



MIC7401 Evaluation Board

**Configurable PMIC, Five-Channel
Buck Regulator plus One-Boost with
HyperLight Load[®], I²C Control and Enable**

General Description

The MIC7401 is a powerful, highly-integrated, configurable, power-management IC (PMIC) featuring five synchronous buck regulators, one boost regulator, and high-speed I²C interface with an internal EEPROM and micro-power shutdown. The device offers two distinct modes of operation "standby mode" and "normal mode".

In normal mode, the programmable switching converters can be configured to support a variety of features, including start-up sequencing, timing, soft-start ramp, output voltage levels, current-limit levels, and output discharge for each channel.

In standby mode the PMIC can be configured in a low power state by either disabling an output or by changing the output voltage to a lower level. Independent exit from standby mode can be achieved either by I²C communication or the external STBY pin.

The initial settings of the evaluation board are:

Input: 2.4V to 5.5V	
Output 1: 1.8V/0.8A	Output 4: 1.05V/3.0A
Output 2: 1.1V/0.5A	Output 5: 1.25V/1.0A
Output 3: 1.8V/0.5A	Output 6: 12V/0.2A

Datasheets and support documentation are available on Micrel's web site at: www.micrel.com.

Requirements

The MIC7401 evaluation board requires only a single power supply with 5A (minimum) current capability. The output load can either be an active (electronic) or passive (resistive) load.

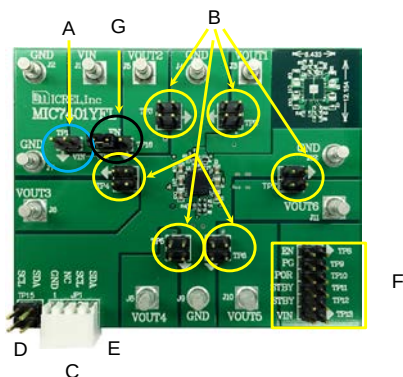
Precautions

The MIC7401 evaluation board does not have reverse polarity protection. Applying a negative voltage to the VIN and GND terminals can damage the device. The maximum operating rating for V_{IN} is 5.5V. Exceeding 5.5V on the VIN could damage the device.

Ordering Information

Part Number	Description
MIC7401EV	MIC7401 Evaluation Board
MICUSB	USB Dongle

Evaluation Board



- A) INPUT VOLTAGE
- B) OUTPUT VOLTAGES
- C) USB DONGLE CONNECTOR
- D) I²C SDA AND SCL
- E) I²C PULL-UP TO VIN
- F) STATUS AND CONTROL BIT HEADER
- G) ENABLE

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Getting Started

1. Download GUI

To download the GUI, select “Software Package/Kit” from the [MIC7401](http://www.micrel.com) product page from the Micrel website (www.micrel.com). Users can either save the compressed installation file to hard drive or extract the compressed file using a program such as PeaZip, WinRAR, or WinZip. Then run MIC7401Install.msi to install the GUI.

When the installation process is complete, click on the Windows “Start” button, then select “All Programs” to view the Start Menu. Find the new Micrel folder and “click” on the Serial Programmer > MIC7401 to locate the GUI program.

Before you launch the GUI, the USB dongle must be connect to the PC by the USB cable, the USB dongle plugged into the evaluation board and the board powered up.

2. Set the USB Dongle and Switch Position

The USB dongle has a micro switch with two positions: “I2C” and “NOM” (refer to [Figure 1](#)). To ensure the PC is capable of communicating to the IC, confirm that the micro switch is in the I²C (or left) position. Pin 1 on the edge connector is the ground pin, which has a square solder pad.

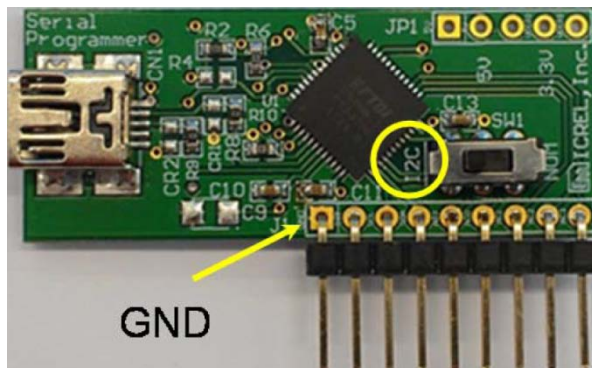


Figure 1. MIC7401 USB Dongle Micro Switch

3. Connect USB Dongle

The USB dongle is inverted and plugged into the 4-pin socket (see [Figure 2](#)). Cutting off the extra pins is recommended. Next, turn on the power supply and slowly ramp up then input voltage. Now, click on the MIC7400 ICON in the Start Menu to launch the GUI.

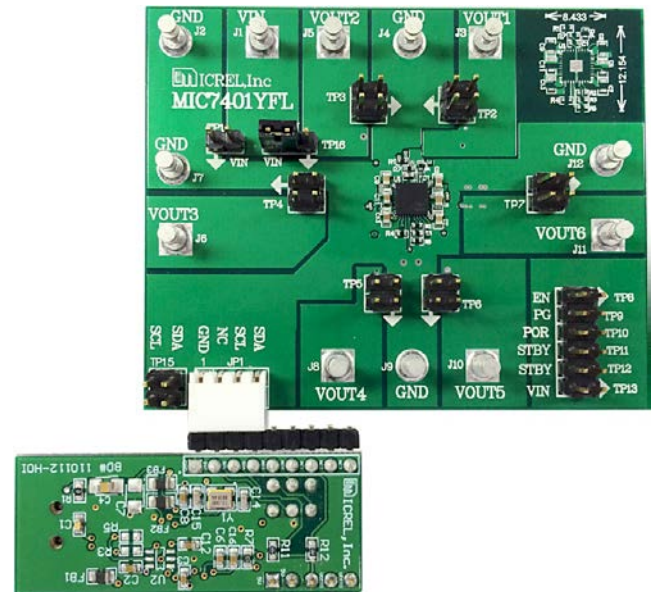


Figure 2. USB Dongle Connection to Evaluation Board

4. Configure the GUI for Direct Editing

When the MIC7401 GUI Interface window appears (see [Figure 3](#)), the connection between the computer and the USB dongle must be verified by clicking on the “Test” button. “Target OK” will appear on the bottom of the GUI window indicating it is operational. Before configuring the MIC7401, the GUI needs to be set for direct editing. To do this click on Link > Link Mode > Directing Editing. Now it is time to program the MIC7401.

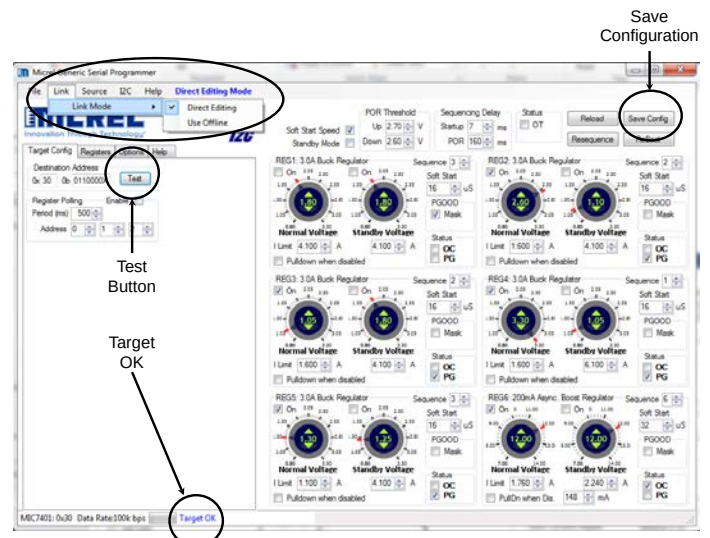


Figure 3. MIC7401 GUI Interface

Evaluation Board Description

Programming Options

Every regulator has its own configuration settings that allow the output voltage, current-limit, and soft-start ramp rate to be set (Figure 4). The global settings like power-on-reset (POR) threshold and start-up delay are at the top of the MIC7401 GUI Interface window (Figure 5).

