
Digitally-Enhanced Power Analog Synchronous Low-Side Dual-Loop PWM Controller

Features

- Input Voltage: 4.5V to 42V
- Individual Analog Control Loops for Current or Voltage Regulation
- Can be configured with multiple topologies including but not limited to:
 - Flyback
 - Ćuk
 - Boost
 - SEPIC (Single-Ended Primary-Inductor Converter)
- Capable of Quasi-Resonant or Fixed-Frequency Operation
- Low Quiescent Current: 5 mA Typical
- Low Sleep Current: 50 μ A Typical
- Low-Side Gate Drivers:
 - +5V gate drive with 0.5A sink/source current
 - +10V gate drive with 1A sink/source current
- Peak Current Mode Control
- Differential Remote Output Sense
- Multiple Output Systems:
 - Master or Slave
- AEC-Q100 Qualified
- Configurable Parameters:
 - V_{REF} Precision I_{OUT}/V_{OUT} Set Point (DAC)
 - ADC Reference Switch (V_{DD} or AV_{DD})
 - Input Undervoltage Lockout (UVLO)
 - Input Overvoltage Lockout (OVLO)
 - Detection and protection
 - Primary current leading edge blanking (0 ns, 50 ns, 100 ns and 200 ns)
 - Gate drive dead time (16 ns to 256 ns)
 - Fixed switching frequency range: 31.25 kHz to 2.0 MHz
 - Slope compensation
 - Quasi-resonant configuration with built-in comparator and programmable offset voltage adjustment
 - Primary current offset adjustment
 - GPIO pin options
- Integrated Low-Side Differential Current Sense Amplifier
- Better than $\pm 5\%$ Current Regulation
- Thermal Shutdown

Microcontroller Features

- Precision 8 MHz Internal Oscillator Block:
 - Factory-calibrated to $\pm 1\%$, typical
- Interrupt-Capable:
 - Firmware
 - Interrupt-on-change pins
- Only 35 Instructions to Learn
- 4095 Words On-Chip Program Memory
- High-Endurance Flash:
 - 100,000 write Flash endurance
 - Flash retention: > 40 years
- Watchdog Timer (WDT) with Independent Oscillator for Reliable Operation
- Programmable Code Protection
- In-Circuit Serial Programming™ (ICSP™) via Two Pins
- Eight I/O Pins and One Input-Only Pin:
 - Two open-drain pins
- Analog-to-Digital Converter (ADC):
 - 10-bit resolution
 - Five external channels
- Timer0: 8-bit Timer/Counter with 8-bit Prescaler
- Enhanced Timer1:
 - 16-bit timer with prescaler
 - Two selectable clock sources
- Timer2: 8-Bit Timer with Prescaler:
 - 8-bit period register
- I²C Communication:
 - 7-bit address masking
 - Two dedicated address registers

MCP19124/5

Pin Diagram – 24-Pin QFN (MCP19124)

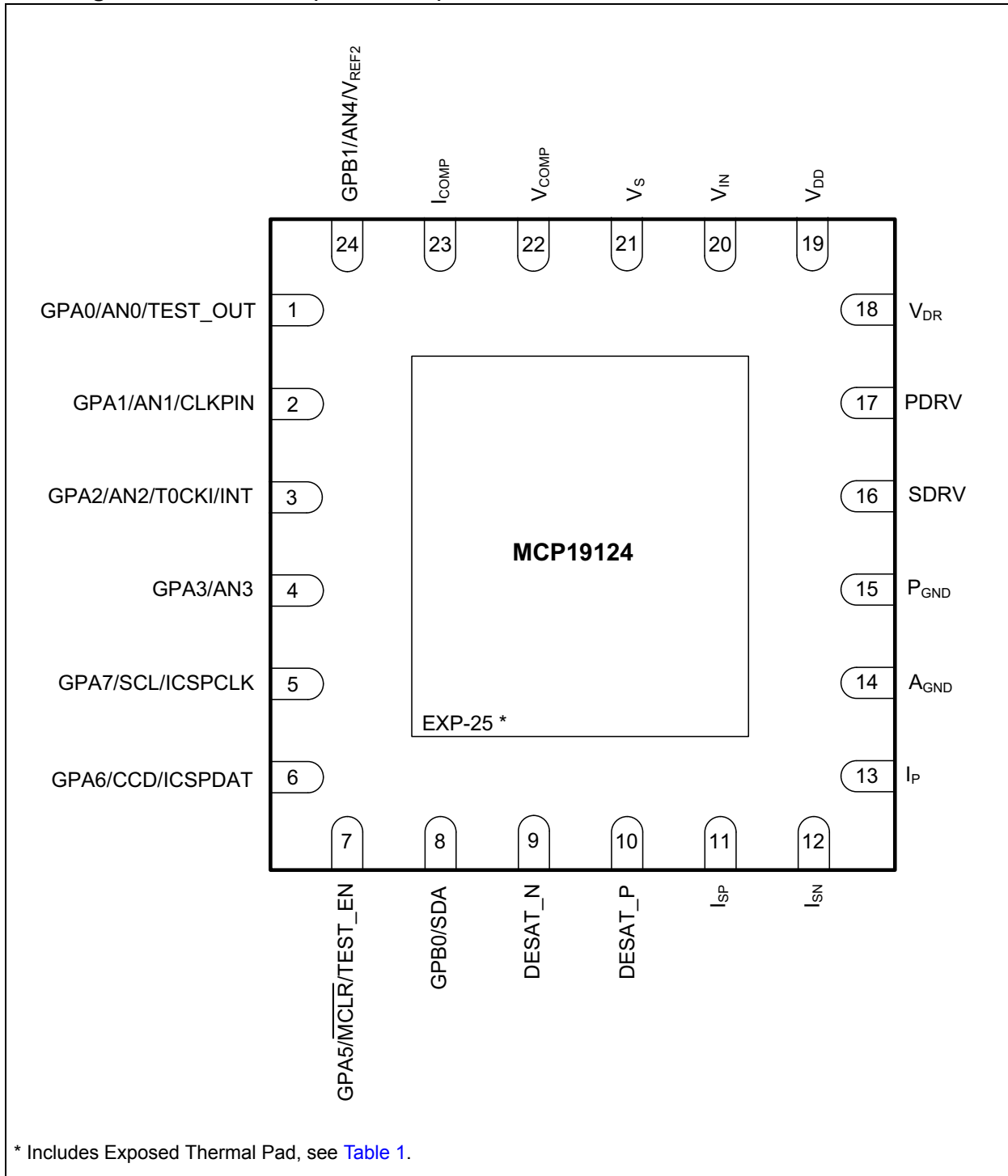


TABLE 1: 24-PIN QFN (MCP19124) SUMMARY

| I/O | 24-Pin QFN | ANSEL | A/D | Timers | MSSP | Interrupt | Pull-Up | Basic | Additional |
|--------------------|------------|-------|-----|--------|------|--------------------|------------------|--------------------------|--|
| GPA0 | 1 | Y | AN0 | — | — | IOC | Y | — | Analog/Digital Debug Output ⁽¹⁾ |
| GPA1 | 2 | Y | AN1 | — | — | IOC | Y | — | Sync Signal In/Out ⁽²⁾ |
| GPA2 | 3 | Y | AN2 | T0CKI | — | IOC INT | Y | — | — |
| GPA3 | 4 | Y | AN3 | — | — | IOC | Y | — | — |
| GPA5 | 7 | N | — | — | — | IOC ⁽³⁾ | Y ⁽⁴⁾ | $\overline{\text{MCLR}}$ | Test Enable Input |
| GPA6 | 6 | N | — | — | — | IOC | Y | ICSPDAT | Dual Capture/Compare Input |
| GPA7 | 5 | N | — | — | SCL | IOC | N | ICSPCLK | — |
| GPB0 | 8 | N | — | — | SDA | IOC | N | — | — |
| GPB1 | 24 | Y | AN4 | — | — | IOC | Y | — | V _{REF2} ⁽⁵⁾ |
| DESAT _N | 9 | N | — | — | — | — | — | — | DESAT Negative Input |
| DESAT _P | 10 | N | — | — | — | — | — | — | DESAT Positive Input |
| I _{SP} | 11 | N | — | — | — | — | Y | — | Current Sense Amplifier Positive Input |
| I _{SN} | 12 | N | — | — | — | — | — | — | Current Sense Amplifier Negative Input |
| I _P | 13 | N | — | — | — | — | — | — | Primary Input Current Sense |
| A _{GND} | 14 | N | — | — | — | — | — | A _{GND} | Small Signal Ground |
| P _{GND} | 15 | N | — | — | — | — | — | P _{GND} | Large Signal Ground |
| SDRV | 16 | N | — | — | — | — | — | — | Secondary LS Gate Drive Output |
| PDRV | 17 | N | — | — | — | — | — | — | Primary LS Gate Drive Output |
| V _{DR} | 18 | N | — | — | — | — | — | V _{DR} | Gate Drive Supply Voltage |
| V _{DD} | 19 | N | — | — | — | — | — | V _{DD} | V _{DD} Output |
| V _{IN} | 20 | N | — | — | — | — | — | V _{IN} | Input Supply Voltage |
| V _S | 21 | N | — | — | — | — | — | — | Output Voltage Sense |
| V _{COMP} | 22 | N | — | — | — | — | — | — | EA2 Voltage Error Amplifier Output |
| I _{COMP} | 23 | N | — | — | — | — | — | — | EA1 Current Error Amplifier Output |
| EXP | 25 | N | — | — | — | — | — | — | Exposed Thermal Pad |

- Note 1:** The Analog/Digital Debug Output is selected through the control of the ABECON register.
- 2:** Selected when functioning as master or slave by proper configuration of the MSC<1:0> bits in the MODECON register.
- 3:** The IOC is disabled when $\overline{\text{MCLR}}$ is enabled.
- 4:** Weak pull-up always enabled when $\overline{\text{MCLR}}$ is enabled, otherwise the pull-up is under user control.
- 5:** V_{REF2} output selected when configured as master by proper configuration of the MSC<1:0> bits in the MODECON register.

MCP19124/5

Pin Diagram – 28-Pin QFN (MCP19125)

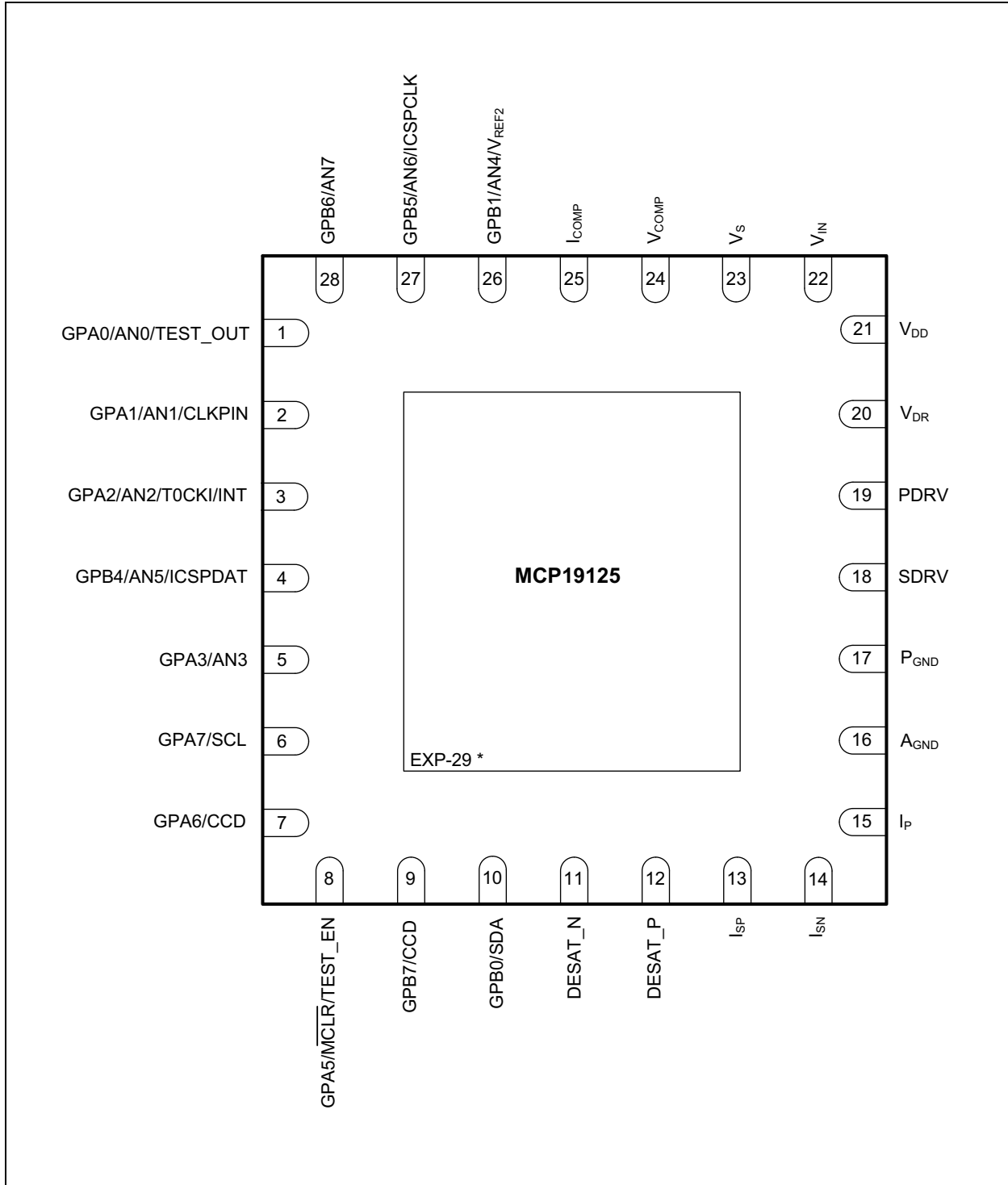


TABLE 2: 28-PIN (MCP19125) SUMMARY

| I/O | 28-Pin QFN | ANSEL | A/D | Timers | MSSP | Interrupt | Pull-Up | Basic | Additional |
|--------------------|------------|-------|-----|--------|------|--------------------|------------------|--------------------------|--|
| GPA0 | 1 | Y | AN0 | — | — | IOC | Y | — | Analog/Digital Debug Output ⁽¹⁾ |
| GPA1 | 2 | Y | AN1 | — | — | IOC | Y | — | Sync Signal In/Out ⁽²⁾ |
| GPA2 | 3 | Y | AN2 | T0CKI | — | IOC INT | Y | — | — |
| GPA3 | 5 | Y | AN3 | — | — | IOC | Y | — | — |
| GPA5 | 8 | N | — | — | — | IOC ⁽³⁾ | Y ⁽⁴⁾ | $\overline{\text{MCLR}}$ | Test Enable Input |
| GPA6 | 7 | N | — | — | — | IOC | Y | — | Dual Capture/Single Compare1 Input |
| GPA7 | 6 | N | — | — | SCL | IOC | N | — | — |
| GPB0 | 10 | N | — | — | SDA | IOC | N | — | — |
| GPB1 | 26 | Y | AN4 | — | — | IOC | Y | — | V _{REF2} ⁽⁵⁾ |
| GPB4 | 4 | Y | AN5 | — | — | IOC | Y | ICSPDAT | — |
| GPB5 | 27 | Y | AN6 | — | — | IOC | Y | ICSPCLK | — |
| GPB6 | 28 | Y | AN7 | — | — | IOC | Y | — | — |
| GPB7 | 9 | Y | — | — | — | IOC | Y | — | Single Compare2 Input |
| DESAT _N | 11 | N | — | — | — | — | — | — | DESAT Negative Input |
| DESAT _P | 12 | N | — | — | — | — | — | — | DESAT Positive input |
| I _{SP} | 13 | N | — | — | — | — | Y | — | Current Sense Amplifier Noninverting Input |
| I _{SN} | 14 | N | — | — | — | — | — | — | Current Sense Amplifier Inverting Input |
| I _P | 15 | N | — | — | — | — | — | — | Primary Input Current Sense |
| A _{GND} | 16 | N | — | — | — | — | — | A _{GND} | Small Signal Ground |
| P _{GND} | 17 | N | — | — | — | — | — | P _{GND} | Large Signal Ground |
| SDRV | 18 | N | — | — | — | — | — | — | Secondary LS Gate Drive Output |
| PDRV | 19 | N | — | — | — | — | — | — | Primary LS Gate Drive Output |
| V _{DR} | 20 | N | — | — | — | — | — | V _{DR} | Gate Drive Supply Voltage |
| V _{DD} | 21 | N | — | — | — | — | — | V _{DD} | V _{DD} Output |
| V _{IN} | 22 | N | — | — | — | — | — | V _{IN} | Input Supply Voltage |
| V _S | 23 | N | — | — | — | — | — | — | Output Voltage Sense |
| V _{COMP} | 24 | N | — | — | — | — | — | — | EA2 Voltage Error Amplifier Output |
| I _{COMP} | 25 | N | — | — | — | — | — | — | EA1 Current Error Amplifier Output |
| EXP | 29 | N | — | — | — | — | — | — | Exposed Thermal Tab |

- Note 1:** The Analog/Digital Debug Output is selected through the control of the ABECON register.
- 2:** Selected when functioning as master or slave by proper configuration of the MSC<1:0> bits in the MODECON register.
- 3:** The IOC is disabled when $\overline{\text{MCLR}}$ is enabled.
- 4:** Weak pull-up always enabled when $\overline{\text{MCLR}}$ is enabled, otherwise the pull-up is under user control.
- 5:** V_{REF2} output selected when configured as master by proper configuration of the MSC<1:0> bits in the MODECON register.

MCP19124/5

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

To determine if an errata sheet exists for a particular device, please check with one of the following:

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MCP19124/5

NOTES:

1.0 DEVICE OVERVIEW

The MCP19124/5 are highly integrated, mixed-signal low-side synchronous controllers that operate from 4.5V to 42V. The family features individual analog PWM control loops for both current regulation or voltage regulation. These features along with an integrated microcontroller core make this an ideal device used for battery charging applications, LED lighting systems and any other low-side switch PWM applications. The MCP19124/5 devices are derived from the MCP19114/5 Enhanced PWM Controllers with the exception of some additional features along with an additional analog control loop designed for voltage regulation. Complete customization of device operating parameters, start-up or shutdown profiles, protection levels and fault handling procedures are accomplished by setting digital registers using Microchip's MPLAB® X Integrated Development Environment software and one of Microchip's many in-circuit debugger and device programmers.

The MCP19124/5 mixed-signal low-side synchronous controllers feature integrated programmable input UVLO/OVLO, programmable output overvoltage (OV), two low-side gate drive outputs with independent programmable dead time, programmable leading edge blanking (four steps), programmable 6-bit slope compensation and an integrated internal programmable oscillator for fixed-frequency applications. If users decide to regulate voltage via EA2 voltage error amplifier and control loop, the output OV is disabled. An integrated 8-bit reference voltage (V_{REF}) is used for setting output current. A separate integrated 8-bit reference voltage (OV_{REF}) is used to set the voltage regulation set point or the overvoltage protection set point. An internal comparator supports quasi-resonant applications. Additional Capture and Compare modules are integrated for additional control, including enhanced dimming capability.

The MCP19124/5 devices contain two internal LDOs. A 5V LDO (V_{DD}) is used to power the internal processor and provide 5V externally. A 4V LDO (AV_{DD}) is used to power the internal analog circuitry. Either V_{DD} or AV_{DD} can be connected internally to the 10 bit Analog-to-Digital Converter reference input. The 5V external output can be used to supply the gate drive. An analog filter between the V_{DD} output and the V_{DR} input is recommended when implementing a 5V gate drive supplied from V_{DD} . Two 4.7 μ F capacitors are recommended with one placed as close as possible to V_{DD} and one as close as possible to V_{DR} , separated by a 10 Ω isolation resistor. DO NOT exceed 10 μ F on the V_{DD} . An external supply is required to implement higher gate drive voltages.

By utilizing a Microchip Technology Incorporated TC1240A voltage doubler supplied from V_{DD} to provide V_{DR} , a 10V gate drive can be achieved.

The 4V LDO is used to power the internal analog circuitry. The two low-side drivers can be used to operate the power converter in bidirectional mode, enabling the "shaping" of LED dimming current in LED applications or developing bidirectional power converters for battery-powered applications.

The MCP19124 is packaged in a 24-lead 4 mm x 4 mm QFN and offers an alternate-bonded 28-lead 5 mm x 5 mm QFN. The MCP19125 is packaged in a 28-lead 5 mm x 5 mm QFN.

The ability for system designers to configure application-specific features allows users of the MCP19124/5 devices to save costly board real estate and additional component costs. The General Purpose Input/Output (GPIO) of the MCP19124/5 can be configured to offer a status output:

- a device enable, to control an external switch
- a switching frequency synchronization output or input
- and even a device status or "heartbeat" indicator.

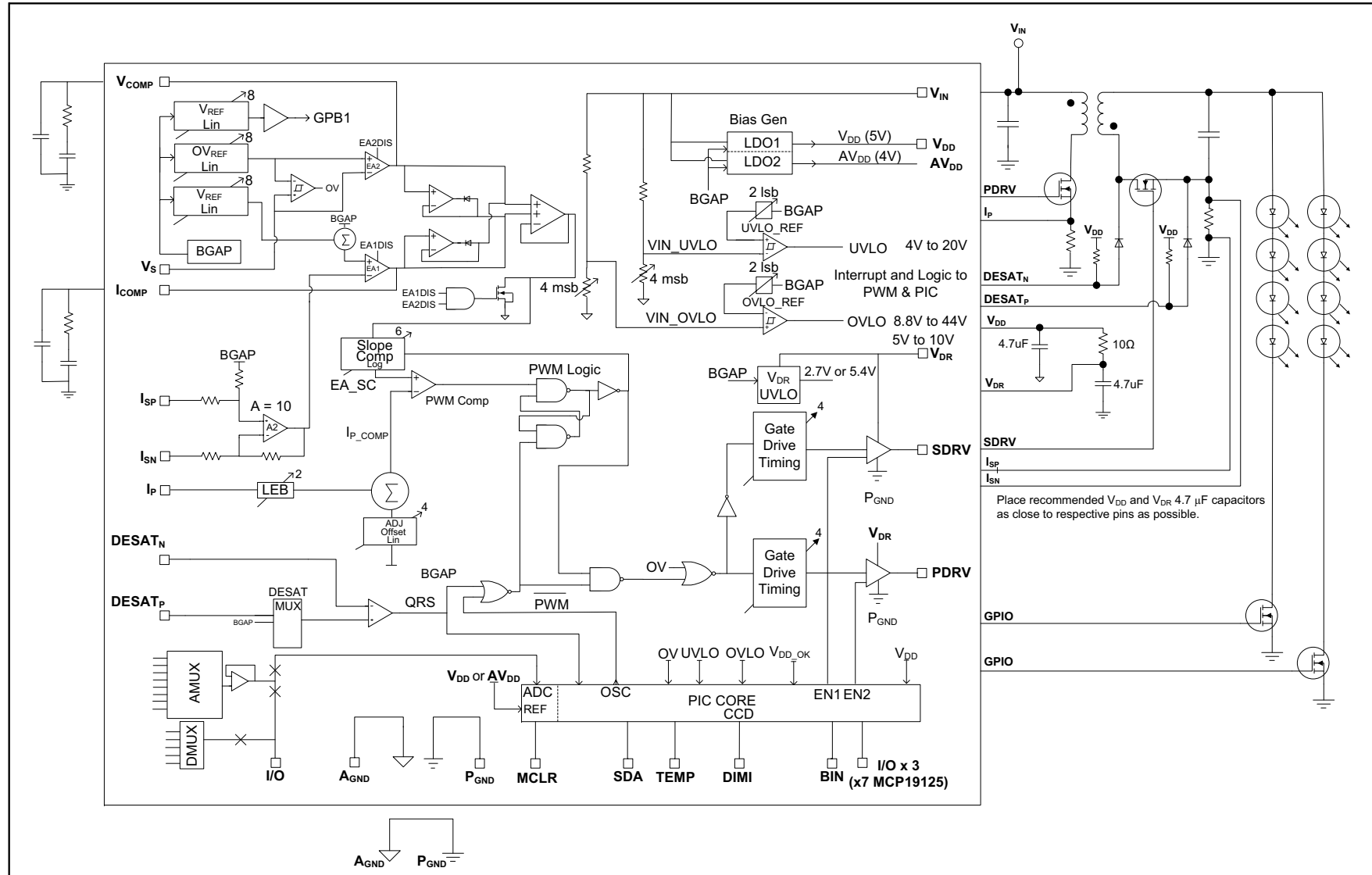
With integrated features like output current adjustment and dynamic output voltage positioning, the MCP19124/5 family has the best in-class performance and highest integration level currently available.

Power trains supported by this architecture include but are not limited to boost, flyback, quasi-resonant flyback, SEPIC, Ćuk, etc.

Two low-side gate drivers are capable of sinking and sourcing 1A at 10V V_{DR} . With a 5V gate drive, the driver is capable of 0.5A sink and source. The user has the option to allow the V_{IN} UVLO to shut down the drivers by setting the UVLOEN bit. When this bit is not set, the device drivers will ride through the UVLO condition and continue to operate until V_{DR} reaches the gate drive UVLO value. This value is selectable at 2.7V or 5.4V and is always enabled. An internal reset for the microcontroller core is set to 2.0V. An internal comparator module is used to sense the desaturation of the flyback transformer to synchronize switching for quasi-resonant applications.

The operating input voltage for normal device operation ranges from 4.5V to 42V with an absolute maximum of 44V. The maximum transient voltage is 48V for 500 ms. An I²C serial bus is used for device communications from the PWM controller to the system.

FIGURE 1-1: MCP19124/5 FLYBACK SYNCHRONOUS QUASI-RESONANT BLOCK DIAGRAM



Place recommended V_{DD} and V_{DR} 4.7 μ F capacitors as close to respective pins as possible.

FIGURE 1-2: MCP19124 ĆUK SYNCHRONOUS POSITIVE OUTPUT APPLICATION DIAGRAM

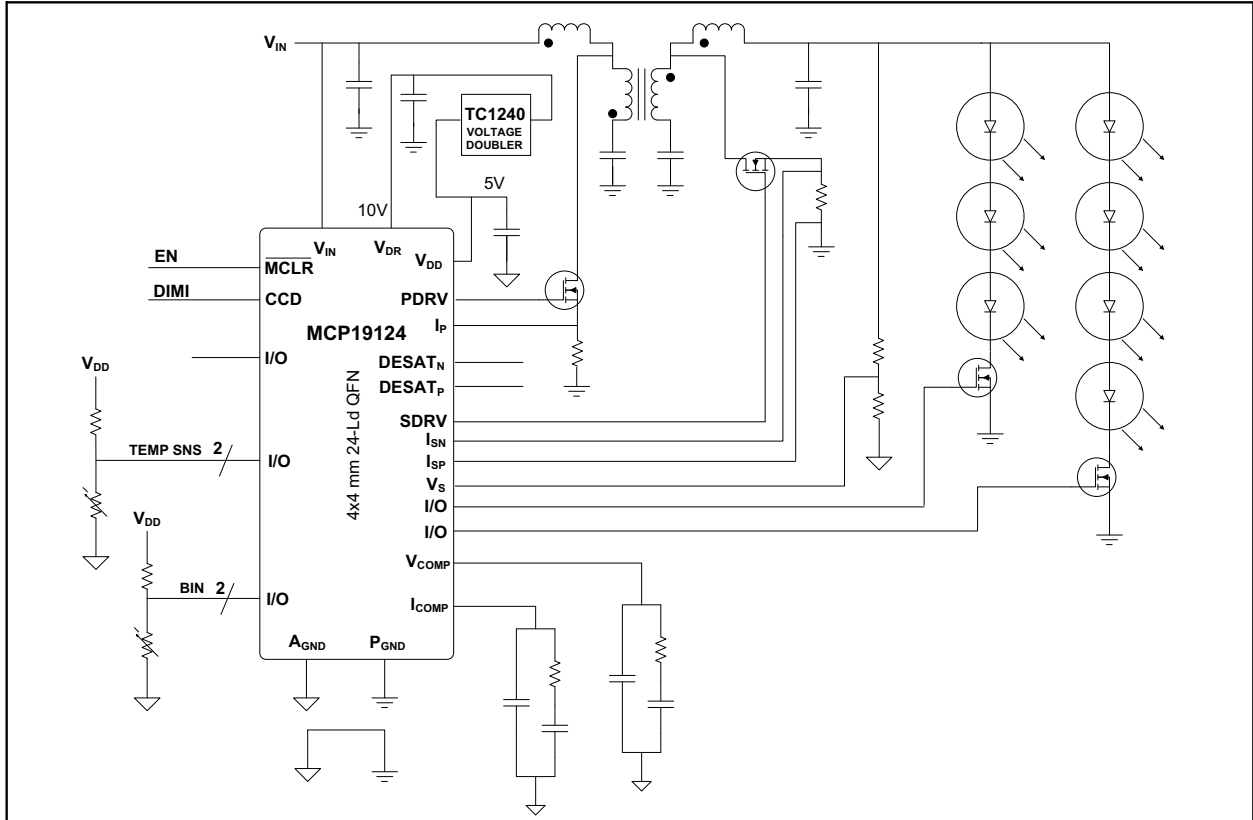
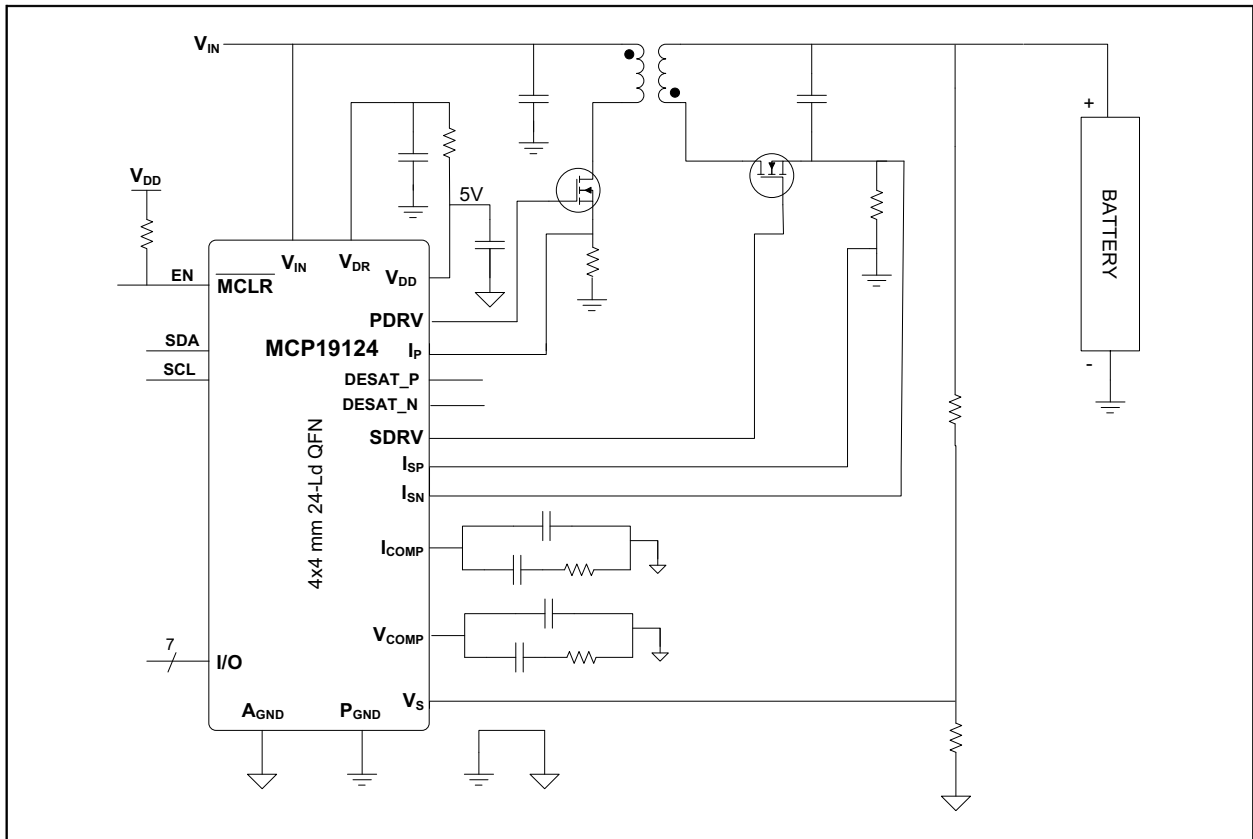
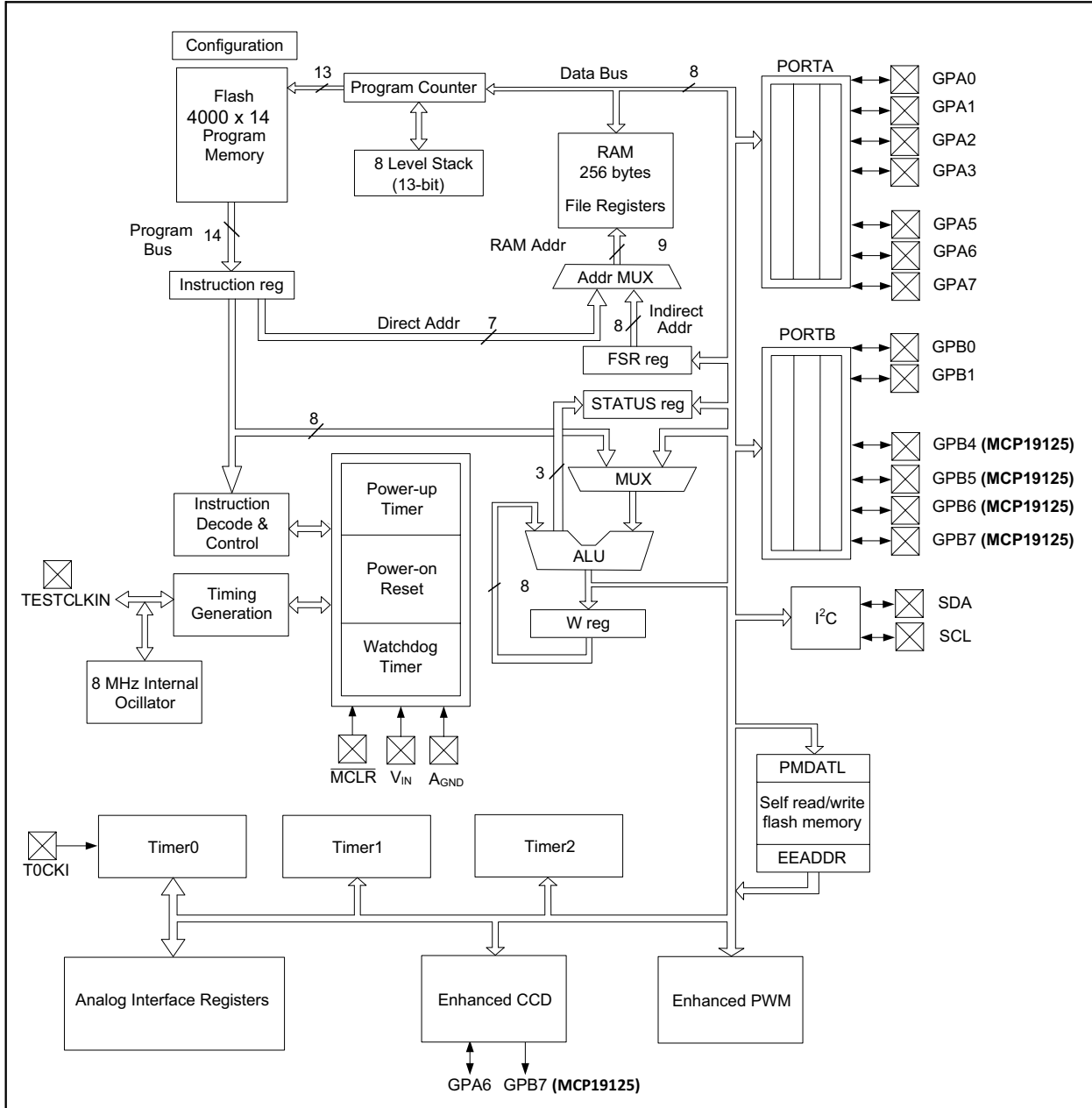


FIGURE 1-3: MCP19124 FLYBACK BATTERY CHARGER APPLICATION DIAGRAM



MCP19124/5

FIGURE 1-4: MICROCONTROLLER CORE BLOCK DIAGRAM



2.0 PIN DESCRIPTION

The 24-lead MCP19124 and 28-lead MCP19125 devices feature pins that have multiple functions associated with each pin. [Table 2-1](#) provides a description of the different functions. Refer to [Section 2.1 “Detailed Pin Functional Description”](#) for more information.

TABLE 2-1: MCP19124/5 PINOUT DESCRIPTION

| Name | Function | Input Type | Output Type | Description |
|----------------------------------|-------------------|------------------|-------------|--|
| GPA0/AN0/TEST_OUT | GPA0 | TTL | CMOS | General-purpose I/O |
| | AN0 | AN | — | A/D Channel 0 input |
| | TEST_OUT | — | — | Internal analog/digital signal multiplexer output ⁽¹⁾ |
| GPA1/AN1/CLKPIN | GPA1 | TTL | CMOS | General-purpose I/O |
| | AN1 | AN | — | A/D Channel 1 input |
| | CLKPIN | ST | CMOS | Switching frequency clock input or output ⁽²⁾ |
| GPA2/AN2/T0CKI/INT | GPA2 | ST | CMOS | General-purpose I/O |
| | AN2 | AN | — | A/D Channel 2 input |
| | T0CKI | ST | — | Timer0 clock input |
| | INT | ST | — | External interrupt |
| GPA3/AN3 | GPA3 | TTL | CMOS | General-purpose I/O |
| | AN3 | AN | — | A/D Channel 3 input |
| GPA5/MCLR | GPA5 | TTL | — | General-purpose input only |
| | MCLR | ST | — | Master Clear with internal pull-up |
| GPA6/CCD/ICSPDAT | GPA6 | ST | CMOS | General-purpose I/O |
| | ICSPDAT | ST | CMOS | Serial Programming Data I/O |
| | CCD | ST | CMOS | Single Compare output. Dual Capture input |
| GPA7/SCL/ICSPCLK | GPA7 | ST | OD | General-purpose open drain I/O |
| | SCL | I ² C | OD | I ² C clock |
| | ICSPCLK | ST | — | Serial Programming Clock |
| GPB0/SDA | GPB0 | TTL | OD | General-purpose I/O |
| | SDA | I ² C | OD | I ² C data input/output |
| GPB1/AN4/V _{REF2} | GPB1 | TTL | CMOS | General-purpose I/O |
| | AN4 | AN | — | A/D Channel 4 input |
| | V _{REF2} | — | AN | V _{REF2} DAC Output ⁽³⁾ |
| GPB4/AN5/ICSPDAT (MCP19125 Only) | GPB4 | TTL | CMOS | General-purpose I/O |
| | AN5 | AN | — | A/D Channel 5 input |
| | ICSPDAT | ST | CMOS | Primary Serial Programming Data I/O |
| GPB5/AN6/ICSPCLK (MCP19125 Only) | GPB5 | TTL | CMOS | General-purpose I/O |
| | AN6 | AN | — | A/D Channel 6 input |
| | ICSPCLK | ST | — | Primary Serial Programming Clock |

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 I²C = Schmitt Trigger input with I²C

- Note 1:** The Analog/Digital Debug Output is selected through the control of the ABECON register.
- 2:** Selected when functioning as master or slave by proper configuration of the MSC<1:0> bits in the MODECON register.
- 3:** V_{REF2} output selected when configured as master by proper configuration of the MSC<1:0> bits in the MODECON register.

MCP19124/5

TABLE 2-1: MCP19124/5 PINOUT DESCRIPTION (CONTINUED)

| Name | Function | Input Type | Output Type | Description |
|--------------------|--------------------|------------|-------------|---|
| GPB6/AN7 | GPB6 | TTL | CMOS | General-purpose I/O |
| | AN7 | AN | — | A/D Channel 7 input |
| GPB7/CCD | GPB7 | TTL | CMOS | General-purpose I/O |
| | CCD | ST | CMOS | Single Compare output. Dual Capture input. |
| V _{IN} | V _{IN} | — | — | Device input supply voltage |
| V _{DD} | V _{DD} | — | — | Internal +5V LDO output pin |
| V _{DR} | V _{DR} | — | — | Gate drive supply voltage |
| A _{GND} | A _{GND} | — | — | Small signal quiet ground |
| P _{GND} | P _{GND} | — | — | Large signal power ground |
| PDRV | PDRV | — | — | Primary Low-Side MOSFET gate drive |
| SDRV | SDRV | — | — | Secondary Low-Side MOSFET gate drive |
| I _P | I _P | — | — | Primary input current sense |
| I _{SN} | I _{SN} | — | — | Secondary current sense amplifier negative input |
| I _{SP} | I _{SP} | — | — | Secondary current sense amplifier positive input |
| V _S | V _S | — | — | Sense voltage compared to overvoltage DAC |
| V _{COMP} | V _{COMP} | — | — | EA2 Voltage Error amplifier output |
| I _{COMP} | I _{COMP} | — | — | EA1 Current Error amplifier output |
| DESAT _P | DESAT _P | — | — | DESAT _P : DESAT detect comparator positive input |
| DESAT _N | DESAT _N | — | — | DESAT _N : DESAT detect comparator negative input |

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 I²C = Schmitt Trigger input with I²C

- Note 1:** The Analog/Digital Debug Output is selected through the control of the ABECON register.
- 2:** Selected when functioning as master or slave by proper configuration of the MSC<1:0> bits in the MODECON register.
- 3:** V_{REF2} output selected when configured as master by proper configuration of the MSC<1:0> bits in the MODECON register.

2.1 Detailed Pin Functional Description

2.1.1 GPA0 PIN

GPA0 is a general-purpose TTL input or CMOS output pin whose data direction is controlled in TRISGPA. An internal weak pull-up and interrupt-on-change are also available.

AN0 is an input to the A/D. To configure this pin to be read by the A/D on channel 0, bits TRISA0 and ANSA0 must be set.

The ABECON register can be configured to set this pin to the TEST_OUT function. It is a buffered output of the internal analog or digital signal multiplexers. Analog signals present on this pin are controlled by the ADCON0 register. Digital signals present on this pin are controlled by the ABECON register.

2.1.2 GPA1 PIN

GPA1 is a general-purpose TTL input or CMOS output pin whose data direction is controlled in TRISGPA. An internal weak pull-up and interrupt-on-change are also available.

AN1 is an input to the A/D. To configure this pin to be read by the A/D on channel 1, bits TRISA1 and ANSA1 must be set.

When the MCP19124/5 are configured as a master or slave, this pin can be configured to be the switching frequency synchronization input or output (CLKPIN).

2.1.3 GPA2 PIN

GPA2 is a general-purpose ST input or CMOS output pin whose data direction is controlled in TRISGPA. An internal weak pull-up and interrupt-on-change are also available.

AN2 is an input to the A/D. To configure this pin to be read by the A/D on channel 2, bits TRISA2 and ANSA2 must be set.

When bit T0CS is set in the OPTION_REG register, the T0CKI function is enabled. Refer to [Section 21.0 “Timer0 Module”](#) for more information.

GPA2 can also be configured as an external interrupt by setting the INTE bit. Refer to [Section 13.2 “GPA2/INT Interrupt”](#) for more information.

2.1.4 GPA3 PIN

GPA3 is a general-purpose TTL input or CMOS output pin whose data direction is controlled in TRISGPA. An internal weak pull-up and interrupt-on-change are also available.

AN3 is an input to the A/D. To configure this pin to be read by the A/D on channel 3, bits TRISA3 and ANSA3 must be set.

2.1.5 GPA5 PIN

GPA5 is a general-purpose TTL input only pin. An internal weak pull-up and interrupt-on-change are also available.

For programming purposes, this pin is to be connected to the $\overline{\text{MCLR}}$ pin of the serial programmer. Refer to [Section 30.0 “In-Circuit Serial Programming™ \(ICSP™\)”](#) for more information.

This pin is $\overline{\text{MCLR}}$ when the MCLRE bit is set in the CONFIG register.

2.1.6 GPA6 PIN

GPA6 is a general-purpose CMOS output ST input pin whose data direction is controlled in TRISGPA.

ICSPDAT is a serial programming data I/O function. This can be used in conjunction with ICSPCLK to serial program the device.

GPA6 is part of the CCD Module. For more information, refer to [Section 24.0 “Dual Capture/Compare \(CCD\) Module”](#).

2.1.7 GPA7 PIN

GPA7 is a true open drain general-purpose pin whose data direction is controlled in TRISGPA. There is no internal connection between this pin and device V_{DD} . This pin does not have a weak pull-up, but interrupt-on-change is available.

This pin is the primary ICSPCLK input. This can be used in conjunction with ICSPDAT to serial program the device.

When the MCP19124/5 is configured for I²C communication, [Section 28.2 “I²C Mode Overview”](#), GPA7 functions as the I²C clock (SCL). This pin must be configured as an input to allow proper operation.

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2.1.8 GPB0 PIN

GPB0 is a true open-drain general-purpose pin whose data direction is controlled in TRISGPB. There is no internal connection between this pin and device V_{DD} . This pin does not have a weak pull-up, but interrupt-on-change is available. When the MCP19124/5 are configured for I²C communication, [Section 28.2 “I²C Mode Overview”](#), GPB0 functions as the I²C clock (SDA). This pin must be configured as an input to allow proper operation.

2.1.9 GPB1 PIN

GPB1 is a general-purpose TTL input or CMOS output pin whose data direction is controlled in TRISGPB. An internal weak pull-up and interrupt-on-change are also available.

AN4 is an input to the A/D. To configure this pin to be read by the A/D on channel 4, bits TRISB1 and ANSB1 must be set.

When the MCP19124/5 are configured as a master, this pin can be configured to be the V_{REF2} DAC output.

2.1.10 GPB4 PIN (MCP19125 ONLY)

GPB4 is a general-purpose TTL input or CMOS output pin whose data direction is controlled in TRISGPB. An internal weak pull-up and interrupt-on-change are also available.

AN5 is an input to the A/D. To configure this pin to be read by the A/D on channel 5, bits TRISB4 and ANSB4 must be set.

ICSPDAT is the primary serial programming data I/O function. This is used in conjunction with ICSPCLK to serial program the device.

2.1.11 GPB5 PIN (MCP19125 ONLY)

GPB5 is a general-purpose TTL input or CMOS output pin whose data direction is controlled in TRISGPB. An internal weak pull-up and interrupt-on-change are also available.

AN6 is an input to the A/D. To configure this pin to be read by the A/D on channel 6, bits TRISB5 and ANSB5 must be set.

ICSPCLK is the primary serial programming clock function. This is used in conjunction with ICSPDAT to serial program the device.

2.1.12 GPB6 PIN (MCP19125 ONLY)

GPB6 is a general-purpose TTL input or CMOS output pin whose data direction is controlled in TRISGPB. An internal weak pull-up and interrupt-on-change are also available.

AN7 is an input to the A/D. To configure this pin to be read by the A/D on channel 7, bits TRISB6 and ANSB6 must be set.

2.1.13 GPB7 PIN (MCP19125 ONLY)

GPB7 is a general-purpose TTL input or CMOS output pin whose data direction is controlled in TRISGPB. An internal weak pull-up and interrupt-on-change are also available.

GPB7 is part of the CCD Module. For more information, refer to [Section 24.0 “Dual Capture/Compare \(CCD\) Module”](#).

2.1.14 DESAT_N PIN

Internal comparator inverting input. Used during quasi-resonant operation for desaturation detection.

2.1.15 DESAT_P PIN

When using the internal comparator for desaturation detection during quasi-resonant operation, this pin connects to the comparator's noninverting input.

2.1.16 I_{SP} PIN

The noninverting input to internal current sense amplifier, typically used to differentially remote sense secondary current. This pin can be internally pulled-up to V_{DD} by setting the ISPUEN bit in the PE1 register.

2.1.17 I_{SN} PIN

The inverting input to internal current sense amplifier, typically used to differentially remote sense secondary current.

2.1.18 I_P PIN

Primary input current sense for current mode control and peak current limit. For voltage mode control, this pin can be connected to an artificial ramp.

2.1.19 A_{GND} PIN

A_{GND} is the small signal ground connection pin. This pin should be connected to the exposed pad on the bottom of the package.

2.1.20 P_{GND} PIN

Connect all large signal level ground returns to P_{GND}. These large-signal level ground traces should have a small loop area and minimal length to prevent coupling of switching noise to sensitive traces.

2.1.21 SDRV PIN

The gate of the low-side secondary MOSFET is connected to SDRV. The PCB trace connecting SDRV to the gate must be of minimal length and appropriate width to handle the high-peak drive current and fast voltage transitions.

2.1.22 PDRV PIN

The gate of the low-side primary MOSFET is connected to PDRV. The PCB tracing connecting PDRV to the gate must be of minimal length and appropriate width to handle the high-peak drive currents and fast voltage transitions.

2.1.23 V_{DR} PIN

The supply for the low-side drivers is connected to this pin and has an absolute maximum rating of +13.5V. This pin can be connected by an RC filter to the V_{DD} pin.

2.1.24 V_{DD} PIN

The output of the internal +5.0V regulator is connected to this pin. It is recommended that a 1.0 μ F minimum/4.7 μ F maximum bypass capacitor be connected between this pin and the GND pin of the device. The bypass capacitor should be physically placed close to the device.

2.1.25 V_{IN} PIN

Input power connection pin of the device. It is recommended that capacitance be placed between this pin and the GND pin of the device.

2.1.26 V_S PIN

Analog input connected to the noninverting input of the overvoltage comparator. Typically used as output voltage overvoltage protection. The inverting input of the overvoltage comparator is controlled by the OV_{REF} DAC.

2.1.27 V_{COMP} PIN

EA2 Error amplifier output signal connecting to external compensation

2.1.28 I_{COMP} PIN

EA1 Error amplifier output signal connecting to external compensation.

2.1.29 EXPOSED PAD (EP)

It is recommended to connect the exposed pad to A_{GND} .

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NOTES:

3.0 FUNCTIONAL DESCRIPTION

3.1 Linear Regulators

The operating input voltage for the MCP19124/5 ranges from 4.5V to 42V. There are two internal Low Dropout (LDO) voltage regulators. A 5V LDO is used to power the internal processor and provide a 5V output for external usage. A second LDO (AV_{DD}) is a 4V regulator and is used to power the remaining analog internal circuitry. AV_{DD} is factory calibrated to 4.096V and is the default ADC reference voltage. The ADC reference is switchable between AV_{DD} and V_{DD} . Before entering SLEEP Mode, the ADC reference should be set to AV_{DD} . Using an LDO to power the MCP19124/5, the input voltage is monitored using a resistor divider. The MCP19124/5 also incorporate brown-out protection. Refer to [Section 12.3 “Brown-Out Reset \(BOR\)”](#) for details. The PIC core will reset at $2.0V_{V_{DD}}$.

3.2 Output Drive Circuitry

The MCP19124/5 integrate two low-side drivers used to drive the external low-side N-Channel power MOSFETs for synchronous applications, such as synchronous flyback and synchronous Ćuk converters. Both converter types can be configured for nonsynchronous control by replacing the synchronous FET with a diode. The flyback is also capable of quasi-resonant operation.

The MCP19124/5 can also be configured as a Boost or SEPIC switch-mode power supply (SMPS). In Boost mode, nonsynchronous fixed-frequency or nonsynchronous quasi-resonant control can be utilized. This device can also be used as a SEPIC SMPS in fixed-frequency nonsynchronous mode. The low-side drive is capable of switching the MOSFET at high frequency in typical SMPS applications. The gate drive (V_{DR}) can be supplied from 5V to 10V. The drive strength is capable of up to 1A sink/source with 10V gate drive and 0.5A sink/source with 5V gate drive. A programmable delay is used to set the gate turn-on dead time. This prevents overlap and shoot-through currents that can decrease the converter efficiency. Each driver has its own EN input controlled by the microcontroller core.

3.3 Current Sense

The output current is differentially sensed by the MCP19124/5. In low-current applications, this helps maintain high system efficiency by minimizing power dissipation in current sense resistors. Differential current sensing also minimizes external ground shift errors. The internal differential amplifier has a typical gain of 10 V/V, and is factory trimmed.

3.4 Peak Current Mode

The MCP19124/5 is a peak current mode controlled device with the current-sensing element in series with the primary side MOSFET. Programmable leading edge blanking can be implemented to blank current spikes resulting from turn on. The blank time is controlled from the ICLEBCON register.

Primary input current offset adjust is also available via user programmability, thus limiting peak primary input current. This offset adjustment is controlled by the ICOACON register.

3.5 Magnetic Desaturation Detection

An internal comparator module is used to detect power train magnetic desaturation for quasi-resonant applications. The comparator output is used as a signal to synchronize the start of the next switching cycle. This operation differs from the traditional fixed-frequency application. The DESAT comparator output can be enabled and routed into the PWM circuitry or disabled for fixed-frequency applications. During Quasi-Resonant (QR) operation, the DESAT comparator output is enabled and combined with a pair of one-shot timers and a flip-flop to sustain PWM operation. Timer2 (TMR2) must be initialized and set to run at a frequency lower than the minimum QR operating frequency. When the CDSWDE bit is set in the DESATCON register, TMR2 serves as a watchdog.

An example of the order of events for a Flyback SMPS in synchronous QR operation is as follows:

- the primary gate drive (PDRV) goes high
- the output of the DESAT comparator is high
- the primary current increases until I_P reaches the level of the Current Error Amp (EA1) and causes PWM comparator output to go low
- the PDRV goes low and the secondary gate drive (SDRV) goes high (after programmed dead time). This triggers the first one-shot to send a 200 ns pulse that resets the flip-flop and TMR2 (WDM_RESET)
- the 200 ns one-shot pulse design is implemented to mask out any spurious transitions at the DESAT comparator output caused by switching noise
- the SDRV stays high until the secondary winding completely runs out of energy, at which time the output capacitance begins to source current back through the winding and secondary MOSFET
- the DESAT comparator detects this and its output goes low. This sets the flip-flop and triggers the second one-shot to send a 33 ns pulse to the control logic, causing the SDRV to go low and the PDRV to go high (after programmed dead time).
- the cycle then repeats. If, for any reason, the reset one-shot does not fire, the WDM_RESET signal

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stays low and TMR2 is allowed to run until the PWM signal kicks off a new cycle.

The desaturation comparator module is controlled by the DESATCON register.

3.6 Start-Up

To control the output current during start-up, the MCP19124/5 have the capability to monotonically increase system current, at the user's discretion. This is accomplished through the control of the reference voltage DAC (V_{REF}). Users also have firmware control over the switching frequency through Timer2 and the PR2 register. Maximum duty cycle control is established through the PWMRL register. See section [Section 27.0 "Enhanced PWM Module"](#) for details. The entire start-up profile is under user control via software.

3.7 Driver Control Circuitry

Internal to the driver control circuitry of the MCP19124/5 are two error amplifiers (EA1/EA2). Both error amplifiers are transconductance designs with external compensation. This dual error amplifier configuration allows the device to regulate current or voltage. 8-bit DAC V_{REF} is summed with the pedestal voltage (VZC) and connected to the noninverting input of the current regulating error amplifier (EA1) to create the current regulation set-point. This is very similar to the current regulation scheme utilized in the MCP19114/5 devices.

In the MCP19124/5 devices, a second control loop utilizing the voltage control error amplifier (EA2) can implement voltage control regulation. The output of each error amplifier is clamped to the other such that the outputs are typically with 50mV. The control loop (voltage or current) that is demanding the smaller error amplifier output signal is in control of the PWM control loop. The 8-bit OV_{REF} DAC is connected to the noninverting input of the voltage control error amplifier (EA2) and sets the voltage command level. When EA2 is disabled via the EA2DIS bit in the ABECON register the overvoltage comparator is enabled and functions as overvoltage detection/protection similar to the MCP19114/5 devices.

When current regulation is implemented, the error amplifier (EA1) generates the control voltage used by the high-speed PWM comparator. There is an internally generated reference voltage, V_{REF} . The difference or error between this internal reference voltage and the actual feedback voltage from the secondary current sense output is the control voltage. When voltage regulation is implemented, the error amplifier (EA2) generates the control voltage used by the high-speed PWM comparator. There is an internally generated reference voltage, OV_{REF} . The difference or error between this internal reference voltage and the actual feedback voltage present at the V_S pin is the control

voltage. Independent external compensation networks are connected at the I_{COMP} and V_{COMP} pins to allow greater compensation flexibility for voltage and current regulation stabilization of the control system.

Since the MCP19124/5 are peak current mode controlled, the comparator compares the primary peak current waveform (I_P) that is based upon the current flowing in the primary side with the error amplifier control output voltage. This error amplifier control output voltage also has user-programmable slope compensation subtracted from it. In fixed-frequency applications, the slope compensation signal is generated to be greater than 1/2 the down slope of the inductor current waveform and is controlled by the SLPCRCON register. Offset adjust ability is also available to set the peak current limit of the primary switch for overcurrent protection. The range of the slope compensation ramp is specified. When the current sense signal reaches the level of the control voltage minus slope compensation, the ON cycle is terminated and the external PDRV switch is latched off until the beginning of the next cycle which begins at the next clock cycle.

To improve current regulation at low levels, a pedestal voltage (VZC) set to the BG (1.23V) is implemented throughout the current regulation analog control loop. This virtual ground serves as the reference for the error amplifier (EA1), slope compensation, current sense amplifier (A2) and the I_P offset adjustment.

An S-R latch (Set-Rest-Flip-Flop) is used to prevent the PWM circuitry from turning the external switch on until the beginning of the next clock cycle.

3.8 Fixed PWM Frequency

The switching frequency of the MCP19124/5, while not controlled by the DESAT comparator output, is generated by using a single edge of the 8 MHz internal clock. The user sets the MCP19124/5 switching frequency by configuring the PR2 register. The maximum allowable PDRV duty cycle is adjustable and is controlled by the PWMRL register. The programmable range of the switching frequency will be 31.25 kHz to 2 MHz. The available switching frequency below 2 MHz is defined as $F_{SW} = 8 \text{ MHz}/N$, where N is a whole number between $4 \leq N \leq 256$. Refer to [Section 27.0 "Enhanced PWM Module"](#) for details.

3.9 V_{REF}

This reference is used to generate the voltage connected to the noninverting input of the current error amplifier (EA1). The entire analog control loop is raised to a virtual ground pedestal (VZC) equal to the Band Gap voltage (1.23V).

3.10 OV REF

This reference is dual purposed and can be used to set the voltage regulation set point or the output overvoltage set point. By default this reference is connected to the noninverting input of the voltage error amplifier (EA2). When the voltage error amplifier is disabled by setting the EA2DIS bit in the ABECON register, this reference is connected to the noninverting input of the over voltage comparator. Here this reference is compared to the V_S input pin, which is typically proportional to the output voltage based on an external resistor divider. OV protection, when enabled, can be set to a value for the protection of system circuitry or it can be used to “ripple” regulate the converter output voltage for repositioning purposes. The comparator output triggers a configurable interrupt such that firmware can take any additional desired action.

3.11 Independent Gate Drive with Programmable Delay

Two independent low-side gate drives are integrated for synchronous applications. Programmable delay has been implemented to improve efficiency and prevent shoot-through currents. Each gate drive has an independent enable input controlled by the PE1 register and programmable dead time controlled by the DEADCON register.

3.12 Temperature Management

3.12.1 THERMAL SHUTDOWN

To protect the MCP19124/5 from overtemperature conditions, a 150°C junction temperature thermal shutdown has been implemented. When the junction temperature reaches this limit, the device disables the output drivers. In Shutdown mode, both PDRV and SDRV outputs are disabled and the overtemperature flag (OTIF) is set in the PIR2 register. When the junction temperature is reduced by 20°C to 130°C, the MCP19124/5 can resume normal output drive switching.

3.12.2 TEMPERATURE REPORTING

The MCP19124/5 have a second on-chip temperature monitoring circuit that can be read by the ADC through the analog test MUX. Refer to [Section 25.0 “Internal Temperature Indicator Module”](#) for details on this internal temperature monitoring circuit.

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4.0 ELECTRICAL CHARACTERISTICS

4.1 ABSOLUTE MAXIMUM RATINGS †

| | |
|--|---|
| $V_{IN} - V_{GND}$ (DC) | -0.3V to +44V |
| V_{IN} (transient < 500 ms) | +48V |
| PDRV | (GND - 0.3V) to ($V_{DR} + 0.3V$) |
| SDRV | (GND - 0.3V) to ($V_{DR} + 0.3V$) |
| V_{DD} Internally Generated | +6.5V |
| V_{DR} Externally Generated | +13.5V |
| Voltage on MCLR with respect to GND | -0.3V to +13.5V |
| Maximum voltage: any other pin | ($V_{GND} - 0.3V$) to ($V_{DD} + 0.3V$) |
| Maximum output current sunk by any single I/O pin | 25 mA |
| Maximum output current sourced by any single I/O pin | 25 mA |
| Maximum current sunk by all GPIO | 90 mA |
| Maximum current sourced by all GPIO | 35 mA |
| Storage Temperature | -65°C to +150°C |
| Maximum Junction Temperature | +150°C |
| Operating Junction Temperature | -40°C to +125°C |
| ESD protection on all pins (CDM) | 2.0 kV |
| ESD protection on all pins (HBM) | 1.0 kV |
| ESD protection on all pins (MM) | 200V |

† **Notice:** Stresses above those listed under “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 operational listings of this specification is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

4.2 Electrical Characteristics

Electrical Specifications: Unless otherwise noted, $V_{IN} = 12V$, $F_{SW} = 150$ kHz, $T_A = +25^\circ C$. **Boldface** specifications apply over the T_A range of $-40^\circ C$ to $+125^\circ C$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|--|-----------------|-------------|------|------------|---------|---|
| Input | | | | | | |
| Input Voltage | V_{IN} | 4.5 | — | 42 | V | |
| Input Quiescent Current | I_Q | — | 5 | 10 | mA | $V_{IN} = 12V$, Not switching |
| | | — | 5 | 10 | | $V_{IN} = 20V$, Not switching |
| Shutdown Current | I_{SHDN} | — | 35 | 80 | μA | $V_{IN} = 12V$ (Note 1) |
| Linear Regulator V_{DD} | | | | | | |
| Internal Circuitry Bias Voltage | V_{DD} | 4.75 | 5.1 | 5.5 | V | $V_{IN} = 6.0V$ to 42V |
| Maximum External V_{DD} Output Current | I_{DD_OUT} | 35 | — | — | mA | $V_{IN} = 6.0V$ to 42V (Note 2) |
| Internal Circuitry Bias Voltage during SLEEP | V_{DD_SLEEP} | 2.8 | — | 4.0 | V | $V_{IN} = 4.5V$ to 42V $I_{DD_OUT} = 1mA$ |

Note 1: Refer to [Section 14.0 “Power-Down Mode \(Sleep\)”](#).

2: V_{DD} is the voltage present at the V_{DD} pin.

3: Dropout voltage is defined as the input-to-output voltage differential at which the output voltage drops 2% below its nominal value measured at a 1V differential between V_{IN} and V_{DD} .

4: Ensured by design, not production tested.

5: These parameters are characterized, but not production tested.

6: The V_{DD} LDO will limit the total source current to a maximum of 35 mA. Individually each pin can source a maximum of 15 mA.

4.2 Electrical Characteristics (Continued)

Electrical Specifications: Unless otherwise noted, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$. **Boldface** specifications apply over the T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|---|---|-------------|-----------|-------------|---------------|--|
| Maximum Available External V_{DD} Output Current during SLEEP | $I_{DD_OUT_SLEEP}$ | 1 | — | — | mA | $V_{IN} = 6.0V$ to $42V$ $V_{DD} = V_{DD_SLEEP}$ |
| Line Regulation | $\frac{\Delta V_{DD_OUT}}{(V_{DD_OUT} \times \Delta V_{IN})}$ | -0.1 | 0.002 | 0.1 | %/V | $(V_{DD} + 1.0V) \leq V_{IN} \leq 20V$ (Note 2) |
| Load Regulation | $\frac{\Delta V_{DD_OUT}}{V_{DD_OUT}}$ | -1 | 0.1 | +1 | % | $I_{DD_OUT} = 1\text{ mA}$ to 20 mA (Note 2) |
| Output Short-Circuit Current | I_{DD_SC} | — | 50 | — | mA | $V_{IN} = (V_{DD} + 1.0V)$ (Note 2) |
| Dropout Voltage | $V_{IN} - V_{DD}$ | — | 0.3 | 0.5 | V | $I_{DD_OUT} = 20\text{ mA}$ (Notes 2 and 3) |
| Power Supply Rejection Ratio | $PSRR_{LDO}$ | — | 60 | — | dB | $f \leq 1000\text{ Hz}$ $I_{DD_OUT} = 25\text{ mA}$ $C_{IN} = 0\text{ }\mu\text{F}$, $C_{DD} = 1\text{ }\mu\text{F}$ |
| Linear Regulator AV_{DD} | | | | | | |
| Internal Analog Supply Voltage | AV_{DD} | — | 4.096 | — | V | |
| AV_{DD} Tolerance | AV_{DD_TOL} | -2.5 | ± 0.1 | 2.5 | % | Trimmed |
| Band Gap Voltage | BG | — | 1.23 | — | V | Trimmed at 1.0% tolerance |
| Band Gap Tolerance | BG_{TOL} | -2.5 | — | +2.5 | % | |
| Input UVLO Voltage | | | | | | |
| UVLO Range | $UVLO_{ON}$ | 4.0 | — | 20 | V | V_{IN} Falling |
| $UVLO_{ON}$ Trip Tolerance | $UVLO_{TOL}$ | -14 | — | 14 | % | V_{IN} Falling UVLO trip set to 9V $V_{INUVLO} = 0x21h$ |
| UVLO Hysteresis | $UVLO_{HYS}$ | 1 | 4 | 8 | % | Hysteresis is based upon the $UVLO_{ON}$ setting UVLO trip set to 9V $V_{INUVLO} = 0x21h$ |
| Resolution | nbits | — | 6 | — | bits | Logarithmic Steps |
| UVLO Comparator | | | | | | |
| Input-to-Output Delay | TD | — | 5 | — | μs | 100 ns rise time to 1V overdrive on V_{IN} $V_{IN} > UVLO$ to flag set |

Note 1: Refer to [Section 14.0 “Power-Down Mode \(Sleep\)”](#).

2: V_{DD} is the voltage present at the V_{DD} pin.

3: Dropout voltage is defined as the input-to-output voltage differential at which the output voltage drops 2% below its nominal value measured at a 1V differential between V_{IN} and V_{DD} .

4: Ensured by design, not production tested.

5: These parameters are characterized, but not production tested.

6: The V_{DD} LDO will limit the total source current to a maximum of 35 mA. Individually each pin can source a maximum of 15 mA.

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4.2 Electrical Characteristics (Continued)

Electrical Specifications: Unless otherwise noted, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$. **Boldface** specifications apply over the T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|--|----------------------|------------|------|-----------|-------|--|
| Input OVLO Voltage | | | | | | |
| OVLO Range | OVLO _{ON} | 8.8 | — | 44 | V | V_{IN} rising |
| OVLO _{ON} Trip Tolerance | OVLO _{TOL} | -18 | — | 18 | % | V_{IN} rising OVLO trip set to 18V $V_{INOVL0} = 0x1Fh$ |
| OVLO Hysteresis | OVLO _{HYS} | 1 | 4 | 8 | % | Hysteresis is based upon the OVLO _{ON} setting OVLO trip set to 18V $V_{INOVL0} = 0x1Fh$ |
| Resolution | nbits | — | 6 | — | bits | Logarithmic Steps |
| OVLO Comparator | | | | | | |
| Input-to-Output Delay | TD | — | 5 | — | μs | 100 ns rise time to 1V overdrive on V_{IN} $V_{IN} > OVLO$ to flag set |
| Output OV DAC (OV_{REF}) | | | | | | |
| Resolution | nbits | — | 8 | — | bits | Linear DAC |
| Full Scale Range | FSR | 0 | — | 2 x BG | V | |
| Tolerance | OVREF _{TOL} | -2.0 | ±0.3 | 2.0 | % | Trimmed @ code 0=CC at 25°C, 0°C to 85°C |
| | | -3.3 | — | 3.3 | % | -45°C to 0°C 85°C to 125°C |
| Output OV Comparator | | | | | | |
| OV Hysteresis | OV _{HYS} | — | 50 | — | mV | |
| Input Bias Current | I _{BIAS} | — | ±1 | — | μA | |
| Common-Mode Input Voltage Range | V _{CMR} | 0 | — | 3.0 | V | Note 4 |
| Input-to-Output Delay | TD | — | 200 | — | ns | 100 ns rise time to 1V overdrive on V_S $V_S > OV$ to flag set (Note 4) |
| Voltage Reference DAC (V_{REF}) | | | | | | |
| Resolution | nbits | — | 8 | — | V/V | Linear DAC |
| Full-Scale Range | FSR | BG | — | 2 x BG | V | Pedestal set to BG |

Note 1: Refer to [Section 14.0 “Power-Down Mode \(Sleep\)”](#).

2: V_{DD} is the voltage present at the V_{DD} pin.

3: Dropout voltage is defined as the input-to-output voltage differential at which the output voltage drops 2% below its nominal value measured at a 1V differential between V_{IN} and V_{DD} .

4: Ensured by design, not production tested.

5: These parameters are characterized, but not production tested.

6: The V_{DD} LDO will limit the total source current to a maximum of 35 mA. Individually each pin can source a maximum of 15 mA.

4.2 Electrical Characteristics (Continued)

Electrical Specifications: Unless otherwise noted, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$. **Boldface** specifications apply over the T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|--|-----------------|--------------|-----------|--------------|------------|---|
| Tolerance | V_{REF_TOL} | -2.0 | ± 0.2 | 2.0 | % | Trimmed @ code 0xCC at 25°C 0°C to 85°C |
| | | -2.5 | — | 2.5 | % | -40°C to 0°C 85°C to 125°C |
| Voltage Reference DAC (V_{REF2}) | | | | | | |
| Resolution | nbits | — | 8 | — | bits | Linear DAC |
| Full-Scale Range | FSR | 0 | — | BG | V | |
| Tolerance | V_{REF2_TOL} | -2.0 | ± 0.2 | 2.0 | % | Trimmed @ code 0xCC at 25°C 0°C to 85°C |
| | | -2.5 | — | 2.5 | % | -40°C to 0°C 85°C to 125°C |
| Sink Current | I_{SINK} | -3 | — | — | mA | $V_{REF2} = 0x29$ $I_{SINK} = 3\text{ mA}$ $\Delta V_{REF2} < 60\text{ mV}$ |
| Source Current | I_{SOURCE} | 3 | — | — | mA | $V_{REF2} = 0xFF$ $I_{SOURCE} = 3\text{ mA}$ $\Delta V_{REF2} < 60\text{ mV}$ |
| Current Sense Amplifier (A2) | | | | | | |
| Amplifier PSRR | PSRR | — | 65 | — | dB | $V_{CM} = 2 \times BG$ |
| Closed-Loop Voltage Gain | $A2_{VCL}$ | — | 10 | — | V/V | $R_L = 5\text{ k}\Omega$ to $2.048V$, $100\text{ mV} < A2 < AV_{DD} - 100\text{ mV}$ $V_{CM} = BG$ |
| Closed Loop Voltage Gain Tolerance | $A2_{VCL_TOL}$ | -1.75 | 0.5 | +1.75 | % | Trimmed |
| Low-Level Output | V_{OL} | — | 300 | — | mV | $R_L = 5\text{ k}\Omega$ to $2.048V$ |
| Gain-Bandwidth Product | GBWP | — | 10 | — | MHz | $AV_{DD} = 4V$ |
| Input Impedance | R_{IN} | — | 10 | — | k Ω | |
| Sink Current | I_{SINK} | -3 | — | — | mA | $I_{SP} = I_{SN} = GND$ $R_L = 300\Omega$ to $2 \times BG$ (Note 4) |
| Source Current | I_{SOURCE} | 3 | — | — | mA | $I_{SP} = I_{SN} = GND$ $R_L = 300\Omega$ to GND (Note 4) |

Note 1: Refer to [Section 14.0 “Power-Down Mode \(Sleep\)”](#).

