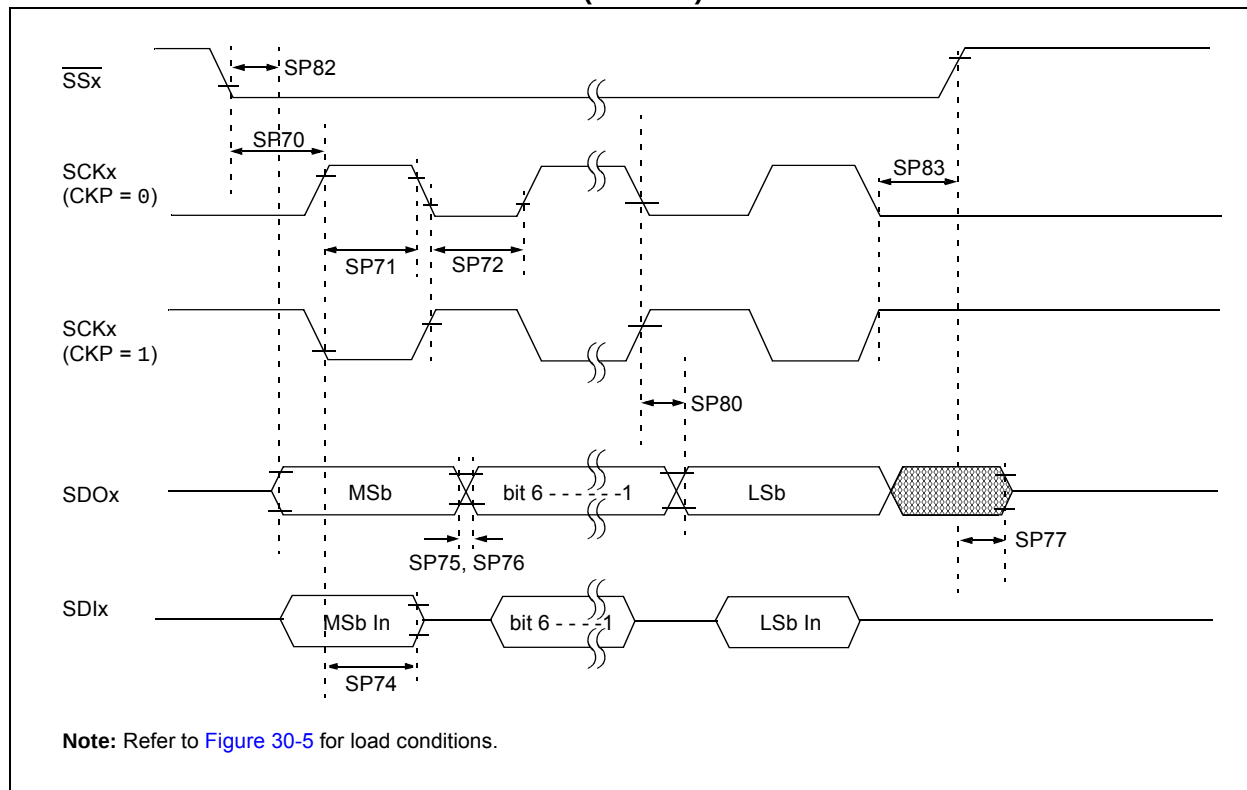


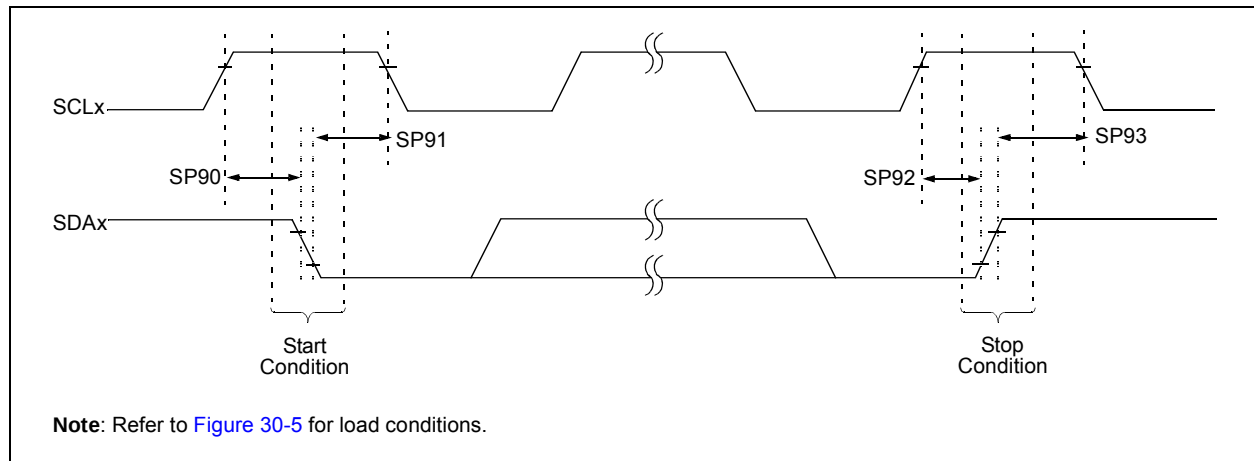
TABLE 30-14: SPI MODE REQUIREMENTS

Param No.	Symbol	Characteristic	Min.	Typ†	Max.	Units	Conditions
SP70*	TssL2sch, TssL2scL	$\overline{SSx}\downarrow$ to SCKx $\downarrow$ or SCKx $\uparrow$ input	Tcy	—	—	ns	
SP71*	Tsch	SCKx input high time (Slave mode)	Tcy + 20	—	—	ns	
SP72*	TscL	SCKx input low time (Slave mode)	Tcy + 20	—	—	ns	
SP73*	TdIV2sch, TdIV2scL	Setup time of SDIx data input to SCKx edge	100	—	—	ns	
SP74*	Tsch2dIL, TscL2dIL	Hold time of SDIx data input to SCKx edge	100	—	—	ns	
SP75*	TdoR	SDO data output rise time	3.0-5.5V	—	10	25	ns
			1.8-5.5V	—	25	50	ns
SP76*	TdoF	SDOx data output fall time	—	10	25	ns	
SP77*	TssH2doZ	$\overline{SSx}\uparrow$ to SDOx output high-impedance	10	—	50	ns	
SP78*	Tscr	SCKx output rise time (Master mode)	3.0-5.5V	—	10	25	ns
			1.8-5.5V	—	25	50	ns
SP79*	TscF	SCKx output fall time (Master mode)	—	10	25	ns	
SP80*	Tsch2doV, TscL2doV	SDOx data output valid after SCKx edge	3.0-5.5V	—	—	50	ns
			1.8-5.5V	—	—	145	ns
SP81*	TdoV2sch, TdoV2scL	SDOx data output setup to SCKx edge	Tcy	—	—	ns	
SP82*	TssL2doV	SDOx data output valid after $\overline{SS}\downarrow$ edge	—	—	50	ns	
SP83*	Tsch2ssH, TscL2ssH	$\overline{SSx}\uparrow$ after SCKx edge	1.5Tcy + 40	—	—	ns	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

FIGURE 30-20: I²C™ BUS START/STOP BITS TIMING



PIC16(L)F1826/27

FIGURE 30-21: I²C™ BUS DATA TIMING

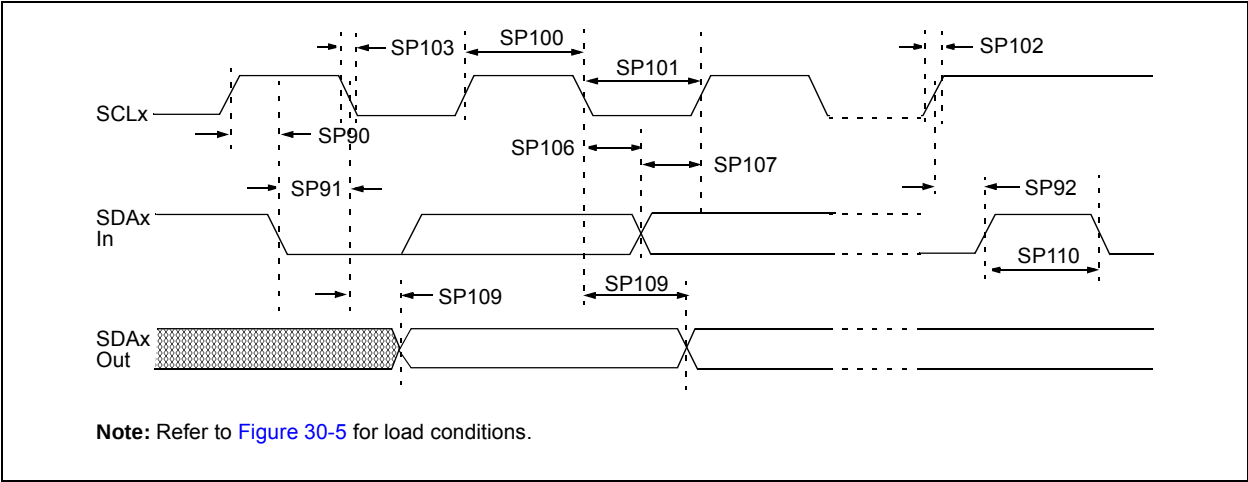


TABLE 30-15: I²C™ BUS START/STOP BITS REQUIREMENTS

Param No.	Symbol	Characteristic		Min.	Typ	Max.	Units	Conditions
SP90*	TSU:STA	Start condition	100 kHz mode	4700	—	—	ns	Only relevant for Repeated Start condition
		Setup time	400 kHz mode	600	—	—		
SP91*	THD:STA	Start condition	100 kHz mode	4000	—	—	ns	After this period, the first clock pulse is generated
		Hold time	400 kHz mode	600	—	—		
SP92*	TSU:STO	Stop condition	100 kHz mode	4700	—	—	ns	
		Setup time	400 kHz mode	600	—	—		
SP93	THD:STO	Stop condition	100 kHz mode	4000	—	—	ns	
		Hold time	400 kHz mode	600	—	—		

* These parameters are characterized but not tested.

