Synchronous Buck Features:

- **Input Voltage**: 4.5V to 32V
- **Output Voltage**: 0.5V to 3.6V
  - Greater than 3.6V requires external divider
- **Switching Frequency**: 100 kHz to 1.6 MHz
- **Quiescent Current**: 5 mA Typical
- **High-Drive**:
  - +5V Gate Drive
  - 1A/2A Source Current
  - 1A/2A Sink Current
- **Low-Drive**:
  - +5V Gate Drive
  - 2A Source Current
  - 4A Sink Current
- **Peak Current Mode Control**
- **Differential Remote Output Sense**
- **Multi-Phase Systems**:
  - Master or Slave
  - Frequency Synchronized
  - Common Error Signal
- **Multiple Output Systems**:
  - Master or Slave
  - Frequency Synchronized
- **Configurable Parameters**:
  - Overcurrent Limit
  - Input Undervoltage Lockout
  - Output Overvoltage
  - Output Undervoltage
  - Internal Analog Compensation
  - Soft Start Profile
  - Synchronous Driver Dead Time
  - Switching Frequency
- **Thermal Shutdown**

Microcontroller Features:

- **Precision 8 MHz Internal Oscillator Block**:
  - Factory Calibrated
- **Interrupt Capable**
  - Firmware
  - Interrupt-on-Change Pins
- **Only 35 Instructions to Learn**
- **4096 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 Debug (ICD) via Two Pins (MCP19111)**
- **In-Circuit Serial Programming™ (ICSP™) via Two Pins**
  - 11 I/O Pins and One Input-Only Pin (MCP19110)
    - Three Open-Drain Pins
  - 14 I/O Pins and One Input-Only Pin (MCP19111)
    - Three Open-Drain Pins
- **Analog-to-Digital Converter (ADC)**:
  - 10-bit Resolution
  - 12 Internal Channels
  - Eight External Channels
- **Timer0**: 8-bit Timer/Counter with 8-Bit Prescaler
- **Enhanced Timer1**:
  - 16-bit Timer/Counter with Prescaler
  - Two Selectable Clock Sources
- **Timer2**: 8-Bit Timer/Counter with Prescaler
  - 8-bit Period Register
- **I^2C™ Communication**:
  - 7-bit Address Masking
  - Two Dedicated Address Registers
  - SMBus/PMBus™ Compatibility
Pin Diagram – 24-Pin QFN (MCP19110)
### TABLE 0-1: 24-PIN SUMMARY

<table>
<thead>
<tr>
<th>I/O</th>
<th>24-Pin QFN</th>
<th>ANSEL</th>
<th>A/D</th>
<th>Timers</th>
<th>MSSP</th>
<th>Interrupt</th>
<th>Pull-up</th>
<th>Basic</th>
<th>Additional</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPA0</td>
<td>1</td>
<td>Y</td>
<td>AN0</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>Analog Debug Output (1)</td>
</tr>
<tr>
<td>GPA1</td>
<td>2</td>
<td>Y</td>
<td>AN1</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>Sync. Signal In/Out (2, 3)</td>
</tr>
<tr>
<td>GPA2</td>
<td>3</td>
<td>Y</td>
<td>AN2</td>
<td>T0CKI</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPA3</td>
<td>5</td>
<td>Y</td>
<td>AN3</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPA4</td>
<td>8</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>N</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPA5</td>
<td>7</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>IOC (4)</td>
<td>Y(6)</td>
<td>MCLR</td>
<td>—</td>
</tr>
<tr>
<td>GPA6</td>
<td>6</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>N</td>
<td>ICSPDAT</td>
<td>—</td>
</tr>
<tr>
<td>GPA7</td>
<td>5</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>SCL</td>
<td>IOC</td>
<td>N</td>
<td>ICSPCLK</td>
<td>—</td>
</tr>
<tr>
<td>GPB0</td>
<td>9</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>N</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPB1</td>
<td>23</td>
<td>Y</td>
<td>AN4</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>Error Signal In/Out (3)</td>
</tr>
<tr>
<td>GPB2</td>
<td>24</td>
<td>Y</td>
<td>AN5</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>VIN</td>
<td>11</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>V&lt;sub&gt;IN&lt;/sub&gt;</td>
<td>Device Input Voltage</td>
</tr>
<tr>
<td>V&lt;sub&gt;DR&lt;/sub&gt;</td>
<td>14</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>V&lt;sub&gt;DR&lt;/sub&gt;</td>
<td>Gate Drive Supply Input Voltage</td>
</tr>
<tr>
<td>V&lt;sub&gt;DD&lt;/sub&gt;</td>
<td>18</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>V&lt;sub&gt;DD&lt;/sub&gt;</td>
<td>Internal Regulator Output</td>
</tr>
<tr>
<td>GND</td>
<td>10</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>GND</td>
<td>Small Signal Ground</td>
</tr>
<tr>
<td>PGND</td>
<td>12</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Large Signal Ground</td>
</tr>
<tr>
<td>LDRV</td>
<td>13</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Low-Side MOSFET Connection</td>
</tr>
<tr>
<td>HDRV</td>
<td>16</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>High-Side MOSFET Connection</td>
</tr>
<tr>
<td>PHASE</td>
<td>15</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Switch Node</td>
</tr>
<tr>
<td>BOOT</td>
<td>17</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Floating Bootstrap Supply</td>
</tr>
<tr>
<td>+V&lt;sub&gt;SEN&lt;/sub&gt;</td>
<td>21</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Output Voltage Differential Sense</td>
</tr>
<tr>
<td>-V&lt;sub&gt;SEN&lt;/sub&gt;</td>
<td>22</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Output Voltage Differential Sense</td>
</tr>
<tr>
<td>+I&lt;sub&gt;SEN&lt;/sub&gt;</td>
<td>20</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Current Sense Input</td>
</tr>
<tr>
<td>-I&lt;sub&gt;SEN&lt;/sub&gt;</td>
<td>19</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Current Sense Input</td>
</tr>
</tbody>
</table>

**Note:**

1. The Analog Debug Output is selected when the ATSTCON<BNCHEN> bit is set.
2. Selected when device is functioning as multiple output master or slave by proper configuration of the MLTPH<2:0> bits in the BUFFCON register.
3. Selected when device is functioning as multi-phase master or slave by proper configuration of the MLTPH<2:0> bits in the BUFFCON register.
4. The IOC is disabled when MCLR is enabled.
5. Weak pull-up always enabled when MCLR is enabled, otherwise the pull-up is under user control.
Pin Diagram – 28-Pin QFN (MCP19111)

MCP19110/11

GPA2
GPB4
GPA4
GPB7
GPB0
GPA1
GPA0
GPA3
GPA7
GPA6
GPA5/MCLR

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28

2
6
18
17
16
15
4
1
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

MCP19111

GPB2
GPB5
GPB1
VSEN
+VSEN
+ISEN
-ISEN

GPB2
GPB5
GPB1
VSEN
+VSEN
+ISEN
-ISEN

EXP-29

VDD
BOOT
HDRV
PHASE
VDR
LDRV

GND

© 2013 Microchip Technology Inc.
### TABLE 0-1: 28-PIN SUMMARY

<table>
<thead>
<tr>
<th>I/O</th>
<th>28-Pin QFN</th>
<th>ANSEL</th>
<th>A/D</th>
<th>Timers</th>
<th>MSSP</th>
<th>Interrupt</th>
<th>Pull-up</th>
<th>Basic</th>
<th>Additional</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPA0</td>
<td>1</td>
<td>Y</td>
<td>AN0</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>Analog Debug Output (1)</td>
</tr>
<tr>
<td>GPA1</td>
<td>2</td>
<td>Y</td>
<td>AN1</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>Sync. Signal In/Out (2, 3)</td>
</tr>
<tr>
<td>GPA2</td>
<td>3</td>
<td>Y</td>
<td>AN2</td>
<td>T0CKI</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPA3</td>
<td>5</td>
<td>Y</td>
<td>AN3</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPA4</td>
<td>9</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPA5</td>
<td>8</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>Y(6)</td>
<td>—</td>
<td>MCLR</td>
<td>—</td>
</tr>
<tr>
<td>GPA6</td>
<td>7</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPA7</td>
<td>6</td>
<td>N</td>
<td>—</td>
<td>SCL</td>
<td>IOC</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPB0</td>
<td>10</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>SDA</td>
<td>IOC</td>
<td>N</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPB1</td>
<td>26</td>
<td>Y</td>
<td>AN4</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>Error Signal In/Out (3)</td>
</tr>
<tr>
<td>GPB2</td>
<td>28</td>
<td>Y</td>
<td>AN5</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPB4</td>
<td>4</td>
<td>Y</td>
<td>AN6</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPB5</td>
<td>27</td>
<td>Y</td>
<td>AN7</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>Alternate Sync Signal In/Out (2, 3)</td>
</tr>
<tr>
<td>GPB6</td>
<td>21</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>GPB7</td>
<td>11</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>IOC</td>
<td>Y</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>V_IN</td>
<td>13</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>V_IN</td>
<td>—</td>
<td>—</td>
<td>Device Input Voltage</td>
</tr>
<tr>
<td>V_DR</td>
<td>16</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>V_DR</td>
<td>—</td>
<td>—</td>
<td>Gate Drive Supply Input Voltage</td>
</tr>
<tr>
<td>V_DD</td>
<td>20</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>V_DD</td>
<td>—</td>
<td>—</td>
<td>Internal Regulator Output</td>
</tr>
<tr>
<td>GND</td>
<td>12</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>GND</td>
<td>—</td>
<td>—</td>
<td>Small Signal Ground</td>
</tr>
<tr>
<td>P_GND</td>
<td>14</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Large Signal Ground</td>
</tr>
<tr>
<td>LDRV</td>
<td>15</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Low-Side MOSFET Connection</td>
</tr>
<tr>
<td>HDRV</td>
<td>18</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>High-Side MOSFET Connection</td>
</tr>
<tr>
<td>PHASE</td>
<td>17</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Switch Node</td>
</tr>
<tr>
<td>BOOT</td>
<td>19</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Floating Bootstrap Supply</td>
</tr>
<tr>
<td>+VSEN</td>
<td>24</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>−−</td>
<td>−−</td>
<td>Output Voltage Differential Sense</td>
</tr>
<tr>
<td>-VSEN</td>
<td>25</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>−−</td>
<td>−−</td>
<td>—</td>
</tr>
<tr>
<td>+ISEN</td>
<td>23</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>−−</td>
<td>−−</td>
<td>Current Sense Input</td>
</tr>
<tr>
<td>-ISEN</td>
<td>22</td>
<td>N</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>−−</td>
<td>−−</td>
<td>Current Sense Input</td>
</tr>
</tbody>
</table>

**Note**

1: The Analog Debug Output is selected when the ATSTCON<BNCHEN> bit is set.
2: Selected when device is functioning as multiple output master or slave by proper configuration of the MLTPH<2:0> bits in the BUFFCON register.
3: Selected when device is functioning as multi-phase master or slave by proper configuration of the MLTPH<2:0> bits in the BUFFCON register.
4: The IOC is disabled when MCLR is enabled.
5: Weak pull-up always enabled when MCLR is enabled, otherwise the pull-up is under user control.
# Table of Contents

1.0 Device Overview ............................................................................................................. 9  
2.0 Pin Description ............................................................................................................. 12  
3.0 Functional Description ................................................................................................. 17  
4.0 Electrical Characteristics ............................................................................................. 23  
5.0 Digital Electrical Characteristics ................................................................................. 29  
6.0 Configuring the MCP19110/11 .................................................................................... 37  
7.0 Typical Performance Curves ......................................................................................... 53  
8.0 System Bench Testing .................................................................................................. 57  
9.0 Device Calibration ........................................................................................................ 69  
10.0 Relative Efficiency Measurement ............................................................................... 67  
11.0 Memory Organization .................................................................................................. 69  
12.0 Device Configuration ................................................................................................... 81  
13.0 Oscillator Modes ......................................................................................................... 83  
14.0 Resets ....................................................................................................................... 85  
15.0 Interrupts .................................................................................................................. 93  
16.0 Power-Down Mode (Sleep) ......................................................................................... 101  
17.0 Watchdog Timer (WDT) ............................................................................................. 103  
18.0 Flash Program Memory Control ............................................................................... 105  
19.0 I/O Ports .................................................................................................................. 111  
20.0 Interrupt-On-Change .................................................................................................. 121  
21.0 Internal Temperature Indicator Module ...................................................................... 123  
22.0 Analog-to-Digital Converter (ADC) Module ............................................................. 125  
23.0 Timer0 Module ......................................................................................................... 135  
24.0 Timer1 Module with Gate Control ............................................................................. 137  
25.0 Timer2 Module ......................................................................................................... 140  
26.0 PWM Module .......................................................................................................... 143  
27.0 Master Synchronous Serial Port (MSSP) Module ...................................................... 147  
28.0 In-Circuit Serial Programming™ (ICSP™) ............................................................... 191  
29.0 Instruction Set Summary ............................................................................................ 193  
30.0 Development Support ............................................................................................... 203  
31.0 Packaging Information ............................................................................................... 207  
Appendix A: Revision History ......................................................................................... 213  
Index ............................................................................................................................. 215  
The Microchip Web Site .................................................................................................. 221  
Customer Change Notification Service ............................................................................ 221  
Customer Support .......................................................................................................... 221  
Product Identification System .......................................................................................... 222
TO OUR VALUED CUSTOMERS

It is our intention to provide our valued customers with the best documentation possible to ensure successful use of your Microchip products. To this end, we will continue to improve our publications to better suit your needs. Our publications will be refined and enhanced as new volumes and updates are introduced.

Most Current Data Sheet
To obtain the most up-to-date version of this data sheet, please register at our World Wide Web site at:

http://www.microchip.com

You can determine the version of a data sheet by examining its literature number found on the bottom outside corner of any page. The last character of the literature number is the version number, (e.g., DS30000000A is version A of document DS30000000).

Errata
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:
• Microchip’s World Wide Web site; http://www.microchip.com
• Your local Microchip sales office (see last page)

When contacting a sales office, please specify which device, revision of silicon and data sheet (include literature number) you are using.

Customer Notification System

Register on our web site at www.microchip.com to receive the most current information on all of our products.
NOTES:
1.0 DEVICE OVERVIEW

The MCP19110/11 is a highly integrated, mixed signal, analog pulse-width modulation (PWM) current mode controller with an integrated microcontroller core for synchronous DC/DC step-down applications. Since the MCP19110/11 uses traditional analog control circuitry to regulate the output of the DC/DC converter, the integration of the PIC® microcontroller mid-range core is used to provide complete customization of device operating parameters, start-up and shut down profiles, protection levels and fault handling procedures.

The MCP19110/11 is designed to efficiently operate from a single 4.5V to 32V supply. It features integrated synchronous drivers, bootstrap device, internal linear regulator and 4 kW nonvolatile memory all in a space-saving 24-pin 4 mm x 4mm QFN package (MCP19110) or 28-pin 5 mm x 5 mm QFN package (MCP19111).

After initial device configuration using Microchip’s MPLAB® X Integrated Development Environment (IDE) software, the PMBus or I²C can be used by a host to communicate with, or modify, the operation of the MCP19110/11.

Two internal linear regulators generate two 5V rails. One 5V rail is used to provide power for the internal analog circuitry and is contained on-chip. The second 5V rail provides power to the PIC device and is present on the VDD pin. It is recommended that a 1 µF capacitor be placed between VDD and PGND. The VDD pin may also be directly connected to the VDR pin, or connected through a low-pass RC filter. The VDR pin provides power to the internal synchronous driver.

FIGURE 1-1: TYPICAL APPLICATION CIRCUIT

![Typical Application Circuit Diagram]

MCP19110/11

V_in

+V_OUT

-V_OUT

MPLAB® X ICD Programmer
FIGURE 1-2: MCP19110/11 SYNCHRONOUS BUCK BLOCK DIAGRAM
FIGURE 1-3: MICROCONTROLLER CORE BLOCK DIAGRAM

- **Configuration**
  - Flash
  - 4K x 14 Program Memory
  - Program Bus

- **Instruction reg**
  - Instruction Decode & Control
  - Timing Generation
  - 8 MHz Internal Oscillator

- **Power-up Timer**
  - Power-on Reset

- **Watchdog Timer**

- **RAM**
  - 256 bytes
  - File Registers
  - RAM Addr

- **Addr MUX**
  - Direct Addr
  - Indirect Addr
  - FSR reg

- **STATUS reg**

- **ALU**
  - MUX
  - W reg

- **PORTA**
  - GPA0
  - GPA1
  - GPA2
  - GPA3
  - GPA4
  - GPA5
  - GPA6
  - GPA7

- **PORTB**
  - GPB0
  - GPB1
  - GPB2
  - GPB3
  - GPB4
  - GPB5
  - GPB6
  - GPB7

- **MSSP**
  - SDA
  - SCL

- **EEADDR**
  - EEADDR

- **PWM**

- **Analog Interface Registers**

- **TESTCLKIN**

- **MCLR**
  - VIN
  - VSS

- **Timer0**

- **Timer1**

- **Timer2**

- **Timers**

- **T0CKI**
2.0 PIN DESCRIPTION

The MCP19110/11 family of devices feature pins that have multiple functions associated with each pin. Table 2-1 provides a description of the different functions. See Section 2.1 “Detailed Pin Functional Description” for more detailed information.

TABLE 2-1: MCP19110/11 PINOUT DESCRIPTION

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Input Type</th>
<th>Output Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPA0/AN0/ANALOG_TEST</td>
<td>GPA0</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>AN0</td>
<td>AN</td>
<td>—</td>
<td>A/D Channel 0 input.</td>
<td></td>
</tr>
<tr>
<td>ANALOG_TEST</td>
<td>—</td>
<td>—</td>
<td>Internal analog signal multiplexer output (1)</td>
<td></td>
</tr>
<tr>
<td>GPA1/AN1/CLKPIN</td>
<td>GPA1</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>AN1</td>
<td>AN</td>
<td>—</td>
<td>A/D Channel 1 input.</td>
<td></td>
</tr>
<tr>
<td>CLKPIN</td>
<td>—</td>
<td>—</td>
<td>Switching frequency clock input or output (2,3)</td>
<td></td>
</tr>
<tr>
<td>GPA2/AN2/T0CKI/INT</td>
<td>GPA2</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>AN2</td>
<td>AN</td>
<td>—</td>
<td>A/D Channel 2 input.</td>
<td></td>
</tr>
<tr>
<td>T0CKI</td>
<td>ST</td>
<td>—</td>
<td>Timer0 clock input.</td>
<td></td>
</tr>
<tr>
<td>INT</td>
<td>ST</td>
<td>—</td>
<td>External interrupt.</td>
<td></td>
</tr>
<tr>
<td>GPA3/AN3</td>
<td>GPA3</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>AN3</td>
<td>AN</td>
<td>—</td>
<td>A/D Channel 3 input.</td>
<td></td>
</tr>
<tr>
<td>GPA4</td>
<td>GPA4</td>
<td>TTL</td>
<td>OD</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>GPA5/MCLR</td>
<td>GPA5</td>
<td>TTL</td>
<td>—</td>
<td>General purpose input only</td>
</tr>
<tr>
<td>MCLR</td>
<td>ST</td>
<td>—</td>
<td>Master Clear with internal pull-up</td>
<td></td>
</tr>
<tr>
<td>GPA6/ICSPDAT</td>
<td>GPA6</td>
<td>ST</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>ICSPDAT</td>
<td>ST</td>
<td>CMOS</td>
<td>Serial Programming Data I/O (MCP19110 Only)</td>
<td></td>
</tr>
<tr>
<td>GPA7/SCL/ICSPCLK</td>
<td>GPA7</td>
<td>ST</td>
<td>OD</td>
<td>General purpose open-drain I/O</td>
</tr>
<tr>
<td>SCL</td>
<td>ST</td>
<td>CMOS</td>
<td>i²C clock.</td>
<td></td>
</tr>
<tr>
<td>ICSPCLK</td>
<td>ST</td>
<td>—</td>
<td>Serial Programming Clock (MCP19110 Only)</td>
<td></td>
</tr>
<tr>
<td>GPB0/SDA</td>
<td>GPB0</td>
<td>TTL</td>
<td>OD</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>SDA</td>
<td>TTL</td>
<td>—</td>
<td>i²C data input/output; i²C = Schmitt Trigger input with i²C</td>
<td></td>
</tr>
<tr>
<td>GPB1/AN4/EAPIN</td>
<td>GPB1</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>AN4</td>
<td>AN</td>
<td>—</td>
<td>A/D Channel 4 input.</td>
<td></td>
</tr>
<tr>
<td>EAPIN</td>
<td>—</td>
<td>—</td>
<td>Error amplifier signal input/output (3)</td>
<td></td>
</tr>
<tr>
<td>GPB2/AN5</td>
<td>GPB2</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>AN5</td>
<td>AN</td>
<td>—</td>
<td>A/D Channel 5 input.</td>
<td></td>
</tr>
<tr>
<td>GPB4/AN6/ICSPDAT (MCP19111 Only)</td>
<td>GPB4</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>AN6</td>
<td>AN</td>
<td>—</td>
<td>A/D Channel 6 input.</td>
<td></td>
</tr>
<tr>
<td>ICSPDAT</td>
<td>ST</td>
<td>CMOS</td>
<td>Serial Programming Data I/O</td>
<td></td>
</tr>
</tbody>
</table>

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: Analog Test is selected when the ATSTCON<BNCHEN> bit is set.  
2: Selected when device is functioning as multiple output master or slave by proper configuration of the MLTPH<2:0> bits in the BUFFER register.  
3: Selected when device is functioning as multi-phase master or slave by proper configuration of the MLTPH<2:0> bits in the BUFFER register.
### TABLE 2-1: MCP19110/11 PINOUT DESCRIPTION (CONTINUED)

<table>
<thead>
<tr>
<th>Name</th>
<th>Function</th>
<th>Input Type</th>
<th>Output Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPB5/AN7/ICSPCLK/ ALT_CLKPIN (MCP19111 Only)</td>
<td>GPB5</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td></td>
<td>AN7</td>
<td>AN</td>
<td>—</td>
<td>A/D Channel 7 input</td>
</tr>
<tr>
<td></td>
<td>ISCPCLK</td>
<td>ST</td>
<td>—</td>
<td>Serial Programming Clock</td>
</tr>
<tr>
<td></td>
<td>ALT_CLKPIN</td>
<td>—</td>
<td>—</td>
<td>Alternate switching frequency clock input or output (2,3)</td>
</tr>
<tr>
<td>GPB6 (MCP19111 Only)</td>
<td>GPB6</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>GPB7 (MCP19111 Only)</td>
<td>GPB7</td>
<td>TTL</td>
<td>CMOS</td>
<td>General purpose I/O</td>
</tr>
<tr>
<td>V_IN</td>
<td>V_IN</td>
<td>—</td>
<td>—</td>
<td>Device input supply voltage</td>
</tr>
<tr>
<td>V_DD</td>
<td>V_DD</td>
<td>—</td>
<td>—</td>
<td>Internal +5V LDO output pin</td>
</tr>
<tr>
<td>V_DV</td>
<td>V_DV</td>
<td>—</td>
<td>—</td>
<td>Gate drive supply input voltage pin</td>
</tr>
<tr>
<td>GND</td>
<td>GND</td>
<td>—</td>
<td>—</td>
<td>Small signal quiet ground</td>
</tr>
<tr>
<td>P_GND</td>
<td>P_GND</td>
<td>—</td>
<td>—</td>
<td>Large signal power ground</td>
</tr>
<tr>
<td>LDRV</td>
<td>LDRV</td>
<td>—</td>
<td>—</td>
<td>High-current drive signal connected to the gate of the low-side MOSFET</td>
</tr>
<tr>
<td>HDRV</td>
<td>HDRV</td>
<td>—</td>
<td>—</td>
<td>Floating high-current drive signal connected to the gate of the high-side MOSFET</td>
</tr>
<tr>
<td>PHASE</td>
<td>PHASE</td>
<td>—</td>
<td>—</td>
<td>Synchronous buck switch node connection</td>
</tr>
<tr>
<td>BOOT</td>
<td>BOOT</td>
<td>—</td>
<td>—</td>
<td>Floating bootstrap supply</td>
</tr>
<tr>
<td>+V_SEN</td>
<td>+V_SEN</td>
<td>—</td>
<td>—</td>
<td>Positive input of the output voltage sense differential amplifier</td>
</tr>
<tr>
<td>-V_SEN</td>
<td>-V_SEN</td>
<td>—</td>
<td>—</td>
<td>Negative input of the output voltage sense differential amplifier</td>
</tr>
<tr>
<td>+I_SEN</td>
<td>+I_SEN</td>
<td>—</td>
<td>—</td>
<td>Current sense input</td>
</tr>
<tr>
<td>-I_SEN</td>
<td>-I_SEN</td>
<td>—</td>
<td>—</td>
<td>Current sense input</td>
</tr>
<tr>
<td>EP</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Exposed Thermal Pad</td>
</tr>
</tbody>
</table>

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

**Note:**
1. Analog Test is selected when the ATSTCON<BNCHEN> bit is set.
2. Selected when device is functioning as multiple output master or slave by proper configuration of the MLTPH<2:0> bits in the BUFFCON register.
3. Selected when device is functioning as multi-phase master or slave by proper configuration of the MLTPH<2:0> bits in the BUFFCON 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.
When the ATSTCON<BNCHEN> bit is set, this pin is configured as the ANALOG_TEST function. It is a buffered output of the internal analog signal multiplexer. Signals present on this pin are controlled by the BUFFCON register, see Register 8-2.

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 MCP19110/11 is configured as a multiple output or multi-phase MASTER or SLAVE, this pin is configured to be the switching frequency synchronization input or output, CLKPIN. See Section 3.10.6 “Multi-Phase System” and Section 3.10.7 “Multiple Output System” for more information.

2.1.3 GPA2 PIN
GPA2 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.
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, the T0CKI function is enabled. See Section 23.0 “Timer0 Module” for more information.
GPA2 can also be configured as an external interrupt by setting of the INTE bit. See Section 15.2 “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 GPA4 PIN
GPA4 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 VDD, making this pin ideal to be used as an SMBus Alert pin. This pin does not have a weak pull-up, but interrupt-on-change is available.

2.1.6 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 MCLR pin of the serial programmer. See Section 28.0 “In-Circuit Serial Programming™ (ICSP™)” for more information.

2.1.7 GPA6 PIN
GPA6 is a general purpose CMOS input/output pin whose data direction is controlled in TRISGPA. An interrupt-on-change is also available.
On the MCP19110, the ISCPDAT is the serial programming data input function. This is used in conjunction with ICSPCLK to serial program the device. This pin function is only implemented on the MCP19110.

2.1.8 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 VDD. This pin does not have a weak pull-up, but interrupt-on-change is available.
When the MCP19110/11 is configured for I2C communication (see Section 27.2 “I2C Mode Overview”), GPA7 functions as the I2C clock, SCL.
On the MCP19110, the ISCPCLK is the serial programming clock function. This is used in conjunction with ISCPDAT to serial program the device. This pin function is only implemented on the MCP19110.

2.1.9 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 VDD. This pin does not have a weak pull-up, but interrupt-on-change is available.
When the MCP19110/11 is configured for I2C communication (see Section 27.2 “I2C Mode Overview”), GPB0 functions as the I2C clock, SDA.
2.1.10 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 MCP19110/11 is configured as a multiple output or multi-phase MASTER or SLAVE, this pin is configured to be the error amplifier signal input or output. See Section 3.10.6 “Multi-Phase System” and Section 3.10.7 “Multiple Output System”, for more information.

2.1.11 GPB2 PIN

GPB2 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 TRISB2 and ANSB2 must be set.

2.1.12 GPB4 PIN

This pin and its associated functions are only available on the MCP19111 device.

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.

AN6 is an input to the A/D. To configure this pin to be read by the A/D on channel 6, bits TRISB4 and ANSB4 must be set.

On the MCP19111, the ISCPDAT is the serial programming data input function. This is used in conjunction with ICSPCLK to serial program the device. This pin function is only implemented on the MCP19111.

2.1.13 GBP5 PIN

This pin and its associated functions are only available on the MCP19111 device.

GBP5 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 TRISB5 and ANSB5 must be set.

On the MCP19111, the ISCPCLK is the serial programming clock function. This is used in conjunction with ICSPDAT to serial program the device. This pin function is only implemented on the MCP19111.

This pin can also be configured as an alternate switching frequency synchronization input or output, ALT_CLKPIN, for use in multiple output or multi-phase systems. See Section 19.1 “Alternate Pin Function” for more information.

2.1.14 GPB6 PIN

This pin and associated functions is only available on the MCP19111 device.

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.

2.1.15 GPB7 PIN

This pin and associated functions is only available on the MCP19111 device.

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.

2.1.16 V IN PIN

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

2.1.17 V DD PIN

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

2.1.18 V DR PIN

The 5V supply for the low-side driver is connected to this pin. The pin can be connected by an RC filter to the VDD pin.

2.1.19 GND PIN

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 PGND PIN

Connect all large signal level ground returns to PGND. 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 LDRV PIN

The gate of the low-side or rectifying MOSFET is connected to LDRV. The PCB tracing connecting LDRV to the gate must be of minimal length and appropriate width to handle the high peak drive currents and fast voltage transitions.
2.1.22 HDRV PIN
The gate of the high-side MOSFET is connected to HDRV. This is a floating driver referenced to PHASE. The PCB trace connecting HDRV to the gate must be of minimal length and appropriate width to handle the high-peak drive current and fast voltage transitions.

2.1.23 PHASE PIN
The PHASE pin provides the return path for the high-side gate driver. The source of the high-side MOSFET, drain of the low-side MOSFET and the inductor are connected to this pin.

2.1.24 BOOT PIN
The BOOT pin is the floating bootstrap supply pin for the high-side gate driver. A capacitor is connected between this pin and the PHASE pin to provide the necessary charge to turn on the high-side MOSFET.

2.1.25 +VSEN PIN
The non-inverting input of the unity gain amplifier used for output voltage remote sensing is connected to the +VSEN pin. This pin can be internally pulled-up to VDD by setting PE1<PUEN> bit.

2.1.26 -VSEN PIN
The inverting input of the unity gain amplifier used for output voltage remote sensing is connected to the -VSEN pin. This pin can be internally pull-down to GND by setting PE1<PDEN> bit.

2.1.27 +ISEN PIN
The non-inverting input of the current sense amplifier is connected to the +ISEN pin.

2.1.28 -ISEN PIN
The inverting input of the current sense amplifier is connected to the -ISEN pin.

2.1.29 EXPOSED PAD (EP)
There is no internal connection to the Exposed Thermal Pad. The EP should be connected to the GND pin and to the GND PCB plane to aid in the removal of the heat.
3.0 FUNCTIONAL DESCRIPTION

3.1 Linear Regulators

Two internal linear regulators generate two 5V rails. One 5V rail is used to provide power for the internal analog circuitry and is contained on-chip. The second 5V rail provides power to the internal PIC core and it is present on the VDD pin. It is recommended that a 1 µF capacitor be placed between VDD and PGROUND.

The VDR pin provides power to the internal synchronous MOSFET driver. VDD can be directly connected to VDR or connected through a low-pass RC filter to provide noise filtering. A 1 µF ceramic bypass capacitor should be placed between VDR and PGROUND. When connecting VDD to VDR, the gate drive current required to drive the external MOSFETs must be added to the MCP19110/11 quiescent current, IQ(max), and the total current must be less than the maximum current, IDD-OUT, available from VDD that is specified in Section 4.2 “Electrical Characteristics”.

EQUATION 3-1: TOTAL REGULATOR CURRENT

\[ I_{DD-OUT} > (I_Q + I_{DRIVE} + I_{EXT}) \]

Where:
- \( I_{DD-OUT} \) is the total current available from VDD
- \( I_Q \) is the device quiescent current
- \( I_{DRIVE} \) is the current required to drive the external MOSFETs
- \( I_{EXT} \) is the amount of current used to power additional external circuitry.

EQUATION 3-2: GATE DRIVE CURRENT

\[ I_{DRIVE} = (Q_{gHIGH} + Q_{gLOW}) \times F_{SW} \]

Where:
- \( I_{DRIVE} \) is the current required to drive the external MOSFETs
- \( Q_{gHIGH} \) is the total gate charge of the high-side MOSFET
- \( Q_{gLOW} \) is the total gate charge of the low-side MOSFET
- \( F_{SW} \) is the switching frequency

Alternatively, an external regulator can be used to power the synchronous driver. An external 5V source can be connected to VDR. The amount of current required from this external source can be found in Equation 3-2. Care must be taken that the voltage applied to VDR does not exceed the maximum ratings found in Section 4.1 “Absolute Maximum Ratings (†)”.

3.2 Internal Synchronous Driver

The internal synchronous driver is capable of driving two N-Channel MOSFETs in a synchronous rectified buck converter topology. The gate of the floating MOSFET is connected to the HDRV pin. The source of this MOSFET is connected to the PHASE pin. The HDRV pin source and sink current is configurable. By setting the DRVSTR bit in the PE1 register, the high-side is capable of sourcing and sinking a peak current of 1A. By clearing this bit, the source and sink peak current is 2A.

Note 1: The PE1<DRVSTR> bit configures the peak source/sink current of the HDRV pin.

The MOSFET connected to the LDRV pin is not floating. The low-side MOSFET gate is connected to the LDRV pin and the source of this MOSFET is connected to PGROUND. The drive strength of the LDRV pin is not configurable. This pin is capable of sourcing a peak current of 2A. The peak sink current is 4A. This helps keep the low-side MOSFET off when the high-side MOSFET is turning on.

Note 1: Refer to Figure 1-1 for a graphical representation of the MOSFET connections.

3.2.1 MOSFET DRIVER DEAD TIME

The MOSFET driver dead time is defined as the time between one drive signal going low and the complimentary drive signal going high. Refer to Figure 6-2. The MCP19110/11 has the capability to adjust both the high-side and low-side driver dead time independently. The adjustment of the driver dead time is controlled by the DEADCON register and is adjustable in 4 ns increments.

Note 1: The DEADCON register controls the amount of dead time added to the HDRV or LDRV signal. The dead time circuitry is enabled by the LDLYBY and HDLYBY bits in the PE1 register.

3.2.2 MOSFET DRIVER CONTROL

The MCP19110/11 has the ability to disable the entire synchronous driver or just one side of the synchronous drive signal. The bits that control the MOSFET driver can be found in the Register 8-1.

By setting ATSTCON<DRVDIS>, the entire synchronous driver is disabled. The HDRV and LDRV signals are set low and the PHASE pin is floating. Clearing this bit allows normal operation.

Individual control of the HDRV or LDRV signal is accomplished by setting or clearing the HIDIS or LODIS bits in the ATSTCON register. When either driver is disabled, the output signal is set low.
3.3 Output Voltage
The output voltage is configured by the settings contained in the OVCCON and OVFCON registers. No external resistor divider is needed to set the output voltage. Refer to Section 6.10 “Output Voltage Configuration”.
The MCP19110/11 contains a unity gain differential amplifier used for remote sensing of the output voltage. Connect the +VSEN and -VSEN pins directly at the load for better load regulation. The +VSEN and -VSEN are the positive and negative inputs, respectively, of the differential amplifier.

3.4 Switching Frequency
The switching frequency is configurable over the range of 100 kHz to 1.6 MHz. The Timer2 module is used to generate the HDRV/LDRV switching frequency. Refer to Section 26.0 “PWM Module” for more information. Example 3-1 shows how to configure the MCP19110/11 for a switching frequency of 300 kHz.

EXAMPLE 3-1: CONFIGURING FSW

```
BANKSEL T2CON
CLRF T2CON ;Turn off Timer2
CLRF TMR2 ;Initialize module
MOVLW 0x19 ;Fsw=300 kHz
MOVWF PR2
MOVLW 0x0A ;Max duty cycle=40%
MOVWF PWMRL
MOVLW 0x00 ;No phase shift
MOVWF PWMPHL
MOVLW 0x04 ;Turn on Timer2
MOVWF T2CON
```

3.5 Compensation
The MCP19110/11 is an analog peak current mode controller with integrated adjustable compensation. The CMPZCON register is used to adjust the compensation zero frequency and gain. Figure 3-1 shows the internal compensation network with the output differential amplifier.

FIGURE 3-1: SIMPLIFIED INTERNAL COMPENSATION

3.6 Slope Compensation
In current mode control systems, slope compensation needs to be added to the control path to help prevent subharmonic oscillation when operating with greater than 50% duty cycle. In the MCP19110/11, a negative slope is added to the error amplifier output signal before it is compared to the current sense signal. The amount of slope added is controlled by the SLPCRCON register, Register 6-7.

Note 1: To enable the slope compensation circuitry, the ABECON<SLCPBY> bit must be cleared.

The amount of slope compensation added should be equal to the inductor current down slope during the high-side off time.

3.7 Current Sense
The output current is differentially sensed by the MCP19110/11. The sense element can be either a resistor placed in series with the output, or the series resistance of the inductor. If the inductor series resistance is used, a filter is needed to remove the large AC component of the voltage that appears across the inductor and leave only the small AC voltage that appears across the inductor resistance, as shown in Figure 3-2. This small AC voltage is representative of the output current.

FIGURE 3-2: INDUCTOR CURRENT SENSE FILTER

The value of RS and CS can be found by using Equation 3-3. When the current sense filter time constant is set equal to the inductor time constant, the voltage appearing across CS approximates the current flowing in the inductor, multiplied by the inductor resistance.
EQUATION 3-3: CALCULATING FILTER VALUES

\[
\frac{L}{R_L} = (R_S \times C_S)
\]

Where:
- \(L\) is the inductance value of the output inductor
- \(R_L\) is the series resistance of the output inductor
- \(R_S\) is the current sense filter resistor
- \(C_S\) is the current sense filter capacitor

Both AC gain and DC gain can be added to the current sense signal. Refer to Section 6.3 “Current Sense AC Gain” and Section 6.4 “Current Sense DC Gain” for more information.

3.7.1 PLACEMENT OF THE CURRENT SENSE FILTER COMPONENTS

The amplitude of the current sense signal is typically less than 100 mV peak-to-peak. Therefore, the small signal current sense traces are very susceptible to circuit noise. When designing the printed circuit board, placement of \(R_S\) and \(C_S\) is very important. The \(+I_{SEN}\) and \(-I_{SEN}\) traces should be routed parallel to each other with minimum spacing. This Kelvin sense routing technique helps minimize noise sensitivity. The filter capacitor (\(C_S\)) should be placed as close to the MCP19110/11 as possible. This will help filter any noise that is injected onto the current sense lines. The trace connecting \(C_S\) to the inductor should occur directly at the inductor and not at any other \(+V_{SEN}\) trace. The filter resistor (\(R_S\)), should be placed close to the inductor. See Figure 3-3 for component placement. Care should also be taken to avoid routing the \(+I_{SEN}\) and \(-I_{SEN}\) traces near the high current switching nodes of the HDRV, LDRV, PHASE, or BOOST traces. It is recommended that a ground layer be placed between these high current traces and the small signal current sense traces.

FIGURE 3-3: CURRENT SENSE FILTER COMPONENT PLACEMENT
3.8 Protection Features

3.8.1 INPUT UNDERVOLTAGE LOCKOUT
The input Undervoltage Lockout (UVLO) threshold is configurable by the VINLVL register, Register 6-1. When the voltage at the VIN pin of the MCP19110/11 is below the configurable threshold, the PIR2<VINIF> flag will be set. This flag is cleared by hardware once the VIN voltage is greater than the configurable threshold. By enabling the global interrupts or polling the VINIF bit, the MCP19110/11 can be disabled when the VIN voltage is below the threshold.

Some techniques that can be used to disable the switching of the MCP19110/11 while the VINIF flag is set include setting the ATSTCON<DVRDIS> bit, setting the reference voltage to 0V, setting the PE1<PUEN> bit, or setting the ATSTCON<HIDIS> and ATSTCON<LODIS> bits.

3.8.2 OUTPUT OVERCURRENT
The MCP19110/11 senses the voltage drop across the high-side MOSFET to determine when an output overcurrent (OC) exists. This voltage drop is configurable by the OCCON register (Register 6-2), and is measured when the high-side MOSFET is conducting. To avoid false OC events, leading edge blanking is applied to the measurements. The amount of blanking is controlled by the OCLEB<1:0> bits in the OCCON register. See Section 6.2 “Output Overcurrent” for more information.

When the input voltage is greater than 20V, or if the $R_{DS(on)}$ of the high-side MOSFET is such that the programmed overcurrent threshold does not produce acceptable peak overcurrent protection, an alternative method must be used to determine an overcurrent situation. An alternative technique can use the configurable output undervoltage protection, and the PE1<UVTEE> bit, to quickly terminate switching when the output voltage drops because of an overcurrent event.

3.8.3 OUTPUT UNDERVOLTAGE
When the output undervoltage DAC is enabled by setting the ABECON<UVDCEN> bit, the voltage measured between the +VSEN and -VSEN pins is monitored and compared to the UV threshold controlled by the OUVCON register (Register 6-12). When the output voltage is below the threshold, the PIR2<UVIF> flag will be set. Once set, firmware can determine how the MCP19110/11 responds to the fault condition and it must clear the UVIF flag.

By setting the PE1<UVTEE> bit, the HDRV and LDRV signals will be asserted low when the UVIF flag is set. The signals will remain low until the flag is cleared.

3.8.4 OUTPUT OVERVOLTAGE
When the output overvoltage DAC is enabled by setting the ABECON<OVDCEN> bit, the voltage measured between the +VSEN and -VSEN pins is monitored and compared to the OV threshold controlled by the OOVCON register (Register 6-13). When the output voltage is above the threshold, the PIR2<OVIF> flag will be set. Once set, firmware can determine how the MCP19110/11 responds to the fault condition and it must clear the OVIF flag.

By setting the PE1<OVTEE> bit, the HDRV and LDRV signals will be asserted low when the OVIF flag is set. The signals will remain low until the flag is cleared.
3.8.5 OVERTEMPERATURE

The MCP19110/11 features a hardware overtemperature shutdown protection typically set at +160°C. No firmware fault-handling procedure is required to shutdown the MCP19110/11 for an overtemperature condition.

3.9 PIC Microcontroller Core

Integrated into the MCP19110/11 is the PIC microcontroller mid-range core. This is a fully functional microcontroller, allowing propriety features to be implemented. Setting the CONFIG<CP> bit enables the code protection. The firmware is then protected from external reads or writes. Various status and fault bits are available to customize the fault handling response.

A minimal amount of firmware is required to properly configure the MCP19110/11. Section 6.0 “Configuring the MCP19110/11” contains detailed information about each register that needs to be set for the MCP19110/11 device to operate. To aid in the development of the required firmware, a Graphical User Interface (GUI) has been developed. This GUI can be used to quickly configure the MCP19110/11 for basic operation. Customized or proprietary features can then be added to the GUI generated firmware.

Note 1: The GUI can be found on the MCP19110/11 product page on www.microchip.com.

Note 2: Microchip’s MPLAB X Integrated Development Environment Software is required to use the GUI.

The MCP19110/11 device features firmware debug support. See Section 30.0 “Development Support” for more information.

3.10 Miscellaneous Features

3.10.1 DEVICE ADDRESSING

The communication address of the MCP19110/11 is stored in the SSPADD register. This value can be loaded when the device firmware is programmed or configured by external components. By reading a voltage on a GPIO with the ADC, a device specific address can be stored into the SSPADD register.

The MCP19110/11 contains a second address register, SSPADD2. This is a 7-bit address that can be used as the SMBus alert address when PMBus communication is used. See Section 27.0 “Master Synchronous Serial Port (MSSP) Module” for more information.

3.10.2 DEVICE ENABLE

A GPIO pin can be configured to be a device enable pin. By configuring the pin as an input, the PORT register or the interrupt on change (IOC) can be used to enable the device. Example 3-2 shows how to configure a GPIO as an enable pin by testing the PORT register.

**EXAMPLE 3-2: CONFIGURING GPA3 AS DEVICE ENABLE**

```assembly
BANKSEL TRISGPA
BSF TRISGPA, 3 ;Set GPA3 as input
BANKSEL ANSELA
BCF ANSELA, 3 ;Set GPA3 as digital input

: ;Insert additional user code here

WAIT_ENABLE:
BANKSEL PORTGPA
BTFSS PORTGPA, 3 ;Test GPA3 to see if pulled high
;A high on GPA3 indicated device to be enabled
GOTO WAIT_ENABLE ;Stay in loop waiting for device enable
BANKSEL ATSTCON
BSF ATSTCON, 0 ;Enable the device by enabling drivers

: ;Insert additional code here
```
3.10.3 OUTPUT POWER GOOD
The output voltage measured between the +VSEN and -VSEN pins can be monitored by the internal ADC. In firmware, when this ADC reading matches a user-defined power good value, a GPIO can be toggled to indicate the system output voltage is within a specified range. Delays, hysteresis and time-out values can all be configured in firmware.

3.10.4 OUTPUT VOLTAGE SOFT-START
During start-up, soft start of the output voltage is accomplished in firmware. By using one of the internal timers and incrementing the OVCCON or OVFCON register on a timer overflow, very long soft start times can be achieved.

3.10.5 OUTPUT VOLTAGE TRACKING
The MCP19110/11 can be configured to track another voltage signal at start-up or shutdown. The ADC is configured to read a GPIO that has the desired tracking voltage applied to it. The firmware then handles the tracking of the internal output voltage reference to this ADC reading.

3.10.6 MULTI-PHASE SYSTEM
In a multi-phase system, the output of each converter is connected together. There is one master device that sets the system switching frequency and provides each slave device with an error signal, in order to regulate the output to the same value.

The MCP19110/11 can be configured as a multi-phase master or slave by the setting of the MLTPH<2:0> bits in the BUFFCON register (Register 8-2). When set as a multi-phase master device, the internal switching frequency clock is connected to GPA1 and a output of the error amplifier is connected to GPB1. The GPIOs need to be configured as outputs.

When set as a multi-phase slave device, the GPA1 pin is configured as the CLKPIN function. The switching frequency clock from the master device must be connected to GPA1. The slave device will synchronize its internal switching frequency clock to the master clock. Phase shift can be applied by setting the PWMPHL register of the slave device. The slave GPB1 pin is configured as the error signal input pin (EAPIN). The master error amplifier output must be connected to GPB1. Gain can be added to the master error amplifier output signal by the SLVGNCON register setting (Register 6-8). The slave device will use this master error signal to regulate the output voltage. When set as a slave device, GPA1 and GPB1 need to be configured as inputs. Refer to Section 26.1 “Standard Pulse-Width Modulation (PWM) Mode” for additional information.

3.10.7 MULTIPLE OUTPUT SYSTEM
In a multiple output system, the switching frequency of each converter should be synchronized to a master clock to prevent beat frequencies from developing. Phase shift is often added to the master clock to help smooth the system input current. The MCP19110/11 has the ability to function as a multiple output master or slave by setting the appropriate MLTPH<2:0> bits in the BUFFCON register (Register 8-2).

When configured as a multiple output master, the GPA1 pin is set as the CLKPIN output function. The internal switching frequency clock is applied to this pin and is to be connected to the GPA1 pin of the slave units.

When configured as a multiple output slave, the GPA1 pin is set as the CLKPIN input function. The switching frequency clock of the master device is connected to this pin. Phase shift can be applied by appropriately setting the PWMPHL register of the slave device. Refer to Section 26.1 “Standard Pulse-Width Modulation (PWM) Mode”.

3.10.8 SYSTEM BENCH TESTING
The MCP19110/11 is a highly integrated controller. To facilitate system prototyping, various internal signals can be measured by configuring the MCP19110/11 in bench test mode. To accomplish this, the ATSTCON<BNCHEN> bit is set. This configures GPA0 as the ANALOG_TEST feature. The signals measured on GPA0 are controlled by the ASEL<4:0> bits of the BUFFCON register. See Section 8.0 “System Bench Testing” for more information.

Note 1: The ALT_CLKPIN can also be used by setting the APFCON<CLKSEL> bit. This function is only available in the MCP19111.

Note 1: The ALT_CLKPIN can also be used by setting the APFCON<CLKSEL> bit. This function is only available in the MCP19111.