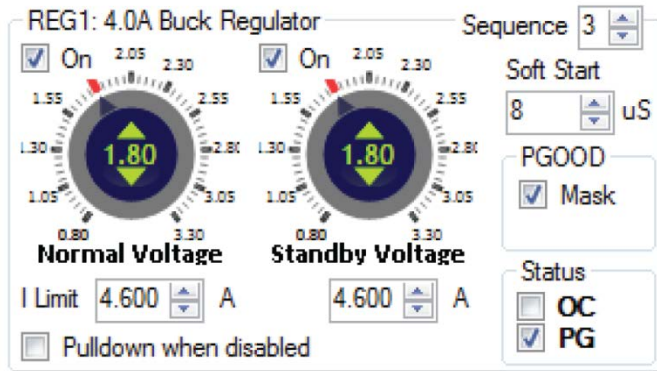


Figure 4. Regulator Settings

The first dial sets the output voltage for normal mode and the second sets standby mode. To change the voltage setting, click on the up/down arrow or click and hold the right mouse button on the pointer and drag the pointer to the desired voltage level, then release the mouse button. Note that the register associated with the output changes on-the-fly every time the mouse is clicked. As the voltage level in the GUI changes, the output of the MIC7401 will also change. The “On” check box is the ON/OFF control for the regulators. If checked, the regulator is enabled.

The soft-start ramp rate is registered in μs -per-step, with each step being 50mV for the buck regulators and 200mV for the boost. It controls both the rising and falling rate of the output voltage.

The PGOOD mask is used to control the global power good output (PG). If this box is checked, then the output will not contribute to the overall power good output. This allows the output to go from normal mode to standby mode without triggering a power good fault. Also the global power good flag will not be affected by an over-current fault.

The PG status box is checked when the output is within 91% of its regulated value. The OC status box indicates an overcurrent condition.

In Figure 5, the POR threshold monitors AVIN and sets the lower and upper limit of the POR comparator. The POR delay time starts as soon as AVIN voltage rises above the upper threshold. The POR output goes low without delay as soon as AVIN fall below the lower threshold limit.

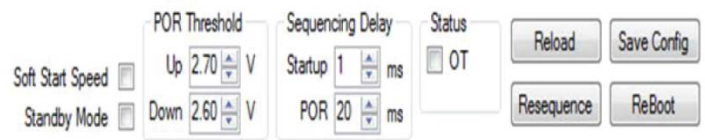


Figure 5. Global Settings

The startup delay sets the delay between the internal power good signal and the enable of the next regulator in the sequence. The sequence setting allows the outputs to come up in any order. There are six time slots. Each time slot can be programmed for up to six regulators to be turned on at once or none at all.

The MIC7401 can be powered up into either standby or normal mode. The IC will start-up in standby mode if the standby-mode check box is checked.

The soft-start speed check box when checked set the soft start ramp to the 8 μs to 1024 μs speed range. The OT check box is a status indicator when checked indicates an overtemperature fault.

Evaluation Board

The MIC7401 evaluation board provides numerous two-pin headers to monitor various system parameters such as input voltage, output voltage, standby mode, and power good. A standard test clip can be used, but for a more elegant solution, use a test cable from Joy Signal PN: 9-905305.

Functional Description

The MIC7401 is one of the industry's most-advanced PMIC devices designed for solid state drives (SSD) on the market today. It is a multi-channel solution which offers software configurable soft-start, sequencing, and digital voltage control (DVC) that minimizes PC board area. These features usually require a pin for programming. However, this approach makes the IC larger by increasing pin count, and also increases BOM cost due to the external components.

The following is a complete list of the programmable features of the MIC7401:

- Buck output voltage (0.8V – 3.3V/50mV steps)
- Boost output voltage (7.0V – 14V/ 200mV steps)
- Power-on-reset (2.25V – 4.25V/50mV steps)
- Power-on-reset delay (5ms – 160ms/5ms steps)
- Power-up sequencing (6 time slots)
- Power-up sequencing delay (0ms – 7ms/1ms steps)
- Soft-start (4 μ s – 1024 μ s per step)
- Buck current-limit threshold
 - (1.1A to 6.1A/0.5A steps)
- Boost current-limit threshold
 - (1.76A to 2.6A/0.12A steps)
- Boost pull-down (37mA to 148mA/37mA steps)
- Buck pull-down (90 Ω)
- Buck standby output voltage programmable
- Boost standby output voltage programmable
- Global power-good masking

These features give the system designer the flexibility to customize the MIC7401 for their application. For example, V_{OUT1} current limit can be programmed to 4.1A and V_{OUT2} can be set to 1.1A. These outputs can be programmed to come up at the same time or 2.0ms apart. In addition, in power-saving standby mode, the outputs can either be turned off or programmed to a lower voltage. With this programmability the MIC7401 can be used in multiple platforms.

The MIC7401 buck regulators are adaptive on-time synchronous step-down DC-to-DC regulators. They are designed to operate over a wide input voltage range from 2.4V to 5.5V and provide a regulated output voltage at up to 3.0A of output current. An adaptive on-time control scheme is employed to obtain a constant switching frequency and to simplify the control compensation. The device includes an internal soft-start function which reduces the power supply input surge current at start-up by controlling the output voltage rise time.

The MIC7401 has a current-mode boost regulator that can deliver up to 200mA of output current and only consumes 70 μ A of quiescent current. The 2.0MHz switching frequency allows small chip inductors to be used. Programmable overcurrent sensing protects the boost from overloads and an output disconnect switch opens to protect against a short-circuit condition. Soft-start is also programmable and controls both the rising and falling output.

Programmable Buck Soft-Start Control

The MIC7401 soft-start feature forces the output voltage to rise gradually, which limits the inrush current during start-up. A slower output rise time will draw a lower input surge current. The soft-start time is based on the least significant bit (LSB) of an internal DAC and the speed of the ramp rate, as shown in Figure 6. Figure 6 illustrates the soft-start waveform for all five synchronous buck converters. The initial step starts at 150mV and each subsequent step is 50mV.

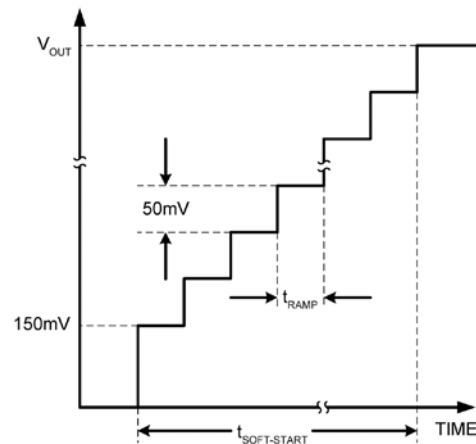


Figure 6. Buck Soft-Start

The output ramp rate (t_{RAMP}) is set by the soft-start registers. Each output ramp rate can be individually set from 4 μ s to 1024 μ s, see Table 1 for details.

