INTRODUCTION

Even though many microcontrollers offer an on-chip brown-out function, it may be desirable to use an external voltage supervisor. This may be due to the microcontroller’s limited trip point selections or the additional current requirement for enabling the brown-out function. In these cases, an external voltage supervisor device may be preferable.

Many standard microcontrollers are Flash memory devices. This means that the device can be programmed in-circuit. Typically, to enter the in-circuit programming mode, some non-typical state needs to be forced. For PICmicro® microcontrollers, the mode is called In-Circuit Serial Programming™ (ICSP™). A typical microcontroller – ICSP system is shown in Figure 1.

ICSP can be used to program the device after assembly as well as for firmware updates in the field.

In most cases, entering the ICSP mode requires that the MCLR pin go from a low voltage (V_{IL}) to the programming high voltage (V_{IH}). The V_{IH} is dependent on the PICmicro microcontroller and typically ranges from a minimum of the PICmicro microcontroller’s V_{DD} + 3.5V to a maximum of 14V.

As can be expected, these voltages are beyond the maximum voltage specification of the voltage supervisor output pin.

FIGURE 1: A TYPICAL PICmicro® MICROCONTROLLER SYSTEM WITH ICSP™

This technical brief will show how the MCP111 and MCP121 may be used in PICmicro microcontroller systems where ICSP is required.

Reset Characteristics

The two main reasons to consider an external voltage supervisor device are:
1. Voltage trip point
2. Operating current

Table 1 shows a voltage trip point and operational current comparison between a couple of PICmicro microcontrollers and either the MCP111 or MCP121. The MCP1X1 offers more voltage trip points and a significantly lower operating current.

**TABLE 1: RESET CHARACTERISTICS**

<table>
<thead>
<tr>
<th>Device</th>
<th>Trip Point Voltages (V) (Typ.)</th>
<th>Operating Current (µA) (min./max.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIC16F87XA</td>
<td>4.00</td>
<td>—/200 (1)</td>
</tr>
<tr>
<td>PIC18F1320</td>
<td>2.72, 4.22, 4.54</td>
<td>19/45 (1)</td>
</tr>
<tr>
<td>MCP121</td>
<td>1.90, 2.32, 2.63, 2.93, 3.08, 4.38, 4.63</td>
<td>—/1.75</td>
</tr>
<tr>
<td>MCP111</td>
<td>1.90, 2.32, 2.63, 2.90, 2.93, 3.08, 4.38, 4.63</td>
<td>—/1.75 (2)</td>
</tr>
</tbody>
</table>

Note 1: This current added to either device I_DD or I_PD current.
Note 2: Power-up Timer Active current is 20 µA. This is NOT the typical state.

Author: Mark Palmer
Microchip Technology Inc.
A LOOK AT ICSP™ OPERATION

When the application board is assembled, the PICmicro microcontroller can either be blank (unprogrammed) or programmed.

Application boards assembled with blank devices require the ICSP feature. Application boards assembled with programmed devices may or may not require the ICSP feature. This is dependent on whether or not the application board supports firmware upgrades.

Application boards (assembled with programmed devices) that do not support firmware upgrades are not an issue for voltage supervisor devices. This is due to the fact that the MCLR pin does not require an ICSP high voltage ($V_{IH}$) to be applied.

Many PICmicro microcontroller applications utilize the ICSP feature of these devices. However, with the ICSP feature, a high voltage ($V_{IH}$) is applied to the MCLR pin. Depending on the device used, this maximum voltage on the MCLR pin may be up to 14V. Most devices specify a maximum of 13.5V or below.

ICSP Requirements

The ICSP requirements for the desired PICmicro microcontroller is shown in that device’s programming specification document. For voltage supervisors and voltage detectors, one of the most important specifications is the $V_{IH}$ specification. The $V_{IH}$ specification states the voltage requirement on the MCLR pin for the device to be in the ICSP mode. The voltage supervisor open-drain output pin typically would be connected to the MCLR pin.

Table 2 shows the minimum and maximum $V_{IH}$ specifications for the $V_{IH}$ voltage on the MCLR pin. Table 2 also shows the Microchip programming specification documents (and the document revision) referenced for this information.

There are only a few devices where the ICSP maximum $V_{IH}$ specification is greater than 13.5V; they are 14.0V devices.

Note: Please check the most current revision of the programming specification for the desired device for $V_{IH}$ and other application requirements.