Note 1: The factory-set calibration words are write-protected even when the MCP19110/11 is placed in a Bench Test mode.
4.0 ELECTRICAL CHARACTERISTICS

4.1 ABSOLUTE MAXIMUM RATINGS (†)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{\text{IN}} - V_{\text{GND}}$</td>
<td>-0.3V to +32V</td>
</tr>
<tr>
<td>$V_{\text{BOOT}} - V_{\text{PHASE}}$</td>
<td>-0.3V to +6.5V</td>
</tr>
<tr>
<td>$V_{\text{PHASE}}$ (continuous)</td>
<td>GND – 0.3V to +38V</td>
</tr>
<tr>
<td>$V_{\text{PHASE}}$ (transient &lt; 100 ns)</td>
<td>GND – 5.0V to +38V</td>
</tr>
<tr>
<td>$V_{\text{DD}}$ internally generated</td>
<td>+5V ±20%</td>
</tr>
<tr>
<td>$V_{\text{HDRV}}$, HDRV Pin</td>
<td>$+V_{\text{PHASE}}$ – 0.3V to $V_{\text{BOOT}}$ +0.3V</td>
</tr>
<tr>
<td>$V_{\text{LDRV}}$, LDRV Pin</td>
<td>$+(V_{\text{GND}}$ – 0.3V) to $(V_{\text{DD}}$ +0.3V)</td>
</tr>
<tr>
<td>Voltage on MCLR with respect to GND</td>
<td>-0.3V to +13.5V</td>
</tr>
<tr>
<td>Maximum output current sunk by any single I/O pin</td>
<td>25 mA</td>
</tr>
<tr>
<td>Maximum output current sourced by any single I/O pin</td>
<td>25 mA</td>
</tr>
<tr>
<td>Maximum current sunk by all GPIO</td>
<td>65 mA</td>
</tr>
<tr>
<td>Maximum current sourced by all GPIO</td>
<td>65 mA</td>
</tr>
<tr>
<td>ESD protection on all pins (HBM)</td>
<td>1.0 kV</td>
</tr>
<tr>
<td>ESD protection on all pins (MM)</td>
<td>100V</td>
</tr>
</tbody>
</table>

† 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, $V_{IN} = 12V$, $V_{REF} = 1.2V$, $F_{SW} = 300$ kHz, $T_A = +25°C$.

**Boldface** specifications apply over the $T_A$ range of $-40°C$ to $+125°C$.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Voltage</td>
<td>$V_{IN}$</td>
<td>4.5</td>
<td></td>
<td>32</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Input Quiescent Current</td>
<td>$I_Q$</td>
<td></td>
<td>5</td>
<td>10</td>
<td>mA</td>
<td>Not switching</td>
</tr>
<tr>
<td>Shutdown Current</td>
<td>$I_{SHDN}$</td>
<td></td>
<td>1.8</td>
<td>2.2</td>
<td>mA</td>
<td>Note 4</td>
</tr>
<tr>
<td>Adjustable Input Under-voltage Lockout Range</td>
<td>$UVLO$</td>
<td>3</td>
<td></td>
<td>32</td>
<td>V</td>
<td>$V_{INLVL}$ is a LOG DAC</td>
</tr>
<tr>
<td>Input Undervoltage Lockout Hysteresis</td>
<td>$UVLO_{HYS}$</td>
<td></td>
<td>13</td>
<td></td>
<td>%</td>
<td>Hysteresis applied to adjustable UVLO setpoint</td>
</tr>
<tr>
<td><strong>Overcurrent</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overcurrent Minimum Threshold</td>
<td>$OC_{MIN}$</td>
<td></td>
<td></td>
<td>160</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Overcurrent Maximum Threshold</td>
<td>$OC_{MAX}$</td>
<td></td>
<td></td>
<td>620</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Overcurrent Mid-Scale Threshold</td>
<td>$OC_{MID}$</td>
<td></td>
<td>240</td>
<td>550</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Overcurrent Step Size</td>
<td>$OC_{STEP_SIZE}$</td>
<td>10</td>
<td>15</td>
<td>20</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Adjustable OC Leading Edge Blanking Minimum Set Point</td>
<td>$LEB_{min}$</td>
<td></td>
<td></td>
<td>114</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>Adjustable OC Leading Edge Blanking Maximum Set Point</td>
<td>$LEB_{max}$</td>
<td></td>
<td></td>
<td>780</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td><strong>Current Sense</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current Sense Minimum AC Gain</td>
<td>$I_{AC_GAIN}$</td>
<td></td>
<td></td>
<td>0</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Current Sense Maximum AC Gain</td>
<td>$I_{AC_GAIN}$</td>
<td></td>
<td></td>
<td>22.8</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Current Sense AC Gain Mid-Set Point</td>
<td>$I_{AC_GAIN}$</td>
<td>8.5</td>
<td>11.5</td>
<td>14</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Current Sense AC Gain Step Size</td>
<td>$I_{AC_GAIN_STEP}$</td>
<td></td>
<td>1.5</td>
<td></td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Current Sense AC Gain Offset Voltage</td>
<td>$I_{AC_OFFSET}$</td>
<td>-175</td>
<td>9</td>
<td>135</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td>Current Sense Minimum DC Gain</td>
<td>$I_{DC_GAIN}$</td>
<td></td>
<td></td>
<td>19.5</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Current Sense Maximum DC Gain</td>
<td>$I_{DC_GAIN}$</td>
<td></td>
<td></td>
<td>35.7</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Current Sense DC Gain Mid-Set Point</td>
<td>$I_{DC_GAIN}$</td>
<td>27</td>
<td>28.6</td>
<td>30.3</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Current Sense DC Gain Step Size</td>
<td>$I_{DC_GAIN_STEP}$</td>
<td></td>
<td>2.3</td>
<td></td>
<td>dB</td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** Ensured by design. Not production tested.  
**Note 2:** $V_{DD\_OUT}$ is the voltage present at the $V_{DD}$ pin. $V_{DD}$ is the internally generated bias voltage. 
**Note 3:** This is the total source current for all GPIO pins combined. Individually, each pin can source a maximum of 25 mA. 
**Note 4:** PE1 = 0x00h, ABECON = 0x00h, ATSTCON = 0x80h, WPUGPA = 0x00h, WPUGPB = 0x00h, and SLEEP command issued to PIC core, see SECTION 16.0.
4.2 Electrical Characteristics (Continued)

Electrical Specifications: Unless otherwise noted, \( V_{\text{IN}} = 12\,\text{V}, V_{\text{REF}} = 1.2\,\text{V}, F_{\text{SW}} = 300\,\text{kHz}, T_A = +25^\circ\text{C} \).

**Boldface** specifications apply over the \( T_A \) range of -40°C to +125°C.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Sense DC Gain Offset Voltage</td>
<td>( I_{\text{DC OFFSET}} )</td>
<td>1.4</td>
<td>1.56</td>
<td>1.7</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Voltage for Zero Current</td>
<td>( V_{\text{ZC}} )</td>
<td>—</td>
<td>1.45</td>
<td>—</td>
<td>V</td>
<td>( V_{\text{ZCCON}} = 0x80h )</td>
</tr>
</tbody>
</table>

**Voltage Reference**

| Adjustable \( V_{\text{OUT}} \) Range | \( V_{\text{OUT RANGE}} \) | 0.5 | — | 3.6 | V | \( V_{\text{OUT}} \) range with no external voltage divider |
| \( V_{\text{OUT}} \) Coarse Resolution | \( V_{\text{OUT COARSE}} \) | 10.8 | 15.8 | 25.8 | mV |
| \( V_{\text{OUT}} \) Coarse Mid Set Point | \( V_{\text{OUT COARSE MID}} \) | 1.85 | 2.04 | 2.25 | V |
| \( V_{\text{OUT}} \) Fine Resolution | \( V_{\text{OUT FINE}} \) | — | 0.8 | 1 | mV |

**Output Overvoltage**

| Adjustable Overvoltage Range | \( O_{\text{VRANGE}} \) | 0 | — | 4.5 | V |
| Adjustable Overvoltage Mid-Set Point | \( O_{\text{VMID}} \) | 1.8 | 2 | 2.3 | V |
| Adjustable Overvoltage Resolution | \( O_{\text{VR}} \) | — | 15 | — | mV |

**Output Undervoltage**

| Adjustable Undervoltage Range | \( U_{\text{VRANGE}} \) | 0 | — | 4.5 | |
| Adjustable Undervoltage Mid-Set Point | \( U_{\text{VMID}} \) | 1.8 | 2 | 2.3 | V |
| Adjustable Undervoltage Resolution | \( U_{\text{VR}} \) | — | 15 | — | mV |

**Remote Sense Differential Amplifier**

| Closed Loop Voltage Gain | \( A_{\text{VOL}} \) | 0.95 | 1 | 1.05 | V/V |
| Common Mode Range | \( V_{\text{CMR}} \) | GND – 0.3 | — | \( V_{\text{DD}} + 1.0 \) | V | Note 1 |
| Common Mode Reject Ratio | \( CMRR \) | — | 57 | — | dB |
| Differential Amplifier Offset | \( V_{\text{OS}} \) | — | 40 | — | mV | See Section 9.5 “Calibration Word 5” and Section 9.6 “Calibration Word 6” |

**Compensation**

| Minimum Zero Frequency | \( F_{\text{ZERO_MIN}} \) | — | 350 | — | Hz |
| Maximum Zero Frequency | \( F_{\text{ZERO_MAX}} \) | — | 35000 | — | Hz |
| Minimum Error Amplifier Gain | \( G_{\text{EA_MIN}} \) | — | 0 | — | dB |
| Maximum Error Amplifier Gain | \( G_{\text{EA_MAX}} \) | — | 36.15 | — | dB |

**Note**

1: Ensured by design. Not production tested.

2: \( V_{\text{DD-OUT}} \) is the voltage present at the \( V_{\text{DD}} \) pin. \( V_{\text{DD}} \) is the internally generated bias voltage.

3: This is the total source current for all GPIO pins combined. Individually, each pin can source a maximum of 25 mA.

4: \( PE1 = 0x00h, ABECON = 0x00h, ATSTCON = 0x80h, WPUGPA = 0x00h, WPUGPB = 0x00h, \) and SLEEP command issued to PIC core, see SECTION 16.0.
### Electrical Characteristics (Continued)

**Electrical Specifications:** Unless otherwise noted, $V_{IN} = 12V$, $V_{REF} = 1.2V$, $F_{SW} = 300$ kHz, $T_A = +25^\circ C$.

*Boldface* specifications apply over the $T_A$ range of -40°C to +125°C.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oscillator</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal Oscillator Frequency</td>
<td>$F_{OSC}$</td>
<td>7.60</td>
<td>8.00</td>
<td>8.40</td>
<td>MHz</td>
<td></td>
</tr>
<tr>
<td>Switching Frequency $F_{SW}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>kHz</td>
<td></td>
</tr>
<tr>
<td>Switching Frequency Range Select</td>
<td>$N$</td>
<td>5</td>
<td></td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Duty Cycle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>%/100</td>
<td></td>
</tr>
<tr>
<td><strong>Dead Time Adjustment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dead Time Step Size</td>
<td>$D_{T STEP}$</td>
<td></td>
<td>4</td>
<td></td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td><strong>HDRV Output Driver</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDRV Source Resistance</td>
<td>$R_{HDRV-SCR}$</td>
<td></td>
<td>1</td>
<td>2.6</td>
<td>$\Omega$</td>
<td>Measured at 500 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>3.5</td>
<td>$\Omega$</td>
<td>Measured at 500 mA</td>
</tr>
<tr>
<td>HDRV Sink Resistance</td>
<td>$R_{HDRV-SINK}$</td>
<td></td>
<td>1</td>
<td>2.6</td>
<td>$\Omega$</td>
<td>Measured at 500 mA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>3.5</td>
<td>$\Omega$</td>
<td>Measured at 500 mA</td>
</tr>
<tr>
<td>HDRV Source Current</td>
<td>$I_{HDRV-SCR}$</td>
<td></td>
<td>2</td>
<td></td>
<td>A</td>
<td>Note 1, High Range</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>A</td>
<td>Note 1, Low Range</td>
</tr>
<tr>
<td>HDRV Sink Current</td>
<td>$I_{HDRV-SINK}$</td>
<td></td>
<td>2</td>
<td></td>
<td>A</td>
<td>Note 1, High Range</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td>A</td>
<td>Note 1, Low Range</td>
</tr>
<tr>
<td>HDRV Rise Time</td>
<td>$t_{RH}$</td>
<td></td>
<td>15</td>
<td>30</td>
<td>ns</td>
<td>Note 1, $C_{LOAD} = 3.3 , nF$, High Range</td>
</tr>
<tr>
<td>HDRV Fall Time</td>
<td>$t_{FH}$</td>
<td></td>
<td>15</td>
<td>30</td>
<td>ns</td>
<td>Note 1, $C_{LOAD} = 3.3 , nF$, High Range</td>
</tr>
<tr>
<td><strong>LDRV Output Driver</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDRV Source Resistance</td>
<td>$R_{LDRV-SCR}$</td>
<td></td>
<td>1</td>
<td>2.5</td>
<td>$\Omega$</td>
<td>Measured at 500 mA</td>
</tr>
<tr>
<td>LDRV Sink Resistance</td>
<td>$R_{LDRV-SINK}$</td>
<td></td>
<td>0.5</td>
<td>1.0</td>
<td>$\Omega$</td>
<td>Measured at 500 mA</td>
</tr>
<tr>
<td>LDRV Source Current</td>
<td>$I_{LDRV-SCR}$</td>
<td></td>
<td>2</td>
<td></td>
<td>A</td>
<td>Note 1</td>
</tr>
<tr>
<td>LDRV Sink Current</td>
<td>$I_{LDRV-SINK}$</td>
<td></td>
<td>4</td>
<td></td>
<td>A</td>
<td>Note 1</td>
</tr>
<tr>
<td>LDRV Rise Time</td>
<td>$t_{RL}$</td>
<td></td>
<td>15</td>
<td>30</td>
<td>ns</td>
<td>Note 1, $C_{LOAD} = 3.3 , nF$</td>
</tr>
<tr>
<td>LDRV Fall Time</td>
<td>$t_{FL}$</td>
<td></td>
<td>7</td>
<td>15</td>
<td>ns</td>
<td>Note 1, $C_{LOAD} = 3.3 , nF$</td>
</tr>
</tbody>
</table>

**Note 1:** Ensured by design. Not production tested.

**Note 2:** $V_{DD-OUT}$ is the voltage present at the $V_{DD}$ pin. $V_{DD}$ is the internally generated bias voltage.

**Note 3:** This is the total source current for all GPIO pins combined. Individually, each pin can source a maximum of 25 mA.

**Note 4:** PE1 = 0x00h, ABECON = 0x00h, ATSTCON = 0x80h, WPUGPA = 0x00h, WPUGPB = 0x00h, and SLEEP command issued to PIC core, see SECTION 16.0.

---

© 2013 Microchip Technology Inc.
### 4.2 Electrical Characteristics (Continued)

**Electrical Specifications:** Unless otherwise noted, $V_{IN} = 12V$, $V_{REF} = 1.2V$, $F_{SW} = 300$ kHz, $T_A = +25^\circ C$.

**Boldface** specifications apply over the $T_A$ range of -40°C to +125°C.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear Regulator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bias Voltage, LDO Output</td>
<td>$V_{DD}$</td>
<td>4.6</td>
<td>5.0</td>
<td>5.4</td>
<td>V</td>
<td>$V_{IN} = 6.0V$ to 32V, Note 2</td>
</tr>
<tr>
<td>Internal Circuitry Bias Voltage</td>
<td>$AV_{DD}$</td>
<td>—</td>
<td>5.0</td>
<td>—</td>
<td>V</td>
<td>$V_{IN} = 6.0V$ to 32V, Note 2</td>
</tr>
<tr>
<td>Maximum $V_{DD}$ Output Current</td>
<td>$I_{DD}$</td>
<td>30</td>
<td>—</td>
<td>—</td>
<td>mA</td>
<td>$V_{IN} = 6.0V$ to 20V, $V_{DD} = 5.0V$, Note 2</td>
</tr>
<tr>
<td>Line Regulation</td>
<td>$\frac{\Delta V_{DD}}{(V_{DD} \times \Delta V_{IN})}$</td>
<td>—</td>
<td>0.05</td>
<td>0.1</td>
<td>%/V</td>
<td>$(V_{DD}+1.0V) \leq V_{IN} \leq 20V$, Note 2</td>
</tr>
<tr>
<td>Load Regulation</td>
<td>$\frac{\Delta V_{DD}}{V_{DD}}$</td>
<td>-1.75</td>
<td>-0.8</td>
<td>+0.5</td>
<td>%</td>
<td>$I_{DD} = 1$ mA to 30 mA, Note 2</td>
</tr>
<tr>
<td>Output Short Circuit Current</td>
<td>$I_{DD_SC}$</td>
<td>—</td>
<td>65</td>
<td>—</td>
<td>mA</td>
<td>$V_{IN} = (V_{DD} + 1.0V)$, Note 2</td>
</tr>
<tr>
<td>Dropout Voltage</td>
<td>$V_{IN} - V_{DD}$</td>
<td>—</td>
<td>0.5</td>
<td>1</td>
<td>V</td>
<td>$I_{DD} = 30$ mA, $V_{IN} = V_{DD} + 1.0V$</td>
</tr>
<tr>
<td>Power Supply Rejection Ratio</td>
<td>$PSRR_{LDO}$</td>
<td>—</td>
<td>60</td>
<td>—</td>
<td>dB</td>
<td>$f \leq 1000$ Hz, $I_{DD} = 25$ mA, $C_{IN} = 0$ $\mu F$, $C_{DD} = 1$ $\mu F$</td>
</tr>
<tr>
<td>Band Gap Voltage</td>
<td>$BG$</td>
<td>-2.5%</td>
<td>1.23</td>
<td>+2.5%</td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

**GPIO Pins**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum GPIO Sink Current</td>
<td>$I_{SINK_GPIO}$</td>
<td>—</td>
<td>—</td>
<td>90</td>
<td>mA</td>
<td>Note 3, Note 1</td>
</tr>
<tr>
<td>Maximum GPIO Source Current</td>
<td>$I_{SOURCE_GPIO}$</td>
<td>—</td>
<td>—</td>
<td>90</td>
<td>mA</td>
<td>Note 3, Note 1</td>
</tr>
<tr>
<td>GPIO Weak Pull-up Current</td>
<td>$I_{PULL-UP_GPIO}$</td>
<td>50</td>
<td>250</td>
<td>400</td>
<td>$\mu A$</td>
<td>$V_{DD} = 5V$</td>
</tr>
<tr>
<td>GPIO Output Low Voltage</td>
<td>$V_{OL}$</td>
<td>—</td>
<td>—</td>
<td>0.6</td>
<td>V</td>
<td>$I_{OL} = 7$ mA, $V_{DD} = 5V$, $T_A = +90^\circ C$</td>
</tr>
<tr>
<td>GPIO Output High Voltage</td>
<td>$V_{OH}$</td>
<td>$V_{DD} - 0.7$</td>
<td>—</td>
<td>—</td>
<td>V</td>
<td>$I_{OH} = -2.5$ mA, $V_{DD} = 5V$, $T_A = +90^\circ C$</td>
</tr>
<tr>
<td>GPIO Input Leakage Current</td>
<td>$GPIO_{I_IL}$</td>
<td>—</td>
<td>±0.1</td>
<td>±1</td>
<td>$\mu A$</td>
<td>Negative current is defined as current sourced by the pin, $T_A = +90^\circ C$</td>
</tr>
<tr>
<td>GPIO Input Low Voltage</td>
<td>$V_{IL}$</td>
<td>GND</td>
<td>—</td>
<td>0.8</td>
<td>V</td>
<td>I/O Port with TTL buffer $V_{DD} = 5V$, $T_A = +90^\circ C$</td>
</tr>
</tbody>
</table>

| | GND | 0.2$V_{DD}$ | V | I/O Port with Schmitt Trigger buffer, $V_{DD} = 5V$, $T_A = +90^\circ C$ |

**Note 1:** Ensured by design. Not production tested.

**Note 2:** $V_{DD\_OUT}$ is the voltage present at the $V_{DD}$ pin. $V_{DD}$ is the internally generated bias voltage.

**Note 3:** This is the total source current for all GPIO pins combined. Individually, each pin can source a maximum of 25 mA.

**Note 4:** $PE1 = 0x00h$, $ABECON = 0x00h$, $ATSTCON = 0x80h$, $WPUGPA = 0x00h$, $WPUGPB = 0x00h$, and SLEEP command issued to PIC core, see SECTION 16.0.
4.2 Electrical Characteristics (Continued)

**Electrical Specifications:** Unless otherwise noted, $V_{IN} = 12\, \text{V}$, $V_{REF} = 1.2\, \text{V}$, $F_{SW} = 300\, \text{kHz}$, $T_A = +25^\circ\text{C}$.

**Boldface** specifications apply over the $T_A$ range of -40°C to +125°C.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPIO Input High Voltage</td>
<td>$V_{IH}$</td>
<td>2.0</td>
<td>—</td>
<td>$V_{DD}$</td>
<td>V</td>
<td>I/O Port with TTL buffer, $V_{DD} = 5, \text{V}$, $T_A = +90^\circ\text{C}$</td>
</tr>
<tr>
<td></td>
<td>0.8$V_{DD}$</td>
<td>—</td>
<td>—</td>
<td>$V_{DD}$</td>
<td>V</td>
<td>I/O Port with Schmitt Trigger buffer, $V_{DD} = 5, \text{V}$, $T_A = +90^\circ\text{C}$</td>
</tr>
<tr>
<td></td>
<td>0.8$V_{DD}$</td>
<td>—</td>
<td>—</td>
<td>$V_{DD}$</td>
<td>V</td>
<td>MCLR, $T_A = +90^\circ\text{C}$</td>
</tr>
<tr>
<td>Thermal Shutdown</td>
<td>$T_{SHD}$</td>
<td>—</td>
<td>160</td>
<td>—</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$T_{SHD, \text{HYS}}$</td>
<td>—</td>
<td>20</td>
<td>—</td>
<td>°C</td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** Ensured by design. Not production tested.

**Note 2:** $V_{DD\, \text{OUT}}$ is the voltage present at the $V_{DD}$ pin. $V_{DD}$ is the internally generated bias voltage.

**Note 3:** This is the total source current for all GPIO pins combined. Individually, each pin can source a maximum of 25 mA.

**Note 4:** $PE1 = 0\times00\, \text{h}$, $ABECON = 0\times00\, \text{h}$, $ATSTCON = 0\times80\, \text{h}$, $WPUGPA = 0\times00\, \text{h}$, $WPUGPB = 0\times00\, \text{h}$, and SLEEP command issued to PIC core, see SECTION 16.0.

4.3 Thermal Specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Ranges</td>
<td>$T_A$</td>
<td>-40</td>
<td>—</td>
<td>+125</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>$T_A$</td>
<td>-40</td>
<td>—</td>
<td>+125</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Maximum Junction Temperature</td>
<td>$T_J$</td>
<td>—</td>
<td>—</td>
<td>+150</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Storage Temperature Range</td>
<td>$T_A$</td>
<td>-65</td>
<td>—</td>
<td>+150</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>Thermal Package Resistances</td>
<td>$\theta_{JA}$</td>
<td>—</td>
<td>42</td>
<td>—</td>
<td>°C/W</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$\theta_{JA}$</td>
<td>—</td>
<td>35.3</td>
<td>—</td>
<td>°C/W</td>
<td></td>
</tr>
</tbody>
</table>
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. Tcc:ST
4. Ts

<table>
<thead>
<tr>
<th>T</th>
<th>F</th>
<th>Frequency</th>
<th>T</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>cc</td>
<td>CCP1</td>
<td>osc</td>
<td>OSC1</td>
<td></td>
</tr>
<tr>
<td>ck</td>
<td>CLKOUT</td>
<td>rd</td>
<td>RD</td>
<td></td>
</tr>
<tr>
<td>cs</td>
<td>CS</td>
<td>rw</td>
<td>RD or WR</td>
<td></td>
</tr>
<tr>
<td>di</td>
<td>SDI</td>
<td>sc</td>
<td>SCK</td>
<td></td>
</tr>
<tr>
<td>do</td>
<td>SDO</td>
<td>ss</td>
<td>SS</td>
<td></td>
</tr>
<tr>
<td>dt</td>
<td>Data in</td>
<td>t0</td>
<td>T0CKI</td>
<td></td>
</tr>
<tr>
<td>io</td>
<td>I/O port</td>
<td>t1</td>
<td>T1CKI</td>
<td></td>
</tr>
<tr>
<td>mc</td>
<td>MCLR</td>
<td>wr</td>
<td>WR</td>
<td></td>
</tr>
</tbody>
</table>

Lowercase letters (pp) and their meanings:

- **cc**: CCP1
- **ck**: CLKOUT
- **cs**: CS
- **di**: SDI
- **do**: SDO
- **dt**: Data in
- **di**: I/O port
- **mc**: MCLR

Uppercase letters and their meanings:

- **S**: Fall
- **H**: High
- **I**: Invalid (high-impedance)
- **L**: Low
- **P**: Period
- **R**: Rise
- **V**: Valid
- **Z**: High-impedance
- **AA**: Output access
- **BUF**: Bus free

**I2C only**

<table>
<thead>
<tr>
<th>TCC:ST (I2C specifications only)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HD</strong>: Hold</td>
</tr>
<tr>
<td><strong>SU</strong>: Setup</td>
</tr>
<tr>
<td><strong>ST</strong>: DATA input hold</td>
</tr>
<tr>
<td><strong>STA</strong>: START condition</td>
</tr>
<tr>
<td><strong>DAT</strong>: DATA input hold</td>
</tr>
<tr>
<td><strong>STO</strong>: STOP condition</td>
</tr>
</tbody>
</table>

**FIGURE 5-1: LOAD CONDITIONS**

Load Condition 1

$$V_{DD}/2$$

$$R_L$$

$$C_L$$

$$V_{SS}$$

Load Condition 2

$$V_{DD}/2$$

$$R_L$$

$$C_L$$

$$V_{SS}$$

- **R_L** = 464Ω
- **C_L** = 50 pF for all GPIO pins
5.2 AC Characteristics: MCP19110/11 (Industrial, Extended)

**FIGURE 5-2: EXTERNAL CLOCK TIMING**

![External Clock Timing Diagram](image)

**TABLE 5-1: EXTERNAL CLOCK TIMING REQUIREMENTS**

<table>
<thead>
<tr>
<th>Param No.</th>
<th>Sym</th>
<th>Characteristic</th>
<th>Min</th>
<th>Typ†</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FOSC</td>
<td>Oscillator Frequency(1)</td>
<td>—</td>
<td>8</td>
<td>—</td>
<td>MHz</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>TOSC</td>
<td>Oscillator Period(1)</td>
<td>—</td>
<td>250</td>
<td>—</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>TCY</td>
<td>Instruction Cycle Time(1)</td>
<td>—</td>
<td>1000</td>
<td>—</td>
<td>ns</td>
<td></td>
</tr>
</tbody>
</table>

* 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: CLKOUT AND I/O TIMING**

![Clockout and I/O Timing Diagram](image)
### TABLE 5-2: CLKOUT AND I/O TIMING REQUIREMENTS

<table>
<thead>
<tr>
<th>Param No.</th>
<th>Sym</th>
<th>Characteristic</th>
<th>Min</th>
<th>Typ†</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>TosH2ioV</td>
<td>OSC1↑ (Q1 cycle) to Port out valid</td>
<td>—</td>
<td>50</td>
<td>150*</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>TosH2ioI</td>
<td>OSC1↑ (Q2 cycle) to Port input invalid (I/O in hold time)</td>
<td>—</td>
<td>—</td>
<td>300</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>TioV2osH</td>
<td>Port input valid to OSC1↑ (I/O in setup time)</td>
<td>0</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>TioR</td>
<td>Port output rise time</td>
<td>—</td>
<td>10</td>
<td>40</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>TioF</td>
<td>Port output fall time</td>
<td>—</td>
<td>10</td>
<td>40</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Tinp</td>
<td>INT pin high</td>
<td>25</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>22A</td>
<td></td>
<td>or low time</td>
<td>40</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Trbp</td>
<td>Port A change INT</td>
<td>Tcy</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>23A</td>
<td></td>
<td>high or low time</td>
<td></td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td></td>
</tr>
</tbody>
</table>

* These parameters are characterized but not tested.
† Data in “Typ” column is at $V_{IN} = 12V$ ($V_{DD} = 5V$), $+25^\circ C$ unless otherwise stated.

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

![Timing Diagram](attachment:Timing_Diagram.png)
TABLE 5-3: RESET, WATCHDOG TIMER, OSCILLATOR START-UP TIMER, AND POWER-UP TIMER REQUIREMENTS

<table>
<thead>
<tr>
<th>Param No.</th>
<th>Sym</th>
<th>Characteristic</th>
<th>Min</th>
<th>Typ†</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>TMCL</td>
<td>MCLR Pulse Width (low)</td>
<td>2</td>
<td>—</td>
<td>—</td>
<td>µs</td>
<td>VDD = 5V, -40°C to +85°C</td>
</tr>
<tr>
<td>31</td>
<td>TWDT</td>
<td>Watchdog Timer Time-out Period (No Prescaler)</td>
<td>7</td>
<td>18</td>
<td>33</td>
<td>ms</td>
<td>VDD = 5V, -40°C to +85°C</td>
</tr>
<tr>
<td>32</td>
<td>TOST</td>
<td>Oscillation Start-up Timer Period</td>
<td>—</td>
<td>1024TOSC</td>
<td>—</td>
<td>—</td>
<td>TOSC = OSC1 period</td>
</tr>
<tr>
<td>33*</td>
<td>TPWRT</td>
<td>Power-up Timer Period (4 x TWDT)</td>
<td>28</td>
<td>64</td>
<td>132</td>
<td>ms</td>
<td>VDD = 5V, -40°C to +85°C</td>
</tr>
<tr>
<td>34</td>
<td>TIOZ</td>
<td>I/O high-impedance from MCLR Low or Watchdog Timer Reset</td>
<td>—</td>
<td>—</td>
<td>2.0</td>
<td>µs</td>
<td></td>
</tr>
</tbody>
</table>

* These parameters are characterized but not tested.
† Data in “Typ” column is at VIN = 12V (VDD = 5V), +25°C unless otherwise stated. These parameters are for design guidance only and are not tested.

FIGURE 5-5: TIMER0 AND TIMER1 EXTERNAL CLOCK TIMINGS

TABLE 5-4: TIMER0 AND TIMER1 EXTERNAL CLOCK REQUIREMENTS

<table>
<thead>
<tr>
<th>Param No.</th>
<th>Sym</th>
<th>Characteristic</th>
<th>Min</th>
<th>Typ†</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>40*</td>
<td>T0H</td>
<td>T0CKI High Pulse Width</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>41*</td>
<td>T0L</td>
<td>T0CKI Low Pulse Width</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>42*</td>
<td>T0P</td>
<td>T0CKI Period</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ns</td>
<td>N = prescale value (2, 4, ..., 256)</td>
</tr>
</tbody>
</table>

* These parameters are characterized but not tested.
† Data in “Typ” column is at VIN = 12V (VDD = 5V), +25°C unless otherwise stated. These parameters are for design guidance only and are not tested.
FIGURE 5-6: PWM TIMING

Note: Refer to Figure 5-1 for load conditions.

TABLE 5-5: PWM REQUIREMENTS

<table>
<thead>
<tr>
<th>Param No.</th>
<th>Sym</th>
<th>Characteristic Description</th>
<th>Min</th>
<th>Typ†</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>53*</td>
<td>TccR</td>
<td>PWM (CLKPIN) output rise time</td>
<td>—</td>
<td>10</td>
<td>25</td>
<td>ns</td>
<td></td>
</tr>
<tr>
<td>54*</td>
<td>TccF</td>
<td>PWM (CLKPIN) output fall time</td>
<td>—</td>
<td>10</td>
<td>25</td>
<td>ns</td>
<td></td>
</tr>
</tbody>
</table>

* These parameters are characterized but not tested.
† Data in “Typ” column is at $V_{IN} = 12V$ ($V_{DD} = 5V$), +25°C unless otherwise stated. Parameters are for design guidance only and are not tested.

TABLE 5-6: MCP19110/11 A/D CONVERTER (ADC) CHARACTERISTICS:

Standard Operating Conditions (unless otherwise stated)
Operating temperature $-40°C \leq T_A \leq +125°C$

<table>
<thead>
<tr>
<th>Param No.</th>
<th>Sym</th>
<th>Characteristic Description</th>
<th>Min</th>
<th>Typ†</th>
<th>Max</th>
<th>Unit s</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD01</td>
<td>$N_R$</td>
<td>Resolution</td>
<td>—</td>
<td>—</td>
<td>10</td>
<td>bit</td>
<td></td>
</tr>
<tr>
<td>AD02</td>
<td>$E_{IL}$</td>
<td>Integral Error</td>
<td>—</td>
<td>—</td>
<td>±1</td>
<td>LSb</td>
<td>$AV_{DD} = 5.0V$</td>
</tr>
<tr>
<td>AD03</td>
<td>$E_{DL}$</td>
<td>Differential Error</td>
<td>—</td>
<td>—</td>
<td>±1</td>
<td>LSb</td>
<td>No missing codes to 10 bits $AV_{DD} = 5.0V$</td>
</tr>
<tr>
<td>AD04</td>
<td>$E_{OFF}$</td>
<td>Offset Error</td>
<td>—</td>
<td>+3.0</td>
<td>+5.0</td>
<td>LSb</td>
<td>$AV_{DD} = 5.0V$</td>
</tr>
<tr>
<td>AD07</td>
<td>$E_{GN}$</td>
<td>Gain Error</td>
<td>—</td>
<td>±2</td>
<td>±5</td>
<td>LSb</td>
<td>$AV_{DD} = 5.0V$</td>
</tr>
<tr>
<td>AD06</td>
<td>$V_{REF}$</td>
<td>Reference Voltage$^{(3)}$</td>
<td>—</td>
<td>$AV_{DD}$</td>
<td>—</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>AD06A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AD07</td>
<td>$V_{AIN}$</td>
<td>Full-Scale Range</td>
<td>GND</td>
<td>—</td>
<td>$AV_{DD}$</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>AD08</td>
<td>$Z_{AIN}$</td>
<td>Recommended Impedance of Analog Voltage Source</td>
<td>—</td>
<td>—</td>
<td>10</td>
<td>kΩ</td>
<td></td>
</tr>
</tbody>
</table>

* 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: Total Absolute Error includes integral, differential, offset and gain errors.
2: The A/D conversion result never decreases with an increase in the input voltage and has no missing codes.
3: 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.
### TABLE 5-7: MCP19110/11 A/D CONVERSION REQUIREMENTS

<table>
<thead>
<tr>
<th>Param No.</th>
<th>Sym</th>
<th>Characteristic</th>
<th>Min</th>
<th>Typ†</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD130*</td>
<td>TAD</td>
<td>A/D Clock Period</td>
<td>1.6</td>
<td>—</td>
<td>9.0</td>
<td>µs</td>
<td>TOSC-based, VREF = 3.0V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A/D Internal RC Oscillator Period</td>
<td>3.0</td>
<td>6.0</td>
<td>9.0</td>
<td>µs</td>
<td>TOSC-based, VREF full range</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.6</td>
<td>4.0</td>
<td>6.0</td>
<td>µs</td>
<td>ADCS&lt;1:0&gt; = 11 (ADRC mode)</td>
</tr>
<tr>
<td>AD131</td>
<td>TCNV</td>
<td>Conversion Time (not including Acquisition Time)(1)</td>
<td>—</td>
<td>11</td>
<td>—</td>
<td></td>
<td>TAD Set GO/DONE bit to new data in A/D Result register</td>
</tr>
<tr>
<td>AD132*</td>
<td>TACQ</td>
<td>Acquisition Time</td>
<td>11.5</td>
<td>—</td>
<td>—</td>
<td>µs</td>
<td></td>
</tr>
<tr>
<td>AD133*</td>
<td>TAMPS</td>
<td>Amplifier Settling Time</td>
<td>—</td>
<td>—</td>
<td>5</td>
<td>µs</td>
<td></td>
</tr>
<tr>
<td>AD134</td>
<td>TGO</td>
<td>Q4 to A/D Clock Start</td>
<td>—</td>
<td>TOSC/2</td>
<td>—</td>
<td></td>
<td>If the A/D clock source is selected as RC, a time of TCY is added before the A/D clock starts. This allows the SLEEP instruction to be executed.</td>
</tr>
</tbody>
</table>

* These parameters are characterized but not tested.
† Data in ‘Typ’ column is at VIN = 12V (VDD = 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 TCY cycle.

### FIGURE 5-7: A/D CONVERSION TIMING (NORMAL MODE)

- **BSF ADCON0, GO**
- **Q4**
- **A/D CLK**
- **A/D DATA**
- **ADRES**
- **ADIF**
- **GO**
- **SAMPLE**

**Note 1:** If the A/D clock source is selected as RC, a time of TCY is added before the A/D clock starts. This allows the SLEEP instruction to be executed.
FIGURE 5-8: A/D CONVERSION TIMING (SLEEP MODE)

Note 1: If the A/D clock source is selected as RC, a time of $T_{CY}$ is added before the A/D clock starts. This allows the SLEEP instruction to be executed.
6.0 CONFIGURING THE MCP19110/11

The MCP19110/11 is an analog controller with digital peripheral. This means that device configuration is handled through register settings instead of adding external components. The following sections detail how to set the analog control registers.

6.1 Input Undervoltage Lockout

The VINLVL register contains the digital value that sets the input Undervoltage Lockout. When the input voltage on the VIN pin to the MCP19110/11 is below this programmed level, the INTCON<VINIF> flag will be set. This bit is automatically cleared when the MCP19110/11 VIN voltage rises above this programmed level.

REGISTER 6-1: VINLVL: INPUT UNDERVOLTAGE LOCKOUT CONTROL REGISTER

<table>
<thead>
<tr>
<th>bit 7</th>
<th>bit 6</th>
<th>bit 5-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVLOEN</td>
<td>—</td>
<td>UVLO5 UVLO4 UVLO3 UVLO2 UVLO1 UVLO0</td>
</tr>
</tbody>
</table>

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 UVLOEN: Undervoltage Lockout DAC Control bit
1 = Undervoltage Lockout DAC is enabled
0 = Undervoltage Lockout DAC is disabled

bit 6 Unimplemented: Read as ‘0’

bit 5-0 UVLO<5:0>: Undervoltage Lockout Configuration bits
UVLO<5:0> = 26.5*ln(UVLOSET_POINT/4)

The VINLVL<UVLOEN> bit must be set to enable the input Undervoltage Lockout circuitry.

Note: The VINIF 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, of the INTCON register.
6.2 Output Overcurrent

The MCP19110/11 features a cycle-by-cycle peak current limit. By monitoring the OCIF interrupt flag, custom overcurrent fault handling can be implemented.

To detect an output overcurrent, the MCP19110/11 senses the voltage drop across the high-side MOSFET while it is conducting. Leading edge blanking is incorporated to mask the overcurrent measurement for a given amount of time. This helps prevent false overcurrent readings. When the input voltage is greater than 20V, or if the $R_{\text{DS(ON)}}$ of the high-side MOSFET is such that the programmed overcurrent threshold does not produce acceptable peak overcurrent protection, an alternative method must be used to determine an output overcurrent situation. An alternative technique can use the configurable output undervoltage protection and the PE1<UVTEE> bit to quickly terminate switching when the output voltage drops because of an overcurrent event.

When an output overcurrent is sensed, the OCIF flag is set and the high-side drive signal is immediately terminated. Without any custom overcurrent handling implemented, the high-side drive signal will be asserted high at the beginning of the next clock cycle. If the overcurrent condition still exists, the high-drive signal will again be terminated.

The OCIF interrupt flag must be cleared in software. However, if a subsequent switching cycle without an overcurrent condition has not occurred, hardware will immediately set the OCIF interrupt flag.

Register OCCON contains the bits used to configure both the output overcurrent limit and the amount of leading edge blanking (see Register 6-2).

The OCCON<OCEN> bit must be set to enable the input overcurrent circuitry.

Note: The OCIF 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, of the INTCON register.
### REGISTER 6-2: OCCON: OUTPUT OVERCURRENT CONTROL REGISTER

<table>
<thead>
<tr>
<th>R/W-0</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCEN</td>
<td>OCLEB1</td>
<td>OCLEB0</td>
<td>OOC4</td>
<td>OOC3</td>
<td>OOC2</td>
<td>OOC1</td>
<td>OOC0</td>
</tr>
</tbody>
</table>

#### 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 OCEN:** Output Overcurrent DAC Control bit
- 1 = Output Overcurrent DAC is enabled
- 0 = Output Overcurrent DAC is disabled

**bit 6-5 OCLEB<1:0>:** Leading Edge Blanking
- 00 = 114 ns blanking
- 01 = 213 ns blanking
- 10 = 400 ns blanking
- 11 = 780 ns blanking

**bit 4-0 OOC<4:0>:** Output Overcurrent Configuration bits
- 00000 = 160 mV drop
- 00001 = 175 mV drop
- 00010 = 190 mV drop
- 00011 = 205 mV drop
- 00100 = 220 mV drop
- 00101 = 235 mV drop
- 00110 = 250 mV drop
- 00111 = 265 mV drop
- 01000 = 280 mV drop
- 01001 = 295 mV drop
- 01010 = 310 mV drop
- 01011 = 325 mV drop
- 01100 = 340 mV drop
- 01101 = 355 mV drop
- 01110 = 370 mV drop
- 01111 = 385 mV drop
- 10000 = 400 mV drop
- 10001 = 415 mV drop
- 10010 = 430 mV drop
- 10011 = 445 mV drop
- 10100 = 460 mV drop
- 10101 = 475 mV drop
- 10110 = 490 mV drop
- 10111 = 505 mV drop
- 11000 = 520 mV drop
- 11001 = 535 mV drop
- 11010 = 550 mV drop
- 11011 = 565 mV drop
- 11100 = 580 mV drop
- 11101 = 595 mV drop
- 11110 = 610 mV drop
- 11111 = 625 mV drop
6.3 Current Sense AC Gain

The current measured across the inductor is a square wave that is averaged by the capacitor (Cq) connected between +ISEN and -ISEN. This very small voltage plus the ripple can be amplified by the current sense AC gain circuitry. The amount of gain is controlled by the CSGSCON register.

REGISTER 6-3: CSGSCON: CURRENT SENSE AC GAIN CONTROL REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>—</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>CSGS3</td>
<td>CSGS2</td>
<td>CSGS1</td>
</tr>
</tbody>
</table>

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

bit 7 Unimplemented: Read as ‘0’
bit 6-4 Reserved
bit 3-0 CSGS<3:0>: Current Sense AC Gain Setting bits
0000 = 0 dB
0001 = 1.0 dB
0010 = 2.5 dB
0011 = 4.0 dB
0100 = 5.5 dB
0101 = 7.0 dB
0110 = 8.5 dB
0111 = 10.0 dB
1000 = 11.5 dB
1001 = 13.0 dB
1010 = 14.5 dB
1011 = 16.0 dB
1100 = 17.5 dB
1101 = 19.0 dB
1110 = 20.5 dB
1111 = 22.0 dB
6.4 Current Sense DC Gain

DC gain can be added to the sensed inductor current to allow it to be read by the ADC. The amount of DC gain added is controlled by the CSDGCON register.

Adding DC gain to the current sense signal used by the control loop may also be needed in some multi-phase systems to account for device and component differences. The CSDGEN bit determines if the gained current sense signal is added back to the AC current signal (see Register 6-4). If the CSDGEN bit is cleared, DC gain can still be added, but the gained signal is not added back to the AC current signal.

REGISTER 6-4: CSDGCON: CURRENT SENSE DC GAIN CONTROL REGISTER

<table>
<thead>
<tr>
<th>R/W-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSDGEN</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Reserved</td>
<td>CSDG2</td>
<td>CSDG1</td>
<td>CSDG0</td>
</tr>
</tbody>
</table>

bit 7: **CSDGEN**: Current Sense DC Gain Enable bit
- **1**: DC gain current sense signal used in control loop.
- **0**: DC gain current sense signal only read by ADC.

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

bit 3: **Reserved**

bit 2-0: **CSDG<2:0>**: Current Sense DC Gain Setting bits
- **000**: 19.5 dB
- **001**: 21.8 dB
- **010**: 24.1 dB
- **011**: 26.3 dB
- **100**: 28.6 dB
- **101**: 30.9 dB
- **110**: 33.2 dB
- **111**: 35.7 dB
6.5 Voltage for Zero Current

In multi-phase systems it may be necessary to provide some offset to the sensed inductor current. The VZCCON register can be used to provide a positive or negative offset in the sensed current. Typically, the VZCCON will be set to 0x80h, which corresponds to the sensed inductor current centered around 1.45V. However, by adjusting the VZCCON register, this centered voltage can be shifted up or down by approximately 3.28 mV per step.

REGISTER 6-5: VZCCON: VOLTAGE FOR ZERO CURRENT CONTROL REGISTER

<table>
<thead>
<tr>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
</tr>
</thead>
<tbody>
<tr>
<td>VZC7</td>
<td>VZC6</td>
<td>VZC5</td>
<td>VZC4</td>
<td>VZC3</td>
<td>VZC2</td>
<td>VZC1</td>
</tr>
</tbody>
</table>

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  VZC<7:0>: Voltage for Zero Current Setting bits

- 00000000 = -420.00 mV Offset
- 00000001 = -416.72 mV Offset
- 
- 10000000 = 0 mV Offset
- 
- 11111110 = +413.12 mV Offset
- 11111111 = +416.40 mV Offset
6.6 Compensation Setting

The MCP19110/11 uses a peak current mode control architecture. A control reference is used to regulate the peak current of the converter directly. The inner current loop essentially turns the inductor into a voltage-controlled current source. This reduces the control-to-output transfer function to a simple single-pole model of a current source feeding a capacitor. The desired response of the overall loop can be tuned by proper placement of the compensation zero frequency and gain. Figure 6-1 shows a simplified drawing of the internal compensation. See Register 6-6 for the adjustable zero frequency and gain settings.

REGISTER 6-6: CMPZCON: COMPENSATION SETTING CONTROL REGISTER

<table>
<thead>
<tr>
<th>Bit 7-4</th>
<th>CMPZF&lt;3:0&gt;: Compensation Zero Frequency Setting bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>1500 Hz</td>
</tr>
<tr>
<td>0001</td>
<td>1850 Hz</td>
</tr>
<tr>
<td>0010</td>
<td>2300 Hz</td>
</tr>
<tr>
<td>0011</td>
<td>2840 Hz</td>
</tr>
<tr>
<td>0100</td>
<td>3460 Hz</td>
</tr>
<tr>
<td>0101</td>
<td>4300 Hz</td>
</tr>
<tr>
<td>0110</td>
<td>5300 Hz</td>
</tr>
<tr>
<td>0111</td>
<td>6630 Hz</td>
</tr>
<tr>
<td>1000</td>
<td>8380 Hz</td>
</tr>
<tr>
<td>1001</td>
<td>9950 Hz</td>
</tr>
<tr>
<td>1010</td>
<td>12200 Hz</td>
</tr>
<tr>
<td>1011</td>
<td>14400 Hz</td>
</tr>
<tr>
<td>1100</td>
<td>18700 Hz</td>
</tr>
<tr>
<td>1101</td>
<td>23000 Hz</td>
</tr>
<tr>
<td>1110</td>
<td>28400 Hz</td>
</tr>
<tr>
<td>1111</td>
<td>35300 Hz</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bit 3-0</th>
<th>CMPZG&lt;3:0&gt;: Compensation Gain Setting bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>36.15 dB</td>
</tr>
<tr>
<td>0001</td>
<td>33.75 dB</td>
</tr>
<tr>
<td>0010</td>
<td>30.68 dB</td>
</tr>
<tr>
<td>0011</td>
<td>28.43 dB</td>
</tr>
<tr>
<td>0100</td>
<td>26.10 dB</td>
</tr>
<tr>
<td>0101</td>
<td>23.81 dB</td>
</tr>
<tr>
<td>0110</td>
<td>21.44 dB</td>
</tr>
<tr>
<td>0111</td>
<td>19.10 dB</td>
</tr>
<tr>
<td>1000</td>
<td>16.78 dB</td>
</tr>
<tr>
<td>1001</td>
<td>14.32 dB</td>
</tr>
<tr>
<td>1010</td>
<td>12.04 dB</td>
</tr>
<tr>
<td>1011</td>
<td>9.54 dB</td>
</tr>
<tr>
<td>1100</td>
<td>7.23 dB</td>
</tr>
<tr>
<td>1101</td>
<td>4.61 dB</td>
</tr>
<tr>
<td>1110</td>
<td>2.28 dB</td>
</tr>
<tr>
<td>1111</td>
<td>0.00 dB</td>
</tr>
</tbody>
</table>

Legend:
- R = Readable bit
- W = Writable bit
- U = Unimplemented bit, read as ‘0’
- ‘1’ = Bit is set
- ‘0’ = Bit is cleared
- x = Bit is unknown
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 Register 6-7.

The slope compensation is enabled by setting the SLCPBY bit in the ABECON register.

