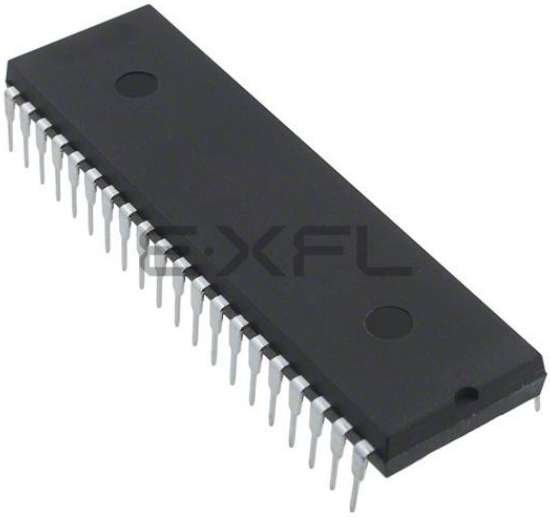

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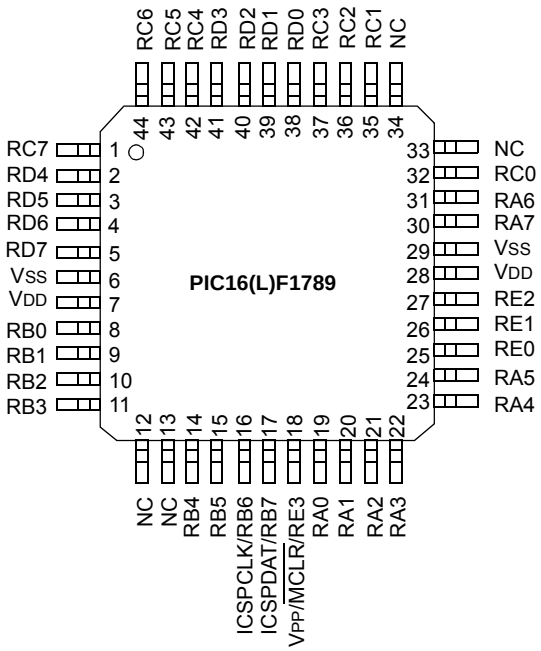
Applications of "Embedded - Microcontrollers"

Details	
Product Status	Active
Core Processor	PIC
Core Size	8-Bit
Speed	32MHz
Connectivity	I²C, LINbus, SPI, UART/USART
Peripherals	Brown-out Detect/Reset, POR, PSMC, PWM, WDT
Number of I/O	35
Program Memory Size	28KB (16K x 14)
Program Memory Type	FLASH
EEPROM Size	256 x 8
RAM Size	2K x 8
Voltage - Supply (Vcc/Vdd)	2.3V ~ 5.5V
Data Converters	A/D 14x12b; D/A 1x8b, 3x5b
Oscillator Type	Internal
Operating Temperature	-40°C ~ 125°C (TA)
Mounting Type	Through Hole
Package / Case	40-DIP (0.600", 15.24mm)
Supplier Device Package	40-PDIP
Purchase URL	https://www.e-xfl.com/product-detail/microchip-technology/pic16f1789-e-p

Pin Diagram – 44-Pin TQFP



Note: See Table 2 for the location of all peripheral functions.

TABLE 1-2: PIC16(L)F1788 PINOUT DESCRIPTION (CONTINUED)

Name	Function	Input Type	Output Type	Description
RC3/PSMC1D/PSMC4A/SCK/SCL	RC3	TTL/ST	CMOS	General purpose I/O.
	PSMC1D	—	CMOS	PSMC1 output D.
	PSMC4A	—	CMOS	PSMC4 output A.
	SCK	ST	CMOS	SPI clock.
	SCL	I^2C	OD	I^2C clock.
RC4/PSMC1E/PSMC4B/SDI/SDA	RC4	TTL/ST	CMOS	General purpose I/O.
	PSMC1E	—	CMOS	PSMC1 output E.
	PSMC4B	—	CMOS	PSMC4 output B.
	SDI	ST	—	SPI data input.
	SDA	I^2C	OD	I^2C data input/output.
RC5/PSMC1F/PSMC3A/SDO	RC5	TTL/ST	CMOS	General purpose I/O.
	PSMC1F	—	CMOS	PSMC1 output F.
	PSMC3A	—	CMOS	PSMC3 output A.
	SDO	—	CMOS	SPI data output.
RC6/PSMC2A/TX/CK/CCP3	RC6	TTL/ST	CMOS	General purpose I/O.
	PSMC2A	—	CMOS	PSMC2 output A.
	TX	—	CMOS	EUSART asynchronous transmit.
	CK	ST	CMOS	EUSART synchronous clock.
	CCP3	ST	CMOS	Capture/Compare/PWM3.
RC7/C4OUT/PSMC2B/RX/DT	RC7	TTL/ST	CMOS	General purpose I/O.
	C4OUT	—	CMOS	Comparator C4 output.
	PSMC2B	—	CMOS	PSMC2 output B.
	RX	ST	—	EUSART asynchronous input.
	DT	ST	CMOS	EUSART synchronous data.
RE3/$\overline{MCLR}$/V_{PP}	RE3	TTL/ST	—	General purpose input.
	$\overline{MCLR}$	ST	—	Master Clear with internal pull-up.
	V_{PP}	HV	—	Programming voltage.
V_{DD}	V_{DD}	Power	—	Positive supply.
V_{SS}	V_{SS}	Power	—	Ground reference.

Legend: AN = Analog input or output CMOS = CMOS compatible input or output OD = Open-Drain
TTL = TTL compatible input ST = Schmitt Trigger input with CMOS levels I^2C = Schmitt Trigger input with I^2C
HV = High Voltage XTAL = Crystal levels

Note 1: Pin functions can be assigned to one of two locations via software. See **Register 13-1**.
2: All pins have interrupt-on-change functionality.

3.3.4 DEVICE MEMORY MAPS

The memory maps for Bank 0 through Bank 31 are shown in the tables in this section.

TABLE 3-3: PIC16(L)F1788 MEMORY MAP (BANKS 0-7)