Table 1. Buck Outputs Default Soft-Start Time (DEFAULT)

	V _{OUT} (V)	t _{RAMP} (μs)	t _{SS} (μs)
V _{OUT1}	1.8	8	264
V _{OUT2}	1.1	8	152
V _{OUT3}	1.8	8	264
V _{OUT4}	1.05	8	144
V _{OUT5}	1.25	8	176

The soft-start time t_{SS} can be calculated by Equation 1:

$$t_{SS} = \left(\frac{V_{OUT} - 0.15V}{50mV} \right) \times t_{RAMP} \quad \text{Eq. 1}$$

Where:

t_{SS} = Output rise time

V_{OUT} = Output voltage

t_{RAMP} = Output dwell time

For example:

$$t_{SS} = \left(\frac{1.8V - 0.15V}{50mV} \right) \times 8\mu s \quad \text{Eq. 2}$$

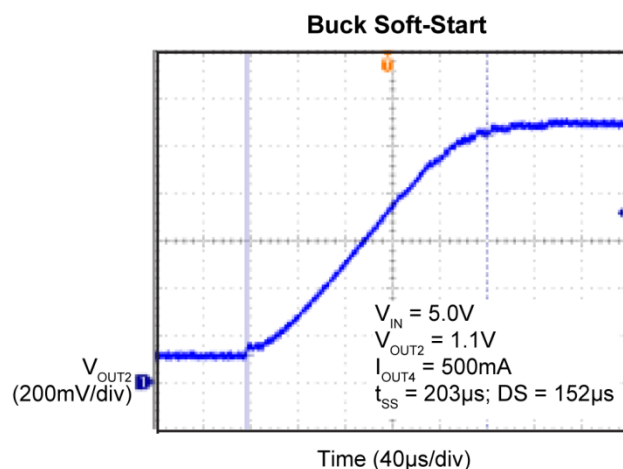
$$t_{SS} = 264\mu s$$

Where:

V_{OUT} = 1.8V

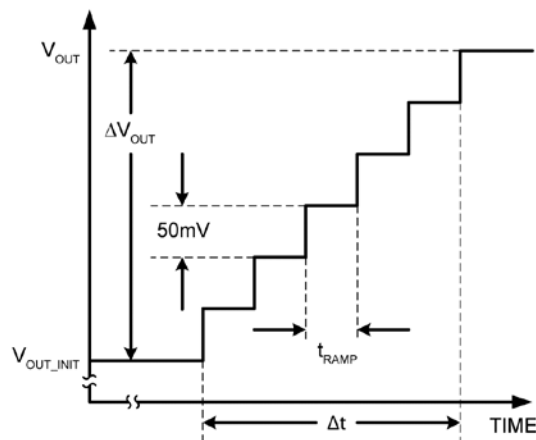
t_{RAMP} = 8.0μs

Figure 7 shows the output of Buck 1 ramping up cleanly, starting from 0.15V to its final 1.1V value.

**Figure 7. Buck Soft-Start**

Buck Digital Voltage Control (DVC)

The output voltage has a 6-bit control DAC that can be programmed from 0.8V to 3.3V in 50mV increments. If the output is programmed to a higher voltage, then the output ramps up, as shown in Figure 8.

**Figure 8. Buck DVC Control Ramp**

The ramp time is determined by Equation 2:

$$\Delta t = \left(\frac{V_{OUT} - V_{OUT_INIT}}{50\text{mV}} \right) \times t_{RAMP} \quad \text{Eq. 2}$$

Where:

V_{OUT_INIT} = Initial output voltage

V_{OUT} = Final output voltage

t_{RAMP} = Output dwell time

When the regulator is set in standby mode or programmed to a lower voltage, then the output voltage ramps down at a rate determined by the output ramp rate (t_{RAMP}), the output capacitance and the external load. Small loads result in slow output voltage decay and heavy loads cause the decay to be controlled by the DAC ramp rate.

In Figure 9, V_{OUT1} is switched to standby mode with an I²C command and then switched back to normal mode either by an I²C command or a low-to-high transition of the STBY pin. In this case, the rise and fall times are the same due to a 1A load on V_{OUT1} .

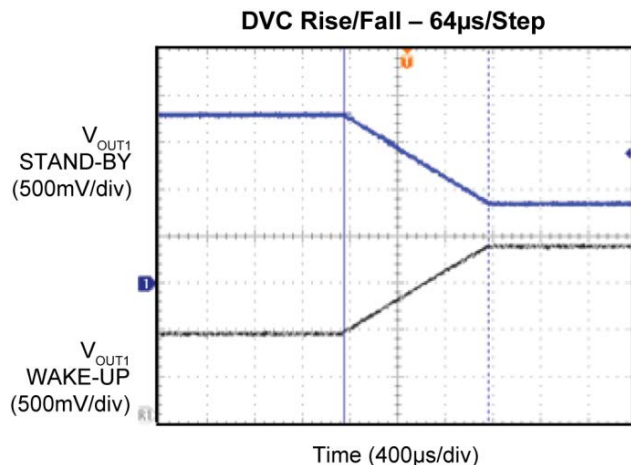


Figure 9. Buck DVC Control Ramp

Programmable Boost Soft-Start Control

The boost soft-start time is divided into two parts as shown in Figure 10. T1 is a fixed 367μs delay starting from when the internal enable goes high. This delay gives enough time for the disconnect switch to turn on and bring the inductor voltage to V_{IN} before the boost is turned on. There is a 50μs delay which is controlled by the parasitic capacitance (C_{gd}) of the disconnect switch before the output starts to rise.

After the T1 period, the DAC output ramp starts, T2. The total soft-start time, t_{SS} , is the sum of both periods. Figure 11 displays the actual boost soft-start waveform.

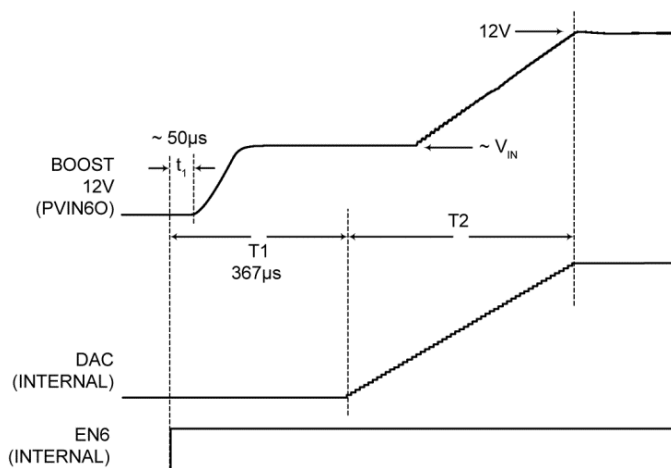


Figure 10. Boost Soft-Start Ramp

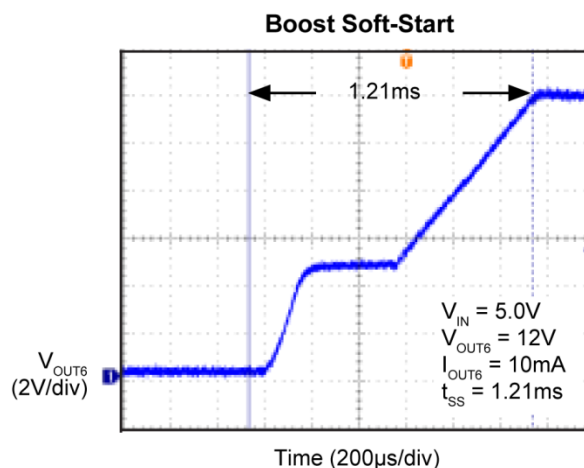


Figure 11. Boost Soft-Start

$$\begin{aligned}
 t_{SS} &= T1 + T2 \\
 T2 &= \left(\frac{V_{OUT} - 1.4V}{0.2V} \right) \times t_{RAMP} \\
 T2 &= \left(\frac{12V - 1.4V}{0.2V} \right) \times 16\mu s
 \end{aligned}
 \quad \text{Eq. 3}$$

Where:

$$T1 = 367\mu s$$

$$T2 = 848\mu s$$

$$t_{SS} = 367\mu s + 848\mu s = 1.215ms$$

V_{OUT} = Output voltage

t_{RAMP} = Output dwell time = $16\mu s$

The ramp time can be computed using Equation 4:

$$\Delta t = \left(\frac{V_{OUT} - V_{OUT_INIT}}{0.2V} \right) \times t_{RAMP} \quad \text{Eq. 4}$$

Where:

V_{OUT_INIT} = Initial output voltage

Table 2. Boost Output Default Soft-Start Time

	V_{OUT} (V)	t_{RAMP} (μs)	t_{ss} (ms)
V_{OUT6}	12	16	1.215

Boost Digital Voltage Control (DVC)

The boost output control works the same way as the buck, except that the voltage steps are 200mV (see [Figure 12](#)). When the boost is programmed to a lower voltage the output ramps down at a rate determined by the output ramp rate (t_{RAMP}), the output capacitance and the external load. During both the ramp up and down time, the power-good output is blanked and will not imitate a fault flag.