REGISTER 6-7: SLPCRCON: SLOPE COMPENSATION RAMP CONTROL REGISTER

<table>
<thead>
<tr>
<th>bit 7-4</th>
<th>bit 3-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLPG&lt;3:0&gt;: Slope Compensation Amplitude Configuration bits</td>
<td></td>
</tr>
<tr>
<td>0000 = 0.017 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>0001 = 0.022 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>0010 = 0.030 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>0011 = 0.040 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>0100 = 0.053 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>0101 = 0.070 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>0110 = 0.094 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>0111 = 0.125 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>1000 = 0.170 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>1001 = 0.220 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>1010 = 0.300 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>1011 = 0.400 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>1100 = 0.530 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>1101 = 0.700 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>1110 = 0.940 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
<tr>
<td>1111 = 1.250 VPK-PK, measured for 50% duty cycle waveform</td>
<td></td>
</tr>
</tbody>
</table>

bit 3-0

SLPS<3:0>: Slope Compensation $\Delta V/\Delta t$ Configuration bits

6.7.1 SLPS<3:0> CONFIGURATION

The SLPS<3:0> directly controls the $\Delta V/\Delta t$ of the added ramp. This byte should be set proportional to the switching frequency according to the following equation:

**EQUATION 6-1:**

$$n = \left( \frac{F_{SW}}{100,000} \right) - 1$$

Where:

- $F_{SW} = $ Device switching frequency
- $n = $ Decimal equivalent of SLPS<3:0>

6.7.2 SLPG<3:0> CONFIGURATION

The SLPG<3:0> controls the amplitude of the added ramp. The values listed above correspond to a 50% duty cycle waveform and is true only if the SLPS<3:0> bits are set according to the equation in **Section 6.7.1 “SLPS<3:0> Configuration”**. If less amplitude is required, the SLPS<3:0> bits can be adjusted to a lower switching frequency.
6.8 MASTER Error Signal Gain

When operating in a multi-phase system, the output of the MASTER's error amplifier is used by all SLAVE devices as their control signal. It is important to balance the current in all phases to maintain a uniform temperature across all phases. Component tolerances make this balancing difficult. Each SLAVE device has the ability to gain or attenuate the MASTER error signal depending upon the settings of Register 6-8.

REGISTER 6-8: SLVGNCON: MASTER ERROR SIGNAL INPUT GAIN CONTROL REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>—</td>
<td>—</td>
<td>SLVGN4</td>
<td>SLVGN3</td>
<td>SLVGN2</td>
<td>SLVGN1</td>
<td>SLVGN0</td>
</tr>
</tbody>
</table>

bit 7-0

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 SLVGN<4:0>: MASTER Error Signal Gain bits

<table>
<thead>
<tr>
<th>Value</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000</td>
<td>-3.3 dB</td>
</tr>
<tr>
<td>00001</td>
<td>-3.1 dB</td>
</tr>
<tr>
<td>00010</td>
<td>-2.9 dB</td>
</tr>
<tr>
<td>00011</td>
<td>-2.7 dB</td>
</tr>
<tr>
<td>00100</td>
<td>-2.5 dB</td>
</tr>
<tr>
<td>00101</td>
<td>-2.3 dB</td>
</tr>
<tr>
<td>00110</td>
<td>-2.1 dB</td>
</tr>
<tr>
<td>00111</td>
<td>-1.9 dB</td>
</tr>
<tr>
<td>01000</td>
<td>-1.7 dB</td>
</tr>
<tr>
<td>01001</td>
<td>-1.4 dB</td>
</tr>
<tr>
<td>01010</td>
<td>-1.2 dB</td>
</tr>
<tr>
<td>01011</td>
<td>-1.0 dB</td>
</tr>
<tr>
<td>01100</td>
<td>-0.8 dB</td>
</tr>
<tr>
<td>01101</td>
<td>-0.6 dB</td>
</tr>
<tr>
<td>01110</td>
<td>-0.4 dB</td>
</tr>
<tr>
<td>01111</td>
<td>-0.2 dB</td>
</tr>
<tr>
<td>10000</td>
<td>0.0 dB</td>
</tr>
<tr>
<td>10001</td>
<td>0.2 dB</td>
</tr>
<tr>
<td>10010</td>
<td>0.4 dB</td>
</tr>
<tr>
<td>10011</td>
<td>0.7 dB</td>
</tr>
<tr>
<td>10100</td>
<td>0.9 dB</td>
</tr>
<tr>
<td>10101</td>
<td>1.1 dB</td>
</tr>
<tr>
<td>10110</td>
<td>1.3 dB</td>
</tr>
<tr>
<td>10111</td>
<td>1.5 dB</td>
</tr>
<tr>
<td>11000</td>
<td>1.7 dB</td>
</tr>
<tr>
<td>11001</td>
<td>1.9 dB</td>
</tr>
<tr>
<td>11010</td>
<td>2.1 dB</td>
</tr>
<tr>
<td>11011</td>
<td>2.3 dB</td>
</tr>
<tr>
<td>11100</td>
<td>2.6 dB</td>
</tr>
<tr>
<td>11101</td>
<td>2.8 dB</td>
</tr>
<tr>
<td>11110</td>
<td>3.0 dB</td>
</tr>
<tr>
<td>11111</td>
<td>3.2 dB</td>
</tr>
</tbody>
</table>

Note: The SLVGNCON register is configured in the multi-phase SLAVE device.
6.9 MOSFET Driver Programmable Dead Time

The turn-on delay of the high-side and low-side drive signals can be configured independently to allow different MOSFETs and circuit board layouts to be used to construct an optimized system. See Figure 6-2.

Setting the HDLYBY and LDLYBY bits of the PE1 register enables the high-side and low-side delay, respectively. The amount of delay added is controlled in the DEADCON register. See Register 6-9 for more information.

**REGISTER 6-9: DEADCON: DRIVER DEAD TIME CONTROL REGISTER**

<table>
<thead>
<tr>
<th>Bit 7-4</th>
<th>HDLY&lt;3:0&gt;: High-Side Dead Time Configuration bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>11 ns delay</td>
</tr>
<tr>
<td>0001</td>
<td>15 ns delay</td>
</tr>
<tr>
<td>0010</td>
<td>19 ns delay</td>
</tr>
<tr>
<td>0011</td>
<td>23 ns delay</td>
</tr>
<tr>
<td>0100</td>
<td>27 ns delay</td>
</tr>
<tr>
<td>0101</td>
<td>31 ns delay</td>
</tr>
<tr>
<td>0110</td>
<td>35 ns delay</td>
</tr>
<tr>
<td>0111</td>
<td>39 ns delay</td>
</tr>
<tr>
<td>1000</td>
<td>43 ns delay</td>
</tr>
<tr>
<td>1001</td>
<td>47 ns delay</td>
</tr>
<tr>
<td>1010</td>
<td>51 ns delay</td>
</tr>
<tr>
<td>1011</td>
<td>55 ns delay</td>
</tr>
<tr>
<td>1100</td>
<td>59 ns delay</td>
</tr>
<tr>
<td>1101</td>
<td>63 ns delay</td>
</tr>
<tr>
<td>1110</td>
<td>67 ns delay</td>
</tr>
<tr>
<td>1111</td>
<td>71 ns delay</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bit 3-0</th>
<th>LDLY&lt;3:0&gt;: Low-Side Dead Time Configuration bits</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>4 ns delay</td>
</tr>
<tr>
<td>0001</td>
<td>8 ns delay</td>
</tr>
<tr>
<td>0010</td>
<td>12 ns delay</td>
</tr>
<tr>
<td>0011</td>
<td>16 ns delay</td>
</tr>
<tr>
<td>0100</td>
<td>20 ns delay</td>
</tr>
<tr>
<td>0101</td>
<td>24 ns delay</td>
</tr>
<tr>
<td>0110</td>
<td>28 ns delay</td>
</tr>
<tr>
<td>0111</td>
<td>32 ns delay</td>
</tr>
<tr>
<td>1000</td>
<td>36 ns delay</td>
</tr>
<tr>
<td>1001</td>
<td>40 ns delay</td>
</tr>
<tr>
<td>1010</td>
<td>44 ns delay</td>
</tr>
<tr>
<td>1011</td>
<td>48 ns delay</td>
</tr>
<tr>
<td>1100</td>
<td>52 ns delay</td>
</tr>
<tr>
<td>1101</td>
<td>56 ns delay</td>
</tr>
<tr>
<td>1110</td>
<td>60 ns delay</td>
</tr>
<tr>
<td>1111</td>
<td>64 ns delay</td>
</tr>
</tbody>
</table>
### 6.10 Output Voltage Configuration

Two registers control the error amplifier reference voltage. The reference is coarsely set in 15 mV steps and then finely adjusted in 0.82 mV steps above the coarse setting (see Registers 6-10 and 6-11). Higher output voltages can be achieved by using a voltage divider connected between the output and the +VSEN pin. Care must be taken to ensure maximum voltage rating compliance on all pins.

**Note:** The OVFCON<VOUTEN> bit must be set to enable the output voltage setting registers.

---

#### REGISTER 6-10: OVCCON: OUTPUT VOLTAGE SET POINT COARSE CONTROL REGISTER

<table>
<thead>
<tr>
<th>R/W</th>
<th>R/W</th>
<th>R/W</th>
<th>R/W</th>
<th>R/W</th>
<th>R/W</th>
<th>R/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>OVC7</td>
<td>OVC6</td>
<td>OVC5</td>
<td>OVC4</td>
<td>OVC3</td>
<td>OVC2</td>
<td>OVC1</td>
</tr>
</tbody>
</table>

**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 OVC<7:0>:** Output Voltage Set Point Coarse Configuration bits
  \[
  OVC<7:0> = \frac{(V_{OUT}/15.8 \text{ mV}) + 15.8 \text{ mV}}{}
  \]

---

#### REGISTER 6-11: OVFCON: OUTPUT VOLTAGE SET POINT FINE CONTROL REGISTER

<table>
<thead>
<tr>
<th>R/W</th>
<th>U</th>
<th>U</th>
<th>R/W</th>
<th>R/W</th>
<th>R/W</th>
<th>R/W</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOUTEN</td>
<td>—</td>
<td>—</td>
<td>OVF4</td>
<td>OVF3</td>
<td>OVF2</td>
<td>OVF1</td>
</tr>
</tbody>
</table>

**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** VOUTEN: Output Voltage DAC Enable bit
  - 1 = Output Voltage DAC is enabled
  - 0 = Output Voltage DAC is disabled

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

- **bit 4-0 OVF<4:0>:** Output Voltage Set Point Fine Configuration bits
  \[
  OVF<4:0> = \frac{(V_{OUT} - V_{OUT,COARSE})}{0.8 \text{ mV}}
  \]
6.11 Output Undervoltage

The output voltage is monitored, and when it is below the output undervoltage threshold, the UVIF flag is set. This flag must be cleared in software. See Section 15.3.1.4 “PIR2 Register” for more information.

The output undervoltage threshold is controlled by the OUVCON register, as shown in Register 6-12.

REGISTER 6-12: OUVCON: OUTPUT UNDERVERTAGE DETECT LEVEL CONTROL REGISTER

<table>
<thead>
<tr>
<th>bit 7</th>
<th>bit 6</th>
<th>bit 5</th>
<th>bit 4</th>
<th>bit 3</th>
<th>bit 2</th>
<th>bit 1</th>
<th>bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUV7</td>
<td>OUV6</td>
<td>OUV5</td>
<td>OUV4</td>
<td>OUV3</td>
<td>OUV2</td>
<td>OUV1</td>
<td>OUV0</td>
</tr>
</tbody>
</table>

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 OUV<7:0>: Output Undervoltage Detect Level Configuration bits

\[ OUV<7:0> = \frac{\text{VOUT}_{\text{UV}\_\text{Detect\_Level}}}{15 \text{ mV}} \]

6.12 Output Overvoltage

The output voltage is monitored, and when it is above the output overvoltage threshold, the OVIF flag is set. This flag must be cleared in software. See Section 15.3.1.4 “PIR2 Register” for more information.

The output overvoltage threshold is controlled by the OOVCON register, as shown in Register 6-13.

REGISTER 6-13: OOVCON: OUTPUT OVERVOLTAGE DETECT LEVEL CONTROL REGISTER

<table>
<thead>
<tr>
<th>bit 7</th>
<th>bit 6</th>
<th>bit 5</th>
<th>bit 4</th>
<th>bit 3</th>
<th>bit 2</th>
<th>bit 1</th>
<th>bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>OOV7</td>
<td>OOV6</td>
<td>OOV5</td>
<td>OOV4</td>
<td>OOV3</td>
<td>OOV2</td>
<td>OOV1</td>
<td>OOV0</td>
</tr>
</tbody>
</table>

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

\[ OOV<7:0> = \frac{\text{VOUT}_{\text{OV}\_\text{Detect\_Level}}}{15 \text{ mV}} \]
6.13 Analog Peripheral Control

The MCP19110/11 has various analog peripherals. These peripherals can be configured to allow customizable operation. Refer to Register 6-14 more information.

6.13.1 DIODE EMULATION MODE

The MCP19110/11 can operate in either diode emulation or synchronous rectification mode. When operating in diode emulation mode, the LDRV signal is terminated when the voltage across the low-side MOSFET is approximately 0V. This condition is true when the inductor current reaches approximately 0A. Both the HDRV and LDRV signals are low until the beginning of the next switching cycle. At that time, the HDRV signal is asserted high, turning on the high-side MOSFET.

When operating in Synchronous Rectification mode, the LDRV signal is held high until the beginning of the next switching cycle. At that time, the HDRV signal is asserted high, turning on the high-side MOSFET.

The PE1<DECON> bit controls the operating mode of the MCP19110/11.

6.13.2 HIGH-SIDE DRIVE STRENGTH

The peak source and sink current of the high-side driver can be configured to either be 1A source/sink or 2A source/sink. The PE1<DVRSTR> bit determines the high-side drive strength.

6.13.3 MOSFET DRIVER DEAD TIME

As described in Section 6.9 “MOSFET Driver Programmable Dead Time”, the MOSFET drive dead time can be adjusted. In order to enable dead time settings, the proper bypass bits must be cleared. PE1<HDLYBY> and PE1<LDLYBY> control the delay circuits. Clearing the respective bits allows the dead time programmed by the DEADCON register to be added to the appropriate turn-on edge.

6.13.4 OUTPUT VOLTAGE SENSE PULL-UP/PULL-DOWN

A high-impedance pull-up on the +VSEN pin can be configured by setting the PE1<PUEN> bit. When set, the +VSEN pin is internally pulled-up to VDD.

A high-impedance pull-down on the -VSEN can be configured by setting the PE1<PDEN> bit. When set, the -VSEN pin is internally pulled-down to ground.

6.13.5 OUTPUT UNDervoltage ACCELERATOR

The MCP19110/11 has additional control circuitry to allow it to respond quickly to an output undervoltage condition. The enabling of this circuitry is handled by the PE1<UVTEE> bit. When this bit is set, the MCP19110/11 will respond to an output undervoltage condition by setting both the HDRV and LDRV signals low and turning off both the high-side and low-side MOSFETs.

6.13.6 OUTPUT OVERvoltage ACCELERATOR

The MCP19110/11 has additional control circuitry to allow it to respond quickly to an output overvoltage condition. The enabling of this circuitry is handled by the PE1<OVTEE> bit. When this bit is set, the MCP19110/11 will respond to an output overvoltage condition by setting both the HDRV and LDRV signals low and turning off both the high-side and low-side MOSFETs.
## REGISTER 6-14: PE1: ANALOG PERIPHERAL ENABLE 1 CONTROL REGISTER

<table>
<thead>
<tr>
<th>Bit</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>DECON</td>
<td>DVRSTR</td>
<td>HDLYBY</td>
<td>LDLYBY</td>
<td>PDEN</td>
<td>PUEN</td>
<td>UVTEE</td>
<td>OVTEE</td>
</tr>
</tbody>
</table>

### 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**
- **DECON**: Diode Emulation Mode bit
  - 1 = Diode emulation mode enabled
  - 0 = Synchronous rectification mode enabled

**bit 6**
- **DVRSTR**: High-Side Drive Strength Configuration bit
  - 1 = High-side 1A source/sink drive strength
  - 0 = High-side 2A source/sink drive strength

**bit 5**
- **HDLYBY**: High-Side Dead Time Bypass bit
  - 1 = High-side dead time bypass is enabled
  - 0 = High-side dead time bypass is disabled

**bit 4**
- **LDLYBY**: Low-Side Dead Time Bypass bit
  - 1 = Low-side dead time bypass is enabled
  - 0 = Low-side dead time bypass is disabled

**bit 3**
- **PDEN**: -VSEN Weak Pull Down Enable bit
  - 1 = -VSEN weak pull down is enabled
  - 0 = -VSEN weak pull down is disabled

**bit 2**
- **PUEN**: +VSEN Weak Pull Up Enable bit
  - 1 = +VSEN weak pull up is enabled
  - 0 = +VSEN weak pull up is disabled

**bit 1**
- **UVTEE**: Output Undervoltage Accelerator Enable bit
  - 1 = Output undervoltage accelerator is enabled
  - 0 = Output undervoltage accelerator is disabled

**bit 0**
- **OVTEE**: Output Overvoltage Accelerator Enable bit
  - 1 = Output overvoltage accelerator is enabled
  - 0 = Output overvoltage accelerator is disabled
6.14 Analog Blocks Enable Control

Various analog circuit blocks can be enabled or disabled, as shown in Register 6-15. Additional enable bits are located in the ATSTCON register.

6.14.1 OUTPUT OVERVOLTAGE ENABLE

The output overvoltage is enabled by setting the ABECON<OVDCEN> bit. Clearing this bit will disable the output overvoltage circuitry and cause the setting in the OOVCON register to be ignored.

6.14.2 OUTPUT UNDERVOLTAGE ENABLE

The output undervoltage is enabled by setting the ABECON<UVDCEN> bit. Clearing this bit will disable the output undervoltage circuitry and cause the setting in the OUVCON register to be ignored.

6.14.3 RELATIVE EFFICIENCY MEASUREMENT CONTROL

Section 10.0 “Relative Efficiency Measurement” describes the procedure used to measure the relative efficiency of the system. Setting the ABECON<MEASEN> bit initiates the relative measurement.

6.14.4 SLOPE COMPENSATION CONTROL

The slope compensation described in Register 6-7 can be bypassed by setting the ABECON<SLCPBY> bit. Under normal operation, this bit will always be set.

6.14.5 CURRENT MEASUREMENT CONTROL

The peak current measurement circuitry is controlled by the ABECON<CRTMEN> bit. Setting this bit enables the current measurement circuitry. Under normal operation, this bit will be set.

6.14.6 INTERNAL TEMPERATURE MEASUREMENT CONTROL

The internal temperature of the silicon can be measured with the ADC. To enable the internal temperature measurement circuitry, the ABECON<TMPSEN> bit must be set.

6.14.7 RELATIVE EFFICIENCY CIRCUITY CONTROL

Section 10.0 “Relative Efficiency Measurement” describes the procedure used to measure the relative efficiency of the system. Setting the ABECON<RECIREN> bit enables the relative efficiency measurement circuitry.

6.14.8 SIGNAL CHAIN CONTROL

Setting the ABECON<PATHEN> bit enables the voltage control path. Under normal operation, this bit is set.
REGISTER 6-15: ABECON: ANALOG BLOCK ENABLE CONTROL REGISTER

<table>
<thead>
<tr>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>OVDCEN</td>
<td>UVDCEN</td>
<td>MEASEN</td>
<td>SLCPBY</td>
<td>CRTMEN</td>
<td>TMPSEN</td>
<td>RECIREN</td>
<td>PATHEN</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>bit 7</th>
<th>bit 0</th>
</tr>
</thead>
</table>

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 OVDCEN**: Output overvoltage DAC control bit
  - 1 = Output overvoltage DAC is enabled
  - 0 = Output overvoltage DAC is disabled

- **bit 6 UVDCEN**: Output undervoltage DAC control bit
  - 1 = Output undervoltage DAC is enabled
  - 0 = Output undervoltage DAC is disabled

- **bit 5 MEASEN**: Relative efficiency measurement control bit
  - 1 = Initiate relative efficiency measurement
  - 0 = Relative efficiency measurement not in progress

- **bit 4 SLCPBY**: Slope compensation bypass control bit
  - 1 = Slope compensation is disabled
  - 0 = Slope compensation is enabled

- **bit 3 CRTMEN**: Current measurement circuitry control bit
  - 1 = Current measurement circuitry is enabled
  - 0 = Current measurement circuitry is disabled

- **bit 2 TMPSEN**: Internal temperature sensor control bit
  - 1 = Internal temperature sensor circuitry is enabled
  - 0 = Internal temperature sensor circuitry is disabled

- **bit 1 RECIREN**: Relative efficiency circuitry control bit
  - 1 = Relative efficiency circuitry is enabled
  - 0 = Relative efficiency circuitry is disabled

- **bit 0 PATHEN**: Signal chain circuitry control bit
  - 1 = Signal chain circuitry is enabled
  - 0 = Signal chain circuitry is disabled
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, $V_{IN} = 12V$, $F_{SW} = 300$ kHz, $T_A = +25^\circ C$.

**FIGURE 7-1:** $I_Q$ vs. Temperature.

**FIGURE 7-2:** OVCCON DAC INL vs. Code and Temperature ($-40^\circ C$ to $+125^\circ C$).

**FIGURE 7-3:** OVCCON DAC DNL vs. Code and Temperature ($-40^\circ C$ to $+125^\circ C$).

**FIGURE 7-4:** OVFCON DAC INL vs. Code and Temperature ($-40^\circ C$ to $+125^\circ C$).

**FIGURE 7-5:** OVFCON DAC DNL vs. Code and Temperature ($-40^\circ C$ to $+125^\circ C$).

**FIGURE 7-6:** $V_{DD}$ vs. Input Voltage.
Note: Unless otherwise indicated, $V_{IN} = 12V$, $F_{SW} = 300$ kHz, $T_A = +25^\circ C$.

**FIGURE 7-7:** $V_{DD}$ vs. Output Current.

**FIGURE 7-8:** $V_{REGREF}$ vs. Temperature ($V_{REGREF} = 0.6V$).

**FIGURE 7-9:** $V_{REGREF}$ vs. Temperature ($V_{REGREF} = 1.8V$).

**FIGURE 7-10:** $V_{REGREF}$ vs. Temperature ($V_{REGREF} = 3.3V$).

**FIGURE 7-11:** HDRV Dead Time vs. HDLY Code.

**FIGURE 7-12:** LDRV Dead Time vs. LDLY Code.
Note: Unless otherwise indicated, $V_{IN} = 12\, V$, $F_{SW} = 300\, kHz$, $T_A = +25\, ^{\circ}\, C$.

**FIGURE 7-13:** \( HDRV\ R_{DSon} \) vs. Temperature.

**FIGURE 7-14:** \( HDRV\ R_{DSon} \) vs. Temperature.

**FIGURE 7-15:** \( LDRV\ R_{DSon} \) vs. Temperature.

**FIGURE 7-16:** Oscillator Frequency vs. Temperature.

**FIGURE 7-17:** \( CRNT\ Voltage \) vs. Output Current.

**FIGURE 7-18:** Remote Sense Amplifier CMRR.
8.0 SYSTEM BENCH TESTING

To allow for easier system design and bench testing, the MCP19110/11 family of devices 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 ATSTCON register, as shown in Register 8-1.

Control of the signals present at the output of the unity gain buffer is found in the BUFFCON register, as shown in Register 8-2.

8.1 Analog Bench Test Control

8.1.1 ATSTCON REGISTER

The ATSTCON register contains the bits used to disable the MOSFET drivers and configure the GPA0 pin as the unity gain buffer out, as shown in Register 8-1.

Note 1: The DRVDIS bit is reset to ‘1’ so the high-side and low-side drivers are in a known state after reset. This bit must be cleared by software for normal operation.

REGISTER 8-1: ATSTCON: ANALOG BENCH TEST CONTROL REGISTER

<table>
<thead>
<tr>
<th>Bit</th>
<th>Description</th>
<th>Value at POR</th>
<th>Readable/Writable</th>
<th>Bit Set/Cleared</th>
<th>Known</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Reserved</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6-5</td>
<td>Unimplemented: Read as '0'</td>
<td></td>
<td></td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4</td>
<td>Reserved</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>HIDIS: High-side driver control bit</td>
<td>1</td>
<td>W</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>LODIS: Low-side driver control bit</td>
<td>1</td>
<td>W</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>1</td>
<td>BNCHEN: GPA0 bench test configuration control bit</td>
<td>1</td>
<td>W</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>0</td>
<td>—</td>
</tr>
<tr>
<td>0</td>
<td>DRVDIS: MOSFET driver disable control bit</td>
<td>1</td>
<td>W</td>
<td>1</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>0</td>
<td>—</td>
</tr>
</tbody>
</table>

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

The unity gain buffer module is used during a multi-phase application and while operating in Bench Test mode.

When the ATSTCON<BNCHEN> bit is set, the device is in Bench Test mode and the ASEL<4:0> bits of the BUFFCON register determine which internal analog signal can be measured on the GPA0 pin.

When measuring signals with the unity gain buffer, the buffer offset must be added to the measured signal. The factory measured buffer offset can be read from memory location 2087h. Refer to Section 11.1.1 “Reading Program Memory as Data” for more information.

REGISTER 8-2: BUFFCON: UNITY GAIN BUFFER CONTROL REGISTER

<table>
<thead>
<tr>
<th>bit 7-5</th>
<th>bit 4-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLTPH&lt;2:0&gt;: System configuration bits</td>
<td></td>
</tr>
<tr>
<td>000 = Device set as stand-alone unit</td>
<td></td>
</tr>
<tr>
<td>001 = Device set as multiple output MASTER</td>
<td></td>
</tr>
<tr>
<td>010 = Device set as multiple output SLAVE</td>
<td></td>
</tr>
<tr>
<td>011 = Device set as multi-phase MASTER</td>
<td></td>
</tr>
<tr>
<td>100 = Device set as multi-phase SLAVE</td>
<td></td>
</tr>
<tr>
<td>bit 4-0</td>
<td>ASEL&lt;4:0&gt;: Multiplexer output control bit</td>
</tr>
<tr>
<td>00000 = Voltage proportional to current in the inductor</td>
<td></td>
</tr>
<tr>
<td>00001 = Error amplifier output plus slope compensation, input to PWM comparator</td>
<td></td>
</tr>
<tr>
<td>00010 = Input to slope compensation circuitry</td>
<td></td>
</tr>
<tr>
<td>00011 = Band gap reference</td>
<td></td>
</tr>
<tr>
<td>00100 = Output voltage reference</td>
<td></td>
</tr>
<tr>
<td>00101 = Output voltage after internal differential amplifier</td>
<td></td>
</tr>
<tr>
<td>00110 = Unimplemented</td>
<td></td>
</tr>
<tr>
<td>00111 = Voltage proportional to the internal temperature</td>
<td></td>
</tr>
<tr>
<td>01000 = Internal ground for current sense circuitry, see Section 6.5 “Voltage for Zero Current”</td>
<td></td>
</tr>
<tr>
<td>01001 = Output overvoltage comparator reference</td>
<td></td>
</tr>
<tr>
<td>01010 = Output undervoltage comparator reference</td>
<td></td>
</tr>
<tr>
<td>01011 = Error amplifier output</td>
<td></td>
</tr>
<tr>
<td>01100 = For a multi-phase SLAVE, error amplifier signal received from MASTER</td>
<td></td>
</tr>
<tr>
<td>01101 = For multi-phase SLAVE, error signal received from MASTER with gain, see Section 6.8 “MASTER Error Signal Gain”</td>
<td></td>
</tr>
<tr>
<td>01110 = VIN divided down by 1/5</td>
<td></td>
</tr>
<tr>
<td>01111 = DC inductor valley current</td>
<td></td>
</tr>
<tr>
<td>10000 = Unimplemented</td>
<td></td>
</tr>
<tr>
<td>•</td>
<td></td>
</tr>
<tr>
<td>•</td>
<td></td>
</tr>
<tr>
<td>11100 = Unimplemented</td>
<td></td>
</tr>
<tr>
<td>11101 = Overcurrent reference</td>
<td></td>
</tr>
<tr>
<td>11110 = Unimplemented</td>
<td></td>
</tr>
<tr>
<td>11111 = Unimplemented</td>
<td></td>
</tr>
</tbody>
</table>
9.0 DEVICE CALIBRATION

Read-only memory locations 2080h through 208Fh contain factory calibration data. Refer to Section 18.0 “Flash Program Memory Control” for information on how to read from these memory locations.

9.1 Calibration Word 1

The DOV<3:0> bits at memory location 2080h set the offset calibration for the output voltage remote sense differential amplifier. Firmware must read these values and write them to the DOVCAL register for proper calibration.

The FCAL<6:0> bits at memory location 2080h set the internal oscillator calibration. Firmware must read these values and write them to the OSCCAL register for proper calibration.

REGISTER 9-1: CALWD1: CALIBRATION WORD 1 REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>DOV3</td>
<td>DOV2</td>
<td>DOV1</td>
<td>DOV0</td>
</tr>
</tbody>
</table>

bit 13

<table>
<thead>
<tr>
<th>U-0</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FCAL6</td>
<td>FCAL5</td>
<td>FCAL4</td>
<td>FCAL3</td>
<td>FCAL2</td>
<td>FCAL1</td>
<td>FCAL0</td>
</tr>
</tbody>
</table>

bit 7

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   DOV<3:0>: Output voltage remote sense differential amplifier offset calibration bits.
bit 7      Unimplemented: Read as ‘0’
bit 6-0    FCAL<6:0>: Internal oscillator calibration bits.
9.2 Calibration Word 2

The TTA<3:0> bits at memory location 2082h calibrate the overtemperature shutdown threshold point. Firmware must read these values and write them to the TTACAL register for proper calibration.

The BGR<3:0> bits at memory location 2082h calibrate the internal band gap. Firmware must read these values and write them to the BGRCAL register for proper calibration.

REGISTER 9-2: CALWD2: CALIBRATION WORD 2 REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TTA3</td>
<td>TTA2</td>
<td>TTA1</td>
<td>TTA0</td>
</tr>
</tbody>
</table>

bit 13

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BGR3</td>
<td>BGR2</td>
<td>BGR1</td>
<td>BGR0</td>
</tr>
</tbody>
</table>

bit 7

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   TTA<3:0>: Overtemperature shutdown threshold calibration bits.
bit 7-4    Unimplemented: Read as ‘0’
bit 3-0    BGR<3:0>: Internal band gap calibration bits.
9.3 Calibration Word 3

The VRO<3:0> bits at memory location 2083h calibrate the offset of the buffer amplifier of the output voltage regulation reference set point. This effectively changes the band gap reference. Firmware must read these values and write them to the VROCAL register for proper calibration.

The ZRO<3:0> bits at memory location 2083h calibrate the offset of the error amplifier. Firmware must read these values and write them to the ZROCAL register for proper calibration.

REGISTER 9-3: CALWD3: CALIBRATION WORD 3 REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>—</td>
<td>VRO3</td>
<td>VRO2</td>
<td>VRO1</td>
<td>VRO0</td>
</tr>
<tr>
<td>bit 13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ZRO3</td>
<td>ZRO2</td>
<td>ZRO1</td>
<td>ZRO0</td>
</tr>
<tr>
<td>bit 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 VRO<3:0>: Reference voltage offset calibration bits.
bit 7-4 Unimplemented: Read as ‘0’
bit 3-0 ZRO<3:0>: Error amplifier offset voltage calibration bits.
9.4 Calibration Word 4

The TANA<9:0> bits at memory location 2084h contain the ADC reading from the internal temperature sensor when the silicon temperature is at +30°C. The temperature coefficient of the internal temperature sensor is 16 mV/°C.

REGISTER 9-4: CALWD4: CALIBRATION WORD 4 REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TANA9</td>
<td>TANA8</td>
</tr>
</tbody>
</table>

bit 13

<table>
<thead>
<tr>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>TANA7</td>
<td>TANA6</td>
<td>TANA5</td>
<td>TANA4</td>
<td>TANA3</td>
<td>TANA2</td>
<td>TANA1</td>
<td>TANA0</td>
</tr>
</tbody>
</table>

bit 7

<table>
<thead>
<tr>
<th>bit 0</th>
</tr>
</thead>
</table>

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 internal temperature sensor at +30°C calibration bits

TANA<9:0> = (Temperature x 13.3 mV/°C) + 1.75
9.5 Calibration Word 5

The DIFC<7:0> bits at memory location 2085h contain the offset voltage information for the output voltage difference amplifier. The value is an 8-bit two’s complement number that represents the number of the OVCCON counts needed to adjust for the differential amplifier offset. This value can be used to completely remove the differential amplifier offset.

For example, the offset of the differential amplifier is measured to be -64 mV. Since one OVCCON count equals 16 mV, this represents four counts of the OVCCON register. Therefore, the value stored at location 2085h would be 0xFCh, where the setting of the DIFC7 bit represents a negative number.

REGISTER 9-5: CALWD5: CALIBRATION WORD 5 REGISTER

<table>
<thead>
<tr>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIFC7</td>
<td>DIFC6</td>
<td>DIFC5</td>
<td>DIFC4</td>
<td>DIFC3</td>
<td>DIFC2</td>
<td>DIFC1</td>
<td>DIFC0</td>
</tr>
</tbody>
</table>

Legend:
- R = Readable bit
- P = Programmable bit
- U = Unimplemented bit, read as ‘0’
- ‘1’ = Bit is set
- ‘0’ = Bit is cleared
- x = Bit is unknown

bit 13-8 Unimplemented: Read as ‘0’
bit 7-0 DIFC<7:0>: OVCCON counts to adjust for differential amplifier offset calibration bits
9.6 Calibration Word 6

The DIFF<7:0> bits at memory location 2086h contain the offset voltage information for the output voltage difference amplifier. The value is an 8-bit two’s complement number that represents the number of the OVFCON counts needed to adjust for the differential amplifier offset. This value can be used to completely remove the differential amplifier offset.

For example, the offset of the differential amplifier is measured to be +4.2 mV. Since one OVFCON count equals 0.7 mV, this represents six counts of the OVFCON register. Therefore the value stored at location 2086h would be 0x06h, where clearing the DIFF7 bit represents a positive number.

REGISTER 9-6: CALWD6: CALIBRATION WORD 6 REGISTER

```
<table>
<thead>
<tr>
<th>bit 13</th>
<th>bit 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-0</td>
<td>U-0</td>
</tr>
<tr>
<td>U-0</td>
<td>U-0</td>
</tr>
<tr>
<td>U-0</td>
<td>U-0</td>
</tr>
<tr>
<td>bit 7</td>
<td>bit 0</td>
</tr>
</tbody>
</table>
```

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

<table>
<thead>
<tr>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIFF7</td>
<td>DIFF6</td>
<td>DIFF5</td>
<td>DIFF4</td>
<td>DIFF3</td>
<td>DIFF2</td>
<td>DIFF1</td>
<td>DIFF0</td>
</tr>
</tbody>
</table>

bit 13-8 Unimplemented: Read as ‘0’
bit 7-0 DIFF<7:0>: OVFCON counts to adjust for differential amplifier offset calibration bits
9.7 Calibration Word 7

The BUFF<7:0> bits at memory location 2087h represent the offset voltage of the unity gain buffer. This is an 8-bit two's complement number. The MSB is the sign bit. If the MSB is set to 1, the resulting number is negative.

**REGISTER 9-7: CALWD7: CALIBRATION WORD 7 REGISTER**

<table>
<thead>
<tr>
<th>bit 13</th>
<th>bit 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-0</td>
<td>U-0</td>
</tr>
<tr>
<td>U-0</td>
<td>U-0</td>
</tr>
<tr>
<td>U-0</td>
<td>U-0</td>
</tr>
<tr>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

**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 7-0**: BUFF<7:0>: Unity gain buffer offset voltage calibration bits
10.0 RELATIVE EFFICIENCY MEASUREMENT

With a constant input voltage, output voltage and load current, any change in the high-side MOSFET on-time represents a change in the system efficiency. The MCP19110/11 is capable of measuring the on-time of the high-side MOSFET. Therefore, the relative efficiency of the system can be measured and optimized by changing the system parameters, such as switching frequency, driver dead time or high-side drive strength.

10.1 Relative Efficiency Measurement Procedure

To measure the relative efficiency, the RELEFF register, ABECON<MEASEN> and ABECON<RECIREN> bits, and the ADC RELEFF input are used. The following steps outlines the measurement process:

1. Set the ABECON<RECIREN> bit to enable the measurement circuitry.
2. Clear the ABECON<MEASEN> bit.
3. With the ADC, read the RELEFF channel and store this reading as the High.
4. With the ADC, read the VZC channel and store this reading as the Low.
5. Set the ABECON<MEASEN> bit to initiate a measurement cycle.
6. Monitor the RELEFF<MSDONE> bit. When set, it indicates the measurement is complete.
7. When the measurement is complete, use the ADC to read the RELEFF channel. This value becomes the Fractional variable in Equation 10-1. This reading should be accomplished approximately 50ms after the RELESS<MSDONE> bit is set.
8. Read the value of the RE<6:0> bits in the RELEFF register and store the reading as Whole.
9. Clear the ABECON<MEASEN> bit.
10. The relative efficiency is then calculated by the following equation:

EQUATION 10-1:

\[
\text{Unicycle} = \frac{(\text{Whole} + (\text{Fractional} - \text{Low}))}{(\text{High} - \text{Low})} \div (PR2 + 1)
\]

Where:
- Whole = Value obtained in Step 8 of the measurement procedure
- Fractional = Value obtained in Step 7 of the measurement procedure
- High = Value obtained in Step 3 of the measurement procedure
- Low = Value obtained in Step 4 of the measurement procedure

Note 1: The RELEFF<MSDONE> bit is set and cleared automatically.

REGISTER 10-1: RELEFF: RELATIVE EFFICIENCY MEASUREMENT REGISTER

<table>
<thead>
<tr>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSDONE</td>
<td>RE6</td>
<td>RE5</td>
<td>RE4</td>
<td>RE3</td>
<td>RE2</td>
<td>RE1</td>
<td>RE0</td>
</tr>
</tbody>
</table>

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

bit 7 MSDONE: Relative efficiency measurement done bit
- 1 = Relative efficiency measurement is complete
- 0 = Relative efficiency measurement is not complete

bit 6-0 RE<6:0>: Whole clock counts for relative efficiency measurement result
11.0 MEMORY ORGANIZATION

There are two types of memory in the MCP19110/11:

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

11.1 Program Memory Organization

The MCP19110/11 has a 13-bit program counter capable of addressing an 8K x 14 program memory space. Only the first 4K x 14 (0000h-0FFFh) is physically implemented. Addressing a location above this boundary will cause a wrap-around within the first 4K x 14 space. The Reset vector is at 0000h and the interrupt vector is at 0004h (see Figure 11-1). The width of the program memory bus (instruction word) is 14-bits. Since all instructions are a single word, the MCP19110/11 has space for 4K of instructions.

Note 1: Not code protected.
11.1.1 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.

11.1.1.1 RETLW Instruction

The `RETLW` instruction can be used to provide access to tables of constants. The recommended way to create such a table is shown in Example 11-1.

**EXAMPLE 11-1: RETLW INSTRUCTION**

```
const
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
```

11.1.1.2 Indirect Read with Files Select Register (FSR)

The program memory can be accessed as data by setting bit 7 of the FSRxH register and reading the matching INDFx register. The `MOVIW` instruction will place the lower 8 bits of the addressed word in the W register. Writes to the program memory cannot be performed via the INDF registers. Instructions that access the program memory via the FSR require one extra instruction cycle to complete. Example 11-2 demonstrates accessing the program memory via an FSR.

The HIGH directive will set bit<7> if a label points to a location in program memory.

**EXAMPLE 11-2: ACCESSING PROGRAM MEMORY VIA FSR**

```
const
RETLW DATA0 ;Index0 data
RETLW DATA1 ;Index1 data
RETLW DATA2
RETLW DATA3

my_function
  ;... LOTS OF CODE...
  MOVLW LOW constants
  MOVWF FSR1L
  MOVLW HIGH constants
  MOVWF FSR1H
  MOVIW 0[FSR1]
  ;THE PROGRAM MEMORY IS IN W
```

11.2 Data Memory Organization

The data memory (see Table 11-1) 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 and 120h-16Fh in Bank 2 are General Purpose Registers, implemented as static RAM. All other RAM is unimplemented and returns '0' when read. The RP<1:0> bits of the STATUS register are the bank select bits.

<table>
<thead>
<tr>
<th>RP1</th>
<th>RP0</th>
<th>Bank</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Bank 0 is selected</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>Bank 1 is selected</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>Bank 2 is selected</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>Bank 3 is selected</td>
</tr>
</tbody>
</table>

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 STATUS register, shown in Register 11-1, 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, then the write to these three bits is disabled. These bits are set or cleared according to the device logic. Furthermore, the TO and 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 uuu'(where u = unchanged).

Therefore, it is recommended that only `BCF`, `BSF`, `SWAPF` and `MOVWF` instructions are used to alter the STATUS register, because these instructions do not affect any Status bits. For other instructions not affecting any Status bits, see the Section 29.0 “Instruction Set Summary”.

**Note 1:** The C and DC bits operate as Borrow and Digit Borrow out bits, respectively, in subtraction.
11.2.1 SPECIAL FUNCTION REGISTERS

The Special Function Registers are registers used by the CPU and peripheral functions for controlling the desired operation of the device (see Table 11-1). 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.