2: V_{DD} is the voltage present at the V_{DD} pin.

3: Dropout voltage is defined as the input-to-output voltage differential at which the output voltage drops 2% below its nominal value measured at a 1V differential between V_{IN} and V_{DD} .

4: Ensured by design, not production tested.

5: These parameters are characterized, but not production tested.

6: The V_{DD} LDO will limit the total source current to a maximum of 35 mA. Individually each pin can source a maximum of 15 mA.

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4.2 Electrical Characteristics (Continued)

Electrical Specifications: Unless otherwise noted, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$. **Boldface** specifications apply over the T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|--|-----------------------|------------------|------|----------------------------------|-----------------|--|
| Common-Mode Range | V_{CMR} | GND - 0.3 | — | $V_{BG} + 0.3$ | V | Note 4 |
| Common-Mode Rejection Ratio | CMRR | — | 70 | — | dB | |
| Pedestal Voltage | | | | | | |
| Pedestal Voltage Level | VZC | — | BG | — | V | |
| Error Amplifier (EA1) | | | | | | |
| Input Offset Current | I_{OS} | — | 2 | — | μA | Trimmed |
| Error Amplifier PSRR | PSRR | — | 99 | — | dB | $V_{CM} = \text{BG}$ |
| Common-Mode Input Range | V_{CM} | 0.8V | — | 3 | V | Note 4 |
| Common-Mode Rejection Ratio | CMRR | — | 65 | — | dB | $V_{CM} = 0V$ to BG |
| Open-Loop Voltage Gain | A_{VOL} | — | 70 | — | dB | Note 4 |
| Transconductance | Gm | 180 | 200 | 220 | $\mu\text{A/V}$ | Trimmed |
| Gain-Bandwidth Product | GBWP | — | 3.5 | — | MHz | Note 4 |
| Error Amplifier (EA2) | | | | | | |
| Input Offset Voltage | V_{OS} | — | 2 | — | mV | Trimmed |
| Error Amplifier PSRR | PSRR | — | 99 | — | dB | $V_{CM} = \text{BG}$ |
| Common-Mode Input Range | V_{CM} | 0.8 | — | 3 | V | Note 4 |
| Common-Mode Rejection Ratio | CMRR | — | 65 | — | dB | $V_{CM} = 0V$ to BG |
| Open-Loop Voltage Gain | A_{VOL} | — | 70 | — | dB | Note 4 |
| Transconductance | Gm | 180 | 200 | 220 | $\mu\text{A/V}$ | Trimmed |
| Gain-Bandwidth Product | GBWP | — | 3.5 | — | MHz | |
| EA1/EA2 Error Amplifiers Output Clamp | | | | | | |
| Maximum Positive Output Offset Voltage (EA not in control of loop) | $V_{EA_OUTOFF_MAX}$ | — | — | +50 | mV | Applies to EA not in control of the loop |
| Peak Current Sense Input | | | | | | |

Note 1: Refer to [Section 14.0 “Power-Down Mode \(Sleep\)”](#).

2: V_{DD} is the voltage present at the V_{DD} pin.

3: Dropout voltage is defined as the input-to-output voltage differential at which the output voltage drops 2% below its nominal value measured at a 1V differential between V_{IN} and V_{DD} .

4: Ensured by design, not production tested.

5: These parameters are characterized, but not production tested.

6: The V_{DD} LDO will limit the total source current to a maximum of 35 mA. Individually each pin can source a maximum of 15 mA.

4.2 Electrical Characteristics (Continued)

Electrical Specifications: Unless otherwise noted, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$. **Boldface** specifications apply over the T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|---|--------------------------|------------|---------|----------------------------|-------------------|---|
| Maximum Primary Current Sense Signal Voltage | V_{IP_MAX} | — | BG | 1.5 | V | Note 4 |
| PWM Comparator | | | | | | |
| Input-to-Output Delay | TD | — | 11 | 20 | ns | Note 4 |
| Peak Current Leading Edge Blanking | | | | | | |
| Resolution | LEB | — | 2 | — | bits | |
| Blanking Time Adjustable Range | LEB_{RANGE} | 0 | — | 256 | ns | 4-Step Programmable Range (0, 50, 100, and 200 ns) (Note 4) |
| Offset Adjustment (I_p Sense) | | | | | | |
| Resolution | OS_{ADJ} | — | 4 | — | bits | |
| Offset Adjustment Range | OS_{ADJ_RANGE} | 0 | — | 750 | mV | Note 4 |
| Offset Adjustment Step Size | OS_{ADJ_STEP} | — | 50 | — | mV | Linear Steps |
| Adjustable Slope Compensation | | | | | | |
| Resolution | SC_{RES} | — | 6 | — | bits | Log Steps |
| Slope | m | 4 | — | 437 | mV/ μs | |
| Slope Step Size | SC_{STEP} | — | 8 | — | % | Log Steps |
| Ramp Set Point Tolerance | m_{TOL} | — | ± 1 | ± 32 | % | |
| Desaturation Detection Comparator | | | | | | |
| Input Offset Voltage | V_{OS} | — | ± 1 | — | mV | Trimmed, 5 bits adjustable |
| Input Bias Current | I_{BIAS} | — | ± 1 | — | μA | Internal Circuit Dependent |
| Common-Mode Input Voltage Range | V_{CMR} | GND – 0.3V | — | 2.7 | V | Note 4 |
| Input-to-Output Delay | TD | — | 20 | — | ns | |
| V_{DR} UVLO | | | | | | |
| V_{DR} Input Resistance | V_{DR_RIN} | — | 230 | — | k Ω | |
| V_{DR} UVLO (2.7V V_{DR} Falling) | $V_{DR_UVLO_2.7_F}$ | 2.45 | — | 2.9 | V | |
| V_{DR} UVLO (2.7V V_{DR} Rising) | $V_{DR_UVLO_2.7_R}$ | 2.68 | — | 3.23 | V | |
| V_{DR} UVLO (2.7V Hysteresis) | $V_{DR_UVLO_2.7_HYS}$ | 185 | — | 425 | mV | |

Note 1: Refer to [Section 14.0 “Power-Down Mode \(Sleep\)”](#).

2: V_{DD} is the voltage present at the V_{DD} pin.

3: Dropout voltage is defined as the input-to-output voltage differential at which the output voltage drops 2% below its nominal value measured at a 1V differential between V_{IN} and V_{DD} .

4: Ensured by design, not production tested.

5: These parameters are characterized, but not production tested.

6: The V_{DD} LDO will limit the total source current to a maximum of 35 mA. Individually each pin can source a maximum of 15 mA.

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4.2 Electrical Characteristics (Continued)

Electrical Specifications: Unless otherwise noted, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$. **Boldface** specifications apply over the T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|--|--------------------------|-------------|-------------|---------------------------|----------|---|
| V_{DR} UVLO (5.4V V_{DR} Falling) | $V_{DR_UVLO_5.4_F}$ | 4.7 | — | 5.96 | V | |
| V_{DR} UVLO (5.4V V_{DR} Rising) | $V_{DR_UVLO_5.4_R}$ | 5.2 | — | 6.6 | V | |
| V_{DR} UVLO (5.4V Hysteresis) | $V_{DR_UVLO\ 5.4\ HYS}$ | 360 | — | 840 | mV | |
| Output Driver (PDRV and SDRV) | | | | | | |
| PDRV/SDRV Gate Drive Source Resistance | R_{DR-SRC} | — | — | 13.5 | Ω | $V_{DR} = 4.5V$ (Note 4) |
| PDRV/SDRV Gate Drive Sink Resistance | $R_{DR-SINK}$ | — | — | 12 | Ω | $V_{DR} = 4.5V$ (Note 4) |
| PDRV/SDRV Gate Drive Source Current | I_{DR-SRC} | — | 0.5 | — | A | $V_{DR} = 5V$ $V_{DR} = 10V$ (Note 4) |
| | | — | 1.0 | — | | |
| PDRV/SDRV Gate Drive Sink Current | $I_{DR-SINK}$ | — | 0.5 | — | A | $V_{DR} = 5V$ $V_{DR} = 10V$ (Note 4) |
| | | — | 1.0 | — | | |
| Dead-Time Adjustment | | | | | | |
| Resolution | DT_{RES} | — | 4 | — | bits | |
| Dead-Time Adjustable Range | DT_{RANGE} | 16 | — | 256 | ns | Note 4 |
| Dead-Time Step Size | DT_{STEP} | — | 16 | — | ns | Linear Steps |
| Dead-Time Tolerance | DT_{TOL} | — | ± 8 | — | ns | |
| Oscillator/PWM | | | | | | |
| Internal Oscillator Frequency | F_{OSC} | 7.60 | 8.00 | 8.40 | MHz | |
| Switching Frequency | F_{SW} | — | F_{OSC}/N | — | MHz | |
| Switching Frequency Range Select | N | 4 | — | 255 | — | $F_{MAX} = 2\text{ MHz}$ |
| A/D Converter (ADC) Characteristics | | | | | | |
| Resolution | N_R | — | — | 10 | bits | |
| Integral Error | E_{IL} | — | — | ± 1 | LSb | $V_{REF_ADC} = AV_{DD}$ $V_{REF_ADC} = V_{DD}$ |

Note 1: Refer to [Section 14.0 “Power-Down Mode \(Sleep\)”](#).

2: V_{DD} is the voltage present at the V_{DD} pin.

3: Dropout voltage is defined as the input-to-output voltage differential at which the output voltage drops 2% below its nominal value measured at a 1V differential between V_{IN} and V_{DD} .

4: Ensured by design, not production tested.

5: These parameters are characterized, but not production tested.

6: The V_{DD} LDO will limit the total source current to a maximum of 35 mA. Individually each pin can source a maximum of 15 mA.

4.2 Electrical Characteristics (Continued)

Electrical Specifications: Unless otherwise noted, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$. **Boldface** specifications apply over the T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|----------------------------------|---------------------|-------------------------------|-----------|--------------------------------|---------------|--|
| Differential Error | E_{DL} | — | — | ± 1 | LSb | No missing code in 10 bits $V_{REF_ADC} = AV_{DD}$ $V_{REF_ADC} = V_{DD}$ (Note 5) |
| Offset Error | E_{OFF} | — | +3.0 | +7 | LSb | $V_{REF_ADC} = AV_{DD}$ $V_{REF_ADC} = V_{DD}$ |
| Gain Error | E_{GN} | — | ± 2 | ± 6 | LSb | $V_{REF_ADC} = AV_{DD}$ $V_{REF_ADC} = V_{DD}$ |
| Selectable ADC Reference Voltage | V_{REF_ADC} | — | AV_{DD} | — | V | $AV_{DD} = 4V$ ADCON1<VCFG = 0> |
| | | — | V_{DD} | — | V | $V_{DD} = 5V$ ADCON1<VCFG = 1> |
| Full-Scale Range | $FSR_{A/D}$ | GND | — | AV_{DD} | — | AV_{DD} selected as ADC Reference |
| | | GND | — | V_{DD} | — | V_{DD} selected as ADC Reference |
| GPIO Pins | | | | | | |
| Maximum GPIO Sink Current | I_{SINK_GPIO} | — | — | 90 | mA | Note 6 |
| Maximum GPIO Source Current | I_{SOURCE_GPIO} | — | — | 35 | mA | Note 6 |
| GPIO Weak Pull-Up Current | $I_{PULL-UP_GPIO}$ | 50 | 250 | 400 | μA | |
| GPIO Input Low Voltage | V_{GPIO_IL} | GND | — | 0.8 | V | I/O Port with TTL buffer $V_{DD} = 5V$ |
| | | GND | — | $0.2V_{DD}$ | V | I/O Port with Schmitt Trigger buffer, $V_{DD} = 5V$ |
| | | GND | — | $0.2V_{DD}$ | V | \overline{MCLR} |
| GPIO Input High Voltage | V_{GPIO_IH} | 2.0 | — | V_{DD} | V | I/O Port with TTL buffer $V_{DD}=5V$ |
| | | $0.8V_{DD}$ | — | V_{DD} | V | I/O Port with Schmitt Trigger buffer, $V_{DD} = 5V$ |
| | | $0.8V_{DD}$ | — | V_{DD} | V | \overline{MCLR} |
| GPIO Output Low Voltage | V_{GPIO_OL} | — | — | $0.12V_{DD}$ | V | $I_{OL} = 7\text{ mA}$ $V_{DD} = 5V$ |

Note 1: Refer to **Section 14.0 “Power-Down Mode (Sleep)”**.

2: V_{DD} is the voltage present at the V_{DD} pin.

3: Dropout voltage is defined as the input-to-output voltage differential at which the output voltage drops 2% below its nominal value measured at a 1V differential between V_{IN} and V_{DD} .

4: Ensured by design, not production tested.

5: These parameters are characterized, but not production tested.

6: The V_{DD} LDO will limit the total source current to a maximum of 35 mA. Individually each pin can source a maximum of 15 mA.

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4.2 Electrical Characteristics (Continued)

Electrical Specifications: Unless otherwise noted, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$. **Boldface** specifications apply over the T_A range of -40°C to $+125^\circ\text{C}$.

| Parameters | Sym. | Min. | Typ. | Max. | Units | Conditions |
|------------------------------------|----------------|----------------|-----------|---------|------------------|---|
| GPIO Output High Voltage | V_{GPIO_OH} | $V_{DD} - 0.7$ | — | — | V | $I_{OH} = 2.5\text{ mA}$ $V_{DD} = 5V$ |
| GPIO Input Leakage Current | $GPIO_I_{IL}$ | — | ± 0.1 | ± 1 | μA | Negative current is defined as current sourced by the pin |
| POR | | | | | | |
| Power-On Reset Voltage | V_{POR} | — | 2.13 | — | V | V_{DD} rising (Note 4) |
| Power-On Reset Voltage Hysteresis | V_{POR_HYS} | — | 100 | — | mV | |
| BOR | | | | | | |
| Brown-Out Reset Voltage | V_{BOR} | — | 2.7 | — | V | V_{DD} falling (Note 4) |
| Brown-Out Reset Voltage Hysteresis | V_{BOR_HYS} | — | 100 | — | mV | |
| Thermal Shutdown | | | | | | |
| Thermal Shutdown | T_{SHD} | — | 150 | — | $^\circ\text{C}$ | |
| Thermal Shutdown Hysteresis | T_{SHD_HYS} | — | 20 | — | $^\circ\text{C}$ | |

Note 1: Refer to [Section 14.0 “Power-Down Mode \(Sleep\)”](#).

2: V_{DD} is the voltage present at the V_{DD} pin.

3: Dropout voltage is defined as the input-to-output voltage differential at which the output voltage drops 2% below its nominal value measured at a 1V differential between V_{IN} and V_{DD} .

4: Ensured by design, not production tested.

5: These parameters are characterized, but not production tested.

6: The V_{DD} LDO will limit the total source current to a maximum of 35 mA. Individually each pin can source a maximum of 15 mA.

5.0 DIGITAL ELECTRICAL CHARACTERISTICS

5.1 Timing Parameter Symbology

The timing parameter symbols have been created with one of the following formats:

1. TppS2ppS
2. TppS
3. T_{CC:ST} (I²C specifications only)
4. Ts (I²C specifications only)

| | | | |
|----------|-----------|---|------|
| 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 | SDI | sc | SCK |
| do | SDO | ss | \overline{SS} |
| dt | Data in | t0 | T0CKI |
| io | I/O port | wr | \overline{WR} |
| mc | MCLR | | |

Uppercase letters and their meanings:

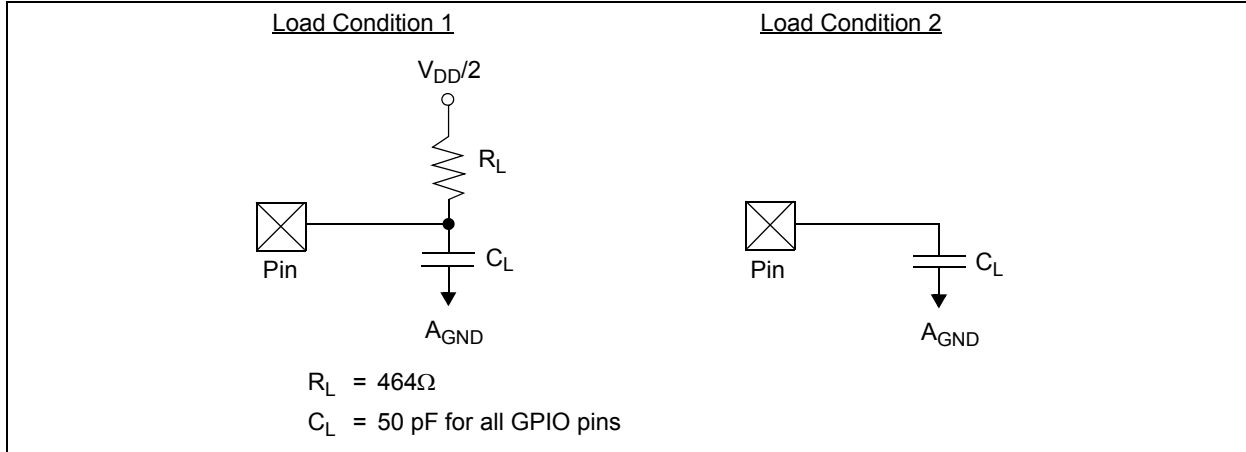
| | | | |
|----------------------------|--------------------------|------|----------------|
| S | | | |
| F | Fall | P | Period |
| H | High | R | Rise |
| I | Invalid (High-Impedance) | V | Valid |
| L | Low | Z | High-Impedance |
| I²C only | | | |
| AA | output access | High | High |
| BUF | Bus free | Low | Low |

T_{CC:ST} (I²C specifications only)

| | | | |
|-----------|-----------------|-----|----------------|
| CC | | | |
| HD | Hold | SU | Setup |
| ST | | | |
| DAT | DATA input hold | STO | STOP condition |
| STA | START condition | | |

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FIGURE 5-1: LOAD CONDITIONS



5.2 AC Characteristics: MCP19124 (Industrial, Extended)

FIGURE 5-2: EXTERNAL CLOCK TIMING

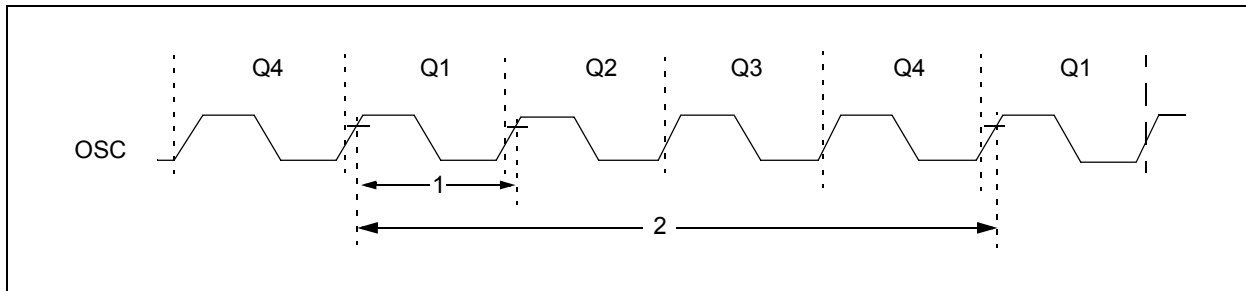


TABLE 5-1: EXTERNAL CLOCK TIMING REQUIREMENTS

| Param. No. | Sym. | Characteristic | Min. | Typ. [†] | Max. | Units | Conditions |
|------------|-----------|---------------------------------------|------|-------------------|----------|-------|-----------------------------|
| — | F_{OSC} | Oscillator Frequency ⁽¹⁾ | — | 8 | — | MHz | |
| 1 | T_{OSC} | Oscillator Period ⁽¹⁾ | — | 250 | — | ns | |
| 2 | T_{CY} | Instruction Cycle Time ⁽¹⁾ | — | T_{CY} | ∞ | ns | $T_{CY} = 4 \times T_{OSC}$ |

* These parameters are characterized but not tested.

† Data in “Typ.” column is at $V_{IN} = 12V$ ($V_{DD} = 5V$), 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.

FIGURE 5-3: I/O TIMING

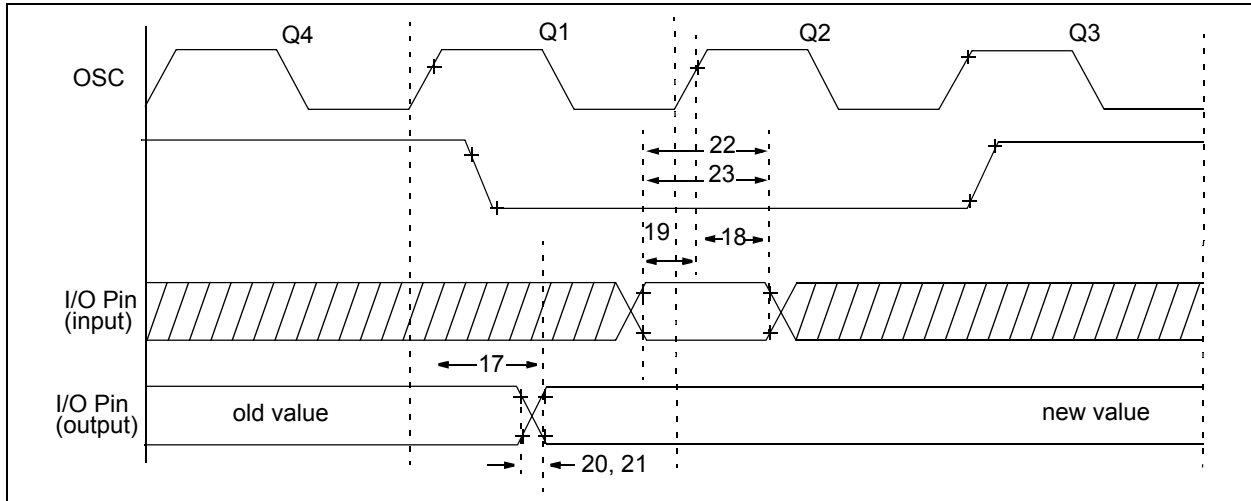


TABLE 5-2: I/O TIMING REQUIREMENTS

| Param. No. | Sym. | Characteristic | Min. | Typ.† | Max. | Units | Conditions |
|------------|-------------------|---|-----------------|-------|------|-------|------------|
| 17 | TosH2ioV | OSC1↑ (Q1 cycle) to Port out valid | — | 50 | 70* | ns | |
| 18 | TosH2ioI | OSC1↑ (Q2 cycle) to Port input invalid (I/O in hold time) | 50 | — | — | ns | |
| 19 | TioV2osH | Port input valid to OSC1↑ (I/O in setup time) | 20 | — | — | ns | |
| 20 | TioR | Port output rise time | — | 32 | 40 | ns | |
| 21 | TioF | Port output fall time | — | 15 | 30 | ns | |
| 22* | Tinp | INT pin high or low time | 25 | — | — | ns | |
| 23* | T _{RABP} | GPIO interrupt-on-change new input level time | T _{CY} | — | — | ns | |

* These parameters are characterized but not tested.

† Data in “Typ” column is at V_{IN} = 12V (V_{DD} = 5V), 25°C unless otherwise stated.

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FIGURE 5-4: RESET, WATCHDOG TIMER, OSCILLATOR START-UP TIMER AND POWER-UP TIMER TIMING

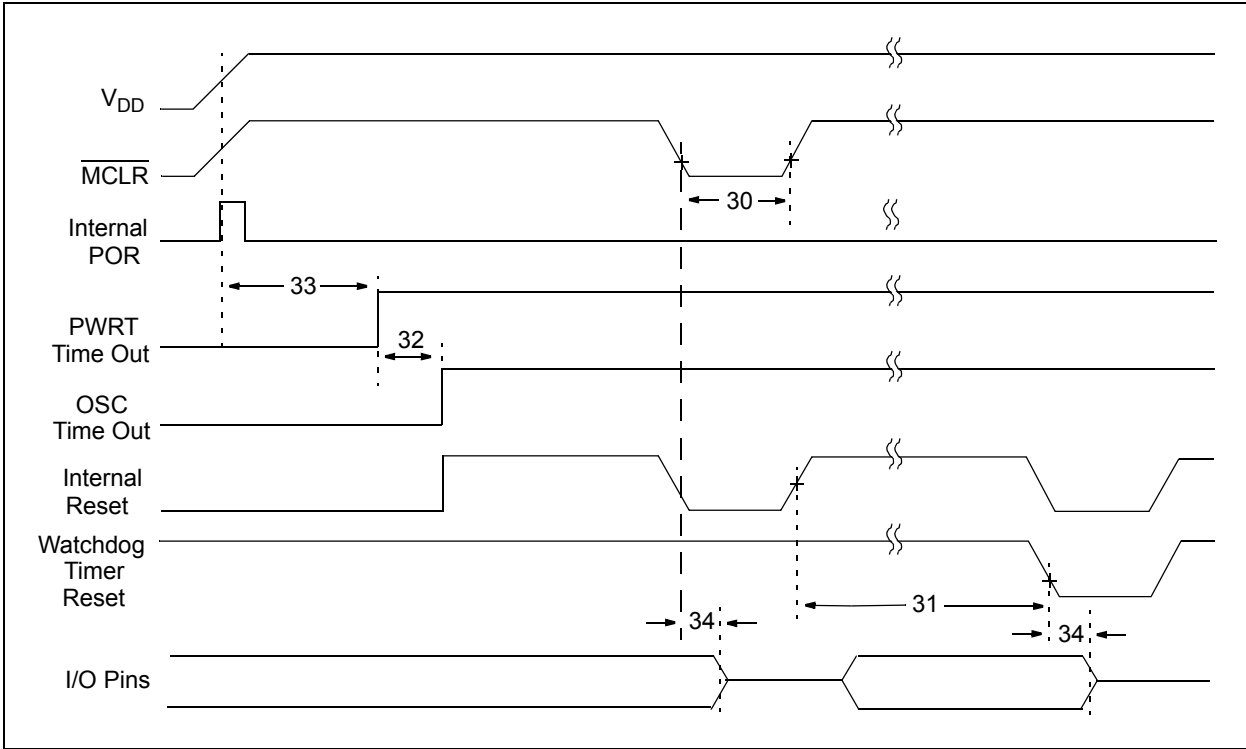


FIGURE 5-5: BROWN-OUT RESET TIMING AND CHARACTERISTICS

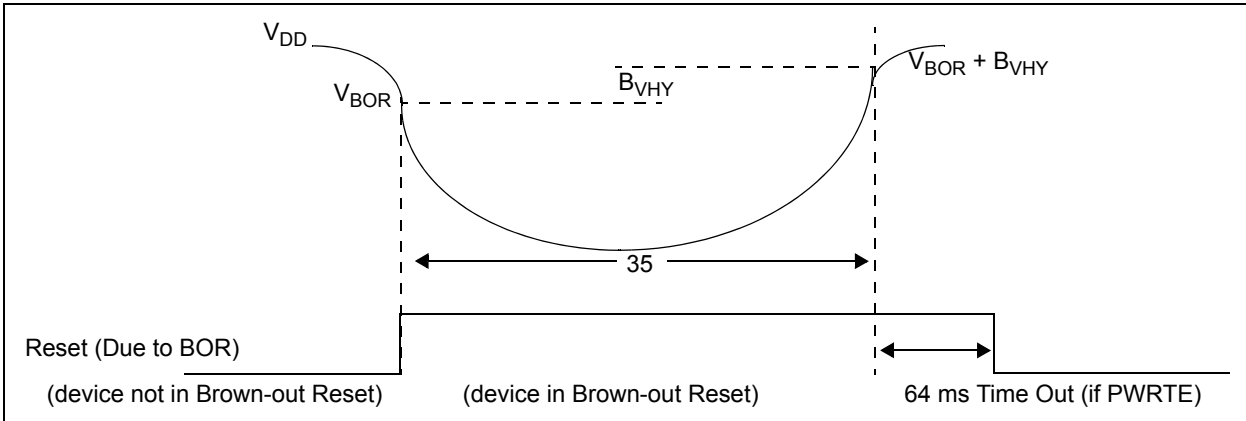


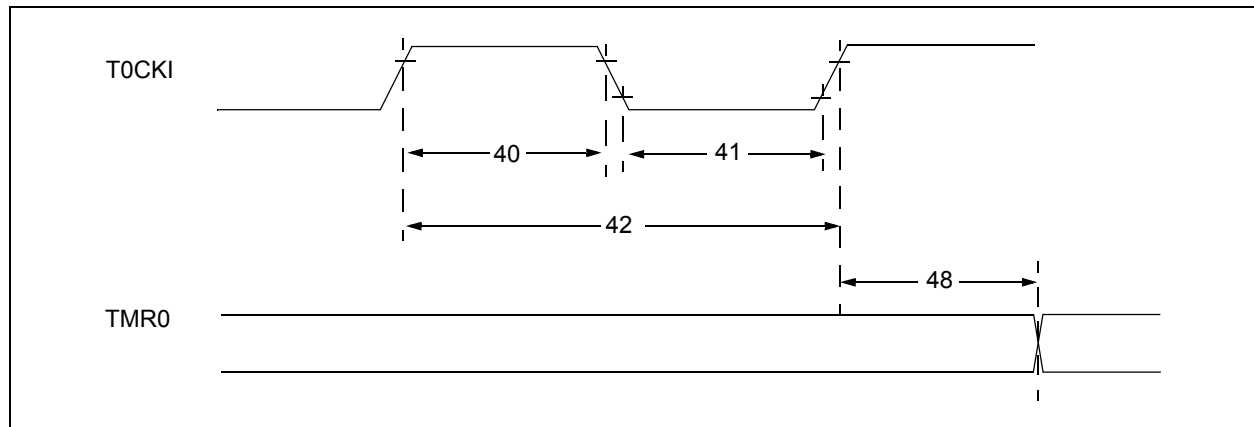
TABLE 5-3: RESET, WATCHDOG TIMER, OSCILLATOR START-UP TIMER AND POWER-UP TIMER REQUIREMENTS

| Param. No. | Sym. | Characteristic | Min. | Typ. [†] | Max. | Units | Conditions |
|------------|----------------------|--|-------------------|----------------------|-------------------|-------|---|
| 30 | T _{MCL} | MCLR Pulse Width (low) | 2 | — | — | μs | V _{DD} = 5 V, -40°C to +85°C |
| 31 | T _{WDT} | Watchdog Timer Time-Out Period (No Prescaler) | 7 | 18 | 33 | ms | V _{DD} = 5 V, -40°C to +85°C |
| 32 | T _{OST} | Oscillation Start-Up Timer Period | — | 1024T _{OSC} | — | — | T _{OSC} = OSC1 period |
| 33* | T _{PWRT} | Power-up Timer Period (4 x T _{WDT}) | 28 | 72 | 132 | ms | V _{DD} = 5 V, -40°C to +85°C |
| 34 | T _{IOZ} | I/O high impedance from MCLR Low or Watchdog Timer Reset | — | — | 2.0 | μs | |
| | V _{BOR} | Brown-out Reset voltage | — | 2.7 | — | V | V _{DD} Falling |
| | B _{VHY} | Brown-out Hysteresis | — | 100 | — | mV | |
| 35 | T _{BCR} | Brown-out Reset pulse width | 100* | — | — | μs | V _{DD} ≤ V _{BOR} (D005) |
| 48 | TCKEZ _{TMR} | Delay from clock edge to timer increment | 2T _{OSC} | — | 7T _{OSC} | | |

* These parameters are characterized but not tested.

† Data in "Typ." column is at V_{IN} = 12V (V_{DD} = AV_{DD} = 5V), 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

FIGURE 5-6: TIMER0 AND TIMER1 EXTERNAL CLOCK TIMING



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TABLE 5-4: TIMER0 EXTERNAL CLOCK REQUIREMENTS

| Param. No. | Sym. | Characteristic | Min. | Typ.† | Max. | Units | Conditions |
|------------|------|------------------------|---|------------------|------|-------|-------------------------------------|
| 40* | Tt0H | T0CKI High Pulse Width | no prescaler | $0.5T_{CY} + 20$ | — | — | ns |
| | | | with prescaler | 10 | — | — | ns |
| 41* | Tt0L | T0CKI Low Pulse Width | no prescaler | $0.5T_{CY} + 20$ | — | — | 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) |

* These parameters are characterized but not tested.

† Data in “Typ.” column is at $V_{IN} = 12V$, $25^{\circ}C$ unless otherwise stated. These parameters are for design guidance only and are not tested.

FIGURE 5-7: PWM TIMINGS

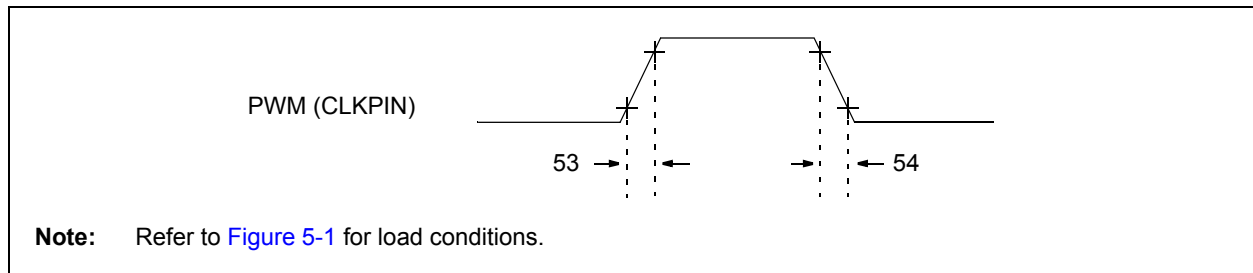


TABLE 5-5: PWM REQUIREMENTS

| Param. No. | Sym. | Characteristic | Min. | Typ.† | Max. | Units | Conditions |
|------------|------|-------------------------------|------|-------|------|-------|------------|
| 53* | TccR | PWM (CLKPIN) output rise time | — | 10 | 25 | ns | |
| 54* | TccF | PWM (CLKPIN) output fall time | — | 10 | 25 | ns | |

* These parameters are characterized but not tested.

† Data in “Typ” column is at $V_{IN} = 12V$ ($AV_{DD} = 4V$), $25^{\circ}C$ unless otherwise stated. Parameters are for design guidance only and are not tested.

TABLE 5-6: MCP19124/5 A/D CONVERTER (ADC) CHARACTERISTICS (Note 1)

| Electrical Specifications: Unless otherwise noted, operating temperature = $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$ | | | | | | | |
|---|------------------|--|------------------|-------------------|------------------|-------|---|
| Param. No. | Sym. | Characteristic | Min. | Typ. [†] | Max. | Units | Conditions |
| AD01 | N _R | Resolution | — | — | 10 bits | bit | |
| AD02 | E _{IL} | Integral Error ⁽²⁾ | — | — | ±1 | LSb | V _{REF_ADC} = AV _{DD} V _{REF_ADC} = V _{DD} |
| AD03 | E _{DL} | Differential Error ⁽²⁾ | — | — | ±1 | LSb | No missing codes to 10 bits ⁽³⁾ V _{REF_ADC} = AV _{DD} V _{REF_ADC} = V _{DD} |
| AD04 | E _{OFF} | Offset Error ⁽²⁾ | — | +3.0 | +7 | LSb | V _{REF_ADC} = AV _{DD} V _{REF_ADC} = V _{DD} |
| AD07 | E _{GN} | Gain Error ⁽²⁾ | — | ±2 | ±6 | LSb | V _{REF_ADC} = AV _{DD} V _{REF_ADC} = V _{DD} |
| AD07 | V _{AIN} | Full-Scale Range | A _{GND} | — | AV _{DD} | V | AV _{DD} selected as ADC Reference |
| | | | A _{GND} | — | V _{DD} | V | V _{DD} selected as ADC Reference |
| AD08 | Z _{AIN} | Recommended Impedance of Analog Voltage Source | — | — | 10 | kΩ | |

* These parameters are characterized but not tested.

† Data in 'Typ.' column is at V_{IN} = 12V (AV_{DD} = 4V), 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

- Note 1:** 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. To minimize Sleep current the ADC Reference must be set to the (default) AV_{DD}.
- 2:** Total Absolute Error includes integral, differential, offset and gain errors.
- 3:** The A/D conversion result never decreases with an increase in the input voltage and has no missing codes.

TABLE 5-7: MCP19124/5 A/D CONVERSION REQUIREMENTS

| Electrical Specifications: Unless otherwise noted, operating temperature = $-40^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$ | | | | | | | |
|---|------------------|---|------|---------------------|------|-----------------|---|
| Param. No. | Sym. | Characteristic | Min. | Typ. [†] | Max. | Units | Conditions |
| AD130* | T _{AD} | A/D Clock Period | 1.6 | — | 9.0 | μs | T _{OSC} -based |
| | | A/D Internal RC Oscillator Period | 1.6 | 4.0 | 6.0 | μs | ADCS<1:0> = 11 (ADRC mode) |
| AD131 | T _{CNV} | Conversion Time (not including Acquisition Time) ⁽¹⁾ | — | 11 | — | T _{AD} | Set GO/DONE bit to new data in A/D Result registers |
| AD132* | T _{ACQ} | Acquisition Time | — | 11.5 | — | μs | |
| AD133* | T _{AMP} | Amplifier Settling Time | — | — | 5 | μs | |
| AD134 | T _{GO} | Q4 to A/D Clock Start | — | T _{OSC} /2 | — | — | |

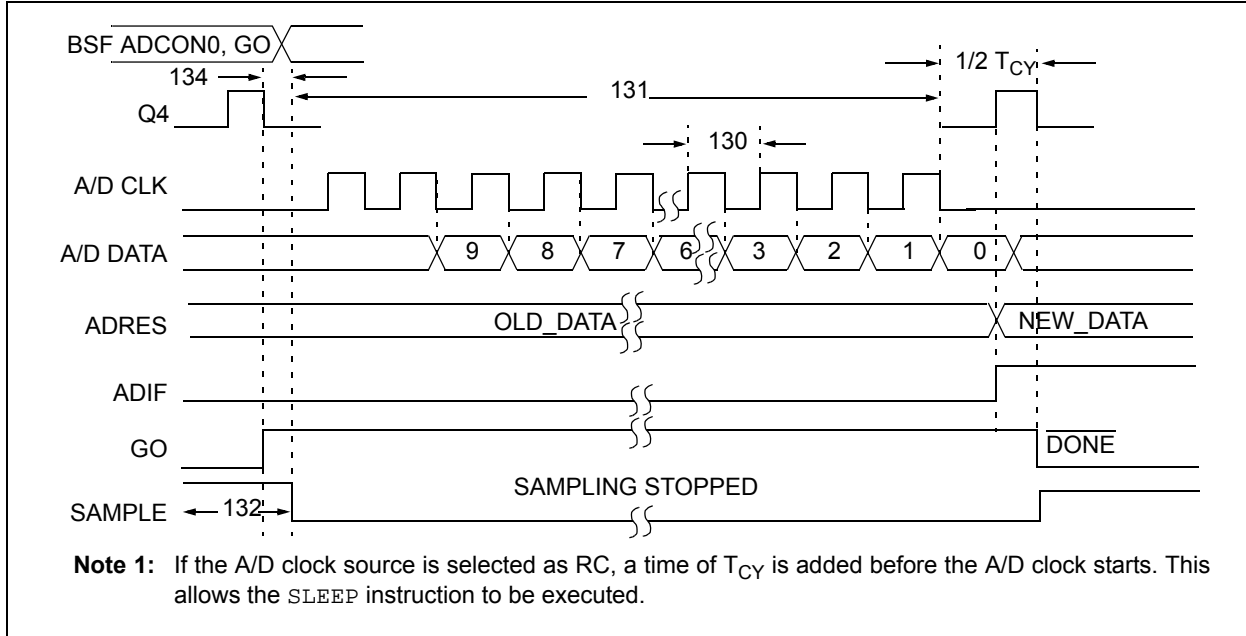
* These parameters are characterized but not tested.

† Data in 'Typ.' column is at V_{IN} = 12V (V_{DD} = AV_{DD} = 5V), 25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

- Note 1:** ADRESH and ADRESL registers may be read on the following T_{CY} cycle.

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FIGURE 5-8: A/D CONVERSION TIMING



6.0 CONFIGURING THE MCP19124/5

The MCP19124/5 are analog controllers with a digital peripheral. This means that device configuration is handled through register settings instead of adding external components. There are several internal configurable comparator modules used to interface analog circuits to digital processing that are very similar to a standard comparator module found in many PIC processors today (i.e., PIC16F1824/1828). The following sections detail how to set the analog control registers for all the configurable parameters.

6.1 Input Undervoltage and Overvoltage Lockout (UVLO and OVLO)

VINCON is the comparator control register for both the VINUVLO and VINOVLO registers. It contains the enable bits, the polarity edge detection bits and the status output bits for both protection circuits. The interrupt flags UVLOIF and OVLOIF in the PIR2 register are independent of the enable UVLOEN and OVLOEN bits in the VINCON register. The UVLOOUT undervoltage lockout status output bit in the VINCON register indicates if an UVLO event has occurred. The OVLOOUT overvoltage lockout status output bit in the VINCON register indicates if an OVLO event has occurred.

The VINUVLO register contains the digital value that sets the input undervoltage lockout. UVLO has a range of 4V to 20V. For V_{IN} values below this range and above processor come-alive ($V_{DD} = 2V$), the UVLO comparator and the UVLOOUT status bit will indicate an undervoltage condition. If using UVLO to determine power-up V_{IN} , it is recommended to poll the UVLOOUT bit for status. When the input voltage on the V_{IN} pin to the MCP19124/5 is below this programmed level and the UVLOEN bit in the VINCON register is set, both PDRV and SDRV gate drivers are disabled. This bit is automatically cleared when the MCP19124/5 V_{IN} voltage rises above this programmed level.

The VINOVLO register contains the digital value that sets the input overvoltage lockout. OVLO has a range of 8.8V to 44V. When the input voltage on the V_{IN} pin to the MCP19124/5 is above this programmed level and the OVLOEN bit in the VINCON register is set, both PDRV and SDRV gate drivers are disabled. This bit is automatically cleared when the MCP19124/5 V_{IN} voltage drops below this programmed level.

Note: The UVLOIF and OVLOIF 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) in the INTCON register.

REGISTER 6-1: VINCON: UVLO AND OVLO COMPARATOR CONTROL REGISTER

| R/W-0 | R-0 | R/W-0 | R/W-0 | R/W-0 | R-0 | R/W-0 | R/W-0 |
|--------|---------|----------|----------|--------|---------|----------|----------|
| UVLOEN | UVLOOUT | UVLOINTP | UVLOINTN | OVLOEN | OVLOOUT | OVLOINTP | OVLOINTN |
| bit 7 | | | | | | | bit 0 |

Legend:

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

- bit 7 **UVLOEN:** UVLO Comparator Module Logic Enable bit
 1 = UVLO Comparator Module Logic enabled
 0 = UVLO Comparator Module Logic disabled
- bit 6 **UVLOOUT:** Undervoltage Lockout Status Output
 1 = UVLO event has occurred
 0 = No UVLO event has occurred
- bit 5 **UVLOINTP:** UVLO Comparator Interrupt on Positive Going Edge Enable bit
 1 = The UVLOIF interrupt flag will be set upon a positive going edge of the UVLO
 0 = No UVLOIF interrupt flag will be set upon a positive going edge of the UVLO
- bit 4 **UVLOINTN:** UVLO Comparator Interrupt on Negative Going Edge Enable bit
 1 = The UVLOIF interrupt flag will be set upon a negative going edge of the UVLO
 0 = No UVLOIF interrupt flag will be set upon a negative going edge of the UVLO

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REGISTER 6-1: VINCON: UVLO AND OVLO COMPARATOR CONTROL REGISTER (CONTINUED)

- bit 3 **OVLOEN:** OVLO Comparator Module Logic enable bit
 1 = OVLO Comparator Module Logic enabled
 0 = OVLO Comparator Module Logic disabled
- bit 2 **OVLOOUT:** Overvoltage Lockout Status Output bit
 1 = OVLO event has occurred
 0 = No OVLO event has occurred
- bit 1 **OVLOINTP:** OVLO Comparator Interrupt on Positive Going Edge Enable bit
 1 = The OVLOIF interrupt flag will be set upon a positive going edge of the OVLO
 0 = No OVLOIF interrupt flag will be set upon a positive going edge of the OVLO
- bit 0 **OVLOINTN:** OVLO Comparator Interrupt on Negative Going Edge Enable bit
 1 = The OVLOIF interrupt flag will be set upon a negative going edge of the OVLO
 0 = No OVLOIF interrupt flag will be set upon a negative going edge of the OVLO

REGISTER 6-2: VINUVLO: INPUT UNDERVOLTAGE LOCKOUT REGISTER

| | | | | | | | |
|-------|-----|-------|-------|-------|-------|-------|-------|
| U-0 | U-0 | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x |
| — | — | UVLO5 | UVLO4 | UVLO3 | UVLO2 | UVLO1 | UVLO0 |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

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

bit 5-0 **UVLO<5:0>:** Undervoltage Lockout Configuration bits
 $UVLO(V) = 3.57 \times (1.028578^N)$ where N = the decimal value written to the VINUVLO Register from 0 to 63

REGISTER 6-3: VINOVLO: INPUT OVERVOLTAGE LOCKOUT REGISTER

| | | | | | | | |
|-------|-----|-------|-------|-------|-------|-------|-------|
| U-0 | U-0 | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x |
| — | — | OVLO5 | OVLO4 | OVLO3 | OVLO2 | OVLO1 | OVLO0 |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

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

bit 5-0 **OVLO<5:0>:** Overvoltage Lockout Configuration bits
 $OVLO(V) = 7.5212 \times (1.028645^N)$ where N = the decimal value written to the VINOVLO Register from 0 to 63

6.2 Output Overvoltage Protection

The MCP19124/5 feature output overvoltage protection. In order to utilize this OV protection circuitry, the voltage regulation error amplifier (EA2) must be disabled by setting the EN2DIS bit in the ABECON register. When the EA2 is disabled, the OV protection feature utilizes a comparator module similar to the standard PIC comparator module. This is used to prevent the power system from being damaged when the load is disconnected. The OVREFCON register contains the digital value that sets the analog DAC voltage at the inverting input of the comparator. By comparing the divided down power train output voltage connected to the noninverting input (V_S) of the comparator with the OV_{REF} reference voltage, the user can determine when an overvoltage event has occurred and can automatically take action.

The OVCON register contains the interrupt flag polarity and OV enable bits along with the output status bit just as VINCON does for the input voltage UVLO and OVLO. When OVEN bit in the OVCON register is set and an overvoltage occurs, the control logic will automatically set the secondary gate drive output (SDRV) high and set the primary gate drive output (PDRV) low.

Note: The OVIF interrupt flag bit is set when an interrupt condition occurs, regardless of the state of its corresponding enable bit or the Global Enable bit (GIE) in the INTCON register.

REGISTER 6-4: OVCON: OUTPUT OVERVOLTAGE COMPARATOR CONTROL REGISTER

| | | | | | | | |
|-------|-----|-----|-----|-------|-------|--------|--------|
| U-0 | U-0 | U-0 | U-0 | R/W-0 | R-0 | R/W-0 | R/W-0 |
| — | — | — | — | OVEN | OVOUT | OVINTP | OVINTN |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

- bit 7-4 **Unimplemented:** Read as '0'
- bit 3 **OVEN:** OV Comparator output enable bit
 - 1 = OV Comparator output is enabled
 - 0 = OV Comparator output is not enabled
- bit 2 **OVOUT:** Output Overvoltage Status Output bit
 - 1 = Output Overvoltage has occurred
 - 0 = No Output Overvoltage has occurred
- bit 1 **OVINTP:** OV Comparator Interrupt on Positive Going Edge Enable bit
 - 1 = The OVIF interrupt flag will be set upon a positive going edge of the OV
 - 0 = No OVIF interrupt flag will be set upon a positive going edge of the OV
- bit 0 **OVINTN:** OV Comparator Interrupt on Negative Going Edge Enable bit
 - 1 = The OVIF interrupt flag will be set upon a negative going edge of the OV
 - 0 = No OVIF interrupt flag will be set upon a negative going edge of the OV

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6.3 Voltage Regulation Configuration

The OVREFCON register controls the voltage error amplifier (EA2) reference voltage. This reference is used to set the voltage regulation set point. OVREFCON holds the digital value used by an 8-bit linear DAC setting the analog equivalent that is connected to the noninverting node of the voltage error amplifier (EA2). This gets compared to the voltage at the EA2 inverting input which is the feedback voltage connected to the V_S pin. The OV_{REF} DAC can be

adjusted in 255 steps of 9.6 mV/step or approximately 0V to 2.46V. However, it should be noted that while in voltage regulation, the error amplifier (EA2) low end of the common mode voltage input range is 0.8V. To maintain accurate voltage regulation, scale the EA2 inputs between 0.8V and 2.46V. The output voltage feedback must be divided down inside of this voltage range before connecting to the V_S pin. Whichever error amplifier (EA1 or EA2) has the lower output signal, takes control of the PWM control loop.

REGISTER 6-5: OVREFCON: VOLTAGE REGULATION AND OUTPUT OVERVOLTAGE DETECT LEVEL REGISTER

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| R/W-x | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x |
| OOV7 | OOV6 | OOV5 | OOV4 | OOV3 | OOV2 | OOV1 | OOV0 |
| 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 = Value at POR

'1' = Bit is set

'0' = Bit is cleared

bit 7-0 **OOV<7:0>**: Output Overvoltage Detect Level Configuration bits

$V_{OV_REF}(V) = 2 \times V_{BG} \times N/255$ where N = the decimal value written to the OVREFCON Register

OOV<7:0> from 0 to 255.

6.4 Desaturation Detection for Quasi-Resonant Operation

The MCP19124/5 have been designed with a built-in desaturation detection comparator module custom made for quasi-resonant topologies. This is especially useful for LED-type applications. Through the use of the MCP19124/5, both synchronous and asynchronous quasi-resonant topologies can be implemented. The DESAT comparator module has the same features as the UVLO/OVLO and OV comparator modules, except that it includes some additional programmable parameters.

The DESATCON register holds the setup control bits for this module. Common control bits are the polarity edge trigger for the interrupt flag <CDSINTP><CDSINTN>, comparator output polarity control CDSPOL, output enable CDSOE and output status CDSOUT bit. As with the other comparator modules, the CDSIF is independent of the CDSOE enable bit. On the front end connected to the DESAT comparator noninverting input, there is a two-channel MUX that connects either to the DESAT_P pin or to the fixed internally generated band gap voltage. Additionally, the input offset voltage of the DESAT comparator is factory-trimmed to within ±1 mV typically. These factory-trimmed values are stored in the CALWD2 register at address 2081h. Firmware must read these values into the DSTCAL register (196h). If more offset is desired, the user can adjust the values written to the DSTCAL per their implementation.

REGISTER 6-6: DESATCON: DESATURATION COMPARATOR CONTROL REGISTER

| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
|--------|--------|----------|--------|-------|--------|---------|---------|
| CDSMUX | CDSWDE | Reserved | CDSPOL | CDSOE | CDSOUT | CDSINTP | CDSINTN |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

| | |
|-------|--|
| bit 7 | CDSMUX: DESAT Comparator Module Multiplexer Channel Selection bit 1 = BG Selected 0 = DESAT _P Selected (Default) |
| bit 6 | CDSWDE: DESAT Comparator Watch Dog Enable bit 1 = Watch Dog signal enables PWM Reset 0 = Watch Dog signal does not allow PWM reset |
| bit 5 | Reserved |
| bit 4 | CDSPOL: DESAT Comparator Polarity Select bit 1 = DESAT Comparator output is inverted 0 = DESAT Comparator output is not inverted |
| bit 3 | CDSOE: DESAT Comparator output enable bit 1 = DESAT Comparator output PWM is enabled 0 = DESAT Comparator output PWM is not enabled |
| bit 2 | CDSOUT: DESAT Comparator Output Status bit <u>If CDSPOL = 1 (inverted polarity)</u> 1 = CDSVP < CDSVN (DESAT detected) 0 = CDSVP > CDSVN (DESAT not detected) <u>If CDSPOL = 0 (noninverted polarity)</u> 1 = CDSVP > CDSVN (DESAT not detected) 0 = CDSVP < CDSVN (DESAT detected) |
| bit 1 | CDSINTP: CDSIF Comparator Interrupt on Positive Going Edge Enable bit 1 = The CDSIF interrupt flag will be set upon a positive going edge 0 = No CDSIF interrupt flag will be set upon a positive going edge |
| bit 0 | CDSINTN: CDSIF Comparator Interrupt on Negative Going Edge Enable bit 1 = The CDSIF interrupt flag will be set upon a negative going edge 0 = No CDSIF interrupt flag will be set upon a negative going edge |

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6.5 Primary Input Current Offset Adjust

Primary input current offset adjust provides the ability to add offset to the primary input current signal, thus setting a peak primary current limit. This offset adjust is controlled using the four bits in the ICOACON register.

REGISTER 6-7: ICOACON: INPUT CURRENT OFFSET ADJUST CONTROL REGISTER

| | | | | | | | |
|-------|-----|-----|-----|--------|--------|--------|--------|
| U-0 | U-0 | U-0 | U-0 | R/W-x | R/W-x | R/W-x | R/W-x |
| — | — | — | — | ICOAC3 | ICOAC2 | ICOAC1 | ICOAC0 |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

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

bit 3-0 **ICOAC<3:0>:** Input Current Offset Adjustment Configuration bits

0000 = 0 mV
0001 = 50 mV
0010 = 100 mV
0011 = 150 mV
0100 = 200 mV
0101 = 250 mV
0110 = 300 mV
0111 = 350 mV
1000 = 400 mV
1001 = 450 mV
1010 = 500 mV
1011 = 550 mV
1100 = 600 mV
1101 = 650 mV
1110 = 700 mV
1111 = 750 mV

6.6 Leading Edge Blanking

The adjustable Leading Edge Blanking (LEB) is used to blank primary current spikes resulting from primary switch turn-on. Implementing adjustable LEB allows the system to ignore turn-on noise to best suit the application without primary current sense distortion from RC filtering. There are four settings available for LEB, including zero. These settings are controlled via the two bits in the ICLEBCON register.

REGISTER 6-8: ICLEBCON: INPUT CURRENT LEADING EDGE BLANKING CONTROL REGISTER

| | | | | | | | |
|-------|-----|-----|-----|-----|-----|---------|---------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 | R/W-x | R/W-x |
| — | — | — | — | — | — | ICLEBC1 | ICLEBC0 |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

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

bit 1-0 **ICLEBC<1:0>:** Input Current Leading Edge Blanking Configuration bits

00 = 0 ns

01 = 50 ns

10 = 100 ns

11 = 200 ns

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6.7 Slope Compensation

A negative voltage slope is added to the output of the error amplifier. This is done to prevent subharmonic instability when:

1. The operating duty cycle is greater than 50%.
2. Wide changes in the duty cycle occur.

The amount of negative slope added to the error amplifier output is controlled by slope compensation slew rate control bits.

The slope compensation is enabled by clearing the SLPBY bit in the SLPCRCON register.

REGISTER 6-9: SLPCRCON: SLOPE COMPENSATION RAMP CONTROL REGISTER

| U-0 | R/W-0 | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x |
|-------|-------|-------|-------|-------|-------|-------|-------|
| — | SLPBY | SLPS5 | SLPS4 | SLPS3 | SLPS2 | SLPS1 | SLPS0 |
| 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 = Value at POR
'1' = Bit is set '0' = Bit is cleared

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

bit 6 **SLPBY:** Slope Compensation Bypass Control bit

1 = Slope compensation is bypassed

0 = Slope compensation is not bypassed (**Default**)

bit 5-0 **SLPS<5:0>:** Slope Compensation Slew Rate Control bits

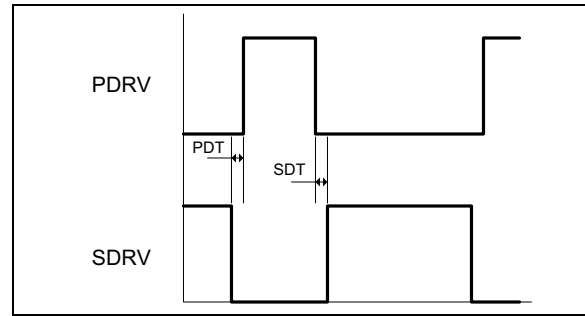
$SLPS (mV/\mu s) = 4.2785 \times 1.0765^N$ where N = the decimal value written to the SLPCRCON Register
SLPS<5:0> from 0 to 63.

6.8 MOSFET Driver Programmable Dead Time

The turn-on dead time of both PDRV and SDRV low-side drive signals can be configured independently to allow different MOSFETs and circuit board layouts to be used to construct an optimized system (refer to Figure 6-1).

Clearing the PDRVBY and SDRVBY bits in the PE1 register enables the PDRV and SDRV low-side dead timers respectively. The amount of dead time added is controlled in the DEADCON register.

FIGURE 6-1: MOSFET DRIVER DEAD TIME



REGISTER 6-10: DEADCON: DRIVER DEAD TIME CONTROL REGISTER

| R/W-x | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x | R/W-x |
|---------|---------|---------|---------|---------|---------|---------|---------|
| PDRVDT3 | PDRVDT2 | PDRVDT1 | PDRVDT0 | SDRVDT3 | SDRVDT2 | SDRVDT1 | SDRVDT0 |
| 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 = Value at POR
 '1' = Bit is set '0' = Bit is cleared

bit 7-4 **PDRVDT<3:0>**: PDRV Dead Time Configuration bits (t_{TD_1})

- 0000 = 16 ns delay
- 0001 = 32 ns delay
- 0010 = 48 ns delay
- 0011 = 64 ns delay
- 0100 = 80 ns delay
- 0101 = 96 ns delay
- 0110 = 112 ns delay
- 0111 = 128 ns delay
- 1000 = 144 ns delay
- 1001 = 160 ns delay
- 1010 = 176 ns delay
- 1011 = 192 ns delay
- 1100 = 208 ns delay
- 1101 = 224 ns delay
- 1110 = 240 ns delay
- 1111 = 256 ns delay

bit 3-0 **SDRVDT<3:0>**: SDRV Dead Time Configuration bits (t_{TD_2})

- 0000 = 16 ns delay
- 0001 = 32 ns delay
- 0010 = 48 ns delay
- 0011 = 64 ns delay
- 0100 = 80 ns delay
- 0101 = 96 ns delay
- 0110 = 112 ns delay
- 0111 = 128 ns delay
- 1000 = 144 ns delay
- 1001 = 160 ns delay
- 1010 = 176 ns delay
- 1011 = 192 ns delay
- 1100 = 208 ns delay
- 1101 = 224 ns delay
- 1110 = 240 ns delay
- 1111 = 256 ns delay

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6.9 Current Regulation Reference Configuration

The VREFCON register controls the error amplifier reference voltage. This reference is used to set the current regulation set point. VREFCON holds the digital value used by an 8-bit linear DAC setting the analog equivalent that gets summed with the pedestal voltage (VZC) at the noninverting node of the current error

amplifier (EA1). VZC is equal to the band gap voltage (1.23V). The output of the current sense amplifier A2 is also raised on the pedestal voltage, effectively canceling its effect on the input. The pedestal is implemented throughout the analog current control loop to improve accuracy at low levels. The V_{REF} DAC can be adjusted in 255 steps of 4.8 mV/step. Whichever error amplifier (EA1 or EA2) has the lower output signal takes control of the PWM control loop.

REGISTER 6-11: VREFCON: CURRENT/VOLTAGE REGULATION SET POINT CONTROL REGISTER

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| VREF7 | VREF6 | VREF5 | VREF4 | VREF3 | VREF2 | VREF1 | VREF0 |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

bit 7-0 **VREF<7:0>**: Voltage-Controlling Current Regulation Set Point bits
 $V_{REF}(V) = V_{BG} \times N/255$ where N = the decimal value written to the VREFCON Register VREF<7:0> from 0 to 255.

6.10 V_{REF2} Voltage Reference

The VREF2CON register controls a second reference DAC that can be used externally. For example, it can be sent off chip and used to set the current regulation set point for a MCP1631 Pulse-Width Modulator. The MCP19124/5 must be configured in Master Mode with bits MSC<0:1> = 01 in the MODECON register to

connect V_{REF2} to GPB1. In Stand-Alone mode, V_{REF2} is not accessible. VREFCON2 holds the digital value used to set the V_{REF2} DAC. Since this reference is intended to go off chip, there is no pedestal offset associated with it and it is referenced to GND. It is an 8-bit linear DAC and has a range from 0V to 1.23V (BG) equating to 255 steps at 4.8 mV/step.

REGISTER 6-12: VREF2CON: V_{REF2} VOLTAGE SET POINT REGISTER

| | | | | | | | |
|------------|-------|-------|-------|-------|-------|-------|-------|
| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| VREF2<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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

bit 7-0 **VREF2<7:0>**: Voltage Controlling Current Regulation Set Point bits
 $V_{REF2}(V) = V_{BG} \times N/255$ where N = the decimal value written to the VREF2CON Register VREF2<7:0> from 0 to 255.

6.11 Analog Peripheral Control

The MCP19124/5 have various analog peripherals. These peripherals can be configured to allow customizable operation. Refer to [Register 6-13](#) for more information.

6.11.1 MOSFET GATE DRIVER ENABLES

The MCP19124/5 can enable and/or disable the MOSFET gate driver outputs for the primary drive (PDRV) and the secondary drive (SDRV) independently. Setting the PDRVEN bit in the PE1 register enables the primary drive. Setting the SDRVEN bit in the PE1 register enables the secondary drive. Refer to [Register 6-13](#) for details.

REGISTER 6-13: PE1: ANALOG PERIPHERAL ENABLE1 CONTROL REGISTER

| | | | | | | | |
|--------|--------|--------|--------|-----|--------|------------|------------|
| R/W-0 | R/W-0 | R/W-0 | R/W-0 | U-0 | R/W-0 | R/W-0 | R/W-0 |
| PDRVEN | SDRVEN | PDRVBY | SDRVBY | — | ISPUEN | PWMSTR_PEN | PWMSTR_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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

bit 7 **PDRVEN**: PDRV Gate Drive Enable bit
 1 = PDRV gate drive is enabled
 0 = PDRV gate drive is disabled

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REGISTER 6-13: PE1: ANALOG PERIPHERAL ENABLE1 CONTROL REGISTER (CONTINUED)

| | |
|-------|---|
| bit 6 | SDRVEN: SDRV Gate Drive Enable bit 1 = SDRV gate drive is enabled 0 = SDRV gate drive is disabled |
| bit 5 | PDRVBY: PDRV Dead Time Bypass bit 1 = PDRV dead time is bypassed 0 = PDRV dead time is not bypassed |
| bit 4 | SDRVBY: SDRV Dead Time Bypass bit 1 = SDRV dead time is bypassed 0 = SDRV dead time is not bypassed |
| bit 3 | Unimplemented: Read as '0' |
| bit 2 | ISPUEN: I_{SP} Weak Pull-Up Enable bit 1 = I_{SP} weak pull-up is enabled 0 = I_{SP} weak pull-up is disabled |
| bit 1 | PWMSTR_PEN: PDRV PWM Steering bit 1 = Enables open-loop PWM control to the PDRV 0 = Disables open-loop PWM control to the PDRV |
| bit 0 | PWMSTR_SEN: SDRV PWM Steering bit 1 = Enables open-loop PWM control to the SDRV 0 = Disables open-loop PWM control to the SDRV |

6.11.2 MOSFET DRIVER DEAD TIME

As described in [Section 6.8 “MOSFET Driver Programmable Dead Time”](#), the MOSFET drive dead time can be adjusted. The dead time can be set independently for each driver from 16 ns to 256 ns in increments of 16 ns using the DEADCON register. Dead time can also be disabled for each driver independently by setting the bypass bits PDRVBY and SDRVBY in the PE1 register.

6.11.3 SECONDARY CURRENT POSITIVE SENSE PULL-UP

A high-impedance pull-up on the I_{SP} pin can be configured by setting the ISPUEN bit in the PE1 register. When set, the I_{SP} pin is internally pulled-up to V_{DD} . Refer to [Register 6-13](#) for details.

6.11.4 PWM STEERING

The MCP19124/5 have additional control circuitry to allow open-loop repositioning of the output. The PWMSTR_PEN bit enables a primary-only PWM signal of fixed frequency and duty cycle to reposition the output voltage up. The PWMSTR_SEN bit enables a secondary-only PWM signal of fixed frequency and duty cycle to reposition the output voltage down. When repositioning output voltage down, the output overvoltage protection must be active along with PWMSTR_SEN for the PWM to pulse the SDRV. Frequency and duty cycle are controlled through TMR2 registers PR2 and TMR1L. PWMSTPR_PEN and PWMSTR_SEN should never be active at the same time, therefore the PWMSTPR_PEN is the dominant

bit. For quasi-resonant operation during open-loop repositioning, the DESAT comparator output should be disabled with the CDSOE bit in the DEADCON register.

6.12 Analog and Digital Test Signal Enable and Control

Various analog and digital test signals can be enabled or disabled, as shown in the ABECON register. These signals can be configured to GPA0. Setting the DIGOEN bit enables the digital test signals to be connected to GPA0. DSEL<2:0> select the digital channels. Setting ANAOEN enables the analog test signals to be connected to GPA0. If ANAOEN and DIGOEN both get set, the DIGOEN bit takes priority. When ANAOEN is not set, the analog test signals are connected to the internal ADC. The analog test channel selections are controlled through the ADCON0 register.

6.12.1 MOSFET DRIVER UNDERVOLTAGE LOCKOUT SELECTION

The MOSFET gate drivers have internal undervoltage protection that is controlled by the DRUVSEL bit in the ABECON register. Since the gate drive supply is provided externally through the V_{DR} pin, the drivers are capable of driving logic level FETs or higher 10V (13.5V maximum) FETs. DRUVSEL defaults to clear, therefore selecting a gate drive UVLO of 2.7V. Setting DRUVSEL selects the higher 5.4V gate drive UVLO. Refer to [Section 4.2 “Electrical Characteristics”](#) for additional electrical specifications.

6.12.2 ERROR AMPLIFIER DISABLES

The error amplifiers can be disabled such that its output relinquishes control of the loop to the other error amplifier. Since the error amplifier outputs are clamped to each other the disabled amplifier output will follow the enabled amplifier output but will not be in control of the loop. If both error amplifiers are disabled, both outputs are pulled low (no demand). The EADIS bits default to zero and the error amplifiers are enabled during normal operation.

REGISTER 6-14: ABECON: ANALOG BLOCK ENABLE CONTROL REGISTER

| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
|--------|-------|-------|-------|---------|--------|--------|-------|
| DIGOEN | DSEL2 | DSEL1 | DSEL0 | DRUVSEL | EA2DIS | EA1DIS | ANAEN |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

| | |
|---------|---|
| bit 7 | DIGOEN: DIG Test MUX to GPA0 Connection Control bit 1 = DIG Test MUX output is connected to external pin GPA0 0 = DIG Test MUX output is not connected to external pin GPA0 |
| bit 6-4 | DSEL<2:0>: DIG Test MUX Signal Channel Select bits 000 = QRS (output of DESAT comparator) 001 = PWM_L (PWM output after monostable) 010 = PWM (oscillator output from the microcontroller) 011 = TMR2EQ (when TMR2 equals PR2) 100 = OV (overvoltage comparator output) 101 = SWFRQ (switching frequency output) 110 = SDRV_ON_ONESHOT (200 ns one-shot signal to reset WDM logic) 111 = Unimplemented |
| bit 3 | DRUVSEL: Selects gate drive undervoltage lockout level 1 = Gate Drive UVLO set to 5.4V 0 = Gate Drive UVLO set to 2.7V |
| bit 2 | EA2DIS: Voltage Error Amplifier Disable bit 1 = Disables the voltage error amplifier (Enables Output OV Comparator Protection) 0 = Enables the voltage error amplifier |
| bit 1 | EA1DIS: Current Error Amplifier Disable bit 1 = Disables the current error amplifier 0 = Enables the current error amplifier |
| bit 0 | ANAEN: Analog MUX Output Control bit 1 = Analog MUX output is connected to external pin GPA0 0 = Analog MUX output is not connected to external pin GPA0 |

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6.13 Mode and RFB MUX Control

The MODECON register controls the Master/Slave configuration.

In Master mode, it allows the V_{REF2} signal of the Master MCP19124/5 device to be buffered and connected to a GPIO pin. This output signal can be connected to a Slave PWM driver (MCP1631) at the V_{REF} input to regulate current via the Slave PWM

Controller. Also in Master mode, the CLKOUT sync signal is routed to GPA1. In Semi-Master Mode users have the option to implement V_{REF2} and CLKOUT independently. In Slave mode the PWM switching frequency is obtained from the CLKIN pin at GPA1. In Stand-Alone mode, the V_{REF2} unity gain buffer is not connected to a separate GPIO Pin and the PWM switching frequency is internally generated.

REGISTER 6-15: MODECON: MASTER/SLAVE AND RFB MUX CONTROL REGISTER

| | | | | | | | |
|-------|-------|-----|-----|-------|-----|-----|-------|
| R/W-0 | R/W-0 | U-0 | U-0 | R/W-0 | U-0 | U-0 | U-0 |
| MSC1 | MSC0 | — | — | MSC2 | — | — | — |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

- bit 7-6 **MSC<1:0>**: Master/Slave Configuration bits
 - 00 = Device set as stand-alone unit (V_{REF2} disabled, switching frequency internally generated)
 - 01 = Device set as MASTER (V_{REF2} to GPB1, CLKOUT sync to GPA1)
 - 10 = Device set as SLAVE MODE (CLKIN switching frequency sync signal to GPA1)
 - 11 = Device set to SEMI-MASTER MODE
- bit 5-4 **Unimplemented**: Read as '0'
- bit 3 **MSC2**: Semi-Master Mode Options bit
 - 0 = GPB1 is V_{REF2} Output, GPA1 is general purpose I/O
 - 1 = GPB1 is general purpose output, GPA1 is CLKOUT
- bit 2-0 **Unimplemented**: Read as '0'

7.0 TYPICAL PERFORMANCE CURVES

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.