TABLE 30-16: I²C™ BUS DATA REQUIREMENTS

Param. No.	Symbol	Characteristic		Min.	Max.	Units	Conditions
SP100*	THIGH	Clock high time	100 kHz mode	4.0	—	μs	Device must operate at a minimum of 1.5 MHz
			400 kHz mode	0.6	—	μs	Device must operate at a minimum of 10 MHz
			SSPx module	1.5Tcy	—	—	
SP101*	TLOW	Clock low time	100 kHz mode	4.7	—	μs	Device must operate at a minimum of 1.5 MHz
			400 kHz mode	1.3	—	μs	Device must operate at a minimum of 10 MHz
			SSPx module	1.5Tcy	—	—	
SP102*	TR	SDAx and SCLx rise time	100 kHz mode	—	1000	ns	
			400 kHz mode	20 + 0.1CB	300	ns	CB is specified to be from 10-400 pF
SP103*	TF	SDAx and SCLx fall time	100 kHz mode	—	250	ns	
			400 kHz mode	20 + 0.1CB	250	ns	CB is specified to be from 10-400 pF
SP106*	THD:DAT	Data input hold time	100 kHz mode	0	—	ns	
			400 kHz mode	0	0.9	μs	
SP107*	TSU:DAT	Data input setup time	100 kHz mode	250	—	ns	(Note 2)
			400 kHz mode	100	—	ns	
SP109*	TAA	Output valid from clock	100 kHz mode	—	3500	ns	(Note 1)
			400 kHz mode	—	—	ns	
SP110*	TBUF	Bus free time	100 kHz mode	4.7	—	μs	Time the bus must be free before a new transmission can start
			400 kHz mode	1.3	—	μs	
SP111	CB	Bus capacitive loading		—	400	pF	

* These parameters are characterized but not tested.

- Note 1:** As a transmitter, the device must provide this internal minimum delay time to bridge the undefined region (min. 300 ns) of the falling edge of SCLx to avoid unintended generation of Start or Stop conditions.
- 2:** A Fast mode (400 kHz) I²C™ bus device can be used in a Standard mode (100 kHz) I²C bus system, but the requirement TSU:DAT ≥ 250 ns must then be met. This will automatically be the case if the device does not stretch the low period of the SCLx signal. If such a device does stretch the low period of the SCLx signal, it must output the next data bit to the SDAx line TR max. + TSU:DAT = 1000 + 250 = 1250 ns (according to the Standard mode I²C bus specification), before the SCLx line is released.

PIC16(L)F1826/27

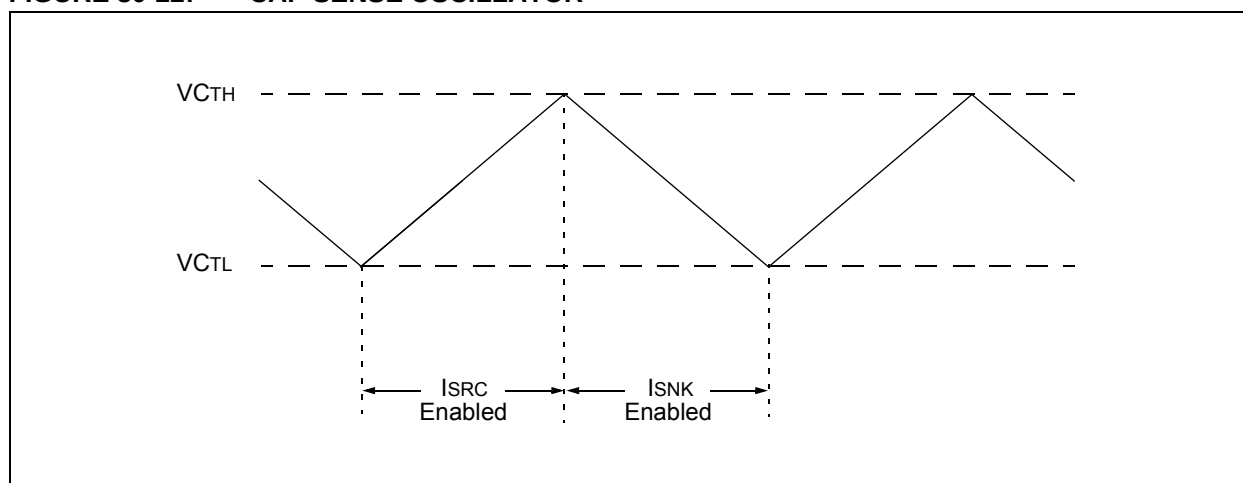
TABLE 30-17: CAP SENSE OSCILLATOR SPECIFICATIONS

Param. No.	Symbol	Characteristic		Min.	Typ†	Max.	Units	Conditions
CS01	ISRC	Current Source	High	-3	-8	-15	μA	
			Medium	-0.8	-1.5	-3	μA	
			Low	-0.1	-0.3	-0.4	μA	
CS02	ISNK	Current Sink	High	2.5	7.5	14	μA	
			Medium	0.6	1.5	2.9	μA	
			Low	0.1	0.25	0.6	μA	
CS03	VCTH	Cap Threshold		—	0.8	—	mV	
CS04	VCTL	Cap Threshold		—	0.4	—	mV	
CS05	VCHYST	CAP HYSTERESIS (VCTH - VCTL)	High	350	525	725	mV	
			Medium	250	375	500	mV	
			Low	175	300	425	mV	

* These parameters are characterized but not tested.

† Data in "Typ" column is at 3.0V, 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

FIGURE 30-22: CAP SENSE OSCILLATOR



31.0 DC AND AC CHARACTERISTICS GRAPHS AND CHARTS

The graphs and tables provided in this section are for **design guidance** and are **not tested**.

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

Note: The graphs and tables provided following this note are a statistical summary based on a limited number of samples and are provided for informational purposes only. The performance characteristics listed herein are not tested or guaranteed. In some graphs or tables, the data presented may be outside the specified operating range (e.g., outside specified power supply range) and therefore, outside the warranted range.

“Typical” represents the mean of the distribution at 25°C. “Maximum” or “minimum” represents (mean + 3 σ) or (mean - 3 σ) respectively, where σ is a standard deviation, over each temperature range.

FIGURE 31-1: V_{OH} VS. I_{OH} OVER TEMPERATURE ($V_{DD} = 5.0V$)

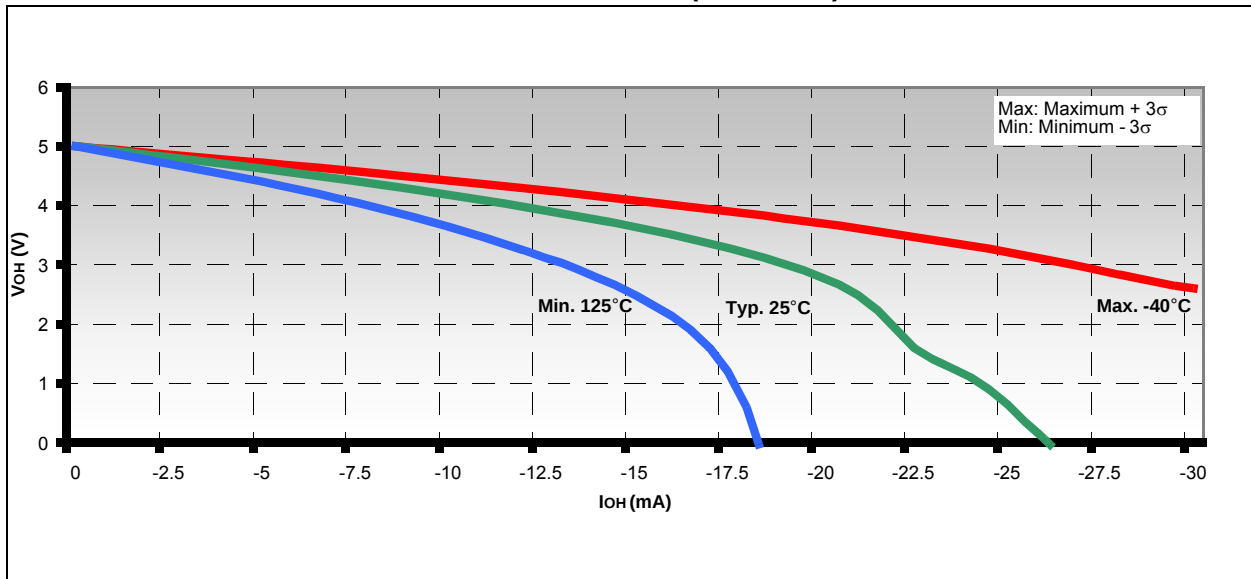
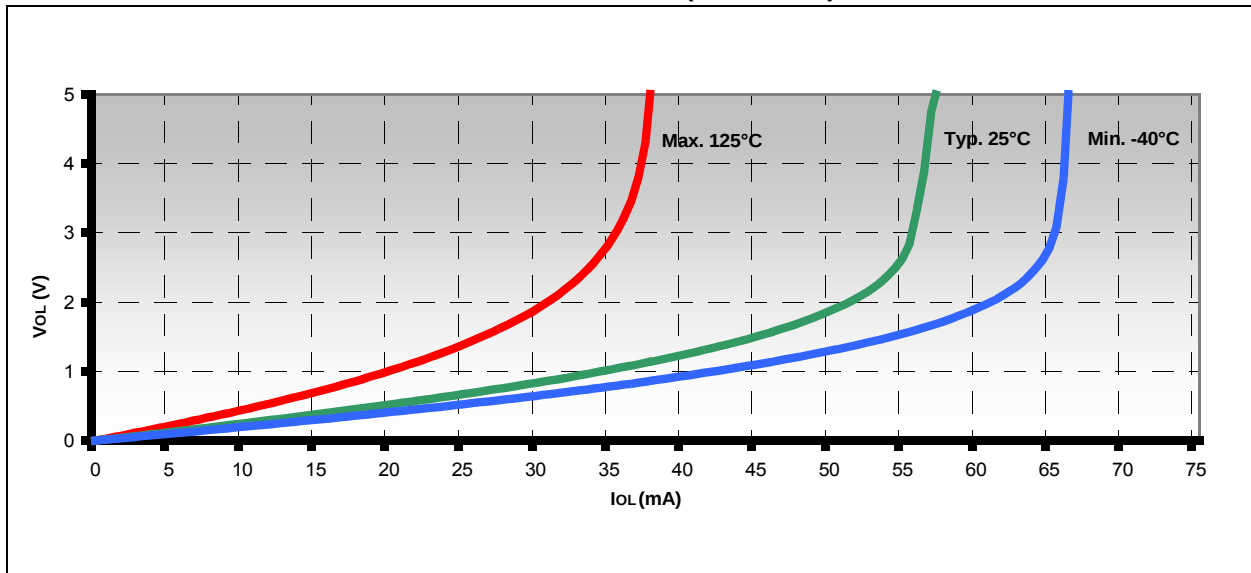


FIGURE 31-2: V_{OL} VS. I_{OL} OVER TEMPERATURE ($V_{DD} = 5.0V$)



PIC16(L)F1826/27

FIGURE 31-3: V_{OH} VS. I_{OH} OVER TEMPERATURE ($V_{DD} = 3.0V$)

