

Powering Up and Down in Sequence

Power sequencers are commonly used in system-level board designs where multiple power supplies are enabled in a sequential manner. Engineers, however, can easily implement a power sequencer design with a small microcontroller, and this can be modified to control varying numbers of voltage modules in different designs. **Stan D'Souza, Technical Fellow, Microchip Technology, Phoenix, USA**

Typically, systems using a power sequencer have different components on them that require different power supply voltages and power levels. The sequence of enabling the different voltages would ensure that there is no conflict between components being powered up and all units are powered up correctly. When shutting down the system, there may also be a sequence. The power-up and power-down sequences are programmable and time based.

Take, for example, a four-channel power sequencer in which the four voltages are 5.0, 3.3, 2.5 and 1.8 V. Each of these voltages is provided through a power module (PM). These PM units typically have five pins: input and output power, ground, enable, and trim. Users are not limited to four PMs as a modular format can support up to ten PMs that can be added or removed to meet specific needs.

An enhanced core Microchip PIC16F1509 device was selected as the MCU for this application. The peripherals used were GPIO, timer1, ADC, I²C and PWM.

The PM units can be off-the-shelf power supply blocks, sold with specific current and power capabilities. The PM used in this design is the VRAE-10E1A0 made by BEL Power Products. Each PM has five pins: input voltage (V_{IN}), output voltage (V_{OUT}), ground, enable input and output trim. The enable signal is active-high and, when enabled, the PM output voltage appears at the output voltage pin. The trim pin with the associated R_{trim} resistor allows the output voltage to be set as desired.

The voltage at the trim pin is typically around 0.591 V. A DC voltage at the trim pin also allows the system to provide some voltage load regulation of V_{OUT} . In this design, the DC voltage is provided by a PWM-driven RC filter circuit that provides a DAC output to the trim pin. Alternately, this DC voltage can be provided by using fixed resistors from the trim pin to GND with no PWM trim DAC voltage. With this option, the PWM, with its associated hardware and

firmware in the microcontroller, would be eliminated.

Power up

The PIC16F1509 operating at 5.0 V and 4 MIPS using the internal RC clock was used to control the power-up sequence. The power-up sequence is initiated by a serial command using the I²C interface and pressing a push button.

Each PM is sequenced on at a set time interval from 1 to 16,393 ms (16.4 s) with a 1 ms accuracy. For example, PM1 can be started at 10 ms from the start command, followed by PM2 at 25 ms, PM4 at 200 ms and PM3 at 1000 ms. Each PM has a corresponding on-time value, which is a 14 bit unsigned integer value in firmware. This value is compared with a timer value incremented every millisecond. If a match between the timer value and the on-time value of the PM occurs, then the corresponding PM is turned on.

The on-off timing can be selected by the user and is saved in flash on the microcontroller. The on-off sequence can be started and stopped using the serial I²C GUI.

When a PM is turned on, the corresponding PWM output is enabled and V_{OUT} is monitored via the microcontroller's ADC. The PWM duty cycle corresponds to the 8 bit DAC value for the PM. This DAC value can be changed by the user in the GUI or in the firmware.

The trim voltage is created by using a combination of R_{trim} and the PWM output from the microcontroller. This PWM output is sent to an RC filter to create a DAC voltage, which, in combination with the trim-resistor, is applied to the trim pin of the PM. The output of the PM is monitored using a 10 bit ADC converter on the microcontroller.

Each PM voltage is averaged over 16 readings to give a 14 bit value. Only the most significant eight bits of this value are used to reference the V_{OUT} voltage value of each PM. The reference voltage of the ADC is V_{DD} or 5.0V. For example, if the PM output voltage is 2.5 V, then the accuracy

of the measurement would be $(2.5 \text{ V}/5.0 \text{ V})/256 = 1.95 \text{ mV}$. All output voltages are constantly monitored to verify they are within the specified over and undervoltage limits specified. If the PM voltage goes above or under the under or overvoltage limits, then a failure is signaled and the system is automatically shut down.

Power down

The MCU also controls the programmable power-down sequencing of the four power modules. The power-down sequence is initiated on a serial command from the I²C, any fault condition on the PMs or input voltage, and pressing a push button.

Each PM is sequenced off at a set time interval from 1 to 16,393 ms (16.4 s) with a 1 ms accuracy.

For example, PM4 can be shut at 20 ms from the stop command, followed by PM2 at 25 ms, PM3 at 200 ms and PM1 at 1000 ms.

Each PM has a corresponding off time value, which is an unsigned integer (14 bit value). This value is independent from the on-time value. This value is compared with a 16 bit counter value incremented every millisecond. If the two are equal, then the corresponding PM is turned off.