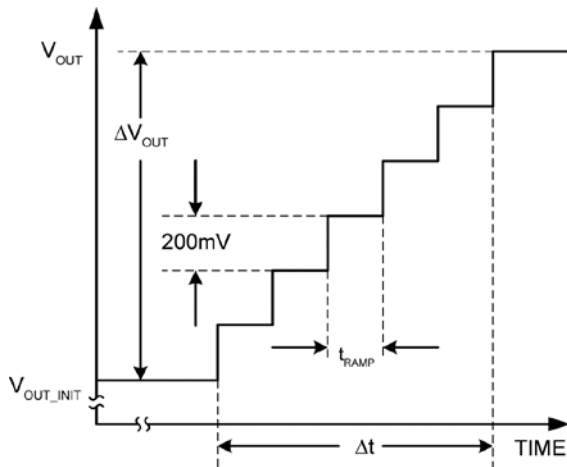


Figure 12. Boost DVC Control Ramp

Buck Current Limit

The MIC7401 buck regulators have high-side current limiting that can be varied by a 4-bit code. If the regulator remains in current limit for more than seven consecutive PWM cycles, the output is latched off, the overcurrent status register bit is set to 1, the power-good status register bit is set to 0 and the global power-good (PG) output pin is pulled low. An overcurrent fault on one output will not disable the remaining outputs. [Table 3](#) shows the current-limit register settings vs. output current. The current-limit register setting is set at twice the maximum output current.

Table 3. Buck Current-Limit Register Settings

$I_{OUT(MAX)}$	I_{PROG}	BINARY	HEX
0.5A	1.1A	1111	F'h
1.0A	2.1A	1101	D'h
1.5A	3.1A	1011	B'h
2.0A	4.1A	1001	9'h
2.5A	5.1A	0111	7'h
3.0A	6.1A	0101	5'h

The output can be turned back on by recycling the input power or by software control. To clear the overcurrent fault by software control, set the enable register bit to "0" then clear the overcurrent fault by setting the fault register bit to "0". This will clear the over-current and power-good status registers. Now the output can be re-enabled by setting the enable register bit to "1".

During start-up sequencing if Output 1 is still shorted, Outputs 2 through 4 will come up normally. Once an overcurrent condition is sensed, then the fault register is set to “1” and the start-up sequence will stop and no further outputs will be enabled.

The programmable current-limit setting sets the peak switch current threshold, not the average outputs current. The peak current is higher than the average due to the inductor ripple current. Figure 13 illustrates how the current limit threshold varies with input voltage.

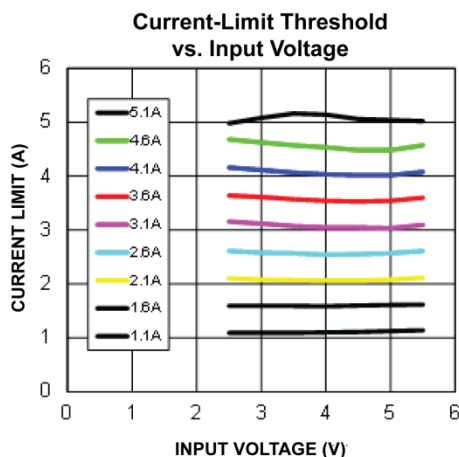


Figure 13. Current-Limit Threshold vs. Input Voltage

Boost Current Limit

The boost current limit features cycle-by-cycle protection. The duty cycle is cut immediately once the current limit is hit. When the boost current limit is hit for five consecutive cycles, the FAULT signal is asserted and remains asserted with the boost converter keeping on running until the boost is powered off.

This protects the boost in normal overload conditions, but not in a short-to-ground case. For a short circuit to ground, the boost current limit will not be able to limit the inductor current. This short-circuit condition is sensed by the current in the disconnect switch. When the disconnect switch current limit is hit for four consecutive master clock cycles (2MHz), regardless if the boost is switching or not, both the disconnect switch and boost are latched off automatically and the FAULT signal is asserted.

The output can be turned back on by recycling the input power or by software control. To clear the overcurrent fault by software control, set the enable register bit to “0” then clear the overcurrent fault by setting the fault register bit to “0”.

Global Power-Good Pin

The global power-good output indicates that all the outputs are above the 91% limit after the power-up sequence is completed. Once the power-up sequence is complete, the global power good output stays high unless an output falls below its power-good limit, a thermal fault occurs, the input voltage drops below the lower UVLO threshold or an output is turned OFF by setting the enable register bit to “0” unless the PGOOD_MASK[x] bit is set to “1” (Default).

A power-good mask bit can be used to control the global power-good output. The power-good mask feature is programmed through the PGOOD_MASK[x] registers and is used to ignore an individual power-good fault. When masked, PGOOD_MASK[x] bit is set to “1”, an individual power good fault will not cause the global power good output to de-assert.

If all the PGOOD_MASK[x] bits are set to “1”, then the power good output de-asserts as soon as the first output starts to rise. The PGOOD_MASK[x] bit of the last output must be set to “0” to have the PG output stay low until the last output reaches 91% of its final value.

The global power-good output is an open-drain output. A pull-up resistor can be connected to V_{IN} or V_{OUT} . Do not connect the pull-up resistor to a voltage higher than AV_{IN} .

Standard Delay

There is a programmable timer that is used to set the standard delay time between each time slot. The timer starts as soon as the previous time slot's output power good goes high. When the delay completes, the regulators assigned to that time slot are enabled, see Figure 14.

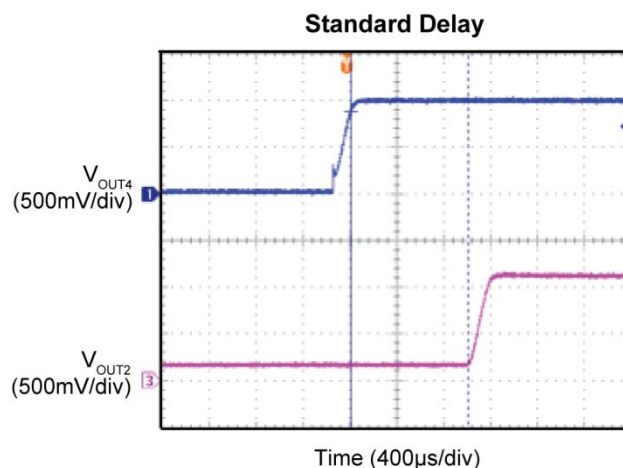


Figure 14. Standard Delay Time

Power-Up Sequencing

When power is first applied to the MIC7401, all I²C registers are loaded with their default values from the EEPROM. There is about a 1.5ms delay before the first regulator is enabled while the MIC7401 goes through the initialization process. The DELAY register's STDEL bits set the delay between powering up each regulator at initial power up.

The sequencing registers allow the outputs to come up in any order. There are six time slots that an output can be configured to power up in. Each time slot can be programmed for up to six regulators to be turned on at once or none at all.

Figure 15 shows an example of this feature. V_{OUT4} is enabled in time slot 1. After a 1ms delay, V_{OUT2} and V_{OUT3} are enable at the same time in time slot 2. The 1ms is the standard delay for all of the outputs and can be programmed from 0ms to 7ms in 1ms. Next, V_{OUT1} is powered up in time slot 3 and V_{OUT5} in time slot 4. There are no regulators programmed for time slot 5. Finally, V_{OUT6} is powered up in time slot 6. The global power-good output, V_{PG} , goes high as soon as the last output reaches 91% of its final value.