Note: Unless otherwise indicated, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$.

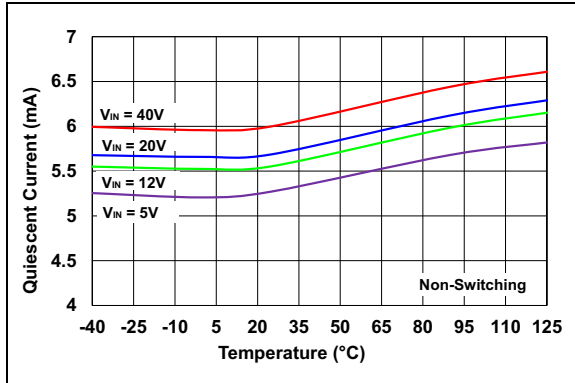


FIGURE 7-1: I_Q vs. Temperature.

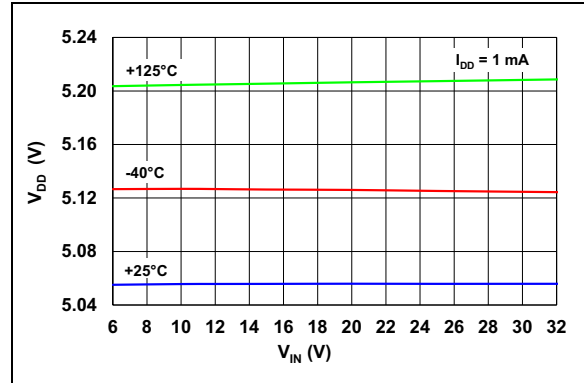


FIGURE 7-4: Line Regulation.

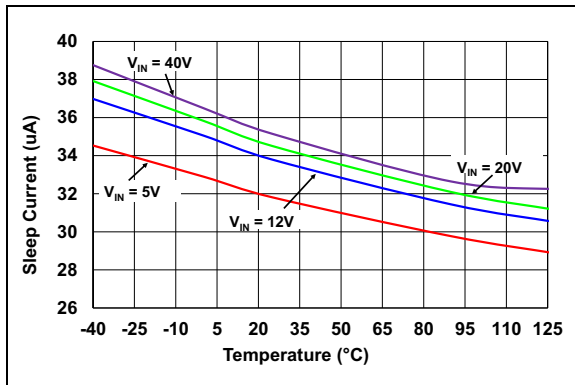


FIGURE 7-2: I_Q vs. Temperature in Sleep Mode.

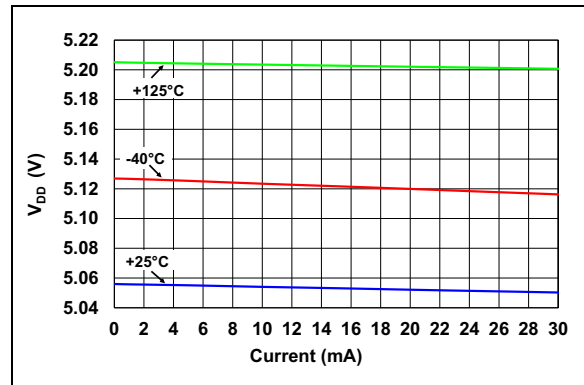


FIGURE 7-5: Load Regulation.

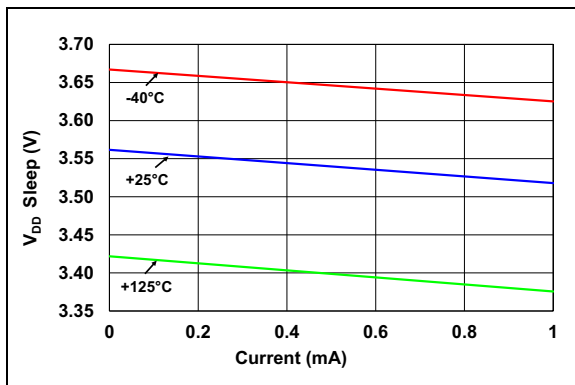


FIGURE 7-3: Sleep V_{DD} vs. Load Current.

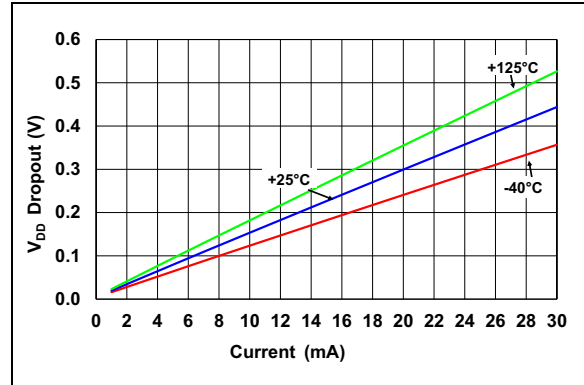


FIGURE 7-6: V_{DD} Dropout Voltage vs. Current.

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Note: Unless otherwise indicated, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$.

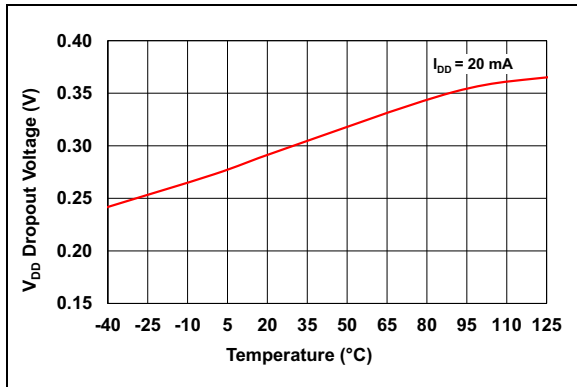


FIGURE 7-7: V_{DD} Dropout Voltage vs. Temperature.

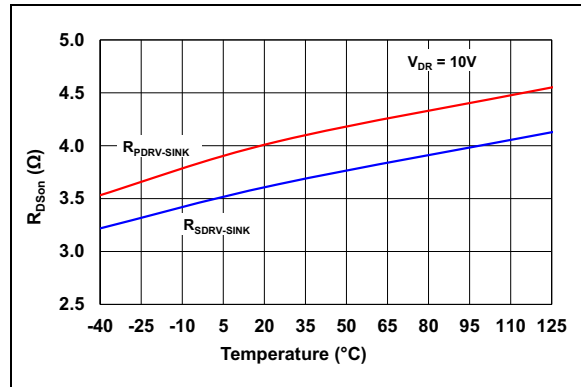


FIGURE 7-10: Sinking Output Driver R_{DSon} vs. Temperature.

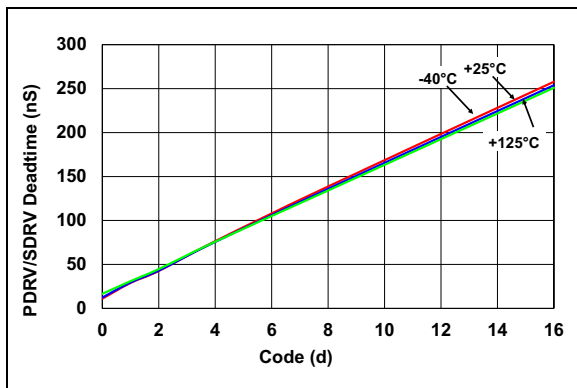


FIGURE 7-8: Output Driver Dead Time vs. Code and Temperature.

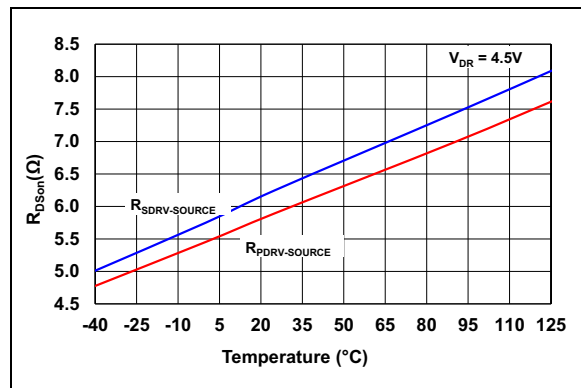


FIGURE 7-11: Sourcing Output Driver R_{DSon} vs. Temperature.

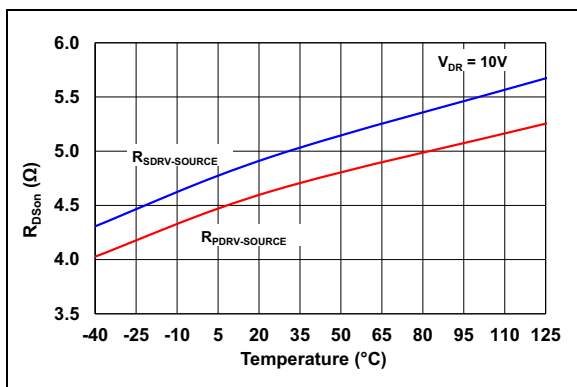


FIGURE 7-9: Sourcing Output Driver R_{DSon} vs. Temperature.

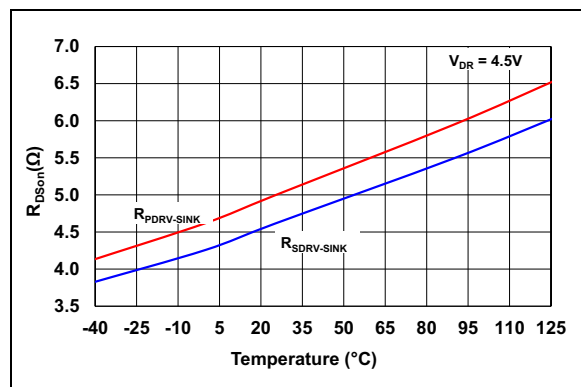


FIGURE 7-12: Sinking Output Driver R_{DSon} vs. Temperature.

Note: Unless otherwise indicated, $V_{IN} = 12V$, $F_{SW} = 150\text{ kHz}$, $T_A = +25^\circ\text{C}$.

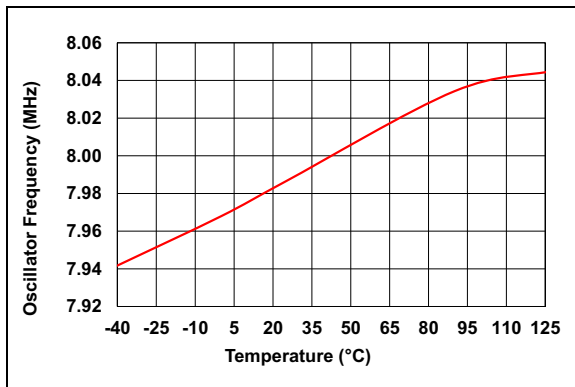


FIGURE 7-13: Oscillator Frequency vs. Temperature.

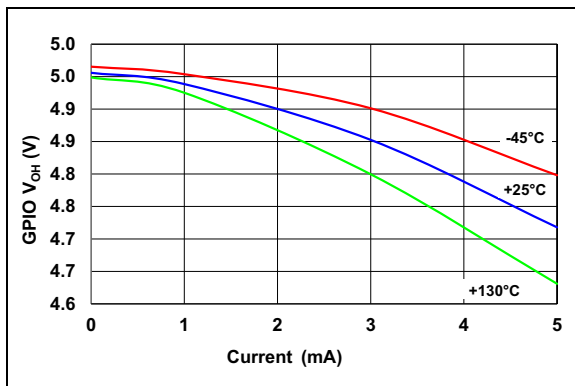


FIGURE 7-14: Average GPIO Output Voltage vs. Current.

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NOTES:

8.0 SYSTEM BENCH TESTING

Control of the signals present at the output of the unity gain analog buffer is found in the ADCON0 register.

To allow for easier system design and bench testing, the MCP19124/5 feature a multiplexer used to output various internal analog signals. These signals can be measured on the GPA0 pin through a unity gain buffer. The configuration control of the GPA0 pin is found in the ABECON register.

REGISTER 8-1: ADCON0: ANALOG-TO-DIGITAL CONTROL REGISTER

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|---------|-------|
| U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| — | CHS4 | CHS3 | CHS2 | CHS1 | CHS0 | 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 = Value at POR |
| '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 = V_{IN}/n analog voltage measurement ($V_{IN}/15.5328$)
- 00001 = $V_{REF} + V_{ZC}$ (DAC reference voltage + VZC pedestal setting current regulation level)
- 00010 = OV_{REF} (reference for overvoltage comparator)
- 00011 = V_{BGR} (band gap reference)
- 00100 = V_S (voltage proportional to V_{OUT})
- 00101 = EA_SC (error amplifier after slope compensation output)
- 00110 = A2 (secondary current sense amplifier output at R_{FB_INT} connection)
- 00111 = Pedestal (Pedestal Voltage)
- 01000 = Reserved
- 01001 = Reserved
- 01010 = IP_ADJ (IP after Pedestal and Offset Adjust (at PWM Comparator))
- 01011 = IP_OFF_REF (IP Offset Reference)
- 01100 = V_{DR}/n (V_{DR}/n analog driver voltage measurement = $0.229V/V \times V_{DR}$)
- 01101 = TEMP_SNS (analog voltage representing internal temperature)
- 01110 = DLL_VCON (Delay Locked Loop Voltage Reference - control voltage for dead time)
- 01111 = SLPCMP_REF (slope compensation reference)
- 10000 = EAOR (OR'd output node from the two error amplifiers EA1 & EA2)
- 10001 = Unimplemented
- 10010 = Unimplemented
- 10011 = Unimplemented
- 10100 = Unimplemented
- 10101 = Unimplemented
- 10110 = Unimplemented
- 10111 = Unimplemented
- 11000 = GPA0/AN0 (i.e. ADDR1)
- 11001 = GPA1/AN1 (i.e. ADDR0)
- 11010 = GPA2/AN2 (i.e. Temperature Sensor Input)
- 11011 = GPA3/AN3 (i.e. BIN)
- 11100 = GPB1/AN4
- 11101 = GPB4/AN5 (**MCP19125 Only**)
- 11110 = GPB5/AN6 (**MCP19125 Only**)
- 11111 = GPB6/AN7 (**MCP19125 Only**)

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REGISTER 8-1: **ADCON0: ANALOG-TO-DIGITAL CONTROL REGISTER (CONTINUED)**

- 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 = A/D converter module is enabled
0 = A/D converter is shut off and consumes no operating current

9.0 DEVICE CALIBRATION

Read-only memory locations 2080h through 208Fh contain factory calibration data. Refer to [Section 20.0 “Flash Program Memory Control”](#) for information on how to read from these memory locations.

9.1 Calibration Word 1

Calibration Word 1 is at memory location 2080h and contains the calibration bits for the Transconductance Gm trim for both the current regulation error amplifier and the voltage regulation error amplifier. The CGM<3:0> bits set the trim for the Transconductance current loop error amp (EA1). The VGM<3:0> bits set the trim for the transconductance voltage loop error amplifier (EA2). Firmware must read these values and copy into the CGMVGMCAL Special Function Register located in Bank 3 at 197h.

REGISTER 9-1: CALWD1: CALIBRATION WORD 1 REGISTER

| | | | | | |
|--------|-----|-----|-----|-----|-------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 |
| — | — | — | — | — | — |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| CGM3 | CGM2 | CGM1 | CGM0 | VGM3 | VGM2 | VGM1 | VGM0 |
| bit 7 | | | | | | | bit 0 |

Legend:

| | | |
|-------------------|----------------------|--|
| R = Readable bit | P = Programmable bit | U = Unimplemented bit, read as '0' |
| -n = Value at POR | '1' = Bit is set | '0' = Bit is cleared x = Bit is unknown |

bit 13-8 **Unimplemented:** Read as '0'
bit 7-4 **CGM<3:0>:** Gm Adjust for the Current Error Amplifier (EA1)
bit 3-0 **VGM<3:0>:** Gm Adjust for the Voltage Error Amplifier (EA2)

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9.2 Calibration Word 2

Calibration Word 2 is at memory location 2081h. It contains the calibration bits for the desaturation comparator current measurement input offset voltage. Firmware must read these values and write them into the DSTCAL register to implement the factory offset calibration. The factory offset calibration will minimize offset voltage. The desaturation comparator is one of the few examples where the user may want to implement their own offset voltage values. Writing user defined values to the DSTCAL register provides this flexibility. Firmware must read these values and copy into the DSTCAL Special Function Register located in Bank 3 at 196h to implement factory calibration values.

REGISTER 9-2: CALWD2: CALIBRATION WORD 2 REGISTER

| | | | | | |
|--------|-----|-----|-----|-----|-------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 |
| — | — | — | — | — | — |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|-----|-----|-------|-------|-------|-------|-------|
| U-0 | U-0 | U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | — | — | DST4 | DST3 | DST2 | DST1 | DST0 |
| bit 7 | | | | | | | bit 0 |

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

- bit 13-5 **Unimplemented:** Read as '0'
- bit 4-0 **DST<4:0>:** Desaturation Comparator Current Measure Offset Calibration bits
 - 11111 = Maximum negative offset calibration (-30 mV)
 -
 -
 -
 - 10000 = Mid scale (0 mV)
 - 00000 = Mid scale (0 mV)
 -
 -
 -
 - 01111 = Maximum positive offset calibration (+30 mV)

9.3 Calibration Word 3

The BGR<4:0> bits at memory location 2082h calibrate the band gap reference. Firmware must read these values and copy into the BGRCAL Special Function Register located in Bank 3 at 19Bh.

REGISTER 9-3: CALWD3: CALIBRATION WORD 3 REGISTER

| | | | | | |
|--------|-----|-----|-----|-----|-------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 |
| — | — | — | — | — | — |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|-----|-----|-------|-------|-------|-------|-------|
| U-0 | U-0 | U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | — | — | BGR4 | BGR3 | BGR2 | BGR1 | BGR0 |
| bit 7 | | | | | | | bit 0 |

Legend:

R = Readable bit

P = Programmable bit

U = Unused bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 13-5 **Unused:** Read as '0'

bit 4-0 **BGR<4:0>:** Band Gap Reference Calibration bits

9.4 Calibration Word 4

The TTA<3:0> bits at memory location 2083h contain the calibration bits for the factory-set overtemperature threshold. Firmware must read these values and copy into the TTACAL Special Function Register located in Bank 3 at 19Ah.

REGISTER 9-4: CALWD4: CALIBRATION WORD 4 REGISTER

| | | | | | |
|--------|-----|-----|-----|-----|-------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 |
| — | — | — | — | — | — |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|-----|-----|-----|-------|-------|-------|-------|
| U-0 | U-0 | U-0 | U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | — | — | — | TTA3 | TTA2 | TTA1 | TTA0 |
| bit 7 | | | | | | | bit 0 |

Legend:

R = Readable bit

P = Programmable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 13-4 **Unimplemented:** Read as '0'

bit 3-0 **TTA<3:0>:** Overtemperature Threshold Calibration bits

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9.5 Calibration Word 5

The TANA<9:0> bits at memory location 2084h contain the ADC reading from the internal temperature sensor when the silicon temperature is at 28°C. This temperature can typically vary +2°C / -3°C. This 10 bit reading can be used to calculate the silicon die

temperature. The temperature coefficient of the internal temperature sensor is typically 14.0mV/°C, +/-0.8mV/°C from -20°C to +125°C. See [Section 25.0 “Internal Temperature Indicator Module”](#) for more details.

REGISTER 9-5: CALWD5: CALIBRATION WORD 5 REGISTER

| | | | | | |
|--------|-----|-----|-----|-------|-------|
| U-0 | U-0 | U-0 | U-0 | R/P-1 | R/P-1 |
| — | — | — | — | TANA9 | TANA8 |
| bit 13 | | | | bit 8 | |

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| TANA7 | TANA6 | TANA5 | TANA4 | TANA3 | TANA2 | TANA1 | TANA0 |
| bit 7 | | | | | | | bit 0 |

Legend:

R = Readable bit P = Programmable bit U = Unimplemented bit, read as '0'
 -n = Value at POR '1' = Bit is set '0' = Bit is cleared x = Bit is unknown

bit 13-10 **Unimplemented:** Read as '0'

bit 9-0 **TANA<9:0>:** ADC Reading of Internal Silicon Temperature at 30°C Calibration bits

9.6 Calibration Word 6

The FCAL<6:0> bits at memory location 2085h set the internal oscillator calibration. Firmware must read these values and copy into the OSCCAL Special Function Register located in Bank 3 at 198h.

REGISTER 9-6: CALWD6: CALIBRATION WORD 6 REGISTER

| | | | | | |
|--------|-----|-----|-----|-----|-------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 |
| — | — | — | — | — | — |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | FCAL6 | FCAL5 | FCAL4 | FCAL3 | FCAL2 | FCAL1 | FCAL0 |
| bit 7 | | | | | | | bit 0 |

Legend:

R = Readable bit P = Programmable bit U = Unimplemented bit, read as '0'
 -n = Value at POR '1' = Bit is set '0' = Bit is cleared x = Bit is unknown

bit 13-7 **Unimplemented:** Read as '0'

bit 6-0 **FCAL<6:0>:** Internal Oscillator Calibration bits

9.7 Calibration Word 7

The DCS<6:0> bits at memory location 2086h store the factory-set offset calibration for the current sense differential amplifier (A2) when configured using I_{SOUT} . Firmware must read these values and copy into the DCSCAL Special Function Register located in Bank 3 at 199h. If using the internal feedback resistor, refer to [Register 9-1](#).

REGISTER 9-7: CALWD7: CALIBRATION WORD 7 REGISTER

| | | | | | |
|--------|-----|-----|-----|-----|-------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 |
| — | — | — | — | — | — |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | DCS6 | DCS5 | DCS4 | DCS3 | DCS2 | DCS1 | DCS0 |
| bit 7 | | | | | | | bit 0 |

Legend:

| | | |
|-------------------|----------------------|------------------------------------|
| R = Readable bit | P = Programmable bit | U = Unimplemented bit, read as '0' |
| -n = Value at POR | '1' = Bit is set | '0' = Bit is cleared |
| | | x = Bit is unknown |

bit 13-7 **Unimplemented:** Read as '0'

bit 6-0 **DCS<6:0>:** Differential Current Sense Amplifier Calibration bits when used with I_{SOUT}

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9.8 Calibration Word 8

Calibration word 8 at memory location 2087h contains the offset voltage calibration bits for the voltage regulation error amplifier. The voltage amplifier offset voltage trim bits are VEAOFFCAL<6:0>. Firmware must read this value and copy the VEAOFFCAL into the Special Function Register located in Bank 2 at 10Dh.

REGISTER 9-8: CALWD8: CALIBRATION WORD 8 REGISTER

| | | | | | |
|--------|-----|-----|-----|-----|-------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 |
| — | — | — | — | — | — |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|------------|------------|------------|------------|------------|------------|------------|
| U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | VEAOFFCAL6 | VEAOFFCAL5 | VEAOFFCAL4 | VEAOFFCAL3 | VEAOFFCAL2 | VEAOFFCAL1 | VEAOFFCAL0 |
| bit 7 | | | | | | | bit 0 |

Legend:

| | | |
|-------------------|----------------------|------------------------------------|
| R = Readable bit | P = Programmable bit | U = Unimplemented bit, read as '0' |
| -n = Value at POR | '1' = Bit is set | '0' = Bit is cleared |
| | | x = Bit is unknown |

bit 13-7 **Unimplemented:** Read as '0'

bit 6-0 **VEAOFFCAL<6:0>:** Voltage Error Amplifier Offset Voltage Calibration bits

9.9 Calibration Word 9

Calibration Word 9 is at memory location 2088h and contains the calibration bits for the OV_{REF} DAC span trim $OVRSPCAL<4:0>$ and the Current Sense Amplifier Gain Calibration $A2GCAL<3:0>$. The $OVRSPCAL<4:0>$ is an individual adjustment specific to calibrating the OV_{REF} DAC span. Firmware must read these values and copy into the $OVRSPCAL$ Special Function Register located in Bank 3 at 19Fh.

A2 Gain calibration trim bits set the 10V/V gain of the current sense amplifier (A2). $A2GCAL<3:0>$ calibration bits values must be copied via firmware into the $A2GCAL$ Special Function Register located in Bank 3 at 19Eh.

REGISTER 9-9: CALWD9: CALIBRATION WORD 9 REGISTER

| | | | | | |
|--------|-----------|-----------|-----------|-----------|-----------|
| U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | OVRSPCAL4 | OVRSPCAL3 | OVRSPCAL2 | OVRSPCAL1 | OVRSPCAL0 |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|-----|-----|-----|---------|---------|---------|---------|
| U-0 | U-0 | U-0 | U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | — | — | — | A2GCAL3 | A2GCAL2 | A2GCAL1 | A2GCAL0 |
| bit 7 | | | | | | | bit 0 |

Legend:

| | | |
|-------------------|----------------------|--|
| R = Readable bit | P = Programmable bit | U = Unimplemented bit, read as '0' |
| -n = Value at POR | '1' = Bit is set | '0' = Bit is cleared x = Bit is unknown |

- bit 13 **Unimplemented:** Read as '0'
- bit 12-8 **OVRSPCAL<4:0>:** OV_{REF} Span Adjustment bits
- bit 7-4 **Unimplemented:** Read as '0'
- bit 3-0 **A2GCAL<3:0>:** A2 Current Sense Amplifier Gain Calibration bits

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9.10 Calibration Word 10

Calibration word 10 at memory location 2089h contains the calibration bits for V_{REF2} DAC span trim $VR2SPCAL<4:0>$ and the V_{REF2} DAC span trim $VRSPCAL<4:0>$. The $VR2SPCAL<4:0>$ is an individual adjustment specific to calibrating the V_{REF2} DAC span. Firmware must read these values and copy into the $VR2SPCAL$ Special Function Register located in Bank 2 at 11Ah.

The $VRSPCAL<4:0>$ is an individual adjustment specific to calibrating the V_{REF2} DAC span. Firmware must read these values and copy into the $VRSPCAL$ Special Function Register located in Bank 2 at 119h.

REGISTER 9-10: CALWD10: CALIBRATION WORD 10 REGISTER

| | | | | | |
|--------|-----------|-----------|-----------|-----------|-----------|
| U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | VR2SPCAL4 | VR2SPCAL3 | VR2SPCAL2 | VR2SPCAL1 | VR2SPCAL0 |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|-----|-----|----------|----------|----------|----------|----------|
| U-0 | U-0 | U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | — | — | VRSPCAL4 | VRSPCAL3 | VRSPCAL2 | VRSPCAL1 | VRSPCAL0 |
| bit 7 | | | | | | | bit 0 |

Legend:

| | | |
|-------------------|----------------------|--|
| R = Readable bit | P = Programmable bit | U = Unimplemented bit, read as '0' |
| -n = Value at POR | '1' = Bit is set | '0' = Bit is cleared x = Bit is unknown |

bit 13 **Unimplemented:** Read as '0'

bit 12-8 **VR2SPCAL<4:0>:** V_{REF2} Span Adjustment bits

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

bit 4-0 **VRSPCAL<4:0>:** V_{REF} Span Adjustment bits

9.11 Calibration Word 11

Calibration word 11 at memory location 208Ah contains the calibration bits for the 4V LDO (AV_{DD}) trim $AVDDCAL<3:0>$ and the offset voltage of the analog test buffer $BUFF<7:0>$. AV_{DD} supplies the internal analog circuitry and is the default ADC Reference voltage. Firmware must read these values and copy into the $AVDDCAL$ Special Function Register located in Bank 3 at 19Dh.

Also stored at address 208Ah is the Analog test MUX buffer offset value. This is an 8 bit, 2's complement word that represents the buffer's offset voltage in units of mV. This value can be used to correct for buffer offset of the analog test signal measurements. See [Section 8.0 "System Bench Testing"](#) for test signal details.

REGISTER 9-11: CALWD11: CALIBRATION WORD 11 REGISTER

| | | | | | |
|--------|-----|----------|----------|----------|----------|
| U-0 | U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | — | AVDDCAL3 | AVDDCAL2 | AVDDCAL1 | AVDDCAL0 |
| bit 13 | | bit 8 | | | |

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| BUFF7 | BUFF6 | BUFF5 | BUFF4 | BUFF3 | BUFF2 | BUFF1 | BUFF0 |
| bit 7 | | | | | | bit 0 | |

Legend:

| | | |
|-------------------|----------------------|--|
| R = Readable bit | P = Programmable bit | U = Unimplemented bit, read as '0' |
| -n = Value at POR | '1' = Bit is set | '0' = Bit is cleared x = Bit is unknown |

bit 13-12 **Unimplemented:** Read as '0'

bit 11-8 **AVDDCAL<3:0>:** AV_{DD} 4V LDO Trim bits

bit 7-0 **BUFF<7:0>:** Analog Test Mux Buffer Offset bits
 11111111 = Mid scale (-1 mV)
 •
 •
 10000000 = Largest negative offset (-128 mV)
 01111111 = Largest positive offset (+128 mV)
 •
 •
 00000000 = Mid scale (0 mV)

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9.12 Calibration Word 12

Calibration word 12 at memory location 208Bh contains the offset voltage calibration bits for the current regulation error amplifier. Current regulation amplifier offset voltage trim bits are CEAOFFCAL<6:0>.

Firmware must read this value and copy the CEAOFFCAL into the Special Function Register located in Bank 3 at 19Ch.

REGISTER 9-12: CALWD12: CALIBRATION WORD 12 REGISTER

| | | | | | |
|--------|-----|-----|-----|-----|-------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 |
| — | — | — | — | — | — |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|------------|------------|------------|------------|------------|------------|------------|
| U-0 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 |
| — | CEAOFFCAL6 | CEAOFFCAL5 | CEAOFFCAL4 | CEAOFFCAL3 | CEAOFFCAL2 | CEAOFFCAL1 | CEAOFFCAL0 |
| bit 7 | | | | | | | bit 0 |

Legend:

R = Readable bit P = Programmable bit U = Unimplemented bit, read as '0'
 -n = Value at POR '1' = Bit is set '0' = Bit is cleared x = Bit is unknown

bit 13-7 **Unimplemented:** Read as '0'
 bit 6-0 **CEAOFFCAL<6:0>:** Current Error Amplifier Offset Voltage Calibration bits

10.0 MEMORY ORGANIZATION

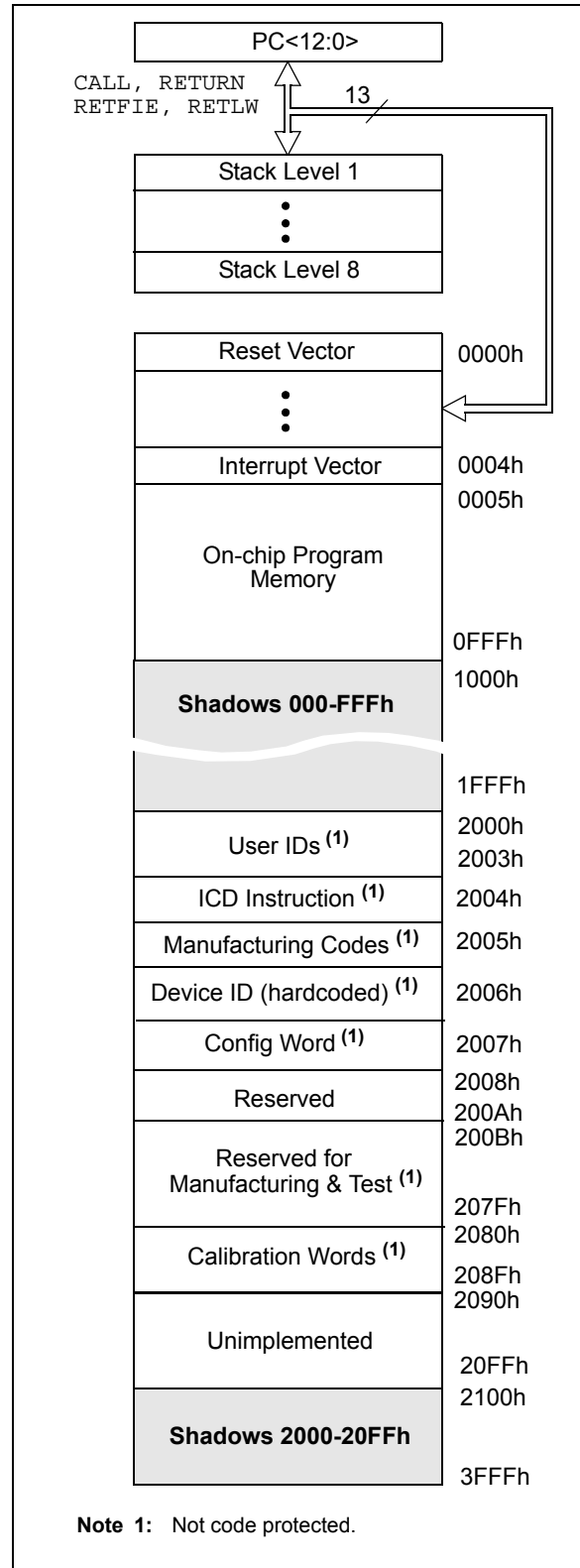
There are two types of memory in the MCP19124/5:

- Program Memory
- Data Memory:
 - Special Function Registers (SFRs)
 - General-Purpose RAM

10.1 Program Memory Organization

The MCP19124/5 have a 13-bit program counter capable of addressing an 8000 x 14 program memory space. Only the first 4000 x 14 (0000h-0FFFh) is physically implemented. Addressing a location above this boundary will cause a wrap-around within the first 4000 x 14 space. The Reset vector is at 0000h and the interrupt vector is at 0004h (refer to [Figure 10-1](#)). The width of the program memory bus (instruction word) is 14 bits. Since all instructions are a single word, the MCP19124/5 have space for 8000 instructions.

FIGURE 10-1: PROGRAM MEMORY MAP AND STACK FOR MCP19124/5



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10.1.1 READING PROGRAM MEMORY AS DATA

There are two methods of accessing constants in program memory. The first method is to use tables of RETLW instructions. The second method is to set a Files Select Register (FSR) to point to the program memory.

10.1.1.1 RETLW Instruction

The RETLW instruction can be used to provide access to the tables of constants. The recommended way to create such tables is shown in [Example 10-1](#).

EXAMPLE 10-1: RETLW INSTRUCTION

```
constants
    BRW          ;Add Index in W to
                ;program counter to
                ;select data
    RETLW DATA0 ;Index0 data
    RETLW DATA1 ;Index1 data
    RETLW DATA2
    RETLW DATA3

my_function
    ;... LOTS OF CODE...
    MOVLW      DATA_INDEX
    call constants
    ;... THE CONSTANT IS IN W
```

The BRW instruction makes this type of table very simple to implement. If your code must remain portable with previous generations of microcontrollers, then the BRW instruction is not available, so the older table-read method must be used.

10.2 Data Memory Organization

The data memory (refer to [Figure 10-1](#)) is partitioned into four banks, which contain the General Purpose Registers (GPR) and the Special Function Registers (SFR). The Special Function Registers are located in the first 32 locations of each bank. Register locations 20h-7Fh in Bank 0, A0h-EFh in Bank 1, 120h-16Fh in Bank 2 and 1A0h-1EFh in Bank 3 are General Purpose Registers, implemented as static RAM. All other RAM is unimplemented and returns '0' when read. The RP<1:0> bits in the STATUS register are the bank select bits.

EXAMPLE 10-2: BANK SELECT

| RP1 | RP0 | |
|-----|-----|----------------------|
| 0 | 0 | → Bank 0 is selected |
| 0 | 1 | → Bank 1 is selected |
| 1 | 0 | → Bank 2 is selected |
| 1 | 1 | → Bank 3 is selected |

To move values from one register to another register, the value must pass through the W register. This means that for all register-to-register moves, two instruction cycles are required.

The entire data memory can be accessed either directly or indirectly. Direct addressing may require the use of the RP<1:0> bits. Indirect addressing requires the use of the FSR. Indirect addressing uses the Indirect Register Pointer (IRP) bit in the STATUS register for access to the Bank0/Bank1 or the Bank2/Bank3 areas of data memory.

10.2.1 GENERAL PURPOSE REGISTER FILE

The register file is organized as 64 x 8 in the MCP19124/5. Each register is accessed, either directly or indirectly, through the FSR (refer to [Section 10.5 "Indirect Addressing, INDF and FSR Registers"](#)).

10.2.2 CORE REGISTERS

The core registers contain the registers that directly affect the basic operation. The core registers can be addressed from any bank. These registers are listed in [Table 10-1](#). For detailed information, refer to [Table 10-2](#).

TABLE 10-1: CORE REGISTERS

| Addresses | BANKx |
|-----------------------------|--------|
| x00h, x80h, x100h, or x180h | INDF |
| x02h, x82h, x102h, or x182h | PCL |
| x03h, x83h, x103h, or x183h | STATUS |
| x04h, x84h, x104h, or x184h | FSR |
| x0Ah, x8Ah, x10Ah, or x18Ah | PCLATH |
| x0Bh, x8Bh, x10Bh, or x18Bh | INTCON |

10.2.2.1 STATUS Register

The STATUS register contains:

- the arithmetic status of the ALU
- the Reset status
- the bank select bits for data memory (RAM)

The STATUS register can be the destination for any instruction, like any other register. If the STATUS register is the destination for an instruction that affects the Z, DC or C bits, the write to these three bits is disabled. These bits are set or cleared according to the device logic. Furthermore, the \overline{TO} and \overline{PD} bits are not writable. Therefore, the result of an instruction with the STATUS register as destination may be different than intended.

For example, `CLRF STATUS` will clear the upper three bits and set the Z bit. This leaves the STATUS register as '000u u1uu' (where u = unchanged).

It is recommended, therefore, that only `BCF`, `BSF`, `SWAPF` and `MOVWF` instructions are used to alter the STATUS register, because these instructions do not affect any Status bits.

Note 1: The C and DC bits operate as Borrow and Digit Borrow out bits, respectively, in subtraction.

REGISTER 10-1: STATUS: STATUS REGISTER

| R/W-0 | R/W-0 | R/W-0 | R-1 | R-1 | R/W-x | R/W-x | R/W-x |
|-------|-------|-------|-----------------|-----------------|-------|-------------------|------------------|
| IRP | RP1 | RP0 | \overline{TO} | \overline{PD} | Z | DC ⁽¹⁾ | C ⁽¹⁾ |
| bit 7 | | | | | | bit 0 | |

Legend:

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

bit 7 **IRP:** Register Bank Select bit (used for Indirect addressing)

- 1 = Bank 2 & 3 (100h - 1FFh)
- 0 = Bank 0 & 1 (00h - FFh)

bit 6-5 **RP<1:0>:** Register Bank Select bits (used for Direct addressing)

- 00 = Bank 0 (00h - 7Fh)
- 01 = Bank 1 (80h - FFh)
- 10 = Bank 2 (100h - 17Fh)
- 11 = Bank 3 (180h - 1FFh)

bit 4 **\overline{TO} :** Time-Out bit

- 1 = After power-up, `CLRWDT` instruction or `SLEEP` instruction
- 0 = A WDT time-out occurred

Note 1: For Borrow, the polarity is reversed. A subtraction is executed by adding the two's complement of the second operand. For rotate (`RRF`, `RLF`) instructions, this bit is loaded with either the high-order or low-order bit in the source register.

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REGISTER 10-1: STATUS: STATUS REGISTER (CONTINUED)

| | |
|-------|---|
| bit 3 | $\overline{\text{PD}}$: Power-Down bit 1 = After power-up or by the <code>CLRWDT</code> instruction 0 = By execution of the <code>SLEEP</code> instruction |
| bit 2 | Z : Zero bit 1 = The result of an arithmetic or logic operation is zero 0 = The result of an arithmetic or logic operation is not zero |
| bit 1 | $\overline{\text{DC}}$: Digit Carry/Digit Borrow bit ⁽¹⁾ (<code>ADDWF</code> , <code>ADDLW</code> , <code>SUBLW</code> , <code>SUBWF</code> instructions) 1 = A carry-out from the 4 th low-order bit of the result occurred 0 = No carry-out from the 4 th low-order bit of the result occurred |
| bit 0 | $\overline{\text{C}}$: Carry/Borrow bit ⁽¹⁾ (<code>ADDWF</code> , <code>ADDLW</code> , <code>SUBLW</code> , <code>SUBWF</code> instructions) 1 = A carry-out from the Most Significant bit of the result occurred 0 = No carry-out from the Most Significant bit of the result occurred |

Note 1: For $\overline{\text{Borrow}}$, the polarity is reversed. A subtraction is executed by adding the two's complement of the second operand. For rotate (`RRF`, `RLF`) instructions, this bit is loaded with either the high-order or low-order bit in the source register.

10.2.3 SPECIAL FUNCTION REGISTERS

The Special Function Registers are registers used by the CPU and peripheral functions for controlling the desired operation of the device (refer to [Figure 10-2](#)). These registers are static RAM.

The special registers can be classified into two sets:

- core and
- peripheral

The Special Function Registers associated with the microcontroller core are described in this section. Those related to the operation of the peripheral features are described in the associated section for that peripheral feature.

10.3 DATA MEMORY

FIGURE 10-2: MCP19124/5 DATA MEMORY MAP

| File Address | File Address | File Address | File Address |
|--------------------------------------|--------------------------------------|--------------------------------------|------------------------------------|
| Indirect addr. ⁽¹⁾ 00h | Indirect addr. ⁽¹⁾ 80h | Indirect addr. ⁽¹⁾ 100h | Indirect addr. ⁽¹⁾ 180h |
| TMR0 01h | OPTION_REG 81h | TMR0 101h | OPTION_REG 181h |
| PCL 02h | PCL 82h | PCL 102h | PCL 182h |
| STATUS 03h | STATUS 83h | STATUS 103h | STATUS 183h |
| FSR 04h | FSR 84h | FSR 104h | FSR 184h |
| PORTGPA 05h | TRISGPA 85h | WPUGPA 105h | IOCA 185h |
| PORTGPB 06h | TRISGPB 86h | WPUGPB 106h | IOCB 186h |
| PIR1 07h | PIE1 87h | PE1 107h | ANSELA 187h |
| PIR2 08h | PIE2 88h | MODECON 108h | ANSELB 188h |
| PCON 09h | | ABECON 109h | |
| PCLATH 0Ah | PCLATH 8Ah | PCLATH 10Ah | PCLATH 18Ah |
| INTCON 0Bh | INTCON 8Bh | INTCON 10Bh | INTCON 18Bh |
| TMR1L 0Ch | | Reserved 10Ch | PORTICD ⁽²⁾ 18Ch |
| TMR1H 0Dh | | VEAOFFCAL 10Dh | TRISICD ⁽²⁾ 18Dh |
| T1CON 0Eh | | | ICKBUG ⁽²⁾ 18Eh |
| TMR2 0Fh | | | BIGBUG ⁽²⁾ 18Fh |
| T2CON 10h | VINUVLO 90h | SSPADD 110h | PMCON1 190h |
| PR2 11h | VINOVLO 91h | SSPBUF 111h | PMCON2 191h |
| | VINCON 92h | SSPCON1 112h | PMADRL 192h |
| PWMPHL 13h | CC1RL 93h | SSPCON2 113h | PMADRH 193h |
| PWMPHH 14h | CC1RH 94h | SSPCON3 114h | PMDATL 194h |
| PWMRL 15h | CC2RL 95h | SSPMSK1 115h | PMDATH 195h |
| PWMRH 16h | CC2RH 96h | SSPSTAT 116h | DSTCAL 196h |
| | CCDCON 97h | SSPADD2 117h | CGMVGMCAL 197h |
| | DESATCON 98h | SSPMSK2 118h | OSCCAL 198h |
| VREFCON 19h | OVCON 99h | VRSPCAL 119h | DCSCAL 199h |
| VREF2CON 1Ah | OVREFCON 9Ah | VR2SPCAL 11Ah | TTACAL 19Ah |
| OSCTUNE 1Bh | DEADCON 9Bh | | BGRCAL 19Bh |
| ADRESL 1Ch | SLPCRCON 9Ch | | CEAOFFCAL 19Ch |
| ADRESH 1Dh | ICOACON 9Dh | | AVDDCAL 19Dh |
| ADCON0 1Eh | ICLEBCON 9Eh | | A2GCAL 19Eh |
| ADCON1 1Fh | | | OVRSPCAL 19Fh |
| General Purpose Register 96 Bytes | General Purpose Register 80 Bytes | General Purpose Register 80 bytes | |
| | Accesses Bank 0 | Accesses Bank 0 | Accesses Bank 0 |
| 7Fh | EFh | 16F | 1EF |
| | F0h | 170h | 1F0h |
| | FFh | 17Fh | 1FFh |

Bank 0 Bank 1 Bank2 Bank3

■ Unimplemented data memory locations, read as '0'.

Note 1: Not a physical register.

2: Only accessible when `DBGEN = 0` and `ICKBUG<INBUG> = 1`.

TABLE 10-2: MCP19124/5 SPECIAL REGISTERS SUMMARY BANK 0

| Addr. | Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Value on POR Reset | Value on all other resets ⁽¹⁾ |
|--------|----------|--|-------|---------|--|----------------------|--------|----------------------|---------------------|--------------------|--|
| Bank 0 | | | | | | | | | | | |
| 00h | INDF | Addressing this location uses contents of FSR to address data memory (not a physical register) | | | | | | | | xxxx xxxx | xxxx xxxx |
| 01h | TMR0 | Timer0 Module's Register | | | | | | | | xxxx xxxx | uuuu uuuu |
| 02h | PCL | Program Counter's (PC) Least Significant byte | | | | | | | | 0000 0000 | 0000 0000 |
| 03h | STATUS | IRP | RP1 | RP0 | \overline{TO} | \overline{PD} | Z | DC | C | 0001 1xxx | 000q quuu |
| 04h | FSR | Indirect data memory address pointer | | | | | | | | xxxx xxxx | uuuu uuuu |
| 05h | PORTGPA | GPA7 | GPA6 | GPA5 | — | GPA3 | GPA2 | GPA1 | GPA0 | xxx- xxxx | uuu- uuuu |
| 06h | PORTGPB | GPB7 | GPB6 | GPB5 | GPB4 | — | — | GPB1 | GPB0 | xxxx --xx | uuuu --uu |
| 07h | PIR1 | — | — | BCLIF | SSPIF | CC2IF | CC1IF | TMR2IF | TMR1IF | --00 0000 | --00 0000 |
| 08h | PIR2 | CDSIF | ADIF | — | OTIF | OVIF | DRUVIF | OVLOIF | UVLOIF | 00-0 0000 | 00-0 0000 |
| 09h | PCON | ADC_REFR | — | — | — | $\overline{VDDFLAG}$ | VDDOK | \overline{POR} | \overline{BOR} | 0--- 10qq | 0--- 10uu |
| 0Ah | PCLATH | — | — | — | Write buffer for upper 5 bits of program counter | | | | | ---0 0000 | ---0 0000 |
| 0Bh | INTCON | GIE | PEIE | TOIE | INTE | IOCE | T0IF | INTF | IOCF ⁽²⁾ | 0000 000x | 0000 000u |
| 0Ch | TMR1L | Holding register for the Least Significant byte of the 16-bit TMR1 | | | | | | | | xxxx xxxx | uuuu uuuu |
| 0Dh | TMR1H | Holding register for the Most Significant byte of the 16-bit TMR1 | | | | | | | | xxxx xxxx | uuuu uuuu |
| 0Eh | T1CON | — | — | T1CKPS1 | T1CKPS0 | — | — | TMR1CS | TMR1ON | --00 --00 | --uu --uu |
| 0Fh | TMR2 | Timer2 Module Register | | | | | | | | 0000 0000 | uuuu uuuu |
| 10h | T2CON | — | — | — | — | — | TMR2ON | T2CKPS1 | T2CKPS0 | ---- -000 | ---- -000 |
| 11h | PR2 | Timer2 Module Period Register | | | | | | | | 1111 1111 | 1111 1111 |
| 12h | — | Unimplemented | | | | | | | | — | — |
| 13h | PWMPHL | SLAVE Phase Shift Register | | | | | | | | xxxx xxxx | uuuu uuuu |
| 14h | PWMPHH | SLAVE Phase Shift Register | | | | | | | | xxxx xxxx | uuuu uuuu |
| 15h | PWMRL | PWM Register Low Byte | | | | | | | | xxxx xxxx | uuuu uuuu |
| 16h | PWMRH | PWM Register High Byte | | | | | | | | xxxx xxxx | uuuu uuuu |
| 17h | — | Unimplemented | | | | | | | | — | — |
| 18h | — | Unimplemented | | | | | | | | — | — |
| 19h | VREFCON | VREF7 | VREF6 | VREF5 | VREF4 | VREF3 | VREF2 | VREF1 | VREF0 | 0000 0000 | 0000 0000 |
| 1Ah | VREF2CON | VREF2<7:0> | | | | | | | | 0000 0000 | 0000 0000 |
| 1Bh | OSCTUNE | — | — | — | TUN4 | TUN3 | TUN2 | TUN1 | TUN0 | ---0 0000 | ---0 0000 |
| 1Ch | ADRESL | Least significant 8 bits of the A/D result | | | | | | | | xxxx xxxx | uuuu uuuu |
| 1Dh | ADRESH | Most significant 2 bits of the A/D result | | | | | | | | 0000 00xx | 0000 00uu |
| 1Eh | ADCON0 | — | CHS4 | CHS3 | CHS2 | CHS1 | CHS0 | $\overline{GO/DONE}$ | ADON | -000 0000 | -000 0000 |
| 1Fh | ADCON1 | — | ADCS2 | ADCS1 | ADCS0 | — | — | — | VCFG | -000 ---0 | -000 ---0 |

Legend: — = Unimplemented locations read as '0', u = unchanged, x = unknown, q = value depends on condition, shaded = unimplemented

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

Note 2: MCLR and WDT reset does not affect the previous value data latch. The IOCF bit will be cleared upon reset but will be set again if the mismatch exists.

TABLE 10-3: MCP19124/5 SPECIAL REGISTERS SUMMARY BANK 1

| Addr. | Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Value on POR Reset | Values on all other resets ⁽¹⁾ |
|--------|------------|--|---------|----------|--|-----------------|---------|----------|---------------------|--------------------|---|
| Bank 1 | | | | | | | | | | | |
| 80h | INDF | Addressing this location uses contents of FSR to address data memory (not a physical register) | | | | | | | | xxxx xxxx | uuuu uuuu |
| 81h | OPTION_REG | RAPU | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 | 1111 1111 | 1111 1111 |
| 82h | PCL | Program Counter's (PC) Least Significant byte | | | | | | | | 0000 0000 | 0000 0000 |
| 83h | STATUS | IRP | RP1 | RP0 | \overline{TO} | \overline{PD} | Z | DC | C | 0001 1xxx | 000q quuu |
| 84h | FSR | Indirect data memory address pointer | | | | | | | | xxxx xxxx | uuuu uuuu |
| 85h | TRISGPA | TRISA7 | TRISA6 | TRISA5 | — | TRISA3 | TRISA2 | TRISA1 | TRISA0 | 1110 1111 | 1110 1111 |
| 86h | TRISGPB | TRISB7 | TRISB6 | TRISB5 | TRISB4 | — | — | TRISB1 | TRISB0 | 1111 0011 | 1111 0011 |
| 87h | PIE1 | — | — | BCLIE | SSPIE | CC2IE | CC1IE | TMR2IE | TMR1IE | --00 0000 | --00 0000 |
| 88h | PIE2 | CDSIE | ADIE | — | OTIE | OVIE | DRUVIE | OVLOIE | UVLOIE | 00-0 0000 | 00-0 0000 |
| 89h | — | Unimplemented | | | | | | | | — | — |
| 8Ah | PCLATH | — | — | — | Write buffer for upper 5 bits of program counter | | | | --- | 0000 | ---0 0000 |
| 8Bh | INTCON | GIE | PEIE | T0IE | INTE | IOCE | T0IF | INTF | IOCF ⁽²⁾ | 0000 000x | 0000 000u |
| 8Ch | — | Unimplemented | | | | | | | | — | — |
| 8Dh | — | Unimplemented | | | | | | | | — | — |
| 8Eh | — | Unimplemented | | | | | | | | — | — |
| 8Fh | — | Unimplemented | | | | | | | | — | — |
| 90h | VINUVO | — | — | UVLO5 | UVLO4 | UVLO3 | UVLO2 | UVLO1 | UVLO0 | --xx xxxx | --uu uuuu |
| 91h | VINOVO | — | — | OVLO5 | OVLO4 | OVLO3 | OVLO2 | OVLO1 | OVLO0 | --xx xxxx | --uu uuuu |
| 92h | VINCON | UVLOEN | UVLOOUT | UVLOINTP | UVLOINTN | OVLOEN | OVLOOUT | OVLOINTP | OVLOINTN | 0x00 0x00 | 0u00 0u00 |
| 93h | CC1RL | Capture1/Compare1 Register1 x Low Byte (LSB) | | | | | | | | xxxx xxxx | uuuu uuuu |
| 94h | CC1RH | Capture1/Compare1 Register2 x High Byte (MSB) | | | | | | | | xxxx xxxx | uuuu uuuu |
| 95h | CC2RL | Capture2/Compare2 Register1 x Low Byte (LSB) | | | | | | | | xxxx xxxx | uuuu uuuu |
| 96h | CC2RH | Capture2/Compare2 Register2 x High Byte (MSB) | | | | | | | | xxxx xxxx | uuuu uuuu |
| 97h | CCDCON | CC2M<3:0> | | | | CC1M<3:0> | | | | xxxx xxxx | uuuu uuuu |
| 98h | DESATCON | CDSMUX | CDSWDE | Reserved | CDSPOL | CDSOE | CDSOUT | CDSINTP | CDSINTN | 0000 0x00 | 0000 0u00 |
| 99h | OVCON | — | — | — | — | OVEN | OVOUT | OVINTP | OVINTN | ---- 0x00 | ---- 0u00 |
| 9Ah | OVREFCON | OOV7 | OOV6 | OOV5 | OOV4 | OOV3 | OOV2 | OOV1 | OOV0 | xxxx xxxx | uuuu uuuu |
| 9Bh | DEADCON | PDRVDT3 | PDRVDT2 | PDRVDT1 | PDRVDT0 | SDRVDT3 | SDRVDT2 | SDRVDT1 | SDRVDT0 | xxxx xxxx | uuuu uuuu |
| 9Ch | SLPCRCON | — | SLPBY | SLPS5 | SLPS4 | SLPS3 | SLPS2 | SLPS1 | SLPS0 | -xxx xxxx | -uuu uuuu |
| 9Dh | ICOACON | — | — | — | — | ICOAC3 | ICOAC2 | ICOAC1 | ICOAC0 | ---- xxxx | ---- uuuu |
| 9Eh | ICLEBCON | — | — | — | — | — | — | ICLEBC1 | ICLEBC0 | ---- --xx | ---- --uu |
| 9Fh | — | Unimplemented | | | | | | | | — | — |

Legend: — = Unimplemented locations read as '0', u = unchanged, x = unknown, q = value depends on condition, shaded = unimplemented

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

Note 2: MCLR and WDT reset does not affect the previous value data latch. The IOCF bit will be cleared upon reset but will be set again if the mismatch exists.

TABLE 10-4: MCP19124/5 SPECIAL REGISTERS SUMMARY BANK 2

| Addr. | Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Value on POR Reset | Value on all other resets ⁽¹⁾ | |
|--------|-----------|--|------------|------------------|--|-----------------|------------------|------------|---------------------|--------------------|--|------|
| Bank 2 | | | | | | | | | | | | |
| 100h | INDF | Addressing this location uses contents of FSR to address data memory (not a physical register) | | | | | | | | xxxx xxxx | xxxx xxxx | |
| 101h | TMR0 | Timer0 Module's Register | | | | | | | | xxxx xxxx | uuuu uuuu | |
| 102h | PCL | Program Counter's (PC) Least Significant byte | | | | | | | | 0000 0000 | 0000 0000 | |
| 103h | STATUS | IRP | RP1 | RP0 | \overline{TO} | \overline{PD} | Z | DC | C | 0001 1xxx | 000q quuu | |
| 104h | FSR | Indirect data memory address pointer | | | | | | | | xxxx xxxx | uuuu uuuu | |
| 105h | WPUGPA | — | — | WPUA5 | — | WPUA3 | WPUA2 | WPUA1 | WPUA0 | --1- 1111 | --u- uuuu | |
| 106h | WPUGPB | WPUB7 | WPUB6 | WPUB5 | WPUB4 | — | — | WPUB1 | — | 1111 --1- | uuuu --u- | |
| 107h | PE1 | PDRVEN | SDRVEN | PDRVBY | SDRVBY | — | ISPUEN | PWMSTR_PEN | PWMSTR_SEN | 0000 -100 | 0000 -100 | |
| 108h | MODECON | MSC1 | MSC0 | — | — | MSC2 | — | — | — | 00-- 0--- | 00-- 0--- | |
| 109h | ABECON | DIGOEN | DSEL2 | DSEL1 | DSEL0 | DRUVSEL | EA2DIS | EA1DIS | ANAOEN | 0000 0000 | 0000 0000 | |
| 10Ah | PCLATH | — | — | — | Write buffer for upper 5 bits of program counter | | | | --- | 0000 | --- | 0000 |
| 10Bh | INTCON | GIE | PEIE | TOIE | INTE | IOCE | TOIF | INTF | IOCF ⁽²⁾ | 0000 000x | 0000 000u | |
| 10Ch | — | Reserved | | | | | | | | — | — | |
| 10Dh | VEAOFFCAL | — | VEAOFFCAL6 | VEAOFFCAL5 | VEAOFFCAL4 | VEAOFFCAL3 | VEAOFFCAL2 | VEAOFFCAL1 | VEAOFFCAL0 | -xxx xxxx | -uuu uuuu | |
| 10Eh | — | Unimplemented | | | | | | | | — | — | |
| 10Fh | — | Unimplemented | | | | | | | | — | — | |
| 110h | SSPADD | ADD<7:0> | | | | | | | | 0000 0000 | 0000 0000 | |
| 111h | SSPBUF | Synchronous Serial Port Receive Buffer/Transmit Register | | | | | | | | xxxx xxxx | uuuu uuuu | |
| 112h | SSPCON1 | WCOL | SSPOV | SSPEN | CKP | SSPM<3:0> | | | | 0000 0000 | 0000 0000 | |
| 113h | SSPCON2 | GCEN | ACKSTAT | ACKDT | ACKEN | RCEN | PEN | RSEN | SEN | 0000 0000 | 0000 0000 | |
| 114h | SSPCON3 | ACKTIM | PCIE | SCIE | BOEN | SDAHT | SBCDE | AHEN | DHEN | 0000 0000 | 0000 0000 | |
| 115h | SSPMSK1 | MSK<7:0> | | | | | | | | 1111 1111 | 1111 1111 | |
| 116h | SSPSTAT | SMP | CKE | D/\overline{A} | P | S | R/\overline{W} | UA | BF | — | — | |
| 117h | SSPADD2 | ADD2<7:0> | | | | | | | | 0000 0000 | 0000 0000 | |
| 118h | SSPMSK2 | MSK2<7:0> | | | | | | | | 1111 1111 | 1111 1111 | |
| 119h | VRSPCAL | — | — | — | VRSPCAL4 | VRSPCAL3 | VRSPCAL2 | VRSPCAL1 | VRSPCAL0 | ---x xxxx | ---u uuuu | |
| 11Ah | VR2SPCAL | — | — | — | VR2SPCAL4 | VR2SPCAL3 | VR2SPCAL2 | VR2SPCAL1 | VR2SPCAL0 | ---x xxxx | ---u uuuu | |
| 11Bh | — | Unimplemented | | | | | | | | — | — | |
| 11Ch | — | Unimplemented | | | | | | | | — | — | |
| 11Dh | — | Unimplemented | | | | | | | | — | — | |
| 11Eh | — | Unimplemented | | | | | | | | — | — | |
| 11Fh | — | Unimplemented | | | | | | | | — | — | |

Legend: — = Unimplemented locations read as '0', u = unchanged, x = unknown, q = value depends on condition, shaded = unimplemented

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

Note 2: MCLR and WDT reset does not affect the previous value data latch. The IOCF bit will be cleared upon reset but will be set again if the mismatch exists.

TABLE 10-5: MCP19124/5 SPECIAL REGISTERS SUMMARY BANK 3

| Addr. | Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Value on POR Reset | Values on all other resets ⁽¹⁾ |
|--------|------------------------|--|------------|------------|--|-----------------|------------|------------|---------------------|--------------------|---|
| Bank 3 | | | | | | | | | | | |
| 180h | INDF | Addressing this location uses contents of FSR to address data memory (not a physical register) | | | | | | | | xxxx xxxx | uuuu uuuu |
| 181h | OPTION_REG | RAPU | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 | 1111 1111 | 1111 1111 |
| 182h | PCL | Program Counter's (PC) Least Significant byte | | | | | | | | 0000 0000 | 0000 0000 |
| 183h | STATUS | IRP | RP1 | RP0 | \overline{TO} | \overline{PD} | Z | DC | C | 0001 1xxx | 000q quuu |
| 184h | FSR | Indirect data memory address pointer | | | | | | | | xxxx xxxx | uuuu uuuu |
| 185h | IOCA | IOCA7 | IOCA6 | IOCA5 | — | IOCA3 | IOCA2 | IOCA1 | IOCA0 | 000- 0000 | 0000 0000 |
| 186h | IOCB | IOCB7 | IOCB6 | IOCB5 | IOCB4 | — | — | IOCB1 | IOCB0 | 0000 --00 | 0000 --00 |
| 187h | ANSELA | — | — | — | — | ANSA3 | ANSA2 | ANSA1 | ANSA0 | ---- 1111 | ---- 1111 |
| 188h | ANSELB | — | ANSB6 | ANSB5 | ANSB4 | — | — | ANSB1 | — | -111 --1- | -111 --1- |
| 189h | — | Unimplemented | | | | | | | | — | — |
| 18Ah | PCLATH | — | — | — | Write buffer for upper 5 bits of program counter | | | | --- | 0000 | ---0 0000 |
| 18Bh | INTCON | GIE | PEIE | T0IE | INTE | IOCE | T0IF | INTF | IOCF ⁽²⁾ | 0000 000x | 0000 000u |
| 18Ch | PORTICD ⁽³⁾ | In-Circuit Debug Port Register | | | | | | | | xxx --xx | uuuu --uu |
| 18Dh | TRISICD ⁽³⁾ | In-Circuit Debug TRIS Register | | | | | | | | 1111 0011 | 1111 0011 |
| 18Eh | ICKBUG ⁽³⁾ | In-Circuit Debug Register | | | | | | | | 0000 0000 | 000u uuuu |
| 18Fh | BIGBUG ⁽³⁾ | In-Circuit Debug Breakpoint Register | | | | | | | | 0000 0000 | uuuu uuuu |
| 190h | PMCON1 | — | CALSEL | — | — | — | WREN | WR | RD | -0-- -000 | -0-- -000 |
| 191h | PMCON2 | Program Memory Control Register 2 (not a physical register) | | | | | | | | ---- ---- | ---- ---- |
| 192h | PMADRL | PMADRL7 | PMADRL6 | PMADRL5 | PMADRL4 | PMADRL3 | PMADRL2 | PMADRL1 | PMADRL0 | 0000 0000 | 0000 0000 |
| 193h | PMADRH | — | — | — | — | PMADRH3 | PMADRH2 | PMADRH1 | PMADRH0 | ---- 0000 | ---- 0000 |
| 194h | PMDATL | PMDATL7 | PMDATL6 | PMDATL5 | PMDATL4 | PMDATL3 | PMDATL2 | PMDATL1 | PMDATL0 | 0000 0000 | 0000 0000 |
| 195h | PMDATH | — | — | PMDATH5 | PMDATH4 | PMDATH3 | PMDATH2 | PMDATH1 | PMDATH0 | --00 0000 | --00 0000 |
| 196h | DSTCAL | — | — | — | DSTCAL4 | DSTCAL3 | DSTCAL2 | DSTCAL1 | DSTCAL0 | --x xxxx | --u uuuu |
| 197h | CGMVGMCAL | CGMICAL3 | CGMICAL2 | CGMICAL1 | CGMICAL0 | VGMCAL3 | VGMCAL2 | VGMCAL1 | VGMCAL0 | xxxx xxxx | uuuu uuuu |
| 198h | OSCCAL | — | FCALT6 | FCALT5 | FCALT4 | FCALT3 | FCALT2 | FCALT1 | FCALT0 | -xxx xxxx | -uuu uuuu |
| 199h | DCSCAL | — | DCSCAL6 | DCSCAL5 | DCSCAL4 | DCSCAL3 | DCSCAL2 | DCSCAL1 | DCSCAL0 | -xxx xxxx | -uuu uuuu |
| 19Ah | TTACAL | — | — | — | — | TTA3 | TTA2 | TTA1 | TTA0 | ---- xxxx | ---- uuuu |
| 19Bh | BGRCAL | — | — | — | BGRT4 | BGRT3 | BGRT2 | BGRT1 | BGRT0 | --x xxxx | --u uuuu |
| 19Ch | CEAOFFCAL | — | CEAOFFCAL6 | CEAOFFCAL5 | CEAOFFCAL4 | CEAOFFCAL3 | CEAOFFCAL2 | CEAOFFCAL1 | CEAOFFCAL0 | -xxx xxxx | --u uuuu |
| 19Dh | AVDDCAL | — | — | — | — | AVDDCAL3 | AVDDCAL2 | AVDDCAL1 | AVDDCAL0 | ---- xxxx | ---- uuuu |
| 19Eh | A2GCAL | — | — | — | — | A2GCAL3 | A2GCAL2 | A2GCAL1 | A2GCAL0 | ---- xxxx | ---- uuuu |
| 19Fh | OVRSPCAL | — | — | — | OVRSPCAL4 | OVRSPCAL3 | OVRSPCAL2 | OVRSPCAL1 | OVRSPCAL0 | --x xxxx | --u uuuu |

Legend: — = Unimplemented locations read as '0', u = unchanged, x = unknown, q = value depends on condition, shaded = unimplemented

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

Note 2: MCLR and WDT reset does not affect the previous value data latch. The IOCF bit will be cleared upon reset but will be set again if the mismatch exists.

Note 3: Only accessible when $\overline{DBGEN} = 0$ and ICKBUG<INBUG> = 1.

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10.3.1 OPTION_REG REGISTER

The OPTION_REG register is a readable and writable register, which contains various control bits to configure:

- Timer0/WDT prescaler
- External GPA2/INT interrupt
- Timer0
- Weak pull-ups on PORTGPA and PORTGPB

Note: To achieve a 1:1 prescaler assignment for Timer0, assign the prescaler to the WDT by setting PSA bit to '1' in the OPTION_REG register. Refer to [Section 21.1.3 “Software Programmable Prescaler”](#).

REGISTER 10-2: OPTION_REG: OPTION REGISTER

| | | | | | | | |
|-------|--------|-------|-------|-------|-------|-------|-------|
| R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 |
| RAPU | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 |
| bit 7 | | | | | | | bit 0 |

Legend:

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

- bit 7 **RAPU:** Port GPx Pull-Up Enable bit ⁽¹⁾
 1 = Port GPx pull-ups are disabled
 0 = Port GPx pull-ups are enabled
- bit 6 **INTEDG:** Interrupt Edge Select bit
 0 = Interrupt on rising edge of INT pin
 1 = Interrupt on falling edge of INT pin
- bit 5 **T0CS:** TMR0 Clock Source Select bit
 1 = Transition on T0CKI pin
 0 = Internal instruction cycle clock
- bit 4 **T0SE:** TMR0 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 assigned to WDT
 0 = Prescaler is assigned to the Timer0 module
- bit 2-0 **PS<2:0>:** Prescaler Rate Select bits

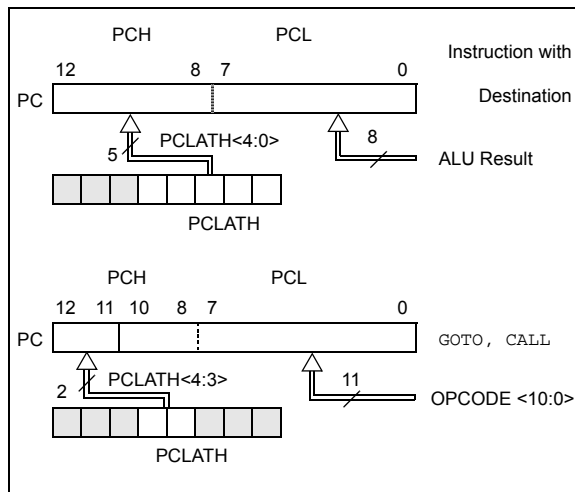
| Bit Value | TMR0 Rate | WDT Rate |
|-----------|-----------|----------|
| 000 | 1: 2 | 1: 1 |
| 001 | 1: 4 | 1: 2 |
| 010 | 1: 8 | 1: 4 |
| 011 | 1: 16 | 1: 8 |
| 100 | 1: 32 | 1: 16 |
| 101 | 1: 64 | 1: 32 |
| 110 | 1: 128 | 1: 64 |
| 111 | 1: 256 | 1: 128 |

Note 1: Individual WPUx bit must also be enabled.

10.4 PCL and PCLATH

The Program Counter (PC) is 13 bits wide. The low byte comes from the PCL register, which is a readable and writable register. The high byte (PC<12:8>) is not directly readable or writable and comes from PCLATH. On any reset, the PC is cleared. Figure 10-3 shows the two situations for loading the PC: the upper example shows how the PC is loaded on a write to PCL (PCLATH <4:0> → PCH), while the lower example in Figure 10-3 shows how the PC is loaded during a CALL or GOTO instruction (PCLATH<4:3> → PCH).

FIGURE 10-3: PROGRAM COUNTER (PC) LOADING IN DIFFERENT SITUATIONS



10.4.1 MODIFYING PCL REGISTER

Executing any instruction with the PCL register as the destination simultaneously causes the Program Counter PC<12:8> bits (PCH) to be replaced by the contents of the PCLATH register. This allows the entire contents of the program counter to be changed by writing the desired upper 5 bits to the PCLATH register. When the lower 8 bits are written to the PCL register, all 13 bits of the program counter will change to the values contained in the PCLATH register and those being written to the PCL register.

10.4.2 COMPUTED GOTO

A computed GOTO is accomplished by adding an offset to the program counter (ADDWF PCL). Care should be exercised when jumping into a look-up table or program branch table (computed GOTO) by modifying the PCL register. Assuming that PCLATH is set to the table start address, if the table length is greater than 255 instructions or if the lower 8 bits of the memory address roll over from 0xFFh to 0X00h in the middle of the table, then PCLATH must be incremented for each address rollover that occurs between the table beginning and the table location within the table.

For more information, refer to Application Note AN556, "Implementing a Table Read" (DS00000556).

10.4.3 COMPUTED FUNCTION CALLS

A computed function CALL allows programs to maintain tables of functions and provide another way to execute state machines or look-up tables. When performing a table read using a computed function CALL, care should be exercised if the table location crosses a PCL memory boundary (each 256-byte block).

If using the CALL instruction, the PCH<2:0> and PCL registers are loaded with the operand of the CALL instruction. PCH<4:3> is loaded with PCLATH<4:3>.