For these devices (with the 14V maximum $V_{IH}$), the maximum voltage on the MCLR pin would then be limited by the MCP111 or MCP121 device, which has a maximum of 13.5V. This should NOT be an issue since the minimum $V_{IH}$ voltage of these devices is 12.0V and 10.0V (when the device Vdd is 5.5V). Therefore, a significant ICSP $V_{IH}$ voltage window remains (1.5V, worst-case).

Table 2: $V_{IH}$ Programming Specifications

<table>
<thead>
<tr>
<th>$V_{IH}$ on MCLR</th>
<th>Min.</th>
<th>Max.</th>
<th>Document</th>
<th>Rev</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{DD}$ + 4.0V</td>
<td>12.5V</td>
<td>13.25V</td>
<td>DS30480, DS39622, DS39643</td>
<td>B, C, A</td>
<td></td>
</tr>
<tr>
<td>12.5V</td>
<td>13.5V</td>
<td>13.5V</td>
<td>DS30190, DS30467, DS41207, DS41208, DS41226, DS41227, DS41228, DS41243</td>
<td>H, A, C, B, D, D, D, A</td>
<td></td>
</tr>
<tr>
<td>10.0V</td>
<td>12.0V</td>
<td>13.5V</td>
<td>DS39624, DS41237, DS41244</td>
<td>A, A, B</td>
<td></td>
</tr>
<tr>
<td>10.0V</td>
<td>13.5V</td>
<td>13.5V</td>
<td>DS41196</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>$V_{DD}$ + 3.5V</td>
<td>13.5V</td>
<td>13.5V</td>
<td>DS30034, DS39025, DS39589, DS39603, DS39607, DS41191</td>
<td>D, F, B, C, B, C</td>
<td></td>
</tr>
<tr>
<td>12.0V</td>
<td>14.0V</td>
<td>14.0V</td>
<td>DS30262</td>
<td>E, Note 1</td>
<td></td>
</tr>
<tr>
<td>$V_{DD}$ + 4.5V</td>
<td>14.0V</td>
<td>14.0V</td>
<td>DS41156, DS41157, DS41163</td>
<td>D, D, D, Note 1, Note 1</td>
<td></td>
</tr>
<tr>
<td>11.0V</td>
<td>13.5V</td>
<td>13.5V</td>
<td>DS40245</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>10.0V</td>
<td>13.0V</td>
<td>13.0V</td>
<td>DS41204</td>
<td>D</td>
<td></td>
</tr>
</tbody>
</table>

Note 1: MCP1X1 maximum = 13.5V.


**$V_{IH}$ on the MCLR pin**

Figure 2 shows a typical microcontroller–voltage supervisor system circuit with this in-line resistance ($R_S$). $R_{PU}$ is the MCLR pull-up resistor, $R_S$ is the in-line resistor to the open-drain output of the voltage supervisor or voltage detector. $V_{RS}$ is the voltage into the MCLR pin.

It is recommended that the current into the open-drain output ($I_{RS}$) be limited to 2 mA, even though characterization was done using a 1 kΩ resistor. This was to allow PICmicro MCU devices with the internal pull-up on the MCLR pin to also be used, since the minimum pull-up resistance can be calculated to 12.5 kΩ. This ensures the $V_{OI}$ of the voltage supervisor can meet the requirements of the MCLR pin $V_{IL}$.

**WHEN USING THE MCLR’S INTERNAL PULL-UP RESISTOR**

Some PICmicro microcontrollers have an internal pull-up resistor option on their MCLR pin.

For example, the PIC16F684 has a typical internal 20 kΩ pull-up on the MCLR pin. Looking at the specifications, the minimum pull-up resistance can be calculated to 12.5 kΩ from the maximum current specification. With the in-line 1 kΩ resistance, the minimum PIC16F684 $V_{IL}$ specification (0.2 x $V_{DD}$) is not a problem (see VDR calculation from Table 4 and VRS calculation from Table 5).

**OPEN-DRAIN HIGH VOLTAGE SPECIFICATION**

Table 3 shows an example voltage supervisor/voltage detector device data sheet open-drain high voltage ($V_{ODH}$) specification.

| Note: | The device is not specified to constantly maintain the maximum $V_{ODH}$ voltage on the open-drain output pin. This is intended for short ICSP programming cycles. |

This specification is specified for a worst-case scenario, where the device $V_{DD}$ is 3V and a $V_{PP}$ of 13.5V. This causes a voltage differential of 10.5V. If the device $V_{DD}$ is 5V, there are less issues since the voltage differential is reduced to 8.5V, decreasing the current into the voltage supervisor open-drain output pin.