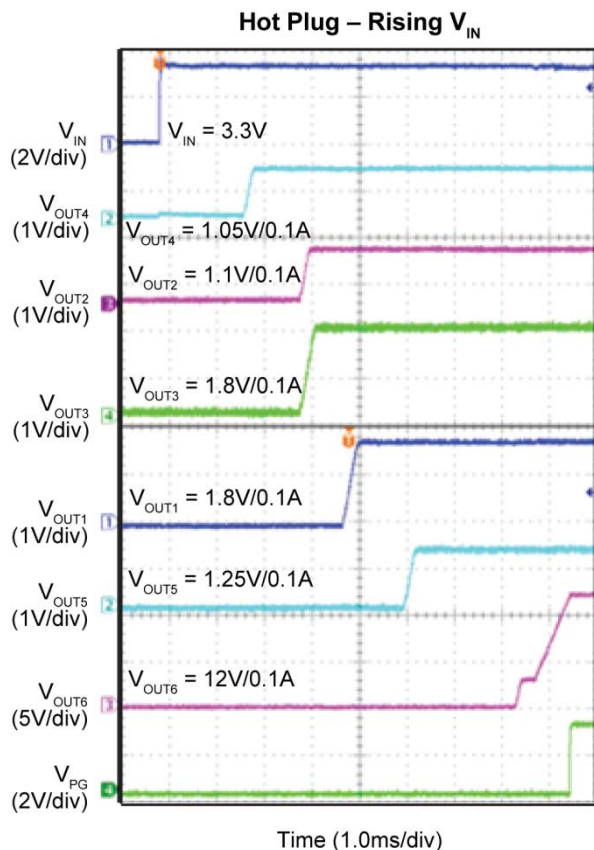


Figure 15. Hot Plug – V_{IN} Rising

Global Enable Pin

When the enable pin rises above the enable threshold voltage, the MIC7401 enters its start-up sequence.

Programmable Power-on-Reset (POR) Delay

The POR output pin provides the user with a way to let the SOC know that the input power is failing. If the input voltage falls below the power-on reset lower threshold level, the POR output immediately goes low. The lower threshold is set in the PORDN register and the upper threshold uses PORUP register.

The low-to-high POR transition can be delayed from 5ms to 160ms in 5ms increments. This feature can be used to signal the SOC that the power supplies are stable. The PORDEL register sets the delay of the POR pin. The POR delay starts as soon as the AVIN pin voltage rises above the power-on-reset upper threshold limit. Figure 16 shows the POR operation.

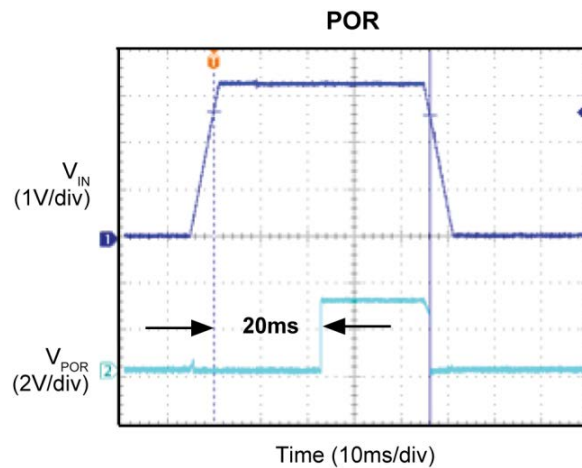


Figure 16. Power-on-Reset (POR)

Timing Diagrams

Normal Power-Up Sequence for Outputs

The STDEL register sets the delay between powering up of each regulator at initial power-up (see power-up sequencing in [Figure 17](#)). Once all the internal power-good registers PGOOD[1-6] are all 1, then the global PG pin goes high without delay if the PGOOD_MASK[6] bit is set to "0".

The PORDEL register sets the delay for the POR flag pin. The POR delay time starts as soon as AVIN pin voltage rises above the system UVLO upper threshold set by the PORUP register. The POR output goes low without delay if AVIN falls below the lower UVLO threshold set by the PORDN register.

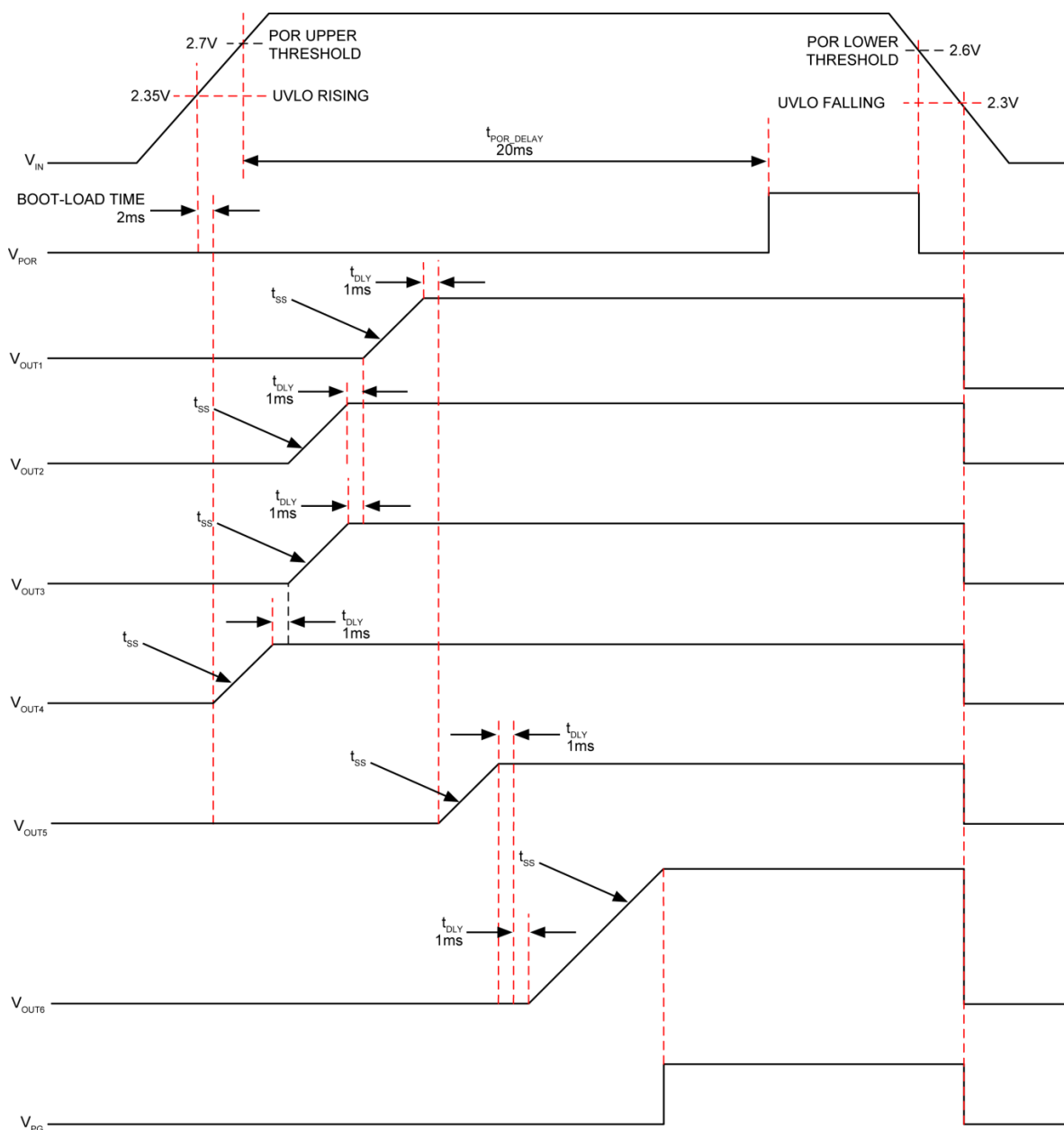


Figure 17. MIC7401 Power-Up/Down

Standby (STBY) Pin (Wake-Up)

An I²C write command to the STBY_CTRL_REG register or the STBY pin can be used to set the MIC7401 into stand-by mode. The standby (STBY) pin provides a hardware-specific manner in which to wake-up from stand-by mode and go into normal mode. Figure 18 shows the STBY pin operation. A low-to-high transition on the STBY pin switches the output from stand-by mode to normal mode.