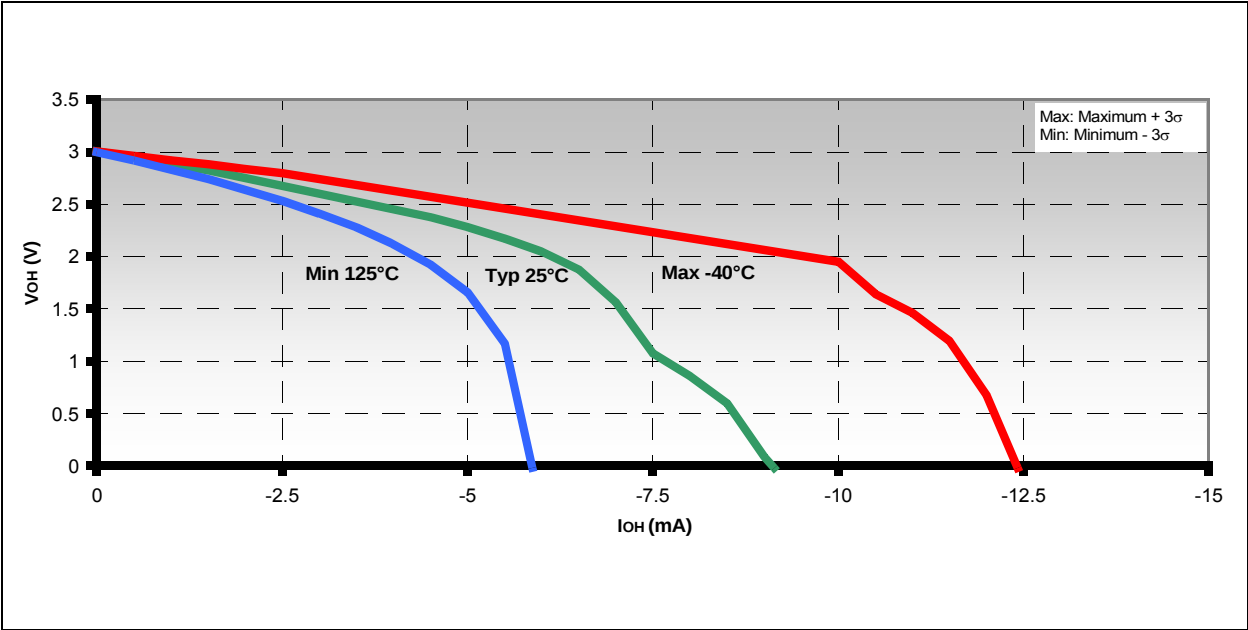


FIGURE 31-4: V_{OL} VS. I_{OL} OVER TEMPERATURE ($V_{DD} = 3.0V$)

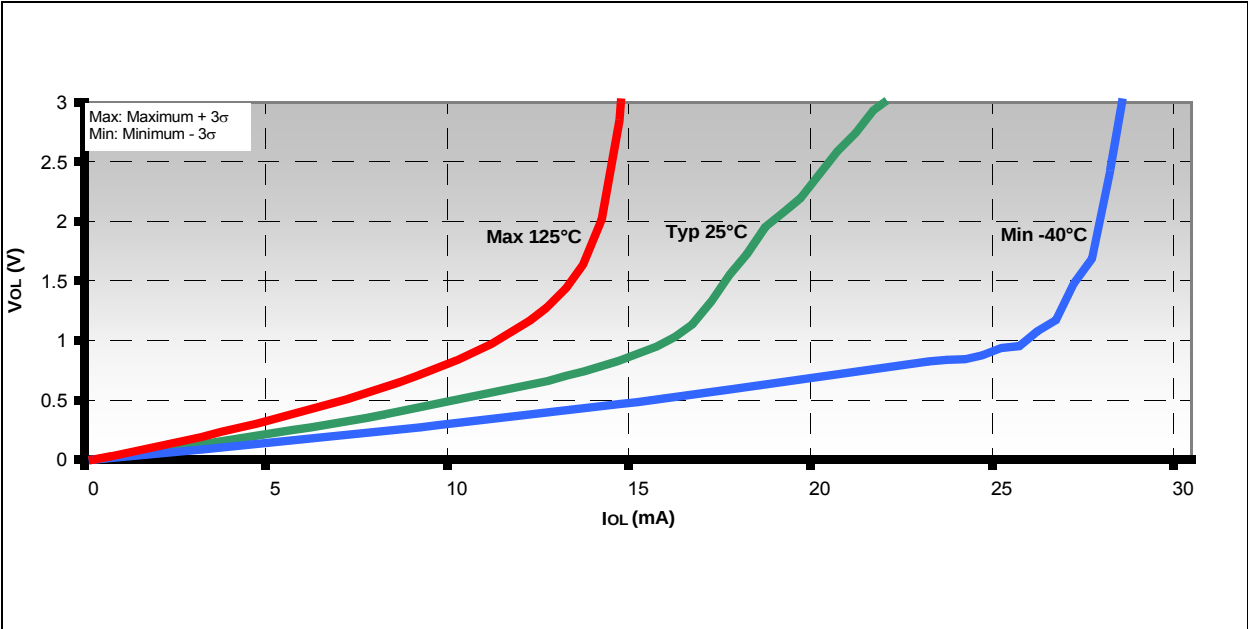


FIGURE 31-5: V_{OH} VS. I_{OH} OVER TEMPERATURE ($V_{DD} = 1.8V$)

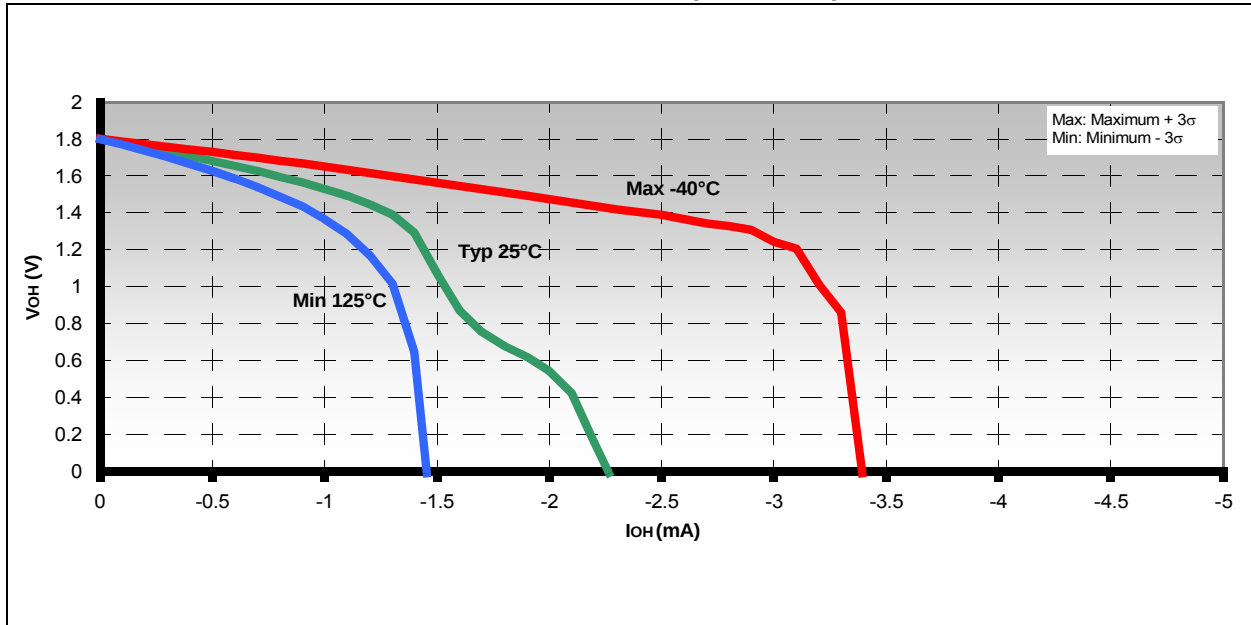
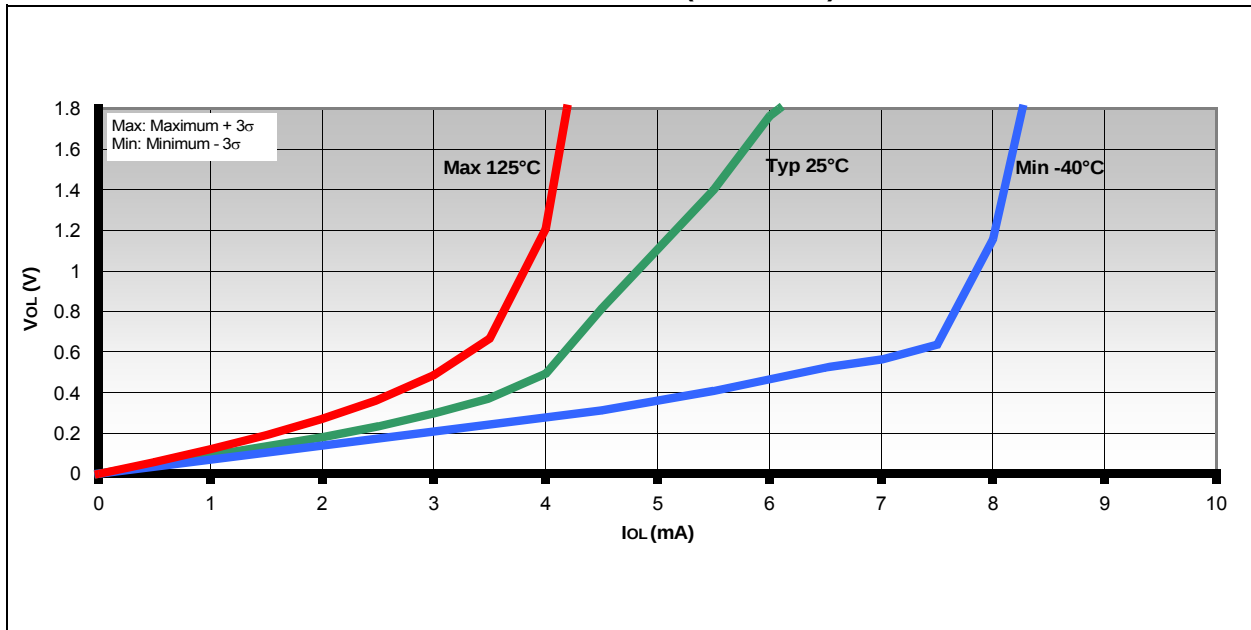


FIGURE 31-6: V_{OL} VS. I_{OL} OVER TEMPERATURE ($V_{DD} = 1.8V$)



PIC16(L)F1826/27

FIGURE 31-7: PIC16(L)F1826/27 RESET VOLTAGE (BOR = 1.9V)