10.4.4 STACK

The MCP19124/5 have an 8-level x 13-bit wide hardware stack (refer to Figure 10-1). The stack space is not part of either program or data space and the Stack Pointer is not readable or writable. The PC is PUSHed onto the stack when CALL instruction is executed or an interrupt causes a branch. The stack is POPed in the event of a RETURN, RETLW or a RETFIE instruction execution. PCLATH is not affected by a PUSH or POP operation.

The stack operates as a circular buffer. This means that after the stack has been PUSHed eight times, the 9th push overwrites the value that was stored from the first push. The 10th push overwrites the second push (and so on).

- Note 1:** There are no Status bits to indicate Stack Overflow or Stack Underflow conditions.
- 2:** There are no instructions/mnemonics called PUSH or POP. These are actions that occur from the execution of the CALL, RETURN, RETLW and RETFIE instructions or the vectoring to an interrupt address.

10.5 Indirect Addressing, INDF and FSR Registers

The INDF register is not a physical register. Addressing the INDF register will cause indirect addressing.

Indirect addressing is possible by using the INDF register. Any instruction using the INDF register actually accesses data pointed to by the File Select Register (FSR). Reading INDF itself indirectly will produce 00h. Writing to the INDF register directly results in a no operation (although Status bits may be affected). An effective 9-bit address is obtained by concatenating the 8-bit FSR and the IRP bit in the STATUS register, as shown in Figure 10-4.

A simple program to clear RAM location 40h-7Fh using indirect addressing is shown in Example 10-3.

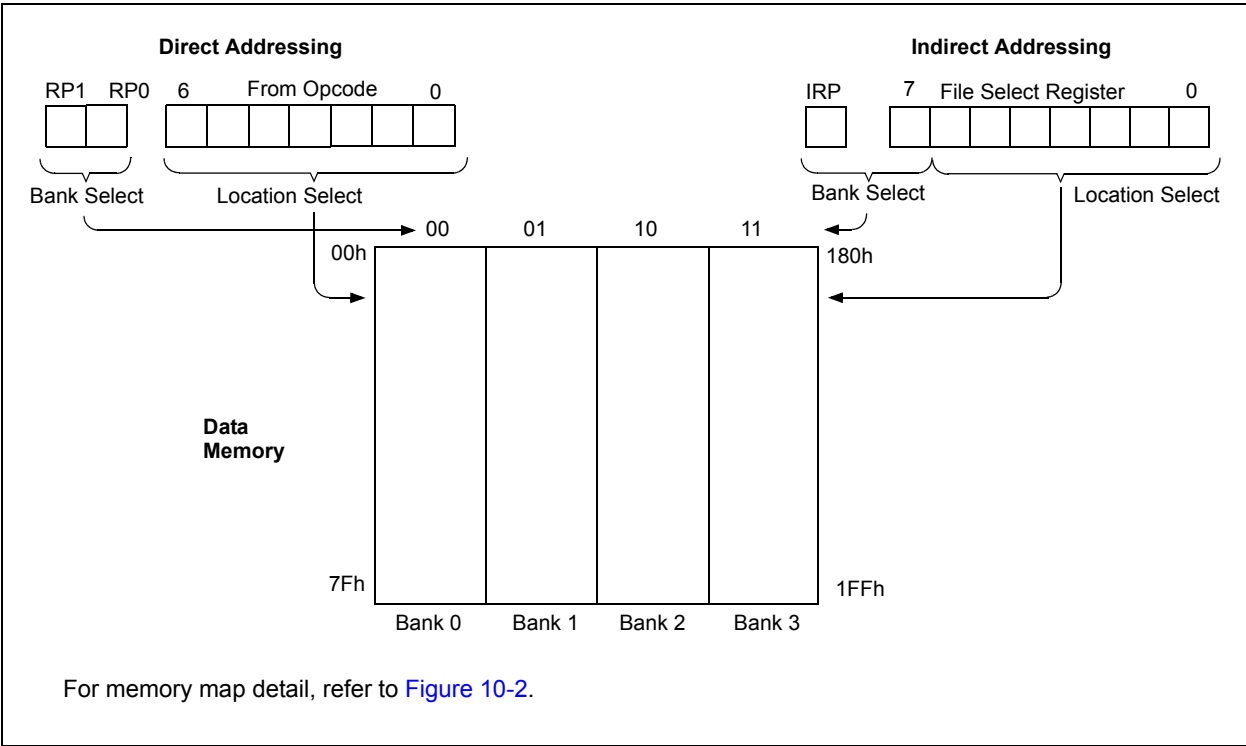
MCP19124/5

EXAMPLE 10-3: INDIRECT ADDRESSING

```

MOVW 0x40 ;initialize pointer
MOVWF FSR ;to RAM
NEXT  CLRF INDF ;clear INDF register
      INCF FSR ;inc pointer
      BTFSS FSR,7 ;all done?
      GOTO NEXT ;no clear next
CONTINUE ;yes continue
    
```

FIGURE 10-4: DIRECT/INDIRECT ADDRESSING



11.0 DEVICE CONFIGURATION

Device Configuration consists of Configuration Word, Code Protection and Device ID.

Note: The $\overline{\text{DBGEN}}$ bit in Configuration Word is managed automatically by device development tools, including debuggers and programmers. For normal device operation, this bit should be maintained as a '1'. Debug is available only on the MCP19125.

11.1 Configuration Word

There are several Configuration Word bits that allow different timers to be enabled and allow memory protection options. These are implemented as Configuration Word at 2007h.

REGISTER 11-1: CONFIG: CONFIGURATION WORD

| | | | | | |
|---------------------------|-----|-------|-------|-----|-------|
| R/P-1 | U-1 | R/P-1 | R/P-1 | U-1 | R/P-1 |
| $\overline{\text{DBGEN}}$ | — | WRT1 | WRT0 | — | BOREN |
| bit 13 | | | | | bit 8 |

| | | | | | | | |
|-------|------------------------|-------|----------------------------|-------|-----|-----|-------|
| U-1 | R/P-1 | R/P-1 | R/P-1 | R/P-1 | U-1 | U-1 | U-1 |
| — | $\overline{\text{CP}}$ | MCLRE | $\overline{\text{PWRT\#}}$ | WDTE | — | — | — |
| bit 7 | | | | | | | bit 0 |

Legend:

| | | |
|-------------------|----------------------|------------------------------------|
| R = Readable bit | P = Programmable bit | U = Unimplemented bit, read as '1' |
| -n = Value at POR | '1' = Bit is set | '0' = Bit is cleared |
| | | x = Bit is unknown |

- bit 13 **$\overline{\text{DBGEN}}$** : ICD Debug bit
1 = ICD debug mode disabled
0 = ICD debug mode enabled
- bit 12 **Unimplemented**: Read as '1'
- bit 11-10 **WRT<1:0>**: Flash Program Memory Self Write Enable bit
11 = Write protection off
10 = 000h to 3FFh write protected, 400h to FFFh may be modified by PMCON1 control
01 = 000h to 7FFh write protected, 800h to FFFh may be modified by PMCON1 control
00 = 000h to FFFh write protected, entire program memory is write protected.
- bit 9 **Unimplemented**: Read as '1'
- bit 8 **BOREN**: Brown-Out Reset Enable bit
1 = BOR disabled during Sleep and enabled during operation
0 = BOR disabled
- bit 7 **Unimplemented**: Read as '1'
- bit 6 **$\overline{\text{CP}}$** : Code Protection
1 = Program memory is not code protected
0 = Program memory is external read and write protected
- bit 5 **MCLRE**: MCLR Pin Function Select
1 = $\overline{\text{MCLR}}$ pin is $\overline{\text{MCLR}}$ function and weak internal pull-up is enabled
0 = MCLR pin is alternate function, MCLR function is internally disabled
- bit 4 **PWRT\#**: Power-Up Timer Enable bit ⁽¹⁾
1 = PWRT disabled
0 = PWRT enabled
- bit 3 **WDTE**: Watchdog Timer Enable bit
1 = WDT enabled
0 = WDT disabled
- bit 2-0 **Unimplemented**: Read as '1'

Note 1: Bit is reserved and not controlled by user.

11.2 Code Protection

Code protection allows the device to be protected from unauthorized access. Internal access to the program memory is unaffected by any code protection setting.

11.2.1 PROGRAM MEMORY PROTECTION

The entire program memory space is protected from external reads and writes by the \overline{CP} bit in the Configuration Word. When $\overline{CP} = 0$, external reads and writes of program memory are inhibited and a read will return all '0's. The CPU can continue to read program memory, regardless of the protection bit settings. Writing the program memory is dependent upon the write protection setting. Refer to [Section 11.3 "Write Protection"](#) for more information.

11.3 Write Protection

Write protection allows the device to be protected from unintended self-writes. Applications, such as boot loader software, can be protected while allowing other regions of the program memory to be modified.

The WRT<1:0> bits in the Configuration Word define the size of the program memory block that is protected.

11.4 ID Locations

Four memory locations (2000h-2003h) are designated as ID locations where the user can store checksum or other code identification numbers. These locations are not accessible during normal execution but are readable and writable during Program/Verify mode. Only the Least Significant 7 bits of the ID locations are reported when using MPLAB Integrated Development Environment (IDE).

12.0 RESETS

The reset logic is used to place the MCP19124/5 into a known state. The source of the reset can be determined by using the device status bits.

There are multiple ways to reset the MCP19124/5 devices:

- Power-On Reset (POR)
- Overtemperature Reset (OT)
- MCLR Reset
- WDT Reset
- Brown-Out Reset (BOR)

To allow V_{DD} to stabilize, an optional power-up timer can be enabled to extend the Reset time after a POR event.

Some registers are not affected in any Reset condition; their status is unknown on POR and unchanged in any other Reset. Most other registers are reset to a “Reset state” on:

- Power-On Reset
- MCLR Reset
- MCLR Reset during Sleep
- WDT Reset
- Brown-Out Reset

WDT (Watchdog Timer) wake-up does not cause register resets in the same manner as a WDT Reset, since wake-up is viewed as the resumption of normal operation. \overline{TO} and \overline{PD} bits are set or cleared differently in different Reset situations, as indicated in Table 12-1. The software can use these bits to determine the nature of the Reset. Refer to Table 12-2 for a full description of Reset states of all registers.

A simplified block diagram of the On-Chip Reset Circuit is shown in Figure 12-1.

The MCLR Reset path has a noise filter to detect and ignore small pulses. Refer to Section 5.0 “Digital Electrical Characteristics” for pulse-width specifications.

FIGURE 12-1: SIMPLIFIED BLOCK DIAGRAM OF ON-CHIP RESET CIRCUIT

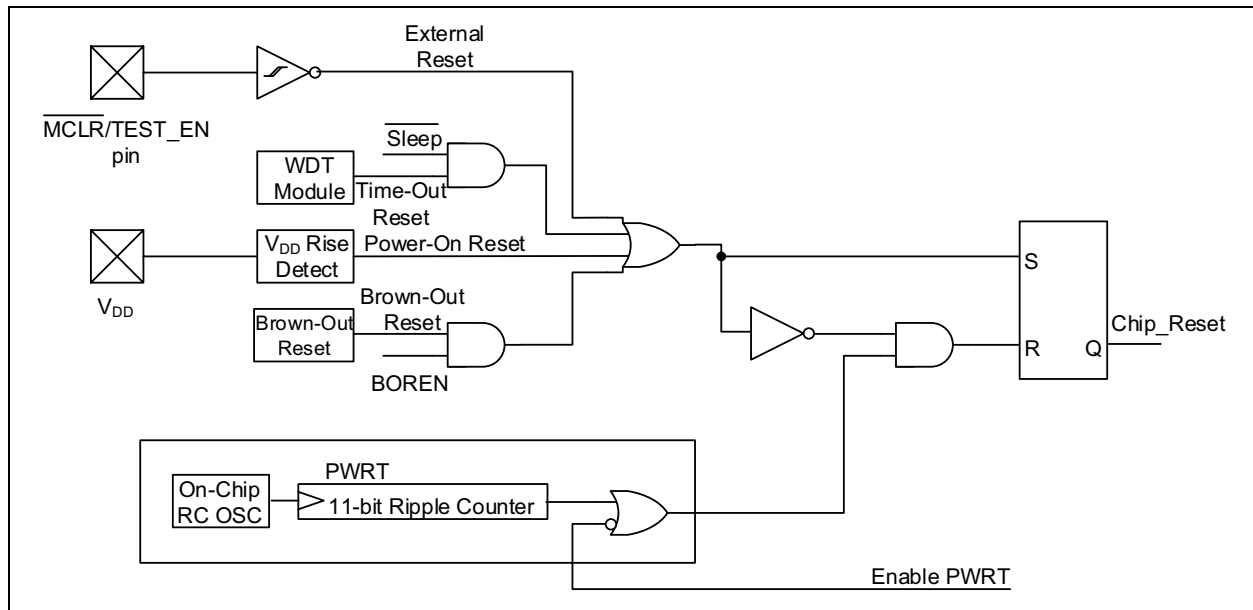


TABLE 12-1: TIME-OUT IN VARIOUS SITUATIONS

| Power-Up | | Wake-Up from Sleep |
|------------------------|------------------------|--------------------|
| $\overline{PWRTE} = 0$ | $\overline{PWRTE} = 1$ | |
| T_{PWRT} | — | — |

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TABLE 12-2: STATUS/PCON BITS AND THEIR SIGNIFICANCE

| $\overline{\text{POR}}$ | $\overline{\text{BOR}}$ | $\overline{\text{TO}}$ | $\overline{\text{PD}}$ | Condition |
|-------------------------|-------------------------|------------------------|------------------------|--|
| 0 | x | 1 | 1 | Power-On Reset |
| u | 0 | 1 | 1 | Brown-Out Reset |
| u | u | 0 | u | WDT Reset |
| u | u | 0 | 0 | WDT Wake-Up |
| u | u | u | u | $\overline{\text{MCLR}}$ Reset during normal operation |
| u | u | 1 | 0 | $\overline{\text{MCLR}}$ Reset during Sleep |

Legend: u = unchanged, x = unknown

12.1 Power-On Reset (POR)

The on-chip POR circuit holds the chip in Reset until V_{DD} has reached a high enough level for proper operation. To take advantage of the POR, simply connect the $\overline{\text{MCLR}}$ pin through a resistor to V_{DD} . This will eliminate external RC components usually needed to create Power-On Reset.

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

12.2 $\overline{\text{MCLR}}$

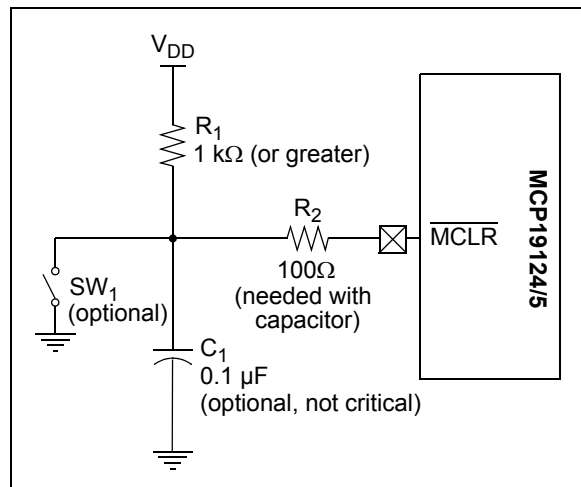
MCP19124/5 have a noise filter in the $\overline{\text{MCLR}}$ Reset path. The filter will detect and ignore small pulses.

It should be noted that a WDT Reset does not drive $\overline{\text{MCLR}}$ pin low.

Voltages applied to the $\overline{\text{MCLR}}$ pin that exceed its specification can result in both $\overline{\text{MCLR}}$ Resets and excessive current beyond the device specification during the ESD event. For this reason, Microchip recommends that the $\overline{\text{MCLR}}$ pin no longer be tied directly to V_{DD} . The use of a Resistor-Capacitor (RC) network, as shown in Figure 12-2, is suggested.

An internal $\overline{\text{MCLR}}$ option is enabled by clearing the MCLRE bit in the CONFIG register. When MCLRE = 0, the Reset signal to the chip is generated internally. When MCLRE = 1, the $\overline{\text{MCLR}}$ pin becomes an external Reset input. In this mode, the $\overline{\text{MCLR}}$ pin has a weak pull-up to V_{DD} .

FIGURE 12-2: RECOMMENDED $\overline{\text{MCLR}}$ CIRCUIT



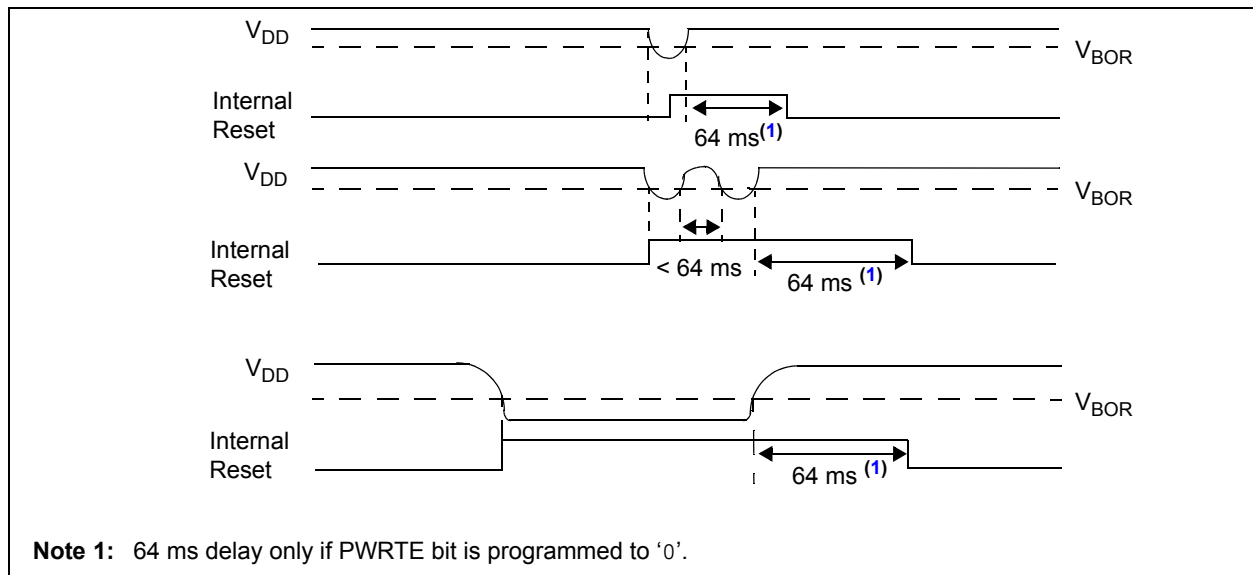
12.3 Brown-Out Reset (BOR)

The BOREN bit 8 in the CONFIG register enables or disables the BOR mode, as defined in the CONFIG register. A brown-out occurs when V_{DD} falls below V_{BOR} for greater than 100 μ s minimum. On any Reset (Power-On, Brown-Out, Watchdog Timer, etc.), the chip will remain in Reset until V_{DD} rises above V_{BOR} (refer to Figure 12-3). If enabled, the Power-Up Timer will be invoked by the Reset and will keep the chip in Reset an additional 64 ms. During power-up, it is recommended that the BOR configuration bit is enabled, holding the MCU in Reset (OSC turned off and no code execution) until V_{DD} exceeds the V_{BOR} threshold. Users have the option of adding an additional 64 ms delay by clearing the PWRTE bit. At this time, the V_{DD} voltage level is high enough to operate the MCU functions only; all other device functionality is not operational. This is independent of

the value of V_{IN} , which is typically $V_{DD} + V_{DROPOUT}$. During power-down with BOR enabled, the MCU operation will be held in Reset when V_{DD} falls below the V_{BOR} threshold. With BOR disabled or while operating in Sleep mode, the POR will hold the part in Reset when V_{DD} falls below the V_{POR} threshold.

Note: The Power-Up Timer is enabled by the \overline{PWRTE} bit in the CONFIG register. If V_{DD} drops below V_{BOR} while the Power-Up Timer is running, the chip will go back into a Brown-Out Reset and the Power-Up Timer will be re-initialized. Once the V_{DD} rises above V_{BOR} , the Power-Up Timer will execute a 64 ms reset.

FIGURE 12-3: BROWN-OUT SITUATIONS



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12.4 Power-Up Timer (PWRT)

The Power-Up Timer provides a fixed 64 ms (nominal) time-out on power-up only, from POR Reset. The Power-Up Timer operates from an internal RC oscillator. The chip is kept in Reset as long as PWRT is active. The PWRT delay allows the V_{DD} to rise to an acceptable level. A bit (\overline{PWRT}) in the CONFIG register can disable (if set) or enable (if cleared or programmed) the Power-Up Timer.

The Power-Up Timer delay will vary from chip to chip due to:

- V_{DD} variation
- Temperature variation
- Process variation

Note: Voltage spikes below A_{GND} at the MCLR pin, inducing currents greater than 80 mA, may cause latch-up. Thus, a series resistor of 50-100 Ω should be used when applying a “low” level to the MCLR pin, rather than pulling this pin directly to A_{GND} .

The Power-Up Timer optionally delays device execution after a POR event. This timer is typically used to allow V_{DD} to stabilize before allowing the device to start running.

The Power-Up Timer is controlled by the \overline{PWRT} bit in the CONFIG register.

12.5 Watchdog Timer (WDT) Reset

The Watchdog Timer generates a Reset if the firmware does not issue a \overline{CLRWDT} instruction within the time-out period. The \overline{TO} and \overline{PD} bits in the STATUS register are changed to indicate the WDT Reset. Refer to [Section 15.0 “Watchdog Timer \(WDT\)”](#) for more information.

12.6 Start-Up Sequence

Upon the release of a POR, the following must occur before the device begins executing:

- Power-Up Timer runs to completion (if enabled)
- Oscillator start-up timer runs to completion
- \overline{MCLR} must be released (if enabled)

The total time-out will vary based on \overline{PWRT} bit status. For example, with \overline{PWRT} bit erased (PWRT disabled), there will be no time-out at all. [Figures 12-4, 12-5](#) and [12-6](#) depict time-out sequences.

Since the time-outs occur from the POR pulse, if \overline{MCLR} is kept low long enough, the time-outs will expire. Then, bringing MCLR high will begin execution immediately (refer to [Figure 12-5](#)). This is useful for testing purposes or to synchronize more than one MCP19124/5 device operating in parallel.

12.6.1 POWER CONTROL (PCON) REGISTER

The Power Control (PCON) register (address 8Eh) has two Status bits to indicate what type of Reset occurred last.

FIGURE 12-4: TIME-OUT SEQUENCE ON POWER-UP (DELAYED \overline{MCLR}): CASE 1

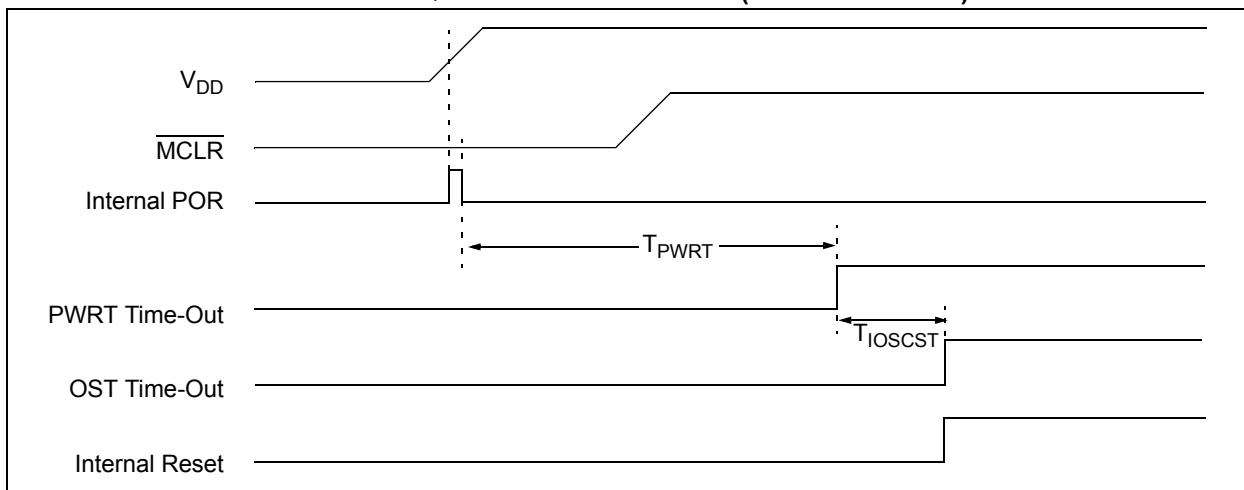


FIGURE 12-5: TIME-OUT SEQUENCE ON POWER-UP (DELAYED $\overline{\text{MCLR}}$): CASE 2

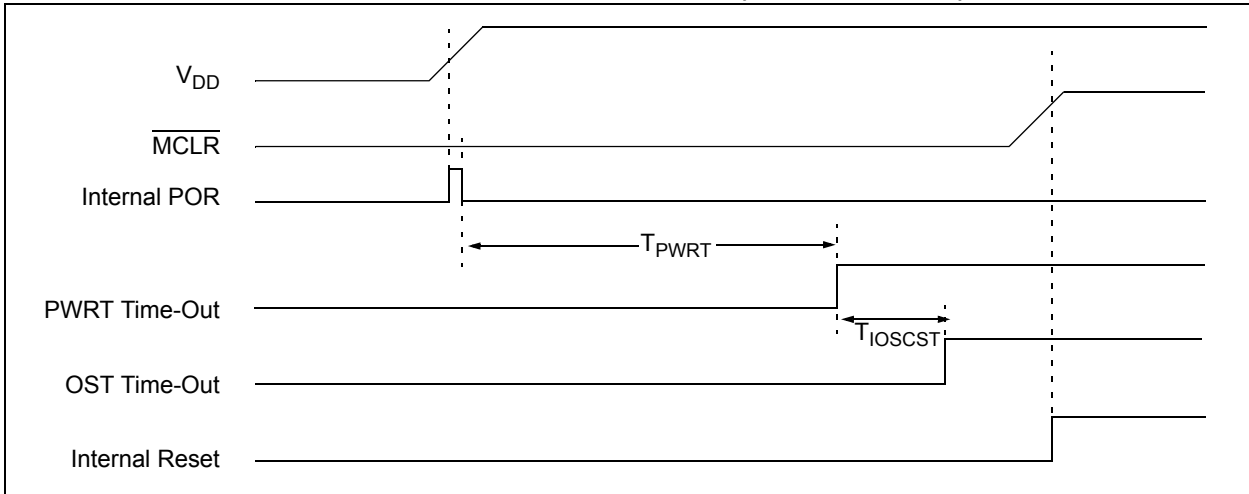
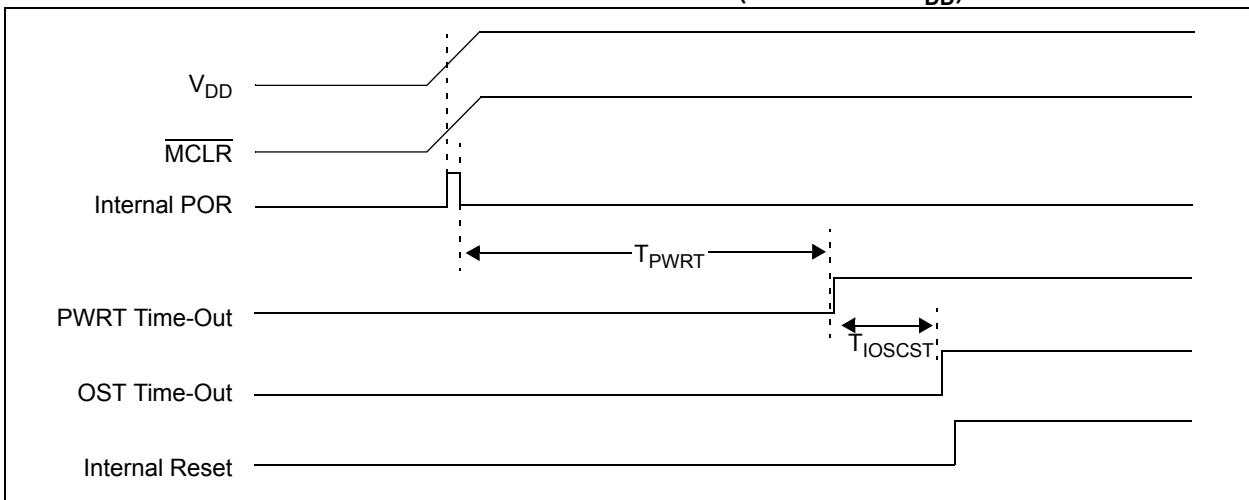


FIGURE 12-6: TIME-OUT SEQUENCE ON POWER-UP ($\overline{\text{MCLR}}$ WITH V_{DD})



12.7 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. Tables 12-3 and 12-4 show the Reset conditions of these registers.

TABLE 12-3: RESET STATUS BITS AND THEIR SIGNIFICANCE

| $\overline{\text{POR}}$ | $\overline{\text{BOR}}$ | $\overline{\text{TO}}$ | $\overline{\text{PD}}$ | Condition |
|-------------------------|-------------------------|------------------------|------------------------|--|
| 0 | x | 1 | 1 | Power-On Reset |
| u | 0 | 1 | 1 | Brown-Out Reset |
| u | u | 0 | u | WDT Reset |
| u | u | 0 | 0 | WDT Wake-Up from Sleep |
| u | u | 1 | 0 | Interrupt Wake-Up from Sleep |
| u | u | u | u | $\overline{\text{MCLR}}$ Reset during normal operation |
| u | u | 1 | 0 | $\overline{\text{MCLR}}$ Reset during Sleep |
| 0 | u | 0 | x | Not allowed. $\overline{\text{TO}}$ is set on POR. |
| 0 | u | x | 0 | Not allowed. $\overline{\text{PD}}$ is set on POR. |

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TABLE 12-4: RESET CONDITION FOR SPECIAL REGISTERS (Note 1)

| Condition | Program Counter | STATUS Register | PCON Register |
|------------------------------------|-----------------------|-----------------|---------------|
| Power-On Reset | 0000h | 0001 1xxx | ---- --0u |
| Brown-Out Reset | 0000 | 0001 1xxx | ---- --u0 |
| MCLR Reset during normal operation | 0000h | 000u uuuu | ---- --uu |
| MCLR Reset during Sleep | 0000h | 0001 0uuu | ---- --uu |
| WDT Reset | 0000h | 0000 uuuu | ---- --uu |
| WDT Wake-Up from Sleep | PC + 1 | uuu0 0uuu | ---- --uu |
| Interrupt Wake-Up from Sleep | PC + 1 ⁽²⁾ | uuu1 0uuu | ---- --uu |

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

Note 1: If a Status bit is not implemented, that bit will be read as '0'.

2: 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.

12.8 Power Control (PCON) Register

The PCON register bits are shown in [Register 12-1](#).

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

- Power-On Reset ($\overline{\text{POR}}$)
- Brown-Out Reset ($\overline{\text{BOR}}$)

REGISTER 12-1: PCON: POWER CONTROL REGISTER

| | | | | | | | |
|----------|-----|-----|-----|-----------------------------|-------|-------------------------|-------------------------|
| R/W-0 | U-0 | U-0 | U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| ADC_REFR | — | — | — | $\overline{\text{VDDFLAG}}$ | VDDOK | $\overline{\text{POR}}$ | $\overline{\text{BOR}}$ |
| bit 7 | | | | | | | bit 0 |

Legend:

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

- bit 7 **ADC_REFR:** $V_{DD} > AV_{DD}$ Status bit that shows if the ADC Reference is present at the ADC
 1 = V_{DD} is greater than AV_{DD} and the ADC Reference is present at the ADC
 0 = V_{DD} is not greater than AV_{DD} and the ADC Reference is not present at the ADC
- bit 6-4 **Unimplemented:** Read as '0'
- bit 3 **VDDFLAG:** VDDOK history status bit
 1 = V_{DD} LDO has not dropped out of regulation (VDDOK has not gone low since this bit was last set)
 0 = V_{DD} LDO has dropped out of regulation at some time since this bit was last set. Must be set by firmware when VDDOK = 1
- bit 2 **VDDOK:** V_{DD} Status bit
 1 = V_{DD} is in regulation
 0 = V_{DD} is not in regulation
- bit 1 **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 **BOR:** Brown-Out Reset bit
 1 = No Brown-Out Reset occurred
 0 = A Brown-Out Reset occurred (must be set in software after a Brown-Out Reset occurs)

TABLE 12-5: SUMMARY OF REGISTERS ASSOCIATED WITH RESETS (Note 1)

| Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Register on Page |
|--------|-------|-------|-------|------------------------|------------------------|-------|-------------------------|-------------------------|--------------------|
| PCON | — | — | — | — | — | — | $\overline{\text{POR}}$ | $\overline{\text{BOR}}$ | 89 |
| STATUS | IPR | RP1 | RP0 | $\overline{\text{TO}}$ | $\overline{\text{PD}}$ | Z | DC | C | 71 |

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

Note 1: Other (non power-up) Resets include $\overline{\text{MCLR}}$ Reset and Watchdog Timer Reset during normal operation.

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NOTES:

13.0 INTERRUPTS

The MCP19124/5 have multiple sources of interrupt:

- External Interrupt (INT pin)
- Interrupt-On-Change (IOC) Interrupts
- Timer0 Overflow Interrupt
- Timer1 Overflow Interrupt
- Timer2 Match Interrupt
- ADC Interrupt
- System Input Undervoltage Error
- System Input Overvoltage Error
- SSP
- BCL
- Desaturation Detection
- Gate Drive UVLO
- Capture/Compare 1
- Capture/Compare 2
- Overtemperature

The Interrupt Control (INTCON) register and the Peripheral Interrupt Request (PIRx) registers record individual interrupt requests in flag bits. The INTCON register also has individual and global interrupt enable bits.

The Global Interrupt Enable bit (GIE) in the INTCON register enables (if set) all unmasked interrupts or disables (if cleared) all interrupts. Individual interrupts can be disabled through their corresponding enable bits in the INTCON register and PIEx registers. GIE is cleared on Reset.

When an interrupt is serviced, the following actions occur automatically:

- The GIE is cleared to disable any further interrupt
- The return address is pushed onto the stack
- The PC is loaded with 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.

Note 1: Individual interrupt flag bits are set, regardless of the status of their corresponding mask bit or the GIE bit.

2: When an instruction that clears the GIE bit is executed, any interrupts that were pending for execution in the next cycle are ignored. The interrupts which were ignored are still pending to be serviced when the GIE bit is set again.

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 interrupts operation, refer to its peripheral chapter.

13.1 Interrupt Latency

For external interrupt events, such as the INT pin or PORTGPx change interrupt, the interrupt latency will be three or four instruction cycles. The exact latency depends upon when the interrupt event occurs (refer to [Figure 13-2](#)). The latency is the same for one- or two-cycle instructions.

13.2 GPA2/INT Interrupt

The external interrupt on the GPA2/INT pin is edge-triggered, either on the rising edge if the INTEDG bit in the OPTION_REG register is set, or the falling edge if the INTEDG bit is clear. When a valid edge appears on the GPA2/INT pin, the INTF bit in the INTCON register is set. This interrupt can be disabled by clearing the INTE control bit in the INTCON register. The INTF bit must be cleared by software in the Interrupt Service Routine before re-enabling this interrupt. The GPA2/INT interrupt can wake up the processor from Sleep, if the INTE bit was set prior to going into Sleep. Refer to [Section 14.0 “Power-Down Mode \(Sleep\)”](#) for details on Sleep and [Section 14.1 “Wake-Up from Sleep”](#) for timing of wake-up from Sleep through GPA2/INT interrupt.

Note: The ANSEL register must be initialized to configure an analog channel as a digital input. Pins configured as analog inputs will read '0' and cannot generate an interrupt.

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FIGURE 13-1: INTERRUPT LOGIC

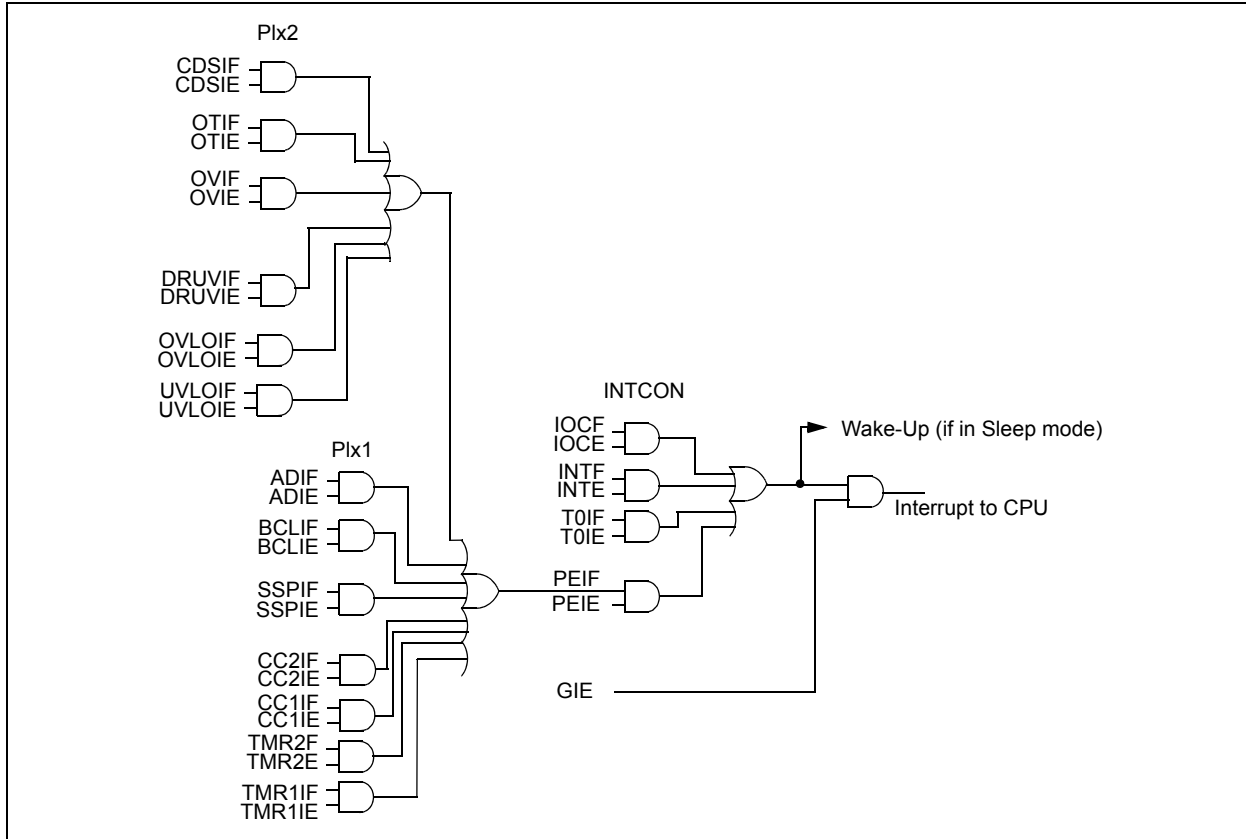
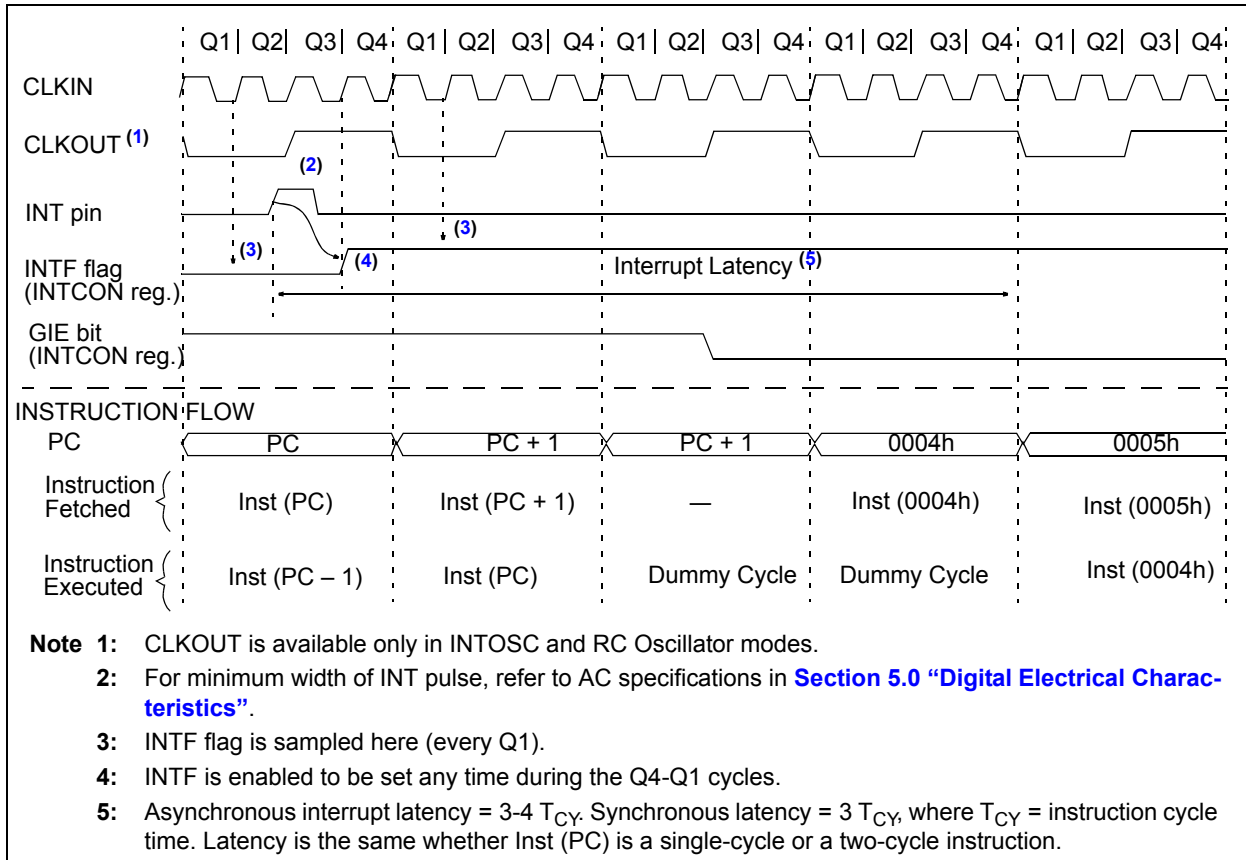


FIGURE 13-2: INT PIN INTERRUPT TIMING



13.3 Interrupt Control Registers

13.3.1 INTCON REGISTER

The INTCON register is a readable and writable register that contains the various enable and flag bits for the 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) in the INTCON register. The user's software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

REGISTER 13-1: INTCON: INTERRUPT CONTROL REGISTER

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-x |
| GIE | PEIE | TOIE | INTE | IOCE | T0IF | INTF | IOCF |
| bit 7 | | | | | | | bit 0 |

Legend:

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

- bit 7 **GIE:** Global Interrupt Enable bit
 1 = Enables all unmasked interrupts
 0 = Disables all interrupts
- bit 6 **PEIE:** Peripheral Interrupt Enable bit
 1 = Enables all unmasked peripheral interrupts
 0 = Disables all peripheral interrupts
- bit 5 **TOIE:** TMR0 Overflow Interrupt Enable bit
 1 = Enables the TMR0 interrupt
 0 = Disables the TMR0 interrupt
- bit 4 **INTE:** INT External Interrupt Enable bit
 1 = Enables the INT external interrupt
 0 = Disables the INT external interrupt
- bit 3 **IOCE:** Interrupt-on-Change Enable bit ⁽¹⁾
 1 = Enables the interrupt-on-change
 0 = Disables the interrupt-on-change
- bit 2 **T0IF:** TMR0 Overflow Interrupt Flag bit ⁽²⁾
 1 = TMR0 register has overflowed (must be cleared in software)
 0 = TMR0 register did not overflow
- bit 1 **INTF:** External Interrupt Flag bit
 1 = The external interrupt occurred (must be cleared in software)
 0 = The external interrupt did not occur
- bit 0 **IOCF:** Interrupt-on-Change Interrupt Flag bit
 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: IOCx registers must also be enabled.

2: T0IF bit is set when TMR0 rolls over. TMR0 is unchanged on Reset and should be initialized before clearing T0IF bit.

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13.3.1.1 PIE1 Register

The PIE1 register contains the Peripheral Interrupt Enable bits, as shown in [Register 13-2](#).

Note 1: Bit PEIE in the INTCON register must be set to enable any peripheral interrupt.

REGISTER 13-2: PIE1: PERIPHERAL INTERRUPT ENABLE REGISTER 1

| | | | | | | | |
|-------|-----|-------|-------|-------|-------|--------|--------|
| U-0 | U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| — | — | BCLIE | SSPIE | CC2IE | CC1IE | TMR2IE | TMR1IE |
| bit 7 | | | | | | | bit 0 |

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

- bit 7-6 **Unimplemented:** Read as '0'
- bit 5 **BCLIE:** MSSP Bus Collision Interrupt Enable bit
1 = Enables the MSSP Bus Collision interrupt
0 = Disables the MSSP Bus Collision interrupt
- bit 4 **SSPIE:** Synchronous Serial Port (MSSP) Interrupt Enable bit
1 = Enables the MSSP interrupt
0 = Disables the MSSP interrupt
- bit 3 **CC2IE:** Capture2/Compare2 Interrupt Enable bit
1 = Enables the Capture2/Compare2 interrupt
0 = Disables the Capture2/Compare2 interrupt
- bit 2 **CC1IE:** Capture1/Compare1 Interrupt Enable bit
1 = Enables the Capture1/Compare1 interrupt
0 = Disables the Capture1/Compare1 interrupt
- bit 1 **TMR2IE:** Timer2 Interrupt Enable
1 = Enables the Timer2 interrupt
0 = Disables the Timer2 interrupt
- bit 0 **TMR1IE:** Timer1 Interrupt Enable
1 = Enables the Timer1 interrupt
0 = Disables the Timer1 interrupt

13.3.1.2 PIE2 Register

The PIE2 register contains the Peripheral Interrupt Enable bits, as shown in [Register 13-3](#).

Note 1: Bit PEIE in the INTCON register must be set to enable any peripheral interrupt.

REGISTER 13-3: PIE2: PERIPHERAL INTERRUPT ENABLE REGISTER 2

| | | | | | | | |
|-------|-------|-----|-------|-------|--------|--------|--------|
| R/W-0 | R/W-0 | U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| CDSIE | ADIE | — | OTIE | OVIE | DRUVIE | OVLOIE | UVLOIE |
| bit 7 | | | | | | | bit 0 |

Legend:

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

- bit 7 **CDSIE:** Desaturation Detection Interrupt Enable bit
 1 = Enables the DESAT Detect interrupt
 0 = Disables the DESAT Detect interrupt
- bit 6 **ADIE:** ADC Interrupt Enable bit
 1 = Enables the ADC interrupt
 0 = Disables the ADC interrupt
- bit 5 **Unimplemented:** Read as '0'
- bit 4 **OTIE:** Overtemperature Interrupt Enable bit
 1 = Enables overtemperature interrupt
 0 = Disables overtemperature interrupt
- bit 3 **OVIE:** V_{OUT} Overvoltage Interrupt Enable bit
 1 = Enables the OV interrupt
 0 = Disables the OV interrupt
- bit 2 **DRUVIE:** Gate Drive Undervoltage Lockout Interrupt Enable bit
 1 = Enables Gate Drive UVLO interrupt
 0 = Disables Gate Drive UVLO interrupt
- bit 1 **OVLOIE:** V_{IN} Overvoltage Lockout Interrupt Enable bit
 1 = Enables OVLO interrupt
 0 = Disables OVLO interrupt
- bit 0 **UVLOIE:** V_{IN} Undervoltage Lockout Interrupt Enable bit
 1 = Enables UVLO interrupt
 0 = Disables UVLO interrupt

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13.3.1.3 PIR1 Register

The PIR1 register contains the Peripheral Interrupt Flag bits, as shown in [Register 13-4](#).

Note 1: 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) in the INTCON register. The user's software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

REGISTER 13-4: PIR1: PERIPHERAL INTERRUPT FLAG REGISTER 1

| | | | | | | | |
|-------|-----|-------|-------|-------|-------|--------|--------|
| U-0 | U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| — | — | BCLIF | SSPIF | CC2IF | CC1IF | TMR2IF | TMR1IF |
| bit 7 | | | | | | | bit 0 |

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

- bit 7-6 **Unimplemented:** Read as '0'
- bit 5 **BCLIF:** MSSP Bus Collision Interrupt Flag bit
 - 1 = Interrupt is pending
 - 0 = Interrupt is not pending
- bit 4 **SSPIF:** Synchronous Serial Port (MSSP) Interrupt Flag bit
 - 1 = Interrupt is pending
 - 0 = Interrupt is not pending
- bit 3 **CC2IF:** Capture2/Compare2 Interrupt Flag bit
 - 1 = Capture or Compare has occurred
 - 0 = Capture or Compare has not occurred
- bit 2 **CC1IF:** Capture1/Compare1 Interrupt Flag bit
 - 1 = Capture or Compare has occurred
 - 0 = Capture or Compare has not occurred
- bit 1 **TMR2IF:** Timer2 to PR2 Match Interrupt Flag
 - 1 = Timer2 to PR2 match occurred (must be cleared in software)
 - 0 = Timer2 to PR2 match did not occur
- bit 0 **TMR1IF:** Timer1 Interrupt Flag
 - 1 = Timer1 rolled over (must be cleared in software)
 - 0 = Timer1 has not rolled over

13.3.1.4 PIR2 Register

The PIR2 register contains the Peripheral Interrupt Flag bits, as shown in [Register 13-5](#).

Note 1: 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) in the INTCON register. The user's software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

REGISTER 13-5: PIR2: PERIPHERAL INTERRUPT FLAG REGISTER 2

| | | | | | | | |
|-------|-------|-----|-------|-------|--------|--------|--------|
| R/W-0 | R/W-0 | U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| CDSIF | ADIF | — | OTIF | OVIF | DRUVIF | OVLOIF | UVLOIF |
| bit 7 | | | | | | | bit 0 |

Legend:

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

- bit 7 **CDSIF:** DESAT Detect Comparator Module Interrupt Flag bit
 1 = An interrupt is pending
 0 = An interrupt is not pending
- bit 6 **ADIF:** ADC Interrupt Flag bit
 1 = ADC conversion complete
 0 = ADC conversion has not completed or has not been started
- bit 5 **Unimplemented:** Read as '0'
- bit 4 **OTIF:** Overtemperature Interrupt Flag bit
 1 = Overtemperature event has occurred
 0 = Overtemperature event has not occurred
- bit 3 **OVIF:** Overvoltage Interrupt Flag bit
 With OVINTP bit set:
 1 = A V_{OUT} Not Overvoltage to Overvoltage edge has been detected
 0 = A V_{OUT} Not Overvoltage to Overvoltage edge has not been detected
 With OVINTN bit set:
 1 = A V_{OUT} Overvoltage to Not Overvoltage edge has been detected
 0 = A V_{OUT} Overvoltage to Not Overvoltage edge has not been detected
- bit 2 **DRUVIF:** Gate Drive Undervoltage Lockout Interrupt Flag bit
 1 = Gate Drive Undervoltage Lockout has occurred
 0 = Gate Drive Undervoltage Lockout has not occurred
- bit 1 **OVLOIF:** V_{IN} Overvoltage Lockout Interrupt Flag bit
 With OVLOINTP bit set:
 1 = A V_{IN} Not Overvoltage to V_{IN} Overvoltage edge has been detected
 0 = A V_{IN} Not Overvoltage to V_{IN} Overvoltage edge has not been detected
 With OVLOINTN bit set:
 1 = A V_{IN} Overvoltage to V_{IN} Not Overvoltage edge has been detected
 0 = A V_{IN} Overvoltage to V_{IN} Not Overvoltage edge has not been detected

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REGISTER 13-5: PIR2: PERIPHERAL INTERRUPT FLAG REGISTER 2 (CONTINUED)

bit 0 **UVLOIF:** V_{IN} Undervoltage Lockout Interrupt Flag bit
With UVLOINTP bit set:
 1 = A V_{IN} Not Undervoltage to V_{IN} Undervoltage edge has been detected
 0 = A V_{IN} Not Undervoltage to V_{IN} Undervoltage edge has not been detected
With UVLOINTN bit set:
 1 = A V_{IN} Undervoltage to V_{IN} Not Undervoltage edge has been detected
 0 = A V_{IN} Undervoltage to V_{IN} Not Undervoltage edge has not been detected

TABLE 13-1: 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 | T0IE | INTE | IOCE | T0IF | INTF | IOCF | 93 |
| OPTION_REG | RAPU | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 | 78 |
| PIE1 | TXIE | RCIE | BCLIE | SSPIE | CC2IE | CC1IE | TMR2IE | TMR1IE | 94 |
| PIE2 | CDSIE | ADIE | — | OTIE | OVIE | DRUVIE | OVLOIE | UVLOIE | 95 |
| PIR1 | TXIF | RCIF | BCLIF | SSPIF | — | — | TMR2IF | TMR1IF | 96 |
| PIR2 | CDSIF | ADIF | — | OTIF | OVIF | DRUVIF | OVLOIF | UVLOIF | 97 |

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

13.4 Context Saving During Interrupts

During an interrupt, only the return PC value is saved on the stack. Typically, users may wish to save key registers during an interrupt (e.g., W and STATUS registers). This must be implemented in software.

Temporary holding registers W_TEMP and STATUS_TEMP should be placed in the last 16 bytes of GPR. These 16 locations are common to all banks and do not require banking. This makes context save and restore operations simpler. The code shown in [Example 13-1](#) can be used to:

- Store the W register
- Store the STATUS register
- Execute the ISR code
- Restore the Status (and Bank Select Bit) register
- Restore the W register

Note: The MCP19124/5 do not require saving the PCLATH. However, if computed GOTOS are used in both the ISR and the main code, the PCLATH must be saved and restored in the ISR.

EXAMPLE 13-1: SAVING STATUS AND W REGISTERS IN RAM

```
MOVWF  W_TEMP           ;Copy W to TEMP register
SWAPF  STATUS,W        ;Swap status to be saved into W
                        ;Swaps are used because they do not affect the status bits
MOVWF  STATUS_TEMP     ;Save status to bank zero STATUS_TEMP register
:
:(ISR)                  ;Insert user code here
:
SWAPF  STATUS_TEMP,W   ;Swap STATUS_TEMP register into W
                        ;(sets bank to original state)
MOVWF  STATUS          ;Move W into STATUS register
SWAPF  W_TEMP,F        ;Swap W_TEMP
SWAPF  W_TEMP,W        ;Swap W_TEMP into W
```

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NOTES:

14.0 POWER-DOWN MODE (SLEEP)

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

Upon entering Sleep mode, the following conditions occur:

1. WDT will be cleared but keeps running, if enabled for operation during Sleep.
2. \overline{PD} bit in the STATUS register is cleared.
3. \overline{TO} bit in the STATUS register is set.
4. CPU clock is disabled.
5. The ADC is inoperable due to the absence of the 4V LDO power (AV_{DD}) while the ADC Reference is set to AV_{DD} . To minimize sleep current the ADC Reference must be set to the default AV_{DD} .
6. I/O ports maintain the status they had before `SLEEP` was executed (driving high, low or high-impedance).
7. Resets other than WDT and BOR are not affected by Sleep mode.
8. Analog Circuit power (AV_{DD}) is removed during Sleep mode.

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

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

- Disable both Error Amplifiers by setting bits 1 and 2 in the ABECON Register.
- 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 Timer1 oscillator
- ADC Reference must be set to the default condition (AV_{DD}).
- V_{DR} will draw a small amount of current from V_{DD} when powered from V_{DD} . To eliminate this small current, disconnect V_{DR} from V_{DD} during Sleep.
- I/O pins that are high-impedance inputs should be pulled to V_{DD} or GND externally to avoid switching currents caused by floating inputs.

The `SLEEP` instruction removes power from the analog circuitry. AV_{DD} is shut down to minimize current draw in Sleep mode and to maintain a shutdown current of 50 μ A typical. The 5V LDO (V_{DD}) voltage drops to 2.9V minimum in Sleep mode. External current draw from the 5V LDO (V_{DD}) should be limited to less than 1mA. Loads drawing more than 1mA externally during Sleep mode risk loading down the V_{DD} voltage and tripping POR.

A POR event during Sleep mode will wake the device from Sleep. The enable state of the analog circuitry does not change with the execution of the `SLEEP` instruction.

14.1 Wake-Up from Sleep

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

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

The first two 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 12.7 “Determining the Cause of a Reset”](#).

The following peripheral interrupts can wake the device from Sleep:

1. Interrupt-on-change
2. External Interrupt from INT pin

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 and will then call the Interrupt Service Routine. In cases where the execution of the instruction following `SLEEP` is not desirable, the user should have an `NOP` after the `SLEEP` instruction.

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

14.1.1 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 in the STATUS register will not be set.
 - \overline{PD} bit in the STATUS register will not be cleared.

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- 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
 - $\overline{\text{TO}}$ bit in the **STATUS** register will be set
 - $\overline{\text{PD}}$ bit in 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 $\overline{\text{PD}}$ bit. If the $\overline{\text{PD}}$ bit is set, the **SLEEP** instruction was executed as a **NOP**.

FIGURE 14-1: WAKE-UP FROM SLEEP THROUGH INTERRUPT

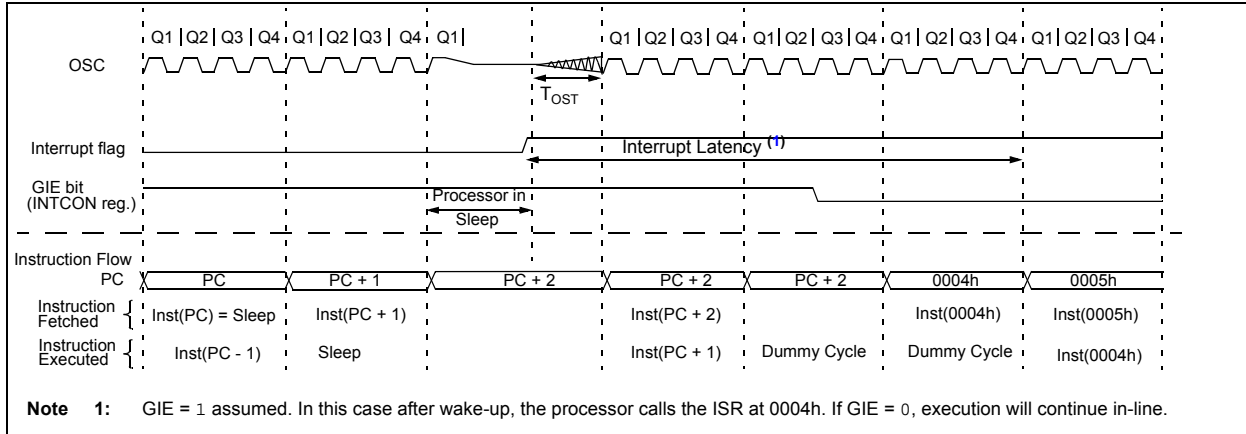


TABLE 14-1: SUMMARY OF REGISTERS ASSOCIATED WITH POWER-DOWN MODE

| Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Register on Page |
|--------|-------|-------|-------|------------------------|------------------------|--------|--------|--------|------------------|
| INTCON | GIE | PEIE | T0IE | INTE | IOCE | T0IF | INTF | IOCF | 93 |
| IOCA | IOCA7 | IOCA6 | IOCA5 | — | IOCA3 | IOCA2 | IOCA1 | IOCA0 | 116 |
| IOCB | IOCB7 | IOCB6 | IOCB5 | IOCB4 | — | — | IOCB1 | IOCB0 | 116 |
| PIE1 | TXIE | RCIE | BCLIE | SSPIE | CC2IE | CC1IE | TMR2IE | TMR1IE | 94 |
| PIE2 | CDSIE | ADIE | — | OTIE | OVIE | DRUVIE | OVLOIE | UVLOIE | 95 |
| PIR1 | TXIF | RCIF | BCLIF | SSPIF | CC2IF | CC1IF | TMR2IF | TMR1IF | 96 |
| PIR2 | CDSIF | ADIF | — | OTIF | OVIF | DRUVIF | OVLOIF | UVLOIF | 97 |
| STATUS | IRP | RP1 | RP0 | $\overline{\text{TO}}$ | $\overline{\text{PD}}$ | Z | DC | C | 71 |

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

15.0 WATCHDOG TIMER (WDT)

The Watchdog Timer is a free running timer. The WDT is enabled by setting the WDTE bit in the CONFIG register (default setting).

During normal operation, a WDT time-out generates a device reset. If the device is in Sleep mode, a WDT time-out causes the device to wake up and continue with normal operation.

The WDT can be permanently disabled by clearing the WDTE bit in the CONFIG register. Refer to [Section 11.1 “Configuration Word”](#) for more information.

15.1 Watchdog Timer (WDT) Operation

During normal operation, a WDT time-out generates a device reset. If the device is in Sleep mode, a WDT time-out causes the device to wake-up and continue with normal operation; this is known as a WDT wake-up. The WDT can be permanently disabled by clearing the WDTE configuration bit.

The postscaler assignment is fully under software control and can be changed during program execution.

15.2 WDT Period

The WDT has a nominal time-out period of 18 ms (with no prescaler). The time-out periods vary with temperature, V_{DD} and process variations from part to part (refer to [Table 12-1](#)). If longer time-out periods are desired, a prescaler with a division ratio of up to 1:128 can be assigned to the WDT under software control by writing to the OPTION_REG register. Thus, time-out periods up to 2.3 seconds can be realized.

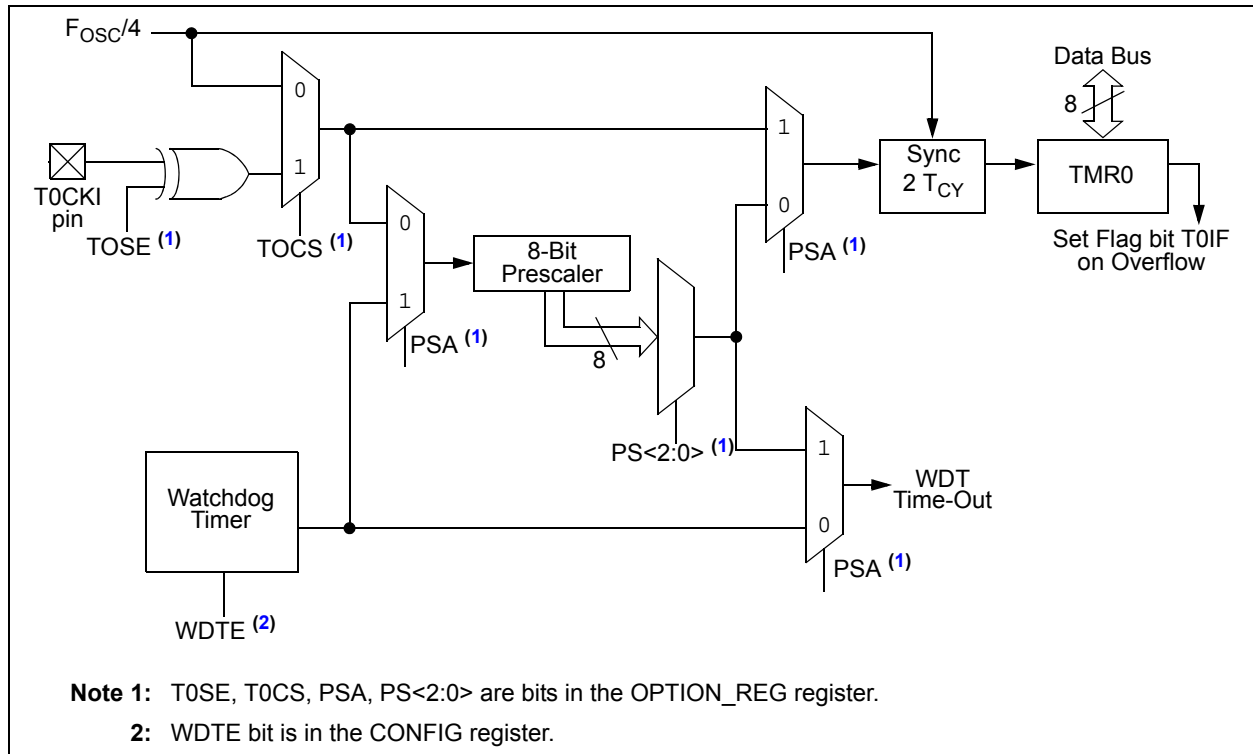
The CLRWDT and SLEEP instructions clear the WDT and the prescaler, if assigned to the WDT, and prevent it from timing out and generating a device reset.

The \overline{TO} bit in the STATUS register will be cleared upon a Watchdog Timer time-out.

15.3 WDT Programming Considerations

Under worst-case conditions (i.e., V_{DD} = Minimum, Temperature = Maximum, Maximum WDT prescaler), it may take several seconds before a WDT time-out occurs.

FIGURE 15-1: WATCHDOG TIMER WITH SHARED PRESCALE BLOCK DIAGRAM



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TABLE 15-1: WDT STATUS

| Conditions | WDT |
|----------------|---------|
| WDTE = 0 | Cleared |
| CLRWDT Command | |
| Exit Sleep | |

TABLE 15-2: 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 |
|------------|--------------------------|--------|-------|-------|-------|-------|-------|-------|------------------|
| OPTION_REG | $\overline{\text{RAPU}}$ | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 | 78 |

Legend: Shaded cells are not used by the Watchdog Timer.

Note 1: Refer to [Register 11-1](#) for operation of all the bits in the CONFIG register.

TABLE 15-3: SUMMARY OF CONFIGURATION WORD ASSOCIATED 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 |
|--------|------|---------|------------------------|----------|---------------------------|----------|----------|---------|---------|------------------|
| CONFIG | 13:8 | — | — | DBGEN | — | WRT1 | WRT0 | — | BOREN | 81 |
| | 7:0 | — | $\overline{\text{CP}}$ | MCLRE | $\overline{\text{PWRTE}}$ | WDTE | — | — | — | |

Legend: — = unimplemented location, read as '1'. Shaded cells are not used by Watchdog Timer.

16.0 OSCILLATOR MODES

The MCP19124/5 have one oscillator configuration, which is an 8 MHz internal oscillator.

16.1 Internal Oscillator (INTOSC)

The Internal Oscillator module provides a system clock source of 8 MHz. The frequency of the internal oscillator can be trimmed with a calibration value in the OSCTUNE register.

16.2 Oscillator Calibration

The 8 MHz internal oscillator is factory-calibrated. The factory calibration values reside in the read-only CALWD6 register. These values must be read from the CALWD6 register and stored in the OSCCAL register.

Refer to [Section 20.0 “Flash Program Memory Control”](#) for the procedure on reading the program memory.

Note: The FCAL<6:0> bits in the CALWD6 register must be written into the OSCCAL register to calibrate the internal oscillator.

16.3 Frequency Tuning in User Mode

In addition to the factory calibration, the base frequency can be tuned in the user's application. This frequency tuning capability allows the user to deviate from the factory-calibrated frequency. The user can tune the frequency by writing to the OSCTUNE register (refer to [Register 16-1](#)).

REGISTER 16-1: OSCTUNE: OSCILLATOR TUNING REGISTER

| | | | | | | | |
|-------|-----|-----|-------|-------|-------|-------|-------|
| U-0 | U-0 | U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| — | — | — | TUN4 | TUN3 | TUN2 | TUN1 | TUN0 |
| bit 7 | | | | | | | bit 0 |

Legend:

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

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

bit 4-0 **TUN<4:0>:** Frequency Tuning bits

01111 = Maximum frequency

01110 = Maximum frequency

•

•

•

00001 =

00000 = Center frequency. Oscillator Module is running at the calibrated frequency.

11111 =

•

•

•

10000 = Minimum frequency

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16.3.1 OSCILLATOR DELAY UPON POWER-UP, WAKE-UP AND BASE FREQUENCY CHANGE

In applications where the OSCTUNE register is used to shift the frequency of the internal oscillator, the application should not expect the frequency of the internal oscillator to stabilize immediately. In this case, the frequency may shift gradually toward the new value. The time for this frequency shift is less than eight cycles of the base frequency.

On power-up, the device is held in reset by the power-up time if the power-up timer is enabled.

Following a wake-up from Sleep mode or POR, an internal delay of ~10 μ s is invoked to allow the memory bias to stabilize before program execution can begin.

TABLE 16-1: 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 |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|------------------|
| OSCTUNE | — | — | — | TUN4 | TUN3 | TUN2 | TUN1 | TUN0 | 105 |

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

TABLE 16-2: 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 |
|--------|------|---------|---------|----------|----------|----------|----------|---------|---------|------------------|
| CALWD6 | 13:8 | — | — | — | — | — | — | — | — | 62 |
| | 7:0 | — | FCAL6 | FCAL5 | FCAL4 | FCAL3 | FCAL2 | FCAL1 | FCAL0 | |

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

17.0 I/O PORTS

In general, when a peripheral is enabled, that pin may not be used as a general-purpose I/O pin.

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

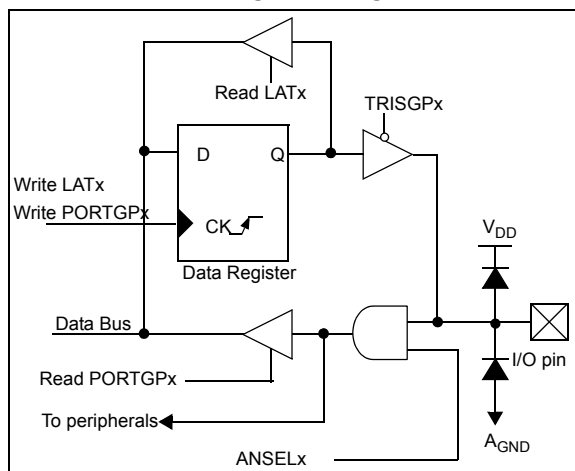
- TRISGPx registers (data direction register)
- PORTGPx registers (read the levels on the pins of the device)

Some ports may have one or more of the following additional registers. These registers are:

- ANSELx (analog select)
- WPUGPx (weak pull-up)

Ports with analog functions also have an ANSELx register, which can disable the digital input and save power. A simplified model of a generic I/O port, without the interfaces to other peripherals, is shown in [Figure 17-1](#).

FIGURE 17-1: GENERIC I/O PORTGPX OPERATION



EXAMPLE 17-1: INITIALIZING PORTGPA

```

; This code example illustrates
; initializing the PORTGPA register. The
; other ports are initialized in the same
; manner.

BANKSEL PORTGPA;
CLRF   PORTGPA;Init PORTA
BANKSEL ANSELA;
CLRF   ANSELA;digital I/O
BANKSEL TRISGPA;
MOVLW  B'00011111';Set GPA<3:0> as
        ;inputs
MOVWF  TRISGPA;and set GPA<7:5> as
        ;outputs
    
```

17.1 PORTGPA and TRISGPA Registers

PORTGPA is an 8-bit wide, bidirectional port consisting of five CMOS I/Os, one open-drain I/O and one open-drain input-only pin (GPA4 is not available). The corresponding data direction register is TRISGPA. Setting a TRISGPA bit to '1' will make the corresponding PORTGPA pin an input (i.e., disable the output driver). Clearing a TRISGPA bit set to '0' will make the corresponding PORTGPA pin an output (i.e., enables output driver). The exception is GPA5, which is input only and its TRISGPA bit will always read as '1'. [Example 17-1](#) shows how to initialize an I/O port.