There is a 100μs STBY deglitch time that eliminates nuisance tripping, allowing all regulators to enable at the same time and ramp up with their programmed ramp rates.

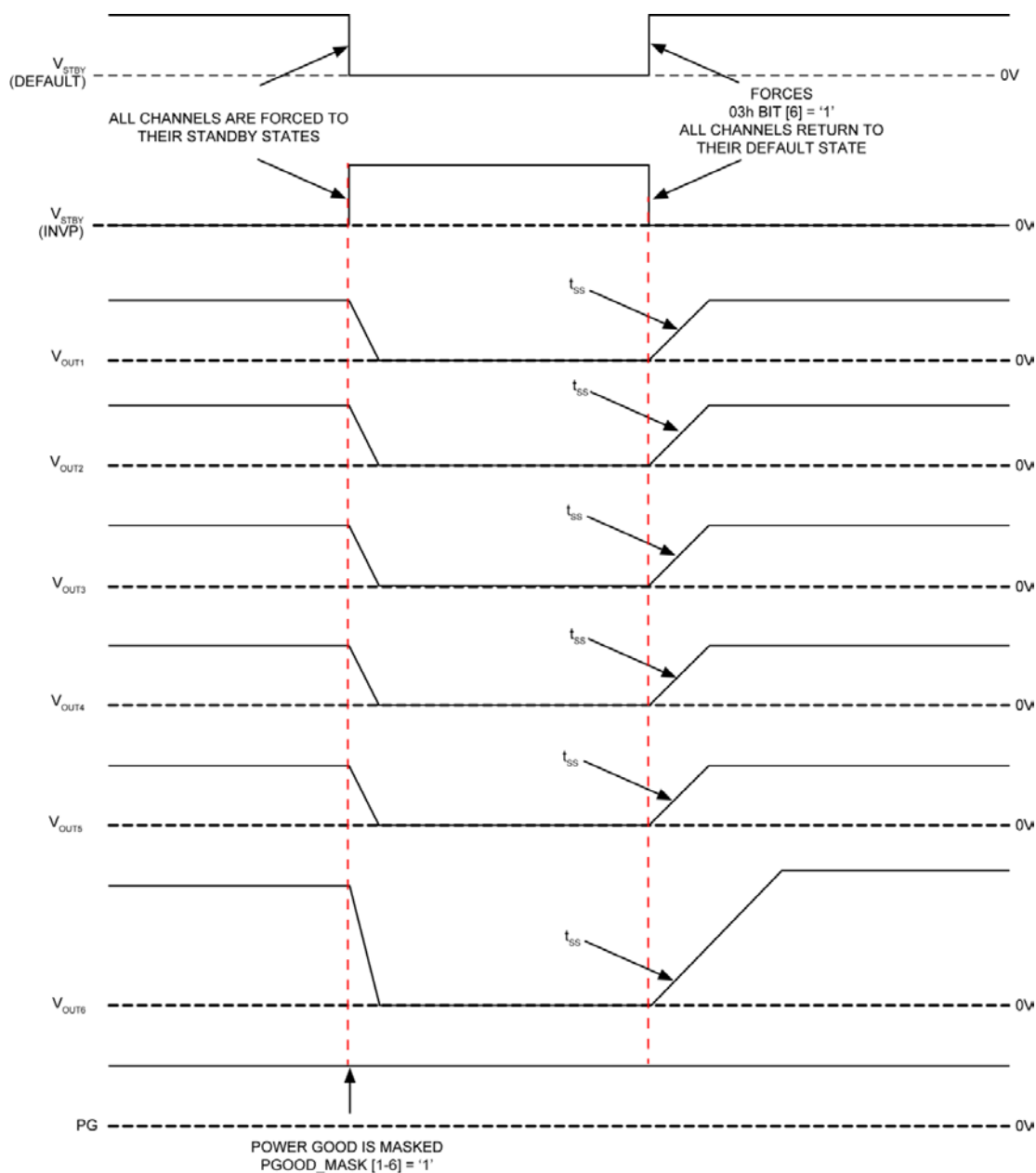
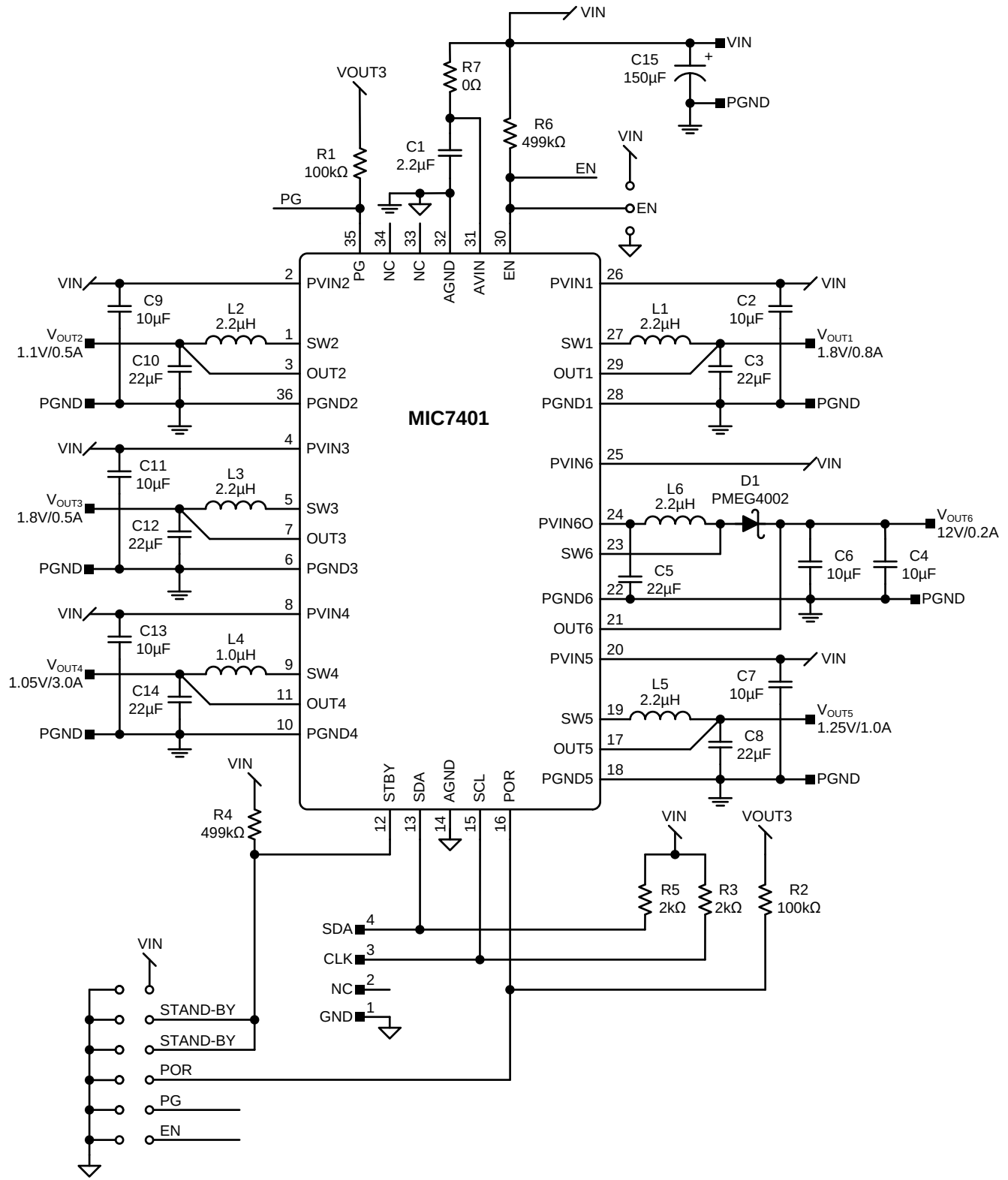