**FIGURE 2:** A TYPICAL PICmicro® MICROCONTROLLER SYSTEM WITH ICSP™ AND AN EXTERNAL VOLTAGE SUPervisor

![Diagram of a typical microcontroller system with ICSP and an external voltage supervisor](image)

**TABLE 3: EXAMPLE DATA SHEET SPECIFICATION**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sym</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Drain High Voltage on Output</td>
<td>$V_{ODH}$</td>
<td>—</td>
<td>—</td>
<td>13.5 (1)</td>
<td>V</td>
<td>$V_{DD} = 3.0V$. Time voltage &gt; 5.5V applied ≤ 100s, current into pin limited to 2 mA. 25°C operation recommended. <strong>Note 1, Note 2</strong></td>
</tr>
</tbody>
</table>

**Note 1:** This specification allows this device to be used in PICmicro microcontroller applications that require the ICSP feature (see device-specific programming specifications for voltage requirements). This specification does NOT allow a continuous high voltage to be present on the open-drain output pin ($V_{OUT}$). The total time that the $V_{OUT}$ pin can be above the maximum device operational voltage (5.5V) is 100s. Current into the $V_{OUT}$ pin should be limited to 2 mA; it is recommended that the device operational temperature be maintained between 0°C to 70°C (25°C preferred). For additional information, please refer to Figure 4.

**Note 2:** This parameter is established by characterization and not 100% tested.

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**RS and RPU**

The value of the RPU pull-up resistor and the RS in-line resistor should be selected to ensure that the voltage supervisor output voltage (VOL) can meet the PICmicro microcontroller MCLR VIL specification.

Figure 3 shows a typical circuit with symbols for each of the components.

Equation 1 shows the equation for the Voltage Divider Ratio (VDR) of the RS and RPU resistors.

Equation 2 show the equation for calculating the worst case low voltage on the MCLR pin, where VOL is the maximum output low voltage from the MCP1X1 device.

The VRS voltage must not exceed the MCLR VIL specification.

Table 4 shows some values for RS and the resultant maximum current into the open-drain output pin (IRS). Furthermore, it shows a recommended RPU value for cases when the RPU resistor is external. Given the RS and the RPU, the VDR is shown.

Table 5 shows values for voltage divider ratios, and how these values relate to the VRS voltage at different system VDD levels.

---

**FIGURE 3: VOLTAGE SUPERVISOR CIRCUIT**

**EQUATION 1: VOLTAGE DIVIDER RATIO (VDR)**

\[
VDR = \frac{R_S}{R_S + R_{PU}}
\]

**EQUATION 2: VRS**

\[
V_{RS} = \left((\frac{VDD}{V_O} \times VDR) + V_{OL}\right)
\]

**TABLE 4: RS AND RPU**

<table>
<thead>
<tr>
<th>RS (kΩ)</th>
<th>RPU (kΩ)</th>
<th>IRS (1) (mA)</th>
<th>VDR</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.5 (2)</td>
<td>10.5</td>
<td>0.0741</td>
<td></td>
</tr>
<tr>
<td>5.25</td>
<td>63</td>
<td>2</td>
<td>0.0769</td>
<td>Recommended IRS</td>
</tr>
</tbody>
</table>

Note 1: When VDD = 3V and VHH = 13.5V
Note 2: This is in the minimum MCLR pin internal pull-up resistance.

**TABLE 5: VDR, VRS CALCULATIONS**

<table>
<thead>
<tr>
<th>VDR</th>
<th>VRS</th>
<th>Comment (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0741</td>
<td>0.592</td>
<td>0.778V</td>
</tr>
<tr>
<td>0.0769</td>
<td>0.6</td>
<td>0.792</td>
</tr>
<tr>
<td>0.1219</td>
<td>—</td>
<td>1.022</td>
</tr>
<tr>
<td>0.1304</td>
<td>—</td>
<td>1.065</td>
</tr>
<tr>
<td>0.1373</td>
<td>—</td>
<td>1.1V</td>
</tr>
</tbody>
</table>

Note 1: When MCLR VIL = 0.2 VDD
MCP111 and MCP121 Open-Drain High Voltage Characterization

Figure 4 shows the characterization curve of the current into the voltage supervisor devices (MCP111 and MCP121) as the voltage on the open-drain pin is increased. This characterization was done with a 1 kΩ in-line resistance to limit current into the device. This low current will not damage the structure of the output pin. We suggest that the lower the voltage on the output pin, the better. However, there should not be any issues with a limited time duration (100 sec.) at 13.5V (through the 1 kΩ resistor).