BANK 0		BANK 1		BANK 2		BANK 3		BANK 4		BANK 5		BANK 6		BANK 7	
000h	Core Registers (Table 3-2)	080h	Core Registers (Table 3-2)	100h	Core Registers (Table 3-2)	180h	Core Registers (Table 3-2)	200h	Core Registers (Table 3-2)	280h	Core Registers (Table 3-2)	300h	Core Registers (Table 3-2)	380h	Core Registers (Table 3-2)
00Bh		08Bh		10Bh		18Bh		20Bh		28Bh		30Bh		38Bh	
00Ch	PORTA	08Ch	TRISA	10Ch	LATA	18Ch	ANSELA	20Ch	WPUA	28Ch	ODCONA	30Ch	SLRCONA	38Ch	INLVLA
00Dh	PORTB	08Dh	TRISB	10Dh	LATB	18Dh	ANSELB	20Dh	WPUB	28Dh	ODCONB	30Dh	SLRCONB	38Dh	INLVLB
00Eh	PORTC	08Eh	TRISC	10Eh	LATC	18Eh	ANSELC	20Eh	WPUC	28Eh	ODCONC	30Eh	SLRCONC	38Eh	INLVLC
00Fh	—	08Fh	—	10Fh	—	18Fh	—	20Fh	—	28Fh	—	30Fh	—	38Fh	—
010h	PORTE	090h	TRISE	110h	—	190h	—	210h	WPUE	290h	—	310h	—	390h	INLVLE
011h	PIR1	091h	PIE1	111h	CM1CON0	191h	EEADRL	211h	SSP1BUF	291h	CCPR1L	311h	CCPR3L	391h	IOCAP
012h	PIR2	092h	PIE2	112h	CM1CON1	192h	EEADRH	212h	SSP1ADD	292h	CCPR1H	312h	CCPR3H	392h	IOCAN
013h	PIR3	093h	PIE3	113h	CM2CON0	193h	EEDATL	213h	SSP1MSK	293h	CCP1CON	313h	CCP3CON	393h	IOCAF
014h	PIR4	094h	PIE4	114h	CM2CON1	194h	EEDATH	214h	SSP1STAT	294h	—	314h	—	394h	IOCBP
015h	TMR0	095h	OPTION_REG	115h	CMOUT	195h	EECON1	215h	SSP1CON1	295h	—	315h	—	395h	IOCBN
016h	TMR1L	096h	PCON	116h	BORCON	196h	EECON2	216h	SSP1CON2	296h	—	316h	—	396h	IOCBF
017h	TMR1H	097h	WDTCON	117h	FVRCON	197h	VREGCON(1)	217h	SSP1CON3	297h	—	317h	—	397h	IOCCP
018h	T1CON	098h	OSCTUNE	118h	DAC1CON0	198h	—	218h	—	298h	CCPR2L	318h	—	398h	IOCCN
019h	T1GCON	099h	OSCCON	119h	DAC1CON1	199h	RC1REG	219h	—	299h	CCPR2H	319h	—	399h	IOCCF
01Ah	TMR2	09Ah	OSCSTAT	11Ah	CM4CON0	19Ah	TX1REG	21Ah	—	29Ah	CCP2CON	31Ah	—	39Ah	—
01Bh	PR2	09Bh	ADRESL	11Bh	CM4CON1	19Bh	SP1BRGL	21Bh	—	29Bh	—	31Bh	—	39Bh	—
01Ch	T2CON	09Ch	ADRESH	11Ch	APFCON2	19Ch	SP1BRGH	21Ch	—	29Ch	—	31Ch	—	39Ch	—
01Dh	—	09Dh	ADCON0	11Dh	APFCON1	19Dh	RC1STA	21Dh	—	29Dh	—	31Dh	—	39Dh	—
01Eh	—	09Eh	ADCON1	11Eh	CM3CON0	19Eh	TX1STA	21Eh	—	29Eh	—	31Eh	—	39Eh	—
01Fh	—	09Fh	ADCON2	11Fh	CM3CON1	19Fh	BAUD1CON	21Fh	—	29Fh	—	31Fh	—	39Fh	—
020h	General Purpose Register 80 Bytes	0A0h	General Purpose Register 80 Bytes	120h	General Purpose Register 80 Bytes	1A0h	General Purpose Register 80 Bytes	220h	General Purpose Register 80 Bytes	2A0h	General Purpose Register 80 Bytes	320h	General Purpose Register 80 Bytes	3A0h	General Purpose Register 80 Bytes
06Fh		0EFh		16Fh		1EFh		26Fh		2EFh		36Fh		3EFh	
070h	Common RAM 70h – 7Fh	0F0h	Accesses 70h – 7Fh	170h	Accesses 70h – 7Fh	1F0h	Accesses 70h – 7Fh	270h	Accesses 70h – 7Fh	2F0h	Accesses 70h – 7Fh	370h	Accesses 70h – 7Fh	3F0h	Accesses 70h – 7Fh
07Fh		0FFh		17Fh		1FFh		27Fh		2FFh		37Fh		3FFh	

Legend: = Unimplemented data memory locations, read as '0'.

Note 1: PIC16F1788 only.

REGISTER 4-2: CONFIG2: CONFIGURATION WORD 2

R/P-1	R/P-1	R/P-1	R/P-1	R/P-1	R/P-1
LVP	$\overline{\text{DEBUG}}$	$\overline{\text{LPBOR}}$	BORV	STVREN	PLLEN
bit 13					bit 8

U-1	U-1	R/P-1	U-1	U-1	U-1	R/P-1	R/P-1
—	—	$\overline{\text{VCAPEN}}$	—	—	—	WRT<1:0>	
bit 7							bit 0

Legend:		
R = Readable bit	P = Programmable bit	U = Unimplemented bit, read as '1'
'0' = Bit is cleared	'1' = Bit is set	-n = Value when blank or after Bulk Erase

bit 13 **LVP:** Low-Voltage Programming Enable bit(1)
1 = Low-voltage programming enabled
0 = High-voltage on $\overline{\text{MCLR}}$ must be used for programming

bit 12 **$\overline{\text{DEBUG}}$:** In-Circuit Debugger Mode bit(3)
1 = In-Circuit Debugger disabled, ICSPCLK and ICSPDAT are general purpose I/O pins
0 = In-Circuit Debugger enabled, ICSPCLK and ICSPDAT are dedicated to the debugger

bit 11 **$\overline{\text{LPBOR}}$:** Low-Power BOR Enable bit
1 = Low-Power Brown-out Reset is disabled
0 = Low-Power Brown-out Reset is enabled

bit 10 **BORV:** Brown-out Reset Voltage Selection bit(4)
1 = Brown-out Reset voltage (V_{BOR}), low trip point selected.
0 = Brown-out Reset voltage (V_{BOR}), high trip point selected.

bit 9 **STVREN:** Stack Overflow/Underflow Reset Enable bit
1 = Stack Overflow or Underflow will cause a Reset
0 = Stack Overflow or Underflow will not cause a Reset

bit 8 **PLLEN:** PLL Enable bit
1 = 4xPLL enabled
0 = 4xPLL disabled

bit 7-6 **Unimplemented:** Read as '1'

bit 5 **$\overline{\text{VCAPEN}}$:** Voltage Regulator Capacitor Enable bit(2)
1 = V_{CAP} functionality is disabled on RA6
0 = V_{CAP} functionality is enabled on RA6

bit 4-2 **Unimplemented:** Read as '1'

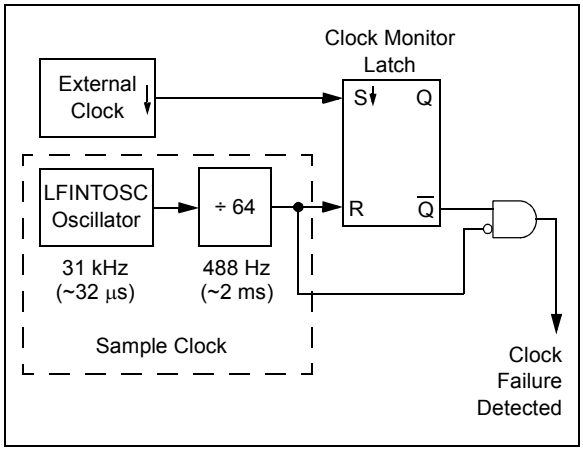
bit 1-0 **WRT<1:0>:** Flash Memory Self-Write Protection bits
8 kW Flash memory (PIC16(L)F1788/9 only):
11 = Write protection off
10 = 0000h to 01FFh write-protected, 0200h to 1FFFh may be modified by EECON control
01 = 0000h to 0FFFh write-protected, 1000h to 1FFFh may be modified by EECON control
00 = 0000h to 1FFFh write-protected, no addresses may be modified by EECON control

Note 1: The LVP bit cannot be programmed to '0' when Programming mode is entered via LVP.
2: Not implemented on "LF" devices.
3: The $\overline{\text{DEBUG}}$ bit in Configuration Words is managed automatically by device development tools including debuggers and programmers. For normal device operation, this bit should be maintained as a '1'.
4: See V_{BOR} parameter for specific trip point voltages.