Figure 18. MIC7401 STBY Function (DEFAULT)

Evaluation Board Schematic



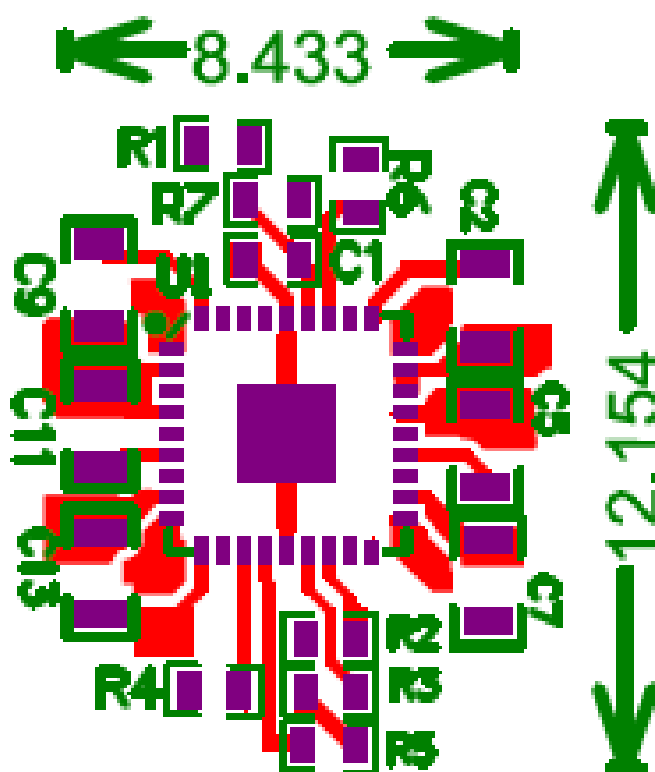
Bill of Materials

Item	Part Number	Manufacturer	Description	Qty.
C1	CL05A225KO5NQNC	Samsung ⁽¹⁾	2.2μF/16V, Ceramic, X5R, 0402, 0.8mm, ±10%	1
C2, C7, C9, C11, C13	CL10A106MO8NQNC	Samsung	10μF/16V, Ceramic, X5R, 0603, 0.8mm, ±20%	5
C4, C6	CL21A106KAYNNNE	Samsung	10μF/25V, Ceramic, X5R, 0805, 1.25mm, ±20%	2
C3, C5, C8, C10, C12, C14	CL10A226MQ8NUNE	Samsung	22μF/6.3V, Ceramic, X5R, 0603, 0.8mm, ±20%	6
C15	EEF-CX0J151XR	Panasonic ⁽²⁾	150μF/6.3V, POS Capacitor, SP, ±20%	1
D1	PMEG4002EL	NXP ⁽³⁾	0.2A/40V, Schottky, SOD-882	1
R1, R2	RC1005F104CS	Samsung	100kΩ, Resistor, 0402, 1%	3
R3, R5	RC1005F202CS	Samsung	2.0kΩ, Resistor, 0402, 1%	2
R4, R6	RC1005F4993CS	Samsung	499kΩ, Resistor, 0402, 1%	1
R7	RC1005J000CS	Samsung	0.00Ω, Resistor, 0402, Jumper	1
L1, L2, L3, L5, L6	CIG22H2R2MNE	Samsung	2.2μH, 1.6A Inductor, 116mΩ, 2520 × 1.2mm (maximum)	5
L4	CIGW252010GM1R0MNE	Samsung	1.0μH, 3.3A Inductor 40mΩ, 2520 × 1.0mm (maximum)	1
U1	MIC7401YFL	Micrel ⁽⁴⁾	Five-Channel Buck Regulator Plus One Boost with HyperLight Load and I ² C Control	1

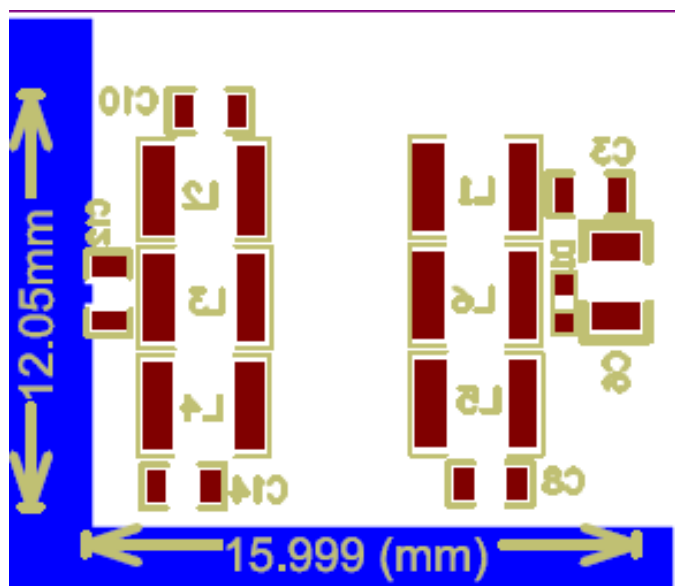
Notes:

1. Samsung: www.samsung.com.
2. Panasonic: www.panasonic.com.
3. NXP: www.nxp.com.
4. Micrel, Inc.: www.micrel.com.

PCB Layout Recommendations

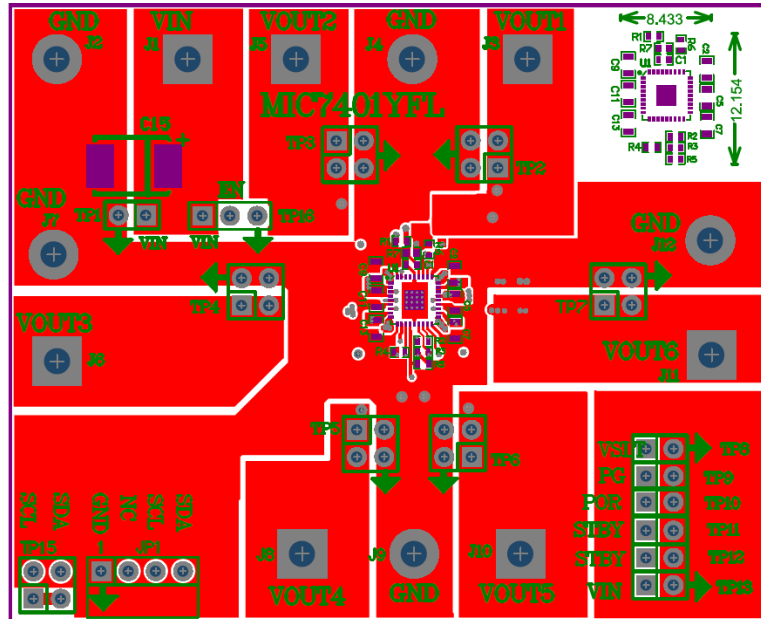


Evaluation Board Top Layer – Power Component Placement

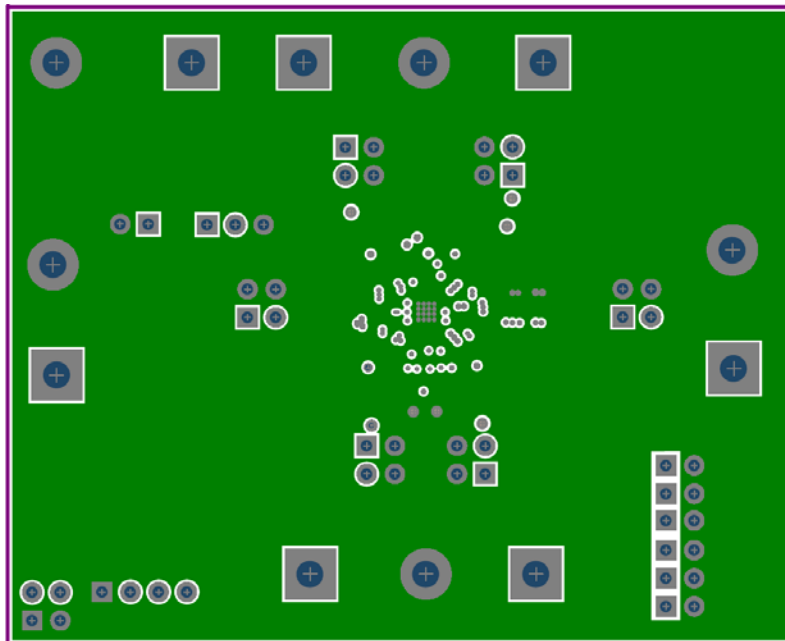


Evaluation Board Top Layer – Layer 1 (Power Routing Layer)