### REGISTER 11-1: STATUS: STATUS REGISTER

<table>
<thead>
<tr>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R-1</th>
<th>R-1</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRP</td>
<td>RP1</td>
<td>RP0</td>
<td>TO</td>
<td>PD</td>
<td>Z</td>
<td>DC(1)</td>
<td>C(1)</td>
</tr>
</tbody>
</table>

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

**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**
- **TO**: Time-out bit
  - 1 = After power-up, CLRWDT instruction or SLEEP instruction
  - 0 = A WDT time-out occurred

**bit 3**
- **PD**: Power-down bit
  - 1 = After power-up or by the CLRWDT instruction
  - 0 = By execution of the SLEEP 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**
- **DC**: Digit Carry/Digit Borrow bit(1) (ADDWF, ADDLW, SUBLW, SUBWF instructions)
  - 1 = A carry-out from the 4th low-order bit of the result occurred
  - 0 = No carry-out from the 4th low-order bit of the result

**bit 0**
- **C**: Carry/Borrow bit(1) (ADDWF, ADDLW, SUBLW, SUBWF instructions)(1)
  - 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 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 of the source register.
### 11.3 DATA MEMORY

#### TABLE 11-1: MCP19110/11 DATA MEMORY MAP

<table>
<thead>
<tr>
<th>File Address</th>
<th>File Address</th>
<th>File Address</th>
<th>File Address</th>
<th>File Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect addr. (1)</td>
<td>00h</td>
<td>Indirect addr. (1)</td>
<td>80h</td>
<td>Indirect addr. (1)</td>
</tr>
<tr>
<td>TMR0</td>
<td>01h</td>
<td>OPTION_REG</td>
<td>81h</td>
<td>TMR0</td>
</tr>
<tr>
<td>PCL</td>
<td>02h</td>
<td>PCL</td>
<td>82h</td>
<td>PCL</td>
</tr>
<tr>
<td>STATUS</td>
<td>03h</td>
<td>STATUS</td>
<td>83h</td>
<td>STATUS</td>
</tr>
<tr>
<td>FSR</td>
<td>04h</td>
<td>FSR</td>
<td>84h</td>
<td>FSR</td>
</tr>
<tr>
<td>PORTGPA</td>
<td>05h</td>
<td>TRISGPA</td>
<td>85h</td>
<td>WPUGPA</td>
</tr>
<tr>
<td>PORTGPB</td>
<td>06h</td>
<td>TRISGPB</td>
<td>86h</td>
<td>WPUGPB</td>
</tr>
<tr>
<td>PIR1</td>
<td>07h</td>
<td>PIE1</td>
<td>87h</td>
<td>PE1</td>
</tr>
<tr>
<td>PIR2</td>
<td>08h</td>
<td>PIE2</td>
<td>88h</td>
<td>BUFFCON</td>
</tr>
<tr>
<td>PCON</td>
<td>09h</td>
<td>APFCON</td>
<td>89h</td>
<td>ABECON</td>
</tr>
<tr>
<td>PCLATH</td>
<td>0Ah</td>
<td>PCLATH</td>
<td>8Ah</td>
<td>PCLATH</td>
</tr>
<tr>
<td>INTC</td>
<td>0Bh</td>
<td>INTCON</td>
<td>8Bh</td>
<td>INTCON</td>
</tr>
<tr>
<td>TMR1</td>
<td>0Ch</td>
<td>TMR1</td>
<td>8Ch</td>
<td>TMR1</td>
</tr>
<tr>
<td>TMR1H</td>
<td>0Dh</td>
<td>TMR1H</td>
<td>8Dh</td>
<td>TMR1H</td>
</tr>
<tr>
<td>T1C</td>
<td>0Eh</td>
<td>T1C</td>
<td>8Eh</td>
<td>T1C</td>
</tr>
<tr>
<td>TMR2</td>
<td>0Fh</td>
<td>TMR2</td>
<td>8Fh</td>
<td>TMR2</td>
</tr>
<tr>
<td>T2C</td>
<td>10h</td>
<td>T2C</td>
<td>90h</td>
<td>T2C</td>
</tr>
<tr>
<td>PR2</td>
<td>11h</td>
<td>PR2</td>
<td>91h</td>
<td>PR2</td>
</tr>
<tr>
<td>12h</td>
<td>92h</td>
<td>12h</td>
<td>92h</td>
<td>12h</td>
</tr>
<tr>
<td>PWMPHL</td>
<td>13h</td>
<td>PWMPHL</td>
<td>93h</td>
<td>PWMPHL</td>
</tr>
<tr>
<td>PWMPHH</td>
<td>14h</td>
<td>PWMPHH</td>
<td>94h</td>
<td>PWMPHH</td>
</tr>
<tr>
<td>PWMRL</td>
<td>15h</td>
<td>PWMRL</td>
<td>95h</td>
<td>PWMRL</td>
</tr>
<tr>
<td>PWMRH</td>
<td>16h</td>
<td>PWMRH</td>
<td>96h</td>
<td>PWMRH</td>
</tr>
<tr>
<td>17h</td>
<td>97h</td>
<td>17h</td>
<td>97h</td>
<td>17h</td>
</tr>
<tr>
<td>OVCCON</td>
<td>18h</td>
<td>OVCCON</td>
<td>98h</td>
<td>OVCCON</td>
</tr>
<tr>
<td>OFCON</td>
<td>19h</td>
<td>OFCON</td>
<td>99h</td>
<td>OFCON</td>
</tr>
<tr>
<td>OVFCON</td>
<td>1Ah</td>
<td>OVFCON</td>
<td>9Ah</td>
<td>OVFCON</td>
</tr>
<tr>
<td>OSCTUNE</td>
<td>1Bh</td>
<td>OSCTUNE</td>
<td>9Bh</td>
<td>OSCTUNE</td>
</tr>
<tr>
<td>ADRESL</td>
<td>1Ch</td>
<td>ADRESL</td>
<td>9Ch</td>
<td>ADRESL</td>
</tr>
<tr>
<td>ADRESH</td>
<td>1Dh</td>
<td>ADRESH</td>
<td>9Dh</td>
<td>ADRESH</td>
</tr>
<tr>
<td>ADCON0</td>
<td>1Eh</td>
<td>ADCON0</td>
<td>9Eh</td>
<td>ADCON0</td>
</tr>
<tr>
<td>ADCON1</td>
<td>1Fh</td>
<td>ADCON1</td>
<td>9Fh</td>
<td>ADCON1</td>
</tr>
<tr>
<td>20h</td>
<td>General Purpose Register</td>
<td>80 Bytes</td>
<td>120h</td>
<td>General Purpose Register</td>
</tr>
<tr>
<td>20h</td>
<td>EFh</td>
<td>16F</td>
<td>1EF</td>
<td></td>
</tr>
<tr>
<td>7Fh</td>
<td>Accesses Bank 0</td>
<td>F0h</td>
<td>170h</td>
<td>Accesses Bank 0</td>
</tr>
<tr>
<td>7Fh</td>
<td>FFh</td>
<td>17F</td>
<td>1FFh</td>
<td></td>
</tr>
</tbody>
</table>

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

**Note:**
1. Not a physical register.
2. Only accessible when DBGEN = 0 and ICKBUG<INBUG> = 1.
### Table 11-2: MCP19110/11 Special Registers Summary Bank 0

| Bank 0 | Adr | Name     | Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Value on | Value on |
|--------|-----|----------|-------|-------|-------|-------|-------|-------|-------|-------| POR Reset | all other resets(1) |
| 00h    | INDF| Addressing this location uses contents of FSR to address data memory (not a physical register) | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 01h    | TMR0| Timer0 Module's Register | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 02h    | PCL | Program Counter's (PC) Least Significant byte | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 03h    | STATUS| IRP | RP1 | RP0 | TO | PD | Z | DC | C | 0001 | 1xxxx | 000q quuu |
| 04h    | FSR | Indirect data memory address pointer | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 05h    | PORTGPA | GPA7 | GPA6 | GPA5 | GPA4 | GPA3 | GPA2 | GPA1 | GPA0 | xxxx | xxxx | xxxx | xxxx |
| 06h    | PORTGPB | GPB7 | GPB6 | GPB5 | GPB4 | GPB3 | GPB2 | GPB1 | GPB0 | xxxx | xxxx | xxxx | xxxx |
| 07h    | PIR1 | ADIF | BCLIF | SSPIF | — | — | TMR2IF | TMR1IF | 0-00 | 0-00 | 0-00 | 0-00 | 0-00 |
| 08h    | PIR2 | UVIF | OCIF | OVIF | — | — | VINIF | DCERIF | 0-00 | 0-00 | 0-00 | 0-00 | 0-00 |
| 09h    | PCON | — | — | — | — | — | — | — | — | — | — | — |
| 0Ah    | PCLATH | — | — | — | — | — | Write buffer for upper 5 bits of program counter | 0-00 | 0000 | 0-00 | 0000 | 0-00 |
| 0Bh    | INTCON | GIE | PEIE | T0IE | INTE | IOCE | T0IF | INTF | IOCF | 0000 | 0005x | 0000 | 0000 |
| 0Ch    | TMR1L | Holding register for the Least Significant byte of the 16-bit TMR1 | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 0Dh    | TMR1H | Holding register for the Most Significant byte of the 16-bit TMR1 | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 0Eh    | T1CON | — | — | — | — | — | — | — | — | — | — | — |
| 0Fh    | TMR2 | Timer2 Module Register | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 | 0000 |
| 10h    | T2CON | — | — | — | — | — | — | — | — | — | — | — |
| 11h    | PR2 | Timer2 Module Period Register | 1111 | 1111 | 1111 | 1111 | 1111 | 1111 | 1111 | 1111 | 1111 | 1111 | 1111 |
| 12h    | — | — | — | — | — | — | — | — | — | — | — | — |
| 13h    | PWMPHL | SLAVE Phase Shift Register | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 14h    | PWMPHH | SLAVE Phase Shift Register | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 15h    | PWMRL | PWM Register Low Byte | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 16h    | PWMRH | PWM Register High Byte | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 17h    | — | — | — | — | — | — | — | — | — | — | — | — |
| 18h    | — | — | — | — | — | — | — | — | — | — | — | — |
| 19h    | OVCCON | OVC7 | OVC6 | OVC5 | OVC4 | OVC3 | OVC2 | OVC1 | OVC0 | 0000 | 0000 | 0000 | 0000 |
| 1Ah    | OVFCON | VOUTON | — | — | OFV4 | OFV3 | OFV2 | OFV1 | OFV0 | 0-00 | 0000 | 0-00 | 0000 |
| 1Bh    | OSCFUSE | — | — | — | — | — | — | — | — | — | — | — |
| 1Ch    | ADRESL | Least significant 8 bits of the right-shifted result | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx | xxxx |
| 1Dh    | ADRESH | Most significant 2 bits of right-shifted result | — | — | — | — | — | — | — | — | — | — | — |
| 1Eh    | ADCON0 | — | CHS4 | CHS3 | CHS2 | CHS1 | CHS0 | G0/DONE | ADON | 0-00 | 0000 | 0-00 | 0000 |
| 1Fh    | ADCON1 | — | ADCS2 | ADCS1 | ADCS0 | — | — | — | — | — | — | — |

**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.
2: IRP & RP1 bits are reserved, always maintain these bits clear.
3: MCLR and WDT reset does not affect the previous value data latch. The IOCF bit will be cleared upon reset but will set again if the mismatch exists.
## TABLE 11-3: MCP19110/11 SPECIAL REGISTERS SUMMARY BANK 1

<table>
<thead>
<tr>
<th>Addr</th>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Value on POR Reset</th>
<th>Values on all other resets(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80h</td>
<td>INDF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>xxxxx xxxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>81h</td>
<td>OPTION_REG</td>
<td>RAPU</td>
<td>INTEDG</td>
<td>T0CS</td>
<td>T0SE</td>
<td>PSA</td>
<td>PS2</td>
<td>PS1</td>
<td>PS0</td>
<td>1111 1111</td>
<td>1111 1111</td>
</tr>
<tr>
<td>82h</td>
<td>PCL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
<tr>
<td>83h</td>
<td>STATUS</td>
<td>IRP(3)</td>
<td>RP1(2)</td>
<td>RP0</td>
<td>TO</td>
<td>PD</td>
<td>Z</td>
<td>DC</td>
<td>C</td>
<td>0001 1xxx</td>
<td>000q quuu</td>
</tr>
<tr>
<td>84h</td>
<td>FSR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>xxxxx xxxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>85h</td>
<td>TRISGA</td>
<td>TRISA7</td>
<td>TRISA6</td>
<td>TRISA5</td>
<td>TRISA4</td>
<td>TRISA3</td>
<td>TRISA2</td>
<td>TRISA1</td>
<td>TRISA0</td>
<td>1111 1111</td>
<td>1111 1111</td>
</tr>
<tr>
<td>86h</td>
<td>TRISGB</td>
<td>TRISB7</td>
<td>TRISB6</td>
<td>TRISB5</td>
<td>TRISB4</td>
<td>TRISB3</td>
<td>TRISB2</td>
<td>TRISB1</td>
<td>TRISB0</td>
<td>1111 1111</td>
<td>1111 1111</td>
</tr>
<tr>
<td>87h</td>
<td>PIE1</td>
<td></td>
<td>ADIE</td>
<td>BCLIE</td>
<td>SSPIE</td>
<td>—</td>
<td>—</td>
<td>TMRIE</td>
<td>TMRIE</td>
<td>-000 --00</td>
<td>-000 --00</td>
</tr>
<tr>
<td>88h</td>
<td>PIE2</td>
<td></td>
<td>UVIE</td>
<td>OCIE</td>
<td>OCIE</td>
<td>OVIE</td>
<td>—</td>
<td>VINIE</td>
<td>DCERIE</td>
<td>0-00 --00</td>
<td>0-00 --00</td>
</tr>
<tr>
<td>89h</td>
<td>APFCON</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>8Ah</td>
<td>PCLATH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>--0 0000</td>
<td>--0 0000</td>
</tr>
<tr>
<td>8Bh</td>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCE</td>
<td>T0IF</td>
<td>INTF</td>
<td>IOCF(4)</td>
<td>0000 00xx</td>
<td>0000 0000</td>
</tr>
<tr>
<td>8Ch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>8Dh</td>
<td></td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>8Eh</td>
<td></td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>8Fh</td>
<td></td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>90h</td>
<td>VINLVL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0-xx xxxxx</td>
<td>0-uu uuuu</td>
</tr>
<tr>
<td>91h</td>
<td>OCCON</td>
<td>OCEN</td>
<td>OCLEG</td>
<td>OCLEG</td>
<td>OCLEG</td>
<td>OOC3</td>
<td>OOC2</td>
<td>OOC1</td>
<td>OOC0</td>
<td>0xxx xxxxx</td>
<td>0uuu uuuu</td>
</tr>
<tr>
<td>92h</td>
<td></td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>--xx xxxxx</td>
<td>--uu uuuu</td>
</tr>
<tr>
<td>93h</td>
<td>CSGSCON</td>
<td>—</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>CSGS3</td>
<td>CSGS2</td>
<td>CSGS1</td>
<td>CSGS0</td>
<td>--xx xxxxx</td>
<td>--uu uuuu</td>
</tr>
<tr>
<td>94h</td>
<td></td>
<td>—</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>xxxxx xxxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>95h</td>
<td>CSDGCON</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Reserved</td>
<td>CSDG2</td>
<td>CSDG1</td>
<td>CSDG0</td>
<td>0--- xxxxx</td>
<td>0---- uuuu</td>
</tr>
<tr>
<td>96h</td>
<td></td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>---- ---- XXX</td>
<td>---- ---- ----</td>
</tr>
<tr>
<td>97h</td>
<td>VZCCON</td>
<td>VZC7</td>
<td>VZC6</td>
<td>VZC5</td>
<td>VZC4</td>
<td>VZC3</td>
<td>VZC2</td>
<td>VZC1</td>
<td>VZC0</td>
<td>xxxxx xxxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>98h</td>
<td>CMPZCON</td>
<td>CMPZ3</td>
<td>CMPZ2</td>
<td>CMPZ1</td>
<td>CMPZ0</td>
<td>CMPZG3</td>
<td>CMPZG2</td>
<td>CMPZG1</td>
<td>CMPZG0</td>
<td>xxxxx xxxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>99h</td>
<td>OUVCON</td>
<td>OUV7</td>
<td>OUV6</td>
<td>OUV5</td>
<td>OUV4</td>
<td>OUV3</td>
<td>OUV2</td>
<td>OUV1</td>
<td>OUV0</td>
<td>xxxxx xxxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>9Ah</td>
<td>OOVCN</td>
<td>OOV7</td>
<td>OOV6</td>
<td>OOV5</td>
<td>OOV4</td>
<td>OOV3</td>
<td>OOV2</td>
<td>OOV1</td>
<td>OOV0</td>
<td>xxxxx xxxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>9Bh</td>
<td>DEADCON</td>
<td>HDLY3</td>
<td>HDLY2</td>
<td>HDLY1</td>
<td>HDLY0</td>
<td>LDLY3</td>
<td>LDLY2</td>
<td>LDLY1</td>
<td>LDLY0</td>
<td>xxxxx xxxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>9Ch</td>
<td>SLPCRCN</td>
<td>SLPG3</td>
<td>SLPG2</td>
<td>SLPG1</td>
<td>SLPG0</td>
<td>SLPS3</td>
<td>SLPS2</td>
<td>SLPS1</td>
<td>SLPS0</td>
<td>xxxxx xxxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>9Dh</td>
<td>SLVGNCON</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>SLVGN4</td>
<td>SLVGN3</td>
<td>SLVGN2</td>
<td>SLVGN1</td>
<td>---- ---- XXX</td>
<td>---- ---- ----</td>
</tr>
<tr>
<td>9 Eh</td>
<td>RELEFF</td>
<td>MSDONE</td>
<td>RE6</td>
<td>RE5</td>
<td>RE4</td>
<td>RE3</td>
<td>RE2</td>
<td>RE1</td>
<td>RE0</td>
<td>0000 0000</td>
<td>0000 0000</td>
</tr>
<tr>
<td>9Fh</td>
<td></td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unimplemented</td>
<td>—</td>
</tr>
</tbody>
</table>

**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.
2. IRP & RP1 bits are reserved, always maintain these bits clear.
3. RA3 pull-up is enabled when pin is configured as MCLR in Configuration Word.
4. MCLR and WDT Reset does not affect the previous value data latch. The IOCF bit will be cleared upon reset but will set again if the mismatch exists.
## TABLE 11-4: MCP19110/11 SPECIAL REGISTERS SUMMARY BANK 2

<table>
<thead>
<tr>
<th>Adr</th>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Value on POR Reset</th>
<th>Value on all other resets(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bank 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100h</td>
<td>INDF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Program Counter's (PC) Least Significant byte</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>102h</td>
<td>PCL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Timer0 Module's Register</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0001 1xxx 000q quuu</td>
<td></td>
</tr>
<tr>
<td>103h</td>
<td>STATUS</td>
<td>IRP(2)</td>
<td>RP1(2)</td>
<td>RP0</td>
<td>T0</td>
<td>PD</td>
<td>Z</td>
<td>DC</td>
<td>C</td>
<td>0011 1xxx 000q quuu</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Indirect data memory address pointer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>104h</td>
<td>FSR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>105h</td>
<td>WPUGPA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>--1- 1111 --u- uuuu</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WPUGPB</td>
<td></td>
<td>WPUB7</td>
<td>WPUB6</td>
<td>WPUB5</td>
<td>WPUB4</td>
<td></td>
<td></td>
<td></td>
<td>0000 1100 0000 1100</td>
<td></td>
</tr>
<tr>
<td>107h</td>
<td>PE1</td>
<td>DECON</td>
<td>DVRSTR</td>
<td>HDLYBY</td>
<td>LDLYBY</td>
<td>PDEN</td>
<td>PUEN</td>
<td>UVTEE</td>
<td>OVTIE</td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ASEL4</td>
<td>ASEL3</td>
<td>ASEL2</td>
<td>ASEL1</td>
<td>ASEL0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>108h</td>
<td>ABECON</td>
<td>OVDCE</td>
<td>UVDCE</td>
<td>MEASEN</td>
<td>SLCPBY</td>
<td>CRTMEN</td>
<td>TMCSEN</td>
<td>RECIREN</td>
<td>PATHEN</td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>109h</td>
<td>PCLATH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10Ah</td>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>TOIE</td>
<td>INTE</td>
<td>IOCE</td>
<td>TOIF</td>
<td>INTF</td>
<td>IOCF(3)</td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Indirect data memory address pointer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>10Ch</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10Dh</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10Fh</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>110h</td>
<td>SSPADD</td>
<td>ADD&lt;7:0&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>111h</td>
<td>SSPBUF</td>
<td>Synchronous Serial Port Receive Buffer/Transmit Register</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>112h</td>
<td>SSPCON1</td>
<td>WCOL</td>
<td>SSPOV</td>
<td>SSPEN</td>
<td>CKP</td>
<td>SSPM&gt;3:0&gt;</td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>113h</td>
<td>SSPCON2</td>
<td>GCEN</td>
<td>ACKSTAT</td>
<td>ACKDT</td>
<td>ACKEN</td>
<td>REN</td>
<td>RSEN</td>
<td>SEN</td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>114h</td>
<td>SSPCON3</td>
<td>ACKTIM</td>
<td>PCIE</td>
<td>SCIIE</td>
<td>BOEN</td>
<td>SDAHT</td>
<td>SBCDE</td>
<td>ASEN</td>
<td>DHEN</td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>115h</td>
<td>SSPMSK</td>
<td>MSK&lt;7:0&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1111 1111 1111 1111</td>
<td></td>
</tr>
<tr>
<td>116h</td>
<td>SSPSTAT</td>
<td>SMP</td>
<td>CKE</td>
<td>DIA</td>
<td>P</td>
<td>S</td>
<td>R/W</td>
<td>UA</td>
<td>BF</td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>117h</td>
<td>SSPADD2</td>
<td>ADD&lt;7:0&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>118h</td>
<td>SSPMSK2</td>
<td>MSK&lt;7:0&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1111 1111 1111 1111</td>
<td></td>
</tr>
<tr>
<td>119h</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11Ah</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11Bh</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11Ch</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11Dh</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11Eh</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11Fh</td>
<td>—</td>
<td>Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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.
2: IRP & RP1 bits are reserved, always maintain these bits clear.
3: MCLR and WDT reset does not affect the previous value data latch. The IOCF bit will be cleared upon reset but will set again if the mismatch exists.
<table>
<thead>
<tr>
<th>Addr</th>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Value on POR Reset</th>
<th>Value on all other resets(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bank 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180h</td>
<td>INDF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>xxxxx xxxxx uuuu uuuu</td>
<td></td>
</tr>
<tr>
<td>181h</td>
<td>OPTION_REG</td>
<td>RAPU</td>
<td>INTEDG</td>
<td>T0CS</td>
<td>T0SE</td>
<td>PSA</td>
<td>PS2</td>
<td>PS1</td>
<td>PS0</td>
<td>1111 1111 1111 1111</td>
<td></td>
</tr>
<tr>
<td>182h</td>
<td>PCL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>183h</td>
<td>STATUS</td>
<td>IRp(2)</td>
<td>RP1(2)</td>
<td>RP0</td>
<td>TO7</td>
<td>TO6</td>
<td>TO5</td>
<td>TO4</td>
<td>TO3</td>
<td>0001 1xxx 000q quuuu</td>
<td></td>
</tr>
<tr>
<td>184h</td>
<td>FSR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>xxxxx xxxxx uuuu uuuu</td>
<td></td>
</tr>
<tr>
<td>185h</td>
<td>IOCA</td>
<td>IOCA7</td>
<td>IOCA6</td>
<td>IOCA5</td>
<td>IOCA4</td>
<td>IOCA3</td>
<td>IOCA2</td>
<td>IOCA1</td>
<td>IOCA0</td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>186h</td>
<td>IOCB</td>
<td>IOCB7</td>
<td>IOCB6</td>
<td>IOCB5</td>
<td>IOCB4</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>187h</td>
<td>ANSELA</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ANSA3</td>
<td>ANSA2</td>
<td>ANSA1</td>
<td>ANSA0</td>
<td>1111 1111 1111 1111</td>
<td></td>
</tr>
<tr>
<td>188h</td>
<td>ANSELB</td>
<td>—</td>
<td>—</td>
<td>ANSB5</td>
<td>ANSB4</td>
<td>—</td>
<td>—</td>
<td>ANSB2</td>
<td>ANSB1</td>
<td>— —11 —11 —11 —11</td>
<td></td>
</tr>
<tr>
<td>189h</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18Ah</td>
<td>PCLATH</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Write buffer for upper 5 bits of program counter</td>
<td>0000 0000 0000 0000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18Bh</td>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCE</td>
<td>TOIF</td>
<td>INTF</td>
<td>IOCF</td>
<td>0000 000x 0000 000u</td>
<td></td>
</tr>
<tr>
<td>18Ch</td>
<td>PORTICD(5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18Dh</td>
<td>TRISICD(5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18Eh</td>
<td>ICKBUG(5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18Fh</td>
<td>BIGBUG(5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>190h</td>
<td>PMCON1</td>
<td>—</td>
<td>CALSEL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>WREN</td>
<td>WR</td>
<td>—0-- —000 —0-- —000</td>
<td></td>
</tr>
<tr>
<td>191h</td>
<td>PMCON2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>192h</td>
<td>PMADRL</td>
<td>PMADRL7</td>
<td>PMADRL6</td>
<td>PMADRL5</td>
<td>PMADRL4</td>
<td>PMADRL3</td>
<td>PMADRL2</td>
<td>PMADRL1</td>
<td>PMADRL0</td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>193h</td>
<td>PMADRH</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—000 0000 —000 0000</td>
<td></td>
</tr>
<tr>
<td>194h</td>
<td>PMDATL</td>
<td>PMDATL7</td>
<td>PMDATL6</td>
<td>PMDATL5</td>
<td>PMDATL4</td>
<td>PMDATL3</td>
<td>PMDATL2</td>
<td>PMDATL1</td>
<td>PMDATL0</td>
<td>0000 0000 0000 0000</td>
<td></td>
</tr>
<tr>
<td>195h</td>
<td>PMDATL</td>
<td>PMDATHL</td>
<td>PMDATH4</td>
<td>PMDATH3</td>
<td>PMDATH2</td>
<td>PMDATH1</td>
<td>PMDATH0</td>
<td>—000 0000 —000 0000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>196h</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>197h</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>198h</td>
<td>OSCCAL</td>
<td>—</td>
<td>FCALT6</td>
<td>FCALT5</td>
<td>FCALT4</td>
<td>FCALT3</td>
<td>FCALT2</td>
<td>FCALT1</td>
<td>FCAL T0</td>
<td>xxxxx xxxxx uuuu uuuu</td>
<td></td>
</tr>
<tr>
<td>199h</td>
<td>DOVCAL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>DOVT3</td>
<td>DOVT2</td>
<td>DOVT1</td>
<td>DOVT0</td>
<td>xxxxx xxxxx uuuu uuuu</td>
<td></td>
</tr>
<tr>
<td>19Ah</td>
<td>TTACAL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>xxxxx xxxxx uuuu uuuu</td>
<td></td>
</tr>
<tr>
<td>19Bh</td>
<td>BGRCAL</td>
<td>Reserve</td>
<td>Reserved</td>
<td>Reserved</td>
<td>Reserved</td>
<td>BGRT3</td>
<td>BGRT2</td>
<td>BGRT1</td>
<td>BGRT0</td>
<td>xxxxx xxxxx uuuu uuuu</td>
<td></td>
</tr>
<tr>
<td>19Ch</td>
<td>VROCAL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>VROT3</td>
<td>VROT2</td>
<td>VROT1</td>
<td>VROT0</td>
<td>xxxxx xxxxx uuuu uuuu</td>
<td></td>
</tr>
<tr>
<td>19Dh</td>
<td>ZROCAL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ZROT3</td>
<td>ZROT2</td>
<td>ZROT1</td>
<td>ZROT0</td>
<td>xxxxx xxxxx uuuu uuuu</td>
<td></td>
</tr>
<tr>
<td>19Eh</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19Fh</td>
<td>ATSTCON</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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.
2. IRP & RP1 bits are reserved, always maintain these bits clear.
3. RA3 pull-up is enabled when pin is configured as MCLR in Configuration Word.
4. MCLR and WDT Reset does not affect the previous value data latch. The IOCF bit will be cleared upon reset but will set again if the mismatch exists.
5. Only accessible when DBGEN = 0 and ICKBUG<INBUG> = 1.
11.3.0.1 OPTION Register

The OPTION 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

**REGISTER 11-2: OPTION_REG: OPTION REGISTER (Note 1)**

<table>
<thead>
<tr>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAPU</td>
<td>INTEDG</td>
<td>T0CS</td>
<td>T0SE</td>
<td>PSA</td>
<td>PS2</td>
<td>PS1</td>
<td>PS0</td>
</tr>
</tbody>
</table>

**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**  
  RAPU: Port GPx Pull-up Enable bit
  - 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**  
  T0CE: 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

<table>
<thead>
<tr>
<th>Bit Value</th>
<th>TMR0 Rate</th>
<th>WDT Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>1: 2</td>
<td>1: 1</td>
</tr>
<tr>
<td>001</td>
<td>1: 4</td>
<td>1: 2</td>
</tr>
<tr>
<td>010</td>
<td>1: 8</td>
<td>1: 4</td>
</tr>
<tr>
<td>011</td>
<td>1: 16</td>
<td>1: 8</td>
</tr>
<tr>
<td>100</td>
<td>1: 32</td>
<td>1: 16</td>
</tr>
<tr>
<td>101</td>
<td>1: 64</td>
<td>1: 32</td>
</tr>
<tr>
<td>110</td>
<td>1: 128</td>
<td>1: 64</td>
</tr>
<tr>
<td>111</td>
<td>1: 256</td>
<td>1: 128</td>
</tr>
</tbody>
</table>

**Note 1:** Individual WPUx bit must also be enabled.
11.4 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 11-2 shows the two situations for loading the PC. The upper example in Figure 11-2 shows how the PC is loaded on a write to PCL (PCLATH<4:0> → PCH). The lower example in Figure 11-2 shows how the PC is loaded during a CALL or GOTO instruction (PCLATH<4:3> → PCH).

![FIGURE 11-2: LOADING OF PC IN DIFFERENT SITUATIONS](image.png)

11.4.1 MODIFYING PCL

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 content 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.

11.4.2 COMPUTED GOTO

A computed GOTO is accomplished by adding an offset to the program counter (ADDF 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 rolls 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” (DS00556).

11.4.3 COMPUTED FUNCTION CALLS

A computed function CALL allows programs to maintain tables of functions and provides 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<6:3> is loaded with PCLATH<6:3>.

11.4.4 STACK

The MCP19110/11 has an 8-level x 1-bit wide hardware stack (refer to Figure 11-1). 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 a 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 ninth push overwrites the value that was stored from the first push. The tenth 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.

11.5 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 of the STATUS register, as shown in Figure 11-3.

A simple program to clear RAM location 40h-7Fh using indirect addressing is shown in Example 11-3.
EXAMPLE 11-3: INDIRECT ADDRESSING

MOVLW 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 11-3: DIRECT/INDIRECT ADDRESSING

For memory map detail, see Figure 11-2.
12.0 DEVICE CONFIGURATION

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

12.1 Configuration Word

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

**REGISTER 12-1: CONFIG – CONFIGURATION WORD REGISTER**

<table>
<thead>
<tr>
<th>R/P-1</th>
<th>U-1</th>
<th>R/P-1</th>
<th>R/P-1</th>
<th>U-1</th>
<th>U-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBGEN</td>
<td>—</td>
<td>WRT1</td>
<td>WRT0</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

**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**  
  **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 9-7**  
  **Unimplemented**: Read as ‘1’

- **bit 6**  
  **CP**: Code Protection
  
  1 = Program memory code protection is disabled
  0 = Program memory code protection is enabled

- **bit 5**  
  **MCLRE**: MCLR Pin Function Select
  
  1 = MCLR pin is MCLR function and weak internal pull-up is enabled
  0 = MCLR pin is alternate function, MCLR function is internally disabled

- **bit 4**  
  **PWRTE**: Power-up Timer Enable bit
  
  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:** The 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’.
12.2 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.

12.2.1 PROGRAM MEMORY PROTECTION

The entire program memory space is protected from external reads and writes by the CP bit in the Configuration Word. When CP = 0, external reads and writes of the 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. See Section 12.3 “Write Protection” for more information.

12.3 Write Protection

Write protection allows the device to be protected from unintended self-writes. Applications, such as bootloader 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.

12.4 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 seven bits of the ID locations are reported when using MPLAB Integrated Development Environment (IDE).

12.5 Device ID and Revision ID

The memory location 2006h is where the Device ID and Revision ID are stored. The upper nine bits hold the Device ID. The lower five bits hold the Revision ID.

Development tools, such as device programmers and debuggers, may be used to read the Device ID and Revision ID.

REGISTER 12-2: DEVICEID: DEVICE ID REGISTER

<table>
<thead>
<tr>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEV&lt;8:3&gt;</td>
<td>bit 13</td>
<td>bit 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DEV&lt;2:0&gt;</td>
<td>REV&lt;4:0&gt;</td>
<td>bit 7</td>
<td>bit 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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  **DEV<8:0>: Device ID bits**

<table>
<thead>
<tr>
<th>Device</th>
<th>DEVICEID&lt;13:0&gt; Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DEV&lt;8:0&gt;</td>
</tr>
<tr>
<td>MCP19110</td>
<td>00 0111 111</td>
</tr>
<tr>
<td>MCP19111</td>
<td>10 1111 100</td>
</tr>
</tbody>
</table>

bit 4-0  **REV<4:0>: Revision ID bits**

These bits are used to identify the revision.

**Note 1:** This location cannot be written.
13.0 OSCILLATOR MODES

The MCP19110/11 has one oscillator configuration which is an 8 MHz internal oscillator.

13.1 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.

13.2 Oscillator Calibration

The 8 MHz internal oscillator is factory calibrated. The factory calibration values reside in the read-only Calibration Word 1 register. These values must be read from the Calibration Word 1 register and stored in the OSCCAL register. Refer to Section 18.0 “Flash Program Memory Control” for the procedure on reading from program memory.

**Note 1:** The FCAL<6:0> bits from the Calibration Word 1 register must be written into the OSCCAL register to calibrate the internal oscillator.

**REGISTER 13-1: OSCTUNE – OSCILLATOR TUNING REGISTER**

<table>
<thead>
<tr>
<th>bit 7-5</th>
<th>bit 4-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unimplemented: Read as ‘0’</td>
<td><strong>TUN&lt;4:0&gt;: Frequency Tuning bits</strong></td>
</tr>
<tr>
<td>bit 7-5</td>
<td>Unimplemented: Read as ‘0’</td>
</tr>
<tr>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>bit 7-5</th>
<th>bit 4-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000 = Center frequency. Oscillator Module is running at the calibrated frequency.</td>
<td></td>
</tr>
<tr>
<td>10000 = Minimum frequency</td>
<td></td>
</tr>
</tbody>
</table>

13.3 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 (see Register 13-1).
13.3.1 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 µs is invoked to allow the memory bias to stabilize before program execution can begin.

### TABLE 13-1: SUMMARY OF REGISTERS ASSOCIATED WITH CLOCK SOURCES

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>OSCTUNE</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>TUN4</td>
<td>TUN3</td>
<td>TUN2</td>
<td>TUN1</td>
<td>TUN0</td>
</tr>
</tbody>
</table>

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

### TABLE 13-2: SUMMARY OF CALIBRATION WORD ASSOCIATED WITH CLOCK SOURCES

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Bit 7/8-7</th>
<th>Bit 7/6-6</th>
<th>Bit 13/5</th>
<th>Bit 12/4</th>
<th>Bit 11/3</th>
<th>Bit 10/2</th>
<th>Bit 9/1</th>
<th>Bit 8/0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>CALWD1</td>
<td>13:8</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>DOV3</td>
<td>DOV2</td>
<td>DOV1</td>
<td>DOV0</td>
<td>59</td>
</tr>
<tr>
<td></td>
<td>7:0</td>
<td>FCAL6</td>
<td>FCAL5</td>
<td>FCAL4</td>
<td>FCAL3</td>
<td>FCAL2</td>
<td>FCAL1</td>
<td>FCAL0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend: — = unimplemented locations read as ‘0’. Shaded cells are not used by clock sources.
14.0 RESETS

The reset logic is used to place the MCP19110/11 into a known state. The source of the reset can be determined by using the device status bits.

There are multiple ways to reset this device:
- Power-on Reset (POR)
- Overtemperature Reset (OT)
- MCLR Reset
- WDT Reset

To allow VDD 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

WDT 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. TO and PD bits are set or cleared differently in different Reset situations, as indicated in Table 14-1. Software can use these bits to determine the nature of the Reset. See Table 14-2 for a full description of Reset states of all registers.

A simplified block diagram of the On-Chip Reset Circuit is shown in Figure 14-1.

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

<table>
<thead>
<tr>
<th>Power-up</th>
<th>Wake-up from Sleep</th>
</tr>
</thead>
<tbody>
<tr>
<td>PWRTEN = 0</td>
<td>PWRTEN = 1</td>
</tr>
<tr>
<td>T_PWRT</td>
<td>—</td>
</tr>
</tbody>
</table>

Note 1: Refer to the Configuration Word register (Register 12-1).
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 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.

### 14.2 MCLR

MCP19110/11 has a noise filter in the MCLR Reset path. The filter will detect and ignore small pulses. It should be noted that a WDT Reset does not drive MCLR pin low.

Voltages applied to the MCLR pin that exceed its specification can result in both MCLR Resets and excessive current beyond the device specification during the ESD event. For this reason, Microchip recommends that the MCLR pin no longer be tied directly to $V_{DD}$. The use of an RC network, as shown in Figure 14-2, is suggested.

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

### TABLE 14-2: STATUS/PCON BITS AND THEIR SIGNIFICANCE

<table>
<thead>
<tr>
<th>POR</th>
<th>TO</th>
<th>PD</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>Power-on Reset</td>
</tr>
<tr>
<td>u</td>
<td>0</td>
<td>u</td>
<td>WDT Reset</td>
</tr>
<tr>
<td>u</td>
<td>0</td>
<td>0</td>
<td>WDT Wake-up</td>
</tr>
<tr>
<td>u</td>
<td>u</td>
<td>u</td>
<td>MCLR Reset during normal operation</td>
</tr>
<tr>
<td>u</td>
<td>1</td>
<td>0</td>
<td>MCLR Reset during Sleep</td>
</tr>
</tbody>
</table>

**Legend:** $u$ = unchanged, $x$ = unknown

**Note:** The POR circuit does not produce an internal Reset when $V_{DD}$ declines. To re-enable the POR, $V_{DD}$ must reach $V_{SS}$ for a minimum of 100 µs.
14.3 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 VDD to rise to an acceptable level. A Configuration bit (PWRTE), 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:
• VDD variation
• Temperature variation
• Process variation

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

14.4 Watchdog Timer (WDT) Reset

The Watchdog Timer generates a Reset if the firmware does not issue a CLRWD廷 instruction within the time-out period. The TO and PD bits in the STATUS register are changed to indicate the WDT Reset. See Section 17.0 “Watchdog Timer (WDT)” for more information.

14.5 Power-Up Timer

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

The Power-Up Timer is controlled by the PWRTE bit of Configuration Word.

14.6 Start-up Sequence

Upon the release of a POR, the following must occur before the device will begin executing:
• Power-up Timer runs to completion (if enabled)
• Oscillator start-up timer runs to completion
• MCLR must be released (if enabled)

The total time-out will vary based on PWRTE bit status. For example, with PWRTE bit erased (PWRT disabled), there will be no time-out at all. Figures 14-3, 14-4 and 14-5 depict time-out sequences.

Since the time-outs occur from the POR pulse, if MCLR is kept low long enough, the time-outs will expire. Then, bringing MCLR high will begin execution immediately (see Figure 14-4). This is useful for testing purposes or to synchronize more than one MCP19110/11 device operating in parallel.

14.6.1 POWER CONTROL (PCON) REGISTER

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

FIGURE 14-3: TIME-OUT SEQUENCE ON POWER-UP (DELAYED MCLR): CASE 1
FIGURE 14-4: TIME-OUT SEQUENCE ON POWER-UP (DELAYED MCLR): CASE 2

FIGURE 14-5: TIME-OUT SEQUENCE ON POWER-UP (MCLR WITH V_DD)
## TABLE 14-3: INITIALIZATION CONDITION FOR REGISTERS

<table>
<thead>
<tr>
<th>Register</th>
<th>Address</th>
<th>Power-on Reset</th>
<th>MCLR Reset WDT Reset</th>
<th>Wake-up from Sleep through Interrupt Wake-up from Sleep through WDT Time-out</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>—</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>INDF</td>
<td>00h/80h/100h/180h</td>
<td>xxxx xxxx</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>TMR0</td>
<td>01h/101h</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>PCL</td>
<td>02h/82h/102h/182h</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>PC + 1 (3)</td>
</tr>
<tr>
<td>STATUS</td>
<td>03h/83h/103h/183h</td>
<td>0001 1xxx</td>
<td>000q quuu (4)</td>
<td>uuuq quuu (4)</td>
</tr>
<tr>
<td>FSR</td>
<td>04h/84h/104h/184h</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>PORTGPA</td>
<td>05h</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>PORTGPB</td>
<td>06h</td>
<td>xxx- xxxx</td>
<td>uuu- uuuu</td>
<td>uuu- uuuu</td>
</tr>
<tr>
<td>PIR1</td>
<td>07h</td>
<td>-000 --00</td>
<td>-000 --00</td>
<td>-uuu --uu</td>
</tr>
<tr>
<td>PIR2</td>
<td>08h</td>
<td>0--0 --00</td>
<td>0--0 --00</td>
<td>uu- uu --uu</td>
</tr>
<tr>
<td>PCON</td>
<td>09h</td>
<td>---- -qq-</td>
<td>---- -uu-</td>
<td>---- -uu-</td>
</tr>
<tr>
<td>PCLATH</td>
<td>0Ah/8Ah/10Ah/18Ah</td>
<td>----0 0000</td>
<td>----0 0000</td>
<td>---- 0000</td>
</tr>
<tr>
<td>INTCON</td>
<td>0Bh/8Bh/10Bh/18Bh</td>
<td>0000 0000x</td>
<td>0000 0000u</td>
<td>uuuu uuuu (2)</td>
</tr>
<tr>
<td>TMR1L</td>
<td>0Ch</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>TMR1H</td>
<td>0Dh</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>T1CON</td>
<td>0Eh</td>
<td>--00 --00</td>
<td>--uu --uu</td>
<td>--uu --uu</td>
</tr>
<tr>
<td>TMR2</td>
<td>0Fh</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>T2CON</td>
<td>10h</td>
<td>---- --00</td>
<td>---- --00</td>
<td>---- --uu</td>
</tr>
<tr>
<td>PR2</td>
<td>11h</td>
<td>1111 1111</td>
<td>1111 1111</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>PWMPHL</td>
<td>12h</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>PWMPPH</td>
<td>13h</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>PWMRL</td>
<td>14h</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>PWMRH</td>
<td>15h</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>OVCCON</td>
<td>16h</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>OVFCON</td>
<td>17h</td>
<td>0-0-0 0000</td>
<td>0-0-0 0000</td>
<td>uu- uu uu</td>
</tr>
<tr>
<td>OSC TUNE</td>
<td>18h</td>
<td>----0 0000</td>
<td>----0 0000</td>
<td>---- uu uu</td>
</tr>
<tr>
<td>ADRESL (1)</td>
<td>1Ch</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>ADRESH (1)</td>
<td>1Dh</td>
<td>---- --xx</td>
<td>---- --uu</td>
<td>---- --uu</td>
</tr>
<tr>
<td>ADCON0 (1)</td>
<td>1Eh</td>
<td>--00 0000</td>
<td>--00 0000</td>
<td>-- uu uu uu</td>
</tr>
<tr>
<td>ADCON1 (1)</td>
<td>1Fh</td>
<td>--00 ----</td>
<td>--00 ----</td>
<td>-- uu uu uu</td>
</tr>
<tr>
<td>OPTION_REG</td>
<td>81h/81h</td>
<td>1111 1111</td>
<td>1111 1111</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>TRISGPA</td>
<td>85h</td>
<td>1111 1111</td>
<td>1111 1111</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>TRISGPB</td>
<td>86h</td>
<td>1111 1111</td>
<td>1111 1111</td>
<td>uuuu uuuu</td>
</tr>
</tbody>
</table>

**Legend:**
- u = unchanged,
- x = unknown,
- - = unimplemented bit, reads as ‘0’,
- q = value depends on condition.

**Note**
1. If VDD goes too low, Power-on Reset will be activated and registers will be affected differently.
2. One or more bits in INTCON and/or PIRx will be affected (to cause wake-up).
3. When the wake-up is due to an interrupt and the GIE bit is set, the PC is loaded with the interrupt vector (0004h).
4. See Table 14-5 for Reset value for specific condition.
### TABLE 14-3: INITIALIZATION CONDITION FOR REGISTERS (CONTINUED)

<table>
<thead>
<tr>
<th>Register</th>
<th>Address</th>
<th>Power-on Reset</th>
<th>MCLR Reset WDT Reset</th>
<th>Wake-up from Sleep through Interrupt Wake-up from Sleep through WDT Time-out</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIE1</td>
<td>87h</td>
<td>-000 --000</td>
<td>-000 --000</td>
<td>-u-uu --uu</td>
</tr>
<tr>
<td>PIE2</td>
<td>88h</td>
<td>0-00 --000</td>
<td>0-00 --000</td>
<td>u-uu --uu</td>
</tr>
<tr>
<td>APFCON</td>
<td>89h</td>
<td>---- ---- 0</td>
<td>---- ---- 0</td>
<td>---- ---- u</td>
</tr>
<tr>
<td>VINLVL</td>
<td>90h</td>
<td>0-xx xxxx</td>
<td>0-u-uu uu-uu</td>
<td>u-uu uu-uu</td>
</tr>
<tr>
<td>OCCON</td>
<td>91h</td>
<td>0xxxx xxxx</td>
<td>0uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>CSGSCON</td>
<td>93h</td>
<td>-xxx xxxx</td>
<td>-uuuu uuuu</td>
<td>-uuuu uuuu</td>
</tr>
<tr>
<td>CSDGCON</td>
<td>95h</td>
<td>0--- xxxx</td>
<td>0--- uu-uu</td>
<td>u--- uuuu</td>
</tr>
<tr>
<td>VZCCON</td>
<td>97h</td>
<td>xxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>CMPZCON</td>
<td>98h</td>
<td>xxxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>OUVCON</td>
<td>99h</td>
<td>xxxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>OOVCN</td>
<td>9Ah</td>
<td>xxxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>DEADCON</td>
<td>9Bh</td>
<td>xxxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>SLPCRCN</td>
<td>9Ch</td>
<td>xxxxx xxxx</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>SLVGNCN</td>
<td>9Dh</td>
<td>---- ---- 0</td>
<td>---- ---- u</td>
<td>---- ---- uu</td>
</tr>
<tr>
<td>RELEFF</td>
<td>9Eh</td>
<td>0000 0000</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>WPUGPA</td>
<td>105h</td>
<td>--1- 1111</td>
<td>--u- uu-uu</td>
<td>--u- uu-uu</td>
</tr>
<tr>
<td>WPUGPB</td>
<td>106h</td>
<td>1111 -11-</td>
<td>uuuu -uu-</td>
<td>uuuu -uu-</td>
</tr>
<tr>
<td>PE1</td>
<td>107h</td>
<td>0000 1100</td>
<td>0000 1100</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>BUFFCON</td>
<td>108h</td>
<td>000- 0000</td>
<td>000- 0000</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>ABECN</td>
<td>109h</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>SSPADD2</td>
<td>112h</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>SSPOC1</td>
<td>113h</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>SSPOC2</td>
<td>114h</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>SSPCON3</td>
<td>115h</td>
<td>1111 1111</td>
<td>1111 1111</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>SSPMST</td>
<td>116h</td>
<td>1111 1111</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>SSPMSK2</td>
<td>117h</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>SSPMSK3</td>
<td>118h</td>
<td>1111 1111</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>I0CA</td>
<td>185h</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>I0CB</td>
<td>186h</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>ANSELA</td>
<td>187h</td>
<td>---- 1111</td>
<td>---- 1111</td>
<td>---- uuuu</td>
</tr>
<tr>
<td>ANSELB</td>
<td>188h</td>
<td>--1- -11-</td>
<td>--11 -11-</td>
<td>---- uu-uu</td>
</tr>
<tr>
<td>PMCON1</td>
<td>190h</td>
<td>-0-- -000</td>
<td>0-00 -000</td>
<td>u--u uu-</td>
</tr>
<tr>
<td>PMCON2</td>
<td>191h</td>
<td>---- ----</td>
<td>---- ----</td>
<td>---- ---- uu</td>
</tr>
<tr>
<td>PMADRL</td>
<td>192h</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
<tr>
<td>PMADR</td>
<td>193h</td>
<td>---- ----</td>
<td>---- ----</td>
<td>---- ---- uu</td>
</tr>
<tr>
<td>PMDATL</td>
<td>194h</td>
<td>0000 0000</td>
<td>uuuu uuuu</td>
<td>uuuu uuuu</td>
</tr>
</tbody>
</table>

**Legend:**
- \( u = \) unchanged,
- \( x = \) unknown,
- \( - = \) unimplemented bit, reads as '0',
- \( q = \) value depends on condition.

**Note**

1. If \( V_{DD} \) goes too low, Power-on Reset will be activated and registers will be affected differently.
2. One or more bits in INTCON and/or PIRx will be affected (to cause wake-up).
3. When the wake-up is due to an interrupt and the GIE bit is set, the PC is loaded with the interrupt vector (0004h).
4. See Table 14-5 for Reset value for specific condition.
14.7 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. Table 14-4 and Table 14-5 show the Reset conditions of these registers.

### Table 14-3: Initialization Condition for Registers (continued)

<table>
<thead>
<tr>
<th>Register</th>
<th>Address</th>
<th>Power-on Reset</th>
<th>MCLR Reset WDT Reset</th>
<th>Wake-up from Sleep through Interrupt Wake-up from Sleep through WDT Time-out</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMDATH</td>
<td>195h</td>
<td>--00 0000</td>
<td>--00 0000</td>
<td>--uu uuuu</td>
</tr>
<tr>
<td>OSCAL</td>
<td>198h</td>
<td>-xxx xxxx</td>
<td>-uuu uuuu</td>
<td>-uuu uuuu</td>
</tr>
<tr>
<td>DOVCAL</td>
<td>199h</td>
<td>---- xxxx</td>
<td>---- uuuu</td>
<td>---- uuuu</td>
</tr>
<tr>
<td>TTACAL</td>
<td>19Ah</td>
<td>---- xxxx</td>
<td>---- uuuu</td>
<td>---- uuuu</td>
</tr>
<tr>
<td>BGRCAL</td>
<td>19Bh</td>
<td>---- xxxx</td>
<td>---- uuuu</td>
<td>---- uuuu</td>
</tr>
<tr>
<td>VROCAL</td>
<td>19Ch</td>
<td>---- xxxx</td>
<td>---- uuuu</td>
<td>---- uuuu</td>
</tr>
<tr>
<td>ZROCAL</td>
<td>19Dh</td>
<td>---- xxxx</td>
<td>---- uuuu</td>
<td>---- uuuu</td>
</tr>
<tr>
<td>ATSTCON</td>
<td>19F</td>
<td>1--- 0001</td>
<td>1--- 0001</td>
<td>uu--- uuuu</td>
</tr>
</tbody>
</table>

**Legend:**
- u = unchanged,
- x = unknown,
- - = unimplemented bit, reads as ‘0’,
- q = value depends on condition.

**Note:**
1. If VDD goes too low, Power-on Reset will be activated and registers will be affected differently.
2. One or more bits in INTCON and/or PIRx will be affected (to cause wake-up).
3. When the wake-up is due to an interrupt and the GIE bit is set, the PC is loaded with the interrupt vector (0004h).
4. See Table 14-5 for Reset value for specific condition.

### Table 14-4: Reset Status Bits and Their Significance

<table>
<thead>
<tr>
<th>POR</th>
<th>TO</th>
<th>PD</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
<td>Power-on Reset</td>
</tr>
<tr>
<td>u</td>
<td>0</td>
<td>u</td>
<td>WDT Reset</td>
</tr>
<tr>
<td>u</td>
<td>0</td>
<td>0</td>
<td>WDT Wake-up from Sleep</td>
</tr>
<tr>
<td>u</td>
<td>1</td>
<td>0</td>
<td>Interrupt Wake-up from Sleep</td>
</tr>
<tr>
<td>u</td>
<td>u</td>
<td>u</td>
<td>MCLR Reset during normal operation</td>
</tr>
<tr>
<td>u</td>
<td>1</td>
<td>0</td>
<td>MCLR Reset during Sleep</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>x</td>
<td>Not allowed. TO is set on POR</td>
</tr>
<tr>
<td>0</td>
<td>x</td>
<td>0</td>
<td>Not allowed. PD is set on POR</td>
</tr>
</tbody>
</table>

### Table 14-5: Reset Condition for Special Registers (Note 2)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Program Counter</th>
<th>STATUS Register</th>
<th>PCON Register</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power-on Reset</td>
<td>0000h</td>
<td>0001 lxxx</td>
<td>---- -u0-</td>
</tr>
<tr>
<td>MCLR Reset during normal operation</td>
<td>0000h</td>
<td>000u uuuu</td>
<td>---- -uu-</td>
</tr>
<tr>
<td>MCLR Reset during Sleep</td>
<td>0000h</td>
<td>0001 0000</td>
<td>---- -uu-</td>
</tr>
<tr>
<td>WDT Reset</td>
<td>0000h</td>
<td>0000 uuuu</td>
<td>---- -uu-</td>
</tr>
<tr>
<td>WDT Wake-up from Sleep</td>
<td>PC + 1</td>
<td>uuuu 0000</td>
<td>---- -uu-</td>
</tr>
<tr>
<td>Interrupt Wake-up from Sleep</td>
<td>PC + 1(1)</td>
<td>uuul 0000</td>
<td>---- -uu-</td>
</tr>
</tbody>
</table>

**Legend:**
- u = unchanged,
- x = unknown,
- - = unimplemented bit, reads as ‘0’.

**Note:**
1. When the wake-up is due to an interrupt and Global Enable bit (GIE) is set, the return address is pushed on the stack and PC is loaded with the interrupt vector (0004h) after execution of PC + 1.
2. If a Status bit is not implemented, that bit will be read as ‘0’.
14.8 Power Control (PCON) Register

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

- Power-on Reset (POR)
- Overtemperature (OT)

The PCON register bits are shown in Register 14-1.

**REGISTER 14-1: PCON – POWER CONTROL REGISTER**

<table>
<thead>
<tr>
<th>Bit 7-3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unimplemented</td>
<td>OT: Overtemperature Reset Status bit</td>
<td>POR: Power-on Reset Status bit</td>
<td>Unimplemented</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Legend:</th>
</tr>
</thead>
<tbody>
<tr>
<td>R = Readable bit</td>
</tr>
<tr>
<td>W = Writable bit</td>
</tr>
<tr>
<td>U = Unimplemented bit, read as '0'</td>
</tr>
<tr>
<td>-n = Value at POR</td>
</tr>
<tr>
<td>‘1’ = Bit is set</td>
</tr>
<tr>
<td>‘0’ = Bit is cleared</td>
</tr>
<tr>
<td>x = Bit is unknown</td>
</tr>
</tbody>
</table>

**TABLE 0-1: SUMMARY OF REGISTERS ASSOCIATED WITH RESETS**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCON</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>OT</td>
<td>POR</td>
<td>—</td>
</tr>
<tr>
<td>STATUS</td>
<td>IPR</td>
<td>RP1</td>
<td>RP0</td>
<td>TO</td>
<td>PD</td>
<td>Z</td>
<td>DC</td>
<td>C</td>
<td>71</td>
</tr>
</tbody>
</table>

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

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

The MCP19110/11 has 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 Overvoltage Error
- System Undervoltage Error
- System Overcurrent Error
- SSP
- BCL
- System Input Undervoltage Error

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

The Global Interrupt Enable bit, GIE of 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 PInX 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 GEI 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.