6.5 Fail-Safe Clock Monitor

The Fail-Safe Clock Monitor (FSCM) allows the device to continue operating should the external oscillator fail. The FSCM can detect oscillator failure any time after the Oscillator Start-up Timer (OST) has expired. The FSCM is enabled by setting the FCMEN bit in the Configuration Words. The FSCM is applicable to all external Oscillator modes (LP, XT, HS, EC, Timer1 Oscillator and RC).

FIGURE 6-9: FSCM BLOCK DIAGRAM



6.5.1 FAIL-SAFE DETECTION

The FSCM module detects a failed oscillator by comparing the external oscillator to the FSCM sample clock. The sample clock is generated by dividing the LFINTOSC by 64. See Figure 6-9. Inside the fail detector block is a latch. The external clock sets the latch on each falling edge of the external clock. The sample clock clears the latch on each rising edge of the sample clock. A failure is detected when an entire half-cycle of the sample clock elapses before the external clock goes low.

6.5.2 FAIL-SAFE OPERATION

When the external clock fails, the FSCM switches the device clock to an internal clock source and sets the bit flag OSFIF of the PIR2 register. Setting this flag will generate an interrupt if the OSFIE bit of the PIE2 register is also set. The device firmware can then take steps to mitigate the problems that may arise from a failed clock. The system clock will continue to be sourced from the internal clock source until the device firmware successfully restarts the external oscillator and switches back to external operation.

The internal clock source chosen by the FSCM is determined by the IRCF<3:0> bits of the OSCCON register. This allows the internal oscillator to be configured before a failure occurs.

6.5.3 FAIL-SAFE CONDITION CLEARING

The Fail-Safe condition is cleared after a Reset, executing a SLEEP instruction or changing the SCS bits of the OSCCON register. When the SCS bits are changed, the OST is restarted. While the OST is running, the device continues to operate from the INTOSC selected in OSCCON. When the OST times out, the Fail-Safe condition is cleared after successfully switching to the external clock source. The OSFIF bit should be cleared prior to switching to the external clock source. If the Fail-Safe condition still exists, the OSFIF flag will again become set by hardware.

6.5.4 RESET OR WAKE-UP FROM SLEEP

The FSCM is designed to detect an oscillator failure after the Oscillator Start-up Timer (OST) has expired. The OST is used after waking up from Sleep and after any type of Reset. The OST is not used with the EC or RC Clock modes so that the FSCM will be active as soon as the Reset or wake-up has completed. When the FSCM is enabled, the Two-Speed Start-up is also enabled. Therefore, the device will always be executing code while the OST is operating.

Note:	Due to the wide range of oscillator start-up times, the Fail-Safe circuit is not active during oscillator start-up (i.e., after exiting Reset or Sleep). After an appropriate amount of time, the user should check the Status bits in the OSCSTAT register to verify the oscillator start-up and that the system clock switchover has successfully completed.

21.3 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 30.0 "Electrical Specifications"** for more information.

21.4 Timer1 Gate Operation

The output resulting from a comparator operation can be used as a source for gate control of Timer1. See **Section 23.6 "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.

21.4.1 COMPARATOR OUTPUT SYNCHRONIZATION

The output from a comparator 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 Diagram (Figure 21-2) and the Timer1 Block Diagram (Figure 23-1) for more information.

21.5 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.

21.6 Comparator Positive Input Selection

Configuring the CxPCH<2:0> bits of the CMxCON1 register directs an internal voltage reference or an analog pin to the non-inverting input of the comparator:

- CxIN+ analog pin
- DAC output
- FVR (Fixed Voltage Reference)
- VSS (Ground)

See **Section 15.0 "Fixed Voltage Reference (FVR)"** for more information on the Fixed Voltage Reference module.

See **Section 19.0 "8-Bit 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.

26.3.9 ECCP COMPATIBLE FULL-BRIDGE PWM

This mode of operation is designed to match the Full-Bridge mode from the ECCP module. It is called ECCP compatible as the term “full-bridge” alone has different connotations in regards to the output waveforms.

Full-Bridge Compatible mode uses the same waveform events as the single PWM mode to generate the output waveforms.

There are both Forward and Reverse modes available for this operation, again to match the ECCP implementation. Direction is selected with the mode control bits.

26.3.9.1 Mode Features

- Dead-band control available on direction switch
  - Changing from forward to reverse uses the falling edge dead-band counters.
  - Changing from reverse to forward uses the rising edge dead-band counters.
- No steering control available
- PWM is output on the following four pins only:
  - PSMCxA
  - PSMCxB
  - PSMCxC
  - PSMCxD

26.3.9.2 Waveform Generation - Forward

In this mode of operation, three of the four pins are static. PSMCxA is the only output that changes based on rising edge and falling edge events.

Static Signal Assignment

- Outputs set to active state
  - PSMCxD
- Outputs set to inactive state
  - PSMCxB
  - PSMCxC

Rising Edge Event

- PSMCxA is set active

Falling Edge Event

- PSMCxA is set inactive

26.3.9.3 Waveform Generation – Reverse

In this mode of operation, three of the four pins are static. Only PSMCxB toggles based on rising edge and falling edge events.

Static Signal Assignment

- Outputs set to active state
  - PSMCxC
- Outputs set to inactive state
  - PSMCxA
  - PSMCxD

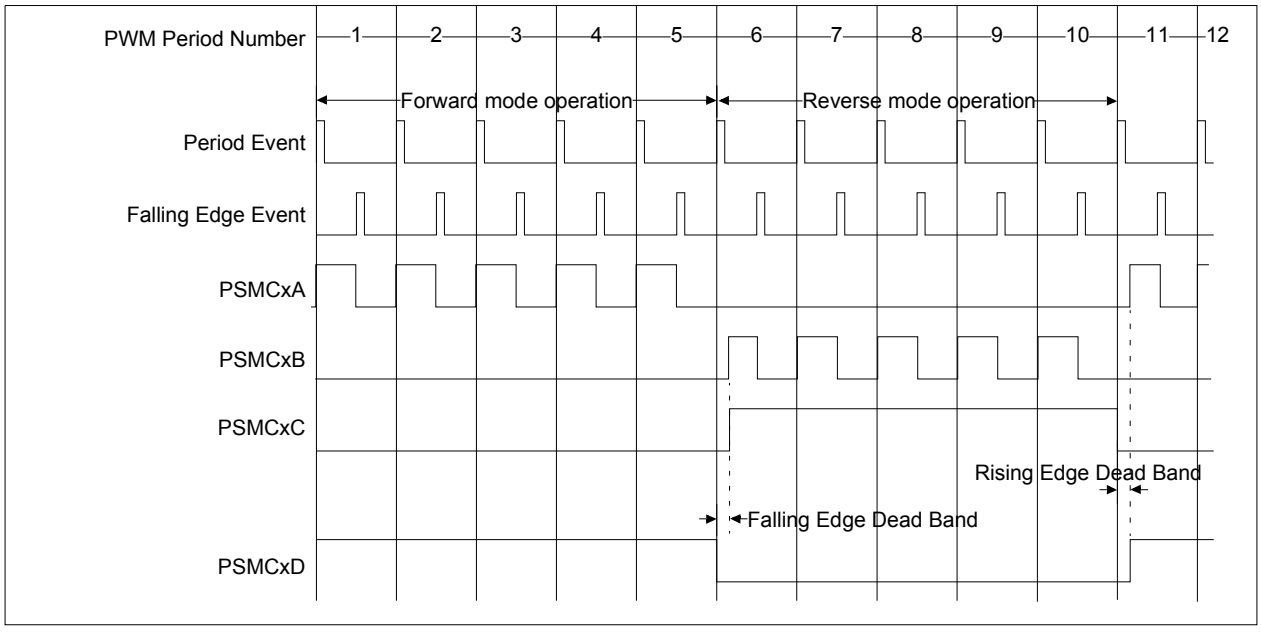
Rising Edge Event

- PSMCxB is set active

Falling Edge Event

- PSMCxB is set inactive

FIGURE 26-12: ECCP COMPATIBLE FULL-BRIDGE PWM WAVEFORM – PSMCXSTR0 = 0FH



26.6 PSMC Modulation (Burst Mode)

PSMC modulation is a method to stop/start PWM operation of the PSMC without having to disable the module. It also allows other modules to control the operational period of the PSMC. This is also referred to as Burst mode.