PCB Layout Recommendations (Continued)

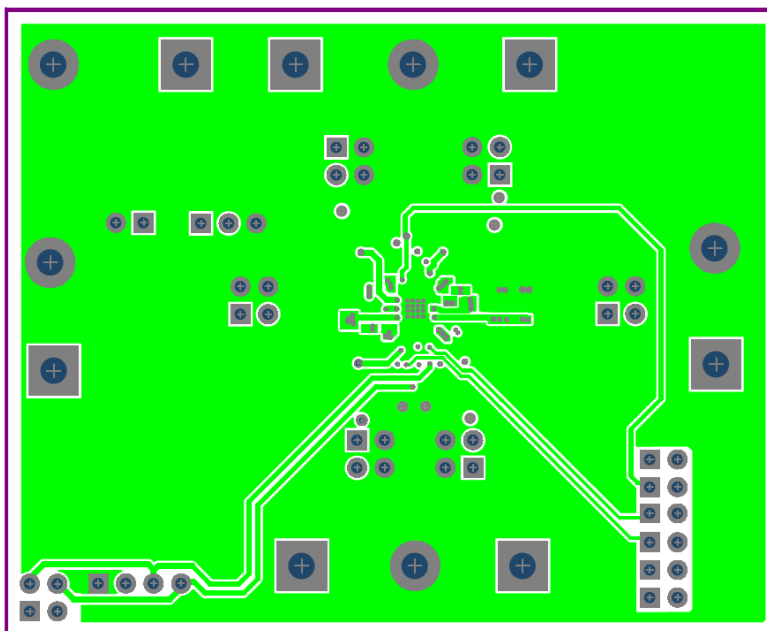


Evaluation Board Top Layer – Layer 1 (Power Routing Layer)

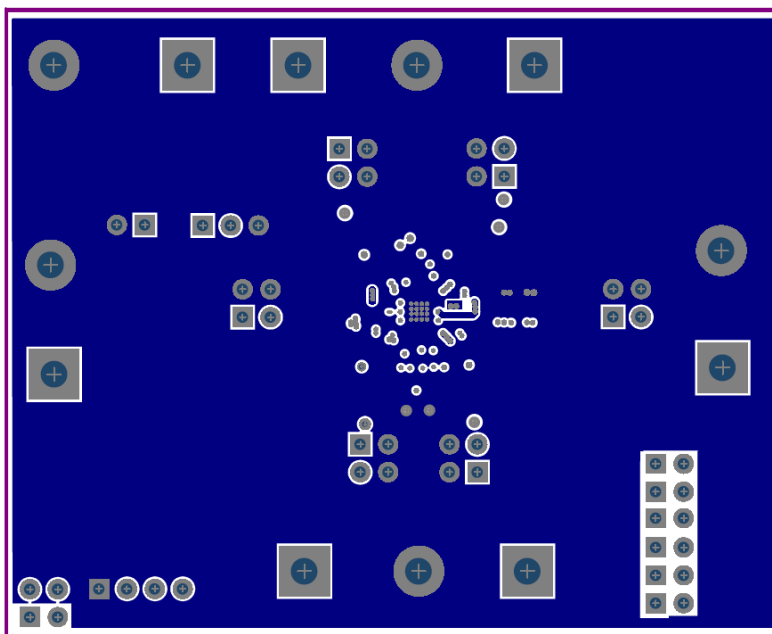


Evaluation Board Layer 2 (Ground Plane)

PCB Layout Recommendations (Continued)

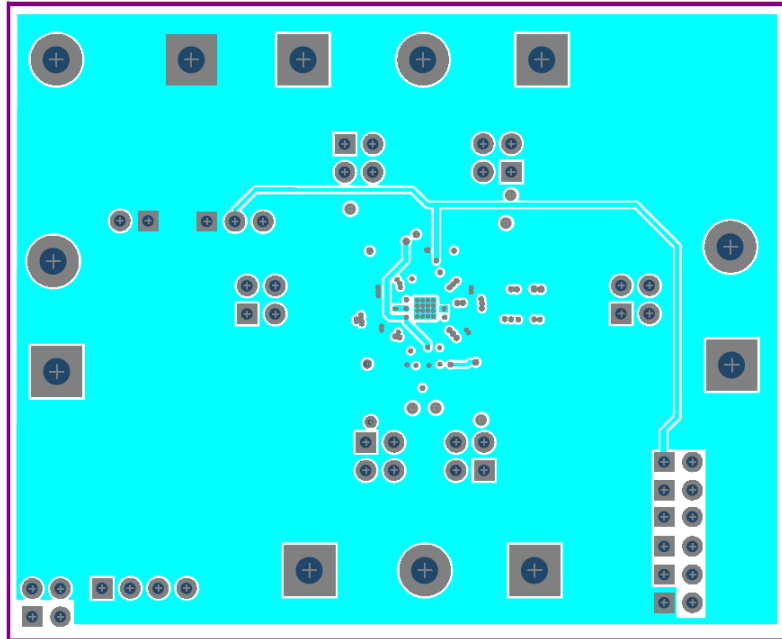


Evaluation Board Top Layer – Layer 3 (Signal Routing Layer)

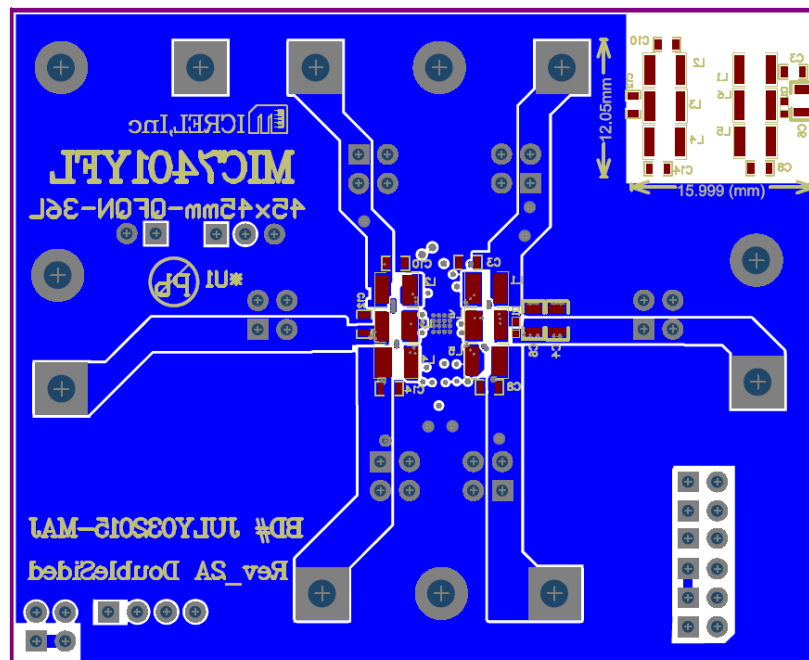


Evaluation Board Layer 4 (Ground Plane)

PCB Layout Recommendations (Continued)



Evaluation Board Layer – Layer 5 (V_{IN} Plane)



Evaluation Board Bottom Layer – Layer 6 (Ground Plane)

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