15.1 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 (see Figure 15-2). The latency is the same for one or two-cycle instructions.

15.2 GPA2/INT Interrupt

The external interrupt on the GPA2/INT pin is edge-triggered; either on the rising edge, if the INTEDG bit of the OPTION register is set, or the falling edge, if the INTEDG bit is cleared. When a valid edge appears on the GPA2/INT pin, the INTF bit of the INTCON register is set. This interrupt can be disabled by clearing the INTE control bit of 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. See Section 16.0 “Power-Down Mode (Sleep)” for details on Sleep, and Section 16.1 “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.

Note:

- Individual interrupt flag bits are set, regardless of the status of their corresponding mask bit or the GIE bit.
- 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 exists the ISR by popping the previous address from the stack, restoring the saved context from the shadow registers and setting the GIE bit.

For additional information on a specific Interrupt’s operation, refer to its Peripheral chapter.
FIGURE 15-1: INTERRUPT LOGIC

- UVIF, UVIE
- OVIF, OVIE
- OCIF, OCIE
- VINIF, VINIE
- ADIF, ADIE
- BCLIF, BCLIE
- SSPIF, SSPIE
- TMR1IF, TMR1IE
- TMR2IF, TMR2IE
- INTE, INTF
- T0IF, T0IE
- IOCF, IOCE
- PEIF, PEIE
- GIE

FIGURE 15-2: INT PIN INTERRUPT TIMING

- CLKIN
- CLKOUT
- INT pin
- INTE
- INTE (INTCON reg.)
- GIE (INTCON reg.)
- Instruction Flow

<table>
<thead>
<tr>
<th>Instruction Fetched</th>
<th>Instruction Executed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inst (PC)</td>
<td>Inst (PC)</td>
</tr>
<tr>
<td>Inst (PC + 1)</td>
<td>Inst (PC)</td>
</tr>
<tr>
<td>—</td>
<td>Dummy Cycle</td>
</tr>
<tr>
<td>—</td>
<td>Dummy Cycle</td>
</tr>
</tbody>
</table>

Note 1: INTF flag is sampled here (every Q1).

2: Asynchronous interrupt latency = 3-4 T CY. Synchronous latency = 3 T CY, where T CY = instruction cycle time. Latency is the same whether Inst (PC) is a single cycle or a 2-cycle instruction.

3: CLKOUT is available only in INTOSC and RC Oscillator modes.

4: For minimum width of INT pulse, refer to AC specifications in Section 5.0 “Digital Electrical Characteristics”.

5: INTF is enabled to be set any time during the Q4-Q1 cycles.
15.3 Interrupt Control Registers

15.3.1 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, of the INTCON register. User software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

REGISTER 15-1: INTCON – INTERRUPT CONTROL REGISTER

<table>
<thead>
<tr>
<th>Bit</th>
<th>Description</th>
<th>Value at POR</th>
<th>R/W</th>
<th>1 = enabled</th>
<th>0 = disabled</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>GIE: Global Interrupt Enable bit</td>
<td>1 = Enables all unmasked interrupts</td>
<td>R/W</td>
<td>1 = enabled</td>
<td>0 = disabled</td>
</tr>
<tr>
<td>6</td>
<td>PEIE: Peripheral Interrupt Enable bit</td>
<td>1 = Enables all unmasked peripheral interrupts</td>
<td>R/W</td>
<td>1 = enabled</td>
<td>0 = disabled</td>
</tr>
<tr>
<td>5</td>
<td>T0IE: TMR0 Overflow Interrupt Enable bit</td>
<td>1 = Enables the TMR0 interrupt</td>
<td>R/W</td>
<td>1 = enabled</td>
<td>0 = disabled</td>
</tr>
<tr>
<td>4</td>
<td>INTE: INT External Interrupt Enable bit</td>
<td>1 = Enables the INT external interrupt</td>
<td>R/W</td>
<td>1 = enabled</td>
<td>0 = disabled</td>
</tr>
<tr>
<td>3</td>
<td>IOCE: Interrupt-on-Change Enable bit¹</td>
<td>1 = Enables the interrupt-on-change</td>
<td>R/W</td>
<td>1 = enabled</td>
<td>0 = disabled</td>
</tr>
<tr>
<td>2</td>
<td>T0IF: TMR0 Overflow Interrupt Flag bit²</td>
<td>1 = TMR0 register has overflowed (must be cleared in software)</td>
<td>R/W</td>
<td>1 = enabled</td>
<td>0 = disabled</td>
</tr>
<tr>
<td>1</td>
<td>INTF: External Interrupt Flag bit</td>
<td>1 = The external interrupt occurred (must be cleared in software)</td>
<td>R/W</td>
<td>1 = enabled</td>
<td>0 = disabled</td>
</tr>
<tr>
<td>0</td>
<td>IOCF: Interrupt-on-Change Interrupt Flag bit</td>
<td>1 = When at least one of the interrupt-on-change pins changed state</td>
<td>R/W-x</td>
<td>1 = enabled</td>
<td>0 = disabled</td>
</tr>
</tbody>
</table>

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

Note 1: IOC register 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.
15.3.1.1 PIE1 Register

The PIE1 register contains the Peripheral Interrupt Enable bits, as shown in Register 15-2.

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

### REGISTER 15-2: PIE1 – PERIPHERAL INTERRUPT ENABLE REGISTER 1

<table>
<thead>
<tr>
<th>U-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>ADIE</td>
<td>BCLIE</td>
<td>SSPIE</td>
<td>—</td>
<td>—</td>
<td>TMR2IE</td>
<td>TMR1IE</td>
</tr>
<tr>
<td>bit 7</td>
<td>bit 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**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 Descriptions:**
- **bit 7** UNIMPLEMENTED: Read as '0'
- **bit 6-0** ADIE: ADC Interrupt Enable bit
  - 1 = Enables the ADC interrupt
  - 0 = Disables the ADC interrupt
- **bit 6-0** BCLIE: MSSP Bus Collision Interrupt Enable bit
  - 1 = Enables the MSSP Bus Collision Interrupt
  - 0 = Disables the MSSP Bus Collision Interrupt
- **bit 6-0** SSPIE: Synchronous Serial Port (MSSP) Interrupt Enable bit
  - 1 = Enables the MSSP interrupt
  - 0 = Disables the MSSP interrupt
- **bit 6-0** UNIMPLEMENTED: Read as 0
- **bit 6-0** TMR2IE: Timer2 Interrupt Enable bit
  - 1 = Enables the Timer2 interrupt
  - 0 = Disables the Timer2 interrupt
- **bit 6-0** TMR1IE: Timer1 Interrupt Enable bit
  - 1 = Enables the Timer1 interrupt
  - 0 = Disables the Timer1 interrupt
15.3.1.2 PIE2 Register

The PIE2 register contains the Peripheral Interrupt Enable bits, as shown in Register 15-3.

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

REGISTER 15-3: PIE2 – PERIPHERAL INTERRUPT ENABLE REGISTER 2

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/W-0</th>
<th>U-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVIE</td>
<td>—</td>
<td>OCIE</td>
<td>OVIE</td>
<td>—</td>
<td>—</td>
<td>VINIE</td>
<td>—</td>
</tr>
</tbody>
</table>

bit 7 UVIE: Output Undervoltage Interrupt enable bit
0 = Enables the UV interrupt
1 = Disables the UV interrupt

bit 6 UNIMPLEMENTED: Read as '0'

bit 5 OCIE: Output Overcurrent Interrupt enable bit
0 = Enables the OC interrupt
1 = Disables the OC interrupt

bit 4 OVIE: Output Overvoltage Interrupt enable bit
0 = Enables the OV interrupt
1 = Disables the OV interrupt

bit 3-2 UNIMPLEMENTED: Read as '0'

bit 1 VINIE: VIN UVLO Interrupt Enable
0 = Enables the VIN UVLO interrupt
1 = Disables the VIN UVLO interrupt

bit 0 UNIMPLEMENTED: Read as '0'
15.3.1.3 PIR1 Register

The PIR1 register contains the Peripheral Interrupt Flag bits, as shown in Register 15-4.

**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 of the INTCON register. User software should ensure the appropriate interrupt flag bits are clear prior to enabling an interrupt.

### REGISTER 15-4: PIR1 – PERIPHERAL INTERRUPT FLAG REGISTER 1

<table>
<thead>
<tr>
<th>Bit</th>
<th>Legend</th>
<th>0x0</th>
<th>0x0</th>
<th>0x0</th>
<th>0x0</th>
<th>0x0</th>
<th>0x0</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>UNIMPLEMENTED: Read as '0'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>ADIF: ADC Interrupt Flag bit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 = ADC conversion complete</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 = ADC conversion has not completed or has not been started</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>BCLIF: MSSP Bus Collision Interrupt Flag bit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 = Interrupt is pending</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 = Interrupt is not pending</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SSPIF: Synchronous Serial Port (MSSP) Interrupt Flag bit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 = Interrupt is pending</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 = Interrupt is not pending</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-2</td>
<td>UNIMPLEMENTED: Read as '0'</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>TMR2IF: Timer2 to PR2 Match Interrupt Flag</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 = Timer2 to PR2 match occurred (must be cleared in software)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 = Timer2 to PR2 match did not occur</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>TMR1IF: Timer1 Interrupt Flag</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 = Timer1 rolled over (must be cleared in software)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 = Timer1 has not rolled over</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
15.3.1.4 PIR2 Register

The PIR2 register contains the Peripheral Interrupt Flag bits, as shown in Register 15-5.

**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 of the INTCON register. User software should ensure the appropriate interrupt flag bits are cleared prior to enabling an interrupt.

**REGISTER 15-5: PIR2 – PERIPHERAL INTERRUPT FLAG REGISTER 2**

```
+-----------------+-----------------+-----------------+-----------------+-----------------+-----------------+-----------------+-----------------+-----------------+-----------------+-----------------+
<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVIF</td>
<td>—</td>
<td>OCIF</td>
<td>OVIF</td>
<td>—</td>
<td>—</td>
<td>VINIF</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>
```

**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 UVIF:** Output undervoltage error interrupt flag bit
- 1 = Output undervoltage error has occurred
- 0 = Output undervoltage error has not occurred

**bit 6 UNIMPLEMENTED: Read as '0'**

**bit 5 OCIF:** Output overcurrent error interrupt flag bit
- 1 = Output overcurrent error has occurred
- 0 = Output overcurrent error has not occurred

**bit 4 OVIF:** Output overvoltage error interrupt flag bit
- 1 = Output overvoltage error has occurred
- 0 = Output overvoltage error has not occurred

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

**bit 1 VINIF:** VIN Status bit
- 1 = VIN is below acceptable level
- 0 = VIN is at acceptable level

**bit 0 UNIMPLEMENTED: Read as '0'**

**TABLE 15-1: SUMMARY OF REGISTERS ASSOCIATED WITH INTERRUPTS**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCE</td>
<td>T0IF</td>
<td>INTF</td>
<td>IOCF</td>
<td>95</td>
</tr>
<tr>
<td>OPTION_REG</td>
<td>RAPU</td>
<td>INTEDG</td>
<td>T0CE</td>
<td>T0SE</td>
<td>PSA</td>
<td>PS2</td>
<td>PS1</td>
<td>PS0</td>
<td>77</td>
</tr>
<tr>
<td>PIE1</td>
<td>—</td>
<td>ADIE</td>
<td>BCLIE</td>
<td>SSPIE</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>TMR2IE</td>
<td>96</td>
</tr>
<tr>
<td>PIE2</td>
<td>UVIE</td>
<td>—</td>
<td>OCIE</td>
<td>OVIE</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>VINIE</td>
<td>97</td>
</tr>
<tr>
<td>PIR1</td>
<td>—</td>
<td>ADIF</td>
<td>BCLIF</td>
<td>SSPIF</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>TMR2IF</td>
<td>98</td>
</tr>
<tr>
<td>PIR2</td>
<td>UVIF</td>
<td>—</td>
<td>OCIF</td>
<td>OVIF</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>VINIF</td>
<td>99</td>
</tr>
</tbody>
</table>

**Legend:**
- = unimplemented locations read as ‘0’. Shaded cells are not used by Interrupts.
15.4 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 (see Figure 11-2). 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 15-1 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 MCP19110/11 device does 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 15-1: SAVING STATUS AND W REGISTERS IN RAM**

```assembly
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
```
16.0 POWER-DOWN MODE (SLEEP)

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

Upon entering Sleep mode, the following conditions exist:
1. WDT will be cleared but keeps running, if enabled for operation during Sleep.
2. PD bit of the STATUS register is cleared.
3. TO bit of the STATUS register is set.
4. CPU clock is not disabled.
5. Timer1 oscillator is unaffected, and peripherals that operate from it may continue operation in Sleep.
6. ADC is unaffected.
7. I/O ports maintain the status they had before SLEEP was executed (driving high, low or high-impedance).
8. Resets other than WDT are not affected by Sleep mode.
9. Analog circuitry is unaffected by execution of SLEEP instruction.

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

To minimize current consumption, the following conditions should be considered:
- I/O pins should not be floating
- External circuitry sinking current from I/O pins
- Internal circuitry sourcing current from I/O pins
- Current draw from pins with internal weak pull-ups
- Modules using Timer1 oscillator

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

The SLEEP instruction does not affect the analog circuitry. The enable state of the analog circuitry does not change with the execution of the SLEEP instruction.

Examples of internal circuitry that might be sourcing current include modules, such as the DAC. See Section 22.0 “Analog-to-Digital Converter (ADC) Module” for more information on this module.

16.1 Wake-up from Sleep

The device can wake-up from Sleep through one of the following events:
1. External Reset input on 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 14.7 “Determining the Cause of a Reset”.

The following peripheral interrupts can wake the device from Sleep:
1. Timer1 interrupt. Timer1 must be operating as an asynchronous counter
2. A/D conversion
3. Interrupt-on-change
4. 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, the device will then call the Interrupt Service Routine. In cases where the execution of the instruction following SLEEP is not desirable, the user should have an NOP after the SLEEP instruction.

The WDT is cleared when the device wakes up from Sleep, regardless of the source of wake-up.
16.1.1 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 an NOP
  - WDT and WDT prescaler will not be cleared
  - TO bit of the STATUS register will not be set
  - PD bit of the STATUS register will not be cleared

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

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

---

**FIGURE 16-1: WAKE-UP FROM SLEEP THROUGH INTERRUPT**

![Diagram showing the wake-up process from Sleep through an interrupt]

**Note 1:** GIE = 1 assumed. In this case, after wake-up, the processor calls the ISR at 0004h. If GIE = 0, execution will continue in-line.

---

**TABLE 16-1: SUMMARY OF REGISTERS ASSOCIATED WITH POWER-DOWN MODE**

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCE</td>
<td>T0IF</td>
<td>INTF</td>
<td>IOCF</td>
<td>95</td>
</tr>
<tr>
<td>IOCA</td>
<td>IOCA7</td>
<td>IOCA6</td>
<td>IOCA5</td>
<td>IOCA4</td>
<td>IOCA3</td>
<td>IOCA2</td>
<td>IOCA1</td>
<td>IOCA0</td>
<td>122</td>
</tr>
<tr>
<td>IOCB</td>
<td>IOCB7</td>
<td>IOCB6</td>
<td>IOCB5</td>
<td>IOCB4</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>122</td>
</tr>
<tr>
<td>PIE1</td>
<td>—</td>
<td>ADIE</td>
<td>BCLIE</td>
<td>SSPIE</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>TMR2IE</td>
<td>96</td>
</tr>
<tr>
<td>PIE2</td>
<td>UVIE</td>
<td>—</td>
<td>OClIE</td>
<td>Ovie</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>VINE</td>
<td>97</td>
</tr>
<tr>
<td>PIR1</td>
<td>—</td>
<td>ADIF</td>
<td>BCLIF</td>
<td>SSPIF</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>TMR2IF</td>
<td>98</td>
</tr>
<tr>
<td>PIR2</td>
<td>UVIF</td>
<td>—</td>
<td>OCIF</td>
<td>OvIF</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>VINIF</td>
<td>99</td>
</tr>
<tr>
<td>STATUS</td>
<td>IRP</td>
<td>RP1</td>
<td>RP0</td>
<td>TO</td>
<td>PD</td>
<td>Z</td>
<td>DC</td>
<td>C</td>
<td>71</td>
</tr>
</tbody>
</table>

**Legend:** — = unimplemented, read as ‘0’. Shaded cells are not used in Power-down mode.
17.0 WATCHDOG TIMER (WDT)

The Watchdog Timer is a free-running timer. The WDT is enabled by setting the WDTE bit of the Configuration Word (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 of the Configuration word. See Section 12.1 “Configuration Word” for more information.

17.1 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.

17.2 WDT Period

The WDT has a nominal time-out period of 18 ms (with no prescaler). The time-out periods vary with temperature, VDD and process variations from part to part (see Table 5-4). 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 register. Thus, time-out periods up to 2.3 seconds can be realized.

The CLRWD 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 TO bit in the STATUS register will be cleared upon a Watchdog Timer time-out.

17.3 WDT Programming Considerations

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

FIGURE 17-1: WATCHDOG TIMER WITH SHARED PRESCALER BLOCK DIAGRAM

Note 1: T0SE, T0CS, PSA, PS<2:0> are bits in the OPTION_REG register.

2: WDTE bit is in the Configuration Word register.
### TABLE 17-1: WDT STATUS

<table>
<thead>
<tr>
<th>Conditions</th>
<th>WDT</th>
</tr>
</thead>
<tbody>
<tr>
<td>WDTE = 0</td>
<td></td>
</tr>
<tr>
<td>CLRWDT Command</td>
<td></td>
</tr>
<tr>
<td>Exit Sleep</td>
<td>Cleared</td>
</tr>
</tbody>
</table>

### TABLE 17-2: SUMMARY OF REGISTERS ASSOCIATED WITH WATCHDOG TIMER

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>OPTION_REG</td>
<td>RAPU</td>
<td>INTEDG</td>
<td>T0CS</td>
<td>T0SE</td>
<td>PSA</td>
<td>PS&lt;2:0&gt;</td>
<td></td>
<td></td>
<td>77</td>
</tr>
</tbody>
</table>

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

### TABLE 17-3: SUMMARY OF CONFIGURATION WORD ASSOCIATED WITH WATCHDOG TIMER

<table>
<thead>
<tr>
<th>Name</th>
<th>Bits</th>
<th>Bit -/7</th>
<th>Bit -/6</th>
<th>Bit 13/5</th>
<th>Bit 12/4</th>
<th>Bit 11/3</th>
<th>Bit 10/2</th>
<th>Bit 9/1</th>
<th>Bit 8/0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONFIG</td>
<td>13:8</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>DBGEN</td>
<td>—</td>
<td>WRT1</td>
<td>WRT0</td>
<td>—</td>
<td>81</td>
</tr>
<tr>
<td></td>
<td>7:0</td>
<td>—</td>
<td>CP</td>
<td>MCLRE</td>
<td>PWRT</td>
<td>—</td>
<td>WDTE</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

**Legend:** — = unimplemented location, read as '1'. Shaded cells are not used by Watchdog Timer.
18.0 FLASH PROGRAM MEMORY CONTROL

The Flash program memory is readable and writable during normal operation (full V\textsubscript{IN} range). This memory is not directly mapped in the register file space. Instead, it is indirectly addressed through the Special Function Registers (SFR) (see Registers 18-1 to 18-5). There are six SFRs used to read and write this memory:

- PMCON1
- PMCON2
- PMDATL
- PMDATH
- PMADRL
- PMADR

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 PMADR registers form a two-byte word, which holds the 13-bit address of the FLASH location being accessed. These devices have 4K words of program Flash with an address range from 0000h to 0FFFh.

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.

18.1 PMADR and PMADRL Registers

The PMADR and PMADRL registers can address up to a maximum of 4K words of program memory.

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

18.2 PMCON1 and PMCON2 Registers

PMCON1 is the control register for the data program memory accesses.

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

The WREN bit, when set, will allow a write operation. 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, and 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.
## 18.3 Flash Program Memory Control Registers

### REGISTER 18-1: PMDATL: PROGRAM MEMORY DATA LOW BYTE REGISTER

<table>
<thead>
<tr>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>PMDATL&lt;7:0&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bit 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bit 0</td>
</tr>
</tbody>
</table>

**Legend:**
- **R** = Readable bit
- **W** = Writable bit
- **U** = Unimplemented bit, read as ‘0’
- ‘-’ = 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 Read from Program Memory

### REGISTER 18-2: PMADRL: PROGRAM MEMORY ADDRESS LOW BYTE REGISTER

<table>
<thead>
<tr>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>PMADRL&lt;7:0&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bit 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bit 0</td>
</tr>
</tbody>
</table>

**Legend:**
- **R** = Readable bit
- **W** = Writable bit
- **U** = Unimplemented bit, read as ‘0’
- ‘-’ = 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 18-3: PMDATH: PROGRAM MEMORY DATA HIGH BYTE REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>PMDATH&lt;5:0&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bit 7</td>
</tr>
</tbody>
</table>

**Legend:**
- **R** = Readable bit
- **W** = Writable bit
- **U** = Unimplemented bit, read as ‘0’
- ‘-’ = 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 Read from Program Memory
REGISTER 18-4:  PMADRH: PROGRAM MEMORY ADDRESS HIGH BYTE REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

bit 7-4  Unimplemented: Read as '0'
bit 3-0  PMADRH<3:0>: Specifies the 4 Most Significant Address bits or High bits for Program Memory Reads.

REGISTER 18-5:  PMCON1: PROGRAM MEMORY CONTROL REGISTER 1

<table>
<thead>
<tr>
<th>U-1</th>
<th>R/W-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/W-0</th>
<th>R/S-0</th>
<th>R/S-0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

bit 7  Unimplemented: Read as '1'
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 Flash Program Memory
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
18.3.1 READING THE FLASH PROGRAM MEMORY

To read a program memory location, the user must write two bytes of the address to the PMADRL and PMADRHL registers, and then set control bit RD (PMCON1<0>). Once the read control bit is set, the program memory Flash controller will use the second instruction cycle after 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 18-1: FLASH PROGRAM READ

```
BANKSELPM_ADR; Change STATUS bits RP1:0 to select bank with PMADR
MOVLWMS_PROG_PM_ADDR;
MOVWFPMADRH; MS Byte of Program Address to read
MOVLWLS_PROG_PM_ADDR;
MOVWFPMADRL; 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 18-1: FLASH PROGRAM MEMORY READ CYCLE EXECUTION – NORMAL MODE

(a) Flash Address

(b) Flash Data

(c) Registers

(d) Flow
18.3.2 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 12.1 “Configuration Word” (bits WRT1:WRT0).

**Note:** The write protect bits are used to protect the users’ 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. See Figures 18-2 and 18-3 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, it must first be loaded into the buffer registers (see Figure 18-2). 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, then the following sequence of events must be executed:

1. Write 55h, then AAh, to PMCON2 (Flash programming sequence).
2. Set the WR control bit of the PMCON1 register.

All four buffer register locations should be written to with correct data. If less than four words are being written to the block of four words, then a read from the program memory location(s) not being written to must be performed. This takes the data from the program memory 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 of 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 sixteen 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 sixteen-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> = xxxxxxx011.

Refer to Figure 18-2 for a block diagram of the buffer registers and the control signals for test mode.

18.3.3 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.

18.3.4 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.

18.3.5 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 can not be modified by the CPU using the PMCON registers. The write protection has no effect in ICSP mode.
FIGURE 18-2: BLOCK WRITES TO 4K FLASH PROGRAM MEMORY

If at new row sixteen words of Flash are erased, then four buffers are transferred to Flash automatically after this word is written.

PMADRL<1:0> = 00
First word of block to be written

PMADRL<1:0> = 01

PMADRL<1:0> = 10

PMADRL<1:0> = 11

Buffer Register

Buffer Register

Buffer Register

Buffer Register

Program Memory

FIGURE 18-3: FLASH PROGRAM MEMORY LONG WRITE CYCLE EXECUTION

Flash ADDR

PC + 1

PMADR, PMADR

PC + 2

PC + 3

PC + 4

Flash DATA

INSTR (PC)

INSTR (PC + 1)

INSTR (PC)

PMADRL

PMADRH

PMADTH

PMADTL

INSTR (PC + 2)

INSTR (PC + 3)

BSF PMCON1, WR

Executed here

INSTR (PC + 1)

Executed here

Processor halted EE Write Time

NOP

Executed here

Flash Memory Location

WR bit

PMWHLT
19.0 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 two registers for its operation. These registers are:

- TRISGPx registers (data direction register)
- PORTGPx registers (reads 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)
- WPUSx (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 19-1.

FIGURE 19-1: GENERIC I/O PORTGPX OPERATION

EXAMPLE 19-1: INITIALIZING PORTA

; 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;
MOVWF TRISGPA;set GPA<4:0> as inputs
MOVWF TRISGPA;set GPA<7:6> as outputs
19.1 Alternate Pin Function

The Alternate Pin Function Control (APFCON) register is used to steer specific peripheral input and output functions between different pins. The APFCON register is shown in Register 19-1. For the MCP19111 device, the following function can be moved between different pins:

- Frequency Synchronization Clock Input/Output

This bit has no effect on the values of any TRIS register. PORT and TRIS overrides will be routed to the correct pin. The unselected pin will be unaffected.

REGISTER 19-1: APFCON: ALTERNATE PIN FUNCTION CONTROL REGISTER

<table>
<thead>
<tr>
<th>bit 7</th>
<th>bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLKSEL: Pin Selection bit</td>
<td></td>
</tr>
<tr>
<td>1 = Multi-phase or multiple output clock function is on GPB5</td>
<td></td>
</tr>
<tr>
<td>0 = Multi-phase or multiple output clock function is on GPA1</td>
<td></td>
</tr>
</tbody>
</table>

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

bit 7-1 Unimplemented: Read as ’0’

19.2 PORTGPA and TRISGPA Registers

PORTGPA is an 8-bit wide, bidirectional port consisting of five CMOS I/O, two open-drain I/O, and one open-drain input-only pin. The corresponding data direction register is TRISGPA (Register 19-3). Setting a TRISGPA bit (= 1) will make the corresponding PORTGPA pin an input (i.e., disable the output driver). Clearing a TRISGPA bit (= 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 19-1 shows how to initialize an I/O port.

Reading the PORTGPA register (Register 19-2) 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 (Register 19-3) 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.

19.2.1 INTERRUPT-ON-CHANGE

Each PORTGPA pin is individually configurable as an interrupt-on-change pin. Control bits IOCA<7:0> enable or disable the interrupt function for each pin. The interrupt-on-change feature is disabled on a Power-on Reset. Reference Section 20.0 “Interrupt-On-Change” for more information.

19.2.2 WEAK PULL-UPS

PORTGPA<3:0> and PORTGPA5 have an internal weak pull-up. PORTGPA<7:6> are special ports for the SSP module and do not have weak pull-ups. Individual control bits can enable or disable the internal weak pull-ups (see Register 19-4). 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 RAPU bit of the OPTION register. The weak pull-up on GPA5 is enabled when configured as MCLR pin by setting bit 5 of the Configuration word, and disabled when GPA5 is an I/O. There is no software control of the MCLR pull-up.
19.2.3 ANSELA REGISTER

The ANSELA register (Register 19-5) 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 allows analog functions on the pin to operate correctly.

The state of the ANSELA bits has no effect on the digital output functions. A pin with TRISGPA clear and ANSELA 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 ANSELA bits must be initialized to ‘0’ by user software.

19.2.4 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 19-1. For additional information, refer to the appropriate section in this data sheet.

PORTGPA pins GPA7 and GPA4 are true open-drain pins with no connection back to $V_D$. When multiple outputs are enabled, the actual pin control goes to the peripheral with the highest priority.

**Table 19-1: PORTGPA OUTPUT PRIORITY**

<table>
<thead>
<tr>
<th>Pin Name</th>
<th>Function Priority (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPA0</td>
<td>GPA0</td>
</tr>
<tr>
<td></td>
<td>AN0 ANALOG_TEST</td>
</tr>
<tr>
<td>GPA1</td>
<td>GPA1 AN1 CLKPIN</td>
</tr>
<tr>
<td>GPA2</td>
<td>GPA2 AN2 T0CKI INT</td>
</tr>
<tr>
<td>GPA3</td>
<td>GPA3 AN3</td>
</tr>
<tr>
<td>GPA4</td>
<td>GPA4 (open-drain input/output)</td>
</tr>
<tr>
<td>GPA5</td>
<td>GPA5 (open-drain data input only)</td>
</tr>
<tr>
<td>GPA6</td>
<td>GPA6 ICSPDAT (MCP19110 Only)</td>
</tr>
<tr>
<td>GPA7</td>
<td>GPA7 (open-drain output) SCL ICSPCLK (MCP19110 Only)</td>
</tr>
</tbody>
</table>

**Note 1:** Priority listed from highest to lowest.

**REGISTER 19-2: PORTGPA: PORTGPA REGISTER**

<table>
<thead>
<tr>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R-x</th>
<th>R-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPA7</td>
<td>GPA6</td>
<td>GPA5</td>
<td>GPA4</td>
<td>GPA3</td>
<td>GPA2</td>
<td>GPA1</td>
<td>GPA0</td>
</tr>
<tr>
<td>bit 7</td>
<td>GPA7</td>
<td>GPA6</td>
<td>GPA5</td>
<td>GPA4</td>
<td>GPA3</td>
<td>GPA2</td>
<td>GPA1</td>
</tr>
</tbody>
</table>

**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 GPA7: General Purpose Open-Drain I/O pin.
- bit 6 GPA6: General Purpose I/O pin.
  - 1 = Port pin is > $V_H$
  - 0 = Port pin is < $V_L$
- bit 5 GPA5/MCLR: General Purpose Open-Drain I/O pin.
- bit 4 GPA4: General Purpose Open-Drain I/O pin.
- bit 3-0 GPA3: General Purpose I/O pin.
  - 1 = Port pin is > $V_H$
  - 0 = Port pin is < $V_L$
REGISTER 19-3: TRISGPA: PORTGPA TRI-STATE REGISTER

<table>
<thead>
<tr>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRISA7</td>
<td>TRISA6</td>
<td>TRISA5</td>
<td>TRISA4</td>
<td>TRISA3</td>
<td>TRISA2</td>
<td>TRISA1</td>
<td>TRISA0</td>
</tr>
</tbody>
</table>

**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   **TRISA<7:6>:** PORTGPA Tri-State Control bit
- 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 4-0   **TRISA<4:0>:** PORTGPA Tri-State Control bit
- 1 = PORTGPA pin configured as an input (tri-stated)
- 0 = PORTGPA pin configured as an output

REGISTER 19-4: WPUGPA: WEAK PULL-UP PORTGPA REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>R/W-1</th>
<th>U-0</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>—</td>
<td>WPUA5</td>
<td>—</td>
<td>WPUA3</td>
<td>WPUA2</td>
<td>WPUA1</td>
<td>WPUA0</td>
</tr>
</tbody>
</table>

**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   **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 bit
- 1 = Pull-up enabled.
- 0 = Pull-up disabled.

**Note 1:** The weak pull-up device is enabled only when the global 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 MCLR in Configuration word.
REGISTER 19-5: ANSELA: ANALOG SELECT PORTGPA REGISTER

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-0</td>
<td>U-0</td>
<td>U-0</td>
<td>R/W-1</td>
<td>R/W-1</td>
<td>R/W-1</td>
<td>R/W-1</td>
<td></td>
</tr>
<tr>
<td>ANSA3</td>
<td>ANSA2</td>
<td>ANSA1</td>
<td>ANSA0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 ANSA<3:0>: Analog Select PORTGPA Register bit
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 TRIS bit must be set to Input mode in order to allow external control of the voltage on the pin.

TABLE 19-2: SUMMARY OF REGISTERS ASSOCIATED WITH PORTGPA

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSELA</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ANSA3</td>
<td>ANSA2</td>
<td>ANSA1</td>
</tr>
<tr>
<td>APFCON</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>OPTION_REG</td>
<td>RAPU</td>
<td>INTEDG</td>
<td>T0CS</td>
<td>T0SE</td>
<td>PSA</td>
<td>PS2</td>
<td>PS1</td>
<td>PS0</td>
<td>—</td>
</tr>
<tr>
<td>PORTGPA</td>
<td>GPA7</td>
<td>GPA6</td>
<td>GPA5</td>
<td>GPA4</td>
<td>GPA3</td>
<td>GPA2</td>
<td>GPA1</td>
<td>GPA0</td>
<td>—</td>
</tr>
<tr>
<td>TRISGPA</td>
<td>TRISA7</td>
<td>TRISA6</td>
<td>TRISA5</td>
<td>TRISA4</td>
<td>TRISA3</td>
<td>TRISA2</td>
<td>TRISA1</td>
<td>TRISA0</td>
<td>—</td>
</tr>
<tr>
<td>WPUGPA</td>
<td>—</td>
<td>—</td>
<td>WPUA5</td>
<td>—</td>
<td>WPUA3</td>
<td>WPUA2</td>
<td>WPUA1</td>
<td>WPUA0</td>
<td>—</td>
</tr>
</tbody>
</table>

Legend: — = unimplemented locations read as ‘0’. Shaded cells are not used by PORTGPA.
19.3 PORTGPB and TRISGPB Registers

PORTGPB is an 8-bit wide, bidirectional port consisting of seven general purpose I/O ports. The corresponding data direction register is TRISGPB (Register 19-7). Setting a TRISGPB bit (\(=1\)) will make the corresponding PORTGPB pin an input (i.e., disable the output driver). Clearing a TRISGPB bit (\(=0\)) will make the corresponding PORTGPB pin an output (i.e., enable the output driver). Example 19-1 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 (Register 19-6) 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 (Register 19-7) 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.

19.3.1 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 20.0 “Interrupt-On-Change” for more information.

19.3.2 WEAK PULL-UPS

Each of the PORTGPB pins has an individually configurable internal weak pull-up. Control bits WPUB<7:4> and WPUB<2:1> enable or disable each pull-up (see Register 19-8). 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 of the OPTION register.

19.3.3 ANSELB REGISTER

The ANSELB register (Register 19-9) 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 allows 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.

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.

19.3.4 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 19-3. For additional information, refer to the appropriate section in this data sheet.

PORTGPB pin GPB0 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 registers. Digital output functions may control the pin when it is in Analog mode, with the priority shown in Table 19-3.

<table>
<thead>
<tr>
<th>Pin Name</th>
<th>Function Priority (^{(1)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPB0</td>
<td>GPB0 (open-drain input/output)</td>
</tr>
<tr>
<td></td>
<td>SDA</td>
</tr>
<tr>
<td>GPB1</td>
<td>GPB1</td>
</tr>
<tr>
<td></td>
<td>AN4</td>
</tr>
<tr>
<td></td>
<td>EAPIN</td>
</tr>
<tr>
<td>GPB2</td>
<td>GPB2</td>
</tr>
<tr>
<td></td>
<td>AN5</td>
</tr>
<tr>
<td>GPB4</td>
<td>GPB4</td>
</tr>
<tr>
<td></td>
<td>AN6</td>
</tr>
<tr>
<td></td>
<td>ICSPDAT/ICDDAT (\text{MCP19111 Only})</td>
</tr>
<tr>
<td>GPB5</td>
<td>GPB5</td>
</tr>
<tr>
<td></td>
<td>AN7</td>
</tr>
<tr>
<td></td>
<td>ICSPCLK/ICDCLK (\text{MCP19111 Only})</td>
</tr>
<tr>
<td></td>
<td>ALT_CLKPIN (\text{MCP19111 Only})</td>
</tr>
<tr>
<td>GPB6</td>
<td>GPB6</td>
</tr>
<tr>
<td>GPB7</td>
<td>GPB7</td>
</tr>
</tbody>
</table>

Note 1: Priority listed from highest to lowest.
### REGISTER 19-6: PORTGPB: PORTGPB REGISTER

<table>
<thead>
<tr>
<th></th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>U-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
<th>R/W-x</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPB7(1)</td>
<td>GPB6(1)</td>
<td>GPB5(1)</td>
<td>GPB4(1)</td>
<td>—</td>
<td>GPB2</td>
<td>GPB1</td>
<td>GPB0</td>
<td></td>
</tr>
</tbody>
</table>

**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**

- **GPB<7:4>: General Purpose I/O Pin bit**
  - 1 = Port pin is > VIH
  - 0 = Port pin is < VIL

**bit 3**

- **Unimplemented:** Read as ‘0’

**bit 2-0**

- **GPB<2:0>: General Purpose I/O Pin bit**
  - 1 = Port pin is > VIH
  - 0 = Port pin is < VIL

**Note 1:** Not implemented on MCP19110.

### REGISTER 19-7: TRISGPB: PORTGPB TRI-STATE REGISTER

<table>
<thead>
<tr>
<th></th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>U-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRISB7(1)</td>
<td>TRISB6(1)</td>
<td>TRISB5(1)</td>
<td>TRISB4(1)</td>
<td>—</td>
<td>TRISB2</td>
<td>TRISB1</td>
<td>TRISB0</td>
<td></td>
</tr>
</tbody>
</table>

**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**

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

**bit 3**

- **Unimplemented:** Read as ‘1’

**bit 2-0**

- **TRISB<2:0>: PORTGPB Tri-State Control bit**
  - 1 = PORTGPB pin configured as an input (tri-stated)
  - 0 = PORTGPB pin configured as an output

**Note 1:** Not implemented on MCP19110.
REGISTER 19-8: WPUGPB: WEAK PULL-UP PORTGPB REGISTER

<table>
<thead>
<tr>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>U-0</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>U-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>WPUB7(2)</td>
<td>WPUB6(2)</td>
<td>WPUB5(2)</td>
<td>WPUB4(2)</td>
<td>—</td>
<td>WPUB2</td>
<td>WPUB1</td>
<td>—</td>
</tr>
</tbody>
</table>

bit 7

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  WPUB<4:0>: Weak Pull-up Register bit
  1 = Pull-up enabled 0 = Pull-up disabled

bit 3  Unimplemented: Read as ‘0’

bit 2-1  WPUB<2:1>: 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 RAPU bit is enabled, the pin is in Input mode (TRISGPA = 1), the individual WPUB bit is enabled (WPUB = 1), and the pin is not configured as an analog input.

2: Not implemented on MCP19110.

REGISTER 19-9: ANSELB: ANALOG SELECT PORTGPB REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>U-0</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>U-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>—</td>
<td>—</td>
<td>ANSB5(2)</td>
<td>ANSB4(2)</td>
<td>—</td>
<td>ANSB2</td>
<td>ANSB1</td>
<td>—</td>
</tr>
</tbody>
</table>

bit 7

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

bit 7-6  Unimplemented: Read as ‘0’

bit 5-4  ANSB<4:3>: Analog Select PORTGPB Register bit
  1 = Analog input. Pin is assigned as analog input(1).
  0 = Digital I/O. Pin is assigned to port or special function.

bit 3  Unimplemented: Read as ‘0’

bit 2-1 ANSB<2:1>: Analog Select PORTGPB Register bit
  1 = Analog input. Pin is assigned as analog input(1).
  0 = Digital I/O. Pin is assigned to port or special function.

bit 0 Unimplemented: Read as ‘0’

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 TRIS bit must be set to Input mode in order to allow external control of the voltage on the pin.

2: Not implemented on MCP19110.
### TABLE 19-4: SUMMARY OF REGISTERS ASSOCIATED WITH PORTGPB

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSELB</td>
<td>—</td>
<td>—</td>
<td>ANSB5</td>
<td>ANSB4</td>
<td>—</td>
<td>ANSB2</td>
<td>ANSB1</td>
<td>—</td>
<td>118</td>
</tr>
<tr>
<td>APFCON</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>112</td>
</tr>
<tr>
<td>OPTION_REG</td>
<td>RAPU</td>
<td>INTEDG</td>
<td>T0CS</td>
<td>T0SE</td>
<td>PSA</td>
<td>PS2</td>
<td>PS1</td>
<td>PS0</td>
<td>77</td>
</tr>
<tr>
<td>PORTGPB</td>
<td>GPB7</td>
<td>GPB6</td>
<td>GPB5</td>
<td>GPB4</td>
<td>—</td>
<td>GPB2</td>
<td>GPB1</td>
<td>GPB0</td>
<td>117</td>
</tr>
<tr>
<td>TRISGPB</td>
<td>TRISB7</td>
<td>TRISB6</td>
<td>TRISB5</td>
<td>TRISB4</td>
<td>—</td>
<td>TRISB2</td>
<td>TRISB1</td>
<td>TRISB0</td>
<td>117</td>
</tr>
<tr>
<td>WPUGPB</td>
<td>WPUB7</td>
<td>WPUB6</td>
<td>WPUB5</td>
<td>WPUB4</td>
<td>—</td>
<td>WPUB2</td>
<td>WPUB1</td>
<td>—</td>
<td>118</td>
</tr>
</tbody>
</table>

**Legend:** — = unimplemented locations read as ‘0’. Shaded cells are not used by PORTGPB.
20.0 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 Register 20-1 and Register 20-2. 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 Configuration Word.

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'ed together to set the Interrupt-on-Change Interrupt Flag bit (IOCF) in the INTCON register (Register 15-1).

20.1 Enabling the Module

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

20.2 Individual Pin Configuration

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

20.3 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.

20.4 Operation in Sleep

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

Note: If a change on the I/O pin should occur when any PORTGPA or PORTGPB operation is being executed, then the IOCF interrupt flag may not get set.
## 20.5 Interrupt-On-Change Registers

### REGISTER 20-1: I OCA: INTERRUPT-ON-CHANGE PORTGPA REGISTER

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/W-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>122</td>
</tr>
<tr>
<td>IOCA7</td>
<td>IOCA6</td>
<td>IOCA5</td>
<td>IOCA4</td>
<td>IOCA3</td>
<td>IOCA2</td>
<td>IOCA1</td>
<td>IOCA0</td>
<td></td>
</tr>
</tbody>
</table>

**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**

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**

IOCA<5>: Interrupt-on-Change PORTGPA Register bits\(^{(1)}\).

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

**bit 4-0**

IOCA<4:0>: 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 MCLR.

### REGISTER 20-2: IOCB: INTERRUPT-ON-CHANGE PORTGPB REGISTER

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>R/W-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>U-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>R/W-0</td>
<td>122</td>
</tr>
<tr>
<td>IOCB7(^{(1)})</td>
<td>IOCB6(^{(1)})</td>
<td>IOCB5(^{(1)})</td>
<td>IOCB4(^{(1)})</td>
<td>—</td>
<td>IOCB2</td>
<td>IOCB1</td>
<td>IOCB0</td>
<td></td>
</tr>
</tbody>
</table>

**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**

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**

Unimplemented: Read as ‘0’

**bit 2-0**

IOCB<2:0>: Interrupt-on-Change PORTGPB Register bits.

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

**Note 1:** Not implemented on MCP19111.

### TABLE 20-1: SUMMARY OF REGISTERS ASSOCIATED WITH INTERRUPT-ON-CHANGE

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANSELA</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ANSA3</td>
<td>ANSA2</td>
<td>ANSA1</td>
<td>ANSA0 115</td>
</tr>
<tr>
<td>ANSELB</td>
<td>—</td>
<td>—</td>
<td>ANSB5</td>
<td>ANSB4</td>
<td>—</td>
<td>ANSB2</td>
<td>ANSB1</td>
<td>—</td>
<td>118</td>
</tr>
<tr>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCE</td>
<td>T0IF</td>
<td>INTF</td>
<td>IOCF</td>
<td>96</td>
</tr>
<tr>
<td>IOCA</td>
<td>IOCA7</td>
<td>IOCA6</td>
<td>IOCA5</td>
<td>IOCA4</td>
<td>IOCA3</td>
<td>IOCA2</td>
<td>IOCA1</td>
<td>IOCA0</td>
<td>122</td>
</tr>
<tr>
<td>IOCB</td>
<td>IOCB7</td>
<td>IOCB6</td>
<td>IOCB5</td>
<td>IOCB4</td>
<td>—</td>
<td>IOCB2</td>
<td>IOCB1</td>
<td>IOCB0</td>
<td>122</td>
</tr>
<tr>
<td>TRISGPA</td>
<td>TRISA7</td>
<td>TRISA6</td>
<td>TRISA5</td>
<td>TRISA4</td>
<td>TRISA3</td>
<td>TRISA2</td>
<td>TRISA1</td>
<td>TRISA0</td>
<td>114</td>
</tr>
<tr>
<td>TRISGBP</td>
<td>TRISB7</td>
<td>TRISB6</td>
<td>TRISB5</td>
<td>TRISB4</td>
<td>—</td>
<td>TRISB2</td>
<td>TRISB1</td>
<td>TRISB0</td>
<td>117</td>
</tr>
</tbody>
</table>

**Legend:**
- — = unimplemented locations read as ‘0’.
- Shaded cells are not used by interrupt-on-change.
21.0 INTERNAL TEMPERATURE INDICATOR MODULE

The MCP19110/11 is equipped with a temperature circuit designed to measure the operating temperature of the silicon die. The circuit's range of the operating temperature falls between -40°C and +125°C. The output is a voltage that is proportional to the device temperature. The output of the temperature indicator is internally connected to the device ADC.

21.1 Circuit Operation

The TMPSEN bit in the ABECOn register, Register 6-15, is set to enable the internal temperature measurement circuit. The MCP19110/11 overtemperature shutdown feature is NOT controlled by this bit.

FIGURE 21-1: TEMPERATURE CIRCUIT DIAGRAM

21.2 Temperature Output

The output of the circuit is measured using the internal analog-to-digital converter. Channel 10 is reserved for the temperature circuit output. Refer to Section 22.0 “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 21-1.

EQUATION 21-1: SILICON DIE TEMPERATURE

\[
TEMP_{DIE} = \frac{ADC \text{ READING} - 1.75}{13.3mV/^\circ C}
\]
22.0 ANALOG-TO-DIGITAL CONVERTER (ADC) MODULE

The Analog-to-Digital Converter (ADC) allows conversion of an analog input signal to a 10-bit binary representation of that signal. This device uses analog inputs, which are multiplexed into a single sample and hold circuit. The output of the sample and hold is connected to the input of the converter. The converter generates a 10-bit binary result via successive approximation and stores the right justified conversion result into the ADC result registers (ADRESH:ADRESL register pair). Figure 22-1 shows the block diagram of the ADC.

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

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

FIGURE 22-1: ADC BLOCK DIAGRAM

Note 1: When ADON = 0, all multiplexer inputs are disconnected.

2: See ADCON0 register (Register 22-1) for detailed analog channel selection per device.

3: Not implemented on MCP19110.
22.1 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

22.1.1 PORT CONFIGURATION

The ADC can be used to convert both analog and digital signals. When converting analog signals, the I/O pin should be configured for analog by setting the associated TRIS and ANSEL bits. Refer to Section 19.0 “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. |

22.1.2 CHANNEL SELECTION

There are up to 19 channel selections available on the MCP19110 and 21 channel selections available on the MCP19111:

- AN<6:0> pins
- VIN: 1/5 of the input voltage (V_IN)
- VREGREF: VOUT reference voltage
- OV_REF: reference for OV comparator
- UV_REF: reference for UV comparator
- VBGR: band gap reference
- VOUT: output voltage
- CRT: voltage proportional to the AC inductor current
- VZC: an internal ground, Voltage for Zero Current
- DEMAND: input to slope compensation circuitry
- REL EFF: relative efficient measurement channel
- TMP_ANA: voltage proportional to silicon die temperature
- ANA_IN: for a multi-phase slave, error amplifier signal received from master
- DCI: DC inductor valley current

The CHS<4:0> bits of the ADCON0 register determine which channel is connected to the sample and hold circuit.

When changing channels, a delay is required before starting the next conversion. Refer to Section 22.2 “ADC Operation” for more information.

22.1.3 ADC CONVERSION CLOCK

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

- FOSC/8
- FOSC/16
- FOSC/32
- FOSC/64
- FR C (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 22-2.

For a correct conversion, the appropriate T_AD specification must be met. Refer to the A/D conversion requirements in Section 5.0 “Digital Electrical Characteristics” for more information. Table 22-1 gives examples of appropriate ADC clock selections.

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

| TABLE 22-1: ADC CLOCK PERIOD (TAD) VS. DEVICE OPERATING FREQUENCIES |
|--------------------------|--------------------------|--------------------------|
| ADC Clock Period (TAD)   | Device Frequency (FOSC)  | 8 MHz                    |
| ADC Clock Source         | ADCS<2:0>                |                          |
| FOSC/8                   | 001                      | 1.0 µs (2)               |
| FOSC/16                  | 010                      | 2.0 µs                   |
| FOSC/32                  | 110                      | 4.0 µs                   |
| FOSC/64                  | 111                      | 8.0 µs (3)               |
| FR C                     | x11                      | 2.0 – 6.0 µs (1,4)       |

Legend: Shaded cells are outside of recommended range.

Note 1: The FR C source has a typical T_AD time of 4 µs for VDD > 3.0V.

2: These values violate the minimum required T_AD time.

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

4: The FR C clock source is only recommended if the conversion will be preformed during Sleep.
22.1.4 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.

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

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

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

Figure 22-3 shows the output format.
22.2 ADC Operation

22.2.1 STARTING A CONVERSION

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

Note: The GO/DONE bit should not be set in the same instruction that turns on the ADC. Refer to Section 22.2.5 “A/D Conversion Procedure”.

22.2.2 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

22.2.3 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, a two TAD delay is 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.

22.2.4 ADC OPERATION DURING SLEEP

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

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

22.2.5 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 TRIS register)
   - Configure pin as analog (Refer to the ANSEL register)

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-up from Sleep and resume in-line code execution.

2: Refer to Section 22.4 “A/D Acquisition Requirements”.

**EXAMPLE 22-1: A/D CONVERSION**