This is a method to implement PWM dimming.

26.6.1 MODULATION ENABLE

The modulation function is enabled by setting the PxMDLEN bit of PSMC Modulation Control (PSMCxMDL) register (Register 26-2).

When modulation is enabled, the modulation source controls when the PWM signals are active and inactive.

When modulation is disabled, the PWM signals operate continuously, regardless of the selected modulation source.

26.6.2 MODULATION SOURCES

There are multiple sources that can be used for modulating the PSMC. However, unlike the PSMC input sources, only one modulation source can be selected at a time. Modulation sources include:

- PSMCxIN pin
- Any CCP output
- Any Comparator output
- PxMDLBIT of the PSMCxMDL register

26.6.2.1 PxMDLBIT Bit

The PxMDLBIT bit of the PSMC Modulation Control (PSMCxMDL) register (Register 26-2) allows for software modulation control without having to enable/disable other module functions.

26.6.3 MODULATION EFFECT ON PWM SIGNALS

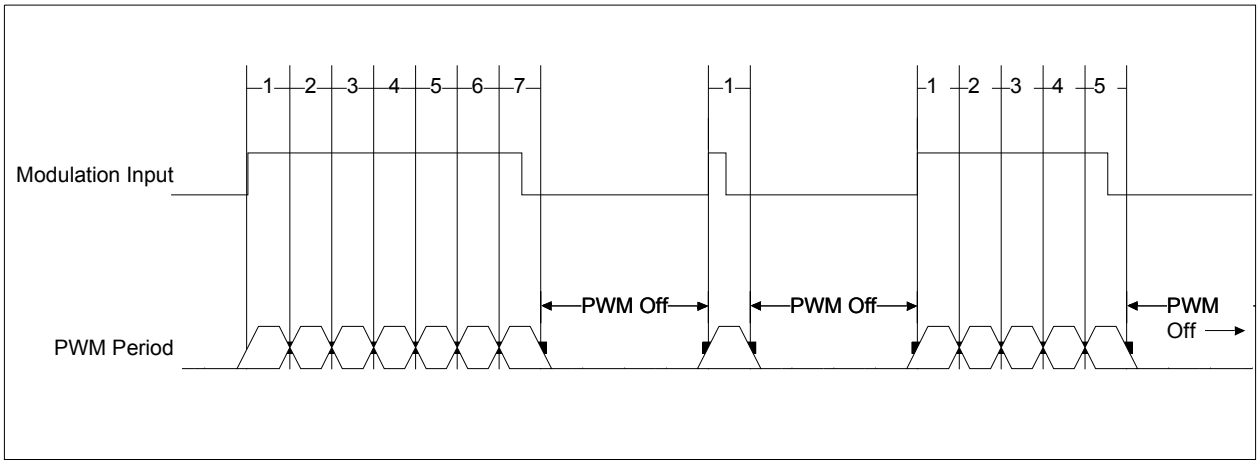
When modulation starts, the PSMC begins operation on a new period, just as if it had rolled over from one period to another during continuous operation.

When modulation stops, its operation depends on the type of waveform being generated.

In operation modes other than Fixed Duty Cycle, the PSMC completes its current PWM period and then freezes the module. The PSMC output pins are forced into the default inactive state ready for use when modulation starts.

In Fixed Duty Cycle mode operation, the PSMC continues to operate until the period event changes the PWM to its inactive state, at which point the PSMC module is frozen. The PSMC output pins are forced into the default inactive state ready for use when modulation starts.

FIGURE 26-19: PSMC MODULATION WAVEFORM



REGISTER 26-18: PSMCxASDS: PSMC AUTO-SHUTDOWN SOURCE REGISTER

R/W-0/0	U-0	U-0	R/W-0/0	R/W-0/0	R/W-0/0	R/W-0/0	U-0
PxASDSIN	—	—	PxASDSC4	PxASDSC3	PxASDSC2	PxASDSC1	—
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 **PxASDSIN:** Auto-shutdown occurs on PSMCxIN pin
1 = Auto-shutdown will occur when PSMCxIN pin goes true
0 = PSMCxIN pin will not cause auto-shutdown

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

bit 4 **PxASDSC4:** Auto-shutdown occurs on sync_C4OUT output
1 = Auto-shutdown will occur when sync_C4OUT output goes true
0 = sync_C4OUT will not cause auto-shutdown

bit 3 **PxASDSC3:** Auto-shutdown occurs on sync_C3OUT output
1 = Auto-shutdown will occur when sync_C3OUT output goes true
0 = sync_C3OUT will not cause auto-shutdown

bit 2 **PxASDSC2:** Auto-shutdown occurs on sync_C2OUT output
1 = Auto-shutdown will occur when sync_C2OUT output goes true
0 = sync_C2OUT will not cause auto-shutdown

bit 1 **PxASDSC1:** Auto-shutdown occurs on sync_C1OUT output
1 = Auto-shutdown will occur when sync_C1OU output goes true
0 = sync_C1OU will not cause auto-shutdown

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

27.2 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 (SCK)
- Serial Data Out (SDO)
- Serial Data In (SDI)
- Slave Select ($\overline{SS}$)

Figure 27-1 shows the block diagram of the MSSP 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 27-4 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 27-5 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 SDO output pin which is connected to, and received by, the slave's SDI input pin. The slave device transmits information out on its SDO output pin, which is connected to, and received by, the master's SDI 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 SDO 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 SDO pin) and the master device is reading this bit and saving it as the LSb of its shift register.

After eight 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.

27.6.13.2 Bus Collision During a Repeated Start Condition

During a Repeated Start condition, a bus collision occurs if:

a) A low level is sampled on SDA when SCL goes from low level to high level.
b) SCL goes low before SDA is asserted low, indicating that another master is attempting to transmit a data '1'.

When the user releases SDA and the pin is allowed to float high, the BRG is loaded with SSPADD and counts down to zero. The SCL pin is then deasserted and when sampled high, the SDA pin is sampled.

If SDA is low, a bus collision has occurred (i.e., another master is attempting to transmit a data '0', Figure 27-35). If SDA is sampled high, the BRG is reloaded and begins counting. If SDA goes from high-to-low before the BRG times out, no bus collision occurs because no two masters can assert SDA at exactly the same time.

If SCL goes from high-to-low before the BRG times out and SDA 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 27-36.

If, at the end of the BRG time-out, both SCL and SDA are still high, the SDA pin is driven low and the BRG is reloaded and begins counting. At the end of the count, regardless of the status of the SCL pin, the SCL pin is driven low and the Repeated Start condition is complete.