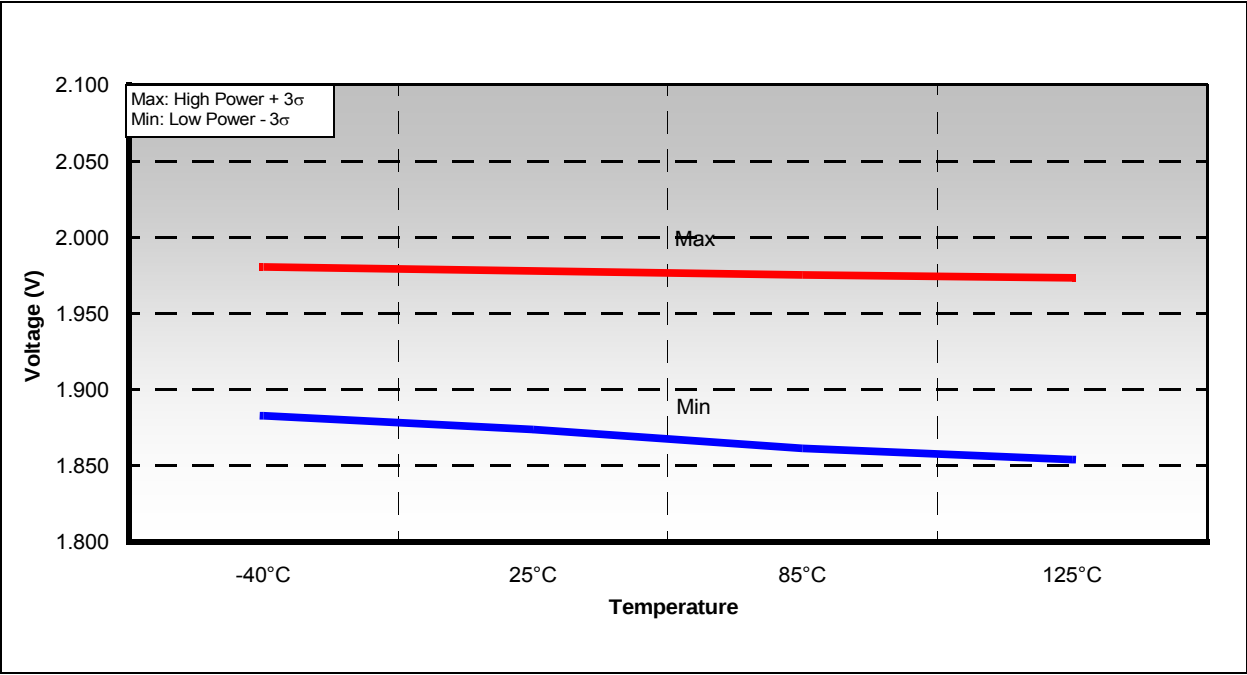


FIGURE 31-8: PIC16(L)F1826/27 RESET VOLTAGE (BOR = 1.9V)

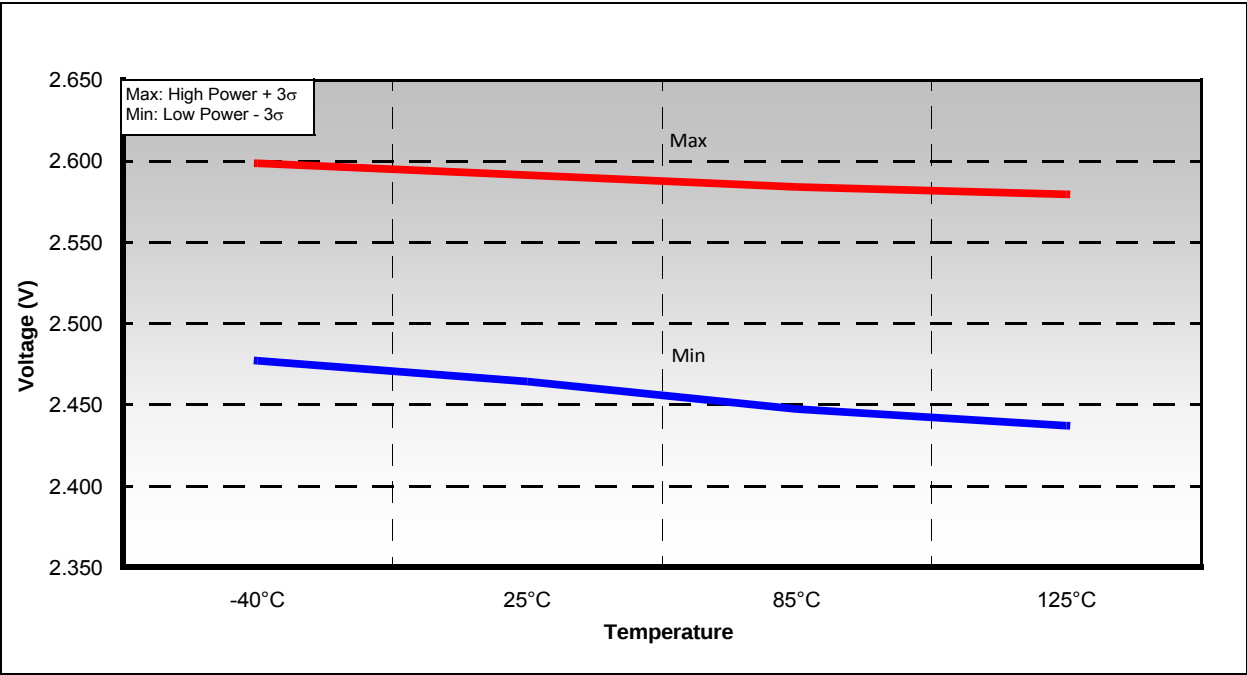


FIGURE 31-9: PIC16(L)F1826/27 POR RELEASE

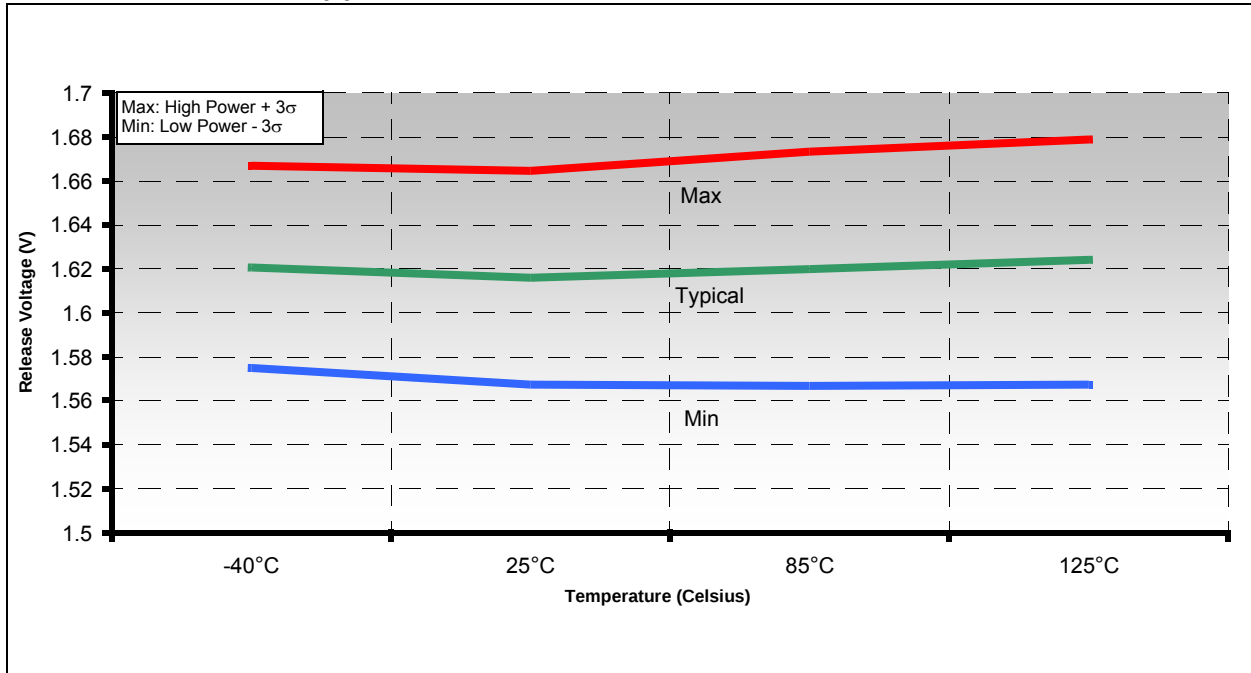
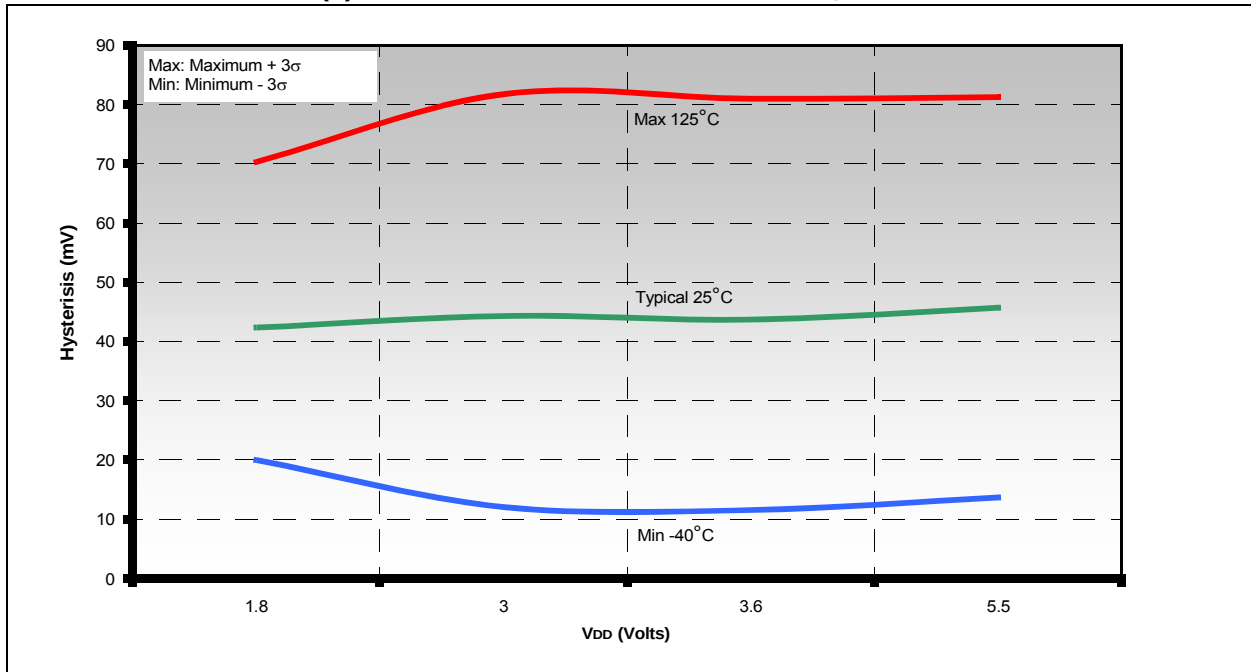