Reading the PORTGPA register reads the status of the pins, whereas writing to it will write to the PORT latch. All write operations are read-modify-write operations.

The TRISGPA register controls the PORTGPA pin output drivers, even when they are being used as analog inputs. The user must ensure the bits in the TRISGPA register are maintained set when using them as analog inputs. I/O pins configured as analog input always read '0'. If the pin is configured for a digital output (either port or alternate function), the TRISGPA bit must be cleared in order for the pin to drive the signal, and a read will reflect the state of the pin.

17.1.1 INTERRUPT-ON-CHANGE

Each PORTGPA pin is individually configurable as an interrupt-on-change pin. Control bits IOCB<7:4> and IOCB<2:0> enable or disable the interrupt function for each pin. The interrupt-on-change feature is disabled on a Power-On Reset. Reference [Section 18.0 "Interrupt-On-Change"](#) for more information.

17.1.2 WEAK PULL-UPS

PORTGPA <3:0> and PORTGPA5 have an internal weak pull-up. PORTGPA<7:6> do not have internal weak pull-ups. Individual control bits can enable or disable the internal weak pull-ups (refer to [Register 17-3](#)). The weak pull-up is automatically turned off when the port pin is configured as an output, an alternative function or on a Power-On Reset setting the R_{APU} bit in the OPTION_REG register. The weak pull-up on GPA5 is enabled when configured as MCLR pin by setting bit 5 in the CONFIG register, and disabled when GPA5 is an I/O. There is no software control of the MCLR pull-up.

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17.1.3 ANSELA REGISTER

The ANSELA register 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 TRISGPA cleared and ANSELx 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 the user's software.

17.1.4 PORTGPA FUNCTIONS AND OUTPUT PRIORITIES

Each PORTGPA pin is multiplexed with other functions. The pins, their combined functions and their output priorities are shown in [Table 17-1](#). For additional information, refer to the appropriate section in this data sheet.

Pin GPA7 in the PORTGPA register is a true open-drain pin with no connection back to V_{DD} .

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

Analog input functions, such as ADC, are not shown in the priority lists. These inputs are active when the I/O pin is set for Analog mode using the ANSELA register. Digital output functions may control the pin when it is in Analog mode with the priority shown in [Table 17-1](#).

TABLE 17-1: PORTGPA OUTPUT PRIORITY

| Pin Name | Function Priority ⁽¹⁾ |
|----------|------------------------------------|
| GPA0 | GPA0 |
| | TEST_OUT |
| GPA1 | GPA1 |
| | CLKPIN |
| GPA2 | GPA2 |
| | T0CKI |
| | INT |
| GPA3 | GPA3 |
| GPA5 | GPA5 (open-drain, input only) |
| | MCLR |
| | TEST_EN |
| GPA6 | GPA6 |
| | CCD |
| | ICSPDAT |
| GPA7 | GPA7 (open-drain output, ST input) |
| | SCL |

Note 1: Output function priority listed from lowest to highest.

REGISTER 17-1: PORTGPA: PORTGPA REGISTER

| R/W-x | R/W-x | R-x | U-0 | R/W-x | R/W-x | R/W-x | R/W-x |
|-------|-------|------|-----|-------|-------|-------|-------|
| GPA7 | GPA6 | GPA5 | — | GPA3 | GPA2 | GPA1 | GPA0 |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

- bit 7 **GPA7:** General-Purpose Open-Drain I/O pin
 1 = Port pin is > V_{IH}
 0 = Port pin is < V_{IL}
- bit 6 **GPA6:** General-Purpose I/O pin
 1 = Port pin is > V_{IH}
 0 = Port pin is < V_{IL}
- bit 5 **GPA5/MCLR/TEST_EN5:** General-Purpose Open-Drain input pin
- bit 4 **Unimplemented:** Read as '0'
- bit 3-0 **GPA<3:0>:** General-Purpose I/O pin
 1 = Port pin is > V_{IH}
 0 = Port pin is < V_{IL}

REGISTER 17-2: TRISGPA: PORTGPA TRI-STATE REGISTER

| R/W-1 | R/W-1 | R-1 | U-0 | R/W-1 | R/W-1 | R/W-1 | R/W-1 |
|--------|--------|--------|-----|--------|--------|--------|--------|
| TRISA7 | TRISA6 | TRISA5 | — | 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

- bit 7-6 **TRISA<7:6>:** PORTGPA Tri-State Control bits
 1 = PORTGPA pin configured as an input (tri-stated)
 0 = PORTGPA pin configured as an output
- bit 5 **TRISA5:** GPA5 Port Tri-State Control bit
 This bit is always '1' as GPA5 is an input only
- bit 4 **Unimplemented:** Read as '0'
- bit 3-0 **TRISA<3:0>:** PORTGPA Tri-State Control bits
 1 = PORTGPA pin configured as an input (tri-stated)
 0 = PORTGPA pin configured as an output

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REGISTER 17-3: WPUGPA: WEAK PULL-UP PORTGPA REGISTER (Note 1)

| U-0 | U-0 | R/W-1 | U-0 | R/W-1 | R/W-1 | R/W-1 | R/W-1 |
|-------|-----|----------------------|-----|-------|-------|-------|-------|
| — | — | WPUA5 ⁽²⁾ | — | WPUA3 | WPUA2 | WPUA1 | WPUA0 |
| 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 = Value at POR
'1' = Bit is set '0' = Bit is cleared

- bit 7-6 **Unimplemented:** Read as '0'
bit 5 **WPUA5:** Weak Pull-Up Register bit
 1 = Pull-up enabled
 0 = Pull-up disabled
bit 4 **Unimplemented:** Read as '0'
bit 3-0 **WPUA<3:0>:** Weak Pull-Up Register bits
 1 = Pull-up enabled
 0 = Pull-up disabled

Note 1: The weak pull-up device is enabled only when the global $\overline{\text{RAPU}}$ bit is enabled, the pin is in input mode (TRISGPA = 1) and the individual WPUA bit is enabled (WPUA = 1), and the pin is not configured as an analog input.

2: GPA5 weak pull-up is also enabled when the pin is configured as $\overline{\text{MCLR}}$ in the CONFIG register.

REGISTER 17-4: ANSELA: ANALOG SELECT GPA REGISTER

| U-0 | U-0 | U-0 | U-0 | R/W-1 | R/W-1 | R/W-1 | R/W-1 |
|-------|-----|-----|-----|-------|-------|-------|-------|
| — | — | — | — | 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 = Value at POR
'1' = Bit is set '0' = Bit is cleared

- bit 7-4 **Unimplemented:** Read as '0'
bit 3-0 **ANSA<3:0>:** Analog Select GPA Register bits
 1 = Analog input. Pin is assigned as analog input ⁽¹⁾.
 0 = Digital I/O. Pin is assigned to port or special function.

Note 1: Setting a pin to an analog input automatically disables the digital input circuitry, weak pull-ups and interrupt-on-change if available. The corresponding TRISA bit must be set to Input mode in order to allow external control of the voltage on the pin.

TABLE 17-2: SUMMARY OF REGISTERS ASSOCIATED WITH PORTGPA

| Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Register on Page |
|------------|--------|--------|--------|-------|--------|--------|--------|--------|------------------|
| ANSELA | — | — | — | — | ANSA3 | ANSA2 | ANSA1 | ANSA0 | 110 |
| OPTION_REG | RAPU | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 | 78 |
| PORTGPA | GPA7 | GPA6 | GPA5 | — | GPA3 | GPA2 | GPA1 | GPA0 | 109 |
| TRISGPA | TRISA7 | TRISA6 | TRISA5 | — | TRISA3 | TRISA2 | TRISA1 | TRISA0 | 109 |
| WPUGPA | — | — | WPUA5 | — | WPUA3 | WPUA2 | WPUA1 | WPUA0 | 110 |

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

17.2 PORTGPB and TRISGPB Registers

Due to special function pin requirements, a limited number of the PORTGPB I/Os are utilized. On the 24-pin 4x4 mm QFN MCP19124, GPB0 and GPB1 are implemented. GPB0 is an open-drain general-purpose I/O and SDA pin. GPB1 is a general-purpose I/O, analog input and V_{REF2} DAC output. The 28-pin 5x5 mm QFN MCP19124 has four additional general-purpose PORTGPB I/O pins. The corresponding data direction register is TRISGPB. Setting a TRISGPB bit to '1' will make the corresponding PORTGPB pin an input (i.e., disable the output driver). Clearing a TRISGPB bit to '0' will make the corresponding PORTGPB pin an output (i.e., enable the output driver). [Example 17-1](#) shows how to initialize an I/O port.

Some pins for PORTGPB are multiplexed with an alternate function for the peripheral or a clock function. In general, when a peripheral or clock function is enabled, that pin may not be used as a general-purpose I/O pin.

Reading the PORTGPB register reads the status of the pins, whereas writing to it will write to the PORT latch. All write operations are read-modify-write operations.

The TRISGPB register controls the PORTGPB pin output drivers, even when they are being used as analog inputs. The user should ensure the bits in the TRISGPB register are maintained set when using them as analog inputs. I/O pins configured as analog input always read '0'. If the pin is configured for a digital output (either port or alternate function), the TRISGPB bit must be cleared in order for the pin to drive the signal and a read will reflect the state of the pin.

17.2.1 INTERRUPT-ON-CHANGE

Each PORTGPB pin is individually configurable as an interrupt-on-change pin. Control bits IOCB<7:4> and IOCB<2:0> enable or disable the interrupt function for each pin. The interrupt-on-change feature is disabled on a Power-On Reset. Reference [Section 18.0 "Interrupt-On-Change"](#) for more information.

17.2.2 WEAK PULL-UPS

Each of the PORTGPB pins has an individually configurable internal weak pull-up. Control bits WPUB<7:4> and WPUB1 enable or disable each pull-up (refer to [Register 17-7](#)). 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 RAPU bit in the OPTION_REG register.

17.2.3 ANSELB REGISTER

The ANSELB register 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 the digital output functions. A pin with TRISGPB 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 TRISGPB register controls the PORTGPB pin output drivers, even when they are being used as analog inputs. The user should ensure the bits in the TRISGPB register are maintained set when using them as analog inputs. I/O pins configured as analog input always read '0'.

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

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17.2.4 PORTGPB FUNCTIONS AND OUTPUT PRIORITIES

Each PORTGPB pin is multiplexed with other functions. The pins, their combined functions and their output priorities are shown in Table 17-3. For additional information, refer to the appropriate section in this data sheet.

GPB0 pin in the PORTGPB register is a true open-drain pin with no connection back to V_{DD} .

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

Analog input functions, such as ADC, and some digital input functions are not included in the list below. These inputs are active when the I/O pin is set for Analog mode using the ANSELB register. Digital output functions may control the pin when it is in Analog mode, with the priority shown in Table 17-3.

TABLE 17-3: PORTGPB OUTPUT PRIORITY

| Pin Name | Function Priority ⁽¹⁾ |
|----------|----------------------------------|
| GPB0 | GPB0 (open-drain input/output) |
| | SDA |
| GPB1 | GPB1 |
| | V_{REF2} |
| GPB4 | GPB4 (MCP19125 only) |
| | ICSPDAT |
| GPB5 | GPB5 (MCP19125 only) |
| GPB6 | GPB6 (MCP19125 only) |
| GPB7 | GPB7 (MCP19125 only) |
| | CCD2 |

Note 1: Output function priority listed from lowest to highest.

REGISTER 17-5: PORTGPB: PORTGPB REGISTER

| | | | | | | | |
|---------------------|---------------------|---------------------|---------------------|-----|-----|-------|-------|
| R/W-x | R/W-x | R/W-x | R/W-x | U-0 | U-0 | R/W-x | R/W-x |
| GPB7 ⁽¹⁾ | GPB6 ⁽¹⁾ | GPB5 ⁽¹⁾ | GPB4 ⁽¹⁾ | — | — | GPB1 | GPB0 |
| 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 = Value at POR
'1' = Bit is set '0' = Bit is cleared

bit 7-4 **GPB<7:4>**: General-Purpose I/O Pin bits

1 = Port pin is $> V_{IH}$
0 = Port pin is $< V_{IL}$

bit 3-2 **Unimplemented**: Read as '0'

bit 1-0 **GPB<1:0>**: General-Purpose I/O Pin bits

1 = Port pin is $> V_{IH}$
0 = Port pin is $< V_{IL}$

Note 1: MCP19125 only.

REGISTER 17-6: TRISGPB: PORTGPB TRI-STATE REGISTER

| R/W-1 | R/W-1 | R/W-1 | R/W-1 | U-0 | U-0 | R/W-1 | R/W-1 |
|-----------------------|-----------------------|-----------------------|-----------------------|-----|-----|--------|--------|
| TRISB7 ⁽¹⁾ | TRISB6 ⁽¹⁾ | TRISB5 ⁽¹⁾ | TRISB4 ⁽¹⁾ | — | — | 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

- bit 7-4 **TRISB<7:4>**: PORTGPB Tri-State Control bits
 1 = PORTGPB pin configured as an input (tri-stated)
 0 = PORTGPB pin configured as an output
- bit 3-2 **Unimplemented**: Read as '0'
- bit 1-0 **TRISB<1:0>**: PORTGPB Tri-State Control bits
 1 = PORTGPB pin configured as an input (tri-stated)
 0 = PORTGPB pin configured as an output

Note 1: MCP19125 only.

REGISTER 17-7: WPUGPB: WEAK PULL-UP PORTGPB REGISTER (Note 1)

| R/W-1 | R/W-1 | R/W-1 | R/W-1 | U-0 | U-0 | R/W-1 | U-0 |
|----------------------|----------------------|----------------------|----------------------|-----|-----|-------|-----|
| WPUB7 ⁽²⁾ | WPUB6 ⁽²⁾ | WPUB5 ⁽²⁾ | WPUB4 ⁽²⁾ | — | — | WPUB1 | — |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

- bit 7-4 **WPUB<7:4>**: Weak Pull-up Register bits
 1 = Pull-up enabled
 0 = Pull-up disabled
- bit 3-2 **Unimplemented**: Read as '0'
- bit 1 **WPUB1**: Weak Pull-up Register bit
 1 = Pull-up enabled
 0 = Pull-up disabled
- bit 0 **Unimplemented**: Read as '0'

Note 1: The weak pull-up device is enabled only when the global $\overline{\text{RAPU}}$ bit is enabled, the pin is in input mode (TRISGPA = 1) and the individual WPUB bit is enabled (WPUB = 1), and the pin is not configured as an analog input.

2: MCP19125 only.

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REGISTER 17-8: ANSELB: ANALOG SELECT GPB REGISTER

| | | | | | | | |
|-------|----------------------|----------------------|----------------------|-----|-----|-------|-------|
| U-0 | R/W-1 | R/W-1 | R/W-1 | U-0 | U-0 | R/W-1 | U-0 |
| — | ANSB6 ⁽¹⁾ | ANSB5 ⁽¹⁾ | ANSB4 ⁽¹⁾ | — | — | 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 = Value at POR
'1' = Bit is set '0' = Bit is cleared

- bit 7 **Unimplemented:** Read as '0'
- bit 6-4 **ANSB<6:4>:** Analog Select GPA Register bits
1 = Analog input. Pin is assigned as analog input ⁽²⁾.
0 = Digital I/O. Pin is assigned to port or special function.
- bit 3-2 **Unimplemented:** Read as '0'
- bit 1 **ANSB<1>:** Analog Select GPA Register bit
1 = Analog input. Pin is assigned as analog input ⁽²⁾.
0 = Digital I/O. Pin is assigned to port or special function.
- bit 0 **Unimplemented:** Read as '0'

- Note 1:** MCP19125 only.
Note 2: Setting a pin to an analog input automatically disables the digital input circuitry, weak pull-ups and interrupt-on-change if available. The corresponding TRIS bit must be set to Input mode in order to allow external control of the voltage on the pin.

TABLE 17-4: SUMMARY OF REGISTERS ASSOCIATED WITH PORTGPB

| Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Register on Page |
|------------|-----------------------|-----------------------|-----------------------|-----------------------|-------|-------|--------|--------|------------------|
| ANSELB | — | ANSB6 ⁽¹⁾ | ANSB5 ⁽¹⁾ | ANSB4 ⁽¹⁾ | — | — | ANSB1 | — | 114 |
| OPTION_REG | RAPU | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 | 78 |
| PORTGPB | GPB7 ⁽¹⁾ | GPB6 ⁽¹⁾ | GPB5 ⁽¹⁾ | GPB4 ⁽¹⁾ | — | — | GPB1 | GPB0 | 112 |
| TRISGPB | TRISB7 ⁽¹⁾ | TRISB6 ⁽¹⁾ | TRISB5 ⁽¹⁾ | TRISB4 ⁽¹⁾ | — | — | TRISB1 | TRISB0 | 113 |
| WPUGPB | WPUB7 ⁽¹⁾ | WPUB6 ⁽¹⁾ | WPUB5 ⁽¹⁾ | WPUB4 ⁽¹⁾ | — | — | WPUB1 | — | 113 |

Legend: — = unimplemented locations, read as '0'. Shaded cells are not used by the PORTGPB register.

Note 1: MCP19125 only.

18.0 INTERRUPT-ON-CHANGE

Each PORTGPA and PORTGPB pin is individually configurable as an interrupt-on-change pin. Control bits IOCA and IOCB enable or disable the interrupt function for each pin. Refer to [Registers 18-1](#) and [18-2](#). The interrupt-on-change is disabled on a Power-On Reset.

The interrupt-on-change on GPA5 is disabled when configured as MCLR pin in the CONFIG register.

For enabled interrupt-on-change pins, the values are compared with the old value latched on the last read of PORTGPA or PORTGPB. The mismatched outputs of the last read of all the PORTGPA and PORTGPB pins are OR'd together to set the Interrupt-on-Change Interrupt Flag (IOCF) bit in the INTCON register.

18.1 Enabling the Module

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

18.2 Individual Pin Configuration

To enable a pin to detect an interrupt-on-change, the associated IOCAx or IOCBx bit in the IOCA or IOCB registers is set.

18.3 Clearing Interrupt Flags

The user, in the Interrupt Service Routine, clears the interrupt by:

- a) Any read of PORTGPA or PORTGPB AND Clear flag bit IOCF. This will end the mismatch condition.
OR
- b) Any write of PORTGPA or PORTGPB AND Clear flag bit IOCF will end the mismatch condition.

A mismatch condition will continue to set flag bit IOCF. Reading PORTGPA or PORTGPB will end the mismatch condition and allow flag bit IOCF to be cleared. The latch holding the last read value is not affected by a MCLR Reset. After this Reset, the IOCF flag will continue to be set if a mismatch is present.

| |
|---|
| <p>Note: If a change on the I/O pin should occur when any PORTGPA or PORTGPB operation is being executed, the IOCF interrupt flag may not get set.</p> |
|---|

18.4 Operation in Sleep

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

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18.5 Interrupt-On-Change Registers

REGISTER 18-1: IOCA: INTERRUPT-ON-CHANGE PORTGPA REGISTER

| R/W-0 | R/W-0 | R/W-0 | U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
|-------|-------|-------|-----|-------|-------|-------|-------|
| IOCA7 | IOCA6 | IOCA5 | — | IOCA3 | IOCA2 | IOCA1 | IOCA0 |
| 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 = Value at POR
'1' = Bit is set '0' = Bit is cleared

bit 7-6 **IOCA<7:6>**: Interrupt-on-Change PORTGPA register bits

1 = Interrupt-on-change enabled on the pin.
0 = Interrupt-on-change disabled on the pin.

bit 5 **IOCA5**: Interrupt-on-Change PORTGPA register bit ⁽¹⁾

1 = Interrupt-on-change enabled on the pin.
0 = Interrupt-on-change disabled on the pin.

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

bit 3-0 **IOCA<3:0>**: Interrupt-on-Change PORTGPA register bits

1 = Interrupt-on-change enabled on the pin.
0 = Interrupt-on-change disabled on the pin.

Note 1: The Interrupt-on-Change on GPA5 is disabled if GPA5 is configured as $\overline{\text{MCLR}}$.

REGISTER 18-2: IOCB: INTERRUPT-ON-CHANGE PORTGPB REGISTER

| R/W-0 | R/W-0 | R/W-0 | R/W-0 | U-0 | U-0 | R/W-0 | R/W-0 |
|----------------------|----------------------|----------------------|----------------------|-----|-----|-------|-------|
| IOCB7 ⁽¹⁾ | IOCB6 ⁽¹⁾ | IOCB5 ⁽¹⁾ | IOCB4 ⁽¹⁾ | — | — | IOCB1 | IOCB0 |
| 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 = Value at POR
'1' = Bit is set '0' = Bit is cleared

bit 7-4 **IOCB<7:4>**: Interrupt-on-Change PORTGPB register bits

1 = Interrupt-on-change enabled on the pin.
0 = Interrupt-on-change disabled on the pin.

bit 3-2 **Unimplemented**: Read as '0'

bit 1-0 **IOCB<1:0>**: Interrupt-on-Change PORTGPB register bits

1 = Interrupt-on-change enabled on the pin.
0 = Interrupt-on-change disabled on the pin.

Note 1: MCP19125 only.

TABLE 18-1: 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 |
|---------|-----------------------|-----------------------|-----------------------|-----------------------|--------|--------|--------|--------|---------------------|
| ANSELA | — | — | — | — | ANSA3 | ANSA2 | ANSA1 | ANSA0 | 110 |
| ANSELB | — | ANSB6 ⁽¹⁾ | ANSB5 ⁽¹⁾ | ANSB4 ⁽¹⁾ | — | — | ANSB1 | — | 114 |
| INTCON | GIE | PEIE | T0IE | INTE | IOCE | T0IF | INTF | IOCF | 93 |
| IOCA | IOCA7 | IOCA6 | IOCA5 | — | IOCA3 | IOCA2 | IOCA1 | IOCA0 | 116 |
| IOCB | IOCB7 ⁽¹⁾ | IOCB6 ⁽¹⁾ | IOCB5 ⁽¹⁾ | IOCB4 ⁽¹⁾ | — | — | IOCB1 | IOCB0 | 116 |
| TRISGPA | TRISA7 | TRISA6 | TRISA5 | — | TRISA3 | TRISA2 | TRISA1 | TRISA0 | 109 |
| TRISGPB | TRISB7 ⁽¹⁾ | TRISB6 ⁽¹⁾ | TRISB5 ⁽¹⁾ | TRISB4 ⁽¹⁾ | — | — | TRISB1 | TRISB0 | 113 |

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

Note 1: MCP19125 only.

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NOTES:

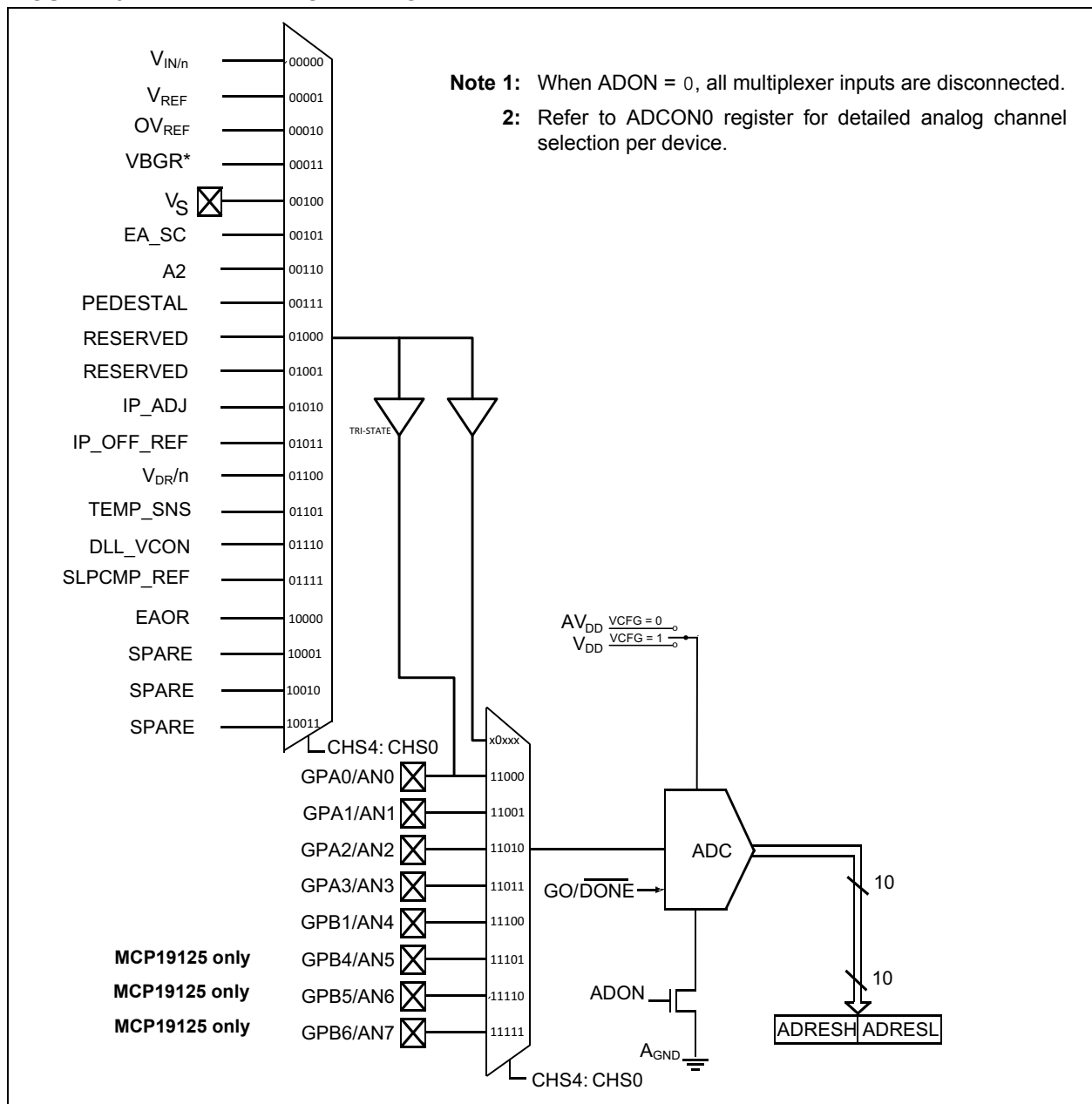
19.0 ANALOG-TO-DIGITAL CONVERTER (ADC) MODULE

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 that 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 right justified conversion result into the ADC result registers (ADRESH:ADRESL register pair). [Figure 19-1](#) shows the block diagram of the ADC.

The internal band gap supplies the voltage reference to the ADC.

Note: Once V_{IN} is greater than $AV_{DD} + V_{DROPOUT}$, AV_{DD} is in regulation, allowing A/D readings to be accurate. Once V_{IN} is greater than $V_{DD} + V_{DROPOUT}$, V_{DD} is in regulation. Setting the ADC reference to V_{DD} allows accurate ratiometric measurements.

FIGURE 19-1: ADC BLOCK DIAGRAM



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19.1 ADC Configuration

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

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

19.1.1 PORT CONFIGURATION

The ADC is used to convert analog signals into a corresponding digital representation. When converting analog signals, the I/O pin should be configured for analog by setting the associated TRIS and ANSEL bits. Refer to [Section 17.0 “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.

19.1.2 CHANNEL SELECTION

There are up to 21 channel selections available for the MCP19124 and 24 channels for the MCP19125:

- AN<4:0> pins
- AN<7:5> pins (**MCP19125 only**)
- V_{IN} : 1/15.53 of the input voltage (V_{IN})
- V_{REF} : voltage reference for regulation set point
- OV_{REF} : reference for OV comparator
- V_{BGR} : band gap reference
- V_S : voltage proportional to V_{OUT}
- EA_SC: error amplifier output after slope compensation
- A2: secondary current sense amplifier output
- Pedestal
- Reserved
- Reserved
- IP_ADJ: I_P after pedestal and offset adjust
- IP_OFF_REF: I_P offset reference
- V_{DR} : $V_{DR} \times 0.229V/V$
- TEMP_SNS: analog voltage representing internal temperature (refer to [Equation 25-1](#))
- DLL_VCON: delay locked loop voltage reference
- SLPCMP_REF: slope compensation reference

The CHS<4:0> bits in 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 19.2 “ADC Operation”](#) for more information.

19.1.3 ADC CONVERSION CLOCK

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

- $F_{OSC}/8$
- $F_{OSC}/16$
- $F_{OSC}/32$
- $F_{OSC}/64$
- F_{RC} (clock derived from internal oscillator with a divisor of 16)

The time to complete one-bit conversion is defined as T_{AD} . One full 10-bit conversion requires 11 T_{AD} periods, as shown in [Figure 19-2](#).

For a correct conversion, the appropriate T_{AD} specification must be met. Refer to the A/D conversion requirements in [Section 4.0 “Electrical Characteristics”](#) for more information. [Table 19-1](#) gives examples of appropriate ADC clock selections.

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

TABLE 19-1: ADC CLOCK PERIOD (T_{AD}) VS. DEVICE OPERATING FREQUENCIES

| ADC Clock Period (T_{AD}) | | Device Frequency (F_{osc}) |
|-------------------------------|-----------|-----------------------------------|
| ADC Clock Source | ADCS<2:0> | 8 MHz |
| $F_{OSC}/8$ | 001 | 1.0 μs ⁽¹⁾ |
| $F_{OSC}/16$ | 101 | 2.0 μs |
| $F_{OSC}/32$ | 010 | 4.0 μs |
| $F_{OSC}/64$ | 110 | 8.0 μs ⁽²⁾ |
| F_{RC} | x11 | 2.0-6.0 μs ^(3, 4) |

Legend: Shaded cells are outside of recommended range.

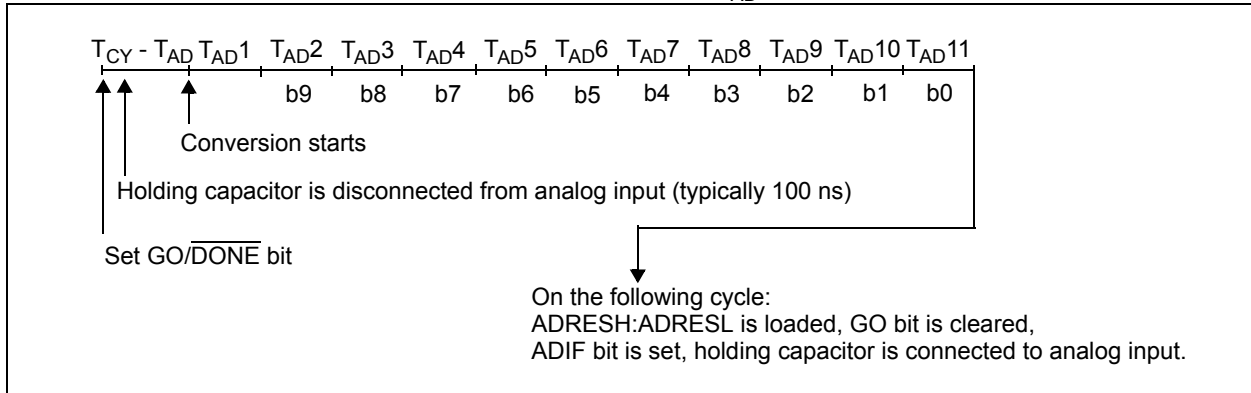
Note 1: These values violate the minimum required T_{AD} time.

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

3: The F_{RC} source has a typical T_{AD} time of 4 μs for $V_{DD} > 3.0V$.

4: The F_{RC} clock source is only recommended if the conversion will be performed during Sleep.

FIGURE 19-2: ANALOG-TO-DIGITAL CONVERSION T_{AD} CYCLES



19.1.4 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.

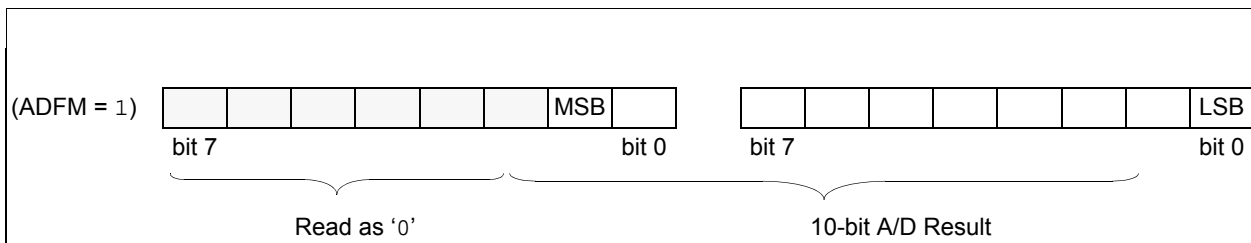
2: The ADC operates during Sleep only when the F_{RC} oscillator is selected.

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

19.1.5 RESULT FORMATTING

The 10-bit A/D conversion result is supplied in right justified format only.

FIGURE 19-3: 10-BIT A/D RESULT FORMAT



19.2 ADC Operation

19.2.1 STARTING A CONVERSION

To enable the ADC module, the ADON bit in the ADCON0 register must be set to a '1'. Setting the GO/DONE bit in 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 19.2.5 “A/D Conversion Procedure”](#).

19.2.2 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:ADRESL registers with new conversion result

19.2.3 TERMINATING A CONVERSION

If a conversion must be terminated before completion, the GO/DONE bit can be cleared in software. The ADRESH:ADRESL registers will not be updated with the partially complete analog-to-digital conversion sample. Instead, the ADRESH:ADRESL register pair will retain the value of the previous conversion. Additionally, two ADC clock cycles are required before another acquisition can be initiated. Following the delay, an input acquisition is automatically started on the selected channel.

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

19.2.4 ADC OPERATION DURING SLEEP

The ADC is not operational during Sleep mode. The AV_{DD} 4V reference has been removed to minimize Sleep current.

19.2.5 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 TRISGPx registers)
 - Configure pin as analog (refer to the ANSELx registers)
2. Configure the ADC module:
 - Select ADC conversion clock
 - 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 the device up from Sleep and resume in-line code execution.

2: Refer to [Section 19.4 “A/D Acquisition Requirements”](#).

EXAMPLE 19-1: A/D CONVERSION

```
;This code block configures the ADC
;for polling, Frc clock and AN0 input.
;
;Conversion start & polling for completion ;
are included.
;
BANKSELADCON1;
MOVLWB'01110000';Frc clock
MOVWFADCON1;
BANKSELTRISGPA;
BSF TRISGPA,0;Set GPA0 to input
BANKSELANSELA;
BSF ANSELA,0;Set GPA0 to analog
BANKSELADCON0;
MOVLWB'01100001';Select channel AN0
MOVWFADCON0;Turn ADC On
CALLSampleTime;Acquisiton delay
BSF ADCON0,1;Start conversion
BTFSCADCON0,1;Is conversion done?
GOTO$-1 ;No, test again
BANKSELADRESH;
MOVFADRESH,W;Read upper 2 bits
MOVWFRESULTHI;store in GPR space
BANKSELADRESL;
MOVFADRESL,W;Read lower 8 bits
MOVWFRESULTLO;Store in GPR space
```

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19.3 ADC Register Definitions

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

REGISTER 19-1: ADCON0: A/D CONTROL REGISTER 0

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|---------|-------|
| U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| — | CHS4 | CHS3 | CHS2 | CHS1 | CHS0 | 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 = Value at POR |
| '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 = $V_{IN/n}$ analog voltage measurement ($V_{IN/n} = V_{IN}/15.5328$)
 00001 = V_{REF} (DAC reference voltage setting current regulation level)
 00010 = OV_{REF} (reference for overvoltage comparator)
 00011 = VBGR (band gap reference)
 00100 = V_S (Voltage proportional to V_{OUT})
 00101 = EA_SC (Error amp after Slope Compensation output)
 00110 = A2 (Secondary Current Sense Amplifier output)
 00111 = Pedestal (Pedestal Voltage)
 01000 = Reserved
 01001 = Reserved
 01010 = IP_ADJ (IP after Pedestal and Offset Adjust (at PWM Comparator))
 01011 = IP_OFF_REF (IP Offset Reference)
 01100 = V_{DR}/n (V_{DR}/n analog driver voltage measurement = $0.229V/V \times V_{DR}$)
 01101 = TEMP_SNS (analog voltage representing internal temperature)
 01110 = DLL_VCON (Delay Locked-Loop Voltage Reference – Control voltage for dead time)
 01111 = SLPCMP_REF (Slope compensation reference)
 10000 = EAOR (OR'd output node from the two error amplifiers EA1 & EA2)
 10001 = Unimplemented
 10010 = Unimplemented
 10011 = Unimplemented
 10100 = Unimplemented
 10101 = Unimplemented
 10110 = Unimplemented
 10111 = Unimplemented
 11000 = GPA0/AN0 (i.e. ADDR1)
 11001 = GPA1/AN1 (i.e. ADDR0)
 11010 = GPA2/AN2 (i.e. Temperature Sensor Input)
 11011 = GPA3/AN3 (i.e. BIN)
 11100 = GPB1/AN4
 11101 = GPB4/AN5 (**MCP19125** only)
 11110 = GPB5/AN6 (**MCP19125** only)
 11111 = GPB6/AN7 (**MCP19125** only)

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

REGISTER 19-1: ADCON0: A/D CONTROL REGISTER 0 (CONTINUED)

bit 0 **ADON:** ADC Enable bit
 1 = ADC is enabled
 0 = ADC is disabled and consumes no operating current

REGISTER 19-2: ADCON1: A/D CONTROL REGISTER 1

| | | | | | | | |
|-------|-------|-------|-------|-----|-----|-----|-------|
| U-0 | R/W-0 | R/W-0 | R/W-0 | U-0 | U-0 | U-0 | R/W-0 |
| — | ADCS2 | ADCS1 | ADCS0 | — | — | — | VCFG |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

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

bit 6-4 **ADCS<2:0>:** A/D Conversion Clock Select bits
 000 = Reserved
 001 = $F_{OSC}/8$
 010 = $F_{OSC}/32$
 x11 = F_{RC} (clock derived from internal oscillator with a divisor of 16)
 100 = Reserved
 101 = $F_{OSC}/16$
 110 = $F_{OSC}/64$

bit 3-1 **Unimplemented:** Read as '0'

bit 0 **VCFG:** ADC Reference Voltage Configuration bit
 0 = AV_{DD}
 1 = V_{DD}

REGISTER 19-3: ADRESH: ADC RESULT REGISTER HIGH

| | | | | | | | |
|-------|-----|-----|-----|-----|-----|--------|--------|
| U-0 | U-0 | U-0 | U-0 | U-0 | U-0 | R-x | R-x |
| — | — | — | — | — | — | ADRES9 | ADRES8 |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

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

bit 1-0 **ADRES<9:8>:** Most Significant A/D Results bits

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REGISTER 19-4: ADRESL: ADC RESULT REGISTER LOW

| R-x | R-x | R-x | R-x | R-x | R-x | R-x | R-x |
|--------|--------|--------|--------|--------|--------|--------|--------|
| ADRES7 | ADRES6 | ADRES5 | ADRES4 | ADRES3 | ADRES2 | ADRES1 | ADRES0 |
| 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 = Value at POR

'1' = Bit is set

'0' = Bit is cleared

bit 7-0 **ADRES<7:0>**: Least Significant A/D results bits

19.4 A/D Acquisition Requirements

For the ADC to meet its specified accuracy, the charge holding capacitor (C_{HOLD}) must be allowed to fully charge to the input channel voltage level. The Analog Input model is shown in [Figure 19-4](#). The source impedance (R_S) and the internal sampling switch (R_{SS}) impedance directly affect the time required to charge the capacitor C_{HOLD} . The sampling switch (R_{SS}) impedance varies over the device voltage (V_{DD}), refer to [Figure 19-4](#). **The maximum recommended impedance for analog sources is 10 k Ω .**

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 19-1](#) 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 19-1: ACQUISITION TIME EXAMPLE

Assumptions: Temperature = +50°C and external impedance of 10 k Ω 5.0V V_{DD}

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

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

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

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

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

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

Solving for T_C :

$$\begin{aligned} T_C &= -C_{HOLD}(R_{IC} + R_{SS} + R_S) \ln(1/2047) \\ &= -10 \text{ pF}(1 \text{ k}\Omega + 7 \text{ k}\Omega + 10 \text{ k}\Omega) \ln(0.0004885) \\ &= 1.37 \mu\text{s} \end{aligned}$$

Therefore:

$$\begin{aligned} T_{ACQ} &= 2 \mu\text{s} + 1.37 \mu\text{s} + [(50^\circ\text{C} - 25^\circ\text{C})(0.05 \mu\text{s}/^\circ\text{C})] \\ &= 4.67 \mu\text{s} \end{aligned}$$

Note 1: The charge holding capacitor (C_{HOLD}) is not discharged after each conversion.

2: The maximum recommended impedance for analog sources is 10 k Ω . This is required to meet the pin leakage specification.

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FIGURE 19-4: ANALOG INPUT MODEL

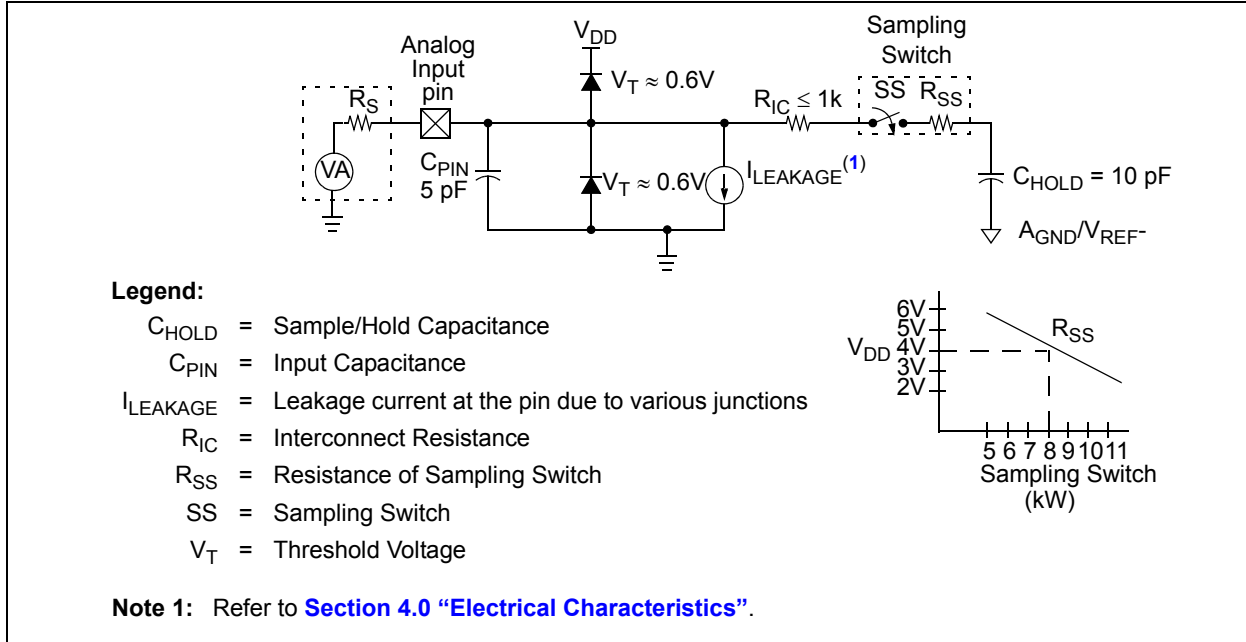


FIGURE 19-5: ADC TRANSFER FUNCTION

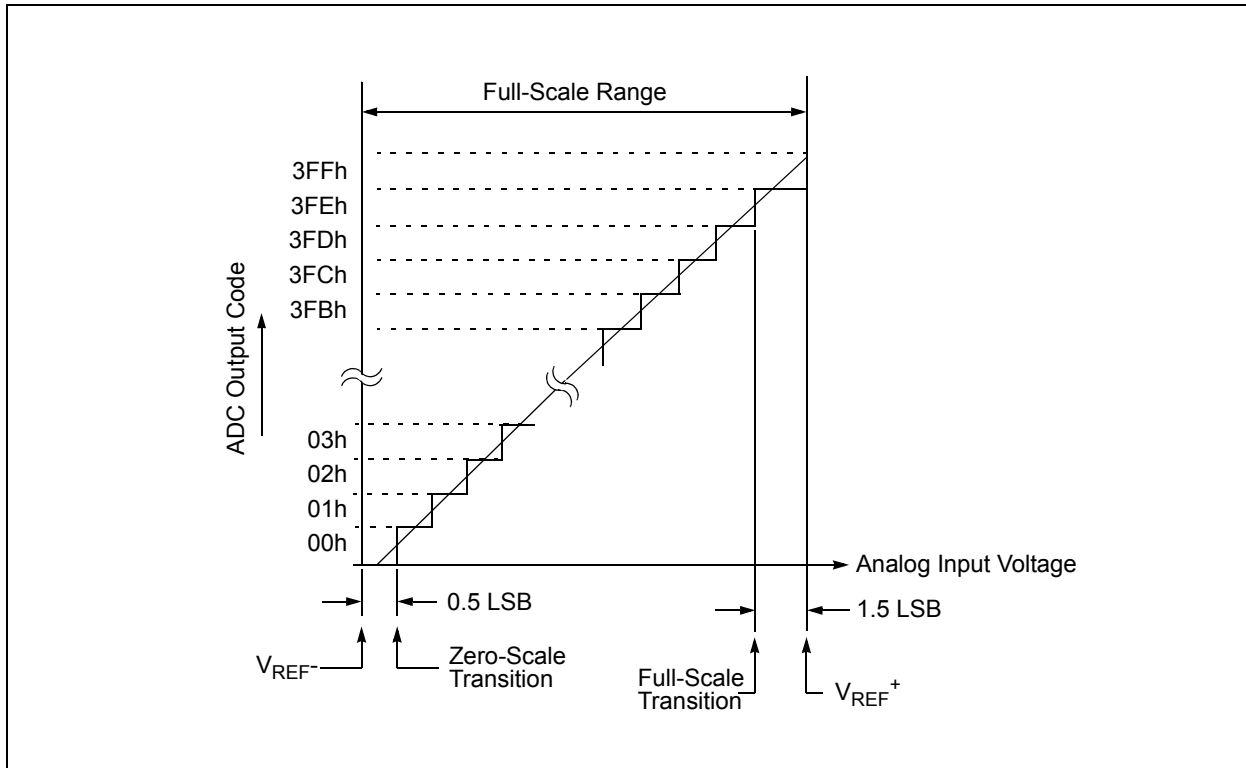


TABLE 19-2: SUMMARY OF REGISTERS ASSOCIATED WITH ADC

| 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 | 124 |
| ADCON1 | — | ADCS2 | ADCS1 | ADCS0 | — | — | — | — | 125 |
| ADRESH | — | — | — | — | — | — | ADRES9 | ADRES8 | 125 |
| ADRESL | ADRES7 | ADRES6 | ADRES5 | ADRES4 | ADRES3 | ADRES2 | ADRES1 | ADRES0 | 126 |
| ANSELA | — | — | — | — | ANSA3 | ANSA2 | ANSA1 | ANSA0 | 110 |
| ANSELB | — | ANSB6 | ANSB5 | ANSB4 | — | — | ANSB1 | — | 114 |
| INTCON | GIE | PEIE | T0IE | INTE | IOCE | T0IF | INTF | IOCF | 93 |
| PIE2 | CDSIE | ADIE | — | OTIE | OVIE | DRUVIE | OVLOIE | UVLOIE | 95 |
| PIR2 | CDSIF | ADIF | — | OTIF | OVIF | DRUVIF | OVLOIF | UVLOIF | 97 |
| TRISGPA | TRISA7 | TRISA6 | TRISA5 | — | TRISA3 | TRISA2 | TRISA1 | TRISA0 | 109 |
| TRISGPB | TRISB7 | TRISB6 | TRISB5 | TRISB4 | — | — | TRISB1 | TRISB0 | 113 |

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

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NOTES:

20.0 FLASH PROGRAM MEMORY CONTROL

The Flash program memory is readable and writable during normal operation (full V_{IN} range). This memory is not directly mapped in the register file space. Instead, it is indirectly addressed through the Special Function Registers (refer to [Registers 20-1](#) to [20-5](#)). There are six SFRs used to read and write this memory:

- PMCON1
- PMCON2
- PMDATL
- PMDATH
- PMADRL
- PMADRH

When interfacing the program memory block, the PMDATL and PMDATH registers form a two-byte word, which holds the 14-bit data for read/write, and the PMADRL and PMADRH registers form a two-byte word, which holds the 13-bit address of the FLASH location being accessed. These devices have 8k words of program Flash with an address range from 0000h to 1FFFh.

The program memory allows single-word read and a four-word write. A four-word write automatically erases the row of 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.

When the device is code-protected, the CPU may continue to read and write the Flash program memory.

Depending on the settings of the Flash Program Memory Enable (WRT<1:0>) bits, the device may or may not be able to write certain blocks of the program memory; however, reads of the program memory are allowed.

When the Flash Program Memory Code Protection (CP) bit is enabled, the program memory is code-protected and the device programmer (ICSP) cannot access data or program memory.

20.1 PMADRH and PMADRL Registers

The PMADRH and PMADRL registers can address up to a maximum of 8k words of program memory.

When selecting a program address value, the Most Significant Byte (MSB) of the address is written to the PMADRH register and the Least Significant Byte (LSB) is written to the PMADRL register.

20.2 PMCON1 and PMCON2 Registers

The PMCON1 register is the control register for the data program memory accesses.

Control bits RD and WR initiate read and write, respectively. In software, these bits can only be set, not cleared. 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. On power-up, the WREN bit is clear.

The CALSEL bit allows the user to read locations in test memory in case there are calibration bits stored in the calibration word locations that need to be transferred to SFR trim registers. The CALSEL bit is only for reads. If a write operation is attempted with CALSEL = 1, no write will occur.

PMCON2 is not a physical register. Reading PMCON2 will read all '0's. The PMCON2 register is used exclusively in the flash memory write sequence.

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20.3 Flash Program Memory Control Registers

REGISTER 20-1: PMDATL: PROGRAM MEMORY DATA LOW BYTE REGISTER

| | | | | | | | |
|-------------|-------|-------|-------|-------|-------|-------|-------|
| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| PMDATL<7:0> | | | | | | | |
| bit 7 | | | | | | | bit 0 |

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 7-0

PMDATL<7:0>: 8 Least Significant Data bits to Write or Read from Program Memory

REGISTER 20-2: PMADRL: PROGRAM MEMORY ADDRESS LOW BYTE REGISTER

| | | | | | | | |
|-------------|-------|-------|-------|-------|-------|-------|-------|
| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| PMADRL<7:0> | | | | | | | |
| bit 7 | | | | | | | bit 0 |

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 7-0

PMADRL<7:0>: 8 Least Significant Address bits for Program Memory Read/Write Operation

REGISTER 20-3: PMDATH: PROGRAM MEMORY DATA HIGH BYTE REGISTER

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

Legend:

R = Readable bit

W = Writable bit

U = Unimplemented bit, read as '0'

-n = Value at POR

'1' = Bit is set

'0' = Bit is cleared

x = Bit is unknown

bit 7-6 **Unimplemented:** Read as '0'bit 5-0 **PMDATH<5:0>**: 6 Most Significant Data bits from Program Memory

REGISTER 20-4: PMADRH: PROGRAM MEMORY ADDRESS HIGH BYTE REGISTER

| | | | | | | | |
|-------|-----|-----|-----|-------------|-------|-------|-------|
| U-0 | U-0 | U-0 | U-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| — | — | — | — | PMADRH<3:0> | | | |
| bit 7 | | | | | | | bit 0 |

Legend:

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

bit 7-4 **Unimplemented:** Read as '0'
 bit 3-0 **PMADRH<3:0>**: 4 Most Significant Address bits or High bits for Program Memory Reads

REGISTER 20-5: PMCON1: PROGRAM MEMORY CONTROL REGISTER 1

| | | | | | | | |
|-------|--------|-----|-----|-----|-------|-------|-------|
| U-0 | R/W-0 | U-0 | U-0 | U-0 | R/W-0 | R/S-0 | R/S-0 |
| — | CALSEL | — | — | — | WREN | WR | RD |
| bit 7 | | | | | | | bit 0 |

Legend:

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

bit 7 **Unimplemented:** Read as '0'
 bit 6 **CALSEL:** Program Memory Calibration Space Select bit
 1 = Select test memory area for reads only (for loading calibration trim registers)
 0 = Select user area for reads
 bit 5-3 **Unimplemented:** Read as '0'
 bit 2 **WREN:** Program Memory Write Enable bit
 1 = Allows write cycles
 0 = Inhibits write to the EEPROM
 bit 1 **WR:** Write Control bit
 1 = Initiates a write cycle to program memory. (The bit is cleared by hardware when write is complete.
 The WR bit can only be set (not cleared) in software.)
 0 = Write cycle to the Flash memory is complete
 bit 0 **RD:** Read Control bit
 1 = Initiates a program memory read. (The read takes one cycle. The RD is cleared in hardware; the
 RD bit can only be set (not cleared) in software.)
 0 = Does not initiate a Flash memory read

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20.3.1 READING THE FLASH PROGRAM MEMORY

To read a program memory location, the user must write two bytes of the address to the PMADRL and PMADRH registers, and then set control bit RD (bit 0 in the PMCON1 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 PMCON1, RD instruction to be ignored. The data is available, in the very next cycle, in the PMDATL and PMDATH registers; it can be read as two bytes in the following instructions. PMDATL and PMDATH registers will hold this value until another read or until it is written to by the user (during a write operation).

EXAMPLE 20-1: FLASH PROGRAM READ

```

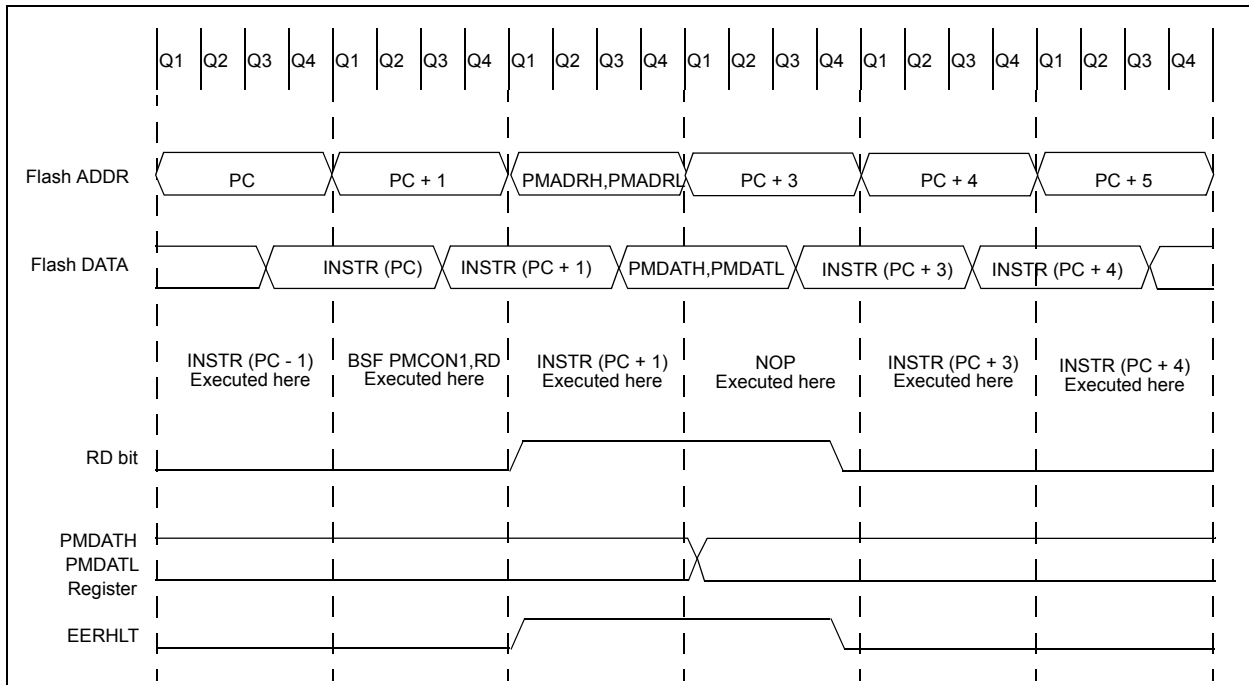
BANKSELPM_ADR; Change STATUS bits RP1:0 to select bank with PMADR
MOVLWMS_PROG_PM_ADDR;
MOVWFPADRH; MS Byte of Program Address to read
MOVLWLS_PROG_PM_ADDR;
MOVWFPADRL; LS Byte of Program Address to read
BANKSELPMCON1; Bank to containing PMCON1
BSF PMCON1, RD; EE Read

NOP      ; First instruction after BSF PMCON1, RD executes normally

NOP      ; Any instructions here are ignored as program
          ; memory is read in second cycle after BSF PMCON1, RD
          ;

BANKSELPMDATL; Bank to containing PMADRL
MOVFPMDATL, W; W = LS Byte of Program PMDATL
MOVFPMDATH, W; W = MS Byte of Program PMDATL
    
```

FIGURE 20-1: FLASH PROGRAM MEMORY READ CYCLE EXECUTION – NORMAL MODE



20.3.2 WRITING TO THE FLASH PROGRAM MEMORY

A word of the Flash program memory may only be written to if the word is in an unprotected segment of memory, as defined in [Section 11.1 “Configuration Word”](#) (bits <WRT1:0>).

Note: The write protect bits are used to protect the user’s program from modification by the user’s code. They have no effect when programming is performed by ICSP. The code-protect bits, when programmed for code protection, will prevent the program memory from being written via the ICSP interface.

Flash program memory must be written in four-word blocks. Refer to [Figures 20-2](#) and [20-3](#) for more details. A block consists of four words with sequential addresses, with a lower boundary defined by an address, where $PMADRL<1:0> = 00$. All block writes to program memory are done as 16-word erase by four-word write operations. The write operation is edge-aligned and cannot occur across boundaries.

To write program data, the WREN bit must first be loaded into the buffer registers (refer to [Figure 20-2](#)). This is accomplished by first writing the destination address to PMADRL and PMADRH and then writing the data to PMDATL and PMDATH. After the address and data have been set, the following sequence of events must be executed:

1. Write 55h, then AAh, to PMCON2 (Flash programming sequence).
2. Set the WR control bit in the PMCON1 register.

All four buffer register locations should be written to with correct data. If fewer than four words are being written to in the block of four words, a read from the program memory location(s) not being written to must be performed. This takes the data from the program location(s) not being written and loads it into the PMDATL and PMDATH registers. Then the sequence of events to transfer data to the buffer registers must be executed.

To transfer data from the buffer registers to the program memory, the PMADRL and PMADRH must point to the last location in the four-word block ($PMADRL<1:0> = 11$). Then the following sequence of events must be executed:

1. Write 55h, then AAh, to PMCON2 (Flash programming sequence).
2. Set control bit WR in the PMCON1 register to begin the write operation.

The user must follow the same specific sequence to initiate the write for each word in the program block, writing each program word in sequence (000, 001, 010, 011). When the write is performed on the last word ($PMADRL<1:0> = 11$), a block of 16 words is automatically erased and the content of the four-word buffer registers are written into the program memory.

After the `BSF PMCON1, WR` instruction, the processor requires two cycles to set up the erase/write operation. The user must place two `NOP` instructions after the WR bit is set. Since data is being written to buffer registers, the writing of the first three words of the block appears to occur immediately. The processor will halt internal operations for the typical 4 ms only during the cycle in which the erase takes place (i.e., the last word of the 16-word block erase). This is not Sleep mode, as the clocks and peripherals will continue to run. After the four-word write cycle, the processor will resume operation with the third instruction after the PMCON1 write instruction. The above sequence must be repeated for the higher 12 words.

Note: An erase is only initiated for the write of four words just after a row boundary; or $PMCON1<WR>$ set with $PMADRL<3:0> = \text{xxxx}0011$.

Refer to [Figure 20-2](#) for a block diagram of the buffer registers and the control signals for test mode.

20.3.3 PROTECTION AGAINST SPURIOUS WRITE

There are conditions when the device should not write to the program memory. To protect against spurious writes, various mechanisms have been built in. On power-up, WREN is cleared. Also, the Power-Up Timer (72 ms duration) prevents program memory writes.

The write initiate sequence and the WREN bit help prevent an accidental write during a power glitch or software malfunction.

20.3.4 OPERATION DURING CODE PROTECT

When the device is code-protected, the CPU is able to read and write unscrambled data to the program memory. The test mode access is disabled.

20.3.5 OPERATION DURING WRITE PROTECT

When the program memory is write-protected, the CPU can read and execute from the program memory. The portions of program memory that are write-protected cannot be modified by the CPU using the PMCON registers. The write protection has no effect in ICSP mode.

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FIGURE 20-2: BLOCK WRITES TO 8K FLASH PROGRAM MEMORY

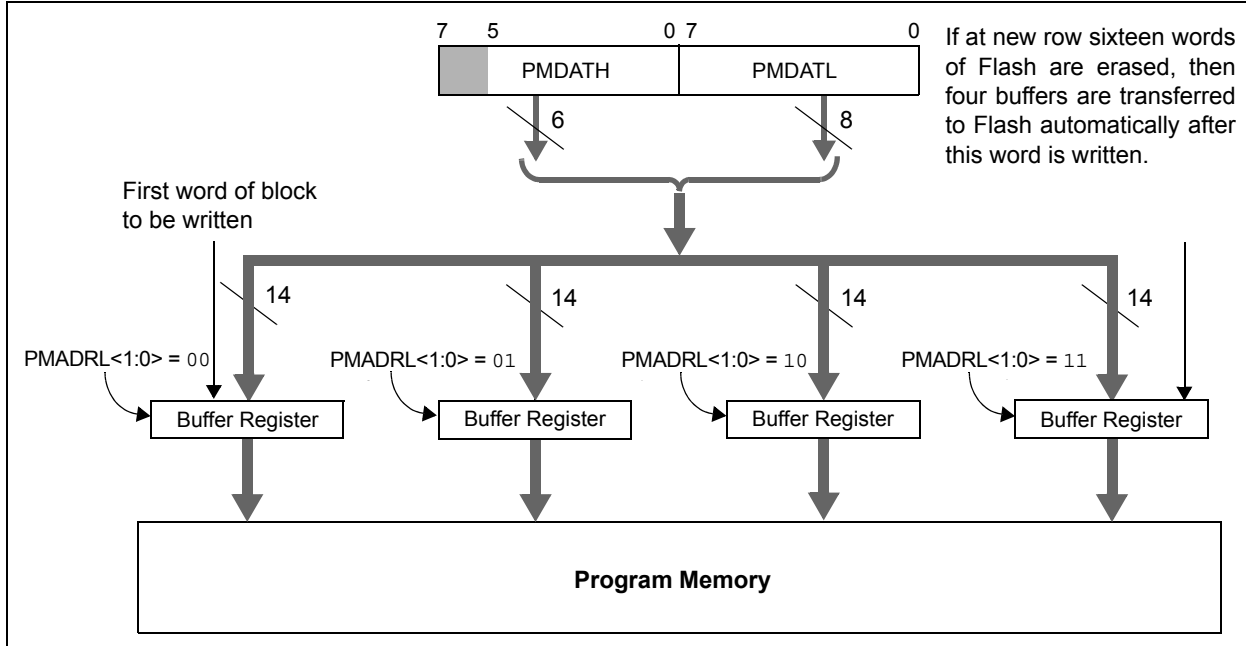
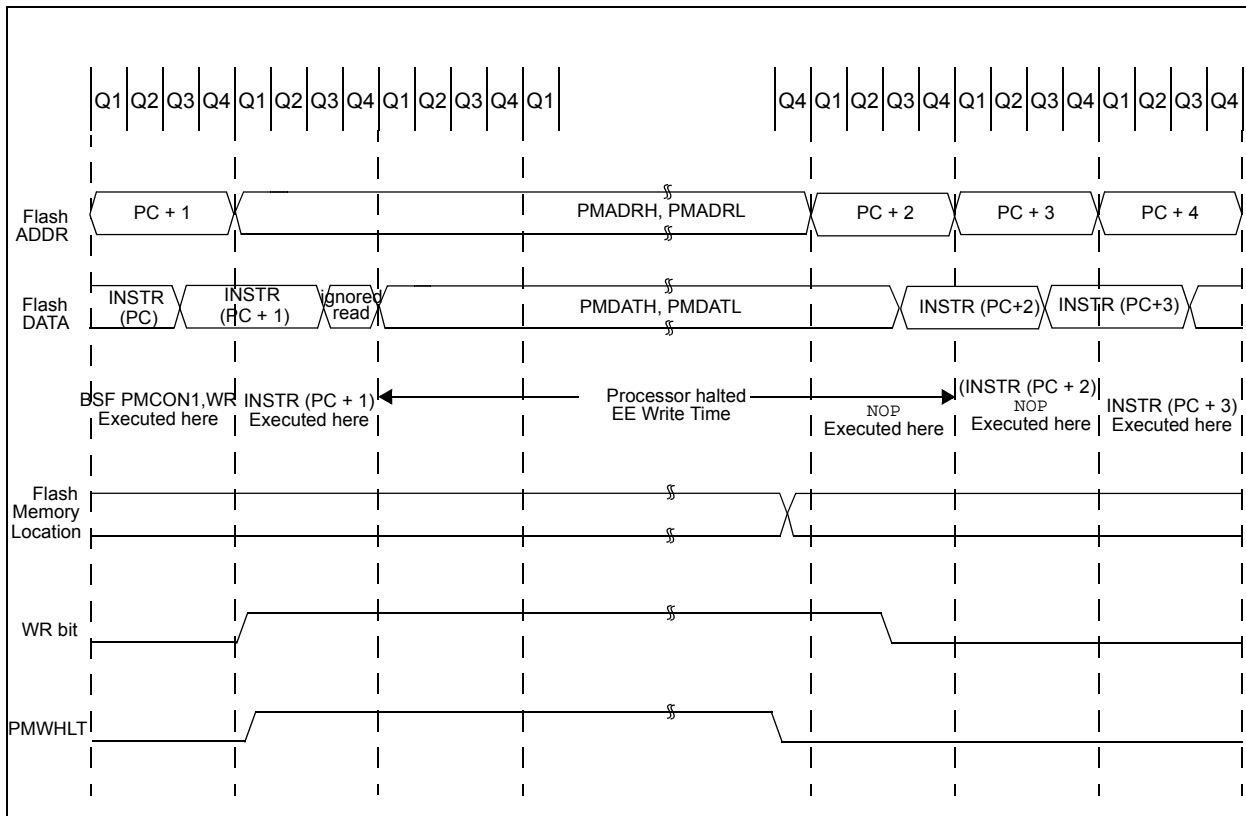


FIGURE 20-3: FLASH PROGRAM MEMORY LONG WRITE CYCLE EXECUTION



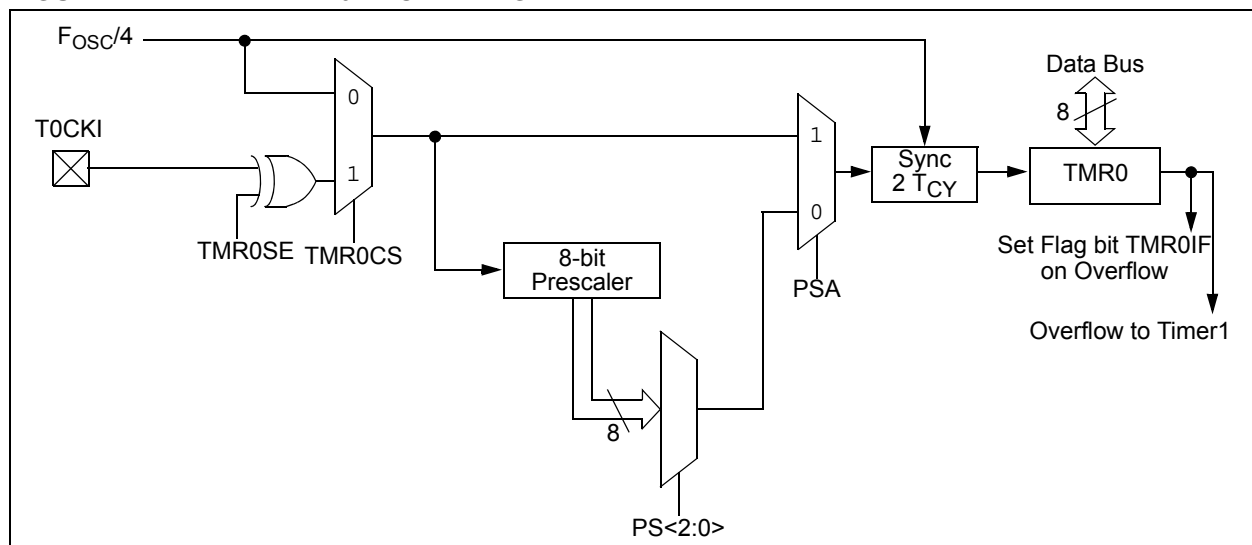
21.0 TIMER0 MODULE

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

- 8-bit timer/counter register (TMR0)
- 8-bit prescaler
- Programmable internal or external clock source
- Programmable external clock edge selection
- Interrupt on overflow

Figure 21-1 is a block diagram of the Timer0 module.

FIGURE 21-1: TIMER0 BLOCK DIAGRAM



21.1 Timer0 Operation

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

21.1.1 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 T0CS bit in 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.

21.1.2 8-BIT COUNTER MODE

In 8-Bit Counter mode, the Timer0 module will increment on every rising or falling edge of the T0CKI pin. The incrementing edge is determined by the T0SE bit in the OPTION_REG register.

8-Bit Counter mode using the T0CKI pin is selected by setting the T0CS bit in the OPTION_REG register to '1'.

21.1.3 SOFTWARE PROGRAMMABLE PRESCALER

A single software programmable prescaler is available for use with either Timer0 or the Watchdog Timer (WDT), but not both simultaneously. The prescaler assignment is controlled by the PSA bit in the OPTION_REG register. To assign the prescaler to Timer0, the PSA bit must be cleared to '0'.

There are eight prescaler options for the Timer0 module ranging from 1:2 to 1:256. The prescale values are selectable via the PS<2:0> bits in 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 in the OPTION_REG register.

The prescaler is not readable or writable. When assigned to the Timer0 module, all instructions writing to the TMR0 register will clear the prescaler.

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21.1.4 SWITCHING PRESCALER BETWEEN TIMER0 AND WDT MODULES

As a result of having the prescaler assigned to either Timer0 or the WDT, it is possible to generate an unintended device reset when switching prescaler values. When changing the prescaler assignment from Timer0 to the WDT module, the instruction sequence shown in [Example 21-1](#) must be executed.