```assembly
;This code block configures the ADC
;for polling, Frc clock and AN0 input.
;Conversion start & polling for completion are included.
;
;BANKSEL ADCON1
;MOVLW B'01110000' ;Frc clock
;MOVF ADCON1 ;
;BANKSEL TRISGA
;BSF TRISGA,0 ;Set GPA0 to input
;BANKSEL ANSELA ;
;BSF ANSELA,0 ;Set GPA0 to analog
;BANKSEL ADCON0 ;
;MOVLW B'01000011' ;Select channel AN0
;MOVF ADCON0 ;Turn ADC On
;CALL SampleTime ;Acquisiton delay
;BSF ADCON0,1 ;Start conversion
;BFFSC ADCON0,1 ;Is conversion done?
;GOTO $-1 ;No, test again
;BANKSEL ADRESH
;MOVF ADRESH,W ;Read upper 2 bits
;MOVF RESULTHI ;store in GPR space
;BANKSEL ADRESL
;MOVF ADRESL,W ;Read lower 8 bits
;MOVF RESULTLO ;Store in GPR space
```
22.3 ADC Register Definitions

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

REGISTER 22-1: ADCON0: A/D CONTROL REGISTER 0

<table>
<thead>
<tr>
<th>bit 7</th>
<th>CHS4</th>
<th>CHS3</th>
<th>CHS2</th>
<th>CHS1</th>
<th>CHS0</th>
<th>GO/DONE</th>
<th>ADON</th>
</tr>
</thead>
<tbody>
<tr>
<td>bit 6-2</td>
<td>Unimplemented: Read as ‘0’</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 5-1</td>
<td>CHS&lt;4:0&gt;: Analog Channel Select bits</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>00000 = VIN_ANA (analog voltage proportional to VIN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>00001 = VREGREF (reference voltage for VREG output)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>00010 = OV_REF (reference for overvoltage comparator)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>00011 = UV_REF (reference for undervoltage comparator)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>00100 = VBGR (band gap reference)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>00101 = INT_VREG (internal version of the VREG load voltage)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>00110 = CRT (voltage proportional to the current in the inductor)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>00111 = VZC (an internal ground, Voltage for Zero Current)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>01000 = DEMAND (input to current loop, output of demand mux)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>01001 = RELEFF (analog voltage proportional to duty cycle)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>01010 = TMP_ANA (analog voltage proportional to temperature)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>01011 = ANA_IN (demanded current from the remote master)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>01100 = DCI (dc inductor valley current)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>01101 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>01110 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>01111 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10000 = GPA0 (i.e. ADDR1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10001 = GPA1 (i.e. ADDR0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10010 = GPA2 (i.e. Temperature Sensor Input)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10011 = GPA3 (i.e. Tracking Voltage)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10100 = GPB1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10101 = GPB2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10110 = GPB4(1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10111 = GPB5(1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11000 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11001 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11011 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11100 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11101 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11110 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11111 = Unimplemented</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 1</td>
<td>GO/DONE: A/D Conversion Status bit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 = A/D conversion cycle in progress. Setting this bit starts an A/D conversion cycle.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>This bit is automatically cleared by hardware when the A/D conversion has completed.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 = A/D conversion completed/not in progress</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 0</td>
<td>ADON: ADC Enable bit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 = ADC is enabled</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 = ADC is disabled and consumes no operating current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note 1: Not implemented on MCP19110.
REGISTER 22-2: ADCON1: A/D CONTROL REGISTER 1

<table>
<thead>
<tr>
<th>bit 7</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>bit 7</td>
<td>ADCS2</td>
<td>ADCS1</td>
<td>ADCS0</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

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 7    Unimplemented: Read as ‘0’
bit 6-4  ADCS<2:0>: A/D Conversion Clock Select bits
000 = Reserved
001 = FOSC/8
010 = FOSC/32
x11 = FRC (clock derived from internal oscillator with a divisor of 16)
100 = Reserved
101 = FOSC/16
110 = FOSC/64

REGISTER 22-3: ADRESH: ADC RESULT REGISTER HIGH (ADRESH)

<table>
<thead>
<tr>
<th>bit 7</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>U-0</th>
<th>ADRES9</th>
<th>ADRES8</th>
</tr>
</thead>
<tbody>
<tr>
<td>bit 7</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>

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 7-2    Unimplemented: Read as ‘0’
bit 1-0    ADRES<9:8>: Most Significant A/D Results

REGISTER 22-4: ADRESL: ADC RESULT REGISTER LOW (ADRESL)

<table>
<thead>
<tr>
<th>bit 7</th>
<th>ADRES7</th>
<th>ADRES6</th>
<th>ADRES5</th>
<th>ADRES4</th>
<th>ADRES3</th>
<th>ADRES2</th>
<th>ADRES1</th>
<th>ADRES0</th>
</tr>
</thead>
<tbody>
<tr>
<td>bit 7</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
</tbody>
</table>

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    ADRES<7:0>: Least Significant A/D results
### 22.4 A/D Acquisition Requirements

For the ADC to meet its specified accuracy, the charge holding capacitor (C\text{HOLD}) must be allowed to fully charge to the input channel voltage level. The Analog Input model is shown in Figure 22-4. The source impedance (R\text{S}) and the internal sampling switch (RSS) impedance directly affect the time required to charge the capacitor C\text{HOLD}. The sampling switch (RSS) impedance varies over the device voltage (V\text{DD}), refer to Figure 22-4.

The maximum recommended impedance for analog sources is 10 kΩ. As the source impedance is decreased, the acquisition time may be decreased. After the analog input channel is selected (or changed), an A/D acquisition must be done before the conversion can be started. To calculate the minimum acquisition time, Equation 22-1 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 22-1: ACQUISITION TIME EXAMPLE

**Assumptions:**
- Temperature = +50°C and external impedance of 10 kΩ 5.0V $V_{DD}$

$$T_{ACQ} = \text{Amplifier Settling Time} + \text{Hold Capacitor Charging Time} + \text{Temperature Coefficient}$$

$$= T_{AMP} + T_C + T_{COFF}$$

$$= 2 \mu s + T_C + [(\text{Temperature} - 25°C)(0.05 \mu s/°C)]$$

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

$$V_{APPLIED}\left(1 - \frac{1}{2^n + 1}\right) = V_{CHOLD}$$

\[\text{[1] } V_{CHOLD} \text{ charged to within 1/2 lsb}\]

$$V_{APPLIED}\left(1 - e^{-\frac{T_C}{RC}}\right) = V_{CHOLD}$$

\[\text{[2] } V_{CHOLD} \text{ charge response to } V_{APPLIED}\]

$$V_{APPLIED}\left(1 - e^{-\frac{T_C}{RC}}\right) = V_{APPLIED}\left(1 - \frac{1}{2^n + 1}\right)$$

\[\text{combining [1] and [2]}\]

**Note:** Where $n = \text{number of bits of the ADC}$.

Solving for $T_C$:

$$T_C = -C_{HOLD}\left(R_{IC} + R_{SS} + R_S\right)\ln(1/2047)$$

$$= -10 \text{ pF}(1 \text{ kΩ} + 7 \text{ kΩ} + 10 \text{ kΩ})\ln(0.0004885)$$

$$= 1.37 \mu s$$

Therefore:

$$T_{ACQ} = 2 \mu s + 1.37 \mu s + [(50°C - 25°C)(0.05 \mu s/°C)]$$

$$= 4.67 \mu s$$

---

**Note 1:** The charge holding capacitor (C\text{HOLD}) is not discharged after each conversion.

**2:** The maximum recommended impedance for analog sources is 10 kΩ. This is required to meet the pin leakage specification.
FIGURE 22-4: ANALOG INPUT MODEL

Legend:

- \( C_{\text{HOLD}} \) = Sample/Hold Capacitance
- \( C_{\text{PIN}} \) = Input Capacitance
- \( I_{\text{LEAKAGE}} \) = Leakage current at the pin due to various junctions
- \( R_{\text{IC}} \) = Interconnect Resistance
- \( R_{SS} \) = Resistance of Sampling Switch
- \( SS \) = Sampling Switch
- \( V_T \) = Threshold Voltage

Note 1: Refer to Section 5.0 “Digital Electrical Characteristics”.

FIGURE 22-5: ADC TRANSFER FUNCTION
### Table 22-2: Summary of Registers Associated with ADC

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADCON0</td>
<td>—</td>
<td>CHS4</td>
<td>CHS3</td>
<td>CHS2</td>
<td>CHS1</td>
<td>CHS0</td>
<td>GO/DONE</td>
<td>ADON</td>
<td>129</td>
</tr>
<tr>
<td>ADCON1</td>
<td>—</td>
<td>ADCS2</td>
<td>ADCS1</td>
<td>ADCS0</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>130</td>
</tr>
<tr>
<td>ADRESH</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ADRES9</td>
<td>ADRES8</td>
</tr>
<tr>
<td>ADRESL</td>
<td>ADRES7</td>
<td>ADRES6</td>
<td>ADRES5</td>
<td>ADRES4</td>
<td>ADRES3</td>
<td>ADRES2</td>
<td>ADRES1</td>
<td>ADRES0</td>
<td>130</td>
</tr>
<tr>
<td>ANSELA</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>ANSA3</td>
<td>ANSA2</td>
<td>ANSA1</td>
<td>ANSA0</td>
</tr>
<tr>
<td>ANSELB</td>
<td>—</td>
<td>ANSB5</td>
<td>ANSB4</td>
<td>—</td>
<td>ANSB2</td>
<td>ANSB1</td>
<td>—</td>
<td>—</td>
<td>118</td>
</tr>
<tr>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCE</td>
<td>T0IF</td>
<td>INTF</td>
<td>IOCF</td>
<td>95</td>
</tr>
<tr>
<td>PIE1</td>
<td>—</td>
<td>ADIE</td>
<td>BCLIE</td>
<td>SSPIE</td>
<td>—</td>
<td>—</td>
<td>TMR2IE</td>
<td>TMR1IE</td>
<td>96</td>
</tr>
<tr>
<td>PIR1</td>
<td>—</td>
<td>ADIF</td>
<td>BCLIF</td>
<td>SSPIF</td>
<td>—</td>
<td>—</td>
<td>TMR2IF</td>
<td>TMR1IF</td>
<td>98</td>
</tr>
<tr>
<td>TRISGPA</td>
<td>TRISA7</td>
<td>TRISA6</td>
<td>TRISA5</td>
<td>TRISA4</td>
<td>TRISA3</td>
<td>TRISA2</td>
<td>TRISA1</td>
<td>TRISA0</td>
<td>114</td>
</tr>
<tr>
<td>TRISGPB</td>
<td>TRISB7</td>
<td>TRISB6</td>
<td>TRISB5</td>
<td>TRISB4</td>
<td>—</td>
<td>TRISB2</td>
<td>TRISB1</td>
<td>TRISB0</td>
<td>117</td>
</tr>
</tbody>
</table>

**Legend:** — = unimplemented read as ‘0’. Shaded cells are not used for ADC module.
23.0 TIMER0 MODULE

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

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

Figure 23-1 is a block diagram of the Timer0 module.

FIGURE 23-1: BLOCK DIAGRAM OF THE TIMER0

23.1 Timer0 Operation

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

23.1.1 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 of the OPTION_REG register.

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

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

23.1.2 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 of 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'.

23.1.3 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 of 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 of the OPTION_REG register. In order to have a 1:1 prescaler value for the Timer0 module, the prescaler must be disabled by setting the PSA bit of the OPTION_REG register.

The prescaler is not readable or writable. When assigned to the Timer0 module, all instructions writing to the TMR0 register will clear the prescaler.
23.1.4 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 23-1 must be executed.

EXAMPLE 23-1: CHANGING PRESCALER (TIMER0 → WDT)

```
BANKSEL TMR0 ;
CLRWDT ;Clear WDT
CLRF TMR0 ;Clear TMR0 and ;prescaler
BANKSEL OPTION_REG ;
BSF OPTION_REG,PSA ;Select WDT
CLRWDT ;
;
MOVlw b'11111000' ;Mask prescaler
ANDWF OPTION_REG,W ;bits
IORLW b'00000101' ;Set WDT prescaler
MOVWF OPTION_REG ;to 1:32
```

When changing the prescaler assignment from the WDT to the Timer0 module, the following instruction sequence must be executed (see Example 23-2).

EXAMPLE 23-2: CHANGING PRESCALER (WDT → TIMER0)

```
CLRWDT ;Clear WDT and ;prescaler
BANKSEL OPTION_REG ;
MOVlw b'11110000' ;Mask Timer0 select and
ANDWF OPTION_REG,W ;prescaler bits
IORlw b'00000011' ;Set prescale to 1:16
MOVWF OPTION_REG ;
```

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

23.1.5 TIMER0 INTERRUPT

Timer0 will generate an interrupt when the TMR0 register overflows from FFh to 00h. The T0IF interrupt flag bit of the INTCON register is set every time the TMR0 register overflows, regardless of whether or not the Timer0 interrupt is enabled. The T0IF bit can only be cleared in software. The Timer0 interrupt enable is the T0IE bit of the INTCON register.

23.1.6 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 5.0 “Digital Electrical Characteristics”.

23.1.7 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 23-1: SUMMARY OF REGISTERS ASSOCIATED WITH TIMER0

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCIE</td>
<td>T0IF</td>
<td>INTF</td>
<td>IOCIF</td>
<td>96</td>
</tr>
<tr>
<td>OPTION_REG</td>
<td>RAPE</td>
<td>INTEDG</td>
<td>T0CS</td>
<td>T0SE</td>
<td>PSA</td>
<td>PS2</td>
<td>PS1</td>
<td>PS0</td>
<td>77</td>
</tr>
<tr>
<td>TMR0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Timer0 Module Register</td>
<td></td>
<td></td>
<td></td>
<td>135*</td>
</tr>
<tr>
<td>TRISGPA</td>
<td>TRISA7</td>
<td>TRISA6</td>
<td>TRISA5</td>
<td>TRISA4</td>
<td>TRISA3</td>
<td>TRISA2</td>
<td>TRISA1</td>
<td>TRISA0</td>
<td>114</td>
</tr>
</tbody>
</table>

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

* Page provides register information.
24.0 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 24-1 is a block diagram of the Timer1 module.

FIGURE 24-1: TIMER1 BLOCK DIAGRAM

24.1 Timer1 Operation

The Timer1 module is a 16-bit incrementing timer which 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. Table 24-1 displays the Timer1 enable selections.

24.2 Clock Source Selection

The TMR1CS bit of the T1CON register is used to select the clock source for Timer1. Table 24-1 displays the clock source selections.

Note 1: TMR1 register increments on rising edge.

24.2.1 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>
<thead>
<tr>
<th>TMR1CS</th>
<th>Clock Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8 MHz system Clock ($F_{OSC}$)</td>
</tr>
<tr>
<td>0</td>
<td>2 MHz instruction clock ($F_{OSC}/4$)</td>
</tr>
</tbody>
</table>
24.3 Timer1 Prescaler

Timer1 has four prescaler options allowing 1, 2, 4 or 8 divisions of the clock input. The T1CKPS bits of the T1CON register control the prescale counter. The prescale counter is not directly readable or writable; however, the prescaler counter is cleared upon a write to TMR1H or TMR1L.

24.4 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 of the PIR1 register is set. To enable the interrupt on rollover, you must set these bits:

- TMR1ON bit of the T1CON register
- TMR1IE bit of the PIE1 register
- PEIE bit of the INTCON register
- GIE bit of the INTCON register

The interrupt is cleared by clearing the TMR1IF bit in the Interrupt Service Routine.

Note: The TMR1H:TMR1L register pair and the TMR1IF bit should be cleared before enabling interrupts.

REGISTER 24-1: T1CON: TIMER1 CONTROL REGISTER

<table>
<thead>
<tr>
<th>U-0</th>
<th>U-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>U-0</th>
<th>U-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T1CKPS1</td>
<td>T1CKPS0</td>
<td></td>
<td></td>
<td>TMR1CS</td>
<td>TMR1ON</td>
</tr>
</tbody>
</table>

bit 7

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

bit 7-6  Unimplemented: Read as ‘0’

bit 5-4  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 (Fosc)
0 = 2 MHz instruction clock (Fosc)

bit 0  TMR1ON: Timer1 On bit

1 = Enables Timer1
0 = Stops Timer1, Clears Timer1 gate flip-flop

24.5 Timer1 in Sleep

Unlike other standard mid-range Timer1 modules, the MCP19110/11 Timer1 module only clocks from an internal system clock, and thus does not run during Sleep mode, nor can it be used to wake the device from this mode.

24.6 Timer1 Control Register

The Timer1 Control register (T1CON), shown in Register 24-1, is used to control Timer1 and select the various features of the Timer1 module.
TABLE 24-2: SUMMARY OF REGISTERS ASSOCIATED WITH TIMER1

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCE</td>
<td>T0IF</td>
<td>INTF</td>
<td>IOCF</td>
<td>95</td>
</tr>
<tr>
<td>PIE1</td>
<td>—</td>
<td>ADIE</td>
<td>BCLIE</td>
<td>SSPIE</td>
<td>—</td>
<td>—</td>
<td>TMR2IE</td>
<td>TMR1IE</td>
<td>95</td>
</tr>
<tr>
<td>PIR1</td>
<td>—</td>
<td>ADIF</td>
<td>BCLIF</td>
<td>SSPIF</td>
<td>—</td>
<td>—</td>
<td>TMR2IF</td>
<td>TMR1IF</td>
<td>98</td>
</tr>
<tr>
<td>TMR1H</td>
<td>Holding Register for the Most Significant Byte of the 16-bit TMR1 Register</td>
<td>137*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TMR1L</td>
<td>Holding Register for the Least Significant Byte of the 16-bit TMR1 Register</td>
<td>137*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T1CON</td>
<td>—</td>
<td>—</td>
<td>T1CKPS1</td>
<td>T1CKPS0</td>
<td>—</td>
<td>—</td>
<td>TMR1CS</td>
<td>TMR1ON</td>
<td>138</td>
</tr>
</tbody>
</table>

Legend: — = unimplemented, read as ‘0’. Shaded cells are not used by the Timer1 module.

* Page provides register information.
25.0 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)

See Figure 25-1 for a block diagram of Timer2.

25.1 Timer2 Operation

The clock input to the Timer2 module is the system clock (FOSC). 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 is cleared when:
- A write to TMR2 occurs.
- A write to T2CON occurs.
- Any device Reset occurs (Power-on Reset, MCLR Reset, Watchdog Timer Reset, or Brown-out Reset).

**Note:** TMR2 is not cleared when T2CON is written.
25.2 Timer2 Control Register

REGISTER 25-1: T2CON: TIMER2 CONTROL REGISTER

| 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 25-1: SUMMARY OF REGISTERS ASSOCIATED WITH TIMER2

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTCON</td>
<td>GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCE</td>
<td>T0IF</td>
<td>INTF</td>
<td>IOCF</td>
<td>95</td>
</tr>
<tr>
<td>PIE1</td>
<td></td>
<td>ADIE</td>
<td>BCLIE</td>
<td>SSPIE</td>
<td></td>
<td></td>
<td></td>
<td>TMR2IE</td>
<td>96</td>
</tr>
<tr>
<td>PIR1</td>
<td></td>
<td>ADIF</td>
<td>BCLIF</td>
<td>SSPIF</td>
<td></td>
<td></td>
<td></td>
<td>TMR2IF</td>
<td>98</td>
</tr>
<tr>
<td>PR2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>140*</td>
</tr>
<tr>
<td>T2CON</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>141</td>
</tr>
<tr>
<td>TMR2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>140*</td>
</tr>
</tbody>
</table>

Legend: — = unimplemented read as ‘0’. Shaded cells are not used for Timer2 module.
* Page provides register information.
26.0 PWM MODULE

The CCP module implemented on the MCP19110/11 is a modified version of the CCP module found in standard mid-range microcontrollers. In the MCP19110/11, the PWM module is used to generate the system clock or system oscillator. This system clock will control the MCP19110/11 switching frequency, as well as set the maximum allowable duty cycle. The PWM module does not continuously adjust the duty cycle to control the output voltage. This is accomplished by the analog control loop and associated circuitry.

26.1 Standard Pulse-Width Modulation (PWM) Mode

The PWM module output signal is used to set the operating switching frequency and maximum allowable duty cycle of the MCP19110/11. The actual duty cycle on the HDRV and LDRV is controlled by the analog PWM control loop. However, this duty cycle cannot be greater than the value in the PWMRL register.

There are two modes of operation that concern the system clock PWM signal. These modes are stand-alone (non-frequency synchronization) and frequency synchronization.

26.1.1 STAND-ALONE (NON-FREQUENCY SYNCHRONIZATION) MODE

When the MCP19110/11 is running stand-alone, the PWM signal functions as the system clock. It is operating at the programmed switching frequency with a programmed maximum duty cycle ($D_{CLOCK}$). The programmed maximum duty cycle is not adjusted on a cycle-by-cycle basis to control the MCP19110/11 system output. The required duty cycle ($D_{BUCK}$) to control the output is adjusted by the MCP19110/11 analog control loop and associated circuitry. $D_{CLOCK}$ does, however, set the maximum allowable $D_{BUCK}$.

EQUATION 26-1:

$$D_{BUCK} < 1 - D_{CLOCK}$$

26.1.2 SWITCHING FREQUENCY SYNCHRONIZATION MODE

The MCP19110/11 can be programmed to be a switching frequency MASTER or SLAVE device. The MASTER device functions as described in Section 26.1.1 “Stand-Alone (Non-Frequency Synchronization) Mode” with the exception of the system clock also being applied to GPA1.

A SLAVE device will receive the MASTER system clock on GPA1. This MASTER system clock will be OR’ed with the output of the TIMER2 module. This OR’ed signal will latch PWMRL into PWMRH and PWMPHL into PWMPHH.

Figure 26-1 shows a simplified block diagram of the CCP module in PWM mode.

The PWMPHL register allows for a phase shift to be added to the SLAVE system clock.

It is desired to have the MCP19110/11 SLAVE device’s system clock start point shifted by a programmed amount from the MASTER system clock. This SLAVE phase shift is specified by writing to the PWMPHL register. The SLAVE phase shift can be calculated by using the following equation.

EQUATION 26-2:

$$SLAVE\ phase\ shift = PWMPHL \cdot TOSCI \cdot (T2\ prescale\ value)$$
A PWM output (Figure 26-2) 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).

**Note 1:** TIMER 2 should be clocked by $F_{OSC}$ (8 MHz).

### FIGURE 26-2: PWM OUTPUT

<table>
<thead>
<tr>
<th>Period</th>
<th>Duty Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMR2 = PR2 + 1</td>
<td>TMR2 = PR2 + 1</td>
</tr>
</tbody>
</table>

### 26.1.3 PWM PERIOD

The PWM period is specified by writing to the PR2 register. The PWM period can be calculated using the following equation:

**EQUATION 26-3:**

$$PWM \ period = \frac{1}{(PR2+1) \times T_{OSC} \times (T2\ prescale\ value)}$$

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
26.1.4 PWM DUTY CYCLE (D\text{CLOCK})

The PWM duty cycle (D\text{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\text{CLOCK}):

\begin{equation}
PWM\text{ DUTY CYCLE} = PWMRL \times T_{OSC} \times (T2\text{ PRESCALE VALUE})
\end{equation}

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.

### TABLE 26-1: SUMMARY OF REGISTERS ASSOCIATED WITH PWM MODULE

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Register on Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>APFCON</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>T2CON</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>TMR2ON, T2CKPS1, T2CKPS0</td>
</tr>
<tr>
<td>PR2</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>Timer2 Module Period Register</td>
</tr>
<tr>
<td>PWMRL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>PWM Register Low Byte</td>
</tr>
<tr>
<td>PWMPHL</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>SLAVE Phase Shift Byte</td>
</tr>
<tr>
<td>BUFFCON</td>
<td>MLTPH2</td>
<td>MLTPH1</td>
<td>MLTPH0</td>
<td>ASEL4</td>
<td>ASEL3</td>
<td>ASEL2</td>
<td>ASEL1</td>
<td>ASEL0</td>
<td>MLTPH2, MLTPH1, MLTPH0</td>
</tr>
</tbody>
</table>

Legend: — = Unimplemented locations, read as ‘0’. Shaded cells are not used by Capture mode.

* Page provides register information.
27.0 MASTER SYNCHRONOUS SERIAL PORT (MSSP) MODULE

27.1 Master SSP (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 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 27-1 is a block diagram of the I2C interface module in Master mode. Figure 27-2 is a diagram of the I2C interface module in Slave mode.

FIGURE 27-1: MSSP BLOCK DIAGRAM (I2C MASTER MODE)
27.2 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 MSSP module has eight registers for I2C operation. They are the:
- MSSP Status Register (SSPSTAT)
- MSSP Control Register1 (SSPCON1)
- MSSP Control Register2 (SSPCON2)
- MSSP Control Register3 (SSPCON3)
- Serial Receive/Transmit Buffer (SSPBUF)
- MSSP Shift Register (SSPSR) - Not directly accessible
- MSSP Address Register (SSPADD)
- MSSP Address Register2 (SSPADD2)
- MSSP Address Mask Register1 (SSPMSK)
- MSSP Address Mask Register2 (SSPMSK2)

The SSPCON1 register is used to define the I2C mode. Four selection bits (SSPCON1<3:0>) allow one of the following I2C modes to be selected:
- I2C Slave mode (7-bit address)
- I2C Slave mode (10-bit address)
- I2C Master mode, clock = OSC/4 (SSPADD +1)
- I2C firmware controlled Master mode (Slave idle)

The SSPSTAT register gives the status of the data transfer. This information includes detection of a START or STOP bit, specifies if the data received byte was data or address, if the next byte is completion of the 10-bit address, and if this will be a read or write data transfer.

The SSPBUF is the register to which transfer data is written to or read from. The SSPSR register shifts the data in or out of the device. In receive operation, the SSPBUF and SSPSR create a double buffer receiver. This allows reception of the next byte to begin before reading the last byte of received data. When the complete byte is received before the SSPBUF register is read, a receiver overflow has occurred and the SSPOV bit (SSPCON1<6>) is set and the byte in the SSPSR is lost.
The \( \text{I}^2\text{C} \) 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.

Before selecting any \( \text{I}^2\text{C} \) mode, the SCL and SDA pins must be programmed to inputs by setting the appropriate TRIS bits. Selecting \( \text{I}^2\text{C} \) mode, by setting the SSPEN bit, enables the SCL and SDA pins to be used as clock and data lines in \( \text{I}^2\text{C} \) mode.

Figure 27-3 shows a typical connection between two devices configured as master and slave.

**FIGURE 27-3: \( \text{I}^2\text{C} \) MASTER/SLAVE CONNECTION**

The \( \text{I}^2\text{C} \) bus can operate with one or more master devices and one or more slave devices.

There are four potential modes of operation for a given device:

- Master Transmit mode (master is transmitting data to a slave)
- Master Receive mode (master is receiving data from a slave)
- Slave Transmit mode (slave is transmitting data to a master)
- Slave Receive mode (slave is receiving data from the master)

To begin communication, a master device starts out in Master Transmit mode. The master device sends out a Start bit followed by the address byte of the slave it intends to communicate with. This is followed by a single Read/Write bit, which determines whether the master intends to transmit to or receive data from the slave device.

If the requested slave exists on the bus, it will respond with an Acknowledge bit, otherwise known as an \( \text{ACK} \). 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.

The Acknowledge bit (\( \text{ACK} \)) is an active-low signal, which 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, then it repeatedly sends out a byte of data, with the slave responding after each byte with an \( \text{ACK} \) bit. In this example, the master device is in Master Transmit mode, and the slave is in Slave Transmit mode.

If the master intends to read from the slave, then it repeatedly receives a byte of data from the slave, and responds after each byte with an \( \text{ACK} \) bit. In this example, the master device is in Master Receive mode, and the slave is Slave Transmit mode.

On the last byte of data communicated, the master device may end the transmission by sending a Stop bit. If the master device is in Receive mode, it sends the Stop bit in place of the last \( \text{ACK} \) 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 reinitiate another transmission. If so, the master device may send another Start bit in place of the Stop bit or last \( \text{ACK} \) bit when it is in receive mode.

The \( \text{I}^2\text{C} \) 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.
27.2.1 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.

27.2.2 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 on 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 also must 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.

27.3 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 user software. Two pins, SDA and SCL, are exercised by the module to communicate with other external I2C devices.

27.3.1 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 below.

27.3.2 DEFINITION OF I2C TERMINOLOGY

There is language and terminology in the description of I2C communication that have definitions specific to I2C. That word usage is defined below and may be used in the rest of this document without explanation. This table was adapted from the Philips I2C specification.

27.3.3 SDA AND SCL PINS

On the MCP19110/11, the SCL and SDA pins are always 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.
27.3.4  SDA HOLD TIME

The hold time of the SDA pin is selected by the SDAHT bit of 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 27-1: I2C BUS TERMS

<table>
<thead>
<tr>
<th>TERM</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmitter</td>
<td>The device which shifts data out onto the bus.</td>
</tr>
<tr>
<td>Receiver</td>
<td>The device which shifts data in from the bus.</td>
</tr>
<tr>
<td>Master</td>
<td>The device that initiates a transfer, generates clock signals and terminates a transfer.</td>
</tr>
<tr>
<td>Slave</td>
<td>The device addressed by the master.</td>
</tr>
<tr>
<td>Multi-Master</td>
<td>A bus with more than one device that can initiate data transfers.</td>
</tr>
<tr>
<td>Arbitration</td>
<td>Procedure to ensure that only one master at a time controls the bus. Winning arbitration ensures that the message is not corrupted.</td>
</tr>
<tr>
<td>Synchronization</td>
<td>Procedure to synchronize the clocks of two or more devices on the bus.</td>
</tr>
<tr>
<td>Idle</td>
<td>No master is controlling the bus, and both SDA and SCL lines are high.</td>
</tr>
<tr>
<td>Active</td>
<td>Any time one or more master devices are controlling the bus.</td>
</tr>
<tr>
<td>Addressed Slave</td>
<td>Slave device that has received a matching address and is actively being clocked by a master.</td>
</tr>
<tr>
<td>Matching Address</td>
<td>Address byte that is clocked into a slave that matches the value stored in SSPADDx.</td>
</tr>
<tr>
<td>Write Request</td>
<td>Slave receives a matching address with R/W bit clear, and is ready to clock in data.</td>
</tr>
<tr>
<td>Read Request</td>
<td>Master sends an address byte with the R/W bit set, indicating that it wishes to clock data out of the Slave. This data is the next and all following bytes until a Restart or Stop.</td>
</tr>
<tr>
<td>Clock Stretching</td>
<td>When a device on the bus holds SCL low to stall communication.</td>
</tr>
<tr>
<td>Bus Collision</td>
<td>Any time the SDA line is sampled low by the module while it is outputting and expected high state.</td>
</tr>
</tbody>
</table>

27.3.5  START CONDITION

The I2C specification defines a Start condition as a transition of SDA from a high 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 27-4 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.

27.3.6  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.

27.3.7  RESTART CONDITION

A Restart is valid any time that a Stop would be valid. A master can issue a Restart if it wishes to hold the bus after terminating the current transfer. A Restart has the same effect on the slave that a Start would, resetting all slave logic and preparing it to clock in an address. The master may want to address the same or another slave.

In 10-bit Addressing Slave mode, a Restart is required for the master to clock data out of the addressed slave. Once a slave has been fully addressed, matching both high and low address bytes, the master can issue a Restart and the high address byte with the R/W bit set. The slave logic will then hold the clock and prepare to clock out data. After a full match with R/W clear in 10-bit mode, a prior match flag is set and maintained. Until a Stop condition, a high address with R/W clear or a high address match fails.
27.3.8 START/STOP CONDITION INTERRUPT MASKING

The SCIE and PCIE bits of 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 27-4: \(\text{I}^{2}\text{C} \text{ START AND STOP CONDITIONS}\)

FIGURE 27-5: \(\text{I}^{2}\text{C} \text{ RESTART CONDITION}\)

27.3.9 ACKNOWLEDGE SEQUENCE

The 9th SCL pulse for any transferred byte in \(\text{I}^{2}\text{C}\) 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 (ACK) is an active-low signal, pulling the SDA line low indicates to the transmitter that the device has received the transmitted data and is ready to receive more.

The result of an ACK is placed in the ACKSTAT bit of the SSPCON2 register.

Slave software, when the AHEN and DHEN bits are set, allow the user to set the ACK value sent back to the transmitter. The ACKDT bit of the SSPCON2 register is set/cleared to determine the response.

Slave hardware will generate an ACK response if the AHEN and DHEN bits of the SSPCON3 register are clear.

There are certain conditions where an ACK will not be sent by the slave. If the BF bit of the SSPSTAT register or the SSPOV bit of the SSPCON1 register are set when a byte is received, an ACK will not be sent.

When the module is addressed, after the 8th falling edge of SCL on the bus, the ACKTIM bit of 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 bit or DHEN bit is enabled.
27.4  I2C SLAVE MODE OPERATION

The MSSP Slave mode operates in one of the four modes selected in the SSPM bits of 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. The exception is the SSPIF bit getting set upon detection of a Start, Restart or Stop condition.

27.4.1 SLAVE MODE ADDRESSES, SSPADD

The SSPADD register (Register 27-7) 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 SSPMSK register (Register 27-6) affects the address matching process. See Section 27.4.10 “SSPMSKx Register” for more information.

27.4.2 SECOND SLAVE MODE ADDRESS, SSPADD2

The SSPADD2 register (Register 27-9) contains a second Slave mode address. To enable the use of this second Slave mode address, bit 0 must be set. 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, Register 27-8, affects the address matching process. See Section 27.4.10 “SSPMSKx Register” for more information.

27.4.2.1 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.

27.4.2.2 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’. A9 and A8 are the two MSb of the 10-bit address and stored in bits 2 and 1 of the SSPADDx register.

After the acknowledge of the high byte, the UA bit is set, and SCL is held low until the user updates SSPADDx with the low address. The low address byte is clocked in and all eight bits are compared to the low address value in SSPADDx. Even if there is no address match, SSPIF and UA are set, and SCL is held low until SSPADDx is updated to receive a high byte again. When SSPADDx 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.

27.4.3 SLAVE RECEPTION

When the R/W bit of a matching received address byte is clear, the R/W bit of 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 of the SSPSTAT register is set, or bit SSPOV of the SSPCON1 register is set. The BOEN bit of the SSPCON3 register modifies this operation. For more information, see Register 27-5.

An MSSP interrupt is generated for each transferred data byte. Flag bit, SSPIF, must be cleared by software. When the SEN bit of 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 of the SSPCON1 register, except sometimes in 10-bit mode.
27.4.3.1 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, all decisions made by hardware or software and their effect on reception. Figure 27-6 and Figure 27-7 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 detected.
2. S bit of SSPSTAT 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 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 ACK to the master, and sets SSPIF bit.
10. Software clears SMDIF.
11. Software reads the received byte from SSPBUF clearing BF.
12. Steps 8–12 are repeated for all received bytes from the Master.

27.4.3.2 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 to ACK the receive address or data byte, rather than the hardware. This functionality adds support for PMBus that was not present on previous versions of this module.

This list describes the steps that need to be taken by slave software to use these options for I2C communication. Figure 27-8 displays a module using both address and data holding. Figure 27-9 includes the operation with the SEN bit of the SSPCON2 register set.

1. S bit of SSPSTAT 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 of the SSPCON3 register to determine if the SSPIF was after or before the ACK.
5. Slave reads the address value from SSPBUF, clearing the BF flag.
6. Slave sets ACK value clocked out to the master by setting ACKDT.
7. Slave releases the clock by setting CKP.
8. SSPxIF is set after an ACK, not after a NACK.
9. If SEN = 1 the slave hardware will stretch the clock after the 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 of SSPCON3 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 ACK = 1, or the master sending a Stop condition. If a Stop is sent and Interrupt on Stop Detect is disabled, the slave will only know by polling the P bit of the SSTSTAT register.
FIGURE 27-6: **I^2C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 0, AHEN = 0, DHEN = 0)**

- Receiving Address
- Receiving Data
- ACK
- A7 A6 A5 A4 A3 A2 A1
- D7 D6 D5 D4 D3 D2 D1 D0
- ACK
- SDA
- SCL
- SSPIF
- BF
- SSPOV
- From Slave to Master
- Bus Master sends Stop condition
- SSPOV set because SSPBUF is still full.
- ACK is not sent.
- ACK
- First byte of data is available in SSPBUF
- SSPBF is read
- Cleared by software
- SSPIF set on 9th falling edge of SCL
- Cleared by software
- Cleared by software
- 12345678 12345678 123456789 9 9
- ACK
- S
- P
FIGURE 27-7: \(^2\)C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 1, AHEN = 0, DHEN = 0)

- Clock is held low until CKP is set to ‘1’
- SSPIF set on 9th falling edge of SCL
- First byte of data is available in SSPBUF
- SSPOV set because SSPBUF is still full, ACK is not sent.
- CKP is written to ‘1’ in software, releasing SCL
- SCL is not held low because \(\text{ACK} = 1\)

Note: SDA and SCL are labeled as 'P'.
FIGURE 27-8: I²C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 0, AHEN = 1, DHEN = 1)
FIGURE 27-9:  \( \text{I}^2\text{C SLAVE, 7-BIT ADDRESS, RECEPTION (SEN = 1, AHEN = 1, DHEN = 1)} \)

- **SDA**: Receiving Address
- **SCL**: Master releases SDA to slave for ACK sequence
- **BF**: Received address is loaded into SSPBUF
- **ACKDT**: Slave software clears ACKDT to ACK the received byte
- **CKP**: When AHEN = 1:
  - on the 8th falling edge of SCL of an address byte, CKP is cleared
  - on the 8th falling edge of SCL of a received data byte, CKP is cleared
- **ACKTIM**: ACKTIM is set by hardware on 8th falling edge of SCL
  - ACKTIM is cleared by hardware on 9th rising edge of SCL
- **R/W = 0**: Master releases SDA to slave for ACK sequence
- **ACK**: ACKDT is cleared by software
- **SSPBUF**: SSPBUF can be set by software, read any time before next byte is loaded
- **SSPIF**: Cleared by software
- **ACKDT**: Slave sends not ACK
- **CKP**: CKP is not cleared if not ACK
- **ACKTIM**: Set by software, release SCL
- **Stop condition**: No interrupt after if not ACK from Slave
- **ACKTIM**: ACKTIM is cleared by hardware on 9th rising edge of SCL
27.4.4 SLAVE TRANSMISSION

When the R/W bit of the incoming address byte is set and an address match occurs, the R/W bit of the SSPSTAT register is set. The received address is loaded into the SSPBUF register, and an ACK pulse is sent by the slave on the ninth bit.

Following the ACK, slave hardware clears the CKP bit and the SCL pin is held low (see Section 27.4.7 “Clock Stretching” for more detail). By stretching the clock, the master will be unable to assert another clock pulse until the slave is done preparing the transmit data.

The transmit data must be loaded into the SSPBUF register which also loads the SSPSR register. Then the SCL pin should be released by setting the CKP bit of 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 ACK pulse from the master-receiver is latched on the rising edge of the ninth SCL input pulse. This ACK value is copied to the ACKSTAT bit of the SSPCON2 register. If ACKSTAT is set (not ACK), then the data transfer is complete. In this case, when the not 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 (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 ninth clock pulse.

27.4.4.1 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 of the SSPCON3 register is set, the BCLIF bit of the PIR register is set. Once a bus collision is detected, the slave goes Idle and waits to be addressed again. User software can use the BCLIF bit to handle a slave bus collision.

27.4.4.2 7-bit Transmission

A master device can transmit a read request to a slave, and then clock data out of the slave. The list below outlines what software for a slave will need to do to accomplish a standard transmission. Figure 27-10 can be used as a reference to this list.

1. Master sends a Start condition on SDA and SCL.
2. S bit of SSPSTAT is set; SSPIF is set if interrupt on Start detect is enabled.
3. Matching address with R/W bit is received by the Slave setting SSPIF bit.
4. Slave hardware generates an ACK and sets SSPIF.
5. SSPIF bit is cleared by user.
6. Software reads the received address from SSPBUF, clearing BF.
7. R/W is set so CKP was automatically cleared after the 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 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 ACKs the clock will be stretched.

2: ACKSTAT is the only bit updated on the rising edge of SCL (9th) rather than the falling.

13. Steps 9-13 are repeated for each transmitted byte.
14. If the master sends a not 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 27-10: \( \text{I}^2\text{C} \) SLAVE, 7-BIT ADDRESS, TRANSMISSION (AHEN = 0)

- **Receiving Address**: Automatic
- **Transmitting Data**: Automatic

- **SDA**: Received address is read from SSPBUF
- **SCL**: When R/W is set, SCL is always held low after 9th SCL falling edge
- **BF**: Data to transmit is loaded into SSPBUF
- **ACKSTAT**: BF is automatically cleared after 8th falling edge of SCL
- **CKP**: CKP is not held for not ACK
- **ACK**: Masters not ACK is copied to ACKSTAT
- **R/W**: R/W is copied from the matching address byte
- **D/A**: Indicates an address has been received

- **SSPIF**: Cleared by software
- **Master sends Stop condition**
27.4.4.3 7-bit Transmission with Address Hold Enabled

Setting the AHEN bit of 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 27-11 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 of SSPSTAT is set; SSPIF is set if interrupt on Start detect is enabled.
3. Master sends matching address with 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 ACKTIM bit of SSPCON3 register, and R/W and D/A of 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 of the SSPCON2 register accordingly.
8. Slave sets the CKP bit releasing SCL.
9. Master clocks in the ACK value from the slave.
10. Slave hardware automatically clears the CKP bit and sets SSPIF after the ACK if the 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 ACK value on the 9th SCL pulse.
15. Slave hardware copies the ACK value into the ACKSTAT bit of 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 ACK, the slave releases the bus, allowing the master to send a Stop and end the communication.

**Note:** Master must send a not ACK on the last byte to ensure that the slave releases the SCL line to receive a Stop.
FIGURE 27-11: I²C SLAVE, 7-BIT ADDRESS, TRANSMISSION (AHEN = 1)

- Master releases SDAx to slave for ACK sequence
- Receiving Address is read from SSPBUF
- BF is automatically cleared after 8th falling edge of SCL
- Data to transmit is loaded into SSPBUF
- ACKDT is cleared by software
- Slave clears ACKDT to ACK
- ACKTIM is set on 8th falling edge of SCL
- ACKTIM is cleared on 9th rising edge of SCL
- Master’s ACK response is copied to SSPSTAT
- CKP not cleared after not ACK

- When AHEN = 1:
  - CKP is cleared by hardware after receiving matching address.
- When R/W = 1:
  - CKP is always cleared after ACK
  - Set by software, releases SCL

- Master sends Stop condition

- Received address
- Automatic
- Transmitting Data
- Automatic
- Transmitting Data

- Received address
- Automatic
- Transmitting Data
- Automatic
- Transmitting Data

- BF
- ACCDT
- ACKSTAT
- CKP
- ACKTIM
- R/W
- D/A
27.4.5 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 27-12 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 of SSPSTAT is set; SSPIF is set, if interrupt on Start detect is enabled.
3. Master sends matching high address with R/W bit clear; UA bit of the SSPSTAT register is set.
4. Slave sends 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 SSPADDx, releasing SCL.
8. Master sends matching low-address byte to the Slave; UA bit is set.

**Note:** Updates to the SSPADDx register are not allowed until after the ACK sequence.

9. Slave sends 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 SSPADDx 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 ACK on the 9th SCL pulse; SSPIF is set.
14. If SEN bit of SSPCON2 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 repeat for each received byte.
19. Master sends Stop to end the transmission.

27.4.6 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 SSPADDx register using the UA bit. All functionality, specifically when the CKP bit is cleared and SCL line is held low, are the same.

Figure 27-13 can be used as a reference of a slave in 10-bit addressing with AHEN set.

Figure 27-14 shows a standard waveform for a slave transmitter in 10-bit Addressing mode.
FIGURE 27-12: \( \text{I}^2\text{C} \) SLAVE, 10-BIT ADDRESS, RECEPTION (SEN = 1, AHEN = 0, DHEN = 0)

- **SSPIF**: Set by hardware on 9th falling edge.
- **BF**: If address matches SSPADD it is loaded into SSPBUF.
- **UA**: When UA = 1; SCL is held low.
- **CKP**: When SEN = 1; CKP is cleared after 9th falling edge of received byte.
- **Receive Second Address Byte**: 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9.
- **Receive Data**: 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9.
- **Receive Data**: 1 2 3 4 5 6 7 8 9 1 2 3 4 5 6 7 8 9.
- **Master sends Stop condition**: SCL is held low while CKP = 0.
- **Data is read from SSPBUF**: Set by software, releasing SCL.
- **Receive address is read from SSPBUF**: Cleared by software.
- **Software updates SSPADD**: and releases SCL.
- **When UA = 1; SCL is held low**: Set by hardware on 9th falling edge. 
- **Receive First Address Byte**: Receive data is read from SSPBUF.
- **Receive Second Address Byte**: Receive data is read from SSPBUF.
- **SCL is held low**: SCL is held low while CKP = 0.
- **Receive First Address Byte**: Receive data is read from SSPBUF.
- **Receive Second Address Byte**: Receive data is read from SSPBUF.
- **SCL is held low**: SCL is held low while CKP = 0.
- **Receive First Address Byte**: Receive data is read from SSPBUF.
- **Receive Second Address Byte**: Receive data is read from SSPBUF.
FIGURE 27-13: \( \text{i}^{2}\text{C SLAVE, 10-BIT ADDRESS, RECEPTION (SEN = 0, AHEN = 1, DHEN = 0)} \)
FIGURE 27-14: **I²C SLAVE, 10-BIT ADDRESS, TRANSMISSION (SEN = 0, AHEN = 0, DHEN = 0)**

- **Receiving Address**
  - Master sends **Stop condition**

- **Receiving Second Address Byte**
  - Master sends **not ACK**

- **Receive First Address Byte**
  - Masters not ACK
  - Data to transmit is loaded into SSPBUF

- **Transmitting Data Byte**
  - ACKSTAT

- **SCL**
  - **BF**
  - **UA**
  - **CKP**
  - **ACKSTAT**
  - **R/W**
  - **D/A**
27.4.7 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 anytime it is active on the bus and not transferring data, it is stretching. Any stretching done by a slave is invisible to the master software and handled by the hardware that generates SCL.

The CKP bit of 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.

27.4.7.1 Normal Clock Stretching

Following an ACK, if the R/W bit of the SSPSTAT 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 of SSPCON2 is set, the slave hardware will always stretch the clock after the ACK sequence. Once the slave is ready; CKP is set by software and communication resumes.

**Note 1:** The BF bit has no effect on if the clock will be stretched or not. This is different than previous versions of the module that would not stretch the clock or clear CKP, if SSPBUF was read before the 9th falling edge of SCL.

**Note 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.

27.4.7.2 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 SSPADDx.

**Note:** Previous versions of the module did not stretch the clock if the second address byte did not match.

27.4.7.3 Byte NACKing

When AHEN bit of SSPCON3 is set; CKP is cleared by the hardware after the 8th falling edge of SCL for a received matching address byte. When DHEN bit of SSPCON3 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.

27.4.8 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 (see Figure 27-15).

**FIGURE 27-15: CLOCK SYNCHRONIZATION TIMING**

![Diagram of clock synchronization timing](image-url)
27.4.9 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 of the SSPCON2 register is set, the slave module will automatically ACK the reception of this address, regardless of the value stored in SSPADDx. 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 27-16 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 the 7-bit mode.

If the AHEN bit of 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 27-16: SLAVE MODE GENERAL CALL ADDRESS SEQUENCE

27.4.10 SSPMSKX REGISTER

An SSP Mask (SSPMSKx) register (Register 27-6 and Register 27-8) is available in I2C Slave mode as a mask for the value held in the SSPSRRx register during an address comparison operation. A zero ('0') bit in the SSPMSKx 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 SSP Mask register is active during:
- 7-bit Address mode: address compare of A<7:1>.
- 10-bit Address mode: address compare of A<7:0> only. The SSP mask has no effect during the reception of the first (high) byte of the address.
27.5  I\(^2\)C 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.

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 I\(^2\)C bus may be taken when the P bit is set, or the bus is Idle.

In Firmware Controlled Master mode, user code conducts all I\(^2\)C bus operations based on Start and Stop bit condition detection. Start and Stop condition detection is the only active circuitry in this mode. All other communication is done by the user software directly manipulating the 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 I\(^2\)C 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.

27.5.1  I\(^2\)C 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 I\(^2\)C bus will not be released.

In Master Transmitter 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 eight 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 eight bits at a time. After each byte is received, an Acknowledge bit is transmitted. Start and Stop conditions indicate the beginning and the end of transmission.

A Baud Rate Generator is used to set the clock frequency output on SCL. See Section 27.6 “Baud Rate Generator” for more detail.

27.5.2  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 27-17).
27.5.3 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 five bits of SSPCON2 is disabled until the Start condition is complete.

27.5.4 I²C MASTER MODE START CONDITION TIMING

To initiate a Start condition, the user sets the Start Enable bit, SEN bit of 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 (TBRG), the SDA pin is driven low. The action of the SDA being driven low while SCL is high is the Start condition and causes the S bit of the SSPSTAT 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 (TBRG), the SEN bit of 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.

2: The Philips I²C Specification states that a bus collision cannot occur on a Start.

**FIGURE 27-18: FIRST START BIT TIMING**

<table>
<thead>
<tr>
<th>Write to SEN bit occurs here</th>
<th>Set S bit (SSPSTAT&lt;3&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDA = 1, SCL = 1</td>
<td></td>
</tr>
<tr>
<td>TBRG</td>
<td></td>
</tr>
<tr>
<td>Write to SSPBUF occurs here</td>
<td></td>
</tr>
<tr>
<td>1st bit</td>
<td>2nd bit</td>
</tr>
<tr>
<td>S</td>
<td></td>
</tr>
<tr>
<td>TBRG</td>
<td></td>
</tr>
<tr>
<td>TBRG</td>
<td></td>
</tr>
</tbody>
</table>
27.5.5  I²C MASTER MODE REPEATED START CONDITION TIMING

A Repeated Start condition occurs when the RSEN bit of the SSPCON2 register is programmed high and the Master state machine is no longer active. When the RSEN bit is set, the SCL pin is asserted low. When the SCL pin is sampled low, the Baud Rate Generator is loaded and begins counting. The SDA pin is released (brought high) for one Baud Rate Generator count (TBRG). When the Baud Rate Generator times out, if SDA is sampled high, the SCL pin will be deasserted (brought high). When SCL is sampled high, the Baud Rate Generator is reloaded and begins counting. SDA and SCL must be sampled high for one TBRG. This action is then followed by the assertion of the SDA pin (SDA = 0) for one TBRG while SCL is high. SCL is asserted low. Following this, the RSEN bit of the SSPCON2 register will be automatically cleared and the Baud Rate Generator will not be reloaded, leaving the SDA pin held low. As soon as a Start condition is detected on the SDA and SCL pins, the S bit of the SSPSTAT register will be set. The SSPIF bit will not be set until the Baud Rate Generator has timed out.

**FIGURE 27-19: REPEAT START CONDITION WAVEFORM**

1. If RSEN is programmed while any other event is in progress, it will not take effect.
2. A bus collision during the Repeated Start condition occurs if:
   - SDA is sampled low when SCL goes from low-to-high.
   - SCL goes low before SDA is asserted low. This may indicate that another master is attempting to transmit a data '1'.

---

© 2013 Microchip Technology Inc.
27.5.6 I\textsuperscript{2}C MASTER MODE

TRANSMISSION

Transmission of a data byte, a 7-bit address or the other half of a 10-bit address is accomplished by simply writing a value to the SSPBUF register. This action will set the Buffer Full flag bit, BF, and will 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 8\textsuperscript{th} bit is shifted out (the falling edge of the 8\textsuperscript{th} clock), the BF flag is cleared and the master releases the SDA. This allows the slave device being addressed to respond with an ACK bit during the 9\textsuperscript{th} 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 9\textsuperscript{th} clock. If the master receives an Acknowledge, the Acknowledge Status bit, ACKSTAT, is cleared. If not, the bit is set. After the 9\textsuperscript{th} 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 27-20).

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 8\textsuperscript{th} clock, the master will release the SDA pin, allowing the slave to respond with an Acknowledge. On the falling edge of the 9\textsuperscript{th} 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 of the SSPCON2 register. Following the falling edge of the 9\textsuperscript{th} 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.

27.5.6.1 BF Status Flag

In Transmit mode, the BF bit of the SSPSTAT register is set when the CPU writes to SSPBUF, and is cleared when all eight bits are shifted out.

27.5.6.2 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.

27.5.6.3 ACKSTAT Status Flag

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

27.5.6.4 Typical transmit sequence

1. The user generates a Start condition by setting the SEN bit of 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 eight 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 of the SSPCON2 register.
8. The MSSP module generates an interrupt at the end of the 9\textsuperscript{th} clock cycle by setting the SSPIF bit.
9. The user loads the SSPBUF with eight bits of data.
10. Data is shifted out the SDA pin until all eight 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 of 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 of the SSPCON2 register. Interrupt is generated once the Stop/Restart condition is complete.
FIGURE 27-20: I²C MASTER MODE WAVEFORM (TRANSMISSION, 7 OR 10-BIT ADDRESS)

1. **Write SSPCON2<0> SEN = 1**
   - Start condition begins

2. **SEN = 0**
   - Transmit Address to Slave
   - R/W = 0
   - Transmitting Data or Second Half of 10-bit Address

3. **Starting from slave, clear ACKSTAT bit SSPCON2<6>**
   - SSPBUF written with 7-bit address and R/W
   - SCL held low while CPU responds to SSPIF
   - SSPBUF written
   - SSPBUF is written by software

4. **Cleared by software service routine from SSP interrupt**
   - Cleared by software

5. **After Start condition, SEN cleared by hardware**

6. **BF (SSPSTAT<0>)**
   - SSPBUF written

7. **Acknowledgment**
   - ACK
   - SSPBUF is written by software

8. **ACKSTAT in SSPCON2 = 1**

9. **Cleared by software**
27.5.7 I2C MASTER MODE RECEPTION

Master mode reception is enabled by programming the Receive Enable bit, RCEN bit, of 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 on each rollover, the state of the SCL pin changes (high-to-low/low-to-high) and data is shifted into the SSPSR. After the falling edge of the eighth clock, the receive enable flag is automatically cleared, the contents of the SSPSR are loaded into the SSPBUF, the BF flag bit is set, the SSPIF flag bit is set and the Baud Rate Generator is suspended from counting, holding SCL low. The MSSP is now in Idle state awaiting the next command. When the buffer is read by the CPU, the BF flag bit is automatically cleared. The user can then send an Acknowledge bit at the end of reception by setting the Acknowledge Sequence Enable, ACKEN bit, of the SSPCON2 register.

27.5.7.1 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.

27.5.7.2 SSPOV Status Flag

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

27.5.7.3 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).

27.5.7.4 Typical Receive Sequence:

1. The user generates a Start condition by setting the SEN bit of the SSPCON2 register.
2. SSPIF is set by hardware on completion of the Start.
3. SSPIF is cleared by software.
4. The user writes SSPBUF with the slave address to transmit and the R/W bit set.
5. Address is shifted out the SDA pin until all eight bits are transmitted. Transmission begins as soon as SSPBUF is written to.
6. The MSSP module shifts in the ACK bit from the slave device and writes its value into the ACKSTAT bit of 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 of 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, clears BF.
11. Master sets ACK value sent to slave in ACKDT bit of the SSPCON2 register and initiates the ACK by setting the ACKEN bit.
12. Masters 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 ACK or Stop to end communication.

Note: The MSSP module must be in an Idle state before the RCEN bit is set, or the RCEN bit will be disregarded.
FIGURE 27-21: I²C MASTER MODE WAVEFORM (RECEPTION, 7-BIT ADDRESS)

- **SSPIF**: Set SSPIF interrupt at end of receive.
- **BF**: (SSPSTAT<0>)
  - **SSPOV**: Set because SSPBUF is still full.
  - **ACKEN**: Set ACKEN, start Acknowledge sequence.
  - **RCEN**: RCEN cleared automatically.
  - **SEN**: Write to SSPCON2<0> (SEN = 1), begin Start condition.
  - **SDA**: Transmit Address to Slave, Write to SSPBUF occurs here, ACK from Slave.
  - **SCL**: Master configured as a receiver by programming SSPCON2<3> (RCEN = 1).
  - **RCEN**: RCEN cleared automatically.
  - **SDA**: ACK from Master.
  - **R/W**: Transmit Address to Slave.
  - **ACK**: Set ACKEN, start Acknowledge sequence.
  - **SSPOV**: SSPOV is set because SSPBUF is still full.
  - **ACKEN**: Set ACKEN, start Acknowledge sequence.
  - **RCEN**: RCEN cleared automatically.
  - **SEN**: Write to SSPCON2<4> to start Acknowledge sequence.
  - **SDA**: ACKDT (SSPCON2<5>) = 0.
27.5.8 ACKNOWLEDGE SEQUENCE TIMING

An Acknowledge sequence is enabled by setting the Acknowledge Sequence Enable bit, ACKEN bit, of 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 (TBRG) and the SCL pin is deasserted (pulled high). When the SCL pin is sampled high (clock arbitration), the Baud Rate Generator counts for TBRG. 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 27-22).

27.5.8.1 WCOL Status Flag

If the user writes the SSPBUF when an Acknowledge sequence is in progress, then WCOL is set and the contents of the buffer are unchanged (the write does not occur).

FIGURE 27-22: ACKNOWLEDGE SEQUENCE WAVEFORM

![Diagram of Acknowledge Sequence Waveform]

Note: TBRG = one Baud Rate Generator period.

27.5.9 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 bit of 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 one TBRG (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 of the SSPSTAT register is set. A TBRG later, the PEN bit is cleared and the SSPIF bit is set (Figure 27-23).

27.5.9.1 WCOL Status Flag

If the user writes the SSPBUF when a Stop sequence is in progress, then the WCOL bit is set and the contents of the buffer are unchanged (the write does not occur).

FIGURE 27-23: STOP CONDITION RECEIVE OR TRANSMIT MODE

![Diagram of Stop Condition Waveform]

Note: TBRG = one Baud Rate Generator period.
27.5.10 SLEEP OPERATION
While in Sleep mode, the \( I^2C \) slave module can receive addresses or data, and when an address match or complete byte transfer occurs, wakes the processor from Sleep (if the MSSP interrupt is enabled).

27.5.11 EFFECTS OF A RESET
A Reset disables the MSSP module and terminates the current transfer.

27.5.12 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 \( I^2C \) bus may be taken when the P bit of 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

27.5.13 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’, then a bus collision has taken place. The master will set the Bus Collision Interrupt Flag, BCLIF and reset the \( I^2C \) port to its Idle state (Figure 27-24).

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 \( I^2C \) 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 \( I^2C \) 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 \( I^2C \) 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 27-24: BUS COLLISION TIMING FOR TRANSMIT AND ACKNOWLEDGE**

![Bus Collision Timing Diagram](image)

- Data changes while SCL = 0
- SDA line pulled low by another source
- SDA released by master
- Sample SDA. While SCL is high, data does not match what is driven by the master. Bus collision has occurred.
- Set bus collision interrupt (BCLIF)
27.5.13.1 Bus Collision During a Start Condition

During a Start condition, a bus collision occurs if:

a) SDA or SCL are sampled low at the beginning of the Start condition (Figure 27-25).
b) SCL is sampled low before SDA is asserted low (Figure 27-26).

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, then 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 27-25).

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 27-27). 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 that bus collision is not a factor during a Start condition is that no two bus masters can assert a Start condition at the exact same time. Therefore, one master will always assert 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 27-25: BUS COLLISION DURING START CONDITION (SDA ONLY)**

- SDA goes low before the SEN bit is set.
  - Set BCLIF, S bit and SSPIF set because SDA = 0, SCL = 1.

- SEN
  - Set SEN, enable Start condition if SDA = 1, SCL = 1
  - SDA sampled low before Start condition. Set BCLIF. S bit and SSPIF set because SDA = 0, SCL = 1.
  - SEN cleared automatically because of bus collision. SSP module reset into Idle state.

- BCLIF
  - SSPIF and BCLIF are cleared by software

- SSPIF
  - SSPIF and BCLIF are cleared by software

- S
  - SDA = 0, SCL = 1.

- SCL
  - SDA = 0, SCL = 1.

DS20002331B-page 178 © 2013 Microchip Technology Inc.
FIGURE 27-26: BUS COLLISION DURING START CONDITION (SCL = 0)

SDA = 0, SCL = 1

SCL

SEN

SCL = 0 before SDA = 0, bus collision occurs. Set BCLIF.

SCL = 0 before SDA = 0, bus collision occurs. Set BCLIF.

Interrupt cleared by software

SDA pulled low by other master.
Reset BRG and assert SDAx.

Set SEN, enable Start sequence if SDA = 1, SCL = 1

FIGURE 27-27: BRG RESET DUE TO SDA ARBITRATION DURING START CONDITION

SDA = 0, SCL = 1

Set S

Set SSPIF

SCL

SEN

SCLx pulled low after BRG time-out

Set SEN, enable Start sequence if SDA = 1, SCL = 1

'B0'

BCLIF

SDAx = 0, SCL = 1, set SSPIF

Interrupts cleared by software

SDA pulled low by other master.
Reset BRG and assert SDAx.

Set S

S

SSPIF

'0'

'0'

SDA

'0'

SSPIF

'0'

'0'
27.5.13.2 Bus Collision During a Repeated Start Condition

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

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

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

If SDA is low, a bus collision has occurred (i.e., another master is attempting to transmit a data ‘0’, Figure 27-28).
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 (see Figure 27-29.)
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 27-28: BUS COLLISION DURING A REPEATED START CONDITION (CASE 1)

FIGURE 27-29: BUS COLLISION DURING REPEATED START CONDITION (CASE 2)
27.5.13.3 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 0. 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 27-30). 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 27-31).

**FIGURE 27-30: BUS COLLISION DURING A STOP CONDITION (CASE 1)**

- **SDA**
- **SCL**
- **PEN**
- **BCLIF**
- **SSPIF**

- **T_{BRG}**
- **T_{BRG}**
- **T_{BRG}**

SDA asserted low

- **SDA**
- **SCL**
- **PEN**
- **BCLIF**
- **SSPIF**

- **T_{BRG}**
- **T_{BRG}**
- **T_{BRG}**

SDA sampled low after T_{BRG} set BCLIF

**FIGURE 27-31: BUS COLLISION DURING A STOP CONDITION (CASE 2)**

- **SDA**
- **SCL**
- **PEN**
- **BCLIF**
- **SSPIF**

- **T_{BRG}**
- **T_{BRG}**
- **T_{BRG}**

SCL goes low before SDA goes high, set BCLIF

- **SDA**
- **SCL**
- **PEN**
- **BCLIF**
- **SSPIF**

- **T_{BRG}**
- **T_{BRG}**
- **T_{BRG}**

Assert SDA

- **SDA**
- **SCL**
- **PEN**
- **BCLIF**
- **SSPIF**

- **T_{BRG}**
- **T_{BRG}**
- **T_{BRG}**

SCL goes low before SDA goes high, set BCLIF

- **P**

- **T_{BRG}**
- **T_{BRG}**
- **T_{BRG}**

Set BCLIF

- **P**

- **T_{BRG}**
- **T_{BRG}**
- **T_{BRG}**

Set BCLIF

- **P**

- **T_{BRG}**
- **T_{BRG}**
- **T_{BRG}**

Set BCLIF

- **P**
TABLE 27-1: SUMMARY OF REGISTERS ASSOCIATED WITH I²C OPERATION

<table>
<thead>
<tr>
<th>Name</th>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
<th>Reset Values on Page:</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTCON GIE</td>
<td>PEIE</td>
<td>T0IE</td>
<td>INTE</td>
<td>IOCE</td>
<td>T0IF</td>
<td>INTF</td>
<td>IOCF</td>
<td></td>
<td>95</td>
</tr>
<tr>
<td>PIE1</td>
<td></td>
<td>ADIE</td>
<td>BCLIE</td>
<td>SSPIE</td>
<td></td>
<td></td>
<td>TMR2IE</td>
<td>TMR1IE</td>
<td>96</td>
</tr>
<tr>
<td>PIR1</td>
<td></td>
<td>ADIF</td>
<td>BCLIF</td>
<td>SSPIF</td>
<td></td>
<td></td>
<td>TMR2IF</td>
<td>TMR1IF</td>
<td>98</td>
</tr>
<tr>
<td>TRISGPA</td>
<td>TRISA7</td>
<td>TRISA6</td>
<td>TRISA5</td>
<td>TRISA4</td>
<td>TRISA3</td>
<td>TRISA2</td>
<td>TRISA1</td>
<td>TRISA0</td>
<td>114</td>
</tr>
<tr>
<td>TRISGPB</td>
<td>TRISB7</td>
<td>TRISB6</td>
<td>TRISB5</td>
<td>TRISB4</td>
<td>TRISB3</td>
<td>TRISB2</td>
<td>TRISB1</td>
<td>TRISB0</td>
<td>117</td>
</tr>
<tr>
<td>SSPADD</td>
<td>ADD7</td>
<td>ADD6</td>
<td>ADD5</td>
<td>ADD4</td>
<td>ADD3</td>
<td>ADD2</td>
<td>ADD1</td>
<td>ADD0</td>
<td>188</td>
</tr>
<tr>
<td>SSPBUF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>148*</td>
</tr>
<tr>
<td>SSPCON1</td>
<td>WCOL</td>
<td>SSPOV</td>
<td>SSPEN</td>
<td>CKP</td>
<td>SSPM3</td>
<td>SSPM2</td>
<td>SSPM1</td>
<td>SSPM0</td>
<td>185</td>
</tr>
<tr>
<td>SSPCON2</td>
<td>GCEN</td>
<td>ACKSTAT</td>
<td>ACKDT</td>
<td>ACKEN</td>
<td>RCEN</td>
<td>PEN</td>
<td>RSEN</td>
<td>SEN</td>
<td>186</td>
</tr>
<tr>
<td>SSPCON3</td>
<td>ACKTIM</td>
<td>PCIE</td>
<td>SCIE</td>
<td>BOEN</td>
<td>SDAHT</td>
<td>SBCDE</td>
<td>AHEN</td>
<td>DHEN</td>
<td>187</td>
</tr>
<tr>
<td>SSPMSK</td>
<td>MSK7</td>
<td>MSK6</td>
<td>MSK5</td>
<td>MSK4</td>
<td>MSK3</td>
<td>MSK2</td>
<td>MSK1</td>
<td>MSK0</td>
<td>188</td>
</tr>
<tr>
<td>SSPSTAT</td>
<td>SMP</td>
<td>CKE</td>
<td>D/A</td>
<td>P</td>
<td>S</td>
<td>R/W</td>
<td>UA</td>
<td>BF</td>
<td>184</td>
</tr>
<tr>
<td>SSPMSK2</td>
<td>MSK27</td>
<td>MSK26</td>
<td>MSK25</td>
<td>MSK24</td>
<td>MSK23</td>
<td>MSK22</td>
<td>MSK21</td>
<td>MSK20</td>
<td>189</td>
</tr>
<tr>
<td>SSPADD2</td>
<td>ADD27</td>
<td>ADD26</td>
<td>ADD25</td>
<td>ADD24</td>
<td>ADD23</td>
<td>ADD22</td>
<td>ADD21</td>
<td>ADD20</td>
<td>189</td>
</tr>
</tbody>
</table>

Legend: — = unimplemented, read as '0'. Shaded cells are not used by the MSSP module in I²C mode.
* Page provides register information.
27.6 BAUD RATE GENERATOR

The MSSP module has a Baud Rate Generator available for clock generation in \(i^2C\) Master mode. The Baud Rate Generator (BRG) reload value is placed in the SSPADD register (Register 27-7). 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 27-32 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 27-2 demonstrates clock rates based on instruction cycles and the BRG value loaded into SSPADD.

EQUATION 27-1:

\[
F_{CLOCK} = \frac{F_{OSC}}{(SSPADD + 1)(4)}
\]

![FIGURE 27-32: BAUD RATE GENERATOR BLOCK DIAGRAM](image)

**TABLE 27-2: MSSP CLOCK RATE W/BRG**

<table>
<thead>
<tr>
<th>Fosc</th>
<th>FCY</th>
<th>BRG Value</th>
<th>F_{CLOCK} (2 Rollovers of BRG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 MHz</td>
<td>2 MHz</td>
<td>04h</td>
<td>400 kHz^1</td>
</tr>
<tr>
<td>8 MHz</td>
<td>2 MHz</td>
<td>0Bh</td>
<td>166 kHz</td>
</tr>
<tr>
<td>8 MHz</td>
<td>2 MHz</td>
<td>13h</td>
<td>100 kHz</td>
</tr>
</tbody>
</table>

**Note 1:** The \(i^2C\) interface does not conform to the 400 kHz \(i^2C\) 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.

Note: Values of 0x00, 0x01 and 0x02 are not valid for SSPADD when used as a Baud Rate Generator for \(i^2C\). This is an implementation limitation.
### REGISTER 27-2: SSPSTAT: SSP STATUS REGISTER

<table>
<thead>
<tr>
<th>bit 7</th>
<th>SMP: Data Input Sample bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slew rate control disabled for standard speed mode (100 kHz and 1 MHz)</td>
</tr>
<tr>
<td>0</td>
<td>Slew rate control enabled for high speed mode (400 kHz)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>bit 6</th>
<th>CKE: Clock Edge Select bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Enable input logic so that thresholds are compliant with SMBus specification</td>
</tr>
<tr>
<td>0</td>
<td>Disable SMBus specific inputs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>bit 5</th>
<th>D/A: Data/Address bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indicates that the last byte received or transmitted was data</td>
</tr>
<tr>
<td>0</td>
<td>Indicates that the last byte received or transmitted was address</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>bit 4</th>
<th>P: Stop bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indicates that a Stop bit has been detected last (this bit is ‘0’ on Reset)</td>
</tr>
<tr>
<td>0</td>
<td>Stop bit was not detected last</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>bit 3</th>
<th>S: Start bit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indicates that a Start bit has been detected last (this bit is ‘0’ on Reset)</td>
</tr>
<tr>
<td>0</td>
<td>Start bit was not detected last</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>bit 2</th>
<th>R/W: Read/Write bit information</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This bit holds the R/W bit information following the last address match. This bit is only valid from the address match to the next Start bit, Stop bit, or not ACK bit.</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>bit 1</th>
<th>UA: Update Address bit (10-bit I²C mode only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indicates that the user needs to update the address in the SSPADD register</td>
</tr>
<tr>
<td>0</td>
<td>Address does not need to be updated</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>bit 0</th>
<th>BF: Buffer Full Status bit</th>
</tr>
</thead>
</table>

**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
REGISTER 27-3:  SSPCON1: SSP CONTROL REGISTER 1

<table>
<thead>
<tr>
<th>R/C/HS-0</th>
<th>R/C/HS-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>WCOL</td>
<td>SSPOV</td>
<td>SSPEN</td>
<td>CKP</td>
<td>SSPM&lt;3:0&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

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 = FOSC/(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.
REGISTER 27-4: SSPCON2: SSP CONTROL REGISTER 2

<table>
<thead>
<tr>
<th>Bit</th>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>GCEN</td>
<td>General Call Enable bit (in I²C Slave mode only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Enable interrupt when a general call address (0x00 or 00h) is received in the SSPSR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 = General call address disabled</td>
</tr>
<tr>
<td>6</td>
<td>ACKSTAT</td>
<td>Acknowledge Status bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Acknowledge was not received</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 = Acknowledge was received</td>
</tr>
<tr>
<td>5</td>
<td>ACKDT</td>
<td>Acknowledge Data bit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In Receive mode: Value transmitted when the user initiates an Acknowledge sequence at the end of a receive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Not Acknowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 = Acknowledge</td>
</tr>
<tr>
<td>4</td>
<td>ACKEN</td>
<td>Acknowledge Sequence Enable bit (in I²C Master mode only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In Master Receive mode: Initiate Acknowledge sequence on SDA and SCL pins, and transmit ACKDT data bit. Automatically cleared by hardware.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Acknowledge sequence Idle</td>
</tr>
<tr>
<td>3</td>
<td>RCEN</td>
<td>Receive Enable bit (in I²C Master mode only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Enables Receive mode for I²C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 = Receive Idle</td>
</tr>
<tr>
<td>2</td>
<td>PEN</td>
<td>Stop Condition Enable bit (in I²C Master mode only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SCK Release Control:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Initiate Stop condition on SDA and SCL pins. Automatically cleared by hardware.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 = Stop condition Idle</td>
</tr>
<tr>
<td>1</td>
<td>RSEN</td>
<td>Repeated Start Condition Enabled bit (in I²C Master mode only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Initiate Repeated Start condition on SDA and SCL pins. Automatically cleared by hardware.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 = Repeated Start condition Idle</td>
</tr>
<tr>
<td>0</td>
<td>SEN</td>
<td>Start Condition Enabled bit (in I²C Master mode only)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In Master mode:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Initiate Start condition on SDA and SCL pins. Automatically cleared by hardware.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 = Start condition Idle</td>
</tr>
<tr>
<td></td>
<td></td>
<td>In Slave mode:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 = Clock stretching is enabled for both slave transmit and slave receive (stretch enabled)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 = Clock stretching is disabled</td>
</tr>
</tbody>
</table>

Note: For bits ACKEN, RCEN, PEN, RSEN, SEN: If the I²C module is not in the Idle mode, this bit may not be set (no spooling) and the SSPBUF may not be written (or writes to the SSPBUF are disabled).
REGISTER 27-5: SSPCON3: SSP CONTROL REGISTER 3

<table>
<thead>
<tr>
<th>Bit 7</th>
<th>Bit 6</th>
<th>Bit 5</th>
<th>Bit 4</th>
<th>Bit 3</th>
<th>Bit 2</th>
<th>Bit 1</th>
<th>Bit 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACKTIM</td>
<td>PCIE</td>
<td>SCIE</td>
<td>BOEN</td>
<td>SDAHT</td>
<td>SBCDE</td>
<td>AHEN</td>
<td>DHEN</td>
</tr>
<tr>
<td>R-0/0</td>
<td>R/W-0/0</td>
<td>R-0/0</td>
<td>R/W-0/0</td>
<td>R-0/0</td>
<td>R/W-0/0</td>
<td>R/W-0/0</td>
<td>R/W-0/0</td>
</tr>
</tbody>
</table>

**Legend:**
- R = Readable bit
- W = Writable bit
- U = Unimplemented bit, read as ‘0’
- -n/n = Value at POR/Value at all other resets

**Legend:**
- ‘1’ = Bit is set
- ‘0’ = Bit is cleared
- x = Bit is unknown

**bit 7 ACKTIM:** Acknowledge Time Status bit\(^{(2)}\)

1 = Indicates the I\(^2\)C bus is in an Acknowledge sequence, set on the 8\(^{th}\) falling edge of SCL clock.
0 = Not an Acknowledge sequence, cleared on the 9\(^{th}\) rising edge of SCL clock.

**bit 6 PCIE:** Stop Condition Interrupt Enable bit

1 = Enable interrupt on detection of Stop condition
0 = Stop detection interrupts are disabled\(^{(1)}\)

**bit 5 SCIE:** Start Condition Interrupt Enable bit

1 = Enable interrupt on detection of Start or Restart conditions
0 = Start detection interrupts are disabled\(^{(1)}\)

**bit 4 BOEN:** Buffer Overwrite Enable bit

- **In I\(^2\)C Master mode:**
  - This bit is ignored.
- **In I\(^2\)C Slave mode:**
  - 1 = SSPBUF is updated and 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 (I\(^2\)C Slave mode only)

If on the rising edge of SCL, SDA is sampled low when the module is outputting a high state, the BCLIF bit of the PIR2 register is set, and bus goes Idle.

- 1 = Enable slave bus collision interrupts
- 0 = Slave bus collision interrupts are disabled

**bit 1 AHEN:** Address Hold Enable bit (I\(^2\)C Slave mode only)

1 = Following the 8\(^{th}\) falling edge of SCL for a matching received address byte; CKP bit of 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 (I\(^2\)C Slave mode only)

1 = Following the 8\(^{th}\) falling edge of SCL for a received data byte; slave hardware clears the CKP bit of the SSPCON1 register and SCL is held low.
0 = Data holding is disabled

**Note 1:** This bit has no effect in Slave modes that Start and Stop condition detection is explicitly listed as enabled.

**Note 2:** The ACKTIM Status bit is only active when the AHEN bit or DHEN bit is set.
### REGISTER 27-6: SSPMSK: SSP MASK REGISTER 1

<table>
<thead>
<tr>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bit 0</td>
</tr>
</tbody>
</table>

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

**bit 7-1**
- **MSK<7:1>:** Mask bits
  - 1 = The received address bit n is compared to SSPADD<n> to detect \(^2\text{C}\) address match
  - 0 = The received address bit n is not used to detect \(^2\text{C}\) address match

**bit 0**
- **MSK<0>:** Mask bit for \(^2\text{C}\) Slave mode, 10-bit Address
  - \(^2\text{C}\) Slave mode, 10-bit address (SSPM<3:0> = 0111 or 1111):
  - 1 = The received address bit 0 is compared to SSPADD<0> to detect \(^2\text{C}\) address match
  - 0 = The received address bit 0 is not used to detect \(^2\text{C}\) address match
  - \(^2\text{C}\) Slave mode, 7-bit address, the bit is ignored

### REGISTER 27-7: SSPADD: MSSP ADDRESS AND BAUD RATE REGISTER 1

<table>
<thead>
<tr>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bit 7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>bit 0</td>
</tr>
</tbody>
</table>

#### 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

**Master mode:**

**bit 7-0**
- **ADD<7:0>:** Baud Rate Clock Divider bits
  - SCL pin clock period = \(((ADD<7:0> + 1) \times 4) / F_{\text{OSC}}\)

**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 \(^2\text{C}\) 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”.

---

© 2013 Microchip Technology Inc.
REGISTER 27-8: SSPMSK2: SSP MASK REGISTER 2

<table>
<thead>
<tr>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
<th>R/W-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSK2&lt;7:0&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

bit 7-1 MSK2<7:1>: Mask bits
1 = The received address bit n is compared to SSPADD2<7> 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 27-9: SSPADD2: MSSP ADDRESS 2

<table>
<thead>
<tr>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
<th>R/W-0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADD2&lt;7:0&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

Master mode:

bit 7-0 ADD2<7:0>: Baud Rate Clock Divider bits
SCL pin clock period = ((ADD<7:0> + 1) *4)/Fosc

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 ADD2<0>: SSPADD2 Enable bit.
1 = Enable address matching with SSPADD2
0 = Disable address matching with SSPADD2

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 ADD2<0>: SSPADD2 Enable bit.
1 = Enable address matching with SSPADD2
0 = Disable address matching with SSPADD2
28.0  IN-CIRCUIT SERIAL PROGRAMMING™ (ICSP™)

ICSP programming allows customers to manufacture circuit boards with unprogrammed devices. Programming can be done after the assembly process, allowing the device to be programmed with the most recent firmware or a custom firmware. Five pins are needed for ICSP programming:
- ICSPCLK
- ICSPDAT
- MCLR
- VDD
- VSS

In Program/Verify mode, the Program Memory, User IDs and the Configuration Words are programmed through serial communications. The ICSPDAT pin is a bidirectional I/O used for transferring the serial data and the ICSPCLK pin is the clock input. The device is placed into a Program/Verify mode by holding the ICSPDAT and ICSPCLK pins low, while raising the MCLR pin from VIL to VWH.

28.1 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 connector) configuration. See Figure 28-1.

FIGURE 28-1: 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 28-2.

FIGURE 28-2: PICkit-STYLE CONNECTOR INTERFACE

* The 6-pin header (0.100" spacing) accepts 0.025" square pins.
For additional interface recommendations, refer to your specific device programmer manual prior to PCB design.

It is recommended that isolation devices be used to separate the programming pins from other circuitry. The type of isolation is highly dependent on the specific application and may include devices, such as resistors, diodes, or even jumpers. See Figure 28-3 for more information.

**FIGURE 28-3: TYPICAL CONNECTION FOR ICSP PROGRAMMING**

![Diagram of typical connection for ICSP programming]

**To Normal Connections**

* Isolation devices (as required)

---

### 28.2 In-Circuit Debugger

In-circuit debugging requires access to the ICDCLK, ICDDATA, and MCLR pins. These pins are only available on the MCP19111 device.
29.0 INSTRUCTION SET SUMMARY

The MCP19110/11 instruction set is highly orthogonal and is comprised of 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 are 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 an **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 **CLR 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 set the IOCF flag.

### Table 29-1: OPCODE FIELD DESCRIPTIONS

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>f</td>
<td>Register file address (0x00 to 0x7F)</td>
</tr>
<tr>
<td>W</td>
<td>Working register (accumulator)</td>
</tr>
<tr>
<td>b</td>
<td>Bit address within an 8-bit file register</td>
</tr>
<tr>
<td>k</td>
<td>Literal field, constant data or label</td>
</tr>
<tr>
<td>x</td>
<td>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.</td>
</tr>
<tr>
<td>d</td>
<td>Destination select; d = 0: store result in W, d = 1: store result in file register f. Default is d = 1.</td>
</tr>
</tbody>
</table>

### Figure 29-1: General Format for Instructions

#### Byte-Oriented file register operations