FIGURE 31-10: PIC16(L)F1826/27 COMPARATOR HYSTERESIS, HIGH-POWER MODE



PIC16(L)F1826/27

FIGURE 31-11: PIC16(L)F1826/27 COMPARATOR HYSTERESIS, LOW-POWER MODE

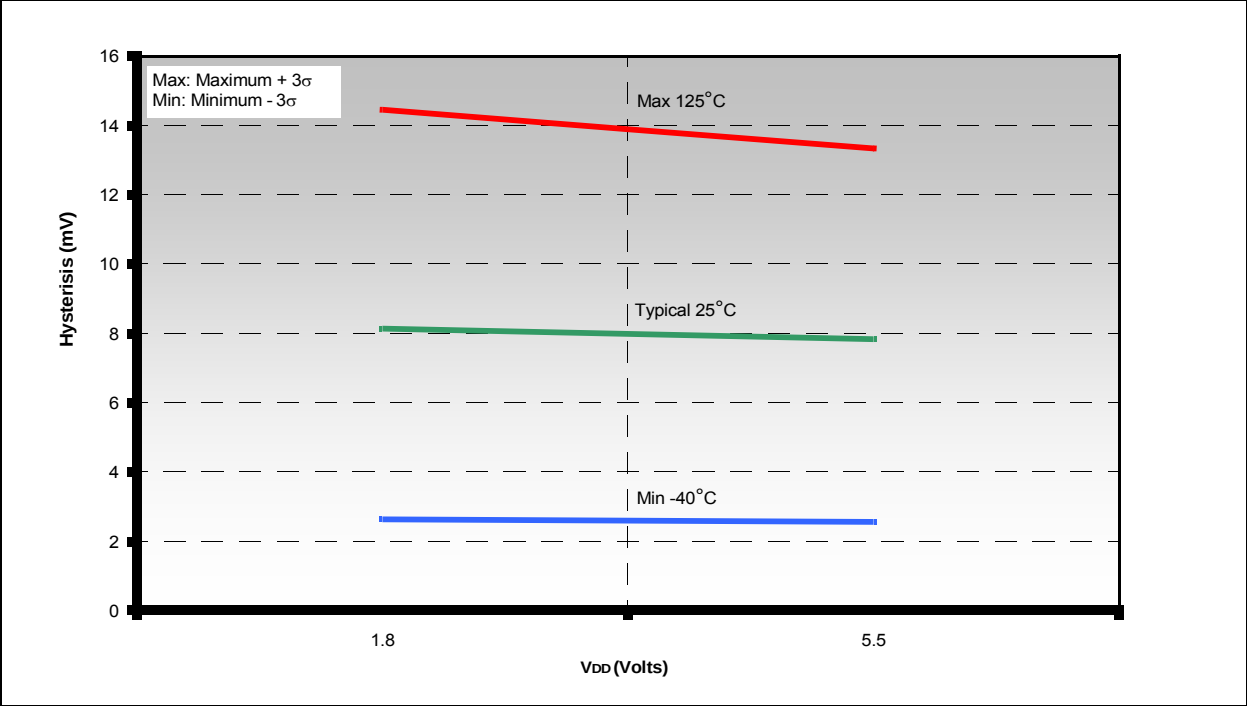


FIGURE 31-12: PIC16(L)F1826/27 COMPARATOR OFFSET, HIGH-POWER MODE (V_{DD} = 5.5V)

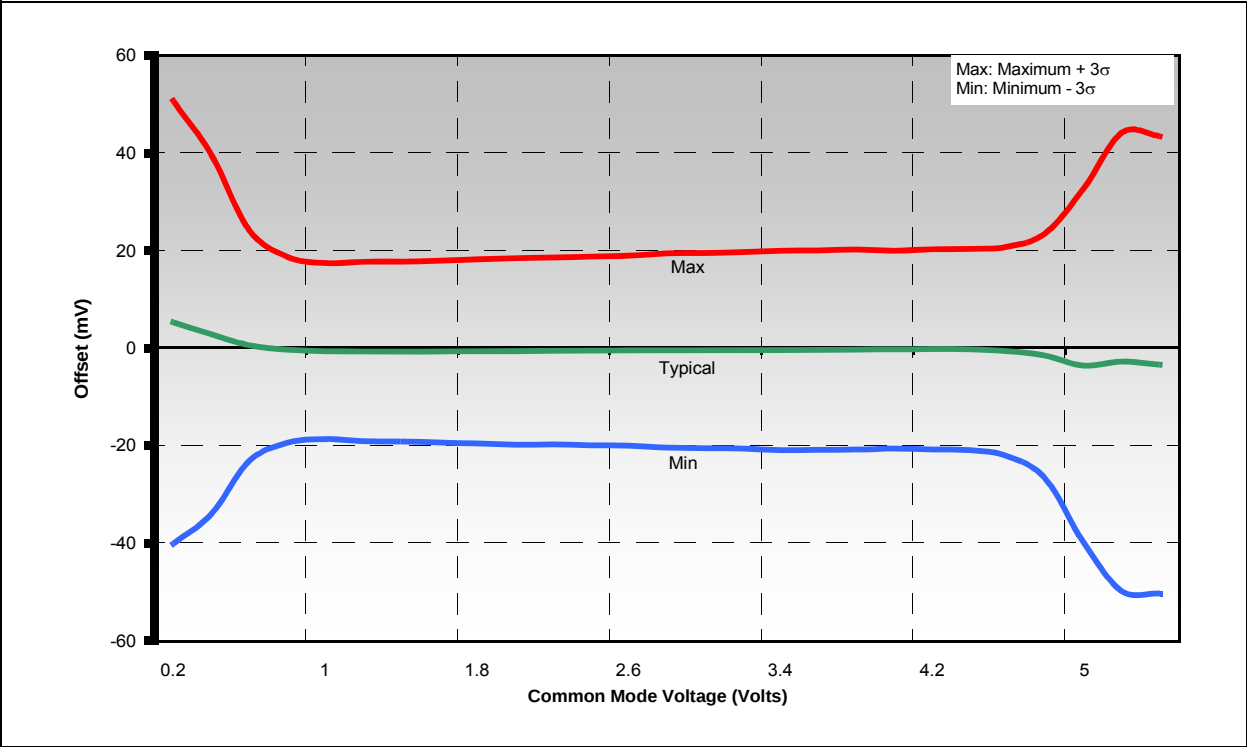


FIGURE 31-13: PIC16(L)F1826/27 COMPARATOR RESPONSE TIME, HIGH-POWER MODE

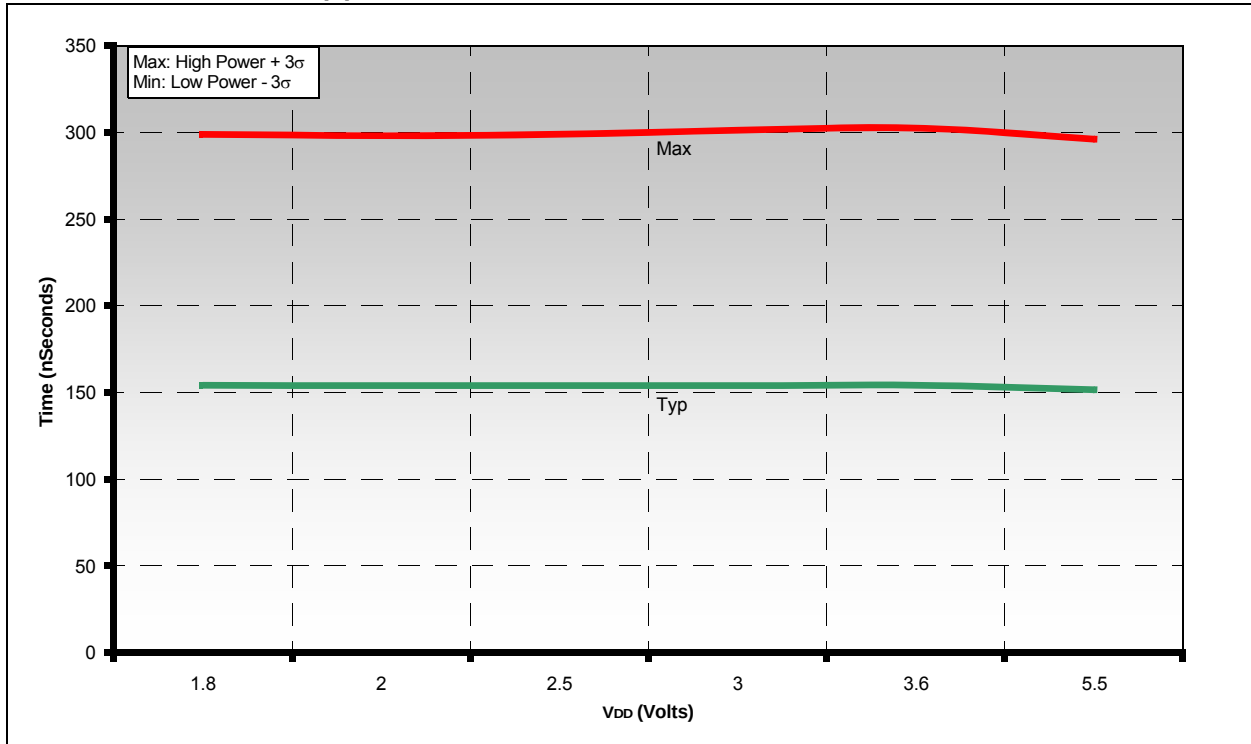
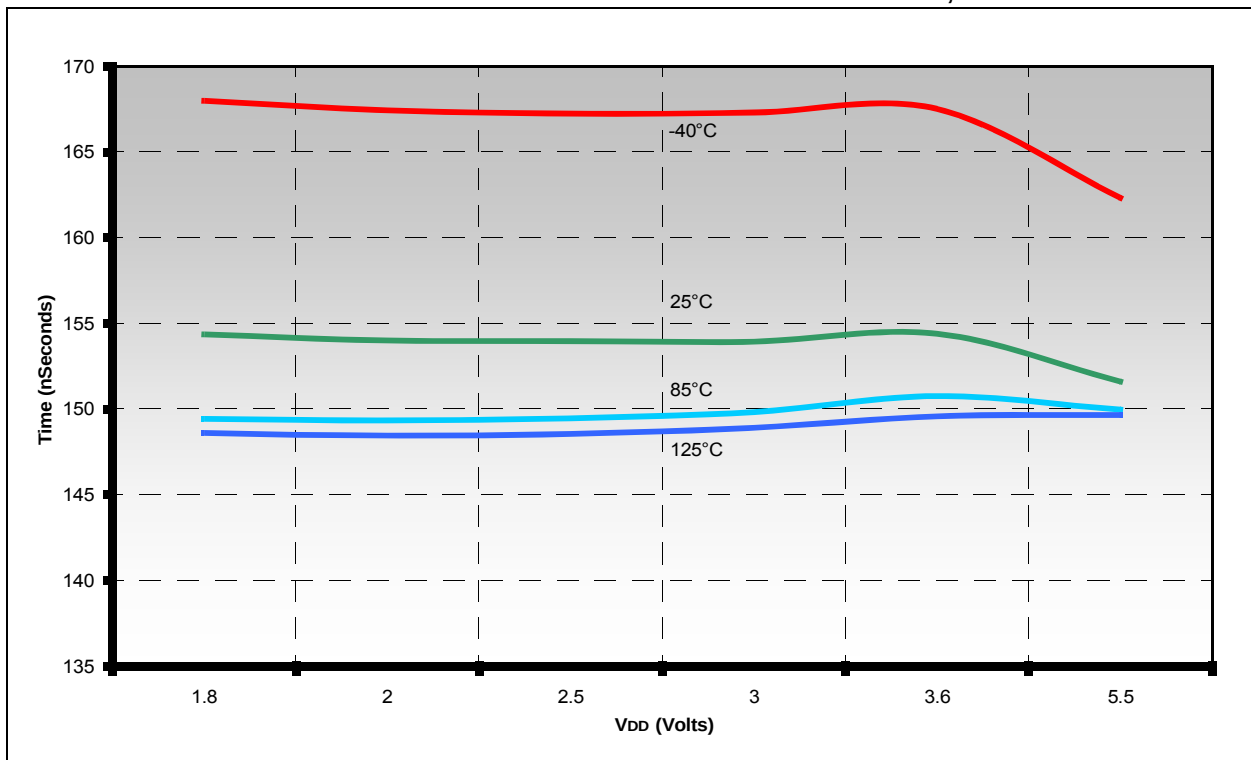