EXAMPLE 21-1: CHANGING PRESCALER (TIMER0 → WDT)

```
BANKSEL TMR0;
CLRWDT ;Clear WDT
CLRFTMR0;Clear TMR0 and
;prescaler
BANKSEL OPTION_REG;
BSF OPTION_REG,PSA;Select WDT
CLRWDT ;
;
MOVLWb'11111000';Mask prescaler
ANDWFOPTION_REG,W;bits
IORLWb'00000101';Set WDT prescaler
MOVWFOPTION_REG;to 1:32
```

When changing the prescaler assignment from the WDT to the Timer0 module, the following instruction sequence must be executed (refer to [Example 21-2](#)).

EXAMPLE 21-2: CHANGING PRESCALER (WDT → TIMER0)

```
CLRWDT ;Clear WDT and
;prescaler
BANKSEL OPTION_REG;
MOVLWb'11110000';Mask TMR0 select and
ANDWFOPTION_REG,W;prescaler bits
IORLWb'00000011';Set prescale to 1:16
MOVWFOPTION_REG;
```

21.1.5 TIMER0 INTERRUPT

Timer0 will generate an interrupt when the TMR0 register overflows from FFh to 00h. The T0IF interrupt flag bit in the INTCON register is set every time the TMR0 register overflows, regardless of whether or not the Timer0 interrupt is enabled. The T0IF bit can only be cleared in software. The Timer0 interrupt enable is the T0IE bit in the INTCON register.

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

21.1.6 USING TIMER0 WITH AN EXTERNAL CLOCK

When Timer0 is in Counter mode, the synchronization of the T0CKI input and the Timer0 register is accomplished by sampling the prescaler output on the Q2 and Q4 cycles of the internal phase clocks. Therefore, the high and low periods of the external clock source must meet the timing requirements as shown in [Section 4.0 “Electrical Characteristics”](#).

21.1.7 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.

TABLE 21-1: 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 |
|------------|------------------------|--------|--------|--------|--------|--------|--------|--------|------------------|
| INTCON | GIE | PEIE | T0IE | INTE | IOCIE | T0IF | INTF | IOCIF | 93 |
| OPTION_REG | RAPU | INTEDG | T0CS | T0SE | PSA | PS2 | PS1 | PS0 | 78 |
| TMR0 | Timer0 Module Register | | | | | | | | 137* |
| TRISGPA | TRISA7 | TRISA6 | TRISA5 | TRISA4 | TRISA3 | TRISA2 | TRISA1 | TRISA0 | 109 |

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

* Page provides register information.

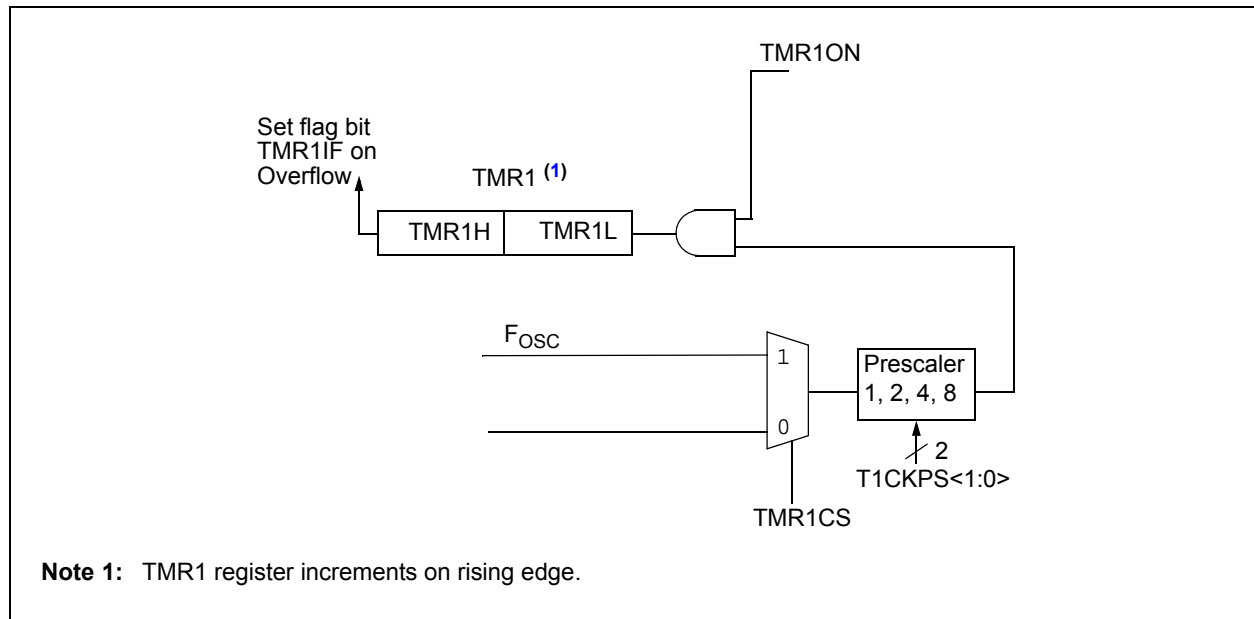
22.0 TIMER1 MODULE WITH GATE CONTROL

The Timer1 module is a 16-bit timer with the following features:

- 16-bit timer register pair (TMR1H:TMR1L)
- Readable and writable (both registers)
- Selectable internal clock source
- 2-bit prescaler
- Interrupt on overflow

Figure 22-1 is a block diagram of the Timer1 module.

FIGURE 22-1: TIMER1 BLOCK DIAGRAM



22.1 Timer1 Operation

The Timer1 module is a 16-bit incrementing timer that is accessed through the TMR1H:TMR1L register pair. Writes to TMR1H or TMR1L directly update the counter. The timer is incremented on every instruction cycle.

Timer1 is enabled by configuring the TMR1ON bit in the T1CON register. Register 22-1 displays the Timer1 enable selections.

22.2 Clock Source Selection

The TMR1CS bit in the T1CON register is used to select the clock source for Timer1. Table 22-1 displays the clock source selections.

22.2.1 INTERNAL CLOCK SOURCE

The TMR1H:TMR1L register pair will increment on multiples of F_{OSC} or $F_{OSC}/4$ as determined by the Timer1 prescaler.

As an example, when the F_{OSC} internal clock source is selected, the Timer1 register value will increment by four counts every instruction clock cycle.

TABLE 22-1: CLOCK SOURCE SELECTIONS

| TMR1CS | Clock Source |
|--------|---|
| 1 | 8 MHz system clock (F_{OSC}) |
| 0 | 2 MHz instruction clock ($F_{OSC}/4$) |

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22.3 Timer1 Prescaler

Timer1 has four prescaler options, allowing 1, 2, 4 or 8 divisions of the clock input. The T1CKPS bits in 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.

22.4 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 in the PIR1 register is set. To enable the interrupt on rollover, these bits must be set:

- TMR1ON bit in the T1CON register
- TMR1IE bit in the PIE1 register
- PEIE bit in the INTCON register
- GIE bit in 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.

22.5 Timer1 in Sleep

Unlike other standard mid-range Timer1 modules, the MCP19124/5 Timer1 module only clocks from an internal system clock, and thus cannot run during Sleep mode, nor can it be used to wake the device from this mode.

22.6 Timer1 Control Register

The Timer1 Control (T1CON) register, shown in [Register 22-1](#), is used to control Timer1 and select the various features of the Timer1 module.

REGISTER 22-1: T1CON: TIMER1 CONTROL REGISTER

| | | | | | | | | |
|-------|-----|---------|---------|-----|-----|--------|--------|-------|
| U-0 | U-0 | R/W-0 | R/W-0 | U-0 | U-0 | R/W-0 | R/W-0 | |
| — | — | T1CKPS1 | T1CKPS0 | — | — | TMR1CS | 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 = Value at POR
'1' = Bit is set '0' = Bit is cleared

- bit 7-6 **Unimplemented:** Read as '0'
- 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 3-2 **Unimplemented:** Read as '0'
- bit 1 **TMR1CS:** Timer1 Clock Source Control bit
1 = 8 MHz system clock (F_{OSC})
0 = 2 MHz instruction clock (F_{OSC/4})
- bit 0 **TMR1ON:** Timer1 On bit
1 = Enables Timer1
0 = Stops Timer1, Clears Timer1 gate flip-flop

TABLE 22-2: 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 |
|--------|---|-------|---------|---------|-------|-------|--------|--------|------------------|
| INTCON | GIE | PEIE | T0IE | INTE | IOCE | T0IF | INTF | IOCF | 93 |
| PIE1 | TXIE | RCIE | BCLIE | SSPIE | CC2IE | CC1IE | TMR2IE | TMR1IE | 94 |
| PIR1 | TXIF | RCIF | BCLIF | SSPIF | CC2IF | CC1IF | TMR2IF | TMR1IF | 96 |
| TMR1H | Holding Register for the Most Significant Byte of the 16-bit TMR1 Register | | | | | | | | 139* |
| TMR1L | Holding Register for the Least Significant Byte of the 16-bit TMR1 Register | | | | | | | | 139* |
| T1CON | — | — | T1CKPS1 | T1CKPS0 | — | — | TMR1CS | TMR1ON | 140 |

Legend: — = unimplemented, read as '0'. Shaded cells are not used by the Timer1 module.

* Page provides register information.

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NOTES:

23.0 TIMER2 MODULE

The Timer2 module is an 8-bit timer with the following features:

- 8-bit timer register (TMR2)
- 8-bit period register (PR2)
- Interrupt on TMR2 match with PR2
- Software programmable prescaler (1:1, 1:4, 1:16)

Refer to [Figure 23-1](#) for a block diagram of Timer2.

23.1 Timer2 Operation

The clock input to the Timer2 module is the system clock (F_{OSC}). The clock is fed into the Timer2 prescaler, which has prescale options of 1:1, 1:4 or 1:16. The output of the prescaler is then used to increment the TMR2 register.

The values of TMR2 and PR2 are constantly compared to determine when they match. TMR2 will increment from 00h until it matches the value in PR2. When a match occurs, TMR2 is reset to 00h on the next increment cycle.

The match output of the Timer2/PR2 comparator is used to set the TMR2IF interrupt flag bit in the PIR1 register.

The TMR2 and PR2 registers are both fully readable and writable. On any Reset, the TMR2 register is set to 00h and the PR2 register is set to FFh.

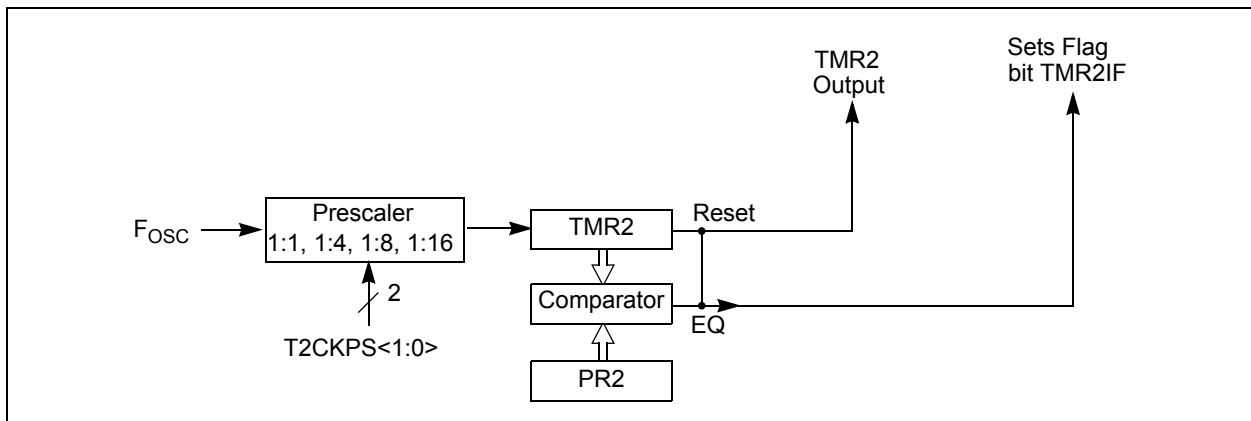
Timer2 is turned on by setting the TMR2ON bit in the T2CON register to a '1'. Timer2 is turned off by clearing the TMR2ON bit to a '0'.

The Timer2 prescaler is controlled by the T2CKPS bits in the T2CON register. The prescaler counter are cleared when:

- A write to TMR2 occurs.
- A write to T2CON occurs.
- Any device reset occurs (Power-On Reset, \overline{MCLR} Reset, Watchdog Timer Reset or Brown-Out Reset).

Note: TMR2 is not cleared when T2CON is written.

FIGURE 23-1: TIMER2 BLOCK DIAGRAM



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23.2 Timer2 Control Register

REGISTER 23-1: T2CON: TIMER2 CONTROL REGISTER

| | | | | | | | |
|-------|-----|-----|-----|-----|--------|---------|---------|
| U-0 | U-0 | U-0 | U-0 | U-0 | R/W-0 | R/W-0 | R/W-0 |
| — | — | — | — | — | TMR2ON | T2CKPS1 | T2CKPS0 |
| 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 = Value at POR
'1' = Bit is set '0' = Bit is cleared

- bit 7-3 **Unimplemented:** Read as '0'
- bit 2 **TMR2ON:** Timer2 On bit
 1 = Timer2 is on
 0 = Timer2 is off
- bit 1-0 **T2CKPS<1:0>:** Timer2 Clock Prescale Select bits
 00 = Prescaler is 1
 01 = Prescaler is 4
 10 = Prescaler is 8
 11 = Prescaler is 16

TABLE 23-1: SUMMARY OF REGISTERS ASSOCIATED WITH TIMER2

| Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Register on Page |
|--------|---|-------|-------|-------|-------|--------|---------|---------|------------------|
| INTCON | GIE | PEIE | TOIE | INTE | IOCE | TOIF | INTF | IOCF | 93 |
| PIE1 | TXIE | RCIE | BCLIE | SSPIE | CC2IE | CC1IE | TMR2IE | TMR1IE | 94 |
| PIR1 | TXIF | RCIF | BCLIF | SSPIF | CC2IF | CC1IF | TMR2IF | TMR1IF | 96 |
| PR2 | Timer2 Module Period Register | | | | | | | | 143* |
| T2CON | — | — | — | — | — | TMR2ON | T2CKPS1 | T2CKPS0 | 144 |
| TMR2 | Holding Register for the 8-bit TMR2 Time Base | | | | | | | | 143* |

Legend: — = unimplemented, read as '0'. Shaded cells are not used for Timer2 module.

* Page provides register information.

24.0 DUAL CAPTURE/COMPARE (CCD) MODULE

The CCD module is implemented on the MCP19124/5. This module is a new module based on the standard CCP module. It has two capture and compare only register sets with no PWM function.

24.1 Capture Mode

In Capture mode, the CCxRH:CCxRL register set captures the 16-bit value of the TMR1 register when an event occurs on the DIM1 pin. An event is defined as one of the following:

- Every falling edge
- Every rising edge
- Every 4th rising edge
- Every 16th rising edge

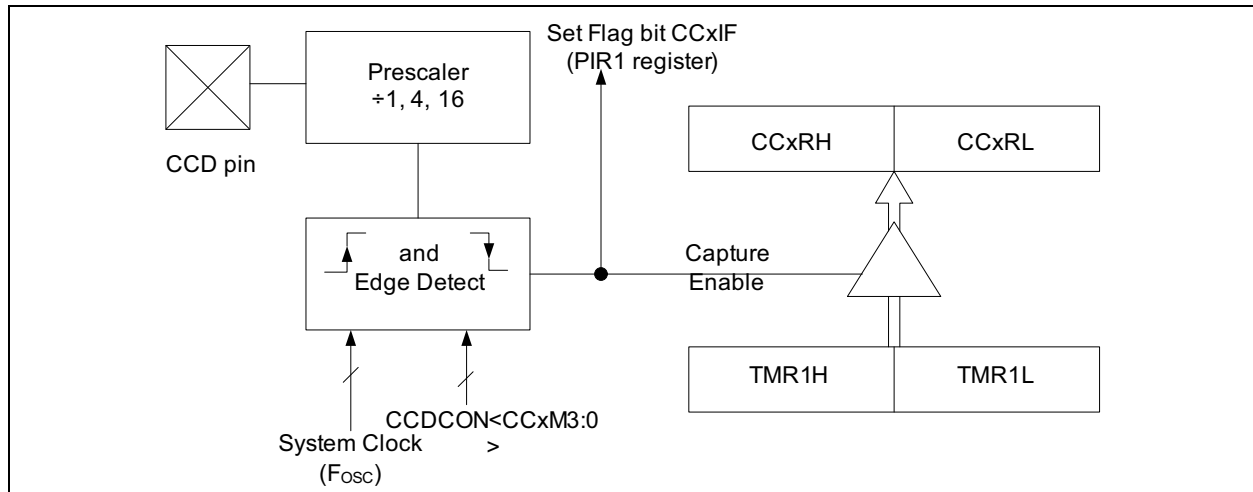
The type of event is configured by control bits CCxM3:CCxM0 (CCDCON<3:0> for register set 1 or CCDCON<7:4> for register set 2). When a capture is made, the interrupt request flag bit, CCxIF (PIR1<2> for register set 1 or PIR1<3> for register set 2), is set. The interrupt flag must be cleared in software. If another capture occurs before the value in the register set is read, the old captured value is overwritten by the new value.

24.1.1 CCX PIN CONFIGURATION

In Capture mode, the DIM1 pin should be configured as an input by setting the TRIS bit for that pin.

Note: If the DIM1 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 SELECTION

Timer1 must be running off of the instruction clock for the CCD module to use the capture feature. If Timer1 is running off of the 8 MHz clock, the capture feature may not function correctly.

24.1.3 SOFTWARE INTERRUPT

When the Capture mode is changed, a false capture interrupt may be generated. The user should keep the enable for the capture interrupt clear in order to avoid false interrupts and should clear the flag bit, CCxIF, following any such change in the operating mode.

24.1.4 CCD PRESCALER

There are four prescaler settings, specified by bits CCxM3:CCxM0. Whenever the CCD register set is disabled or not set to Capture mode, the prescaler counter is cleared. Any reset will clear the prescaler counter.

Switching from one capture prescaler to another may generate an interrupt. Also, the prescaler counter will not be cleared, therefore, the first capture may be from a nonzero prescaler. It is recommended to disable the register set (CCxM3:0 = 00xx) prior to changing the prescaler value.

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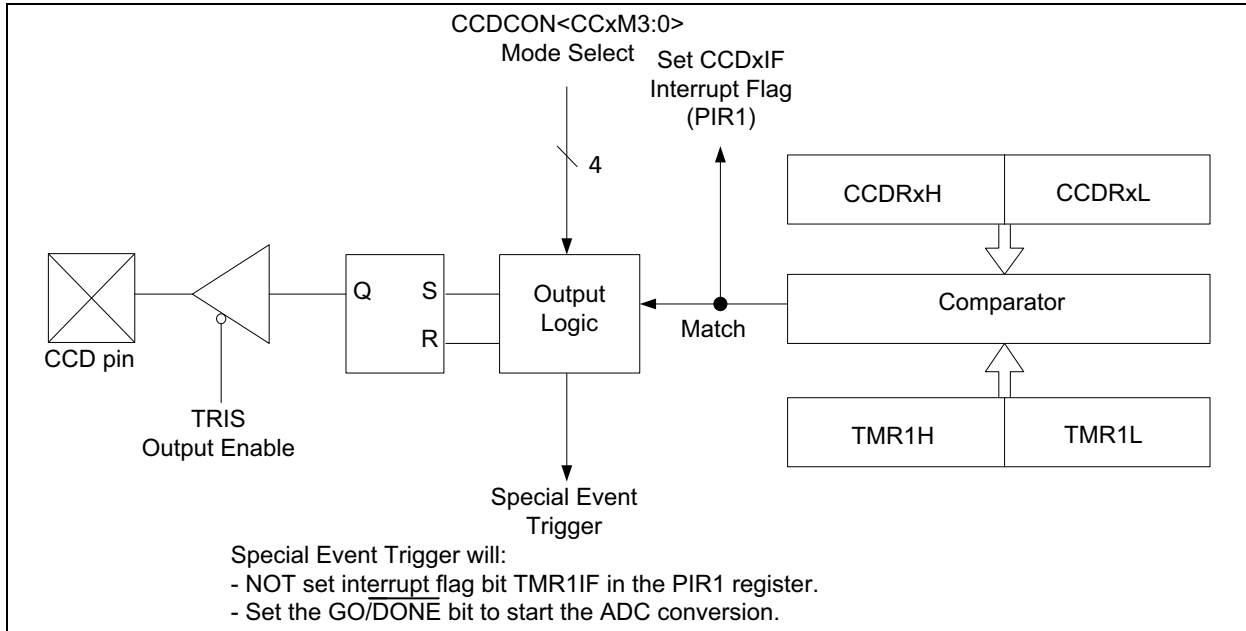
24.2 Compare Mode

In Compare mode, the 16-bit CCDRx register value is constantly compared against the TMR1 register pair value. When a match occurs, the CMPx pin:

- Is driven high
- Is driven low
- Toggles
- Remains unchanged

The action on the pin is based on the value of the control bits, CCxM3:CCxM0. At the same time, interrupt flag bit, CCP1IF, is set.

FIGURE 24-2: COMPARE MODE OPERATION BLOCK DIAGRAM



24.2.1 CMPX PIN CONFIGURATION

The user must configure the CMPx pin as an output by clearing the TRIS bit for that pin.

Note: Clearing the CCxM<3:0> bits will set the CMPx compare output latch to the default state. This is not the GPIO pin data latch. The default state for set on match or toggle on match is '0' but the default state for clear on match is '1'.

24.2.2 TIMER1 MODE SELECTION

Timer1 must be running off of the instruction clock for the CCD module to use the compare feature. If Timer1 is running off of the 8 MHz clock, the compare feature may not function correctly.

24.2.3 SOFTWARE INTERRUPT MODE

When Generate Software Interrupt mode is chosen, the CCP1 pin is not affected. The CCP1IF bit is set, causing a CCx interrupt (if enabled).

24.2.4 SPECIAL EVENT TRIGGER

In this mode, an internal hardware trigger is generated, which may be used to initiate an action. The Special Event Trigger output of CCD does not reset the TMR1 register pair and starts an A/D conversion (if the A/D module is enabled).

Note: The Special Event Trigger from the CCD module will not set the interrupt flag bit TMR1IF (bit 0 in the PIR1 register).

24.3 Dual Capture/Compare Register

The Dual Capture/Compare Module is a new module based on the standard CCP. It has no PWM function.

REGISTER 24-1: CCDCON: DUAL CAPTURE/COMPARE CONTROL MODULE

| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
|-------|-------|-------|-------|-------|-------|-------|-------|
| CC2M3 | CC2M2 | CC2M1 | CC2M0 | CC1M3 | CC1M2 | CC1M1 | CC1M0 |
| 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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

- bit 7-4 **CC2M<3:0>**: CC Register Set 2 Mode Select bits
- 00xx = Capture/Compare off (resets the module)
 - 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, set output on match (CC2IF bit is set)
 - 1001 = Compare mode, clear output on match (CC2IF bit is set)
 - 1010 = Compare mode, toggle output on match (CC2IF bit is set)
 - 1011 = Reserved
 - 11xx = Compare mode, generate software interrupt on match (CC2IF bit is set, CMP2 pin is unaffected and configured as an I/O)
 - 1111 = Compare mode, trigger special event (CC2IF bit is set; **CC2 does not reset TMR1⁽¹⁾ and starts an A/D conversion, if the A/D module is enabled.** CMP2 pin is unaffected and configured as an I/O port).
- bit 3-0 **CC1M<3:0>**: CC Register Set 1 Mode Select bits
- 00xx = Capture/Compare off (resets the module)
 - 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, set output on match (CC1IF bit is set)
 - 1001 = Compare mode, clear output on match (CC1IF bit is set)
 - 1010 = Compare mode, toggle output on match (CC1IF bit is set)
 - 1011 = Reserved
 - 11xx = Compare mode, generate software interrupt on match (CC1IF bit is set, CMP1 pin is unaffected and configured as an I/O)
 - 1111 = Compare mode, trigger special event (CC1IF bit is set; **CC1 resets TMR1 and starts an A/D conversion, if the A/D module is enabled.** CMP1 pin is unaffected and configured as an I/O port).

Note 1: When the Compare interrupt is set, a PIC will typically reset TMR1. This module does NOT reset TMR1.

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NOTES:

25.0 INTERNAL TEMPERATURE INDICATOR MODULE

The MCP19124/5 devices are equipped with a temperature sensor designed to measure operating temperature of the silicon die. The silicon die temperature range of operation is from -40°C and +125°C. The temperature sensing circuitry typically ranges from -20°C to +125°C. The temperature sensing circuit output is a voltage that is proportional to the silicon die temperature. The output is internally connected to the device Analog to Digital Converter.

25.1 Circuit Operation

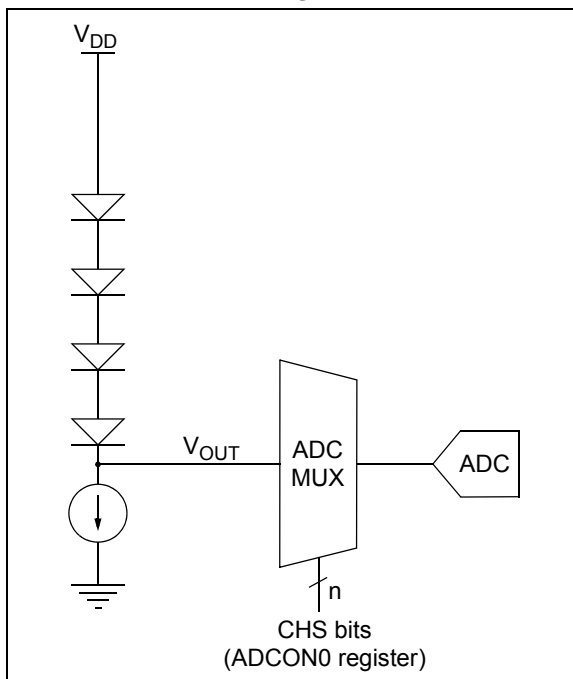
This internal temperature measurement circuit is always enabled.

25.2 Temperature Output

The output of the circuit is measured using the internal analog-to-digital converter. Channel 13 is reserved for the temperature circuit output. Refer to [Section 19.0 “Analog-to-Digital Converter \(ADC\) Module”](#) for detailed information.

The temperature of the silicon die can be calculated by the ADC measurement by using [Equation 25-1](#). A factory-stored 10-bit ADC value for 30°C is located at address 2084h. The temperature coefficient for this circuit is typically 14.0mV/°C +/-0.8mV/°C from -20°C to +125°C. Other temperature readings can be calculated from this 30°C mark as shown in Equation 25-1. Equation 25-1 is based on the ADC Reference connected to the AV_{DD}.

FIGURE 25-1: TEMPERATURE CIRCUIT DIAGRAM



EQUATION 25-1: SILICON DIE TEMPERATURE

$$TEMP_DIE(^{\circ}C) = \frac{(ADC_READING (counts) - ADC_30^{\circ}C_READING (counts))}{3.5(counts/^{\circ}C)} + 30^{\circ}C$$

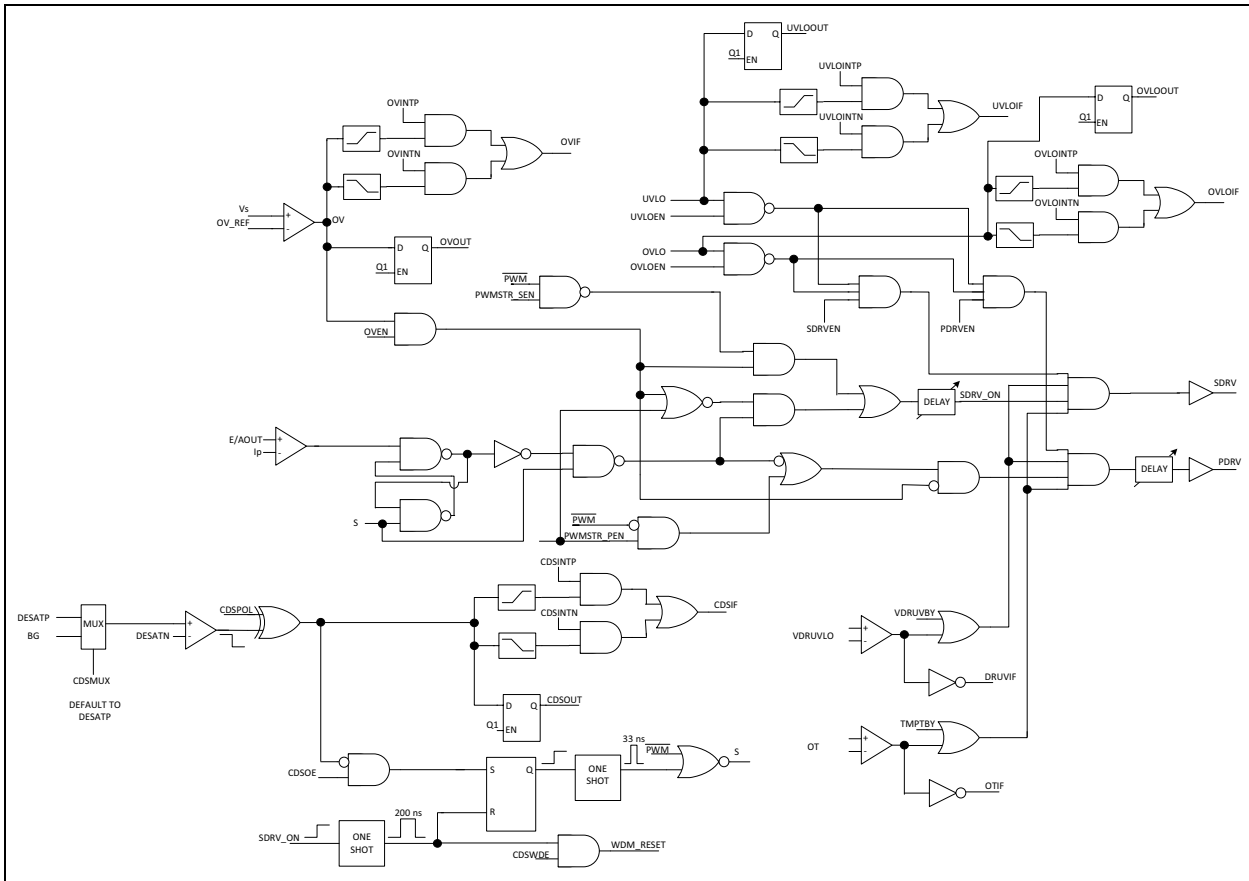
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NOTES:

26.0 PWM CONTROL LOGIC

The PWM Control Logic implements standard comparator modules to identify events such as input undervoltage, input overvoltage and desaturation detection. The control logic takes action in hardware to appropriately enable/disable the output drive (PDRV/SDRV), as well as to set corresponding interrupt flags to be read by software. This control logic also defines normal PWM operation. For definition of individual bits within the control logic, refer to the Special Function Register (SFR) sections.

FIGURE 26-1: PWM CONTROL LOGIC

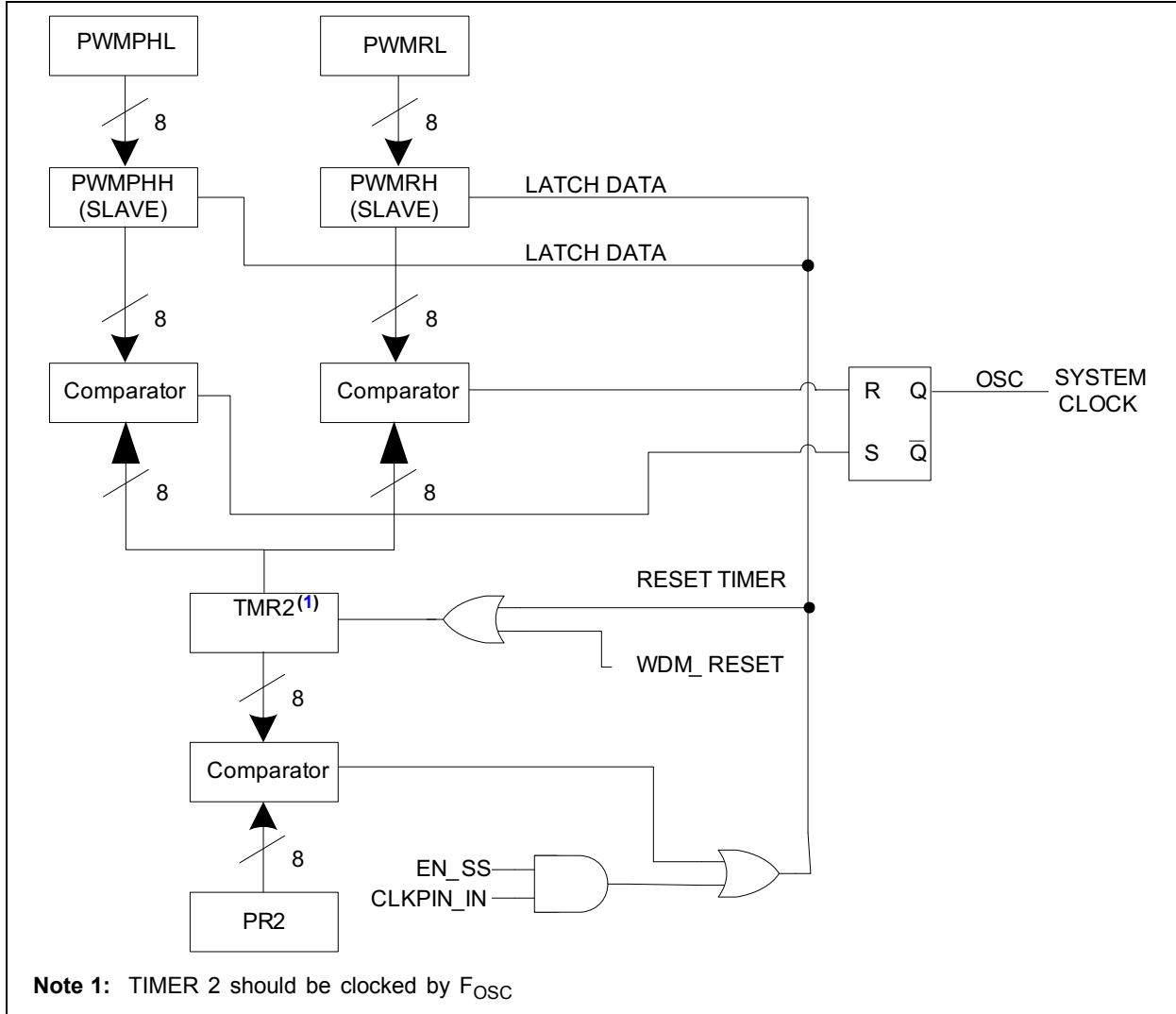


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NOTES:

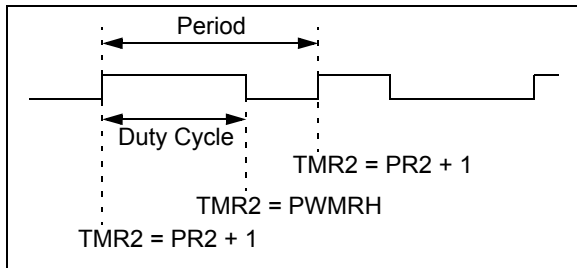
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FIGURE 27-2: SIMPLIFIED PWM BLOCK DIAGRAM



A PWM output (Figure 27-3) has a time base (period) and a time that the output stays high (duty cycle). The frequency of the PWM is the inverse of the period (1/period).

FIGURE 27-3: PWM OUTPUT



27.1.3 PWM PERIOD

The PWM period is specified by writing to the PR2 register. The PWM period can be calculated using the following equation.

EQUATION 27-2:

$$PWM_{PERIOD} = [(PR2) + 1] \times T_{OSC} \times (T2_{PRESCALE\ VALUE})$$

When TMR2 is equal to PR2, the following two events occur on the next increment cycle:

- TMR2 is cleared
- The PWM duty cycle is latched from PWMRL into PWMRH

27.1.4 PWM DUTY CYCLE (D_{CLOCK})

The PWM duty cycle (D_{CLOCK}) is specified by writing to the PWMRL register. Up to 8-bit resolution is available. The following equation is used to calculate the PWM duty cycle (D_{CLOCK}).

EQUATION 27-3:

$$PWM_{\text{DUTY CYCLE}} = PWMRL \times T_{\text{OSC}} \times (T2_{\text{PRESCALE VALUE}})$$

The PWMRL bits can be written to at any time, but the duty cycle value is not latched into PWMRH until after a match between PR2 and TMR2 occurs.

27.2 Operation During Sleep

When the device is placed in Sleep, the allocated timer will not increment and the state of the module will not change. If the CLKPIN pin is driving a value, it will continue to drive that value. When the device wakes up, it will continue from this state.

TABLE 27-1: SUMMARY OF REGISTERS ASSOCIATED WITH PWM MODULE

| Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Register on Page |
|---------|-------------------------------|-------|-------|-------|-------|--------|---------|---------|------------------|
| MODECON | MSC1 | MSC0 | RFB | — | MSC2 | — | — | — | 52 |
| T2CON | — | — | — | — | — | TMR2ON | T2CKPS1 | T2CKPS0 | 144 |
| PR2 | Timer2 Module Period Register | | | | | | | | 153* |
| PWMRL | PWM Register Low Byte | | | | | | | | 153* |
| PWMPHL | Phase Shift Low Byte | | | | | | | | 153* |

Legend: — = Unimplemented locations, read as '0'. Shaded cells are not used by PWM mode.

* Page provides register information.

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NOTES:

28.0 MASTER SYNCHRONOUS SERIAL PORT (MSSP) MODULE

28.1 MSSP Module Overview

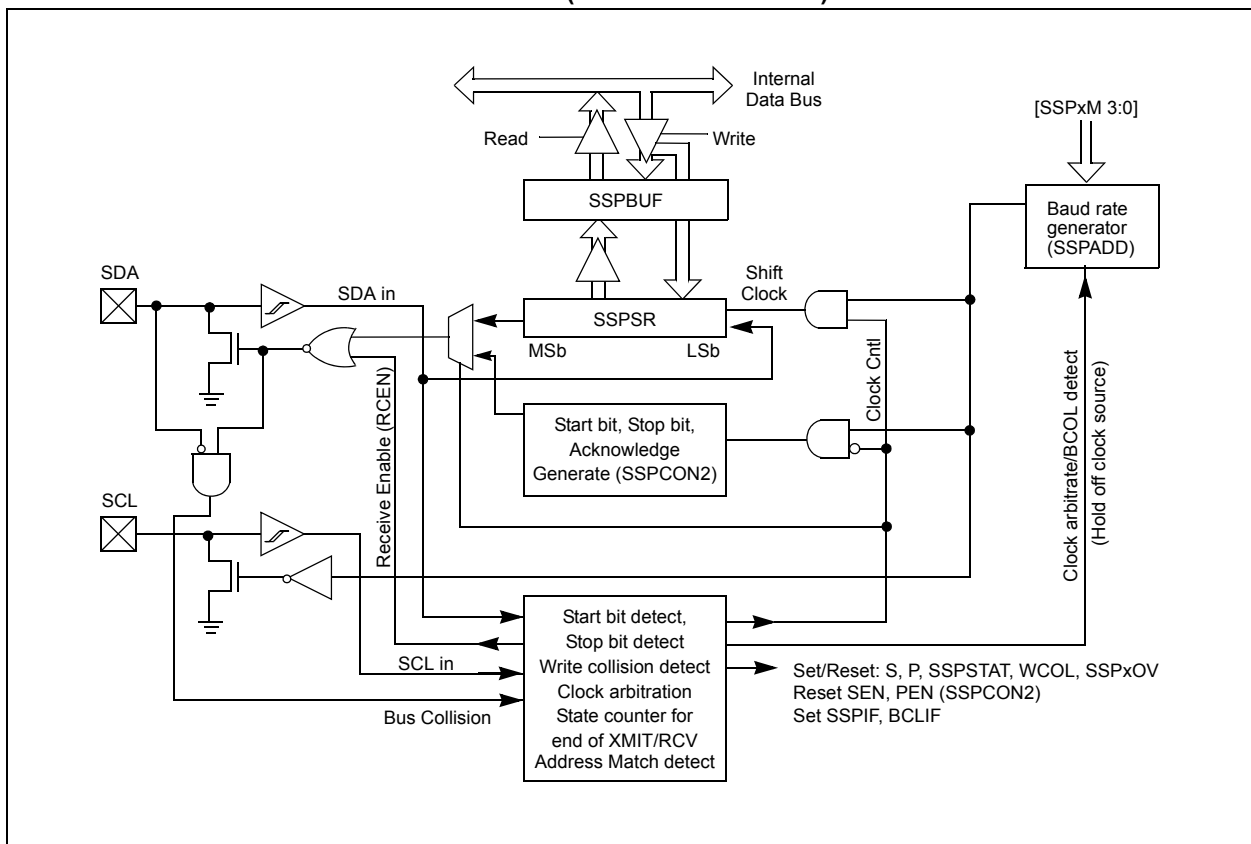
The Master Synchronous Serial Port (MSSP) module is a serial interface useful for communicating with other peripheral or microcontroller devices. These peripheral devices may be Serial EEPROMs, shift registers, display drivers, A/D converters, etc. The MSSP module in the MCP19124/5 only operates in Inter-Integrated Circuit (I²C) mode.

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
- Dual Address masking
- Address Hold and Data Hold modes
- Selectable SDA hold times

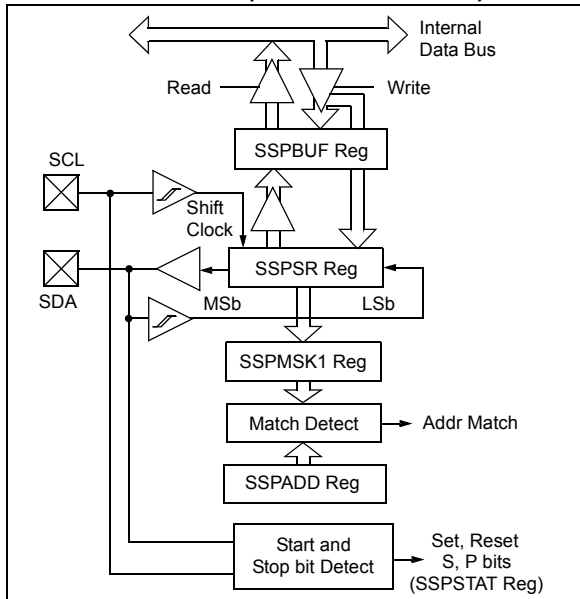
Figure 28-1 is a block diagram of the I²C interface module in Master mode. Figure 28-2 is a diagram of the I²C interface module in Slave mode.

FIGURE 28-1: MSSP BLOCK DIAGRAM (I²C MASTER MODE)



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FIGURE 28-2: MSSP BLOCK DIAGRAM (I²C SLAVE MODE)



28.2 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 (SCL)
- Serial Data (SDA)

Both the SCL and SDA 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; letting the line float is considered a logical one.

Figure 28-3 shows a typical connection between two devices configured as master and slave.

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:

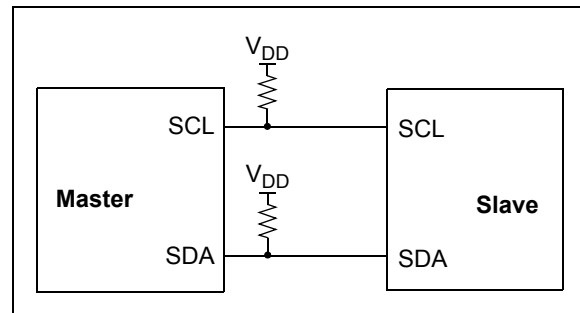
- Master Transmit mode (master is transmitting data to a slave)
- Master Receive mode (master is receiving data from a slave)
- Slave Transmit mode (slave is transmitting data to a master)
- Slave Receive mode (slave is receiving data from a master)

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 SDA line while the SCL 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 28-3: I²C MASTER/SLAVE CONNECTION



The Acknowledge bit ($\overline{\text{ACK}}$) is an active-low signal that holds the SDA 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 SCL line is held low. Transitions that occur while the SCL line is held high are used to indicate Start and Stop bits.

If the master intends to write to the slave, it repeatedly sends out a byte of data, with the slave responding after each byte with an 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, it repeatedly receives a byte of data from the slave and responds after each byte with an 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 SDA line while the SCL 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 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 SCL 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 SDA line, it is called arbitration. Arbitration ensures that there is only one master device communicating at any single time.

28.2.1 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 SCL 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 SCL line in order to transfer the next bit, but will detect that the clock line has not yet been released. Because the SCL 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.

28.2.2 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 at or about the same time. When this occurs, the process of arbitration begins. Each transmitter checks the level of the SDA 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 SDA line.

For example, if one transmitter holds the SDA 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 SDA 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 SDA line. If this transmitter is also a master device, it must also stop driving the SCL 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 SDA 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.

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28.3 I²C MODE OPERATION

All MSSP I²C communication is byte-oriented and shifted out MSb first. Six SFR registers and two interrupt flags interface the module with the PIC microcontroller and with the user's software. Two pins, SDA and SCL, are exercised by the module to communicate with other external I²C devices.

28.3.1 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 SCL line, the device outputting data on the SDA changes that pin to an input and reads in an acknowledge value on the next clock pulse.

The clock signal, SCL, is provided by the master. Data is valid to change while the SCL signal is low, and sampled on the rising edge of the clock. Changes on the SDA line while the SCL line is high define special conditions on the bus, explained in the following sections.

28.3.2 DEFINITION OF I²C TERMINOLOGY

There is language and terminology in the description of I²C communication that have definitions specific to I²C. Such word usage is defined in [Table 28-1](#) and may be used in the rest of this document without explanation. The information in this table is adapted from the Philips I²C specification.

28.3.3 SDA AND SCL PINS

Selecting any I²C mode with the SSPEN bit set forces the SCL and SDA 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.

28.3.4 SDA HOLD TIME

The hold time of the SDA pin is selected by the SDAHT bit in the SSPCON3 register. Hold time is the time SDA is held valid after the falling edge of SCL. Setting the SDAHT bit selects a longer 300 ns minimum hold time and may help on buses with large capacitance.

TABLE 28-1: I²C BUS TERMS

| Term | Description |
|------------------|--|
| Transmitter | The device that shifts data out onto the bus |
| Receiver | The device that 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 SDA and SCL 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 SSPADDx |
| Write Request | Slave receives a matching address with $\overline{R/W}$ bit clear and is ready to clock in data |
| Read Request | Master sends an address byte with the $\overline{R/W}$ 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 holds SCL low to stall communication |
| Bus Collision | Any time the SDA line is sampled low by the module while it is outputting and expected high state |

28.3.5 START CONDITION

The I²C specification defines a Start condition as a transition of SDA from a high state to a low state, while SCL 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 28-4 shows the wave forms for Start and Stop conditions.

A bus collision can occur on a Start condition if the module samples the SDA line low before asserting it low. This does not conform to the I²C Specification that states no bus collision can occur on a Start.

28.3.6 STOP CONDITION

A Stop condition is a transition of the SDA line from low-to-high state while the SCL line is high.

Note: At least one SCL low time must appear before a Stop is valid. Therefore, if the SDA line goes low then high again while the SCL line stays high, only the Start condition is detected.

28.3.7 RESTART CONDITION

A Restart is valid any time that a Stop is 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 a high address match fails.

28.3.8 START/STOP CONDITION INTERRUPT MASKING

The SCIE and PCIE bits in the SSPCON3 register can enable the generation of an interrupt in Slave modes that do not typically support this function. These bits will have no effect on slave modes where interrupt on Start and Stop detect are already enabled.

FIGURE 28-4: I²C START AND STOP CONDITIONS

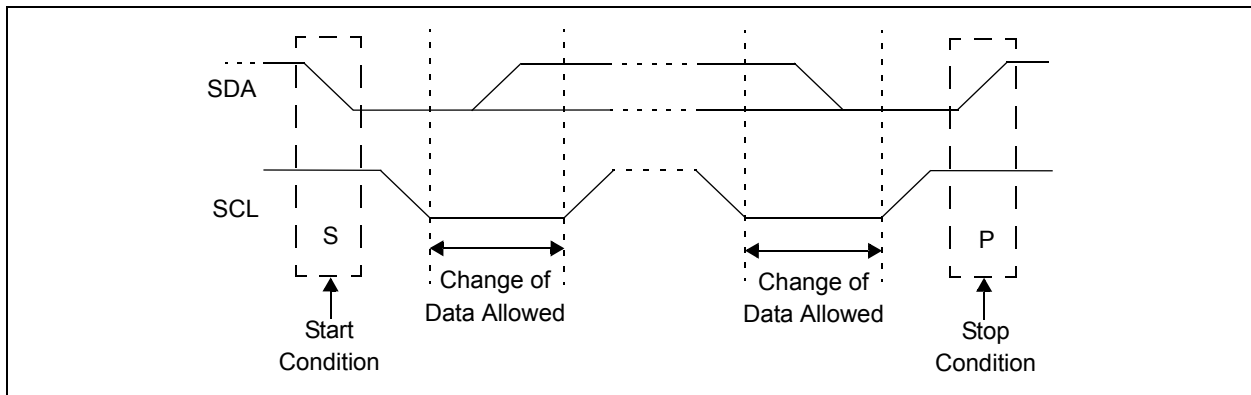
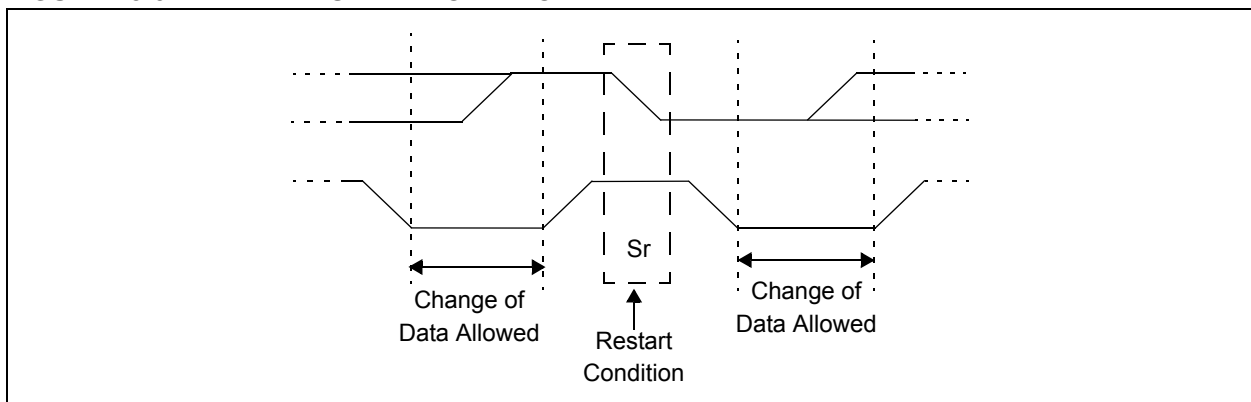


FIGURE 28-5: I²C RESTART CONDITION



28.3.9 ACKNOWLEDGE SEQUENCE

The ninth SCL 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 SDA line low. The transmitter must release control of the line during this time to shift in the response. The Acknowledge ($\overline{\text{ACK}}$) is an active-low signal, pulling the SDA line low, indicating 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 in the SSPCON2 register.

Slave software, when the AHEN and DHEN bits are set, allows the user to set the $\overline{\text{ACK}}$ value sent back to the transmitter. The ACKDT bit in the SSPCON2 register is set/cleared to determine the response.

Slave hardware will generate an $\overline{\text{ACK}}$ response if the AHEN and DHEN bits in the SSPCON3 register are clear.

There are certain conditions where an $\overline{\text{ACK}}$ will not be sent by the slave. If the BF bit in the SSPSTAT register or the SSPOV bit in the SSPCON1 register are set when a byte is received, the $\overline{\text{ACK}}$ will not be sent.

When the module is addressed, after the 8th falling edge of SCL on the bus, the ACKTIM bit in the SSPCON3 register is set. The ACKTIM bit indicates the acknowledge time of the active bus. The ACKTIM status bit is only active when the AHEN or DHEN bits are enabled.

28.4 I²C SLAVE-MODE OPERATION

The MSSP Slave mode operates in one of the four modes selected in the SSPM bits in SSPCON1 register. The modes can be divided into 7-bit and 10-bit Addressing mode. 10-bit Addressing mode operates the same as 7-bit, with some additional overhead for handling the larger addresses.

Modes with Start and Stop bit interrupts operate the same as the other modes, with SSPIF additionally getting set upon detection of a Start, Restart or Stop condition.

28.4.1 SLAVE MODE ADDRESSES

The SSPADD register 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 SSPBUF 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 SSPMSK1 register affects the address matching process. Refer to [Section 28.4.10 “SSPMSK1 Register”](#) for more information.

28.4.2 SECOND SLAVE MODE ADDRESS

The SSPADD2 register contains a second 7-bit 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 SSPBUF 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 SSPMSK2 register affects the address matching process. Refer to [Section 28.4.10 “SSPMSK1 Register”](#) for more information.

28.4.2.1 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.

28.4.2.2 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 are stored in bits 2 and 1 in the SSPADD register.

After the high byte has been acknowledged, the UA bit is set and SCL is held low until the user updates SSPADD with the low address. The low address byte is clocked in, and all 8 bits are compared to the low address value in SSPADD. Even if there is no address match, SSPIF and UA are set and SCL is held low until SSPADD is updated to receive a high byte again. When SSPADD 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.

28.4.3 SLAVE RECEPTION

When the $\overline{\text{R/W}}$ bit of a matching received address byte is clear, the $\overline{\text{R/W}}$ bit in the SSPSTAT register is cleared. The received address is loaded into the SSPBUF register and acknowledged.

When an overflow condition exists for a received address, then Not Acknowledge is given. An overflow condition is defined as either bit BF in the SSPSTAT register is set, or bit SSPOV in the SSPCON1 register is set. The BOEN bit in the SSPCON3 register modifies this operation. For more information, refer to [Register 28-4](#).

An MSSP interrupt is generated for each transferred data byte. Flag bit SSPIF must be cleared by software.

When the SEN bit in the SSPCON2 register is set, SCL will be held low (clock stretch) following each received byte. The clock must be released by setting the CKP bit in the SSPCON1 register, except sometimes in 10-bit mode.

28.4.3.1 7-Bit Addressing Reception

This section describes a standard sequence of events for the MSSP module configured as an I²C Slave in 7-bit Addressing mode, including all decisions made by hardware or software and their effect on reception. Figures 28-5 and 28-6 are 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 is detected.
2. S bit in the SSPSTAT register is set; SSPIF is set if interrupt on Start detect is enabled.
3. Matching address with R/W bit clear is received.
4. The slave pulls SDA low, sending an $\overline{\text{ACK}}$ to the master, and sets SSPIF bit.
5. Software clears the SSPIF bit.
6. Software reads received address from SSPBUF clearing the BF flag.
7. If SEN = 1, Slave software sets CKP bit to release the SCL line.
8. The master clocks out a data byte.
9. Slave drives SDA low sending an $\overline{\text{ACK}}$ to the master, and sets SSPIF bit.
10. Software clears SSPIF.
11. Software reads the received byte from SSPBUF clearing BF.
12. Steps 8–12 are repeated for all received bytes from the Master.
13. Master sends Stop condition, setting P bit in the SSPSTAT register, and the bus goes idle.

28.4.3.2 7-Bit Reception with AHEN and DHEN

Slave device reception with AHEN and DHEN set operates the same as without these options with extra interrupts and clock stretching added after the 8th falling edge of SCL. These additional interrupts allow the slave software to decide whether it wants the $\overline{\text{ACK}}$ to receive address or data byte, rather than the hardware.

Figure 28-7 displays a module using both address and data holding. Figure 28-8 includes the operation with the SEN bit in the SSPCON2 register set. The following list describes the steps that need to be taken by slave software to use these options for I²C communication:

1. S bit in the SSPSTAT register is set; SSPIF is set if interrupt on Start detect is enabled.
2. Matching address with R/W bit clear is clocked in. SSPIF is set and CKP cleared after the 8th falling edge of SCL.
3. Slave clears the SSPIF.
4. Slave can look at the ACKTIM bit in the SSPCON3 register to determine if the SSPIF was after or before the $\overline{\text{ACK}}$.
5. Slave reads the address value from SSPBUF, clearing the BF flag.
6. Slave sets $\overline{\text{ACK}}$ value clocked out to the master by setting ACKDT.
7. Slave releases the clock by setting CKP.
8. SSPxIF is set after an $\overline{\text{ACK}}$, not after a NACK.
9. If SEN = 1 the slave hardware will stretch the clock after the $\overline{\text{ACK}}$.
10. Slave clears SSPIF.

Note: SSPIF is still set after the 9th falling edge of SCL even if there is no clock stretching and BF has been cleared. Only if NACK is sent to Master is SSPIF not set.

11. SSPIF set and CKP cleared after 8th falling edge of SCL for a received data byte.
12. Slave looks at ACKTIM bit in the SSPCON3 register to determine the source of the interrupt.
13. Slave reads the received data from SSPBUF clearing BF.
14. Steps 7-14 are the same for each received data byte.
15. Communication is ended by either the slave sending an $\text{ACK} = 1$ 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 in the SSPSTAT register.

FIGURE 28-6: I²C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 0, AHEN = 0, DHEN = 0)

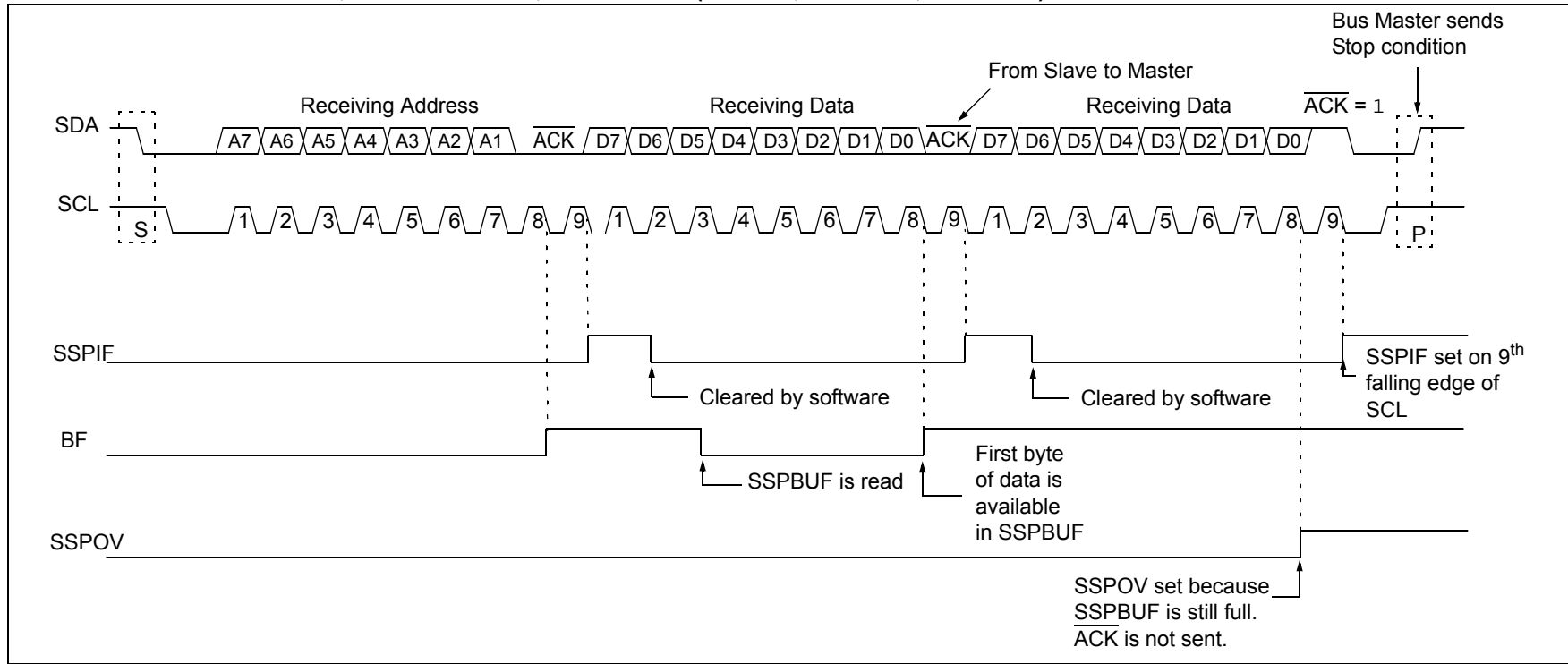


FIGURE 28-7: I²C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 1, AHEN = 0, DHEN = 0)

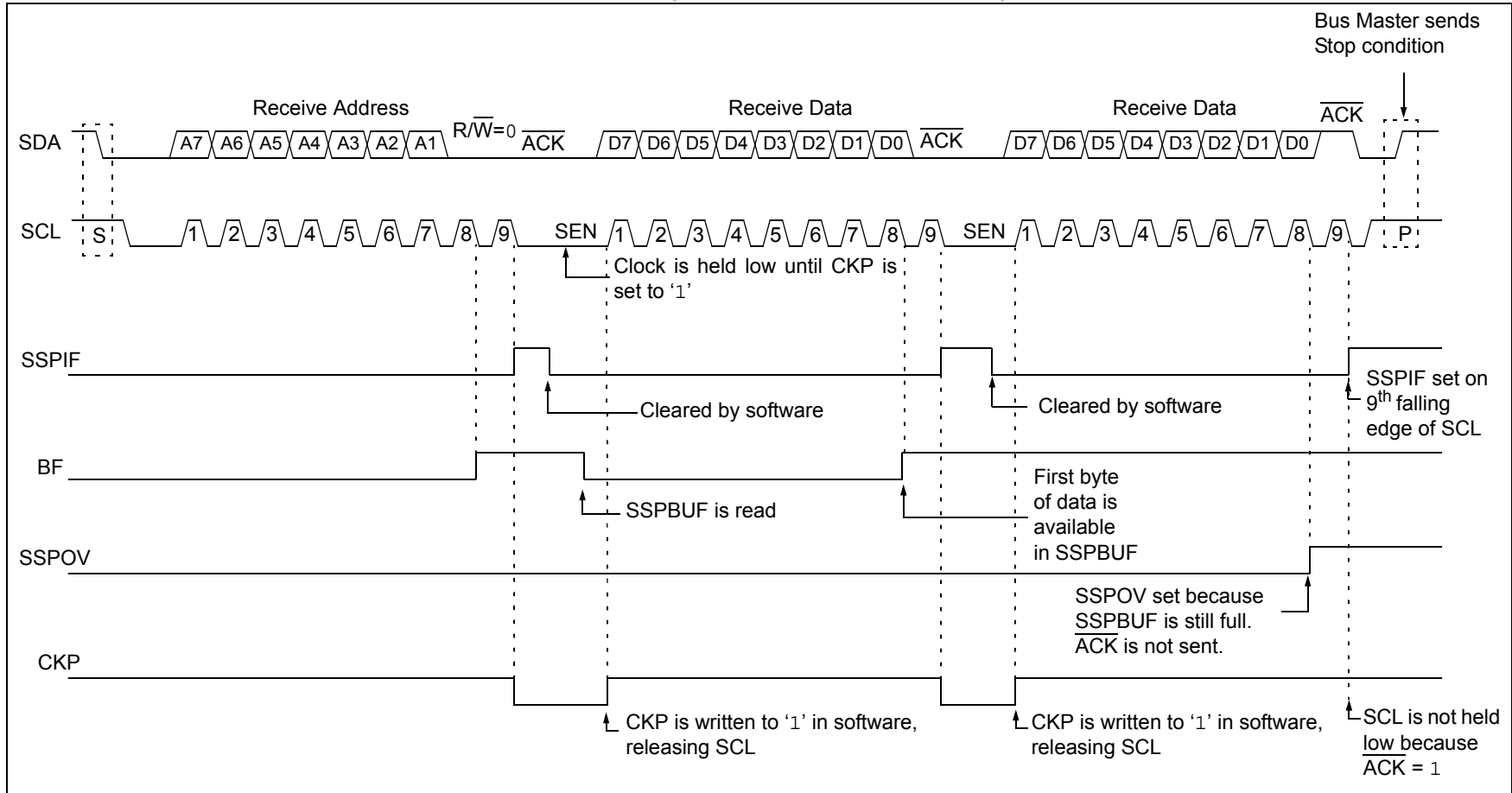


FIGURE 28-8: I²C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 0, AHEN = 1, DHEN = 1)

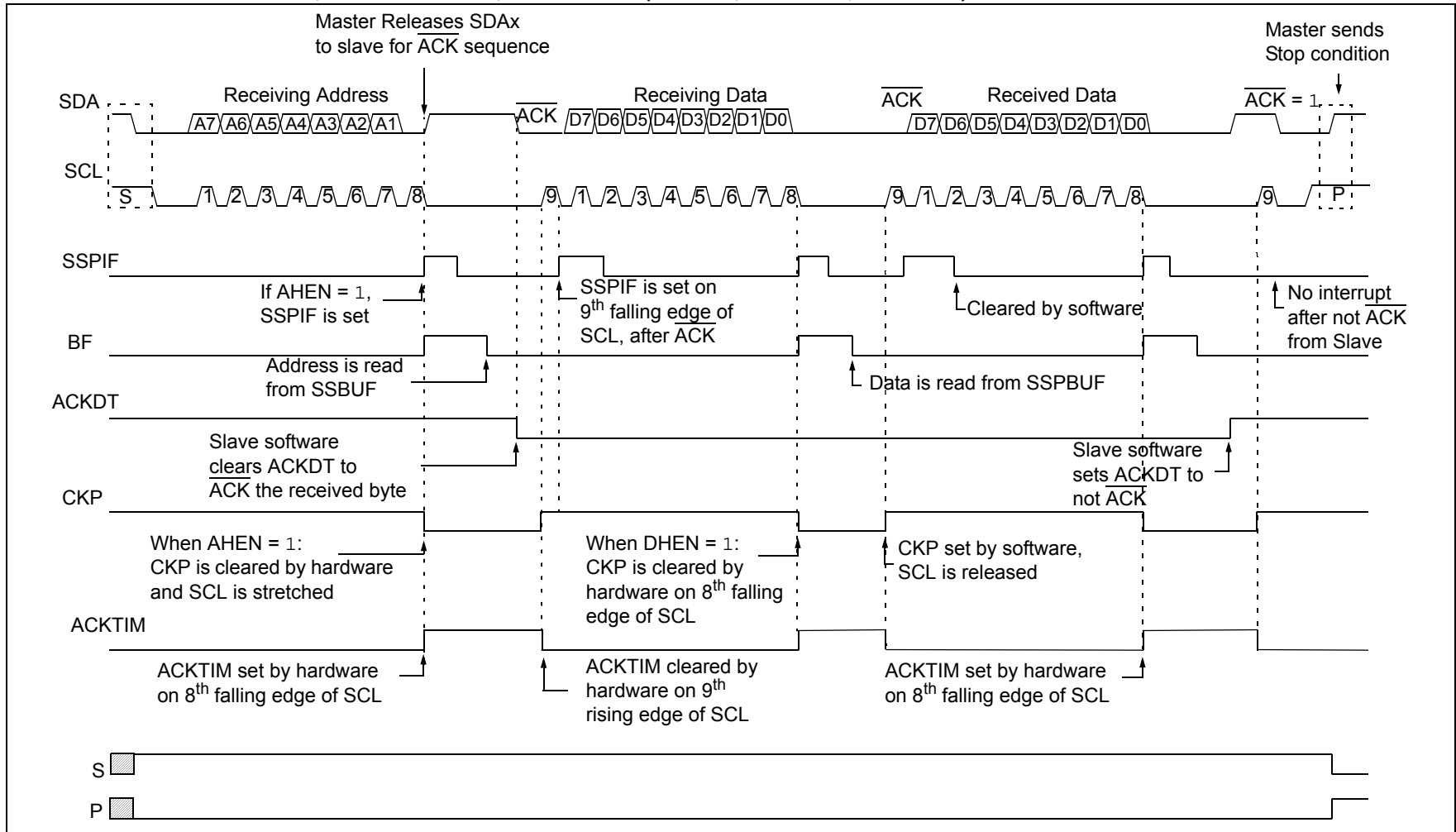
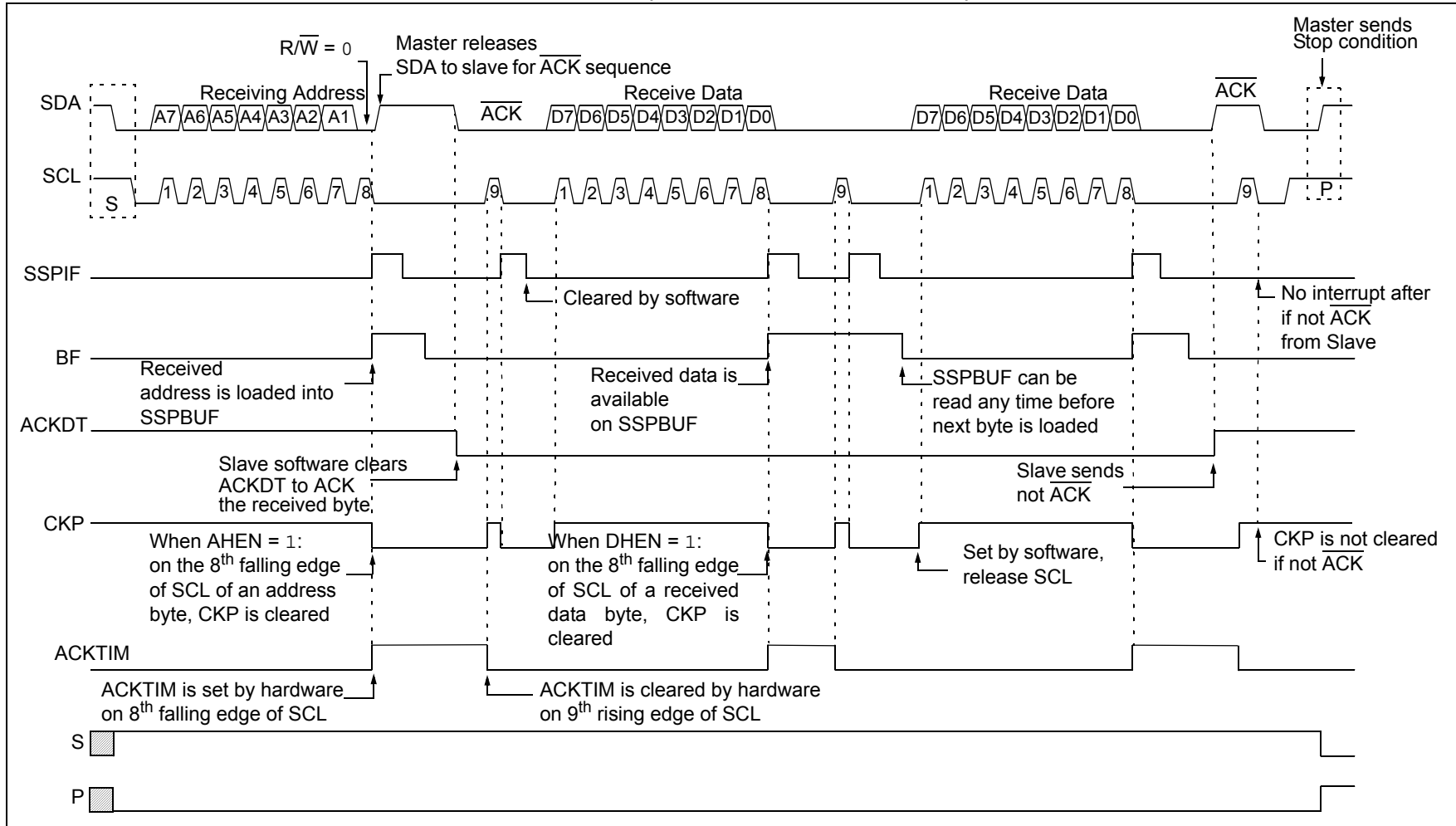


FIGURE 28-9: I²C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 1, AHEN = 1, DHEN = 1)



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28.4.4 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 in the SSPSTAT register is set. The received address is loaded into the SSPBUF register and an \overline{ACK} pulse is sent by the slave on the 9th bit.