```
13 8 7 6 0
OPCODE d f (FILE #)
```

- d = 0 for destination W
- d = 1 for destination f
- f = 7-bit file register address

#### Bit-Oriented file register operations

```
13 10 9 7 6 0
OPCODE b (BIT #) f (FILE #)
```

- b = 3-bit bit address
- f = 7-bit file register address

#### Literal and control operations

**General**

```
13 8 7 0
OPCODE k (literal)
```

- k = 8-bit immediate value

**CALL and GOTO instructions only**

```
13 11 10 0
OPCODE k (literal)
```

- k = 11-bit immediate value
### TABLE 29-2: MCP19110/11 INSTRUCTION SET

<table>
<thead>
<tr>
<th>Mnemonic, Operands</th>
<th>Description</th>
<th>Cycles</th>
<th>14-Bit Opcode</th>
<th>Status Affecte d</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BYTE-ORIENTED FILE REGISTER OPERATIONS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADDWF f, d</td>
<td>Add W and f</td>
<td>1</td>
<td>00 0111 0000 ffff ffff</td>
<td>C, DC, Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>ANDWF f, d</td>
<td>AND W with f</td>
<td>1</td>
<td>00 0101 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>CLRF f</td>
<td>Clear f</td>
<td>1</td>
<td>00 0001 0000 ffff ffff</td>
<td>Z</td>
<td>2</td>
</tr>
<tr>
<td>CLRWF –</td>
<td>Clear W</td>
<td>1</td>
<td>00 0001 0000 ffff ffff</td>
<td>Z</td>
<td>2</td>
</tr>
<tr>
<td>COMF f, d</td>
<td>Complement f</td>
<td>1</td>
<td>00 1001 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>DECf f, d</td>
<td>Decrement f</td>
<td>1</td>
<td>00 0011 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>DECFSZ f, d</td>
<td>Decrement f, Skip if 0</td>
<td>(2)</td>
<td>00 1011 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>INCf f, d</td>
<td>Increment f</td>
<td>1</td>
<td>00 1010 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>INCFSZ f, d</td>
<td>Increment f, Skip if 0</td>
<td>(2)</td>
<td>00 1111 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>IORWF f, d</td>
<td>Inclusive OR W with f</td>
<td>1</td>
<td>00 0100 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>MOVf f, d</td>
<td>Move f</td>
<td>1</td>
<td>00 1000 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>MOVWF f</td>
<td>Move W to f</td>
<td>1</td>
<td>00 0000 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>NOP –</td>
<td>No Operation</td>
<td>1</td>
<td>00 0000 0000 ffff ffff</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RLF f, d</td>
<td>Rotate Left f through Carry</td>
<td>1</td>
<td>01 1101 0000 ffff ffff</td>
<td>C</td>
<td>1, 2</td>
</tr>
<tr>
<td>RRF f, d</td>
<td>Rotate Right f through Carry</td>
<td>1</td>
<td>00 1100 0000 ffff ffff</td>
<td>C</td>
<td>1, 2</td>
</tr>
<tr>
<td>SUBWF f, d</td>
<td>Subtract W from f</td>
<td>1</td>
<td>00 0010 0000 ffff ffff</td>
<td>C, DC, Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>SWAPF f, d</td>
<td>Swap nibbles in f</td>
<td>1</td>
<td>00 1110 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2</td>
</tr>
<tr>
<td>XORWF f, d</td>
<td>Exclusive OR W with f</td>
<td>1</td>
<td>00 0110 0000 ffff ffff</td>
<td>Z</td>
<td>1, 2</td>
</tr>
<tr>
<td><strong>BIT-ORIENTED FILE REGISTER OPERATIONS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BCF f, b</td>
<td>Bit Clear f</td>
<td>1</td>
<td>01 00bb bfff ffff</td>
<td>1, 2</td>
<td></td>
</tr>
<tr>
<td>BSF f, b</td>
<td>Bit Set f</td>
<td>1</td>
<td>01 01bb bfff ffff</td>
<td>1, 2</td>
<td></td>
</tr>
<tr>
<td>BTFSC f, b</td>
<td>Bit Test f, Skip if Clear</td>
<td>1, (2)</td>
<td>01 10bb bfff ffff</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>BTFS S f, b</td>
<td>Bit Test f, Skip if Set</td>
<td>1, (2)</td>
<td>01 11bb bfff ffff</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td><strong>LITERAL AND CONTROL OPERATIONS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADDLW k</td>
<td>Add literal and W</td>
<td>1</td>
<td>11 111x kkkk kkkk</td>
<td>C, DC, Z</td>
<td></td>
</tr>
<tr>
<td>ANDLW k</td>
<td>AND literal with W</td>
<td>1</td>
<td>11 1001 kkkk kkkk</td>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>CALL k</td>
<td>Call Subroutine</td>
<td>2</td>
<td>10 0kkk kkkk kkkk</td>
<td>TO, PD</td>
<td></td>
</tr>
<tr>
<td>CLRWD T k</td>
<td>Clear Watchdog Timer</td>
<td>1</td>
<td>00 0000 0110 0100</td>
<td>TO, PD</td>
<td></td>
</tr>
<tr>
<td>GOTO k</td>
<td>Go to address</td>
<td>2</td>
<td>10 1kkk kkkk kkkk</td>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>IORLW k</td>
<td>Inclusive OR literal with W</td>
<td>1</td>
<td>11 1000 kkkk kkkk</td>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>MOVLW k</td>
<td>Move literal to W</td>
<td>1</td>
<td>11 00xx kkkk kkkk</td>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>RETFIE –</td>
<td>Return from interrupt</td>
<td>2</td>
<td>00 0000 0000 1001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RETLW k</td>
<td>Return with literal in W</td>
<td>2</td>
<td>11 01xx kkkk kkkk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RETURN –</td>
<td>Return from Subroutine</td>
<td>2</td>
<td>00 0000 0000 1000</td>
<td>TO, PD</td>
<td></td>
</tr>
<tr>
<td>SLEEP –</td>
<td>Go into Standby mode</td>
<td>1</td>
<td>00 0000 0110 0011</td>
<td>TO, PD</td>
<td></td>
</tr>
<tr>
<td>SUBLW k</td>
<td>Subtract W from literal</td>
<td>1</td>
<td>11 110x kkkk kkkk</td>
<td>C, DC, Z</td>
<td></td>
</tr>
<tr>
<td>XORLW k</td>
<td>Exclusive OR literal with W</td>
<td>1</td>
<td>11 1010 kkkk kkkk</td>
<td>Z</td>
<td></td>
</tr>
</tbody>
</table>

**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’.

**Note 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.

**Note 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 an `NOP`.

---

[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’.

[Note 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.

[Note 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 an `NOP`.
## 29.2 Instruction Descriptions

### ADDLW
Add literal and W

**Syntax:**

\[ \text{[label]} \ \text{ADDLW} \ k \]

**Operands:**

\[0 \leq k \leq 255\]

**Operation:**

\[(W) + k \rightarrow (W)\]

**Status Affected:**

C, DC, Z

**Description:**

The contents of the W register are added to the eight-bit literal ‘k’ and the result is placed in the W register.

### ADDWF
Add W and f

**Syntax:**

\[ \text{[label]} \ \text{ADDWF} \ f,d \]

**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:**

\[ \text{[label]} \ \text{ANDLW} \ k \]

**Operands:**

\[0 \leq k \leq 255\]

**Operation:**

\[(W) \ .\AND. \ (k) \rightarrow (W)\]

**Status Affected:**

Z

**Description:**

The contents of W register are AND’ed with the eight-bit literal ‘k’. The result is placed in the W register.

### ANDWF
AND W with f

**Syntax:**

\[ \text{[label]} \ \text{ANDWF} \ f,d \]

**Operands:**

\[0 \leq f \leq 127\]

\[d \in [0,1]\]

**Operation:**

\[(W) \ .\AND. \ (f) \rightarrow \text{(destination)}\]

**Status Affected:**

Z

**Description:**

AND the W register with register ‘f’. If ‘d’ is ‘0’, the result is stored in the W register. If ‘d’ is ‘1’, the result is stored back in register ‘f’.

### BCF
Bit Clear f

**Syntax:**

\[ \text{[label]} \ \text{BCF} \ f,b \]

**Operands:**

\[0 \leq f \leq 127\]

\[0 \leq b \leq 7\]

**Operation:**

\[0 \rightarrow (f<b>)\]

**Status Affected:**

None

**Description:**

Bit ‘b’ in register ‘f’ is cleared.

### BSF
Bit Set f

**Syntax:**

\[ \text{[label]} \ \text{BSF} \ f,b \]

**Operands:**

\[0 \leq f \leq 127\]

\[0 \leq b \leq 7\]

**Operation:**

\[1 \rightarrow (f<b>)\]

**Status Affected:**

None

**Description:**

Bit ‘b’ in register ‘f’ is set.

### BTFSC
Bit Test f, Skip if Clear

**Syntax:**

\[ \text{[label]} \ \text{BTFSC} \ f,b \]

**Operands:**

\[0 \leq f \leq 127\]

\[0 \leq b \leq 7\]

**Operation:**

skip if \(f<b> = 0\)

**Status Affected:**

None

**Description:**

If bit ‘b’ in register ‘f’ is ‘1’, the next instruction is executed. If bit ‘b’ in register ‘f’ is ‘0’, the next instruction is discarded, and an NOP is executed instead, making this a two-cycle instruction.
### BTFSS
**Bit Test f, Skip if Set**

**Syntax:**
```c
[ label ] BTFSS  f,b
```

**Operands:**
- `0 ≤ f ≤ 127`
- `0 ≤ b < 7`

**Operation:**
- `skip if (f<b) = 1`

**Status Affected:** None

**Description:**
- If bit 'b' in register 'f' is '0', the next instruction is executed.
- If bit 'b' is '1', then the next instruction is discarded and an `NOP` is executed instead, making this a two-cycle instruction.

### CALL
**Call Subroutine**

**Syntax:**
```c
[ label ] CALL  k
```

**Operands:**
- `0 ≤ k ≤ 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 eleven-bit immediate address is loaded into PC bits <10:0>. The upper bits of the PC are loaded from PCLATH. `CALL` is a two-cycle instruction.

### CLRF
**Clear f**

**Syntax:**
```c
[ label ] CLRF  f
```

**Operands:**
- `0 ≤ f ≤ 127`

**Operation:**
- `00h → (f), 1 → Z`

**Status Affected:** Z

**Description:**
- The contents of register 'f' are cleared and the Z bit is set.

### CLRWD T
**Clear Watchdog Timer**

**Syntax:**
```c
[ label ] CLRWD T
```

**Operands:** None

**Operation:**
- `00h → WDT`
- `0 → WDT prescaler, 1 → T0, 1 → PD`

**Status Affected:** T0, PD

**Description:**
- CLRWDT instruction resets the Watchdog Timer. It also resets the prescaler of the WDT. Status bits T0 and PD are set.

### COMF
**Complement f**

**Syntax:**
```c
[ label ] COMF  f,d
```

**Operands:**
- `0 ≤ f ≤ 127`
- `d ∈ [0,1]`

**Operation:**
- `(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'.

### DECF
**Decrement f**

**Syntax:**
```c
[ label ] DECF  f,d
```

**Operands:**
- `0 ≤ f ≤ 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:**
```c
[ label ] CLRW
```

**Operands:** None

**Operation:**
- `00h → (W), 1 → Z`

**Status Affected:** Z

**Description:**
- W register is cleared. Zero bit (Z) is set.
<table>
<thead>
<tr>
<th>Instruction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DECFSZ</strong> Decrement f, Skip if 0</td>
<td>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.</td>
</tr>
<tr>
<td>Syntax:</td>
<td>[ label ] DECFSZ f,d</td>
</tr>
</tbody>
</table>
| Operands: | $0 \leq f \leq 127$  
| | $d \in [0,1]$ |
| Operation: | $(f) - 1 \rightarrow (\text{destination});$  
| | skip if result = 0 |
| Status Affected: | None |
| **INCFSZ** Increment f, Skip if 0 | 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. |
| Syntax: | [ label ] INCFSZ f,d |
| Operands: | $0 \leq f \leq 127$  
| | $d \in [0,1]$ |
| Operation: | $(f) + 1 \rightarrow (\text{destination});$  
| | skip if result = 0 |
| Status Affected: | None |
| **GOTO** Unconditional Branch | An unconditional branch. The eleven-bit immediate value is loaded into PC bits <10:0>. The upper bits of PC are loaded from PCLATH<4:3>. GOTO is a two-cycle instruction. |
| Syntax: | [ label ] GOTO k |
| Operands: | $0 \leq k \leq 2047$ |
| Operation: | $k \rightarrow \text{PC}<10:0>$  
| | $\text{PCLATH}<4:3> \rightarrow \text{PC}<12:11>$ |
| Status Affected: | None |
| **IORLW** Inclusive OR literal with W | The contents of the W register are OR’ed with the eight-bit literal ‘k’. The result is placed in the W register. |
| Syntax: | [ label ] IORLW k |
| Operands: | $0 \leq k \leq 255$ |
| Operation: | $(W) .\text{OR.} k \rightarrow (W)$ |
| Status Affected: | Z |
| **INCF** Increment f | 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’. |
| Syntax: | [ label ] INCF f,d |
| Operands: | $0 \leq f \leq 127$  
| | $d \in [0,1]$ |
| Operation: | $(f) + 1 \rightarrow (\text{destination})$ |
| Status Affected: | Z |
| **IORWF** Inclusive OR W with f | 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’. |
| Syntax: | [ label ] IORWF f,d |
| Operands: | $0 \leq f \leq 127$  
| | $d \in [0,1]$ |
| Operation: | $(W) .\text{OR.} (f) \rightarrow (\text{destination})$ |
| Status Affected: | Z |
### MOVF Move f

| Syntax: | [label] MOVF f,d |
| Operands: | 0 ≤ f ≤ 127  
|           | d ∈ [0,1] |
| Operation: | (f) → (dest) |
| Status Affected: | Z |
| Description: | The contents of register 'f' is moved to a destination dependent upon the status of 'd'. If d = 0, destination is W register. If d = 1, the destination is file register 'f' itself. d = 1 is useful to test a file register since Status flag Z is affected. |
| Words: | 1 |
| Cycles: | 1 |
| Example: | MOVF FSR, 0 |

After Instruction

\[ W = \text{value in FSR register} \]

\[ Z = 1 \]

### MOVLW Move literal to W

| Syntax: | [label] MOVLW k |
| Operands: | 0 ≤ k ≤ 255 |
| Operation: | k → (W) |
| Status Affected: | None |
| Description: | The eight-bit literal 'k' is loaded into W register. The "don't cares" will assemble as '0's. |
| Words: | 1 |
| Cycles: | 1 |
| Example: | MOVLW 0x5A |

After Instruction

\[ W = 0x5A \]

### MOVWF Move W to f

| Syntax: | [label] MOVWF f |
| Operands: | 0 ≤ f ≤ 127 |
| Operation: | (W) → (f) |
| Status Affected: | None |
| Description: | Move data from W register to register 'f'. |
| Words: | 1 |
| Cycles: | 1 |
| Example: | MOVWF OPTION |

Before Instruction

\[ \text{OPTION} = 0xFF \]

\[ W = 0x4F \]

After Instruction

\[ \text{OPTION} = 0x4F \]

\[ W = 0x4F \]

### NOP No Operation

| Syntax: | [label] NOP |
| Operands: | None |
| Operation: | No operation |
| Status Affected: | None |
| Description: | No operation. |
| Words: | 1 |
| Cycles: | 1 |
| Example: | NOP |
### RETFIE  Return from Interrupt

**Syntax:** 
\[
\text{[ label ]} \ \text{RETFIE}
\]

**Operands:** None

**Operation:**
\[
\text{TOS} \rightarrow \text{PC},  \\
1 \rightarrow \text{GIE}
\]

**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 (INT-CON<7>). This is a two-cycle instruction.

**Words:** 1

**Cycles:** 2

**Example:**