FIGURE 27-36: BUS COLLISION DURING A REPEATED START CONDITION (CASE 1)

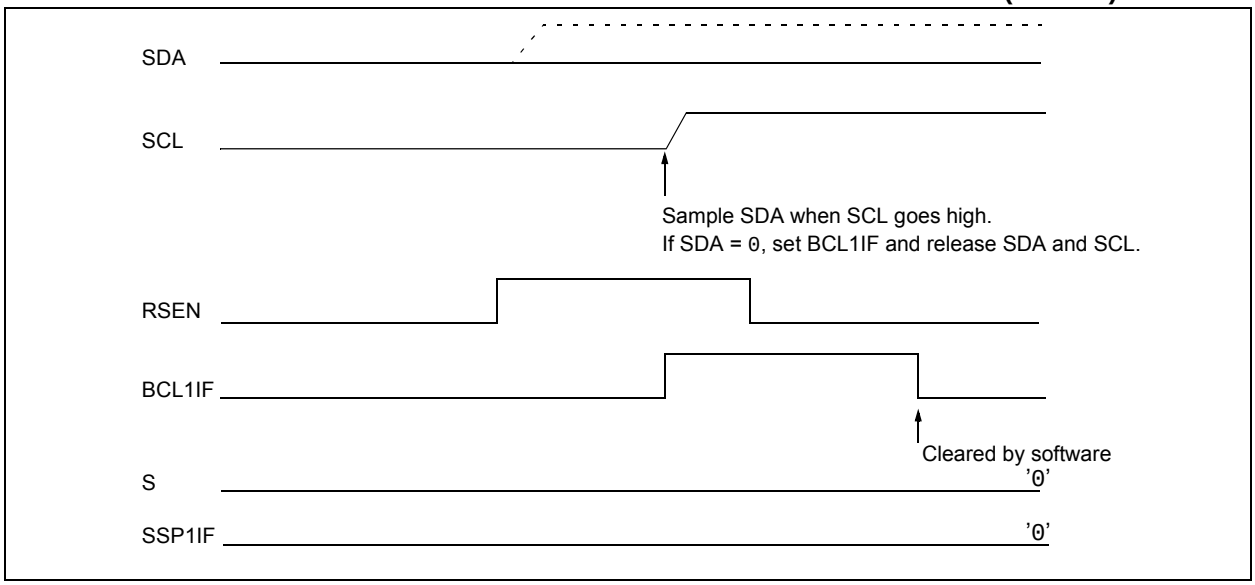
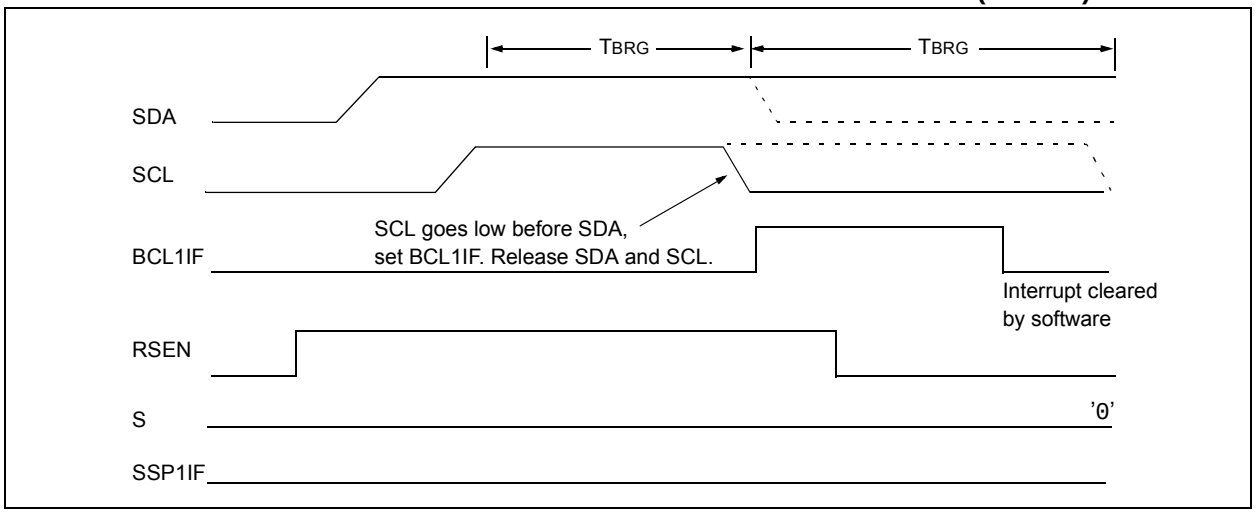


FIGURE 27-37: BUS COLLISION DURING REPEATED START CONDITION (CASE 2)



REGISTER 27-2: SSPCON1: SSP 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	SSPOV	SSPEN	CKP	SSPM<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 SSPBUF register was attempted while the I²C conditions were not valid for a transmission to be started
0 = No collision
Slave mode:
1 = The SSPBUF register is written while it is still transmitting the previous word (must be cleared in software)
0 = No collision

bit 6 **SSPOV:** Receive Overflow Indicator bit(1)
In SPI mode:
1 = A new byte is received while the SSPBUF register is still holding the previous data. In case of overflow, the data in SSPSR is lost. Overflow can only occur in Slave mode. In Slave mode, the user must read the SSPBUF, 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 SSPBUF register (must be cleared in software).
0 = No overflow
In I²C mode:
1 = A byte is received while the SSPBUF register is still holding the previous byte. SSPOV is a "don't care" in Transmit mode (must be cleared in software).
0 = No overflow

bit 5 **SSPEN:** 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 SCK, SDO, SDI and $\overline{SS}$ 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 SDA and SCL 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:
SCL 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 **SSPM<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 = SCK pin, $\overline{SS}$ pin control enabled
0101 = SPI Slave mode, clock = SCK pin, $\overline{SS}$ pin control disabled, $\overline{SS}$ can be used as I/O pin
0110 = I²C Slave mode, 7-bit address
0111 = I²C Slave mode, 10-bit address
1000 = I²C Master mode, clock = FOSC / (4 * (SSPADD+1))(4)
1001 = Reserved
1010 = SPI Master mode, clock = FOSC/(4 * (SSPADD+1))(5)
1011 = I²C firmware controlled Master mode (Slave idle)
1100 = Reserved
1101 = Reserved
1110 = I²C Slave mode, 7-bit address with Start and Stop bit interrupts enabled
1111 = I²C 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 SSPBUF register.
2: When enabled, these pins must be properly configured as input or output.
3: When enabled, the SDA and SCL pins must be configured as inputs.
4: SSPADD values of 0, 1 or 2 are not supported for I²C mode.
5: SSPADD value of '0' is not supported. Use SSPM = 0000 instead.

28.4.4 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 28-9 for the timing of the Break character sequence.

28.4.4.1 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.