FIGURE 31-14: TYPICAL COMPARATOR RESPONSE TIME OVER TEMP, HIGH-POWER MODE



PIC16(L)F1826/27

NOTES:

32.0 DEVELOPMENT SUPPORT

The PIC® microcontrollers and dsPIC® digital signal controllers are supported with a full range of software and hardware development tools:

- Integrated Development Environment
 - MPLAB® IDE Software
- Compilers/Assemblers/Linkers
 - MPLAB C Compiler for Various Device Families
 - HI-TECH C for Various Device Families
 - MPASM™ Assembler
 - MPLINK™ Object Linker/
MPLIB™ Object Librarian
 - MPLAB Assembler/Linker/Librarian for Various Device Families
- Simulators
 - MPLAB SIM Software Simulator
- Emulators
 - MPLAB REAL ICE™ In-Circuit Emulator
- In-Circuit Debuggers
 - MPLAB ICD 3
 - PICKit™ 3 Debug Express
- Device Programmers
 - PICKit™ 2 Programmer
 - MPLAB PM3 Device Programmer
- Low-Cost Demonstration/Development Boards, Evaluation Kits, and Starter Kits

32.1 MPLAB Integrated Development Environment Software

The MPLAB IDE software brings an ease of software development previously unseen in the 8/16/32-bit microcontroller 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)
 - In-Circuit 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
- 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 IAR C Compilers

The MPLAB IDE allows you to:

- Edit your source files (either C or assembly)
- One-touch compile or assemble, and download to emulator and simulator tools (automatically updates all project information)
- Debug using:
 - Source files (C or assembly)
 - Mixed C and assembly
 - 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.

32.2 MPLAB C Compilers for Various Device Families

The MPLAB C Compiler code development systems are complete ANSI C compilers for Microchip's PIC18, PIC24 and PIC32 families of microcontrollers and the dsPIC30 and dsPIC33 families of digital signal controllers. These compilers provide powerful integration capabilities, superior code optimization and ease of use.

For easy source level debugging, the compilers provide symbol information that is optimized to the MPLAB IDE debugger.

32.3 HI-TECH C for Various Device Families

The HI-TECH C Compiler code development systems are complete ANSI C compilers for Microchip's PIC family of microcontrollers and the dsPIC family of digital signal controllers. These compilers provide powerful integration capabilities, omniscient code generation and ease of use.

For easy source level debugging, the compilers provide symbol information that is optimized to the MPLAB IDE debugger.

The compilers include a macro assembler, linker, pre-processor, and one-step driver, and can run on multiple platforms.

32.4 MPASM Assembler

The MPASM Assembler is a full-featured, universal macro assembler for PIC10/12/16/18 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

32.5 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

32.6 MPLAB Assembler, Linker and Librarian for Various Device Families

MPLAB Assembler produces relocatable machine code from symbolic assembly language for PIC24, PIC32 and dsPIC devices. MPLAB 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 device instruction set
- Support for fixed-point and floating-point data
- Command line interface
- Rich directive set
- Flexible macro language
- MPLAB IDE compatibility

32.7 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 C Compilers, and the MPASM and MPLAB 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.

32.8 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 emulator 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 in-circuit debugger systems (RJ11) or with the new high-speed, noise tolerant, Low-Voltage Differential Signal (LVDS) interconnection (CAT5).

The emulator is field upgradable through future firmware downloads in MPLAB IDE. In upcoming releases of MPLAB IDE, new devices will be supported, and new features will be added. MPLAB REAL ICE offers significant advantages over competitive emulators including low-cost, full-speed emulation, run-time variable watches, trace analysis, complex breakpoints, a ruggedized probe interface and long (up to three meters) interconnection cables.

32.9 MPLAB ICD 3 In-Circuit Debugger System

MPLAB ICD 3 In-Circuit Debugger System is Microchip's most cost effective high-speed hardware debugger/programmer for Microchip Flash Digital Signal Controller (DSC) and microcontroller (MCU) devices. It debugs and programs PIC® Flash microcontrollers and dsPIC® DSCs with the powerful, yet easy-to-use graphical user interface of MPLAB Integrated Development Environment (IDE).

The MPLAB ICD 3 In-Circuit Debugger probe is connected to the design engineer's PC using a high-speed USB 2.0 interface and is connected to the target with a connector compatible with the MPLAB ICD 2 or MPLAB REAL ICE systems (RJ-11). MPLAB ICD 3 supports all MPLAB ICD 2 headers.

32.10 PICkit 3 In-Circuit Debugger/Programmer and PICkit 3 Debug Express

The MPLAB PICkit 3 allows debugging and programming of PIC® and dsPIC® Flash microcontrollers at a most affordable price point using the powerful graphical user interface of the MPLAB Integrated Development Environment (IDE). The MPLAB PICkit 3 is connected to the design engineer's PC using a full speed USB interface and can be connected to the target via an Microchip debug (RJ-11) connector (compatible with MPLAB ICD 3 and MPLAB REAL ICE). The connector uses two device I/O pins and the reset line to implement in-circuit debugging and In-Circuit Serial Programming™.

The PICkit 3 Debug Express include the PICkit 3, demo board and microcontroller, hookup cables and CDROM with user's guide, lessons, tutorial, compiler and MPLAB IDE software.

32.11 PICkit 2 Development Programmer/Debugger and PICkit 2 Debug Express

The PICkit™ 2 Development Programmer/Debugger is a low-cost development tool with an easy to use interface for programming and debugging Microchip's Flash families of microcontrollers. The full featured Windows® programming interface supports baseline (PIC10F, PIC12F5xx, PIC16F5xx), midrange (PIC12F6xx, PIC16F), PIC18F, PIC24, dsPIC30, dsPIC33, and PIC32 families of 8-bit, 16-bit, and 32-bit microcontrollers, and many Microchip Serial EEPROM products. With Microchip's powerful MPLAB Integrated Development Environment (IDE) the PICkit™ 2 enables in-circuit debugging on most PIC® microcontrollers. In-Circuit-Debugging runs, halts and single steps the program while the PIC microcontroller is embedded in the application. When halted at a breakpoint, the file registers can be examined and modified.

The PICkit 2 Debug Express include the PICkit 2, demo board and microcontroller, hookup cables and CDROM with user's guide, lessons, tutorial, compiler and MPLAB IDE software.

32.12 MPLAB PM3 Device Programmer

The MPLAB PM3 Device Programmer is a universal, CE compliant device programmer with programmable voltage verification at VDDMIN and VDDMAX 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 MMC card for file storage and data applications.

32.13 Demonstration/Development Boards, Evaluation Kits, and Starter Kits

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.

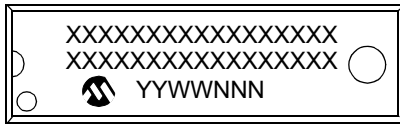
Also available are starter kits that contain everything needed to experience the specified device. This usually includes a single application and debug capability, all on one board.

Check the Microchip web page (www.microchip.com) for the complete list of demonstration, development and evaluation kits.

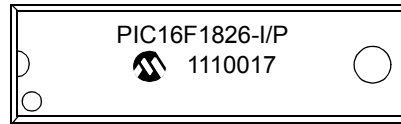
33.0 PACKAGING INFORMATION

33.1 Package Marking Information

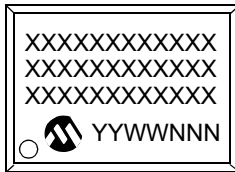
18-Lead PDIP



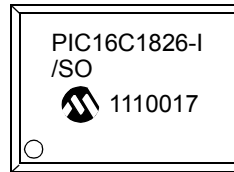
Example



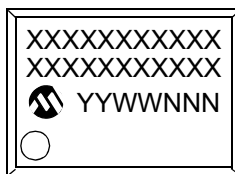
18-Lead SOIC (.300")



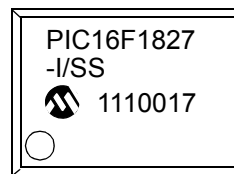
Example



20-Lead SSOP



Example



28-Lead QFN/UQFN



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.

- * Standard PICmicro® device marking consists of Microchip part number, year code, week code and traceability code. For PICmicro device marking beyond this, certain price adders apply. Please check with your Microchip Sales Office. For QTP devices, any special marking adders are included in QTP price.