```assembly
RETFIE
```

**After Interrupt**

\[
\text{PC} = \text{TOS}  \\
\text{GIE} = 1
\]

### RETLW  Return with literal in W

**Syntax:** 
\[
\text{[ label ]} \ \text{RETLW} \ k
\]

**Operands:**
\[
0 \leq k \leq 255
\]

**Operation:**
\[
k \rightarrow (W);  \\
\text{TOS} \rightarrow \text{PC}
\]

**Status Affected:** None

**Description:** The W register is loaded with the eight-bit literal ‘k’. The program counter is loaded from the top of the stack (the return address). This is a two-cycle instruction.

**Words:** 1

**Cycles:** 2

**Example:**

```assembly
CALL TABLE;W contains  
\begin{verbatim}
;table offset 
;value
\end{verbatim}
GOTO DONE

TABLE
\[
\begin{array}{l}
\bullet \\
\bullet
\end{array}
\]

ADDWF PC ;W = offset
RETLW k1 ;Begin table
RETLW k2 ;
\[
\begin{array}{l}
\bullet \\
\bullet
\end{array}
\]
RETLW kn ;End of table

DONE
```

**Before Instruction**

\[
W = 0x07
\]

**After Instruction**

\[
W = \text{value of } k8
\]

### RETURN  Return from Subroutine

**Syntax:** 
\[
\text{[ label ]} \ \text{RETURN}
\]

**Operands:** None

**Operation:**
\[
\text{TOS} \rightarrow \text{PC}
\]

**Status Affected:** None

**Description:** Return from subroutine. The stack is POPed and the top of the stack (TOS) is loaded into the program counter. This is a two-cycle instruction.
**RLF**  Rotate Left f through Carry

<table>
<thead>
<tr>
<th>Syntax:</th>
<th><code>[ label ] RLF f,d</code></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operands:</td>
<td>0 ≤ f ≤ 127</td>
</tr>
<tr>
<td></td>
<td>d ∈ [0,1]</td>
</tr>
<tr>
<td>Operation:</td>
<td>See description below</td>
</tr>
<tr>
<td>Status Affected:</td>
<td>C</td>
</tr>
<tr>
<td>Description:</td>
<td>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’.</td>
</tr>
</tbody>
</table>

**Example:**

Before Instruction

<table>
<thead>
<tr>
<th>REG1</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1110</td>
<td>0</td>
</tr>
</tbody>
</table>

After Instruction

<table>
<thead>
<tr>
<th>REG1</th>
<th>W</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1110</td>
<td>1100</td>
<td>1</td>
</tr>
</tbody>
</table>

**Words:** 1  
**Cycles:** 1

**RRF**  Rotate Right f through Carry

<table>
<thead>
<tr>
<th>Syntax:</th>
<th><code>[ label ] RRF f,d</code></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operands:</td>
<td>0 ≤ f ≤ 127</td>
</tr>
<tr>
<td></td>
<td>d ∈ [0,1]</td>
</tr>
<tr>
<td>Operation:</td>
<td>See description below</td>
</tr>
<tr>
<td>Status Affected:</td>
<td>C</td>
</tr>
<tr>
<td>Description:</td>
<td>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’.</td>
</tr>
</tbody>
</table>

**SLEEP**  Enter Sleep mode

<table>
<thead>
<tr>
<th>Syntax:</th>
<th><code>[ label ] SLEEP</code></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operands:</td>
<td>None</td>
</tr>
<tr>
<td>Operation:</td>
<td>00h → WDT, 0 → WDT prescaler, 1 → TO, 0 → PD</td>
</tr>
<tr>
<td>Status Affected:</td>
<td>TO, PD</td>
</tr>
<tr>
<td>Description:</td>
<td>The power-down Status bit, PD is cleared. Time-out Status bit, TO is set. Watchdog Timer and its prescaler are cleared. The processor is put into Sleep mode with the oscillator stopped.</td>
</tr>
</tbody>
</table>

**SUBLW**  Subtract W from literal

<table>
<thead>
<tr>
<th>Syntax:</th>
<th><code>[ label ] SUBLW k</code></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operands:</td>
<td>0 ≤ k ≤ 255</td>
</tr>
<tr>
<td>Operation:</td>
<td>k - (W) → (W)</td>
</tr>
<tr>
<td>Status Affected:</td>
<td>C, DC, Z</td>
</tr>
<tr>
<td>Description:</td>
<td>The W register is subtracted (two’s complement method) from the eight-bit literal ‘k’. The result is placed in the W register.</td>
</tr>
</tbody>
</table>

**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>
### 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'.

<table>
<thead>
<tr>
<th>C = 0</th>
<th>W &gt; f</th>
</tr>
</thead>
<tbody>
<tr>
<td>C = 1</td>
<td>W ≤ f</td>
</tr>
<tr>
<td>DC = 0</td>
<td>W&lt;3:0&gt; &gt; f&lt;3:0&gt;</td>
</tr>
<tr>
<td>DC = 1</td>
<td>W&lt;3:0&gt; ≤ f&lt;3:0&gt;</td>
</tr>
</tbody>
</table>

### SWAPF
**Swap Nibbles in f**

**Syntax:**

```
[label] SWAPF f, d
```

**Operands:**

\[ 0 \leq f \leq 127 \]
\[ d \in [0,1] \]

**Operation:**

\( (f<3:0>) \rightarrow (\text{destination}<7:4>), \quad (f<7:4>) \rightarrow (\text{destination}<3:0>) \)

**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'.

### XORWF
**Exclusive OR W with f**

**Syntax:**

```
[label] XORWF f, d
```

**Operands:**

\[ 0 \leq f \leq 127 \]
\[ d \in [0,1] \]

**Operation:**

\( (W) \cdot \text{XOR} \cdot (f) \rightarrow (\text{destination}) \)

**Status Affected:**

Z

**Description:**

Exclusive OR the contents of the W register with register 'f'. If 'd' is '0', the result is stored in the W register. If 'd' is '1', the result is stored back in register 'f'.

### XORLW
**Exclusive OR literal with W**

**Syntax:**

```
[label] XORLW k
```

**Operands:**

\[ 0 \leq k \leq 255 \]

**Operation:**

\( (W) \cdot \text{XOR} \cdot k \rightarrow (W) \)

**Status Affected:**

Z

**Description:**

The contents of the W register are XOR'ed with the eight-bit literal 'k'. The result is placed in the W register.
30.0 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

30.1 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
30.2 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

30.3 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

30.4 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

30.5 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
30.6 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.

30.7 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 three meters) interconnection cables.

30.8 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.

30.9 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™).

30.10 MPLAB PM3 Device Programmer

The MPLAB PM3 Device Programmer is a universal, CE compliant device programmer with programmable voltage verification at VDDMIN and VDDMAX for maximum reliability. It features a large LCD display (128 x 64) for menus and error messages, and a modular, detachable socket assembly to support various package types. The ICSP cable assembly is included as a standard item. In Stand-Alone mode, the MPLAB PM3 Device Programmer can read, verify and program PIC devices without a PC connection. It can also set code protection in this mode. The MPLAB PM3 connects to the host PC via an RS-232 or USB cable. The MPLAB PM3 has high-speed communications and optimized algorithms for quick programming of large memory devices, and incorporates an MMC card for file storage and data applications.
30.11 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.

30.12 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, WI2net and IPLogika®
31.0 PACKAGING INFORMATION

31.1 Package Marking Information

24-Lead QFN (4x4x0.9 mm) (MCP19110 only)

Example

28-Lead QFN (5x5x0.9 mm) (MCP19111 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)
- WWW Week code (week of January 1 is week ‘01’)
- NNN Alphanumeric traceability code
- e3 RoHS Compliant JEDEC designator for Matte Tin (Sn)
- * This package is RoHS Compliant. The RoHS Compliant 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.
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

---

<table>
<thead>
<tr>
<th>Units</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension Limits</td>
<td>MIN</td>
</tr>
<tr>
<td>Number of Pins</td>
<td>N</td>
</tr>
<tr>
<td>Pitch</td>
<td>e</td>
</tr>
<tr>
<td>Overall Height</td>
<td>A</td>
</tr>
<tr>
<td>Standoff</td>
<td>A1</td>
</tr>
<tr>
<td>Contact Thickness</td>
<td>A3</td>
</tr>
<tr>
<td>Overall Width</td>
<td>E</td>
</tr>
<tr>
<td>Exposed Pad Width</td>
<td>E2</td>
</tr>
<tr>
<td>Overall Length</td>
<td>D</td>
</tr>
<tr>
<td>Exposed Pad Length</td>
<td>D2</td>
</tr>
<tr>
<td>Contact Width</td>
<td>b</td>
</tr>
<tr>
<td>Contact Length</td>
<td>L</td>
</tr>
<tr>
<td>Contact-to-Exposed Pad</td>
<td>K</td>
</tr>
</tbody>
</table>

Notes:
1. Pin 1 visual index feature may vary, but must be located within the hatched area.
2. Package is saw singulated.
3. 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

![Recommended Land Pattern Diagram](image)

---

<table>
<thead>
<tr>
<th>Units</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension Limits</td>
<td>MIN NOM MAX</td>
</tr>
<tr>
<td>Contact Pitch</td>
<td>E 0.50 BSC</td>
</tr>
<tr>
<td>Optional Center Pad Width</td>
<td>W2 2.60</td>
</tr>
<tr>
<td>Optional Center Pad Length</td>
<td>T2 2.60</td>
</tr>
<tr>
<td>Contact Pad Spacing</td>
<td>C1 3.90</td>
</tr>
<tr>
<td>Contact Pad Spacing</td>
<td>C2 3.90</td>
</tr>
<tr>
<td>Contact Pad Width</td>
<td>X1 0.30</td>
</tr>
<tr>
<td>Contact Pad Length</td>
<td>Y1 0.85</td>
</tr>
</tbody>
</table>

**Notes:**

1. Dimensioning and tolerancing per ASME Y14.5M
2. BSC: Basic Dimension. Theoretically exact value shown without tolerances.

Microchip Technology Drawing No. C04-2143B
Note: For the most current package drawings, please see the Microchip Packaging Specification located at http://www.microchip.com/packaging
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

<table>
<thead>
<tr>
<th>Units</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension Limits</td>
<td>MIN</td>
</tr>
<tr>
<td>Number of Pins</td>
<td>N</td>
</tr>
<tr>
<td>Pitch</td>
<td>e</td>
</tr>
<tr>
<td>Overall Height</td>
<td>A</td>
</tr>
<tr>
<td>Standoff</td>
<td>A1</td>
</tr>
<tr>
<td>Contact Thickness</td>
<td>A3</td>
</tr>
<tr>
<td>Overall Width</td>
<td>E</td>
</tr>
<tr>
<td>Exposed Pad Width</td>
<td>E2</td>
</tr>
<tr>
<td>Overall Length</td>
<td>D</td>
</tr>
<tr>
<td>Exposed Pad Length</td>
<td>D2</td>
</tr>
<tr>
<td>Contact Width</td>
<td>b</td>
</tr>
<tr>
<td>Contact Length</td>
<td>L</td>
</tr>
<tr>
<td>Contact-to-Exposed Pad</td>
<td>K</td>
</tr>
</tbody>
</table>

Notes:
1. Pin 1 visual index feature may vary, but must be located within the hatched area.
2. Package is saw singulated.
3. 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.
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

---

### Microchip Technology Drawing C04-2140A

---

<table>
<thead>
<tr>
<th>Units</th>
<th>MILLIMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension Limits</td>
<td>MIN</td>
</tr>
<tr>
<td>Contact Pitch E</td>
<td>0.50 BSC</td>
</tr>
<tr>
<td>Optional Center Pad Width W2</td>
<td></td>
</tr>
<tr>
<td>Optional Center Pad Length T2</td>
<td></td>
</tr>
<tr>
<td>Contact Pad Spacing C1</td>
<td></td>
</tr>
<tr>
<td>Contact Pad Spacing C2</td>
<td></td>
</tr>
<tr>
<td>Contact Pad Width (X28) X1</td>
<td></td>
</tr>
<tr>
<td>Contact Pad Length (X28) Y1</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**

1. Dimensioning and tolerancing per ASME Y14.5M
   BSC: Basic Dimension. Theoretically exact value shown without tolerances.
APPENDIX A: REVISION HISTORY

Revision B (June 2013)

The following is the list of modifications:
1. Added new device MCP19110 to the family and the related information across the document.
2. Updated information in Features section.
3. Added pinout diagram and pin summary table for the MCP19110 device.
4. Updated Figure 1-1.
5. Updated Section 2.0 “Pin Description”.
6. Updated Section 4.3 “Thermal Specifications”.
7. Added new Section 28.2 “In-Circuit Debugger”.
8. Updated Section 31.1 “Package Marking Information”.
10. Fixed minor typographical errors.

Revision A (January 2013)

• Original Release of this Document.
INDEX

A

A/D Specifications ................................................. 3, 5, 33
A/D Conversion ...................................................... 127
Requirements .......................................................... 34
Timing ........................................................................ 34, 35
Absolute Maximum Ratings ....................................... 23
AC Characteristics ................................................... 30
ACKSTAT ............................................................. 172
ACKSTAT Status Flag ................................................ 172
ADC Acquisition Requirements ..................................... 131
Associated Registers .................................................. 133
Block Diagram .......................................................... 125
Calculating Acquisition Time ....................................... 131
Channel Selection ...................................................... 126
Configuration .......................................................... 126
Configuring Interrupt .................................................. 128
Conversion Clock ...................................................... 126
Conversion Procedure ............................................... 126
Internal Sampling Switch (RSS) IMPEDANCE ............. 131
Interrupts .................................................................. 127
Operation .................................................................. 128
Operation During Sleep .............................................. 128
Port Configuration ...................................................... 126
Register Definitions ................................................... 129
Source Impedance ...................................................... 131
Special Event Trigger .................................................. 128
ADCON0 Register ...................................................... 129
ADCON1 Register ...................................................... 130
ADRESH Register (ADFM = 0) ................................... 130
ADRESL Register (ADFM = 0) ................................... 130
Alternate Pin Function .................................................. 112
Analog Blocks Enable Control ..................................... 51
Analog Peripheral Control ............................................. 49
Analog-to-Digital Converter. See ADC
ANSELA Register ...................................................... 115
ANSELB Register ...................................................... 118
APFCON Register ..................................................... 112
Assembler
MPASM Assembler .................................................. 204

B

Bench Testing
Analog Bench Test Control ......................................... 57
System ...................................................................... 57
BF ........................................................................... 172, 174
BF Status Flag ........................................................... 172, 174
Block Diagrams
ADC ........................................................................ 125
ADC Transfer Function .............................................. 132
Analog Input Model .................................................... 132
Generic I/O Port ......................................................... 111
Interrupt Logic .......................................................... 94
MCLR Circuit ............................................................. 86
MCP19110/11 Synchronous Buck Block Diagram ........... 10
MSSP (I²C Master Mode) .............................................. 147
MSSP (I²C Slave Mode) ............................................... 148
On-Chip Reset Circuit .................................................. 85
Simplified PWM ....................................................... 144
Timer0 ................................................................... 135
Timer1 ................................................................... 137
Timer2 ................................................................... 140
Watchdog Timer ......................................................... 103

C

C Compilers
MPLAB C18 ............................................................. 204
Calibration Word
Associated Registers .................................................. 84
Capture/Compare/PWM ............................................ 143, 145
Clock Switching ......................................................... 84
Code Examples
A/D Conversion .......................................................... 128
Assigning Prescaler to Timer0 ..................................... 136
Assigning Prescaler to WDT ........................................ 136
Initializing PORTA .................................................... 111
Saving Status and W Registers in RAM ..................... 100
Compensation .......................................................... 18
Compensation Setting .................................................. 43
Computed Function Calls .......................................... 78
Computed GOTO ......................................................... 78
Current Measurement Control ..................................... 51
Current Sense ............................................................ 18, 40, 41
Customer Change Notification Service ....................... 221
Customer Support ..................................................... 221

D

Data Memory ............................................................ 70
Data Memory Map ..................................................... 72
DC and AC Characteristics ......................................... 53
Graphs and Tables ..................................................... 53
DC Characteristics ..................................................... 30
Development Support ............................................... 203
Device
Configuration .......................................................... 37, 81
Code Protection ........................................................ 82
Configuration Word .................................................... 81
ID Locations ............................................................. 82
User ID ................................................................. 82
Write Protection ........................................................ 82
Device Calibration ...................................................... 59
Calibration Word 1 ..................................................... 59
Calibration Word 2 ..................................................... 60
Calibration Word 3 ..................................................... 61
Calibration Word 4 ..................................................... 62
Calibration Word 5 ..................................................... 63
Calibration Word 6 ..................................................... 64
Calibration Word 7 ..................................................... 65
Device Overview ......................................................... 9
Digital Electrical Characteristics ................................. 29
Diode Emulation Mode .............................................. 49

E

ECCP/CCP. See Enhanced Capture/Compare/PWM
Electrical Characteristics ............................................. 23, 24
Errata .................................................................... 7
External Clock ......................................................... 30
F

Features
Miscellaneous ........................................... 21
Protection ...................................................... 20
Synchronous Buck ......................................... 1
Firmware Instructions ...................................... 193
Flash Program Memory Control .......................... 105
  Operation During Code Protect ......................... 109
  Operation during write Protect .......................... 109
  Protecting .................................................... 109
  Reading ......................................................... 108
  Writing to ..................................................... 109
Flash Program Memory Control Registers ............... 106

H

High-Side Drive Strength ..................................... 49

I

I/O
Ports .......................................................... 111

I2C Mode (MSSPxx)
 Acknowledge Sequence ..................................... 152
 Acknowledge Sequence Timing ............................. 176
 Associated Registers ......................................... 182
 Bus Collision
  During a Repeated Start Condition ....................... 180
  During a Start Condition .................................. 178
  During a Stop Condition ................................... 181
 Effects of a Reset ............................................ 177
 I2C Clock Rate w/BRG ....................................... 183
 Master Mode .................................................. 169
 Clock Arbitration ......................................... 169
 Operation ...................................................... 169
 Reception ....................................................... 174
 Start Condition Timing ...................................... 170, 171
 Transmission .................................................. 172
 Multi-Master Communication, Bus Collision and Arbitra-
tion ............................................................ 177
 Multi-Master Mode ........................................... 177
 Operation ....................................................... 150
 Overview ......................................................... 148
 Read/Write Bit Information (R/W Bit) .................... 153
 Slave Mode
  10-bit Address Reception .................................. 163
  Bus Collision ............................................... 159
  Clock Synchronization ..................................... 167
  General Call Address Support ......................... 168
  Operation ...................................................... 153
  SSPMSKx Register ......................................... 168
  Transmission .................................................. 159
  Sleep Operation ............................................. 177
  Stop Condition Timing ..................................... 176
 In-Circuit Serial Programming (ICSP) ..................... 191
  Common Programming Interfaces ........................ 191
  In-Circuit Debugger ....................................... 192
  Indirect Addressing ....................................... 78
  Input .......................................................... 24
  Type ........................................................... 12
  Undervoltage Lockout ..................................... 20, 37
 Instruction Format ........................................... 193

Instruction Set .................................................. 193
ADDLW ......................................................... 195
ADDWF ......................................................... 195
ANDLW ......................................................... 195
ANDWF ......................................................... 195
BCF ............................................................. 195
BSF ............................................................. 195
BTFSC .......................................................... 195
BTFSS .......................................................... 196
CALL ............................................................ 196
CLRF ............................................................ 196
CLRW ............................................................ 196
CLRWDT ....................................................... 196
COMF .......................................................... 196
DECFSZ ......................................................... 197
DECF ............................................................ 196
DECB ............................................................ 196
GOTO ........................................................... 197
INCF ............................................................ 197
INCFSZ .......................................................... 197
IORLW .......................................................... 197
IORWF .......................................................... 197
MOVF .......................................................... 198
MOVLW .......................................................... 198
MOVWF .......................................................... 198
NOP .............................................................. 198
RETFIE .......................................................... 199
RETLW .......................................................... 199
RETURN .......................................................... 199
RLF .............................................................. 200
RRF .............................................................. 200
SLEEP ............................................................ 200
SUBLW ........................................................... 200
SUBWF ........................................................... 201
SWAPF ........................................................... 201
XORLW ............................................................ 201
XORWF ............................................................ 201

Summary Table .................................................. 194
Internal Sampling Switch (RSS) IMPEDANCE ............... 131
Internal Synchronous Driver ................................ 17
Internal Temperature Indicator Module ..................... 123
  Circuit Operation ........................................... 123
  Temperature Output ........................................ 123
Internal Temperature Measurement Control ............... 51
Internet Address ............................................ 221
Interrupt-on-Change ........................................ 121
  Associated Registers ....................................... 122
  Clearing Interrupt Flags ................................... 121
  Enabling the Module ....................................... 121
  Operation in Sleep ......................................... 121
  Pin Configuration ......................................... 121
  Registers .................................................... 122

Interrupts
ADC ............................................................. 128
  Associated Registers ....................................... 99
  Context Saving ............................................ 100
  Control Registers .......................................... 95
  RA2/INT ...................................................... 93
  TMR1 ............................................................ 138

L

Linear Regulators ............................................. 17
M

MASTER Error Signal Gain .......................................................... 45
Master Synchronous Serial Port. See MSSPx ............................ 38
MCLR ............................................................................. 86
\textbf{M} ............................................................................. 86
Memory Organization ............................................................ 69
Data ............................................................................. 70
Program .......................................................................... 69
Microchip Internet Web Site .................................................... 221
MOSFET ........................................................................ 15, 16, 17, 38, 46, 49, 57, 67
Driver Dead Time ............................................................ 17
MOSFET Driver
\textbf{M} ............................................................................. 49
Dead Time ........................................................................ 49
Programmable Dead Time .................................................... 46
\textbf{M} ............................................................................. 204
MPLAB Integrated Development Environment Software ..... 203
MPLAB PM3 Device Programmer ........................................... 205
MPLAB REAL ICE In-Circuit Emulator System ................... 205
MPLINK Object Linker/MPLIB Object Librarian .................. 204
MSSPx ............................................................................. 147
\textbf{M} ............................................................................. 147
Arbitration ......................................................................... 150
Baud Rate Generator .......................................................... 183
\textbf{M} ............................................................................. 150
Clock Stretching .................................................................. 150
\textbf{M} ............................................................................. 151
\textbf{I} \textbf{C} Bus Terms ........................................................... 151
\textbf{I} \textbf{C} Master Mode .......................................................... 169
\textbf{I} \textbf{C} Mode .................................................................. 148
\textbf{I} \textbf{C} Mode Operation .................................................. 150
\textbf{I} \textbf{C} Slave Mode Operation ........................................ 153
Module Overview .................................................................. 147
\textbf{M} ............................................................................. 22
Multi-Phase System ............................................................ 22
\textbf{O}

OPCODE Field Descriptions ................................................... 193
Oscillator ........................................................................... 83
\textbf{O} ............................................................................. 84
Associated Registers ........................................................... 84
Calibration .......................................................................... 83
Delay Upon Power-up ......................................................... 84
Frequency Tuning ............................................................... 83
\textbf{O} ............................................................................. 83
Internal Oscillator .................................................................. 83
\textbf{O} ............................................................................. 84
Oscillator Module .................................................................. 84
\textbf{O} ............................................................................. 49
Output ............................................................................. 49
\textbf{O} ............................................................................. 22
Multiple System .................................................................. 22
Overcurrent ....................................................................... 20, 38, 39
Overvoltage ......................................................................... 20, 25, 48
Overvoltage Enable ............................................................ 51
Power Good ......................................................................... 22
Type ................................................................................... 12
Undervoltage ....................................................................... 20, 25, 48
Undervoltage Accelerator .................................................... 49
\textbf{O} ............................................................................. 49
Undervoltage Enable ........................................................... 51
Voltage .............................................................................. 10
\textbf{O} ............................................................................. 22
Soft-Start ........................................................................... 22
Tracking ............................................................................. 22
\textbf{O} ............................................................................. 47
Voltage Configuration .......................................................... 47
\textbf{O} ............................................................................. 49
Overcurrent Sense Pull-up/Pull-down ..................................... 49
\textbf{O} ............................................................................. 39
Overcurrent ......................................................................... 39
\textbf{O} ............................................................................. 49
Overvoltage Accelerator ....................................................... 49
\textbf{O} ............................................................................. 49
P

Packaging ................................................................. 207
Marking ............................................................................. 207
Specifications ................................................................. 208
PCL ................................................................................... 78
Modifying .......................................................................... 78
\textbf{P} ............................................................................. 78
\textbf{P} ............................................................................. 87, 92
\textbf{P} ............................................................................. 2
\textbf{P} ............................................................................. 4
Pin Diagram
\textbf{P} ............................................................................. 3
Pinout Description
\textbf{P} ............................................................................. 2, 3
Pinout Description Table ....................................................... 12
PIR1 Register ...................................................................... 98
PIR2 Register ...................................................................... 99
\textbf{P} ............................................................................. 105
\textbf{P} ............................................................................. 105
\textbf{P} ............................................................................. 106
\textbf{P} ............................................................................. 106
\textbf{P} ............................................................................. 107
\textbf{P} ............................................................................. 117
\textbf{P} ............................................................................. 119
\textbf{P} ............................................................................. 112
\textbf{P} ............................................................................. 112
\textbf{P} ............................................................................. 115
\textbf{P} ............................................................................. 113
\textbf{P} ............................................................................. 112
\textbf{P} ............................................................................. 112
\textbf{P} ............................................................................. 112
\textbf{P} ............................................................................. 116
\textbf{P} ............................................................................. 116
\textbf{P} ............................................................................. 116
\textbf{P} ............................................................................. 116
\textbf{P} ............................................................................. 116
\textbf{P} ............................................................................. 116
\textbf{P} ............................................................................. 101
\textbf{P} ............................................................................. 102
\textbf{P} ............................................................................. 86
\textbf{P} ............................................................................. 87
\textbf{P} ............................................................................. 87
\textbf{P} ............................................................................. 46
Product Identification System .............................................. 223
Program Memory .............................................................. 69
\textbf{P} ............................................................................. 69
\textbf{P} ............................................................................. 82
\textbf{P} ............................................................................. 193
\textbf{P} ............................................................................. 33
\textbf{P} ............................................................................. 145
\textbf{P} ............................................................................. 145
\textbf{P} ............................................................................. 143
\textbf{P} ............................................................................. 143
\textbf{P} ............................................................................. 143
\textbf{P} ............................................................................. 143
\textbf{P} ............................................................................. 143
\textbf{P} ............................................................................. 143

© 2013 Microchip Technology Inc.
### Special Registers Summary

<table>
<thead>
<tr>
<th>Register Name</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABECON (Analog Block Enable Control)</td>
<td>52</td>
</tr>
<tr>
<td>ADCON0 (ADC Control 0)</td>
<td>129</td>
</tr>
<tr>
<td>ADCON1 (ADC Control 1)</td>
<td>130</td>
</tr>
<tr>
<td>ADRESH (ADC Result High)</td>
<td>130</td>
</tr>
<tr>
<td>ADRESL (ADC Result Low)</td>
<td>130</td>
</tr>
<tr>
<td>ANSELA (Analog Select GP)</td>
<td>115</td>
</tr>
<tr>
<td>ANSELB (Analog Select GB)</td>
<td>118</td>
</tr>
<tr>
<td>APFCON (Alternate Pin Function Control)</td>
<td>112</td>
</tr>
<tr>
<td>ATSTCON (Analog Bench Test Control)</td>
<td>57</td>
</tr>
<tr>
<td>BUFFCON (Unity Gain Buffer Control)</td>
<td>58</td>
</tr>
<tr>
<td>CALWD1 (Calibration Word 1)</td>
<td>59</td>
</tr>
<tr>
<td>CALWD2 (Calibration Word 2)</td>
<td>60</td>
</tr>
<tr>
<td>CALWD3 (Calibration Word 3)</td>
<td>61</td>
</tr>
<tr>
<td>CALWD4 (Calibration Word 4)</td>
<td>62</td>
</tr>
<tr>
<td>CALWD5 (Calibration Word 5)</td>
<td>63</td>
</tr>
<tr>
<td>CALWD6 (Calibration Word 6)</td>
<td>64</td>
</tr>
<tr>
<td>CALWD7 (Calibration Word 7)</td>
<td>65</td>
</tr>
<tr>
<td>CFGR (Configuration Word)</td>
<td>81</td>
</tr>
<tr>
<td>CSDGCN (Voltage For Zero Current Control)</td>
<td>41</td>
</tr>
<tr>
<td>CSGS (Current Sense AC Gain Control)</td>
<td>40</td>
</tr>
<tr>
<td>DEADCON (Driver Dead Time Control)</td>
<td>46</td>
</tr>
<tr>
<td>DEVID (Device ID)</td>
<td>82</td>
</tr>
<tr>
<td>INTCON (Interrupt Control)</td>
<td>95</td>
</tr>
<tr>
<td>IOCA (Interrupt-on-Change PORTGPB)</td>
<td>122</td>
</tr>
<tr>
<td>IOCB (Interrupt-on-Change PORTGBP)</td>
<td>122</td>
</tr>
<tr>
<td>LPCRCON (Slope Compensation Ramp Control)</td>
<td>44</td>
</tr>
<tr>
<td>OCOCN (Output OverCurrent Control)</td>
<td>39</td>
</tr>
<tr>
<td>OOVCON (Output Overvoltage Detect Level Control)</td>
<td>48</td>
</tr>
<tr>
<td>OPTION_REG (Option)</td>
<td>77</td>
</tr>
<tr>
<td>OVCN (Output Undervoltage Detect Level Control)</td>
<td>48</td>
</tr>
<tr>
<td>OVVOCN (Output Undervoltage Set Point Coarse Control)</td>
<td>47</td>
</tr>
<tr>
<td>PCON (Power Control)</td>
<td>87, 92</td>
</tr>
<tr>
<td>PE1 (Analog Peripheral Enable 1 Control)</td>
<td>50</td>
</tr>
<tr>
<td>PIE1 (Peripheral Interrupt Enable)</td>
<td>96</td>
</tr>
<tr>
<td>PIR1 (Peripheral Interrupt Flag)</td>
<td>98</td>
</tr>
<tr>
<td>PIR2 (Peripheral Interrupt Flag)</td>
<td>99</td>
</tr>
<tr>
<td>PMADR (Program Memory Address)</td>
<td>106</td>
</tr>
<tr>
<td>PMCON1 (Program Memory Control)</td>
<td>107</td>
</tr>
<tr>
<td>PMDD (Program Memory Data)</td>
<td>106</td>
</tr>
<tr>
<td>PMDATL (Program Memory Data)</td>
<td>106</td>
</tr>
<tr>
<td>PMDRH (Program Memory Address)</td>
<td>107</td>
</tr>
<tr>
<td>PORTGPA</td>
<td>113</td>
</tr>
<tr>
<td>PORTGBP</td>
<td>117</td>
</tr>
<tr>
<td>RELEFF (Relative Efficiency Measurement)</td>
<td>67</td>
</tr>
<tr>
<td>Reset Values</td>
<td>89</td>
</tr>
<tr>
<td>CALWD7 (Calibration Word 7)</td>
<td>65</td>
</tr>
<tr>
<td>CMPCZCON (Compensation Setting Control)</td>
<td>43</td>
</tr>
<tr>
<td>CONFIG (Configuration Word)</td>
<td>81</td>
</tr>
<tr>
<td>CSDD (Current Sense DC Gain Control)</td>
<td>40</td>
</tr>
<tr>
<td>CSF (Current Sense DC Gain Control)</td>
<td>40</td>
</tr>
<tr>
<td>DEADCON (Driver Dead Time Control)</td>
<td>46</td>
</tr>
<tr>
<td>DEVID (Device ID)</td>
<td>82</td>
</tr>
<tr>
<td>INTCON (Interrupt Control)</td>
<td>95</td>
</tr>
<tr>
<td>IOCA (Interrupt-on-Change PORTGPB)</td>
<td>122</td>
</tr>
<tr>
<td>IOCB (Interrupt-on-Change PORTGBP)</td>
<td>122</td>
</tr>
<tr>
<td>LPCRCON (Slope Compensation Ramp Control)</td>
<td>44</td>
</tr>
<tr>
<td>OOVCON (Output Overvoltage Detect Level Control)</td>
<td>48</td>
</tr>
<tr>
<td>OPTION_REG (Option)</td>
<td>77</td>
</tr>
<tr>
<td>OVCN (Output Undervoltage Detect Level Control)</td>
<td>48</td>
</tr>
<tr>
<td>OVVOCN (Output Undervoltage Set Point Coarse Control)</td>
<td>47</td>
</tr>
<tr>
<td>PCON (Power Control)</td>
<td>87, 92</td>
</tr>
<tr>
<td>PE1 (Analog Peripheral Enable 1 Control)</td>
<td>50</td>
</tr>
<tr>
<td>PIE1 (Peripheral Interrupt Enable)</td>
<td>96</td>
</tr>
<tr>
<td>PIR1 (Peripheral Interrupt Flag)</td>
<td>98</td>
</tr>
<tr>
<td>PIR2 (Peripheral Interrupt Flag)</td>
<td>99</td>
</tr>
<tr>
<td>PMADR (Program Memory Address)</td>
<td>106</td>
</tr>
<tr>
<td>PMCON1 (Program Memory Control)</td>
<td>107</td>
</tr>
<tr>
<td>PMDD (Program Memory Data)</td>
<td>106</td>
</tr>
<tr>
<td>PMDATL (Program Memory Data)</td>
<td>106</td>
</tr>
<tr>
<td>PMDRH (Program Memory Address)</td>
<td>107</td>
</tr>
<tr>
<td>PORTGPA</td>
<td>113</td>
</tr>
<tr>
<td>PORTGBP</td>
<td>117</td>
</tr>
<tr>
<td>RELEFF (Relative Efficiency Measurement)</td>
<td>67</td>
</tr>
<tr>
<td>Reset Values</td>
<td>89</td>
</tr>
<tr>
<td>CALWD7 (Calibration Word 7)</td>
<td>65</td>
</tr>
<tr>
<td>CMPCZCON (Compensation Setting Control)</td>
<td>43</td>
</tr>
<tr>
<td>CONFIG (Configuration Word)</td>
<td>81</td>
</tr>
<tr>
<td>CSDD (Current Sense DC Gain Control)</td>
<td>40</td>
</tr>
<tr>
<td>CSF (Current Sense DC Gain Control)</td>
<td>40</td>
</tr>
<tr>
<td>DEADCON (Driver Dead Time Control)</td>
<td>46</td>
</tr>
<tr>
<td>DEVID (Device ID)</td>
<td>82</td>
</tr>
<tr>
<td>INTCON (Interrupt Control)</td>
<td>95</td>
</tr>
<tr>
<td>IOCA (Interrupt-on-Change PORTGPB)</td>
<td>122</td>
</tr>
<tr>
<td>IOCB (Interrupt-on-Change PORTGBP)</td>
<td>122</td>
</tr>
<tr>
<td>LPCRCON (Slope Compensation Ramp Control)</td>
<td>44</td>
</tr>
<tr>
<td>OOVCON (Output Overvoltage Detect Level Control)</td>
<td>48</td>
</tr>
<tr>
<td>OPTION_REG (Option)</td>
<td>77</td>
</tr>
<tr>
<td>OVCN (Output Undervoltage Detect Level Control)</td>
<td>48</td>
</tr>
<tr>
<td>OVVOCN (Output Undervoltage Set Point Coarse Control)</td>
<td>47</td>
</tr>
<tr>
<td>PCON (Power Control)</td>
<td>87, 92</td>
</tr>
<tr>
<td>PE1 (Analog Peripheral Enable 1 Control)</td>
<td>50</td>
</tr>
<tr>
<td>PIE1 (Peripheral Interrupt Enable)</td>
<td>96</td>
</tr>
<tr>
<td>PIR1 (Peripheral Interrupt Flag)</td>
<td>98</td>
</tr>
<tr>
<td>PIR2 (Peripheral Interrupt Flag)</td>
<td>99</td>
</tr>
<tr>
<td>PMADR (Program Memory Address)</td>
<td>106</td>
</tr>
<tr>
<td>PMCON1 (Program Memory Control)</td>
<td>107</td>
</tr>
<tr>
<td>PMDD (Program Memory Data)</td>
<td>106</td>
</tr>
<tr>
<td>PMDATL (Program Memory Data)</td>
<td>106</td>
</tr>
<tr>
<td>PMDRH (Program Memory Address)</td>
<td>107</td>
</tr>
<tr>
<td>PORTGPA</td>
<td>113</td>
</tr>
<tr>
<td>PORTGBP</td>
<td>117</td>
</tr>
<tr>
<td>RELEFF (Relative Efficiency Measurement)</td>
<td>67</td>
</tr>
<tr>
<td>Reset Values</td>
<td>89</td>
</tr>
<tr>
<td>CALWD7 (Calibration Word 7)</td>
<td>65</td>
</tr>
</tbody>
</table>

### Reset Values

- **Bank 0**: 73
- **Bank 1**: 74
- **Bank 2**: 75
- **Bank 3**: 76
- **SSP1ADD Register**: 188, 189
- **SSP3CON1 Register**: 185
- **SSP3CON2 Register**: 186
- **SSP3CON3 Register**: 187
- **SSP3MSK Register**: 188, 189
- **SSP3Ov**: 174
- **SSP3OV Status Flag**: 174
- **SSP3STAT Register**: 184
- **R/W Bit**: 153
- **Stack**: 78
- **Start-up Sequence**: 87
- **STATUS Register**: 71
- **Switching Frequency**: 18
- **System Bench Testing**: 22, 57
- **Read-Modify-Write Operations**: 193
- **Reader Response**: 222
- **Revision History**: 213
- **Read-Modify-Write Operations**: 193
- **Reader Response**: 222
Timer Requirements
  RESET, Watchdog Timer, Oscillator Start-up Timer and
  Power-up.................................................................32
Timer0..............................................................................135, 141
  8-Bit Counter Mode.......................................................135
  8-bit Timer Mode............................................................135
  Associated Registers.....................................................136
  External Clock.............................................................136
  Operation.......................................................................135
  Operation During Sleep..................................................136
  T0CKI...........................................................................136
Timer0 Module .................................................................135
Timer1...............................................................................137
  Associated Registers.....................................................139
  Associated registers......................................................139
  Clock Source Selection..................................................137
  Control Register..........................................................138
  Interrupt.................................................................138
  Operation.......................................................................137
  Operation During Sleep..................................................138
  Prescaler.......................................................................138
  Sleep...........................................................................138
  TMR1H Register .............................................................137
  TMR1L Register.............................................................137
Timer1 Module .................................................................137
Timer2...............................................................................141
  Associated Registers.....................................................141
  Control Register..........................................................141
  Operation.......................................................................140
  Timer2 Module ...............................................................140
Timer2/4/6...........................................................................141
  Associated Registers.....................................................141
Timers
  Timer1
    T1CON.......................................................................138
  Timer2/4/6
    TXCON.......................................................................141
Timing Diagrams
  Acknowledge Sequence..................................................176
  Baud Rate Generator with Clock Arbitration.........................170
  BRG Reset Due to SDA Arbitration During Start Condition........179
  Bus Collision During a Repeated Start Condition (Case 1)..........180
  Bus Collision During a Repeated Start Condition (Case 2)..........180
  Bus Collision During a Start Condition (SCL = 0).................179
  Bus Collision During a Stop Condition (Case 1)....................181
  Bus Collision During a Stop Condition (Case 2)....................181
  Bus Collision During Start Condition (SDA only)..................178
  Bus Collision for Transmit and Acknowledge.........................177
  Capture/Compare/PWM....................................................33
  Clock Synchronization....................................................167
  First Start Bit Timing.....................................................170
  I^2C Master Mode (7 or 10-Bit Transmission)........................173
  I^2C Master Mode (7-Bit Reception)...................................175
  I^2C Stop Condition Receive or Transmit Mode......................176
  INT Pin Interrupt.........................................................94
  Power-up Timer............................................................31
  Repeat Start Condition..................................................171
  Reset............................................................................31
  Start-up Timer............................................................31
  Time-out Sequence
    Case 1...........................................................................87
    Case 2............................................................................88
    Case 3............................................................................88
  Timer0.................................................................32
  Timer1.................................................................32
  Wake-up from Interrupt..................................................102
  Watchdog Timer...........................................................31
  Timing Parameter Symbology...............................................29
  Timing Requirements
    CLKOUT and I/O..........................................................31
    External Clock............................................................30
    TRISA Register...........................................................114
    TRISGPA Register.........................................................112
    TRISGPA Register.........................................................112
    TRISGPB Register.........................................................116, 117
    TXCON (Timer2/4/6) Register...........................................141
  Typical Application Circuit...................................................9
  Typical Performance Curves..................................................53
U
  Undervoltage Lockout
    Input..............................................................................37
  Unity Gain Buffer..........................................................58
V
  Voltage For Zero Current..................................................42
W
  Watchdog Timer (WDT).....................................................87, 103
    Associated Registers.....................................................104
    Configuration Word w/ Watchdog Timer...............................104
    Operation.................................................................103
    Period...........................................................................103
    Programming Considerations...........................................103
    WCOL.................................................................170, 172, 174, 176
    WCOL Status Flag.........................................................170, 172, 174, 176
    WPUB Register...........................................................114
    WPUGPB Register.........................................................118
    WWW Address.............................................................221
    WWW, On-Line Support...................................................7
THE MICROCHIP WEB SITE

Microchip provides online support via our website 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
- **Business of Microchip** – Product selector and ordering guides, latest Microchip press releases, listing of seminars and events, listings of Microchip sales offices, distributors and factory representatives

CUSTOMER CHANGE NOTIFICATION SERVICE

Microchip’s customer notification service helps keep customers current on Microchip products. Subscribers will receive e-mail notification whenever there are changes, updates, revisions or errata related to a specified product family or development tool of interest.

To register, access the Microchip web site at www.microchip.com. Under “Support”, click on “Customer Change Notification” and follow the registration instructions.

CUSTOMER SUPPORT

Users of Microchip products can receive assistance through several channels:

- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Technical Support
- Development Systems Information Line

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://microchip.com/support](http://microchip.com/support)
**PRODUCT IDENTIFICATION SYSTEM**

To order or obtain information, e.g., on pricing or delivery, refer to the factory or the listed sales office.

<table>
<thead>
<tr>
<th>PART NO.</th>
<th>[X]^{(1)}</th>
<th>X</th>
<th>XX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device</td>
<td>Tape and Reel Option</td>
<td>Temperature Range</td>
<td>Package</td>
</tr>
</tbody>
</table>

**Device:**
- MCP19110: Digitally Enhanced Power Analog Controller with Integrated Synchronous Driver
- MCP19111: Digitally Enhanced Power Analog Controller with Integrated Synchronous Driver

**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) MCP19110-E/MJ: Extended temperature, 24LD QFN 4x4 package
- b) MCP19110T-E/MJ: Tape and Reel, Extended temperature, 24LD QFN 4x4 package
- a) MCP19111-E/MQ: Extended temperature, 28LD QFN 5x5 package
- b) MCP19111T-E/MQ: Tape and Reel, Extended temperature, 28LD 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.
NOTICE TO CUSTOMERS

This product is subject to a license from Power-One®, Inc. related to digital power technology (DPT) patents owned by Power-One, Inc. This license does not extend to stand-alone power supply products.
Note the following details of the code protection feature on Microchip devices:

- Microchip products meet the specification contained in their particular Microchip Data Sheet.
- Microchip believes that its family of products is one of the most secure families of its kind on the market today, when used in the intended manner and under normal conditions.
- There are dishonest and possibly illegal methods used to breach the code protection feature. All of these methods, to our knowledge, require using the Microchip products in a manner outside the operating specifications contained in Microchip’s Data Sheets. Most likely, the person doing so is engaged in theft of intellectual property.
- Microchip is willing to work with the customer who is concerned about the integrity of their code.
- Neither Microchip nor any other semiconductor manufacturer can guarantee the security of their code. Code protection does not mean that we are guaranteeing the product as “unbreakable.”

Code protection is constantly evolving. We at Microchip are committed to continuously improving the code protection features of our products. Attempts to break Microchip’s code protection feature may be a violation of the Digital Millennium Copyright Act. If such acts allow unauthorized access to your software or other copyrighted work, you may have a right to sue for relief under that Act.

Information contained in this publication regarding device applications and the like is provided only for your convenience and may be superseded by updates. It is your responsibility to ensure that your application meets with your specifications. MICROCHIP MAKES NO REPRESENTATIONS OR WARRANTIES OF ANY KIND WHETHER EXPRESS OR IMPLIED, WRITTEN OR ORAL, STATUTORY OR OTHERWISE, RELATED TO THE INFORMATION, INCLUDING BUT NOT LIMITED TO ITS CONDITION, QUALITY, PERFORMANCE, MERCHANTABILTY OR FITNESS FOR PURPOSE. Microchip disclaims all liability arising from this information and its use. Use of Microchip devices in life support and/or safety applications is entirely at the buyer's risk, and the buyer agrees to defend, indemnify and hold harmless Microchip from any and all damages, claims, suits, or expenses resulting from such use. No licenses are conveyed, implicitly or otherwise, under any Microchip intellectual property rights.

Trademarks
The Microchip name and logo, the Microchip logo, dsPIC, FlashFlex, KEELoQ, KEELoQ logo, MPLAB, PIC, PICmicro, PICSTART, PIC32 logo, rPIC, SST, SST Logo, SuperFlash and UNI/O are registered trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

FilterLab, Hampshire, Hi-TECH C, Linear Active Thermistor, MTP, SEEVAL and The Embedded Control Solutions Company are registered trademarks of Microchip Technology Incorporated in the U.S.A.

Silicon Storage Technology is a registered trademark of Microchip Technology Inc. in other countries.

Analog-for-the-Digital Age, Application Maestro, BodyCom, chipKIT, chipKIT logo, CodeGuard, dsPICDEM, dsPICDEM.net, dsPICworks, dsSPEAK, ECAN, ECONOMONITOR, FanSense, Hi-TIDE, In-Circuit Serial Programming, ICSP, Mindi, MiWi, MPASM, MPF, MPLAB Certified logo, MPLIB, MPLINK, mTouch, Omniscient Code Generation, PICC, PICC-18, PICDEM, PICDEM.net, PICkit, PICtail, REAL ICE, rFLAB, Select Mode, SQI, Serial Quad I/O, Total Endurance, TSHARC, UniWinDriver, WiperLock, ZENA and Z-Scale are trademarks of Microchip Technology Incorporated in the U.S.A. and other countries.

SQTP is a service mark of Microchip Technology Incorporated in the U.S.A.

GestIC and ULPP are registered trademarks of Microchip Technology Germany II GmbH & Co. KG, a subsidiary of Microchip Technology Inc., in other countries.

All other trademarks mentioned herein are property of their respective companies.

© 2013, Microchip Technology Incorporated, Printed in the U.S.A., All Rights Reserved.

Printed on recycled paper.

Microchip received ISO/TS-16949:2009 certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona; Gresham, Oregon and design centers in California and India. The Company’s quality system processes and procedures are for its PIC® MCUs and dsPIC® DSCs, KEELOQ® code hopping devices, Serial EEPROMs, microperipherals, nonvolatile memory and analog products. In addition, Microchip’s quality system for the design and manufacture of development systems is ISO 9001:2000 certified.