28.4.5 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 28.4.3 "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 28-9: SEND BREAK CHARACTER SEQUENCE

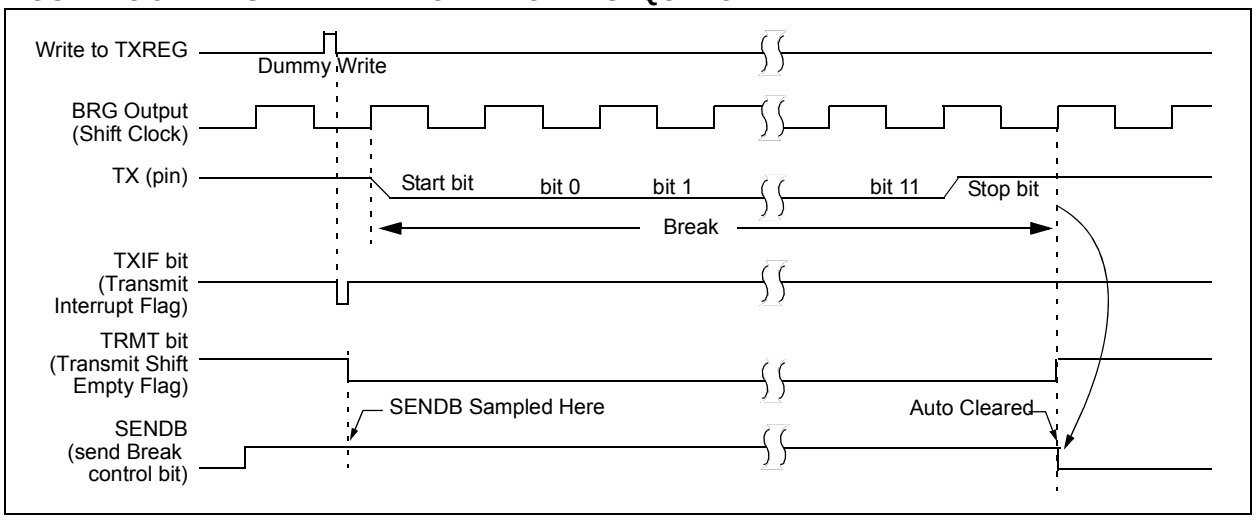
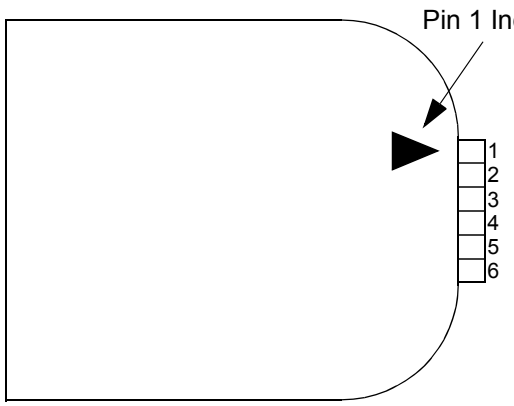


FIGURE 29-2: PICkit™ PROGRAMMER STYLE CONNECTOR INTERFACE



Pin Description*

1 = VPP/$\overline{\text{MCLR}}$

2 = VDD Target

3 = VSS (ground)

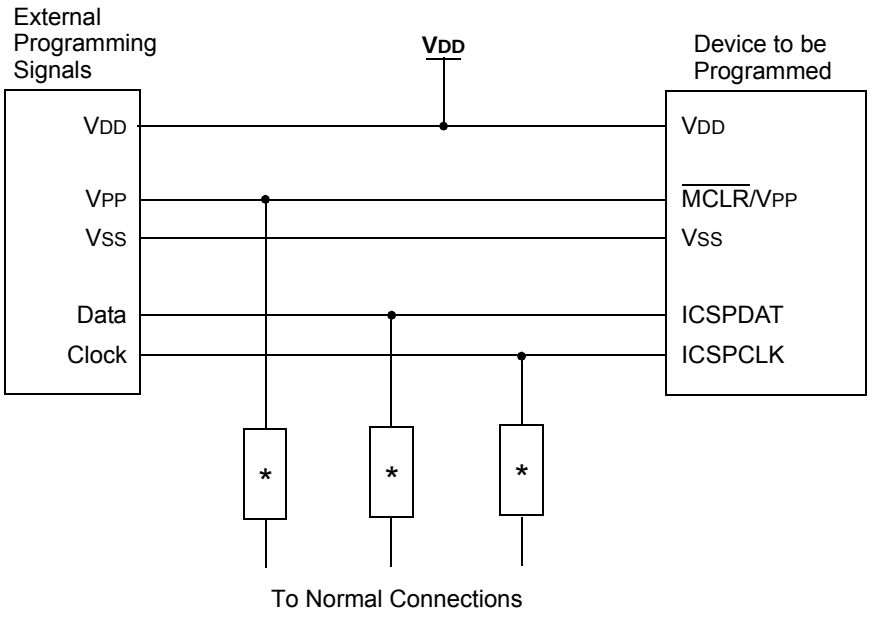
4 = ICSPDAT

5 = ICSPCLK

6 = No Connect

* The 6-pin header (0.100" spacing) accepts 0.025" square pins.

FIGURE 29-3: TYPICAL CONNECTION FOR ICSP™ PROGRAMMING



* Isolation devices (as required).

30.0 INSTRUCTION SET SUMMARY

Each instruction is a 14-bit word containing the operation code (opcode) and all required operands. The opcodes 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 30-3 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)

TABLE 30-1: 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 30-2: ABBREVIATION DESCRIPTIONS

Field	Description
PC	Program Counter
$\overline{TO}$	Time-Out bit
C	Carry bit
DC	Digit Carry bit
Z	Zero bit
PD	Power-Down bit

- 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.

30.1 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.

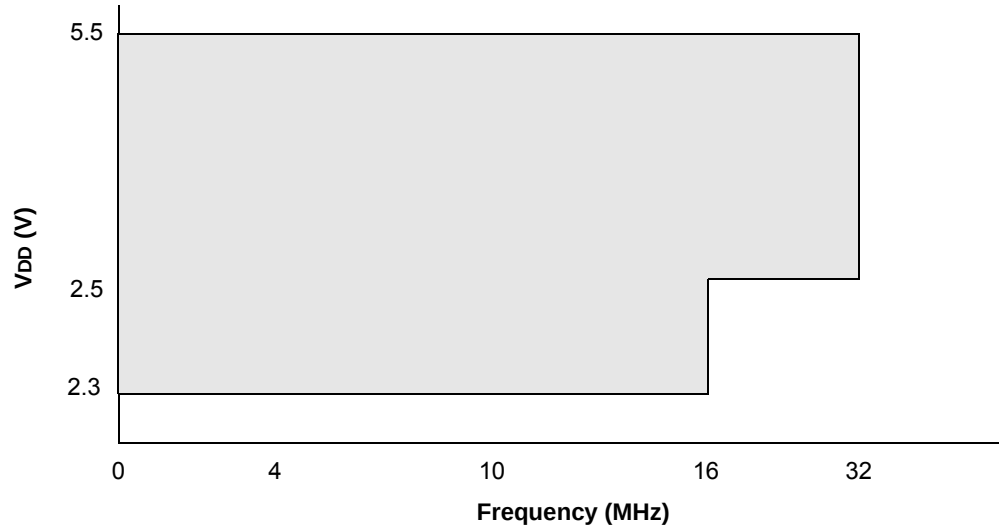
TABLE 30-3: ENHANCED MID-RANGE INSTRUCTION SET

Mnemonic, Operands		Description	Cycles	14-Bit Opcode MSb			LSb	Status Affected	Notes
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	lfff	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.