Following the \overline{ACK} , slave hardware clears the CKP bit and the SCL pin is held low. Refer to [Section 28.4.7 “Clock Stretching”](#) for more details. 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 SSPBUF register, which also loads the SSPSR register. Then the SCL pin should be released by setting the CKP bit in the SSPCON1 register. The eight data bits are shifted out on the falling edge of the SCL input. This ensures that the SDA signal is valid during the SCL high time.

The \overline{ACK} pulse from the master-receiver is latched on the rising edge of the 9th SCL input pulse. This \overline{ACK} value is copied to the ACKSTAT bit in the SSPCON2 register. If ACKSTAT is set (not \overline{ACK}), 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 SDA line was low (\overline{ACK}), the next transmit data must be loaded into the SSPBUF register. Again, the SCL pin must be released by setting bit CKP.

An MSSP interrupt is generated for each data transfer byte. The SSPIF bit must be cleared by software, and the SSPSTAT register is used to determine the status of the byte. The SSPIF bit is set on the falling edge of the 9th clock pulse.

28.4.4.1 Slave Mode Bus Collision

A slave receives a Read request and begins shifting data out on the SDA line. If a bus collision is detected and the SBCDE bit in the SSPCON3 register is set, the BCLIF bit in the PIR register is set. Once a bus collision is detected, the slave goes idle and waits to be addressed again. The user's software can use the BCLIF bit to handle a slave bus collision.

28.4.4.2 7-Bit Transmission

A master device can transmit a read request to a slave, and then it clocks data out of the slave. The list below outlines what software for a slave will need to do to accomplish a standard transmission. [Figure 28-10](#) can be used as a reference to this list:

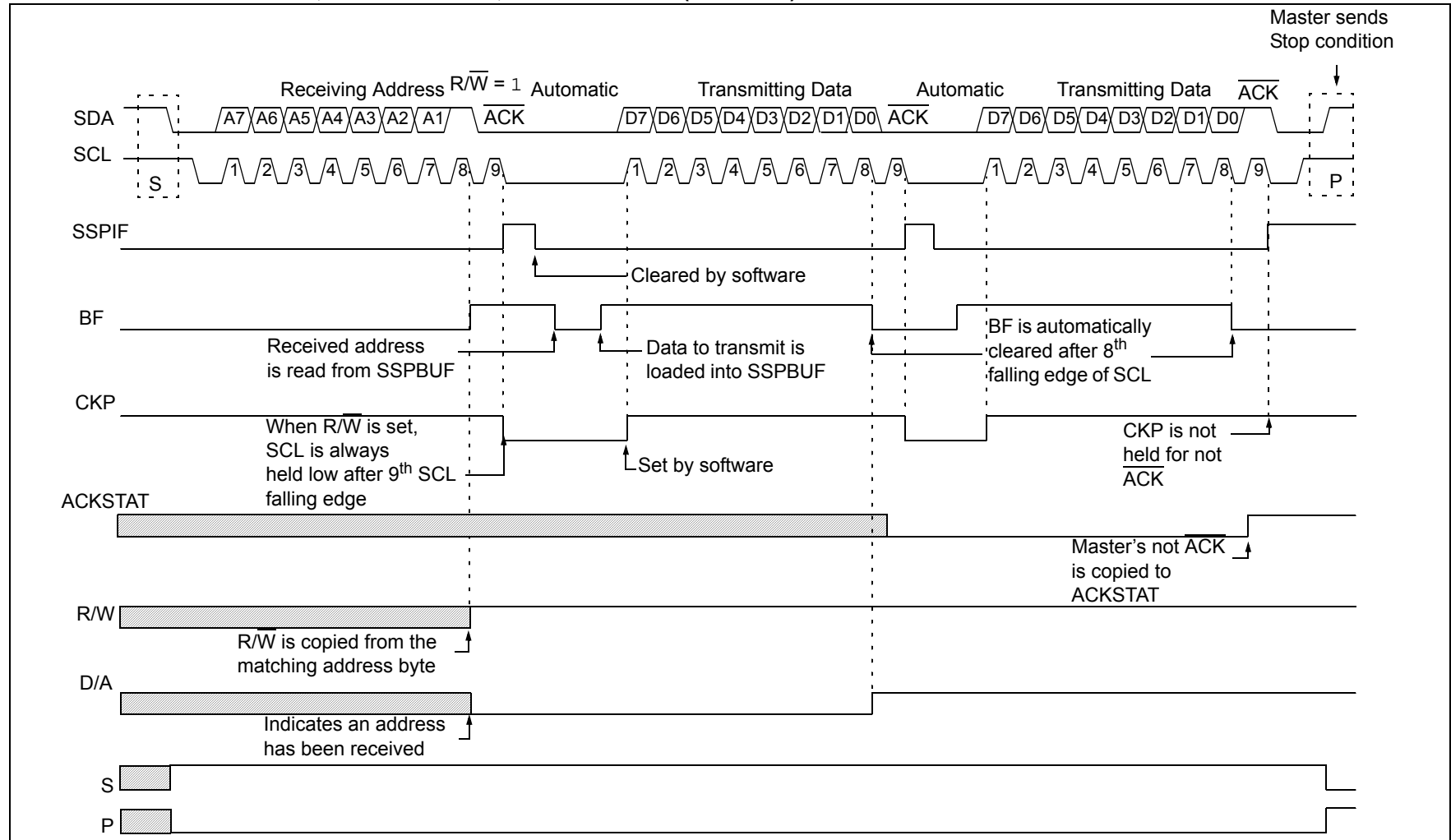
1. Master sends a Start condition on SDA and SCL.
2. S bit in the SSPSTAT register is set; SSPIF is set if interrupt on Start detect is enabled.
3. Matching address with $\overline{R/W}$ bit set is received by the Slave setting SSPIF bit.
4. Slave hardware generates an \overline{ACK} and sets SSPIF.
5. SSPIF bit is cleared by user.
6. Software reads the received address from SSPBUF, 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 SSPBUF.
9. CKP bit is set releasing SCL, allowing the master to clock the data out of the slave.
10. SSPIF is set after the \overline{ACK} response from the master is loaded into the ACKSTAT register.
11. SSPIF 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 SCL (9th) rather than on the falling edge.

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 SSPIF is still set.
15. The master sends a Restart condition or a Stop.
16. The slave is no longer addressed.

FIGURE 28-10: I²C SLAVE, 7-BIT ADDRESS, TRANSMISSION (AHEN = 0)



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28.4.4.3 7-Bit Transmission with Address Hold Enabled

Setting the AHEN bit in the SSPCON3 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 SSPIF interrupt is set.

Figure 28-11 displays a standard waveform of a 7-bit Address Slave Transmission with AHEN enabled:

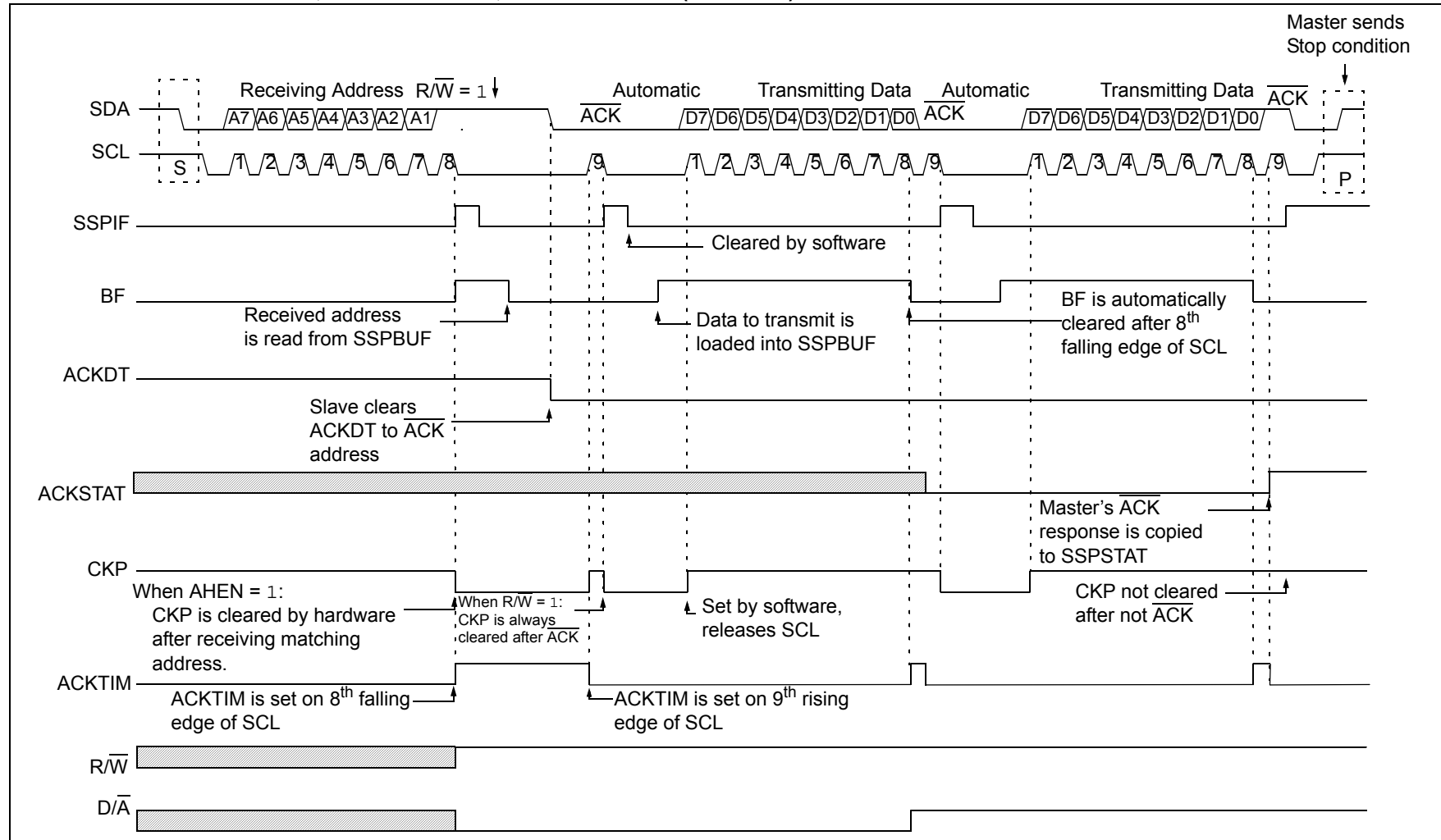
1. Bus starts idle.
2. Master sends Start condition; the S bit in the SSPSTAT register is set; SSPIF is set if interrupt on Start detect is enabled.
3. Master sends matching address with $\overline{R/W}$ bit set. After the 8th falling edge of the SCL line, the CKP bit is cleared and SSPIF interrupt is generated.
4. Slave software clears SSPIF.
5. Slave software reads \overline{ACKTIM} bit in the SSPCON3 register and $\overline{R/W}$ and D/A bits in the SSPSTAT register to determine the source of the interrupt.
6. Slave reads the address value from the SSPBUF register, clearing the BF bit.
7. Slave software decides from this information if it wishes to ACK or not ACK, and sets ACKDT bit in the SSPCON2 register accordingly.
8. Slave sets the CKP bit releasing SCL.
9. Master clocks in the \overline{ACK} value from the slave.
10. Slave hardware automatically clears the CKP bit and sets SSPIF after the ACK if the $\overline{R/W}$ bit is set.
11. Slave software clears SSPIF.
12. Slave loads value to transmit to the master into SSPBUF setting the BF bit.

Note: SSPBUF cannot be loaded until after the 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 SCL pulse.
15. Slave hardware copies the \overline{ACK} value into the ACKSTAT bit in the SSPCON2 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 SCL line to receive a Stop.

FIGURE 28-11: I²C SLAVE, 7-BIT ADDRESS, TRANSMISSION (AHEN = 1)



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28.4.5 SLAVE MODE 10-BIT ADDRESS RECEPTION

This section describes a standard sequence of events for the MSSP module configured as an I²C Slave in 10-bit Addressing mode.

Figure 28-12 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 in the SSPSTAT register is set; SSPIF is set if interrupt on Start detect is enabled.
3. Master sends matching high address with $\overline{R/W}$ bit clear; UA bit in the SSPSTAT register is set.
4. Slave sends \overline{ACK} and SSPIF is set.
5. Software clears the SSPIF bit.
6. Software reads received address from SSPBUF, clearing the BF flag.
7. Slave loads low address into SSPADD, releasing SCL.
8. Master sends matching low-address byte to the Slave; UA bit is set.

Note: Updates to the SSPADD register are not allowed until after the \overline{ACK} sequence.

9. Slave sends \overline{ACK} and SSPIF is set.

Note: If the low address does not match, SSPIF and UA are still set so that the slave software can set SSPADD back to the high address. BF is not set because there is no match. CKP is unaffected.

10. Slave clears SSPIF.
11. Slave reads the received matching address from SSPBUF, clearing BF.
12. Slave loads high address into SSPADD.
13. Master clocks a data byte to the slave and clocks out the slave's \overline{ACK} on the 9th SCL pulse; SSPIF is set.
14. If SEN bit in the SSPCON2 register is set, CKP is cleared by hardware and the clock is stretched.
15. Slave clears SSPIF.
16. Slave reads the received byte from SSPBUF, clearing BF.
17. If SEN is set, the slave sets CKP to release the SCL.
18. Steps 13–17 are repeated for each received byte.
19. Master sends Stop to end the transmission.

28.4.6 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 SSPADD register using the UA bit. All functionality, specifically when the CKP bit is cleared and the SCL line is held low, is the same. Figure 28-13 can be used as a reference of a slave in 10-bit addressing with AHEN set.

Figure 28-14 shows a standard waveform for a slave transmitter in 10-bit Addressing mode.

FIGURE 28-12: I²C SLAVE, 10-BIT ADDRESS, RECEPTION (SEN = 1, AHEN = 0, DHEN = 0)

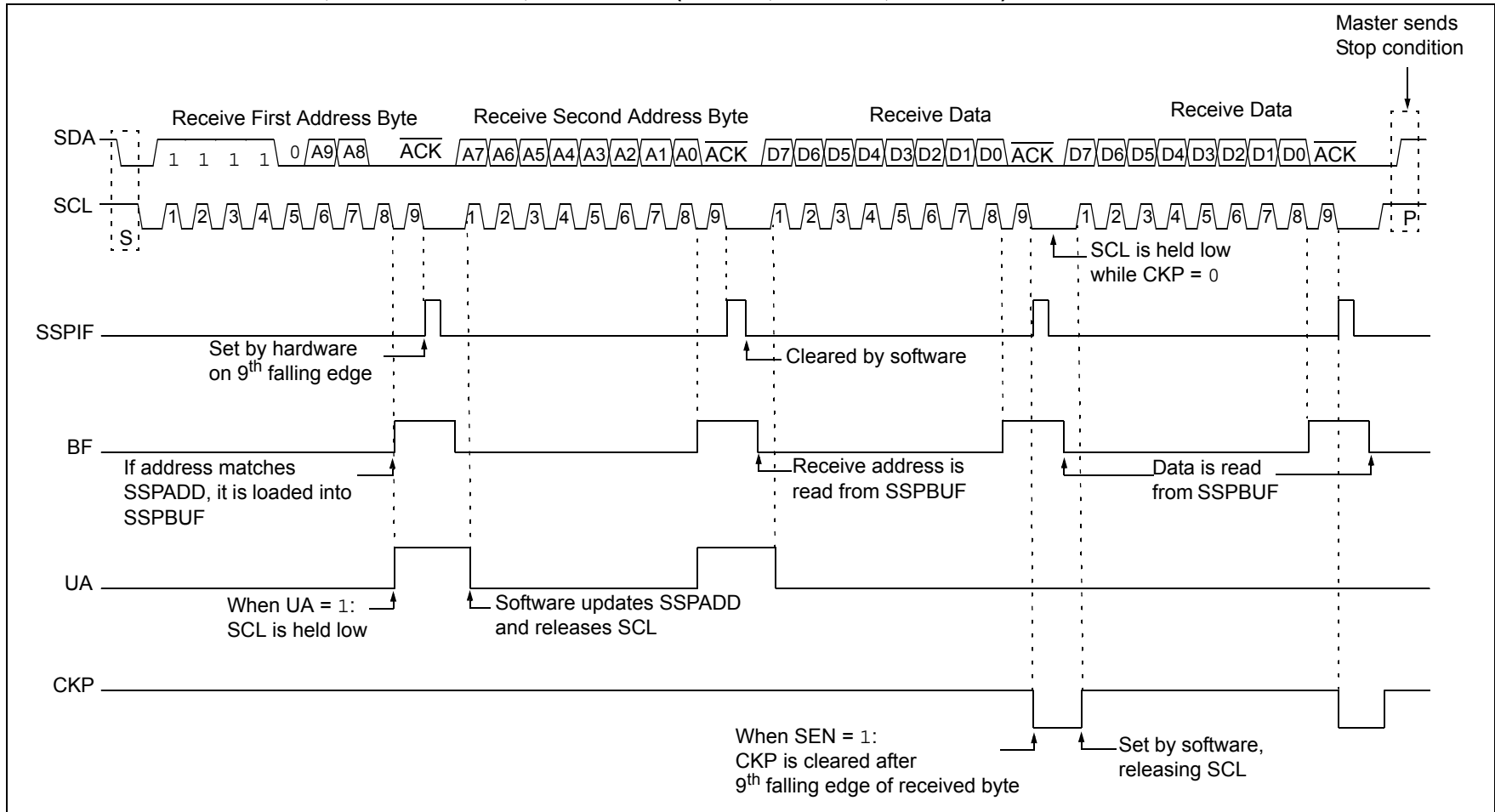


FIGURE 28-13: I²C SLAVE, 10-BIT ADDRESS, RECEPTION (SEN = 0, AHEN = 1, DHEN = 0)

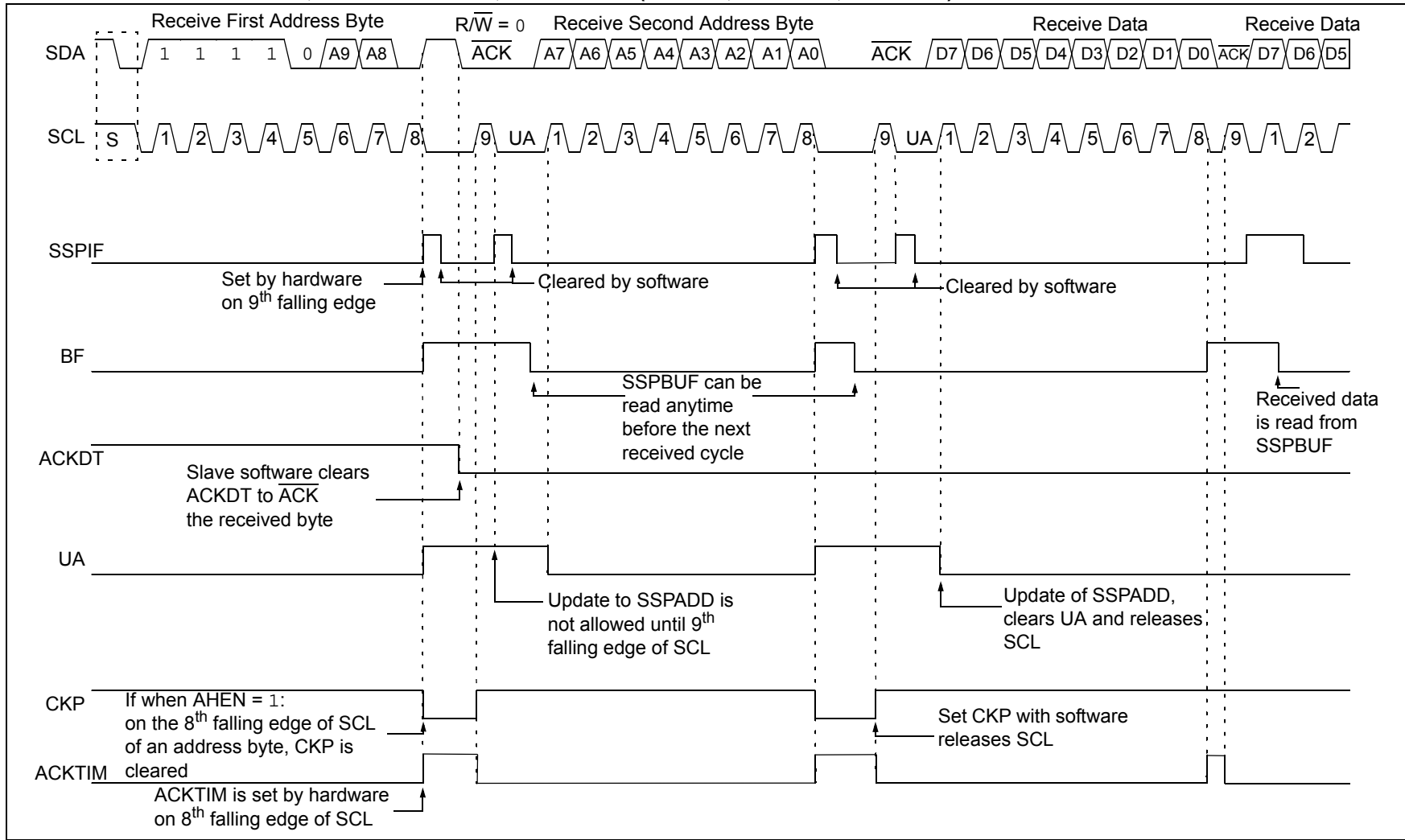
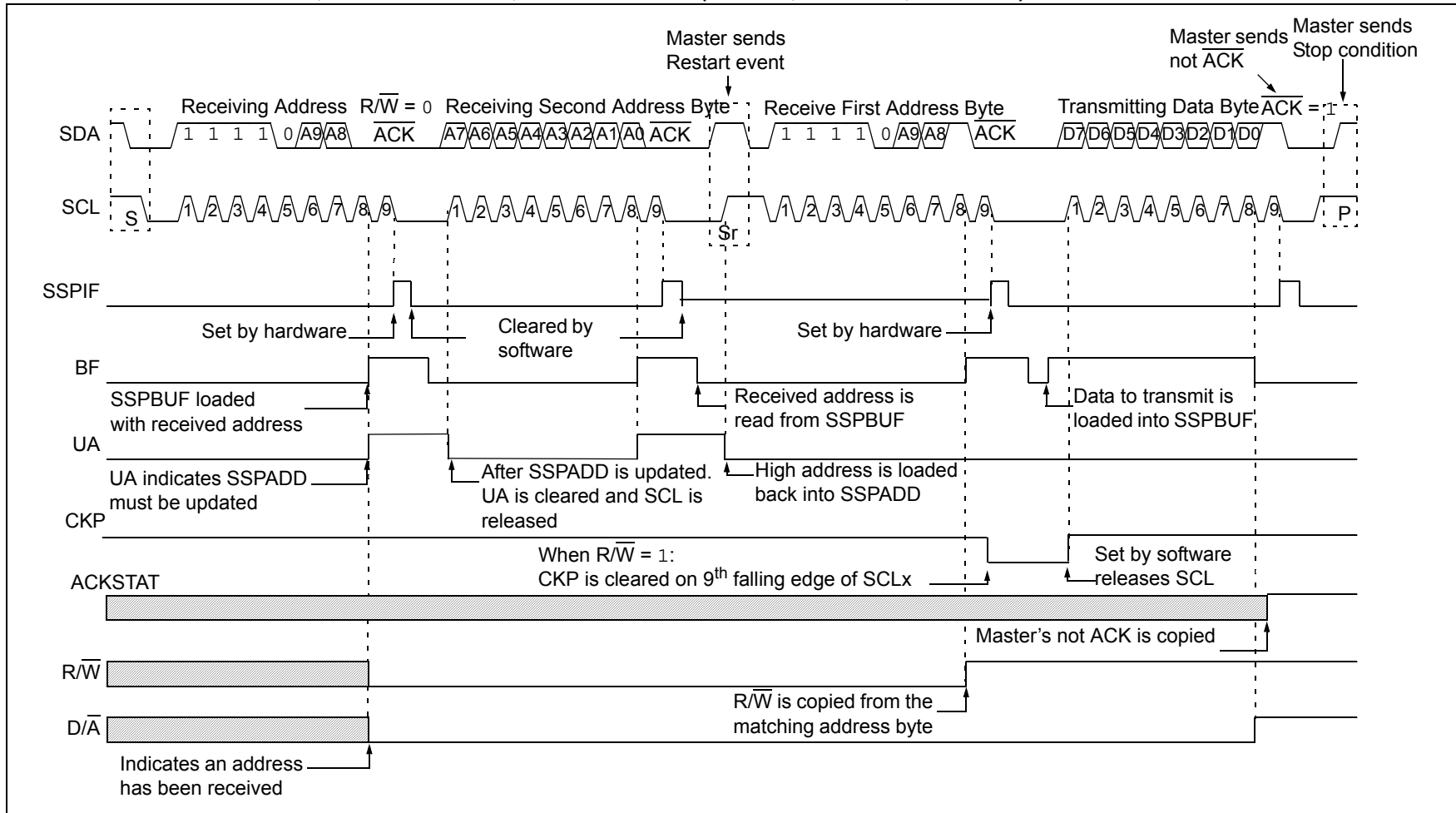


FIGURE 28-14: I²C SLAVE, 10-BIT ADDRESS, TRANSMISSION (SEN = 0, AHEN = 0, DHEN = 0)



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28.4.7 CLOCK STRETCHING

Clock stretching occurs when a device on the bus holds the SCL 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 it is stretching any time it is active on the bus and not transferring data. Any stretching done by a slave is invisible to the master software and handled by the hardware that generates SCL.

The CKP bit in the SSPCON1 register is used to control stretching in software. Any time the CKP bit is cleared, the module will wait for the SCL line to go low and then hold it. Setting CKP will release SCL and allow more communication.

28.4.7.1 Normal Clock Stretching

Following an $\overline{\text{ACK}}$, if the $\text{R}\overline{\text{W}}$ bit in the SSPSTAT register is set, causing a read request, the slave hardware will clear CKP. This allows the slave time to update SSPBUF with data to transfer to the master. If the SEN bit in the SSPCON2 register 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 whether the clock will be stretched or not. This is different from previous versions of the module that would not stretch the clock or clear CKP if SSPBUF was read before the 9th falling edge of SCL.

2: Previous versions of the module did not stretch the clock for a transmission if SSPBUF was loaded before the 9th falling edge of SCL. It is now always cleared for read requests.

28.4.7.2 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 SCL is stretched without CKP being cleared. SCL is released immediately after a write to SSPADD.

Note: Previous versions of the module did not stretch the clock if the second address byte did not match.

28.4.7.3 Byte NACKing

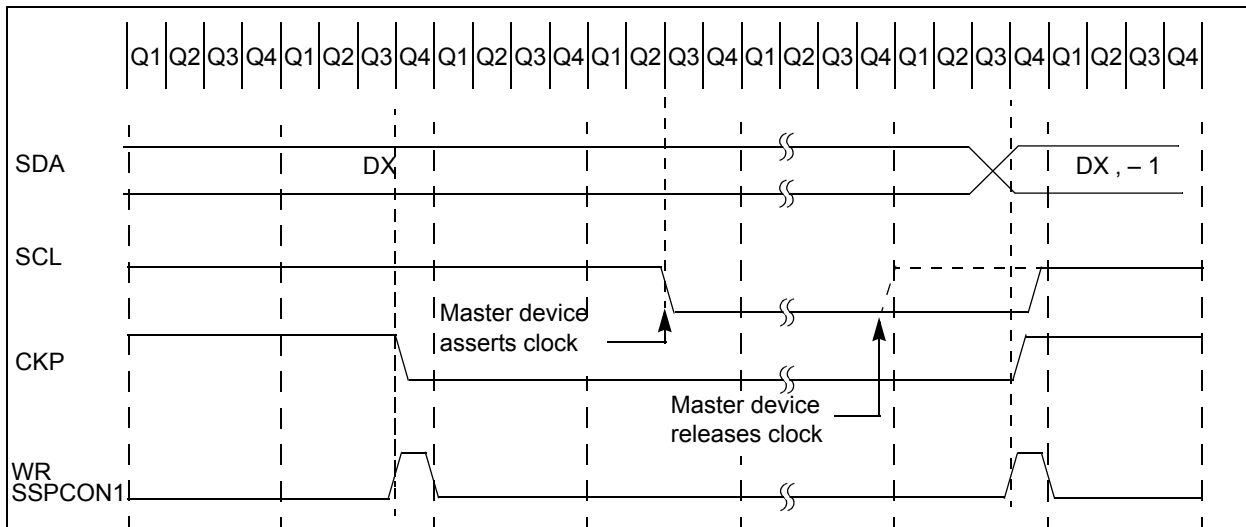
When AHEN bit in the SSPCON3 register is set, CKP is cleared by hardware after the 8th falling edge of SCL for a received matching address byte. When DHEN bit in the SSPCON3 register is set, CKP is cleared after the 8th falling edge of SCL for received data.

Stretching after the 8th falling edge of SCL allows the slave to look at the received address or data and decide if it wants to ACK the received data.

28.4.8 CLOCK SYNCHRONIZATION AND THE CKP BIT

Any time the CKP bit is cleared, the module will wait for the SCL line to go low and then hold it. However, clearing the CKP bit will not assert the SCL output low until the SCL output is already sampled low. Therefore, the CKP bit will not assert the SCL line until an external I²C master device has already asserted the SCL line. The SCL output will remain low until the CKP bit is set and all other devices on the I²C bus have released SCL. This ensures that a write to the CKP bit will not violate the minimum high time requirement for SCL (refer to [Figure 28-15](#)).

FIGURE 28-15: CLOCK SYNCHRONIZATION TIMING



28.4.9 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.

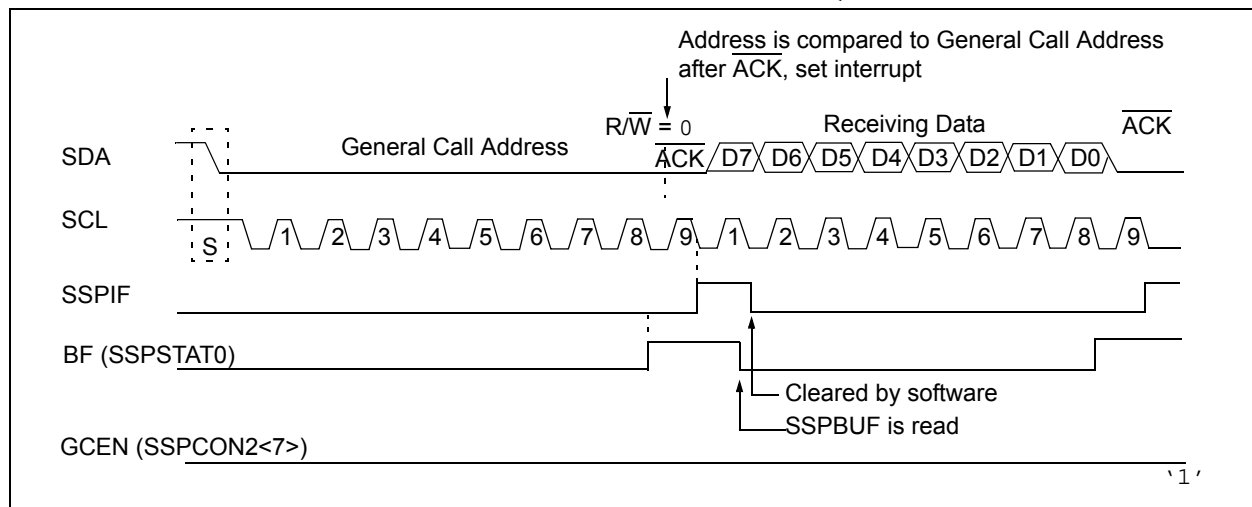
The general call address is a reserved address in the I²C protocol, defined as address 0x00. When the GCEN bit in the SSPCON2 register is set, the slave module will automatically ACK the reception of this address regardless of the value stored in SSPADD. After the slave clocks in an address of all zeros with

the R/W bit clear, an interrupt is generated and slave software can read SSPBUF and respond. Figure 28-16 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 in the SSPCON3 register is set, just as with any other address reception, the slave hardware will stretch the clock after the 8th falling edge of SCL. The slave must then set its ACKDT value and release the clock with communication progressing as it would normally.

FIGURE 28-16: SLAVE MODE GENERAL CALL ADDRESS SEQUENCE



28.4.10 SSPMSK1 REGISTER

An SSP Mask (SSPMSK1) register is available in I²C Slave mode as a mask for the value held in the SSPSR register during an address comparison operation. A zero ('0') bit in the SSPMSK1 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 SSP operation until written with a mask value.

The SSPMSK1 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 SSP mask has no effect during the reception of the first (high) byte of the address.

28.5 I²C MASTER MODE

Master mode is enabled by setting and clearing the appropriate SSPM bits in the SSPCON1 register and by setting the SSPEN bit. In Master mode, the SDA and SCK pins must be configured as inputs. The MSSP peripheral hardware will override the output driver TRIS controls when necessary, to drive the pins low.

The 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 MSSP 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's software directly manipulating the SDA and SCL lines.

The following events will cause the SSP Interrupt Flag bit (SSPIF) to be set (SSP interrupt, if enabled):

- Start condition detected
- Stop condition detected
- Data transfer byte transmitted/received
- Acknowledge transmitted/received
- Repeated Start generated

Note 1: The MSSP module, when configured in I²C Master mode, does not allow queuing of events. For instance, the user is not allowed to initiate a Start condition and immediately write the SSPBUF register to initiate transmission before the Start condition is complete. In this case, the SSPBUF will not be written to and the WCOL bit will be set, indicating that a write to the SSPBUF 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.

28.5.1 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 Transmit mode, serial data is output through SDA while SCL 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.

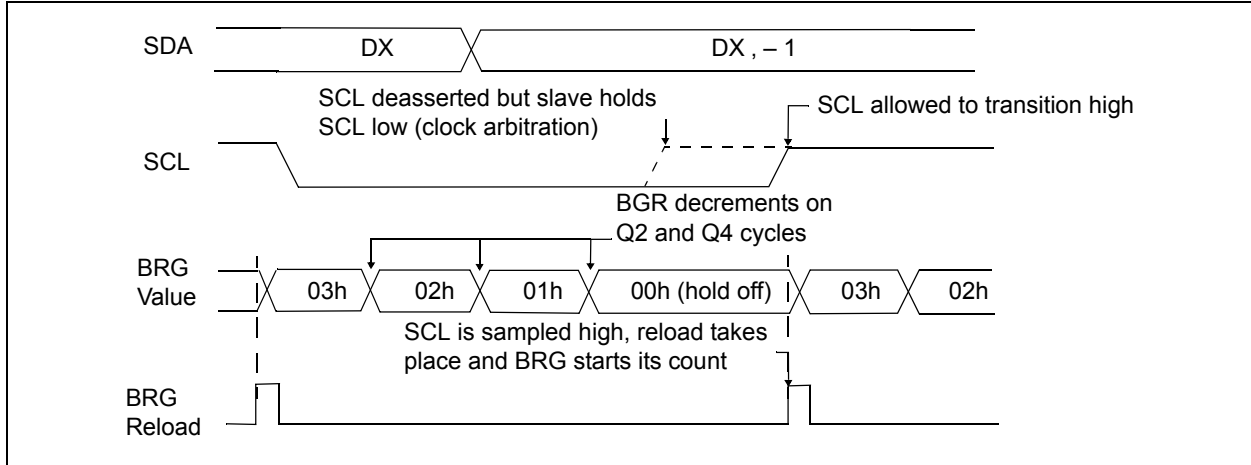
In Master Receive mode, the first byte transmitted contains the slave address of the transmitting device (7 bits) and the R/W bit. In this case, the R/W bit will be logic '1'. Thus, the first byte transmitted is a 7-bit slave address followed by a '1' to indicate the receive bit. Serial data is received via SDA, while SCL 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 SCL. Refer to [Section 28.6 "Baud Rate Generator"](#) for more details.

28.5.2 CLOCK ARBITRATION

Clock arbitration occurs when the master, during any receive, transmit or Repeated Start/Stop condition, releases the SCL pin (SCL allowed to float high). When the SCL pin is allowed to float high, the Baud Rate Generator (BRG) is suspended from counting until the SCL pin is actually sampled high. When the SCL pin is sampled high, the Baud Rate Generator is reloaded with the contents of SSPADD<7:0> and begins counting. This ensures that the SCL 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 28-17](#)).

FIGURE 28-17: BAUD RATE GENERATOR TIMING WITH CLOCK ARBITRATION



28.5.3 WCOL STATUS FLAG

If the user writes the SSPBUF 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 SSPBUF was attempted while the module was not idle.

Note: Because queuing of events is not allowed, writing to the lower 5 bits in the SSPCON2 register is disabled until the Start condition is complete.

of the SDA being driven low while SCL is high is the Start condition and causes the S bit in the SSPSTAT1 register to be set. Following this, the Baud Rate Generator is reloaded with the contents of SSPADD<7:0> and resumes its count. When the Baud Rate Generator times out (T_{BRG}), the SEN bit in the SSPCON2 register will be automatically cleared by hardware; the Baud Rate Generator is suspended, leaving the SDA line held low and the Start condition is complete.

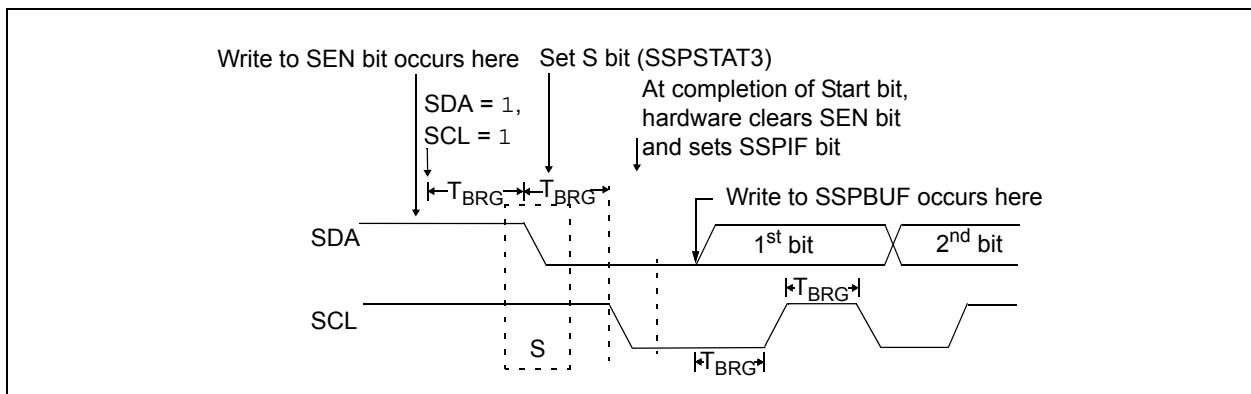
Note 1: If, at the beginning of the Start condition, the SDA and SCL pins are already sampled low, or if, during the Start condition, the SCL line is sampled low before the SDA line is driven low, a bus collision occurs, the Bus Collision Interrupt Flag, BCLIF, is set, the Start condition is aborted and the I²C module is reset into its idle state.

28.5.4 I²C MASTER MODE START CONDITION TIMING

To initiate a Start condition, the user sets the Start Enable bit (SEN) in the SSPCON2 register. If the SDA and SCL pins are sampled high, the Baud Rate Generator is reloaded with the contents of SSPADD<7:0> and starts its count. If SCL and SDA are both sampled high when the Baud Rate Generator times out (T_{BRG}), the SDA pin is driven low. The action

2: The Philips I²C Specification states that a bus collision cannot occur on a Start.

FIGURE 28-18: FIRST START BIT TIMING



28.5.6 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 SSPBUF register. This action will set the Buffer Full (BF) flag bit and allow the Baud Rate Generator to begin counting and start the next transmission. Each bit of address/data will be shifted out onto the SDA pin after the falling edge of SCL is asserted. SCL is held low for one Baud Rate Generator rollover count (T_{BRG}). Data should be valid before SCL is released high. When the SCL pin is released high, it is held that way for T_{BRG} . The data on the SDA pin must remain stable for that duration and some hold time after the next falling edge of SCL. After the 8th bit is shifted out (the falling edge of the 8th clock), the BF flag is cleared and the master releases the SDA. This allows the slave device being addressed to respond with an \overline{ACK} bit during the 9th bit time if an address match occurred or if data was received properly. The status of \overline{ACK} is written into the ACKSTAT bit on the rising edge of the 9th clock. If the master receives an Acknowledge, the Acknowledge Status bit (ACKSTAT) is cleared. If not, the bit is set. After the 9th clock, the SSPIF bit is set and the master clock (Baud Rate Generator) is suspended until the next data byte is loaded into the SSPBUF, leaving SCL low and SDA unchanged (Figure 28-20).

After the write to the SSPBUF, each bit of the address will be shifted out on the falling edge of SCL until all seven address bits and the R/W bit are completed. On the falling edge of the 8th clock, the master will release the SDA pin, allowing the slave to respond with an Acknowledge. On the falling edge of the 9th clock, the master will sample the SDA pin to see if the address was recognized by a slave. The status of the \overline{ACK} bit is loaded into the ACKSTAT status bit in the SSPCON2 register. Following the falling edge of the 9th clock transmission of the address, the SSPIF is set, the BF flag is cleared and the Baud Rate Generator is turned off until another write to the SSPBUF takes place, holding SCL low and allowing SDA to float.

28.5.6.1 BF Status Flag

In Transmit mode, the BF bit in the SSPSTAT register is set when the CPU writes to SSPBUF and is cleared when all 8 bits are shifted out.

28.5.6.2 WCOL Status Flag

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

WCOL must be cleared by software before the next transmission.

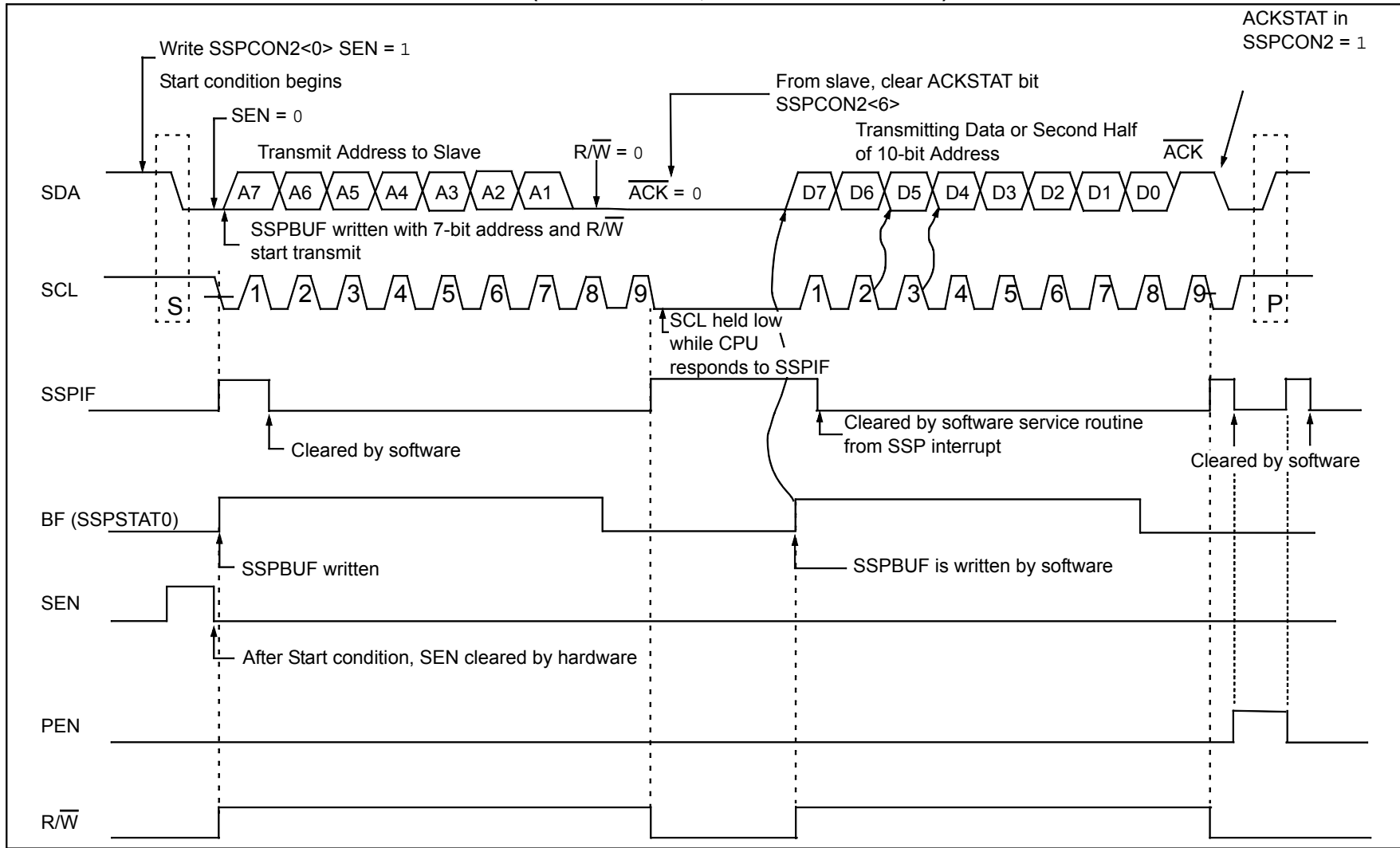
28.5.6.3 ACKSTAT Status Flag

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

28.5.6.4 Typical Transmit Sequence:

1. The user generates a Start condition by setting the SEN bit in the SSPCON2 register.
2. SSPIF is set by hardware on completion of the Start.
3. SSPIF is cleared by software.
4. The MSSP module will wait the required start time before any other operation takes place.
5. The user loads the SSPBUF with the slave address to transmit.
6. Address is shifted out the SDA pin until all 8 bits are transmitted. Transmission begins as soon as SSPBUF is written to.
7. The MSSP module shifts in the \overline{ACK} bit from the slave device and writes its value into the ACKSTAT bit in the SSPCON2 register.
8. The MSSP module generates an interrupt at the end of the 9th clock cycle by setting the SSPIF bit.
9. The user loads the SSPBUF with 8 bits of data.
10. Data is shifted out the SDA pin until all 8 bits are transmitted.
11. The MSSP module shifts in the \overline{ACK} bit from the slave device and writes its value into the ACKSTAT bit in the SSPCON2 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 in the SSPCON2 register. Interrupt is generated once the Stop/Restart condition is complete.

FIGURE 28-20: I²C MASTER MODE WAVEFORM (TRANSMISSION, 7 OR 10-BIT ADDRESS)



28.5.7 I²C MASTER MODE RECEPTION

Master mode reception is enabled by programming the Receive Enable (RCEN) bit in the SSPCON2 register.

Note: The MSSP 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, upon each rollover, the state of the SCL pin changes (high-to-low/low-to-high) and data is shifted into the SSPSR. After the falling edge of the 8th clock, the receive enable flag is automatically cleared, the contents of the SSPSR are loaded into the SSPBUF, the BF flag bit is set, the SSPIF flag bit is set and the Baud Rate Generator is suspended from counting, holding SCL low. The MSSP is now in idle state awaiting the next command. When the buffer is read by the CPU, the BF flag bit is automatically cleared. The user can then send an Acknowledge bit at the end of reception by setting the Acknowledge Sequence Enable (ACKEN) bit in the SSPCON2 register.

28.5.7.1 BF Status Flag

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

28.5.7.2 SSPOV Status Flag

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

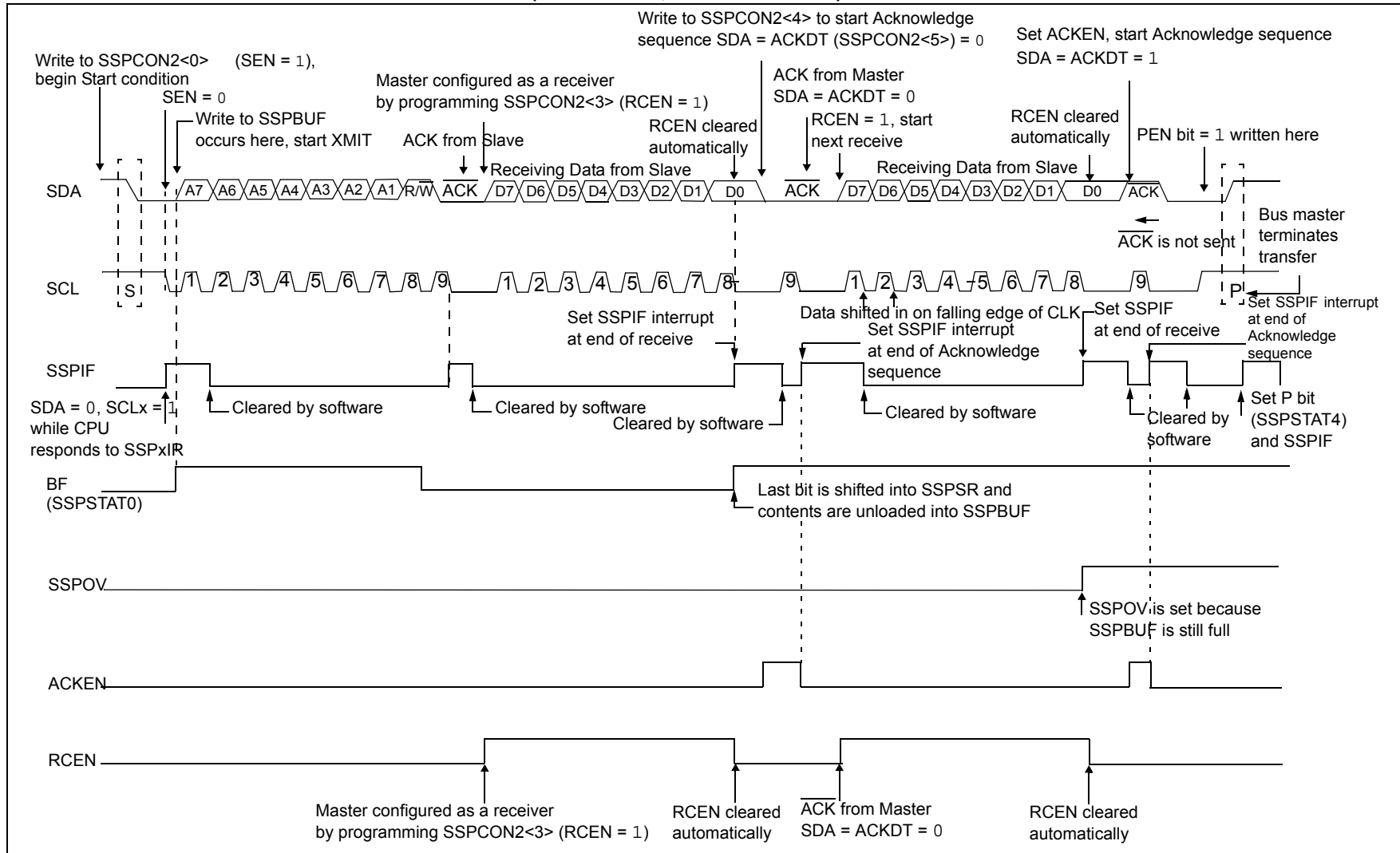
28.5.7.3 WCOL Status Flag

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

28.5.7.4 Typical Receive Sequence

1. The user generates a Start condition by setting the SEN bit in the SSPCON2 register.
2. SSPIF is set by hardware on completion of the Start.
3. SSPIF is cleared by software.
4. User writes SSPBUF with the 7-bit slave address to transmit and sets the R/W bit.
5. Address is shifted out the SDA pin until all 8 bits are transmitted. Transmission begins as soon as SSPBUF is written to.
6. The MSSP module shifts in the $\overline{\text{ACK}}$ bit from the slave device and writes its value into the ACKSTAT bit in the SSPCON2 register.
7. The MSSP module generates an interrupt at the end of the 9th clock cycle by setting the SSPIF bit.
8. User sets the RCEN bit in the SSPCON2 register and the Master clocks in a byte from the slave.
9. After the 8th falling edge of SCL, SSPIF and BF are set.
10. Master clears SSPIF and reads the received byte from SSPBUF, then clears BF.
11. Master sets $\overline{\text{ACK}}$ value sent to slave in ACKDT bit in the SSPCON2 register and initiates the $\overline{\text{ACK}}$ by setting the ACKEN bit.
12. Master's $\overline{\text{ACK}}$ is clocked out to the Slave and SSPIF is set.
13. The user clears SSPIF.
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 28-21: I²C MASTER MODE WAVEFORM (RECEPTION, 7-BIT ADDRESS)



28.5.8 ACKNOWLEDGE SEQUENCE TIMING

An Acknowledge sequence is enabled by setting the Acknowledge Sequence Enable (ACKEN) bit in the SSPCON2 register. When this bit is set, the SCL pin is pulled low and the contents of the Acknowledge data bit are presented on the SDA 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 (T_{BRG}) and the SCL pin is deasserted (pulled high). When the SCL pin is sampled high (clock arbitration), the Baud Rate Generator counts for T_{BRG} . The SCL pin is then pulled low. Following this, the ACKEN bit is automatically cleared, the Baud Rate Generator is turned off and the MSSP module then goes into Idle mode (Figure 28-22).

28.5.8.1 WCOL Status Flag

If the user writes the SSPBUF when an Acknowledge sequence is in progress, WCOL is set and the contents of the buffer are unchanged (the write does not occur).

28.5.9 STOP CONDITION TIMING

A Stop bit is asserted on the SDA pin at the end of a receive/transmit by setting the Stop Sequence Enable bit, PEN, in the SSPCON2 register. At the end of a receive/transmit, the SCL line is held low after the falling edge of the 9th clock. When the PEN bit is set, the master will assert the SDA line low. When the SDA line is sampled low, the Baud Rate Generator is reloaded and counts down to '0'. When the Baud Rate Generator times out, the SCL pin will be brought high and then, one T_{BRG} (Baud Rate Generator rollover count) later, the SDA pin will be deasserted. When the SDA pin is sampled high while SCL is high, the P bit in the SSPSTAT register, is set. A T_{BRG} later, the PEN bit is cleared and the SSPIF bit is set (Figure 28-23).

28.5.9.1 WCOL Status Flag

If the user writes the SSPBUF when a Stop sequence is in progress, the WCOL bit is set and the contents of the buffer are unchanged (the write does not occur).

FIGURE 28-22: ACKNOWLEDGE SEQUENCE WAVEFORM

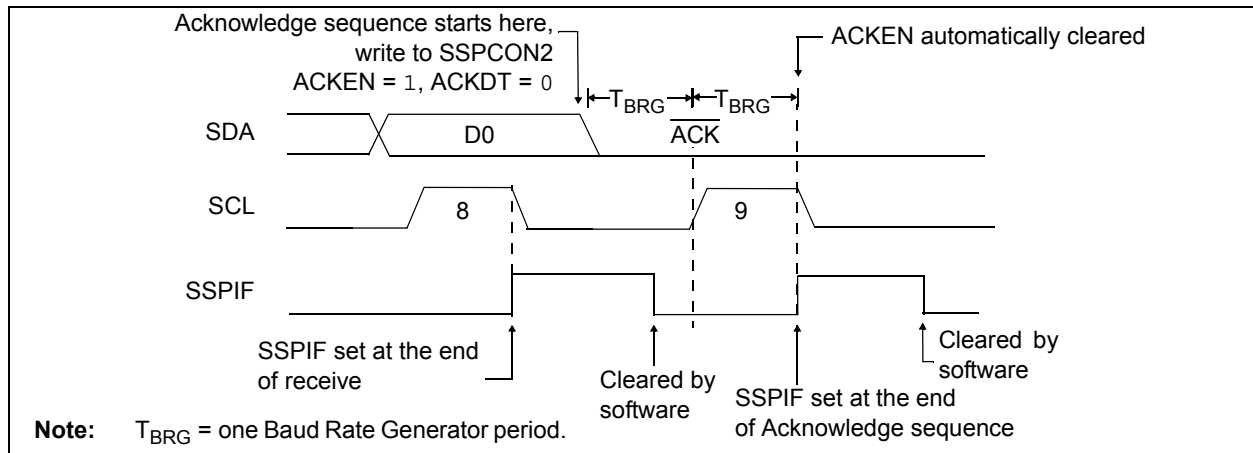
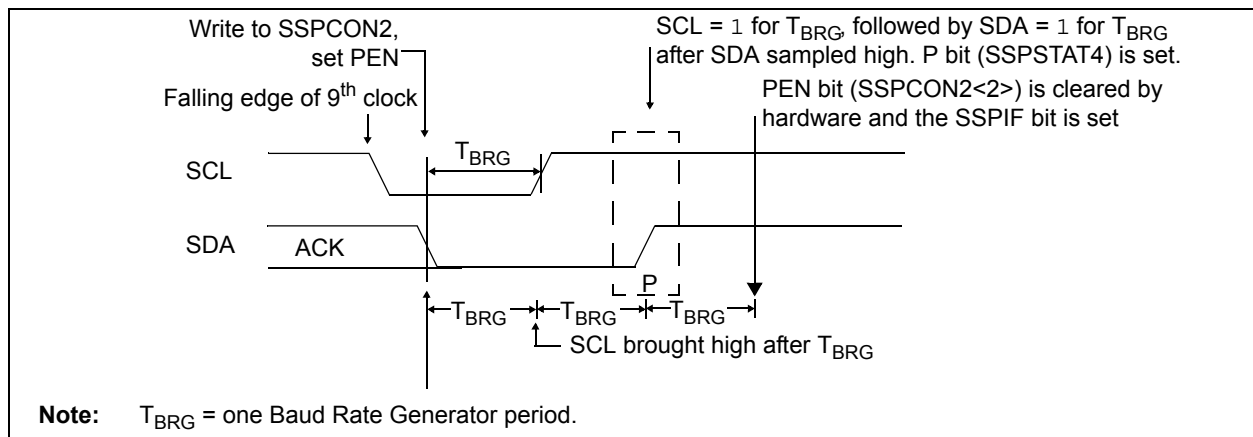


FIGURE 28-23: STOP CONDITION RECEIVE OR TRANSMIT MODE



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28.5.10 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 MSSP interrupt is enabled).

28.5.11 EFFECTS OF A RESET

A Reset disables the MSSP module and terminates the current transfer.

28.5.12 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 in the SSPSTAT register is set or the bus is idle, with both the S and P bits clear. When the bus is busy, enabling the SSP interrupt will generate the interrupt when the Stop condition occurs.

In multi-master operation, the SDA 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 BCLIF bit.

The states where arbitration can be lost are:

- Address Transfer
- Data Transfer
- A Start Condition
- A Repeated Start Condition
- An Acknowledge Condition

28.5.13 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 SDA pin, arbitration takes place when the master outputs a '1' on SDA by letting SDA float high, and another master asserts a '0'. When the SCL pin floats high, data should be stable. If the expected data on SDA is a '1' and the data sampled on the SDA pin is '0', a bus collision has taken place. The master will set the Bus Collision Interrupt Flag (BCLIF) and reset the I²C port to its Idle state (Figure 28-24).

If a transmit was in progress when the bus collision occurred, the transmission is halted, the BF flag is cleared, the SDA and SCL lines are deasserted and the SSPBUF 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.

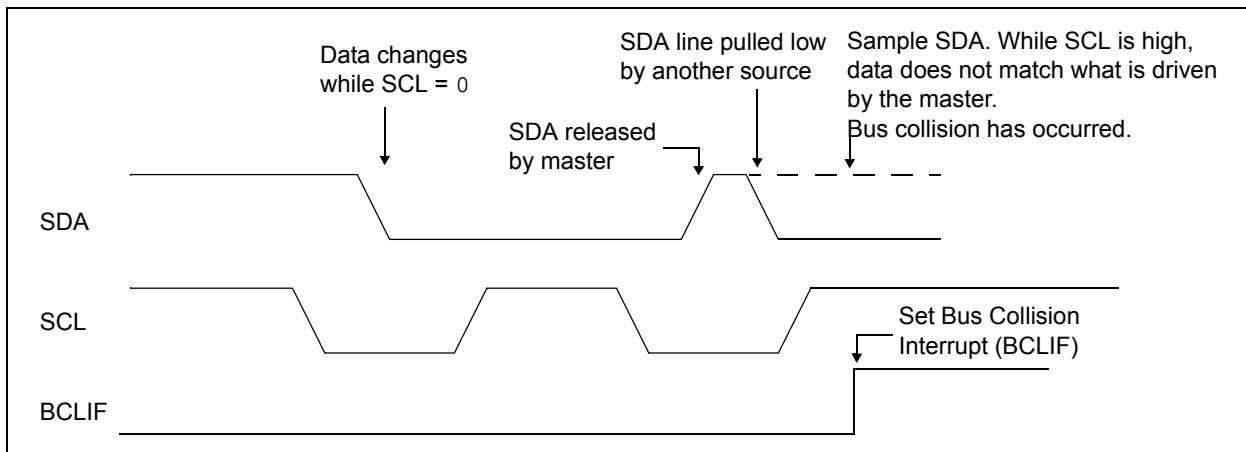
If a Start, Repeated Start, Stop or Acknowledge condition was in progress when the bus collision occurred, the condition is aborted, the SDA and SCL lines are deasserted and the respective control bits in the SSPCON2 register are cleared. When the user services the bus collision Interrupt Service Routine and if the I²C bus is free, the user can resume communication by asserting a Start condition.

The master will continue to monitor the SDA and SCL pins. If a Stop condition occurs, the SSPIF bit will be set.

A write to the SSPBUF 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 SSPSTAT register, or the bus is idle and the S and P bits are cleared.

FIGURE 28-24: BUS COLLISION TIMING FOR TRANSMIT AND ACKNOWLEDGE



28.5.13.1 Bus Collision During a Start Condition

During a Start condition, a bus collision occurs if:

- SDA or SCL are sampled low at the beginning of the Start condition (Figure 28-25).
- SCL is sampled low before SDA is asserted low (Figure 28-26).

During a Start condition, both the SDA and the SCL pins are monitored.

If the SDA pin is already low or the SCL pin is already low, all of the following occur:

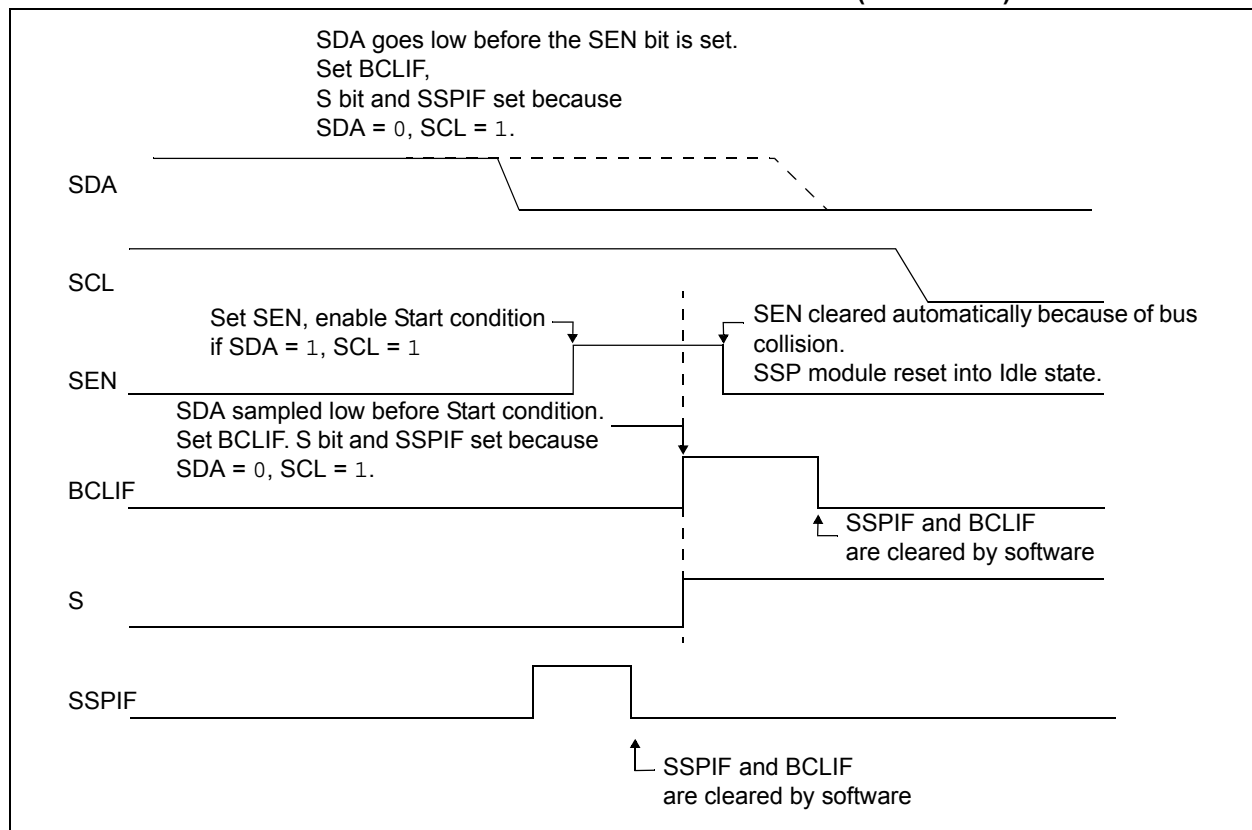
- The Start condition is aborted.
- The BCLIF flag is set.
- The MSSP module is reset to its Idle state (Figure 28-25).

The Start condition begins with the SDA and SCL pins deasserted. When the SDA pin is sampled high, the Baud Rate Generator is loaded and counts down. If the SCL pin is sampled low while SDA 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 SDA pin is sampled low during this count, the BRG is reset and the SDA line is asserted early (Figure 28-27). If, however, a '1' is sampled on the SDA pin, the SDA 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 SCL pin is sampled as '0' during this time, a bus collision does not occur. At the end of the BRG count, the SCL pin is asserted low.

Note: The reason why 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 SDA 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 28-25: BUS COLLISION DURING A START CONDITION (SDA ONLY)



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FIGURE 28-26: BUS COLLISION DURING A START CONDITION (SCL = 0)

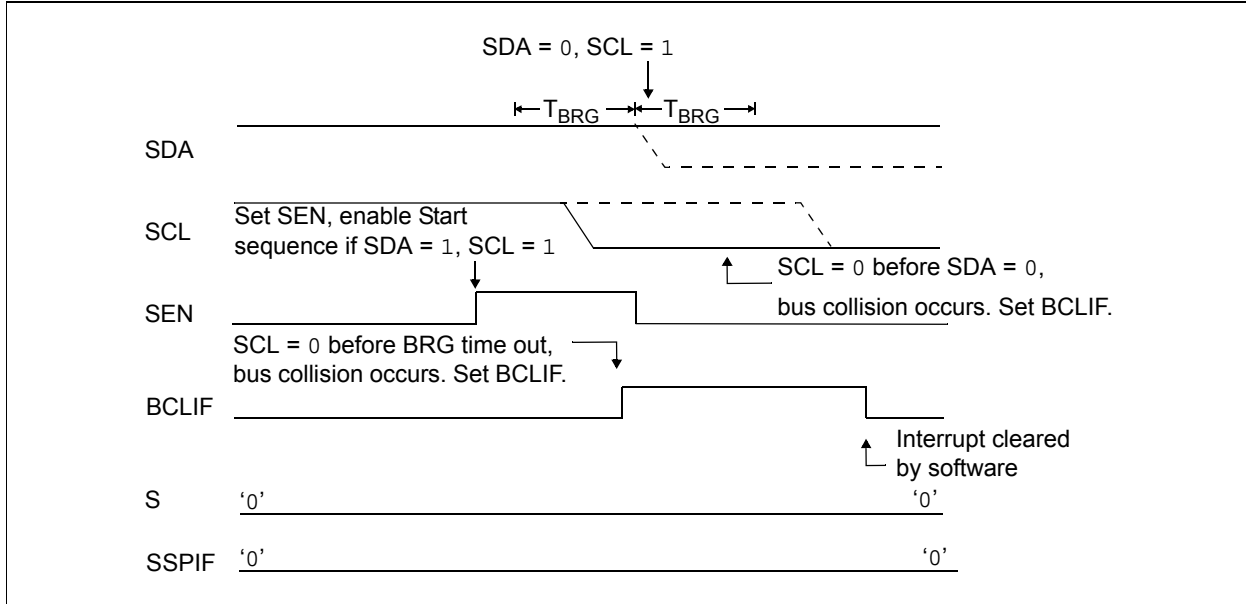
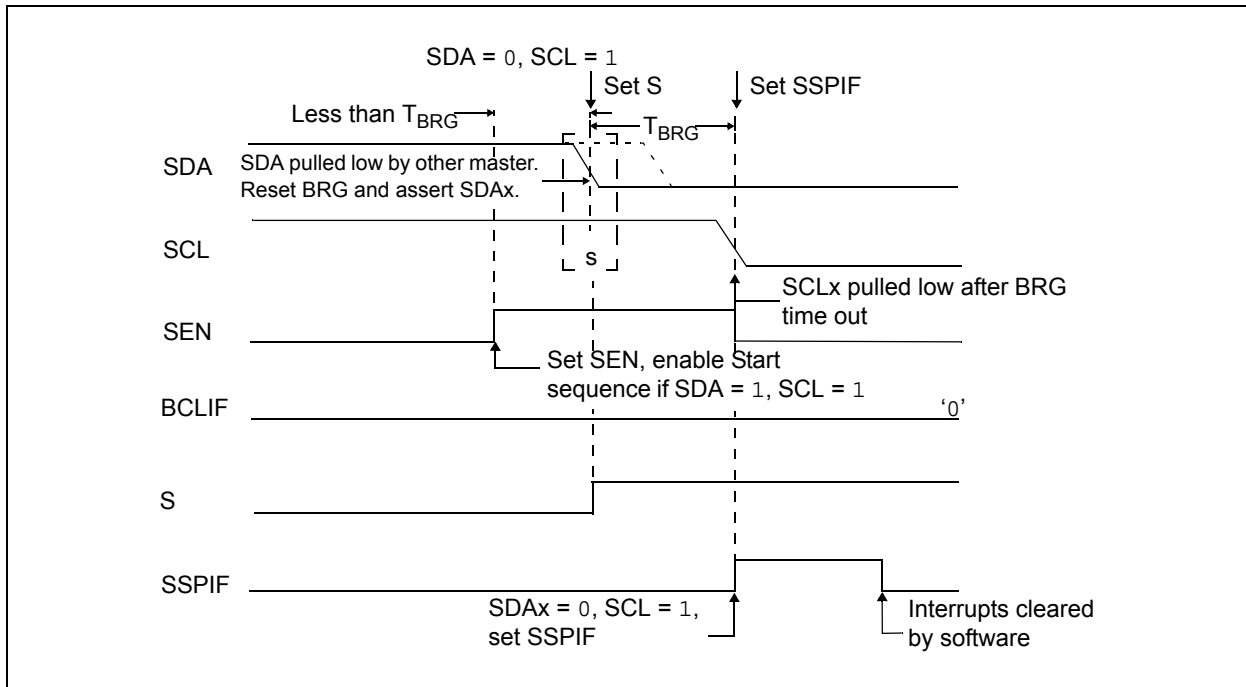


FIGURE 28-27: BRG RESET DUE TO SDA ARBITRATION DURING START CONDITION



28.5.13.2 Bus Collision During a Repeated Start Condition

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

- A low level is sampled on SDA when SCL goes from low level to high level.
- 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 28-28](#)). 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 (refer to [Figure 28-29](#)).