The off-time values are user selectable and are saved in flash. In case of a fault condition power-down, a new power-up sequence will be automatically initiated depending on the number of retries selected by the user. Typically, a user may specify two or three retries. After all retries return a failure, the system is shut down and the fault condition is signaled.

Using the I²C GUI interface, the user can figure out which PM condition or input voltage caused the failure. The user must take the appropriate corrective action to remove the failure condition and reset the system using the I²C serial command or the GUI, and then retry the power-up sequence.

Microcontroller

Since four channels of PMs are used in

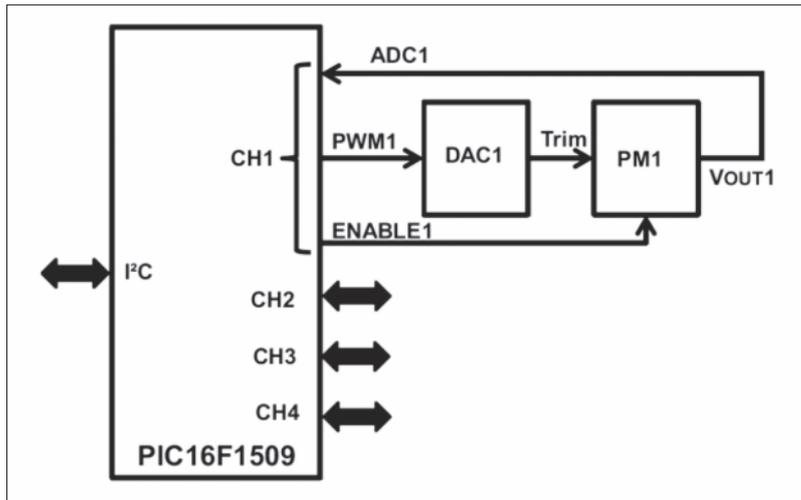


Figure 1: System block diagram

this design, at least four IO lines for the enable and disable function are required. Also required are four ADC channels, four PWM outputs and two lines for I²C. An additional ADC channel was used to sample the input voltage, the MCLR, the VDD, the VSS and the programming pins; a total of 20 pins. Figure 1 shows the system block diagram.

The MCU is powered by 5.0 V via a 5 V regulator. The internal 16 MHz RC clock is used to run the CPU at 4 MIPS. The hardware and firmware can be modified to accommodate up to ten PMs. If more PMs are required, the number of IOs will increase and a larger microcontroller would have to be selected. If fewer PMs are required, then a smaller device can be used.

The trim voltage requirements can also be adjusted. If the user wants to trim the PMs using only the external resistor, then

the DAC voltage and the associated PWM is not required. The software to drive the PWM and DAC will also be eliminated. Each PM has its own normal over and under-voltage limit. The PMs also have margin under and over limits for the trim voltage.

An I²C slave interface is implemented on the MCU for serial communications with an external I²C GUI. An MCP2221 I²C-to-mini-USB interface chip can be implemented by users in their own hardware or, if required, they can implement a different I²C interface.

All the firmware for IO, timer1, ADC, PWM, flash memory and I²C peripherals has been created and initialised using the free MPLab Code Configurator (MCC) software.

The ADC routine essentially runs through and samples the voltage of modules 0 to 4. Module 0 corresponds to

the input voltage, which always gets monitored for a failure. A failure of the input voltage causes a shutdown. No retries will be attempted. The 10 bit ADC routine samples each voltage 16 times and then uses the average 8 bit value to check for an error with the corresponding under- and over-voltage limits.

In the hardware used, the voltage reference is 5.0 V or V_{DD} of the system. A 5.0 V reference will work fine when sampling and converting 1.8, 2.5 and 3.3 V. However, for the 5.0 V module and the input voltage, a resistor divider is needed to bring the full-voltage range within the 5.0 V reference.

The resistor divider factor for the 5.0 V module is 0.55 and the input voltage divide factor is 0.239. Users will have to use this value during the calculation of the under- and over-voltage limit values and define them appropriately in the header files. This is especially true if the user decides to use values other than those used here.

Power sequencer GUI

The power sequencer GUI has been designed for the user to enter relevant data, monitor relevant data and control the power sequencer application. The GUI is shown in Figure 2. The main window has the system options on the left and the module options as tabs on the right.

In the system options, the user can start, stop, reset and read the current firmware values. The status window allows the user to define the V_{OUT} corresponding to the module index. These values can be modified by the user and will be saved when the GUI is closed. The user can also enter the ADC reference value, which for this application note is set at 5.0 V. Finally, the user can burn the updated module settings onto the flash program memory by clicking on the burn-flash button.