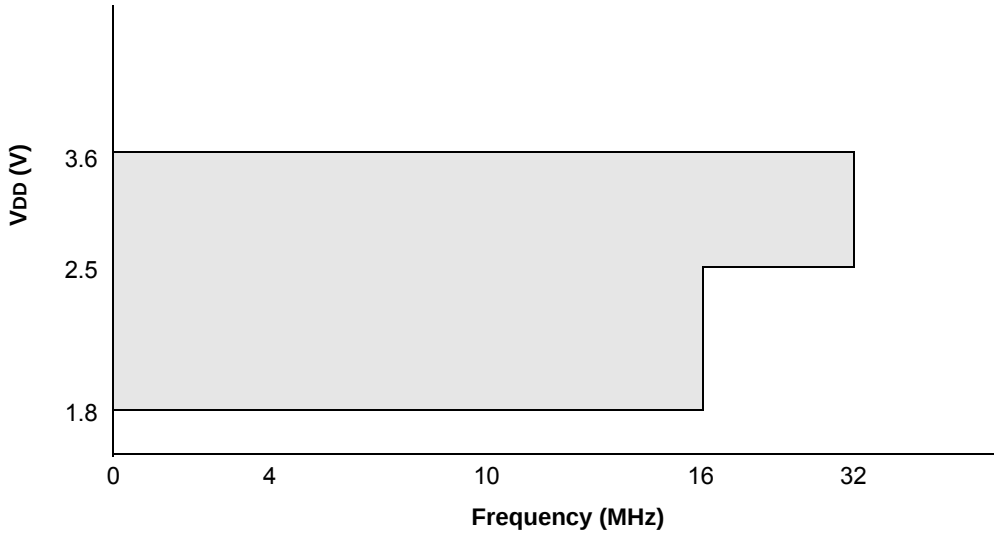
2: If this instruction addresses an INDF register and the MSb of the corresponding FSR is set, this instruction will require one additional instruction cycle.

FIGURE 31-1: PIC16F1788/9 VOLTAGE FREQUENCY GRAPH, -40°C ≤ TA ≤ +125°C



Note 1: The shaded region indicates the permissible combinations of voltage and frequency.
2: Refer to Table 31-6 for each Oscillator mode's supported frequencies.

FIGURE 31-2: PIC16LF1788/9 VOLTAGE FREQUENCY GRAPH, -40°C ≤ TA ≤ +125°C



Note 1: The shaded region indicates the permissible combinations of voltage and frequency.
2: Refer to Table 31-6 for each Oscillator mode's supported frequencies.

TABLE 31-7: OSCILLATOR PARAMETERS

Standard Operating Conditions (unless otherwise stated)								
Param No.	**Sym.**	**Characteristic**	**Freq. Tolerance**	**Min.**	**Typ†**	**Max.**	**Units**	**Conditions**
OS08	HFOSC	Internal Calibrated HFINTOSC Frequency(2)	±2%	—	16.0	—	MHz	0°C ≤ TA ≤ +60°C, VDD ≥ 2.5V
			±3%	—	16.0	—	MHz	60°C ≤ TA ≤ 85°C, VDD ≥ 2.5V
			±5%	—	16.0	—	MHz	-40°C ≤ TA ≤ +125°C
OS08A	MFOSC	Internal Calibrated MFINTOSC Frequency(2)	±2%	—	500	—	kHz	0°C ≤ TA ≤ +60°C, VDD ≥ 2.5V
			±3%	—	500	—	kHz	60°C ≤ TA ≤ 85°C, VDD ≥ 2.5V
			±5%	—	500	—	kHz	-40°C ≤ TA ≤ +125°C
OS09	LFOSC	Internal LFINTOSC Frequency	—	—	31	—	kHz	-40°C ≤ TA ≤ +125°C
OS10*	TWARM	HFINTOSC Wake-up from Sleep Start-up Time	—	—	3.2	8	µs	VREGPM = 0
		MFINTOSC Wake-up from Sleep Start-up Time	—	—	24	35	µs	VREGPM = 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: 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.

FIGURE 31-6: HFINTOSC FREQUENCY ACCURACY OVER DEVICE VDD AND TEMPERATURE

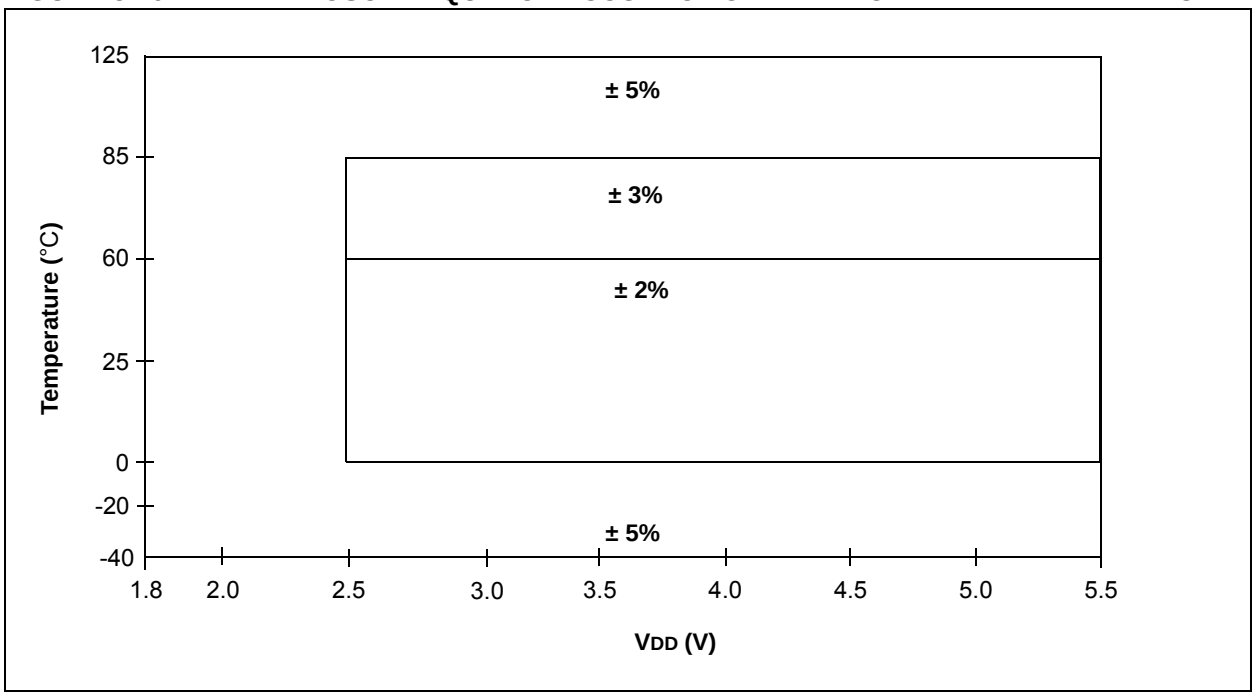


TABLE 31-17: 5-BIT DIGITAL-TO-ANALOG CONVERTER (DAC) SPECIFICATIONS

Operating Conditions: V_{DD} = 3V, Temperature = 25°C (unless otherwise stated).							
Param No.	**Sym.**	**Characteristics**	**Min.**	**Typ.**	**Max.**	**Units**	**Comments**
DAC01*	C_{LSB}5	Step Size	—	V_{DD}/32	—	V	
DAC02*	C_{ACC}5	Absolute Accuracy	—	—	± 1/2	LSb	
DAC03*	C_R5	Unit Resistor Value (R)	—	5K	—	Ω	
DAC04*	C_{ST}5	Settling Time(2)	—	—	10	μs	

* These parameters are characterized but not tested.

Note 1: See **Section 32.0 "DC and AC Characteristics Graphs and Charts"** for operating characterization.

2: Settling time measured while DACR<7:0> transitions from '00000' to '01111'.