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 28-28: BUS COLLISION DURING A REPEATED START CONDITION (CASE 1)

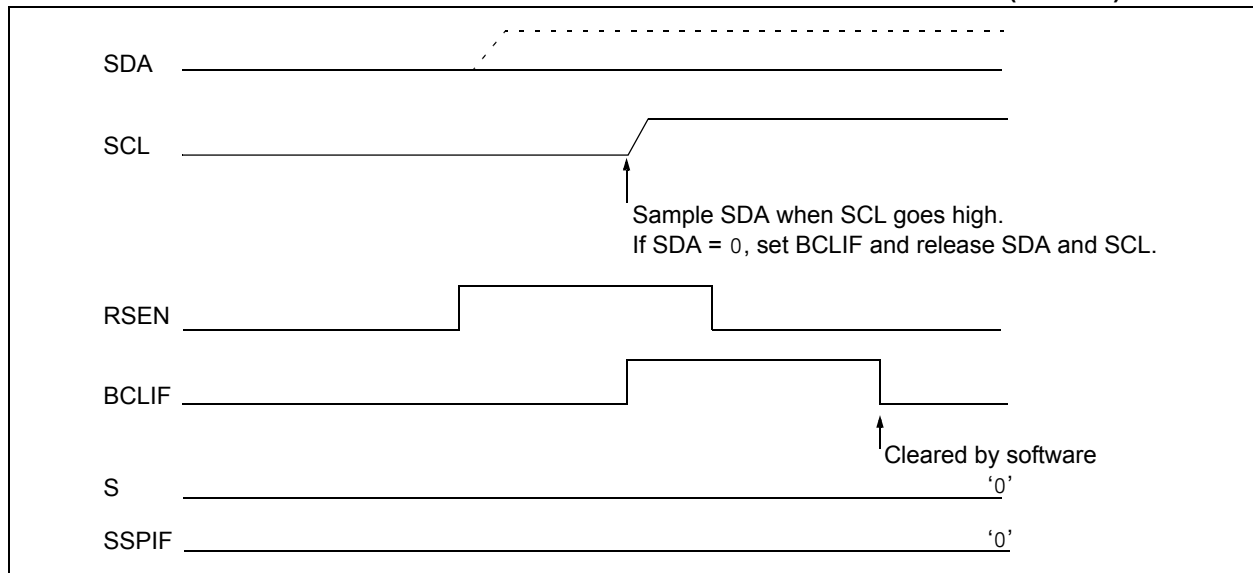
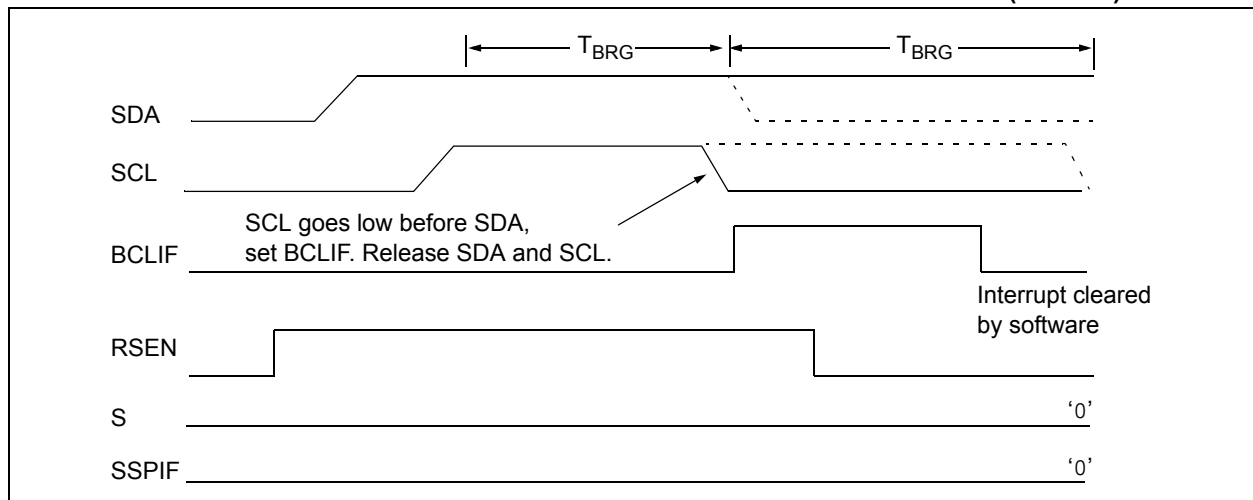


FIGURE 28-29: BUS COLLISION DURING A REPEATED START CONDITION (CASE 2)



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28.5.13.3 Bus Collision During a Stop Condition

Bus collision occurs during a Stop condition if:

- a) After the SDA pin has been deasserted and allowed to float high, SDA is sampled low after the BRG has timed out.
- b) After the SCL pin is deasserted, SCL is sampled low before SDA goes high.

The Stop condition begins with SDA asserted low. When SDA is sampled low, the SCL pin is allowed to float. When the pin is sampled high (clock arbitration), the Baud Rate Generator is loaded with SSPADD and counts down to zero. After the BRG times out, SDA is sampled. If SDA is sampled low, a bus collision has occurred. This is due to another master attempting to drive a data '0' (Figure 28-30). If the SCL pin is sampled low before SDA is allowed to float high, a bus collision occurs. This is another case of another master attempting to drive a data '0' (Figure 28-31).

FIGURE 28-30: BUS COLLISION DURING A STOP CONDITION (CASE 1)

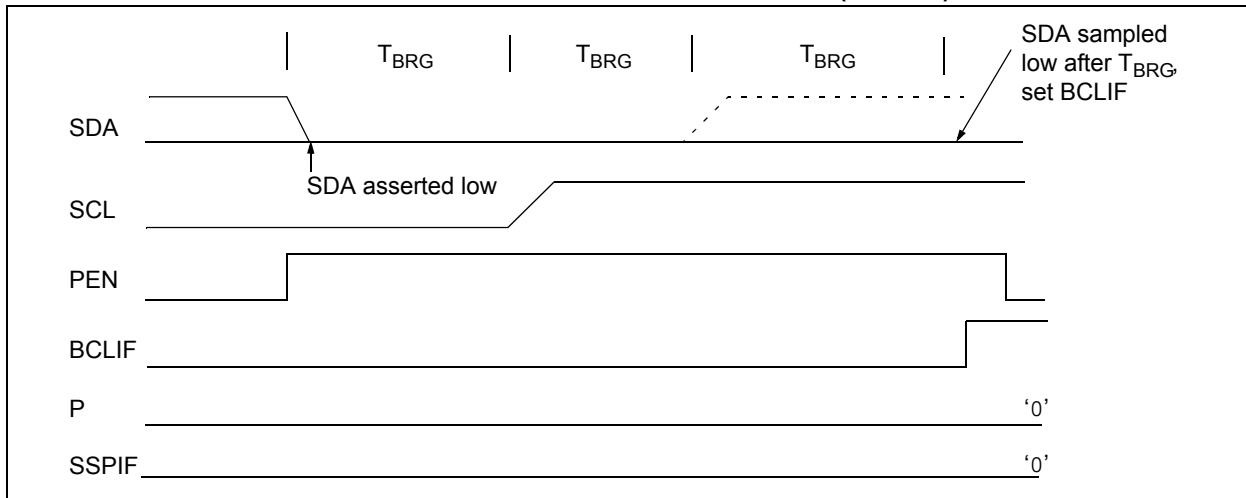


FIGURE 28-31: BUS COLLISION DURING A STOP CONDITION (CASE 2)

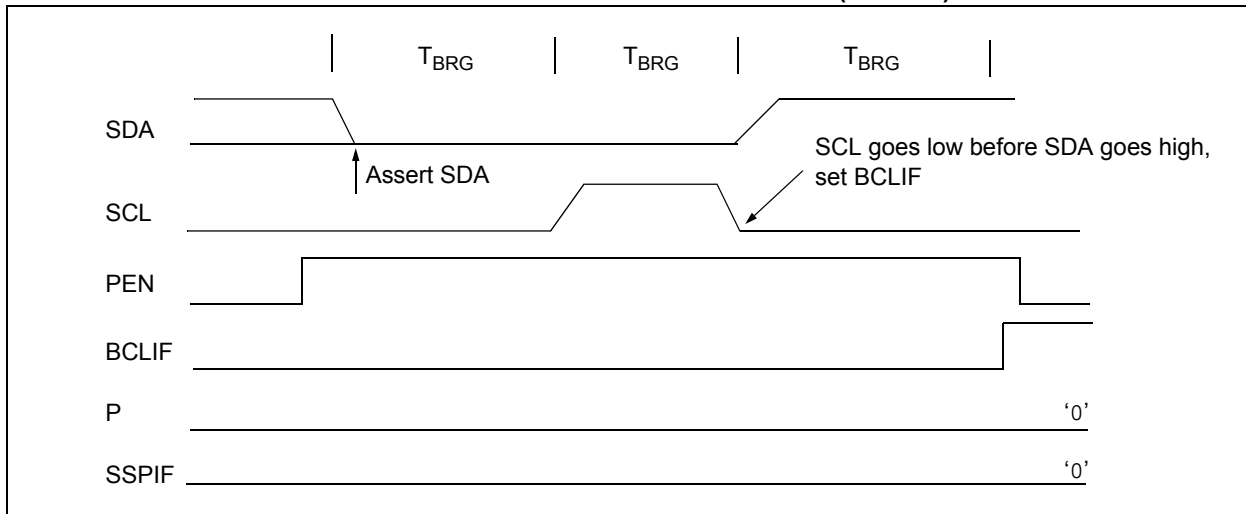


TABLE 28-2: SUMMARY OF REGISTERS ASSOCIATED WITH I²C OPERATION

| Name | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Reset Values on Page: |
|---------|--|---------|-------------|--------|--------|-------------|--------|--------|-----------------------|
| INTCON | GIE | PEIE | T0IE | INTE | IOCE | T0IF | INTF | IOCF | 93 |
| PIE1 | TXIE | RCIE | BCLIE | SSPIE | CC2IE | CC1IE | TMR2IE | TMR1IE | 94 |
| PIR1 | TXIF | RCIF | BCLIF | SSPIF | CC2IF | CC1IF | TMR2IF | TMR1IF | 96 |
| TRISGPA | TRISA7 | TRISA6 | TRISA5 | — | TRISA3 | TRISA2 | TRISA1 | TRISA0 | 109 |
| TRISGPB | TRISB7 | TRISB6 | TRISB5 | TRISB4 | — | — | TRISB1 | TRISB0 | 113 |
| SSPADD | ADD7 | ADD6 | ADD5 | ADD4 | ADD3 | ADD2 | ADD1 | ADD0 | 198 |
| SSPBUF | Synchronous Serial Port Receive Buffer/Transmit Register | | | | | | | | 139* |
| SSPCON1 | WCOL | SSPOV | SSPEN | CKP | SSPM3 | SSPM2 | SSPM1 | SSPM0 | 194 |
| SSPCON2 | GCEN | ACKSTAT | ACKDT | ACKEN | RCEN | PEN | RSEN | SEN | 196 |
| SSPCON3 | ACKTIM | PCIE | SCIE | BOEN | SDAHT | SBCDE | AHEN | DHEN | 197 |
| SSPMSK1 | MSK7 | MSK6 | MSK5 | MSK4 | MSK3 | MSK2 | MSK1 | MSK0 | 198 |
| SSPSTAT | SMP | CKE | D \bar{A} | P | S | R \bar{W} | UA | BF | 193 |
| SSPMSK2 | MSK27 | MSK26 | MSK25 | MSK24 | MSK23 | MSK22 | MSK21 | MSK20 | 199 |
| SSPADD2 | ADD27 | ADD26 | ADD25 | ADD24 | ADD23 | ADD22 | ADD21 | ADD20 | 199 |

Legend: — = unimplemented, read as '0'. Shaded cells are not used by the MSSP module in I²C mode.

* Page provides register information.

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28.6 Baud Rate Generator

The MSSP module has a Baud Rate Generator available for clock generation in the I²C Master mode. The Baud Rate Generator (BRG) reload value is placed in the SSPADD register. When a write occurs to SSPBUF, 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.

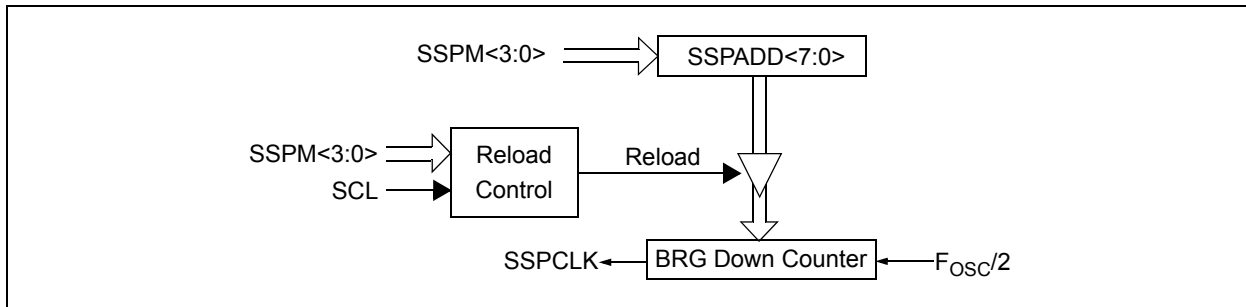
An internal signal “Reload” in Figure 28-32 triggers the value from SSPADD to be loaded into the BRG counter. This occurs twice for each oscillation of the module clock line. The logic dictating when the reload signal is asserted depends on the mode the MSSP is being operated in.

Table 28-3 demonstrates clock rates based on instruction cycles and the BRG value loaded into SSPADD.

EQUATION 28-1:

$$F_{CLOCK} = \frac{F_{OSC}}{(SSPADD + 1)(4)}$$

FIGURE 28-32: BAUD RATE GENERATOR BLOCK DIAGRAM



Note: Values of 0x00, 0x01 and 0x02 are not valid for SSPADD when used as a Baud Rate Generator for I²C. This is an implementation limitation.

TABLE 28-3: MSSP CLOCK RATE W/BRG

| F _{OSC} | F _{CY} | BRG Value | F _{CLOCK} (2 rollovers of BRG) |
|------------------|-----------------|-----------|--|
| 8 MHz | 2 MHz | 04h | 400 kHz ⁽¹⁾ |
| 8 MHz | 2 MHz | 0Bh | 166 kHz |
| 8 MHz | 2 MHz | 13h | 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 28-1: SSPSTAT: SSP STATUS REGISTER

| | | | | | | | |
|-------|-------|--------------|-----|-----|-------------------|-----|-------|
| R/W-0 | R/W-0 | R-0 | R-0 | R-0 | R-0 | R-0 | R-0 |
| SMP | CKE | D/ \bar{A} | P | S | \bar{R}/\bar{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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

- bit 7 **SMP:** Data Input Sample bit
 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:** Clock Edge Select bit
 1 = Enable input logic so that thresholds are compliant with SMBus specification
 0 = Disable SMBus specific inputs
- bit 5 **\bar{D}/\bar{A} :** Data/Address bit
 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
 (This bit is cleared when the MSSP module is disabled, SSPEN 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
 (This bit is cleared when the MSSP module is disabled, SSPEN 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 **\bar{R}/\bar{W} :** Read/Write bit information
 This bit holds the \bar{R}/\bar{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.
In I²C Slave mode:
 1 = Read
 0 = Write
In I²C Master mode:
 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 MSSP is in Idle mode.
- bit 1 **UA:** Update Address bit (10-bit I²C mode only)
 1 = Indicates that the user needs to update the address in the SSPADD register
 0 = Address does not need to be updated
- bit 0 **BF:** Buffer Full status bit
 Receive:
 1 = Receive complete, SSPBUF is full
 0 = Receive not complete, SSPBUF is empty
 Transmit:
 1 = Data transmit in progress (does not include the ACK and Stop bits), SSPBUF is full
 0 = Data transmit complete (does not include the ACK and Stop bits), SSPBUF is empty

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REGISTER 28-2: SSPCON1: SSP CONTROL REGISTER 1

| | | | | | | | |
|----------|----------|-------|-------|-----------|-------|-------|-------|
| R/C/HS-0 | R/C/HS-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-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 = Value at POR |
| '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⁾

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

1 = Enables the serial port and configures the SDA and SCL pins as the source of the serial port pins ⁽²⁾

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

bit 4 **CKP:** Clock Polarity Select bit

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

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, the SDA and SCL pins must be configured as inputs.

3: SSPADD values of 0, 1 or 2 are not supported for I²C mode.

REGISTER 28-2: SSPCON1: SSP CONTROL REGISTER 1 (CONTINUED)

bit 3-0 **SSPM<3:0>**: Synchronous Serial Port Mode Select bits

- 0000 = Reserved
- 0001 = Reserved
- 0010 = Reserved
- 0011 = Reserved
- 0100 = Reserved
- 0101 = Reserved
- 0110 = I²C Slave mode, 7-bit address
- 0111 = I²C Slave mode, 10-bit address
- 1000 = I²C Master mode, clock = F_{OSC}/(4 x (SSPADD+1)) ⁽³⁾
- 1001 = Reserved
- 1010 = Reserved
- 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, the SDA and SCL pins must be configured as inputs.
- 3:** SSPADD values of 0, 1 or 2 are not supported for I²C mode.

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REGISTER 28-3: SSPCON2: SSP 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 ⁽¹⁾ | RCEN ⁽¹⁾ | PEN ⁽¹⁾ | RSEN ⁽¹⁾ | SEN ⁽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 | H = Bit is set 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 SSPSR register
 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 SDA and SCL 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)
SCK Release Control:
 1 = Initiate Stop condition on SDA and SCL 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 SDA and SCL 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 SDA and SCL 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: If the I²C module is not in Idle mode, this bit may not be set (no spooling) and the SSPBUF may not be written (or writes to the SSPBUF are disabled).

REGISTER 28-4: SSPCON3: SSP 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) ⁽¹⁾
 1 = Indicates the I²C bus is in an Acknowledge sequence, set on 8th falling edge of SCL clock
 0 = Not an Acknowledge sequence, cleared on 9th rising edge of SCL 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 I²C Master mode:
 This bit is ignored.
In I²C Slave mode:
 1 = SSPBUF is updated and $\overline{\text{ACK}}$ is generated for a received address/data byte, ignoring the state of the SSPOV bit only if the BF bit = 0.
 0 = SSPBUF is only updated when SSPOV is clear.
- bit 3 **SDAHT:** SDA Hold Time Selection bit
 1 = Minimum of 300 ns hold time on SDA after the falling edge of SCL
 0 = Minimum of 100 ns hold time on SDA after the falling edge of SCL
- bit 2 **SBCDE:** Slave Mode Bus Collision Detect Enable bit (I²C Slave mode only)
 If, on the rising edge of SCL, SDA is sampled low when the module outputs a high state, the BCLIF bit in the PIR1 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 SCL for a matching received address byte; CKP bit in the SSPCON1 register will be cleared and the SCL 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 SCL for a received data byte; slave hardware clears the CKP bit in the SSPCON1 register and SCL is held low.
 0 = Data holding is disabled

Note 1: The ACKTIM status bit is only active when the AHEN bit or DHEN bit is set.

Note 2: This bit has no effect in Slave modes where Start and Stop condition detection is explicitly listed as enabled.

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REGISTER 28-5: SSPMSK1: SSP MASK REGISTER 1

| | | | | | | | |
|----------|-------|-------|-------|-------|-------|-------|-------|
| R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 |
| MSK<7:1> | | | | | | | MSK0 |
| 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 = Value at POR |
| '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 SSPADD<n> to detect I²C address match
- 0 = The received address bit n is not used to detect I²C address match

bit 0 **MSK0**: Mask bit for I²C Slave mode, 10-bit Address

I²C Slave mode, 10-bit address (SSPM<3:0> = 0111 or 1111):

- 1 = The received address bit 0 is compared to SSPADD0 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 28-6: SSPADD: MSSP ADDRESS AND BAUD RATE REGISTER 1

| | | | | | | | |
|----------|-------|-------|-------|-------|-------|-------|-------|
| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

Master mode:

bit 7-0 **ADD<7:0>**: Baud Rate Clock Divider bits

$$\text{SCL pin clock period} = ((\text{ADD}<7:0> + 1) \times 4) / F_{\text{OSC}}$$

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”.

REGISTER 28-7: SSPMSK2: SSP MASK REGISTER 2

| | | | | | | | |
|-----------|-------|-------|-------|-------|-------|-------|---------|
| R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 | R/W-1 |
| MSK2<7:0> | | | | | | | MSK2<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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

- bit 7-1 **MSK2<7:1>**: Mask bits
 1 = The received address bit n is compared to SSPADD2<n> to detect I²C address match
 0 = The received address bit n is not used to detect I²C address match
- bit 0 **MSK2<0>**: Mask bit for I²C Slave mode, 10-bit Address
 I²C Slave mode, 10-bit address (SSPM<3:0> = 0111 or 1111):
 1 = The received address bit 0 is compared to SSPADD2<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 28-8: SSPADD2: MSSP ADDRESS 2

| | | | | | | | |
|-----------|-------|-------|-------|-------|-------|-------|-------|
| R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 | R/W-0 |
| ADD2<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 = Value at POR |
| '1' = Bit is set | '0' = Bit is cleared | |

Master mode:

- bit 7-0 **ADD2<7:0>**: Baud Rate Clock Divider bits
 $SCL \text{ pin clock period} = ((ADD<7:0> + 1) \times 4) / F_{OSC}$

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 **ADD2<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 **ADD2<7:0>**: Eight Least Significant bits of 10-bit address

7-Bit Slave mode:

- bit 7-1 **ADD2<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:

29.0 INSTRUCTION SET SUMMARY

The MCP19124/5 instruction set is highly orthogonal and comprises three basic categories:

- **Byte-oriented** operations
- **Bit-oriented** operations
- **Literal and control** operations

Each instruction is a 14-bit word divided into an **opcode**, which specifies the instruction type, and one or more **operands**, which further specify the operation of the instruction. The formats for each of the categories is presented in [Figure 29-1](#), while the various opcode fields are summarized in [Table 29-1](#).

[Table 29-2](#) lists the instructions recognized by the MPASM™ assembler.

For **byte-oriented** instructions, 'f' represents a file register designator and 'd' represents a destination designator. The file register designator specifies which file register is to be used by the instruction.

The destination designator specifies where the result of the operation is to be placed. If 'd' is zero, the result is placed in the W register. If 'd' is one, the result is placed in the file register specified in the instruction.

For **bit-oriented** instructions, 'b' represents a bit field designator, which selects the bit affected by the operation, while 'f' represents the address of the file in which the bit is located.

For **literal and control** operations, 'k' represents an 8-bit or 11-bit constant, or literal value.

One instruction cycle consists of four oscillator periods; for an oscillator frequency of 4 MHz, this gives a normal instruction execution time of 1 μs. All instructions are executed within a single instruction cycle, unless a conditional test is true, or the program counter is changed as a result of an instruction. When this occurs, the execution takes two instruction cycles, with the second cycle executed as a NOP.

All instruction examples use the format '0xhh' to represent a hexadecimal number, where 'h' signifies a hexadecimal digit.

29.1 Read-Modify-Write Operations

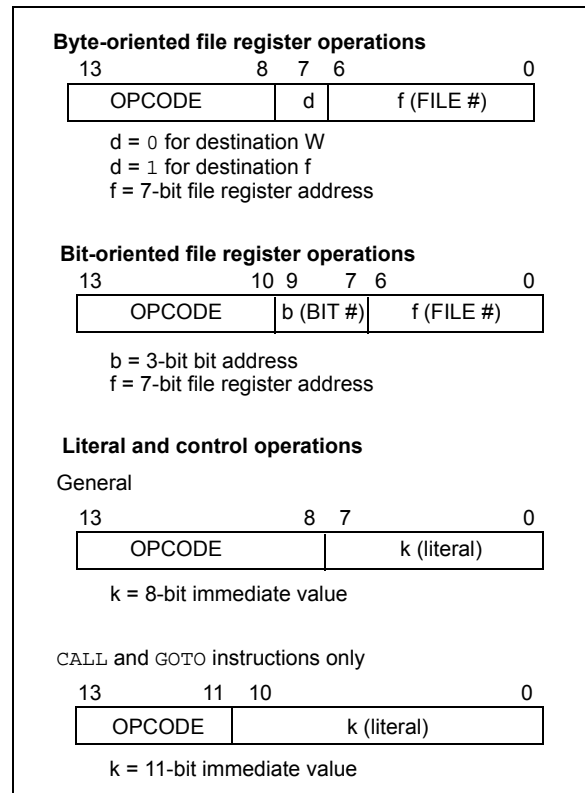
Any instruction that specifies a file register as part of the instruction performs a Read-Modify-Write (RMW) operation. The register is read, the data is modified, and the result is stored according to either the instruction or the destination designator 'd'. A read operation is performed on a register even if the instruction writes to that register.

For example, a `CLRF PORTA` instruction will read PORTGPA, clear all the data bits, then write the result back to PORTGPA. This example would have the unintended consequence of clearing the condition that sets the IOCIF flag.

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. |
| PC | Program Counter |
| \overline{TO} | Time-Out bit |
| C | Carry bit |
| DC | Digit carry bit |
| Z | Zero bit |
| \overline{PD} | Power-down bit |

FIGURE 29-1: GENERAL FORMAT FOR INSTRUCTIONS



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TABLE 29-2: MCP19124/5 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 | 1, 2 |
| ANDWF | f, d | AND W with f | 1 | 00 | 0101 | dfff | ffff | Z | 1, 2 |
| CLRF | f | Clear f | 1 | 00 | 0001 | lfff | ffff | Z | 2 |
| CLRW | – | Clear W | 1 | 00 | 0001 | 0xxx | xxxx | Z | |
| COMF | f, d | Complement f | 1 | 00 | 1001 | dfff | ffff | Z | 1, 2 |
| DECF | f, d | Decrement f | 1 | 00 | 0011 | dfff | ffff | Z | 1, 2 |
| DECFSZ | f, d | Decrement f, Skip if 0 | 1(2) | 00 | 1011 | dfff | ffff | | 1, 2, 3 |
| INCF | f, d | Increment f | 1 | 00 | 1010 | dfff | ffff | Z | 1, 2 |
| INCFSZ | f, d | Increment f, Skip if 0 | 1(2) | 00 | 1111 | dfff | ffff | | 1, 2, 3 |
| IORWF | f, d | Inclusive OR W with f | 1 | 00 | 0100 | dfff | ffff | Z | 1, 2 |
| MOVF | f, d | Move f | 1 | 00 | 1000 | dfff | ffff | Z | 1, 2 |
| MOVWF | f | Move W to f | 1 | 00 | 0000 | lfff | ffff | | |
| NOP | – | No Operation | 1 | 00 | 0000 | 0xx0 | 0000 | | |
| RLF | f, d | Rotate Left f through Carry | 1 | 00 | 1101 | dfff | ffff | C | 1, 2 |
| RRF | f, d | Rotate Right f through Carry | 1 | 00 | 1100 | dfff | ffff | C | 1, 2 |
| SUBWF | f, d | Subtract W from f | 1 | 00 | 0010 | dfff | ffff | C, DC, Z | 1, 2 |
| SWAPF | f, d | Swap nibbles in f | 1 | 00 | 1110 | dfff | ffff | | 1, 2 |
| XORWF | f, d | Exclusive OR W with f | 1 | 00 | 0110 | dfff | ffff | Z | 1, 2 |
| BIT-ORIENTED FILE REGISTER OPERATIONS | | | | | | | | | |
| BCF | f, b | Bit Clear f | 1 | 01 | 00bb | bfff | ffff | | 1, 2 |
| BSF | f, b | Bit Set f | 1 | 01 | 01bb | bfff | ffff | | 1, 2 |
| BTFSC | f, b | Bit Test f, Skip if Clear | 1 (2) | 01 | 10bb | bfff | ffff | | 3 |
| BTFSS | f, b | Bit Test f, Skip if Set | 1 (2) | 01 | 11bb | bfff | ffff | | 3 |
| LITERAL AND CONTROL OPERATIONS | | | | | | | | | |
| ADDLW | k | Add literal and W | 1 | 11 | 111x | kkkk | kkkk | C, DC, Z | |
| ANDLW | k | AND literal with W | 1 | 11 | 1001 | kkkk | kkkk | Z | |
| CALL | k | Call Subroutine | 2 | 10 | 0kkk | kkkk | kkkk | | |
| CLR- | – | Clear Watchdog Timer | 1 | 00 | 0000 | 0110 | 0100 | \overline{TO} , \overline{PD} | |
| WDT | k | Go to address | 2 | 10 | 1kkk | kkkk | kkkk | | |
| GOTO | k | Inclusive OR literal with W | 1 | 11 | 1000 | kkkk | kkkk | Z | |
| IORLW | k | Move literal to W | 1 | 11 | 00xx | kkkk | kkkk | | |
| MOVLW | – | Return from interrupt | 2 | 00 | 0000 | 0000 | 1001 | | |
| RETFIE | k | Return with literal in W | 2 | 11 | 01xx | kkkk | kkkk | | |
| RETLW | – | Return from Subroutine | 2 | 00 | 0000 | 0000 | 1000 | | |
| RETURN | – | Go into Standby mode | 1 | 00 | 0000 | 0110 | 0011 | \overline{TO} , \overline{PD} | |
| SLEEP | k | Subtract W from literal | 1 | 11 | 110x | kkkk | kkkk | C, DC, Z | |
| SUBLW | k | Exclusive OR literal with W | 1 | 11 | 1010 | kkkk | kkkk | Z | |
| XORLW | | | | | | | | | |

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

- 2:** If this instruction is executed on the TMR0 register (and where applicable, d = 1), the prescaler will be cleared if assigned to the Timer0 module.
- 3:** If the Program Counter (PC) is modified, or a conditional test is true, the instruction requires two cycles. The second cycle is executed as a NOP.

29.2 Instruction Descriptions

ADDLW **Add literal and W**

Syntax: [*label*] 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 8-bit literal 'k' and the result is placed in the W register.

ADDWF **Add W and f**

Syntax: [*label*] 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'.

ANDLW **AND literal with W**

Syntax: [*label*] ANDLW k
Operands: $0 \leq k \leq 255$
Operation: $(W) .\text{AND.} (k) \rightarrow (W)$
Status Affected: Z
Description: The contents of W register are AND'ed with the 8-bit literal 'k'. The result is placed in the W register.

ANDWF **AND W with f**

Syntax: [*label*] ANDWF f,d
Operands: $0 \leq f \leq 127$
 $d \in [0,1]$
Operation: $(W) .\text{AND.} (f) \rightarrow (\text{destination})$
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'.

BCF **Bit Clear f**

Syntax: [*label*] BCF f,b
Operands: $0 \leq f \leq 127$
 $0 \leq b \leq 7$
Operation: $0 \rightarrow (f)$
Status Affected: None
Description: Bit 'b' in register 'f' is cleared.

BSF **Bit Set f**

Syntax: [*label*] BSF f,b
Operands: $0 \leq f \leq 127$
 $0 \leq b \leq 7$
Operation: $1 \rightarrow (f)$
Status Affected: None
Description: Bit 'b' in register 'f' is set.

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 $(f) = 0$
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 two-cycle instruction.

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| BTFSF | Bit Test f, Skip if Set |
|------------------|--|
| Syntax: | [<i>label</i>] BTFSF f,b |
| Operands: | $0 \leq f \leq 127$ $0 \leq b < 7$ |
| Operation: | skip if (f) = 1 |
| Status Affected: | None |
| Description: | If bit 'b' in register 'f' is '0', the next instruction is executed. If bit 'b' is '1', the next instruction is discarded and a NOP is executed instead, making this a two-cycle instruction. |

| CLRWDT | Clear Watchdog Timer |
|------------------|---|
| Syntax: | [<i>label</i>] CLRWDT |
| Operands: | None |
| Operation: | 00h → WDT 0 → WDT prescaler, 1 → \overline{TO} 1 → \overline{PD} |
| Status Affected: | \overline{TO} , \overline{PD} |
| Description: | CLRWDT instruction resets the Watchdog Timer. It also resets the prescaler of the WDT. Bits \overline{TO} and \overline{PD} in the STATUS register are set. |

| CALL | Call Subroutine |
|------------------|---|
| Syntax: | [<i>label</i>] CALL k |
| Operands: | $0 \leq k \leq 2047$ |
| Operation: | (PC)+ 1 → TOS, k → PC<10:0>, (PCLATH<4:3>) → PC<12:11> |
| Status Affected: | None |
| Description: | Call Subroutine. First, return address (PC + 1) is pushed onto the stack. The 11-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. |

| COMF | Complement f |
|------------------|--|
| Syntax: | [<i>label</i>] COMF f,d |
| Operands: | $0 \leq f \leq 127$ d ∈ [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: | [<i>label</i>] 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: | [<i>label</i>] DECF f,d |
| Operands: | $0 \leq f \leq 127$ d ∈ [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'. |

| CLRW | Clear W |
|------------------|---|
| Syntax: | [<i>label</i>] CLRW |
| Operands: | None |
| Operation: | 00h → (W) 1 → Z |
| Status Affected: | Z |
| Description: | W register is cleared. Zero (Z) bit is set. |

| DECFSZ | Decrement f, Skip if 0 |
|------------------|---|
| Syntax: | [<i>label</i>] DECFSZ f,d |
| Operands: | $0 \leq f \leq 127$ $d \in [0,1]$ |
| Operation: | $(f) - 1 \rightarrow$ (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', a NOP is executed instead, making it a two-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: | $(f) + 1 \rightarrow$ (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 two-cycle instruction. |

| GOTO | Unconditional Branch |
|------------------|---|
| Syntax: | [<i>label</i>] GOTO k |
| Operands: | $0 \leq k \leq 2047$ |
| Operation: | $k \rightarrow PC<10:0>$ $PCLATH<4:3> \rightarrow PC<12:11>$ |
| Status Affected: | None |
| Description: | GOTO is an unconditional branch. The 11-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 8-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: | $(f) + 1 \rightarrow$ (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: | $(W) .OR. (f) \rightarrow$ (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'. |

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| MOVF | Move f |
|------------------|--|
| Syntax: | [<i>label</i>] MOVF f,d |
| Operands: | $0 \leq f \leq 127$ $d \in [0,1]$ |
| Operation: | (f) → (dest) |
| Status Affected: | Z |
| Description: | The contents of register 'f' are moved to a destination dependent upon the status of 'd'. If d = 0, the 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 |

| MOVLW | Move literal to W |
|------------------|---|
| Syntax: | [<i>label</i>] MOVLW k |
| Operands: | $0 \leq k \leq 255$ |
| Operation: | $k \rightarrow (W)$ |
| Status Affected: | None |
| Description: | The 8-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: | [<i>label</i>] MOVWF f |
| Operands: | $0 \leq f \leq 127$ |
| Operation: | (W) → (f) |
| Status Affected: | None |
| Description: | Move data from W register to register 'f'. |
| Words: | 1 |
| Cycles: | 1 |
| Example: | MOVWF OPTION F Before Instruction OPTION = 0xFF W = 0x4F After Instruction OPTION = 0x4F W = 0x4F |

| NOP | No Operation |
|------------------|----------------------|
| Syntax: | [<i>label</i>] NOP |
| Operands: | None |
| Operation: | No operation |
| Status Affected: | None |
| Description: | No operation |
| Words: | 1 |
| Cycles: | 1 |
| Example: | NOP |

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

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-Stack (TOS) is loaded into the program counter. This is a two-cycle instruction.

RETLW **Return with literal in W**

Syntax: [*label*] RETLW k

Operands: 0 ≤ k ≤ 255

Operation: k → (W);
 TOS → PC

Status Affected: None

Description: The W register is loaded with the 8-bit literal 'k'. The program counter is loaded from the Top-of-Stack (the return address). This is a two-cycle instruction.

Words: 1

Cycles: 2

Example: CALL TABLE;W contains
 ;table offset
 ;value

 GOTO DONE

TABLE •
 •
 ADDWF PC ;W = offset
 RETLW k1 ;Begin table
 RETLW k2 ;
 •
 •
 •
 RETLW kn ;End of table

DONE

 Before Instruction

 W = 0x07

 After Instruction

 W = value of k8

RLF **Rotate Left f through Carry**

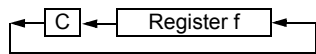
Syntax: [*label*] RLF f,d

Operands: 0 ≤ f ≤ 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

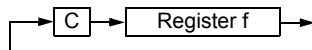
 1100

 C = 1

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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'.



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 (two'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 ≤ f |
| DC = 0 | W<3:0> > f<3:0> |
| DC = 1 | W<3:0> ≤ f<3:0> |

SLEEP Enter Sleep mode

Syntax: [*label*] SLEEP
 Operands: None
 Operation: 00h → WDT,
 0 → WDT prescaler,
 1 → $\overline{\text{TO}}$,
 0 → PD
 Status Affected: $\overline{\text{TO}}$, PD
 Description: The power-down STATUS bit, PD, is cleared. Time-Out STATUS bit, $\overline{\text{TO}}$, is set. Watchdog Timer and its prescaler are cleared. The processor is put into Sleep mode with the oscillator stopped.

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'.

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 (two's complement method) from the 8-bit literal 'k'. The result is placed in the W register.

| Result | Condition |
|--------|-----------------|
| C = 0 | W > k |
| C = 1 | W ≤ k |
| DC = 0 | W<3:0> > k<3:0> |
| DC = 1 | W<3:0> ≤ k<3:0> |

XORLW Exclusive OR literal with W

Syntax: [*label*] XORLW k
 Operands: $0 \leq k \leq 255$
 Operation: $(W) .\text{XOR. } k \rightarrow (W)$
 Status Affected: Z
 Description: The contents of the W register are XOR'ed with the 8-bit literal 'k'. The result is placed in the W register.

| | |
|------------------|---|
| XORWF | Exclusive OR W with f |
| Syntax: | [<i>label</i>] XORWF f,d |
| Operands: | $0 \leq f \leq 127$ $d \in [0,1]$ |
| Operation: | (W) .XOR. (f) → (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'. |

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NOTES:

30.0 IN-CIRCUIT SERIAL PROGRAMMING™ (ICSP™)

ICSP 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:

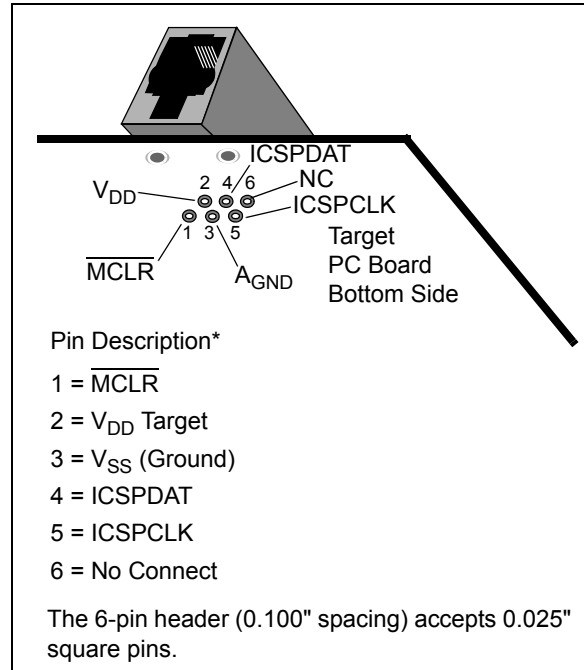
- ICSPCLK
- ICSPDAT
- MCLR
- V_{DD}
- A_{GND}

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. The device is placed into a Program/Verify mode by holding the ICSPDAT and ICSPCLK pins low, while raising the MCLR pin from V_{IL} to V_{IHH}.

30.1 Common Programming Interfaces

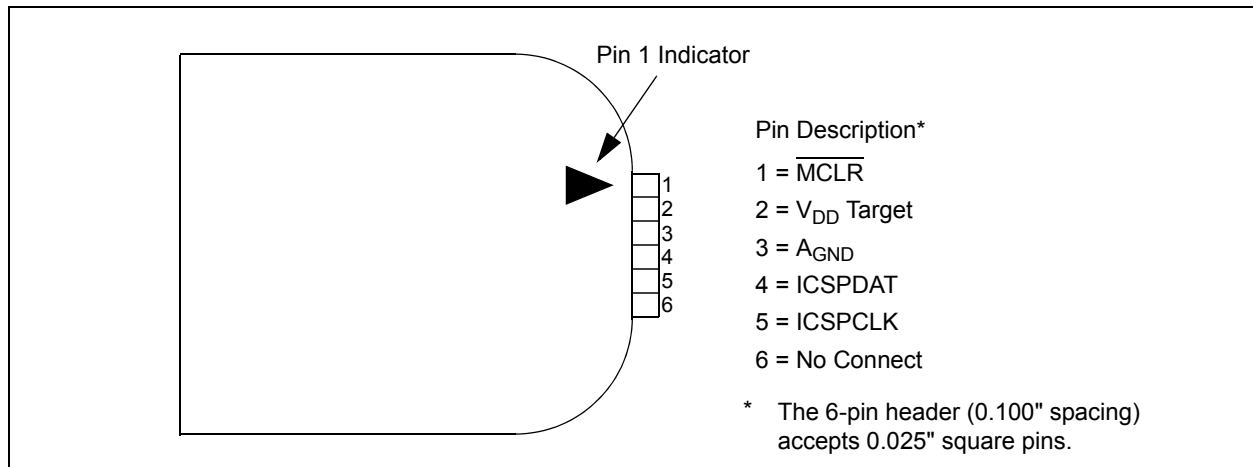
Connection to a target device is typically done through an ICSP header. A commonly found connector on development tools is the RJ-11 in the 6P6C (6-pin, 6-conductor) configuration. Refer to [Figure 30-1](#).

FIGURE 30-1: 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 30-2](#).

FIGURE 30-2: PICKit™ STYLE CONNECTOR INTERFACE

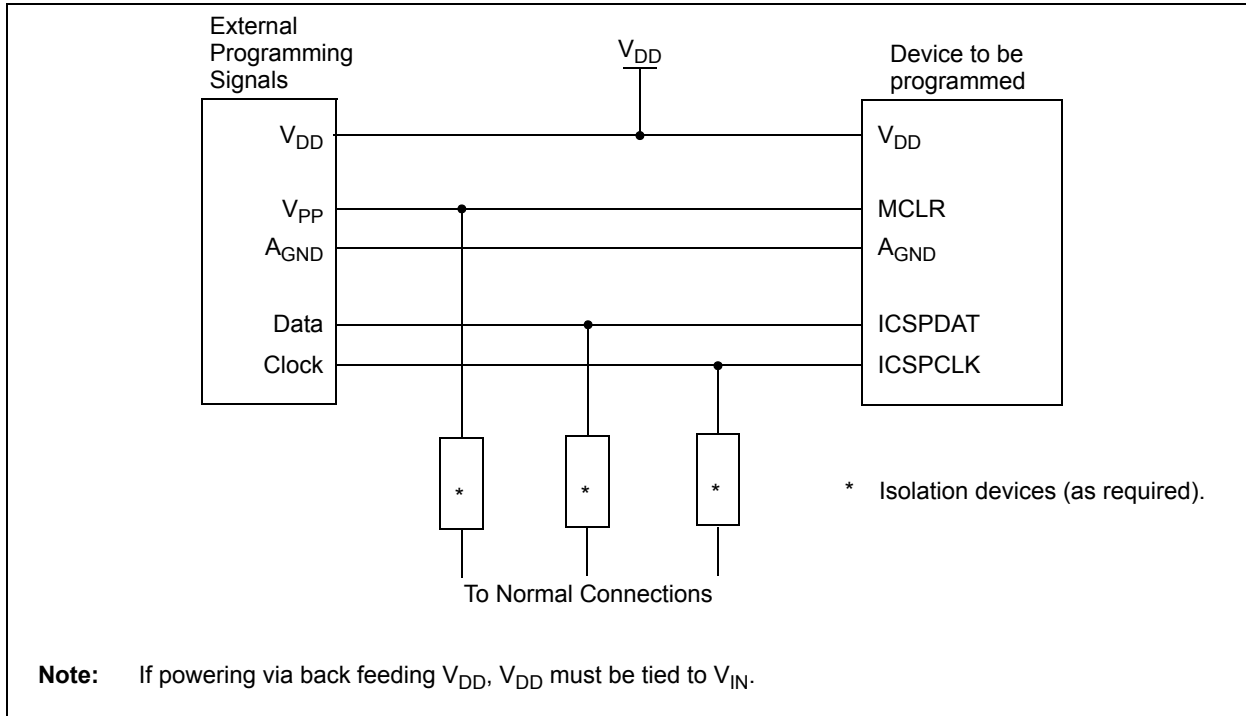


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For additional interface recommendations, refer to your specific device programmer manual prior to PCB design.

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. Refer to [Figure 30-3](#) for more information.

FIGURE 30-3: TYPICAL CONNECTION FOR ICSP™ PROGRAMMING



31.0 DEVELOPMENT SUPPORT

The PIC[®] microcontrollers (MCU) and dsPIC[®] digital signal controllers (DSC) are supported with a full range of software and hardware development tools:

- Integrated Development Environment
 - MPLAB[®] X IDE Software
- Compilers/Assemblers/Linkers
 - MPLAB XC Compiler
 - MPASM[™] Assembler
 - MPLINK[™] Object Linker/
MPLIB[™] Object Librarian
 - MPLAB Assembler/Linker/Librarian for
Various Device Families
- Simulators
 - MPLAB X SIM Software Simulator
- Emulators
 - MPLAB REAL ICE[™] In-Circuit Emulator
- In-Circuit Debuggers/Programmers
 - MPLAB ICD 3
 - PICKit[™] 3
- Device Programmers
 - MPLAB PM3 Device Programmer
- Low-Cost Demonstration/Development Boards,
Evaluation Kits and Starter Kits
- Third-party development tools

31.1 MPLAB X Integrated Development Environment Software

The MPLAB X IDE is a single, unified graphical user interface for Microchip and third-party software, and hardware development tool that runs on Windows[®], Linux and Mac OS[®] X. Based on the NetBeans IDE, MPLAB X IDE is an entirely new IDE with a host of free software components and plug-ins for high-performance application development and debugging. Moving between tools and upgrading from software simulators to hardware debugging and programming tools is simple with the seamless user interface.

With complete project management, visual call graphs, a configurable watch window and a feature-rich editor that includes code completion and context menus, MPLAB X IDE is flexible and friendly enough for new users. With the ability to support multiple tools on multiple projects with simultaneous debugging, MPLAB X IDE is also suitable for the needs of experienced users.

Feature-Rich Editor:

- Color syntax highlighting
- Smart code completion makes suggestions and provides hints as you type
- Automatic code formatting based on user-defined rules
- Live parsing

User-Friendly, Customizable Interface:

- Fully customizable interface: toolbars, toolbar buttons, windows, window placement, etc.
- Call graph window

Project-Based Workspaces:

- Multiple projects
- Multiple tools
- Multiple configurations
- Simultaneous debugging sessions

File History and Bug Tracking:

- Local file history feature
- Built-in support for Bugzilla issue tracker

31.2 MPLAB XC Compilers

The MPLAB XC Compilers are complete ANSI C compilers for all of Microchip's 8, 16, and 32-bit MCU and DSC devices. These compilers provide powerful integration capabilities, superior code optimization and ease of use. MPLAB XC Compilers run on Windows, Linux or MAC OS X.

For easy source level debugging, the compilers provide debug information that is optimized to the MPLAB X IDE.

The free MPLAB XC Compiler editions support all devices and commands, with no time or memory restrictions, and offer sufficient code optimization for most applications.

MPLAB XC Compilers include an assembler, linker and utilities. 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. MPLAB XC Compiler uses the assembler to produce its object 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 X IDE compatibility

31.3 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 X IDE projects
- User-defined macros to streamline assembly code
- Conditional assembly for multipurpose source files
- Directives that allow complete control over the assembly process

31.4 MPLINK Object Linker/ MPLIB Object Librarian

The MPLINK Object Linker combines relocatable objects created by the MPASM Assembler. 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

31.5 MPLAB Assembler, Linker and Librarian for Various Device Families

MPLAB Assembler produces relocatable machine code from symbolic assembly language for PIC24, PIC32 and dsPIC DSC devices. MPLAB XC 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 X IDE compatibility

31.6 MPLAB X SIM Software Simulator

The MPLAB X 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 X SIM Software Simulator fully supports symbolic debugging using the MPLAB XC 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.

31.7 MPLAB REAL ICE In-Circuit Emulator System

The 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 all 8, 16 and 32-bit MCU, and DSC devices with the easy-to-use, powerful graphical user interface of the MPLAB X IDE.

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 (RJ-11) or with the new high-speed, noise tolerant, Low-Voltage Differential Signal (LVDS) interconnection (CAT5).

The emulator is field upgradeable through future firmware downloads in MPLAB X IDE. MPLAB REAL ICE offers significant advantages over competitive emulators including full-speed emulation, run-time variable watches, trace analysis, complex breakpoints, logic probes, a ruggedized probe interface and long (up to 3 meters) interconnection cables.

31.8 MPLAB ICD 3 In-Circuit Debugger System

The MPLAB ICD 3 In-Circuit Debugger System is Microchip's most cost-effective, high-speed hardware debugger/programmer for Microchip Flash DSC and MCU devices. It debugs and programs PIC Flash microcontrollers and dsPIC DSCs with the powerful yet easy-to-use graphical user interface of the MPLAB 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.

31.9 PICkit 3 In-Circuit Debugger/Programmer

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 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 a 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™ (ICSP™).

31.10 MPLAB PM3 Device Programmer

The MPLAB PM3 Device Programmer is a universal, CE compliant device programmer with programmable voltage verification at V_{DDMIN} and V_{DDMAX} for maximum reliability. It features a large LCD display (128 x 64) for menus and error messages, and a modular, detachable socket assembly to support various package types. The ICSP cable assembly is included as a standard item. In Stand-Alone mode, the MPLAB PM3 Device Programmer can read, verify and program PIC devices without a PC connection. It can also set code protection in this mode. The MPLAB PM3 connects to the host PC via an RS-232 or USB cable. The MPLAB PM3 has high-speed communications and optimized algorithms for quick programming of large memory devices, and incorporates an MMC card for file storage and data applications.

31.11 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.

31.12 Third-Party Development Tools

Microchip also offers a great collection of tools from third-party vendors. These tools are carefully selected to offer good value and unique functionality:

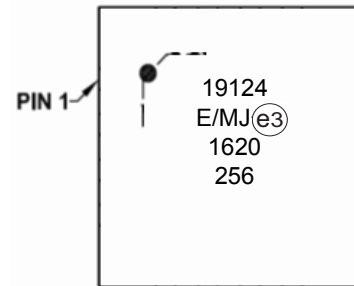
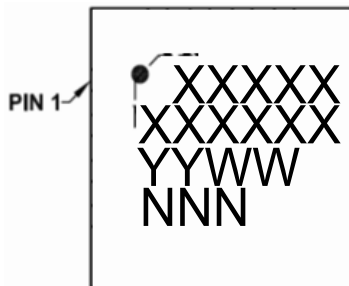
- Device Programmers and Gang Programmers from companies, such as SoftLog and CCS
- Software Tools from companies, such as Gimpel and Trace Systems
- Protocol Analyzers from companies, such as Saleae and Total Phase
- Demonstration Boards from companies, such as MikroElektronika, Digilent® and Olimex
- Embedded Ethernet Solutions from companies, such as EZ Web Lynx, WIZnet and IPLogika®

32.0 PACKAGING INFORMATION

32.1 Package Marking Information

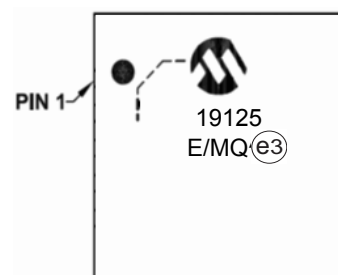
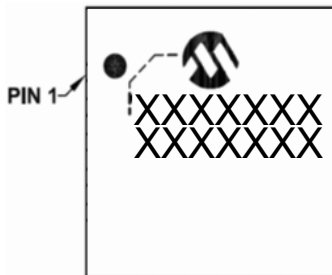
24-Lead QFN (4x4x0.9 mm) (MCP19124 only)

Example



28-Lead QFN (5x5x0.9 mm) (MCP19125 only)

Example

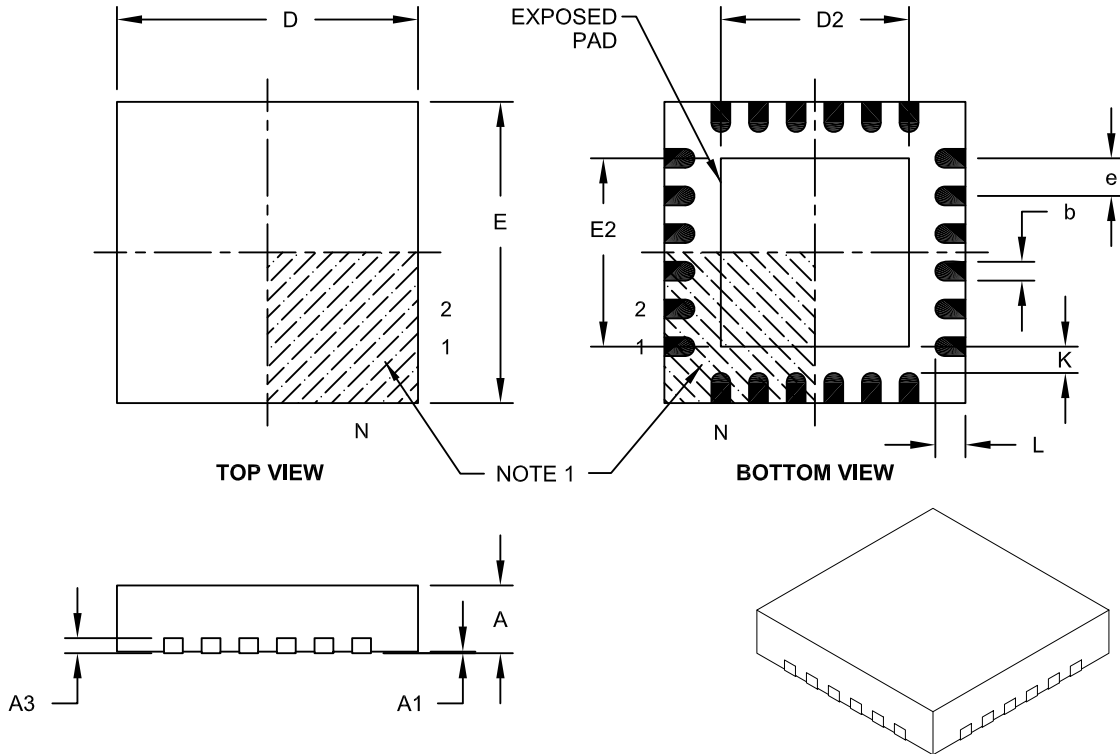


| | | |
|----------------|---|--|
| Legend: | XX...X | Customer-specific information |
| | Y | Year code (last digit of calendar year) |
| | YY | Year code (last 2 digits of calendar year) |
| | WW | Week code (week of January 1 is week '01') |
| | NNN | Alphanumeric traceability code |
| | (e3) | Pb-free 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. | |

MCP19124/5

24-Lead Plastic Quad Flat, No Lead Package (MJ) – 4x4x0.9 mm Body [QFN]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



| Dimension Limits | Units | MILLIMETERS | | |
|------------------------|-------|-------------|------|------|
| | | MIN | NOM | MAX |
| Number of Pins | N | 24 | | |
| Pitch | e | 0.50 BSC | | |
| Overall Height | A | 0.80 | 0.85 | 0.90 |
| Standoff | A1 | 0.00 | 0.02 | 0.05 |
| Contact Thickness | A3 | 0.20 REF | | |
| Overall Width | E | 4.00 BSC | | |
| Exposed Pad Width | E2 | 2.40 | 2.50 | 2.60 |
| Overall Length | D | 4.00 BSC | | |
| Exposed Pad Length | D2 | 2.40 | 2.50 | 2.60 |
| Contact Width | b | 0.20 | 0.25 | 0.30 |
| Contact Length | L | 0.30 | 0.40 | 0.50 |
| Contact-to-Exposed Pad | K | 0.20 | - | - |

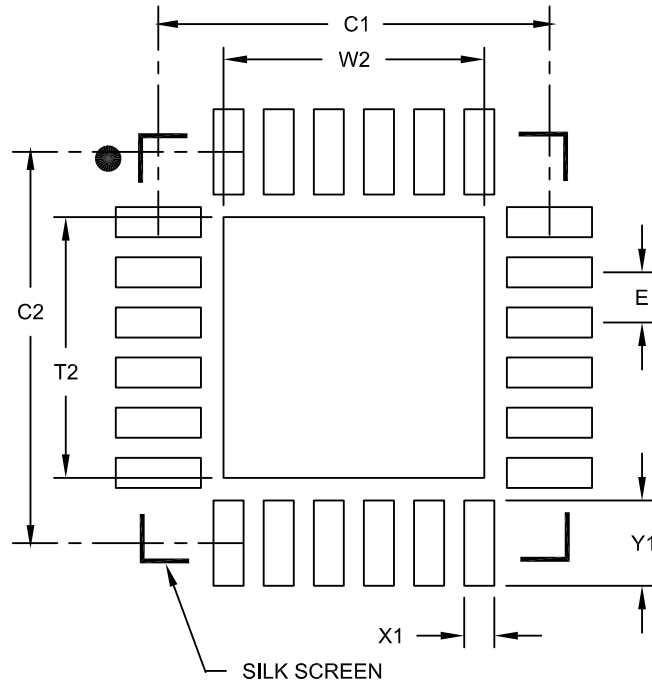
Notes:

- 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 C04-143A

24-Lead Plastic Quad Flat, No Lead Package (MJ) - 4x4 mm Body [QFN]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



RECOMMENDED LAND PATTERN

| Dimension Limits | Units | MILLIMETERS | | |
|----------------------------|-------|-------------|------|------|
| | | MIN | NOM | MAX |
| Contact Pitch | E | 0.50 BSC | | |
| Optional Center Pad Width | W2 | | | 2.60 |
| Optional Center Pad Length | T2 | | | 2.60 |
| Contact Pad Spacing | C1 | | 3.90 | |
| Contact Pad Spacing | C2 | | 3.90 | |
| Contact Pad Width | X1 | | | 0.30 |
| Contact Pad Length | Y1 | | | 0.85 |

Notes:

1. Dimensioning and tolerancing per ASME Y14.5M

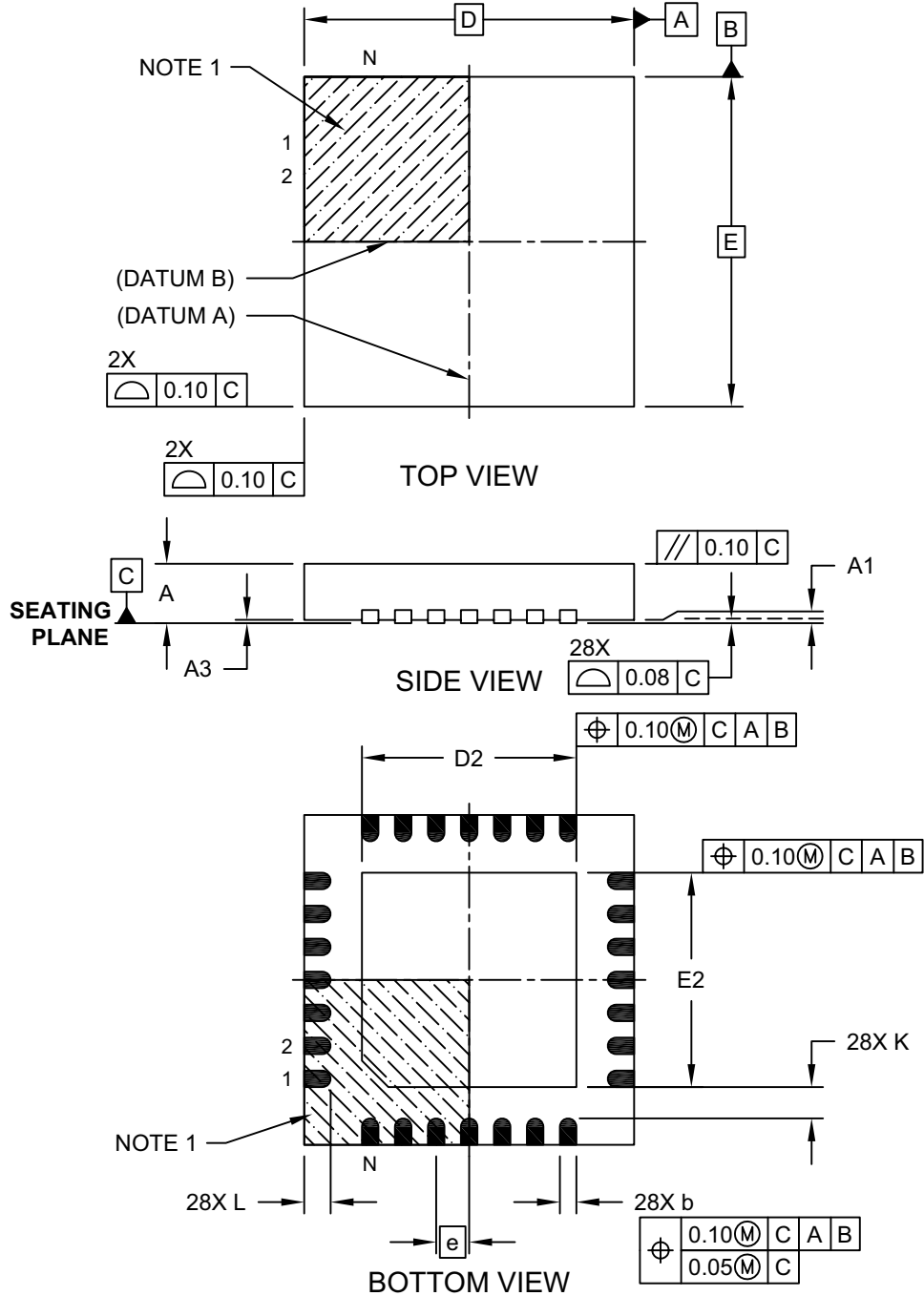
BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2143B

MCP19124/5

28-Lead Plastic Quad Flat, No Lead Package (MQ) – 5x5x0.9 mm Body [QFN]

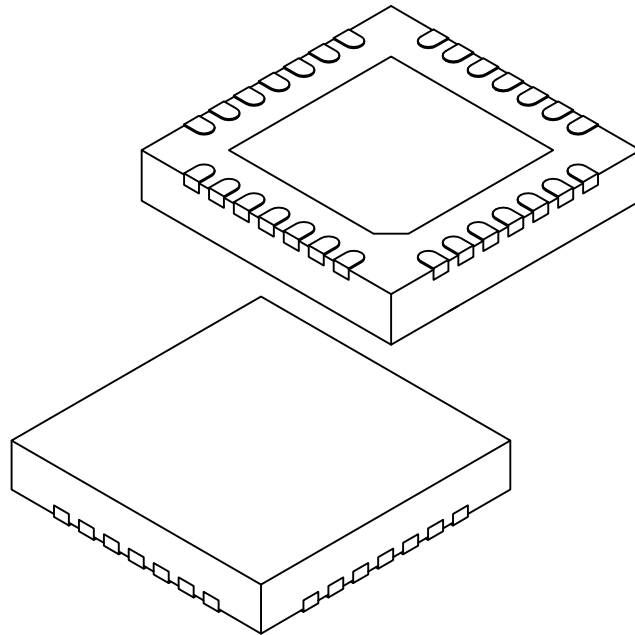
Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



Microchip Technology Drawing C04-140C Sheet 1 of 2

28-Lead Plastic Quad Flat, No Lead Package (MQ) – 5x5x0.9 mm Body [QFN]

Note: For the most current package drawings, please see the Microchip Packaging Specification located at <http://www.microchip.com/packaging>



| Dimension Limits | Units | MILLIMETERS | | |
|------------------------|-------|-------------|------|------|
| | | MIN | NOM | MAX |
| Number of Pins | N | 28 | | |
| Pitch | e | 0.50 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 | 5.00 BSC | | |
| Exposed Pad Width | E2 | 3.15 | 3.25 | 3.35 |
| Overall Length | D | 5.00 BSC | | |
| Exposed Pad Length | D2 | 3.15 | 3.25 | 3.35 |
| Contact Width | b | 0.18 | 0.25 | 0.30 |
| Contact Length | L | 0.35 | 0.40 | 0.45 |
| Contact-to-Exposed Pad | K | 0.20 | - | - |

Notes:

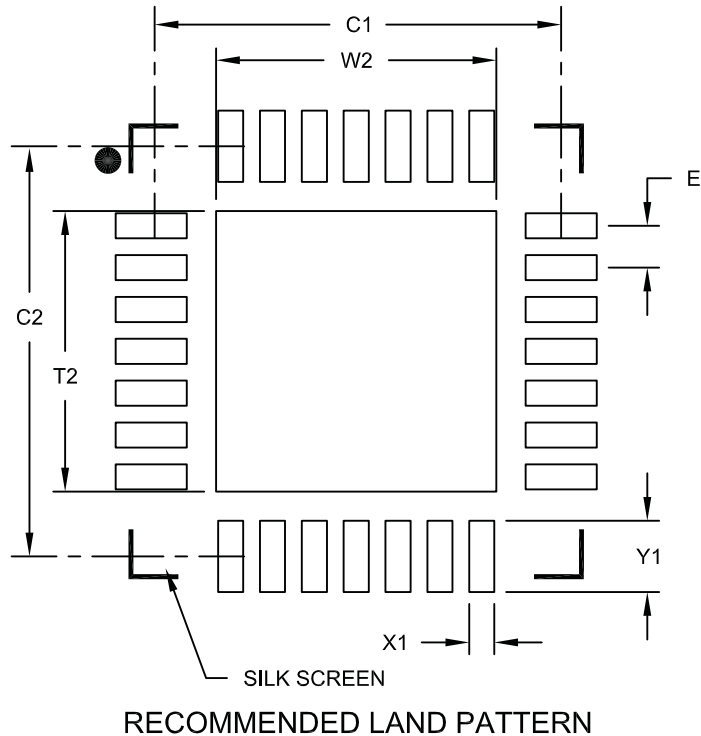
- Pin 1 visual index feature may vary, but must be located within the hatched area.
- Package is saw singulated.
- Dimensioning and tolerancing per ASME Y14.5M.
 - BSC: Basic Dimension. Theoretically exact value shown without tolerances.
 - REF: Reference Dimension, usually without tolerance, for information purposes only.

Microchip Technology Drawing C04-140C Sheet 2 of 2

MCP19124/5

28-Lead Plastic Quad Flat, No Lead Package (MQ) – 5x5 mm Body [QFN] Land Pattern 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>



| Dimension Limits | Units | MILLIMETERS | | |
|----------------------------|-------|-------------|------|------|
| | | MIN | NOM | MAX |
| Contact Pitch | E | 0.50 BSC | | |
| Optional Center Pad Width | W2 | | | 3.35 |
| Optional Center Pad Length | T2 | | | 3.35 |
| Contact Pad Spacing | C1 | | 4.90 | |
| Contact Pad Spacing | C2 | | 4.90 | |
| Contact Pad Width (X28) | X1 | | | 0.30 |
| Contact Pad Length (X28) | Y1 | | | 0.85 |

Notes:

1. Dimensioning and tolerancing per ASME Y14.5M

BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing C04-2140A

APPENDIX A: REVISION HISTORY

Revision A (September 2016)

- Original Release of this Document.

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NOTES:

THE MICROCHIP WEB SITE

Microchip provides online support via our web site at www.microchip.com. This web site is used as a means to make files and information easily available to customers. Accessible by using your favorite Internet browser, the web site contains the following information:

- **Product Support** – Data sheets and errata, application notes and sample programs, design resources, user's guides and hardware support documents, latest software releases and archived software
- **General Technical Support** – Frequently Asked Questions (FAQ), technical support requests, online discussion groups, Microchip consultant program member listing
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- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support

Customers should contact their distributor, representative or Field Application Engineer (FAE) for support. Local sales offices are also available to help customers. A listing of sales offices and locations is included in the back of this document.

Technical support is available through the web site at: <http://www.microchip.com/support>

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PRODUCT IDENTIFICATION SYSTEM

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

| PART NO. | | [X] ⁽¹⁾ | - | X | /XX |
|---|--|--------------------|---|-------------------|---------|
| Device | Tape and Reel Option | | | Temperature Range | Package |
| Device: | MCP19124: Digitally Enhanced PWM Power Analog High-Speed Controller MCP19125: Digitally Enhanced PWM Power Analog High-Speed Controller | | | | |
| Tape and Reel Option: | Blank = Standard packaging (tube) T = Tape and Reel | | | | |
| Temperature Range: | E = -40°C to +125°C (Extended) | | | | |
| Package: | MJ = 24-Lead Plastic Quad Flat, No Lead Package - 4x4x0.9 mm Body [QFN] MQ = 28-Lead Plastic Quad Flat, No Lead Package - 5x5x0.9 mm Body [QFN] | | | | |
| Examples: | | | | | |
| a) MCP19124-E/MJ: Extended temperature 24-LD QFN 4x4 package | | | | | |
| b) MCP19124T-E/MJ: Tape and Reel Extended temperature 24 LD QFN 4x4 package | | | | | |
| a) MCP19125-E/MQ: Extended Temperature 28 LD QFN 5x5 package | | | | | |
| b) MCP19125T-E/MQ: Tape and Reel Extended Temperature 28 LD QFN 5x5 package | | | | | |
| Note 1: Tape and Reel identifier only appears in the catalog part number description. This identifier is used for ordering purposes and is not printed on the device package. Check with your Microchip Sales Office for package availability with the Tape and Reel option. | | | | | |

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