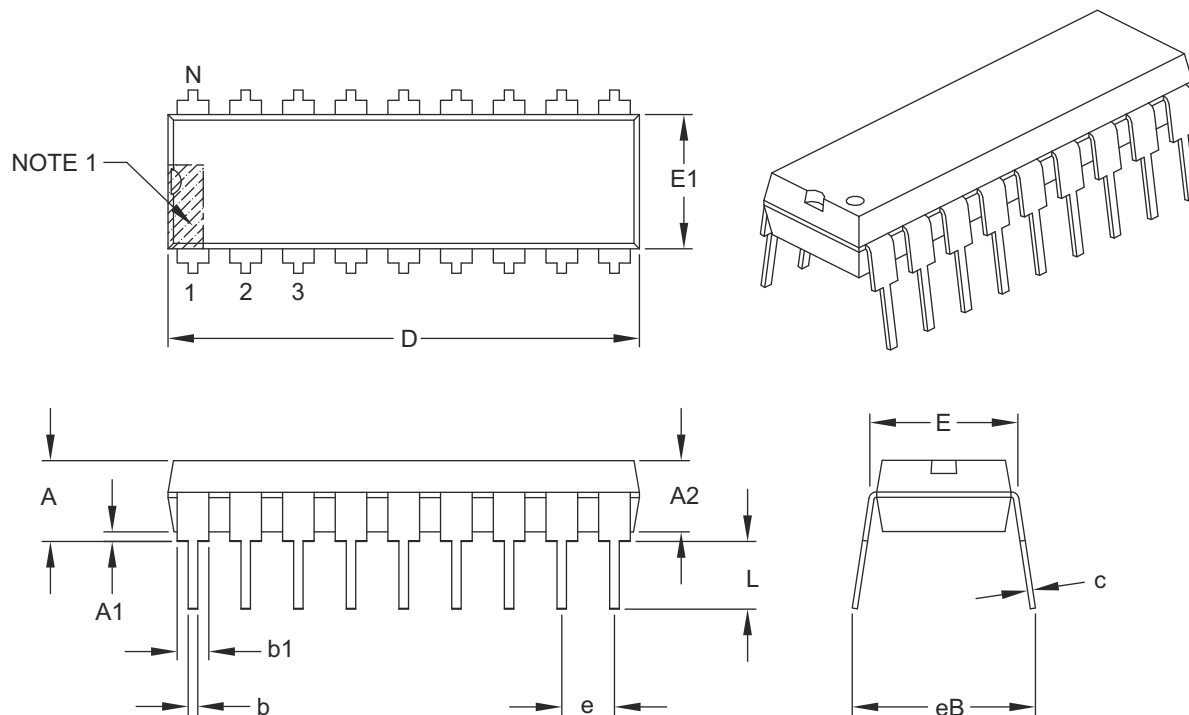
PIC16(L)F1826/27

33.2 Package Details

The following sections give the technical details of the packages.

18-Lead Plastic Dual In-Line (P) – 300 mil Body [PDIP]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



Dimension Limits	Units	INCHES		
		MIN	NOM	MAX
Number of Pins	N	18		
Pitch	e	.100 BSC		
Top to Seating Plane	A	–	–	.210
Molded Package Thickness	A2	.115	.130	.195
Base to Seating Plane	A1	.015	–	–
Shoulder to Shoulder Width	E	.300	.310	.325
Molded Package Width	E1	.240	.250	.280
Overall Length	D	.880	.900	.920
Tip to Seating Plane	L	.115	.130	.150
Lead Thickness	c	.008	.010	.014
Upper Lead Width	b1	.045	.060	.070
Lower Lead Width	b	.014	.018	.022
Overall Row Spacing §	eB	–	–	.430

Notes:

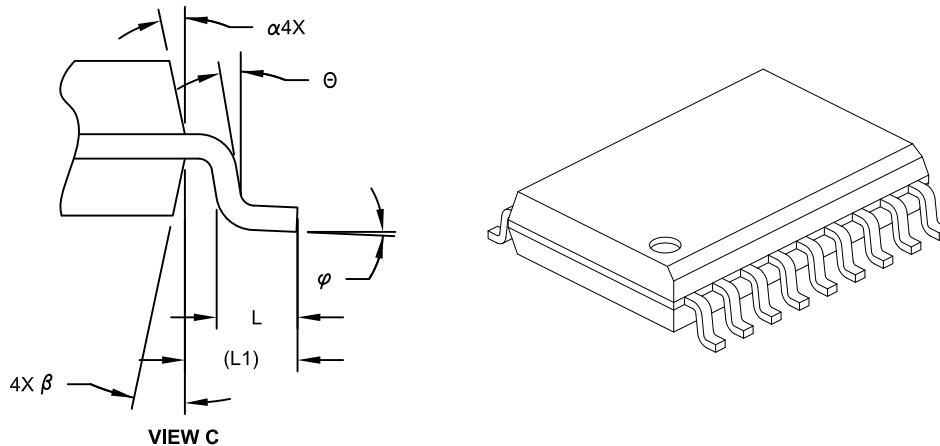
- Pin 1 visual index feature may vary, but must be located within the hatched area.
- § Significant Characteristic.
- Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" per side.
- Dimensioning and tolerancing per ASME Y14.5M.

BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing C04-007B

18-Lead Plastic Small Outline (SO) - Wide, 7.50 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	18		
Pitch	e	1.27 BSC		
Overall Height	A	-	-	2.65
Molded Package Thickness	A2	2.05	-	-
Standoff §	A1	0.10	-	0.30
Overall Width	E	10.30 BSC		
Molded Package Width	E1	7.50 BSC		
Overall Length	D	11.55 BSC		
Chamfer (Optional)	h	0.25	-	0.75
Foot Length	L	0.40	-	1.27
Footprint	L1	1.40 REF		
Lead Angle	Θ	0°	-	-
Foot Angle	φ	0°	-	8°
Lead Thickness	c	0.20	-	0.33
Lead Width	b	0.31	-	0.51
Mold Draft Angle Top	α	5°	-	15°
Mold Draft Angle Bottom	β	5°	-	15°

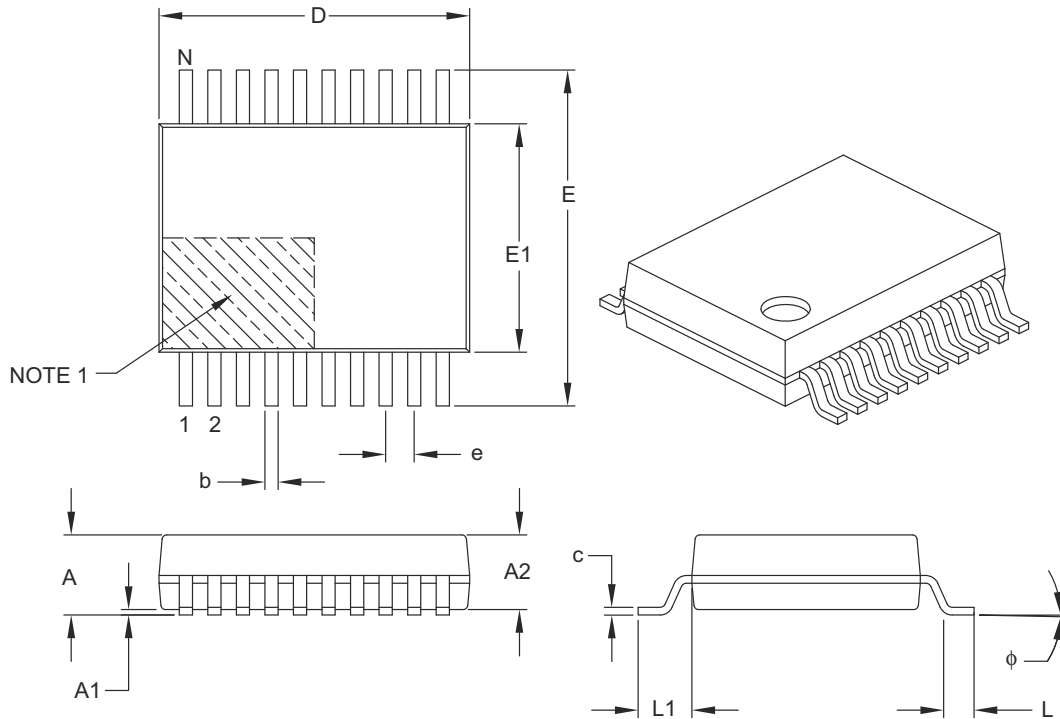
Notes:

- Pin 1 visual index feature may vary, but must be located within the hatched area.
- § Significant Characteristic
- Dimension D does not include mold flash, protrusions or gate burrs, which shall not exceed 0.15 mm per end. Dimension E1 does not include interlead flash or protrusion, which shall not exceed 0.25 mm per side.
- Dimensioning and tolerancing per ASME Y14.5M
 - BSC: Basic Dimension. Theoretically exact value shown without tolerances.
 - REF: Reference Dimension, usually without tolerance, for information purposes only.
- Datums A & B to be determined at Datum H.

Microchip Technology Drawing No. C04-051C Sheet 2 of 2

20-Lead Plastic Shrink Small Outline (SS) – 5.30 mm Body [SSOP]

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		20		
Pitch	e		0.65 BSC		
Overall Height	A		–	–	2.00
Molded Package Thickness	A2		1.65	1.75	1.85
Standoff	A1		0.05	–	–
Overall Width	E		7.40	7.80	8.20
Molded Package Width	E1		5.00	5.30	5.60
Overall Length	D		6.90	7.20	7.50
Foot Length	L		0.55	0.75	0.95
Footprint	L1		1.25 REF		
Lead Thickness	c		0.09	–	0.25
Foot Angle	φ		0°	4°	8°
Lead Width	b		0.22	–	0.38

Notes:

- Pin 1 visual index feature may vary, but must be located within the hatched area.
- Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed 0.20 mm per side.
- Dimensioning and tolerancing per ASME Y14.5M.

BSC: Basic Dimension. Theoretically exact value shown without tolerances.

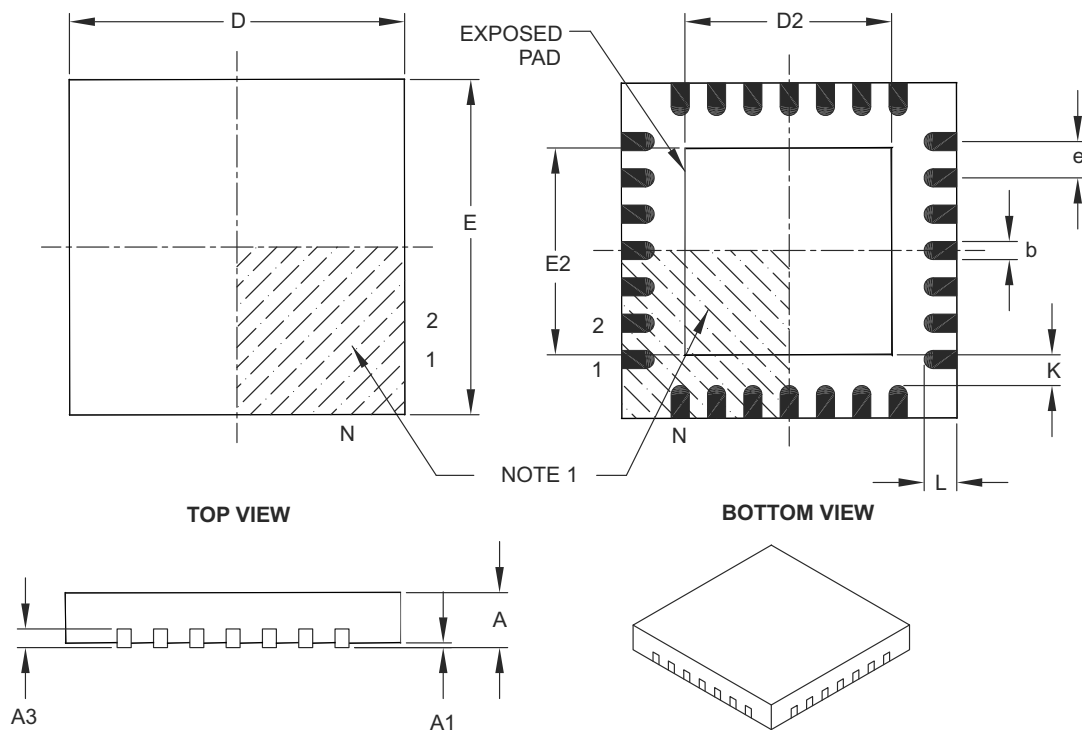
REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-072B

PIC16(L)F1826/27

28-Lead Plastic Quad Flat, No Lead Package (ML) – 6x6 mm Body [QFN] with 0.55 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	28		
Pitch	e	0.65 BSC		
Overall Height	A	0.80	0.90	1.00
Standoff	A1	0.00	0.02	0.05
Contact Thickness	A3	0.20 REF		
Overall Width	E	6.00 BSC		
Exposed Pad Width	E2	3.65	3.70	4.20
Overall Length	D	6.00 BSC		
Exposed Pad Length	D2	3.65	3.70	4.20
Contact Width	b	0.23	0.30	0.35
Contact Length	L	0.50	0.55	0.70
Contact-to-Exposed Pad	K	0.20	—	—

Notes:

- Pin 1 visual index feature may vary, but must be located within the hatched area.
- Package is saw singulated.
- Dimensioning and tolerancing per ASME Y14.5M.