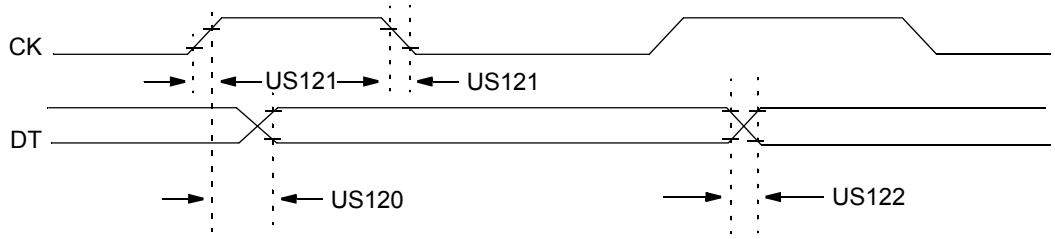
TABLE 31-18: 8-BIT DIGITAL-TO-ANALOG CONVERTER (DAC) SPECIFICATIONS

Operating Conditions: V_{DD} = 3V, Temperature = 25°C (unless otherwise stated).							
Param No.	**Sym.**	**Characteristics**	**Min.**	**Typ.**	**Max.**	**Units**	**Comments**
DAC05*	C_{LSB}8	Step Size	—	V_{DD}/256	—	V	
DAC06*	C_{ACC}8	Absolute Accuracy	—	—	± 1.5	LSb	
DAC07*	C_R8	Unit Resistor Value (R)	—	600	—	Ω	
DAC08*	C_{ST}8	Settling Time(1)	—	—	10	μs	

* These parameters are characterized but not tested.

Note 1: Settling time measured while DACR<7:0> transitions from '0x00' to '0xFF'.

FIGURE 31-14: EUSART SYNCHRONOUS TRANSMISSION (MASTER/SLAVE) TIMING



Note: Refer to Figure 31-4 for load conditions.

TABLE 31-19: EUSART SYNCHRONOUS TRANSMISSION REQUIREMENTS

Standard Operating Conditions (unless otherwise stated)							
Param. No.	**Symbol**	**Characteristic**		**Min.**	**Max.**	**Units**	**Conditions**
US120	$T_{CK}H2_{DT}V$	SYNC XMIT (Master and Slave) Clock high to data-out valid	3.0-5.5V	—	80	ns	
			1.8-5.5V	—	100	ns	
US121	T_{CKRF}	Clock out rise time and fall time (Master mode)	3.0-5.5V	—	45	ns	
			1.8-5.5V	—	50	ns	
US122	T_{DTRF}	Data-out rise time and fall time	3.0-5.5V	—	45	ns	
			1.8-5.5V	—	50	ns	

Note: Unless otherwise noted, V_{IN} = 5V, F_{OSC} = 300 kHz, C_{IN} = 0.1 µF, T_A = 25°C.

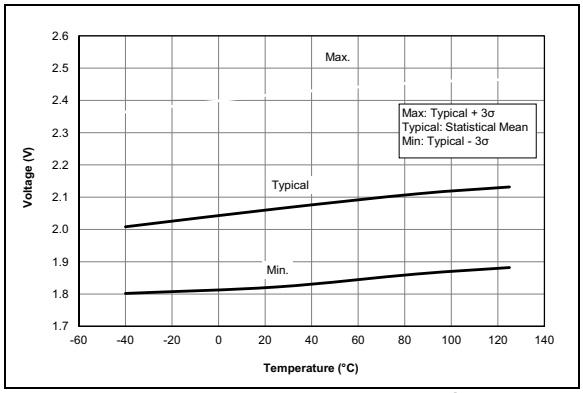


FIGURE 32-67: *LPBOR Reset Voltage.*

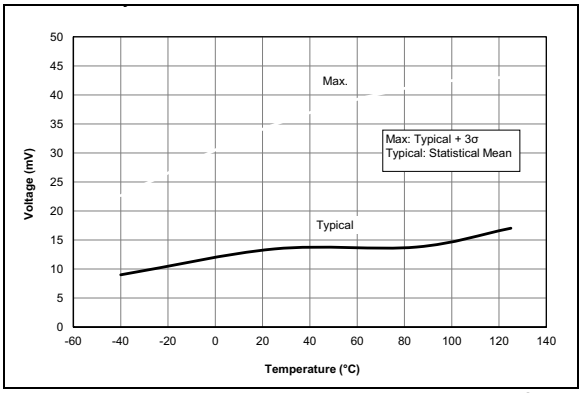


FIGURE 32-68: *LPBOR Reset Hysteresis.*

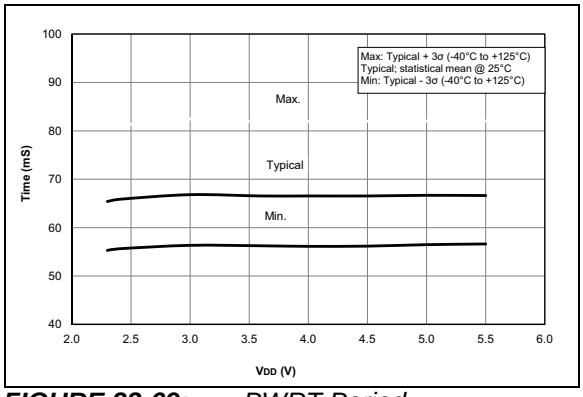


FIGURE 32-69: *PWRT Period, PIC16F1788/9 Only.*

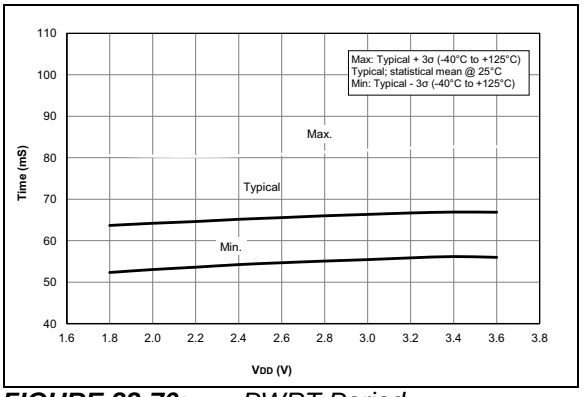


FIGURE 32-70: *PWRT Period, PIC16LF1788/9 Only.*

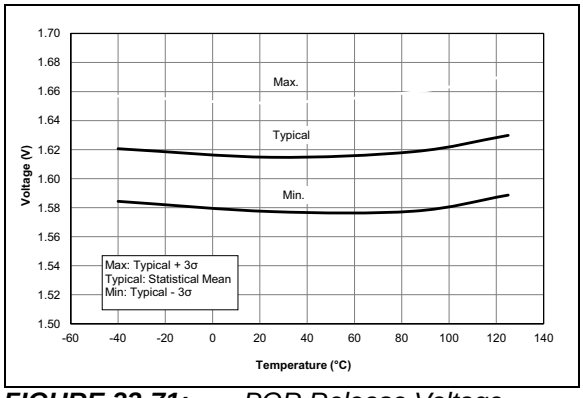


FIGURE 32-71: *POR Release Voltage.*

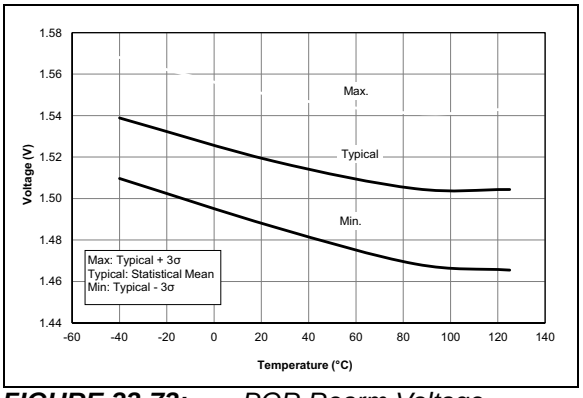


FIGURE 32-72: *POR Rearm Voltage, NP Mode (VREGPM = 0), PIC16F1788/9 Only.*