Under each module tab, the user can

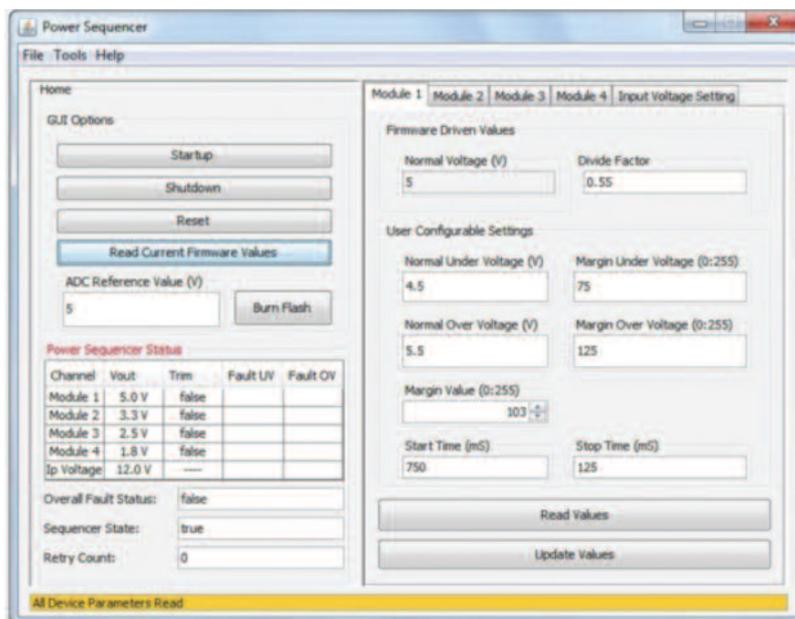


Figure 2: Power sequencer graphical user interface (GUI)

also set or read existing values for each module. Module 1 is the 5 V module and the user can set the normal and margin, over- and under-limits for this module, along with start and stop times in

milliseconds. Also, the voltage divide factor can be edited and entered in this tab. In each module tab, the DAC value can be incremented or decremented using the up and down arrow at one side of the DAC

value box. The value increments or decrements and, if the module is on, then the output voltage will be read and updated.

To see the voltage change, more than one increment or decrement may have to be performed. This feature allows the user to increase or decrease the output voltage during a system test when voltages reach their limit. This is called voltage limit testing and allows the user to test a complete system when one or more of the output voltages reaches their under- or over-voltage limits. The voltage values are displayed as actual voltage values (3.3 or 2.5 V). The DAC value and the margin limits are displayed as 8 bit values from 0 to 255.

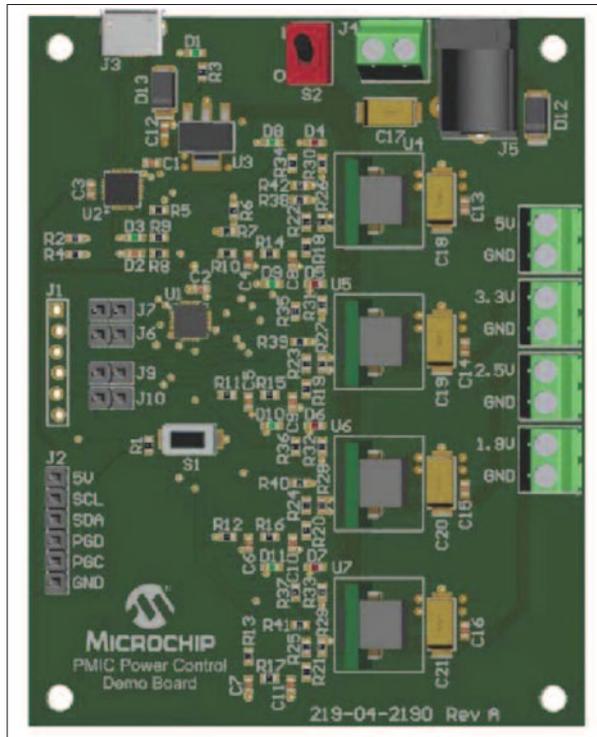


Figure 3: Power control demo board

Conclusion

An engineer can implement a power sequencer using a PIC16F1XXX device. The user can easily modify this to control four voltage modules in their own design. Additionally, they can add more power modules to their applications or remove modules for a smaller application. The hardware and firmware have been created in a modular format to accomplish these goals easily. The completed board is shown in Figure 3.

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