The majority of programming specifications for the PICmicro microcontrollers recommend a programming temperature of 25°C. Only at low temperature, and voltages above 13.5V, does this pin current start to rise, leveling off at the mA range.

Although this curve shows that the device can support operation at -40°C at 13.5V, it is recommended that the device be operated as close as possible to 25°C. Also, the lower the voltage, the better, since this adds to the “safety margin” for your system.

Based on the design of the device and the characterization data, here are the recommended operating rules:

1. Minimize the voltage differential between the device $V_{DD}$ and the $V_{PP}$ voltage.
   - a $V_{DD} = 5.0V$ and $V_{PP} = 13.0V$ (8V delta) is much better than
   - a $V_{DD} = 3.0V$ and $V_{PP} = 13.5V$ (10.5V delta)
2. Maximize size of current limiting resistor ($R_S$).
   - an $R_S = 10 k\Omega$ is better than an $R_S = 1 k\Omega$.
3. Apply the high voltage at warmer temperatures.
4. Limit time at high voltage.

FIGURE 4: EXAMPLE VOLTAGE SUPERVISOR OUTPUT PIN CURRENT VS. VOLTAGE GRAPH
OTHER MICROCHIP VOLTAGE SUPERVISOR DEVICES

Other Microchip voltage supervisor devices with an open-drain output have not yet been evaluated for their ability to support the ICSP $V_{IH}$ voltage requirements on their open-drain output pin.

Devices that have a push-pull output (or those open-drain devices that have an internal pull-up resistor) are not suitable due to the high currents that can occur when the internal semiconductor devices become forward-biased. These high currents can lead to the device being damaged after programming (immediate or long-term reliability).

Figure 5 shows an alternate circuit that can be used with any voltage supervisor device. There are two drawbacks for these types of circuit implementations. First is the additional cost of the Schottky diode (with a low voltage drop, ~ 0.3V). Second is the additional current consumption.

The operation of the circuit is as follows:

When the RST pin is not driven low, the Schottky diode will "block" the VPP voltage from the RST pin (so the voltage on the RST pin does not violate the device specifications). When the VPP signal is disconnected (open), the $R_{PU}$ will pull up the voltage on the MCLR pin to above it’s $V_{IH}$ level.

When the RST pin is driven low (and the VPP signal is disconnected), the Schottky diode will block the RST pin’s $V_{OL}$ from the MCLR pin. The MCLR pin will essentially be floating. So something needs to ensure that the voltage level on the MCLR pin does not exceed the MCLR pin’s $V_{IL}$ specification. This could be attributed to either the leakage characteristics of the Schottky diode, or an external pull-down resistor.

The selection of the $R_{PU}$ and $R_{PD}$ resistor values should ensure that both the MCLR $V_{IH}$ and $V_{IL}$ specifications can be met ($R_{PD} \approx 10^* R_{PU}$).

FIGURE 5: ALTERNATE VOLTAGE SUPERVISOR CIRCUIT

OTHER MANUFACTURER’S DEVICES

After inspecting many other competitor’s voltage supervisor/voltage detector data sheets, it did not appear that their open-drain outputs are specified to support the $V_{IH}$ voltage requirements of the PICmicro microcontroller ICSP feature.

When using a voltage supervisor or voltage detector, ensure that the device’s specifications meet the ICSP operation conditions of your application. Failure to do so may result in damage to the voltage supervisor or voltage detector (immediate or long-term reliability).

QUICK EVALUATIONS

Microchip offers a SOT-23-3 evaluation board (Part Number: VSUPEV). This board can be purchased via the Microchip web site and allows the voltage supervisor and in-line resistor to be installed and then connected to the PICmicro MCU circuit. When installing the in-line resistor (R3, see Figure 6), be sure to cut the default trace that shorts out this component. Additional information can be found in the “Voltage Supervisor SOT23 Evaluation Board User’s Guide”, DS51510.

FIGURE 6: SOT-23-3 EVALUATION BOARD – VSUPEV

SUMMARY

This technical brief has shown how Microchip’s MCP111 or MCP121 can be interfaced to devices that require a temporary high voltage on one of their pins. This is particularly relevant to applications using the In-Circuit Serial Programming (ICSP) feature with one of Microchip Technology’s PICmicro microcontrollers.

Not all applications require the use of an external voltage supervisor solution. But if they do, ensure that a device is selected that is specified to allow the high voltage required by ICSP.
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