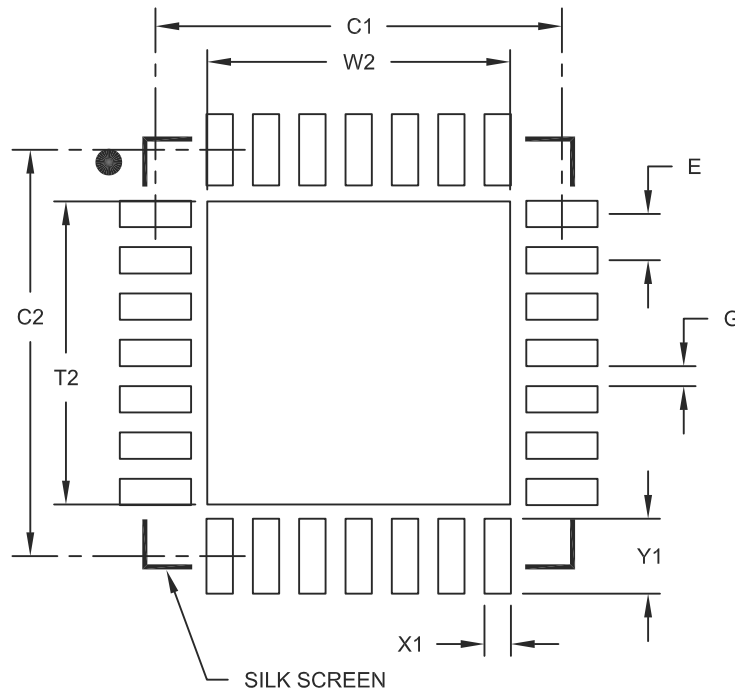
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-105B

28-Lead Plastic Quad Flat, No Lead Package (ML) – 6x6 mm Body [QFN] with 0.55 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

Dimension Limits	Units	MILLIMETERS		
		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

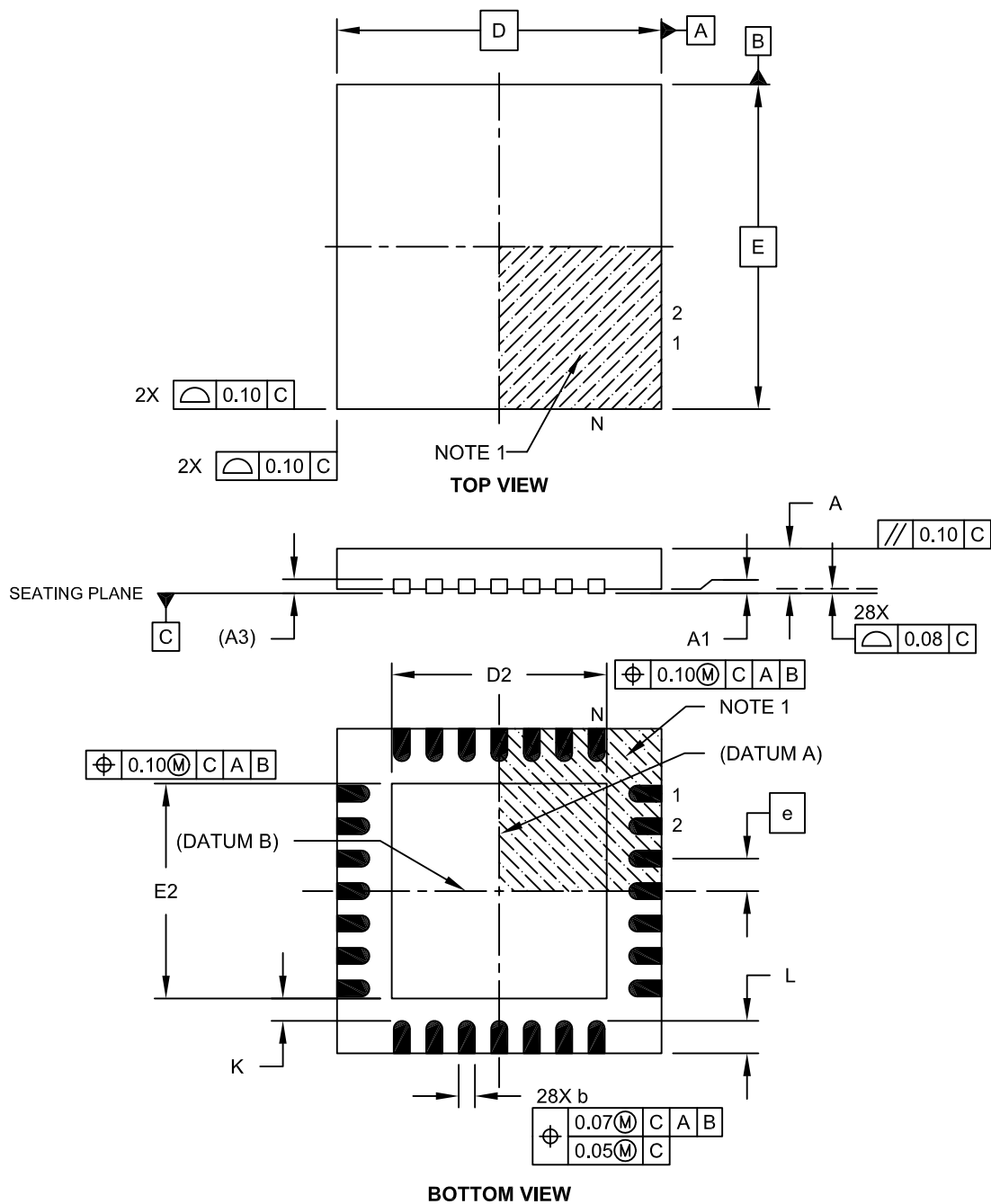
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2105A

PIC16(L)F1826/27

28-Lead Plastic Ultra Thin Quad Flat, No Lead Package (MV) – 4x4x0.5 mm Body [UQFN]

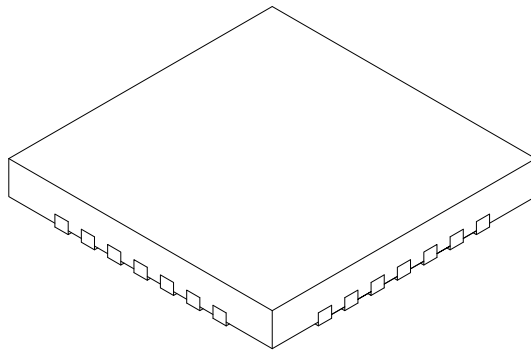
Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



Microchip Technology Drawing C04-152A Sheet 1 of 2

28-Lead Plastic Ultra Thin Quad Flat, No Lead Package (MV) – 4x4x0.5 mm Body [UQFN]

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	28		
Pitch	e	0.40 BSC		
Overall Height	A	0.45	0.50	0.55
Standoff	A1	0.00	0.02	0.05
Contact Thickness	A3	0.127 REF		
Overall Width	E	4.00 BSC		
Exposed Pad Width	E2	2.55	2.65	2.75
Overall Length	D	4.00 BSC		
Exposed Pad Length	D2	2.55	2.65	2.75
Contact Width	b	0.15	0.20	0.25
Contact Length	L	0.30	0.40	0.50
Contact-to-Exposed Pad	K	0.20	-	-

Notes:

- Pin 1 visual index feature may vary, but must be located within the hatched area.
- Package is saw singulated.
- Dimensioning and tolerancing per ASME Y14.5M.
 - BSC: Basic Dimension. Theoretically exact value shown without tolerances.
 - REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-152A Sheet 2 of 2

PIC16(L)F1826/27

NOTES:

APPENDIX A: DATA SHEET REVISION HISTORY

Revision A

Original release (06/2009)

Revision B (08/09)

Revised Tables 5-3, 6-2, 12-2, 12-3; Updated Electrical Specifications; Added UQFN Package; Added SOIC and QFN Land Patterns; Updated Product ID section.

Revision C (06/10)

Updated Electrical Specification and included Enhanced Core Golden Chapters.

Revision D (04/11)

Added Char Data to release Final data sheet.

APPENDIX B: MIGRATING FROM OTHER PIC® DEVICES

This section provides comparisons when migrating from other similar PIC® devices to the PIC16(L)F1826/27 family of devices.

B.1 PIC16F648A to PIC16(L)F1827

TABLE B-1: FEATURE COMPARISON

Feature	PIC16F648A	PIC16(L)F1827
Max. Operating Speed	20 MHz	32 MHz
Max. Program Memory (Words)	4K	4K
Max. SRAM (Bytes)	256	384
Max. EEPROM (Bytes)	256	256
A/D Resolution	10-bit	10-bit
Timers (8/16-bit)	2/1	4/1
Brown-out Reset	Y	Y
Internal Pull-ups	RB<7:0>	RB<7:0>, RA5
Interrupt-on-Change	RB<7:4>	RB<7:0>, Edge Selectable
Comparator	2	2
AUSART/EUSART	1/0	0/2
Extended WDT	N	Y
Software Control Option of WDT/BOR	N	Y
INTOSC Frequencies	48 kHz or 4 MHz	31 kHz - 32 MHz
Clock Switching	Y	Y
Capacitive Sensing	N	Y
CCP/ECCP	2/0	2/2
Enhanced PIC16 CPU	N	Y
MSSPx/SSPx	0	2/0
Reference Clock	N	Y
Data Signal Modulator	N	Y
SR Latch	N	Y
Voltage Reference	N	Y
DAC	Y	Y

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VREF. *SEE* ADC Reference Voltage

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