TI Designs: PMP15040
Wide Vin Power Supply Reference Design for Size-Constraint Industrial Sensors

Description

This reference design provides an example of how to power FPGAs, ASICs, or MCUs in sensor applications when space-constraints are a primary concern. The wide 6-V to 60-V input voltage range and the use of ultra-small and highly efficient DC/DC converters makes the design well suited for applications like industrial sensors, field transmitters, motor drives, and PLC modules. The output voltages are adjustable and can be adapted to the specific needs of the user.

Resources

PMP15040	Design Folder
LMR36006	Product Folder
LMR36015	Product Folder

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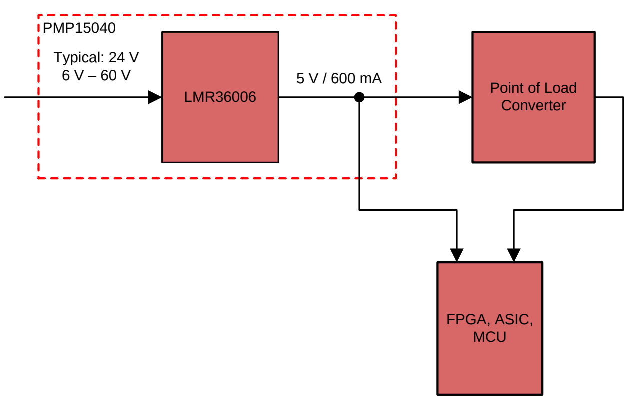
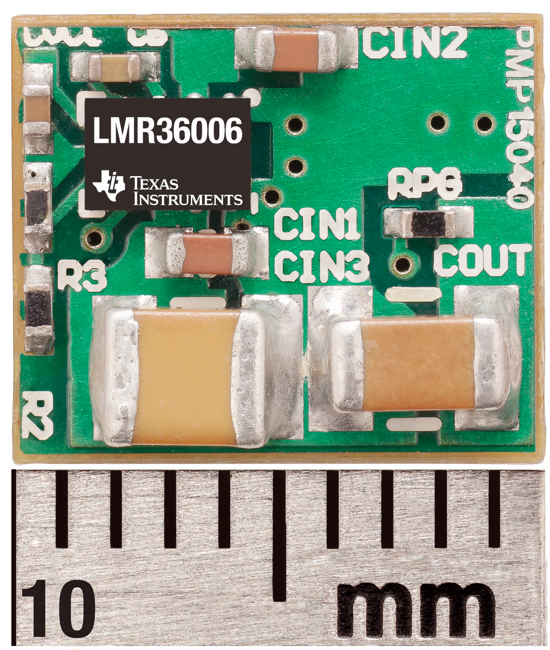
Features

- Optimized Solution Size – 8.3 mm × 10 mm
  - Low Component Count
  - Double-Sided Populated Board
  - 1-MHz Switching Frequency
  - Tight Current Limit
- Wide Input Voltage (6 V to 60 V) Range to Accommodate Line Variation
- Low Noise Signature With Quiet Switch Node
- Output Rail:
  - 5 V at 600 mA (±1.5% Accuracy)
  - Voltage Adjustable to Adapt to Specific User Requirements

Applications

- Factory Automation – Displacement Transmitter
- Factory Automation – Flow Transmitters
- Factory Automation – Machine Vision
- Motor Drives – AC Drive – AC Position Feedback





An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

1 System Description

The PMP15040 is optimized for size-sensitive sensor applications, specifically Field Transmitters and AC Drive Feedback systems. The standard power stage uses a Wide Vin DC/DC converter that enables peak efficiency > 90% as shown in Figure 18.

A displacement transmitter uses an analog front-end to convert a signal of a sensor to an electrical representation and digital processor to convert this signal to a digital representation. A standard displacement transmitter uses a non-isolated Wide Vin DC/DC converter as the primary power stage. Figure 1 highlights the PMP15040 standard placement within the field transmitter system.

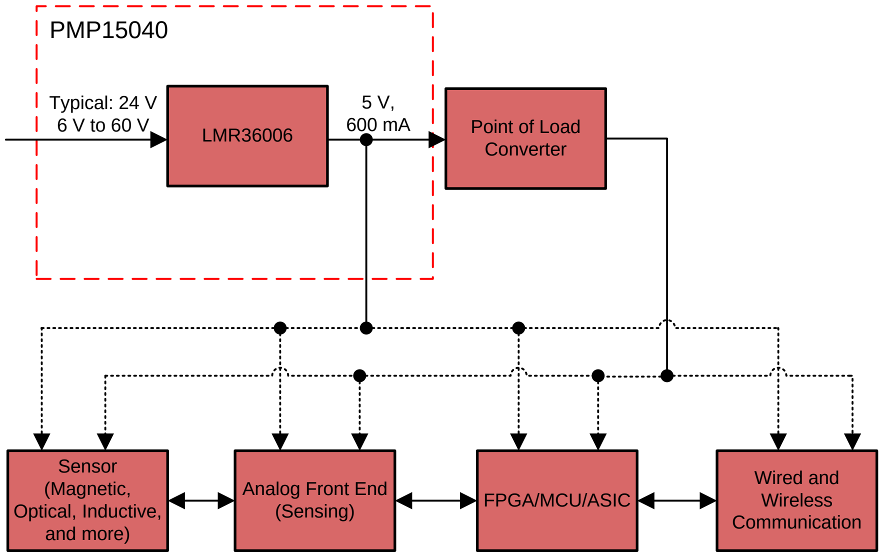


Figure 1. PMP15040 Field Transmitter Block Diagram

An AC Drive Feedback system converts SIN/COS differential inputs from the resolver or encoder to digital outputs, which enables accurate rotor position feedback of AC drives. AC Drive Position Feedback uses a non-isolated Wide Vin DC/DC converter as the primary power stage paired with a Point-of-Load DC/DC converter. These two power rails are necessary to power the Digital Processing component of the system. Figure 2 highlights PMP15040 standard placement within the AC Drive Position Feedback system.

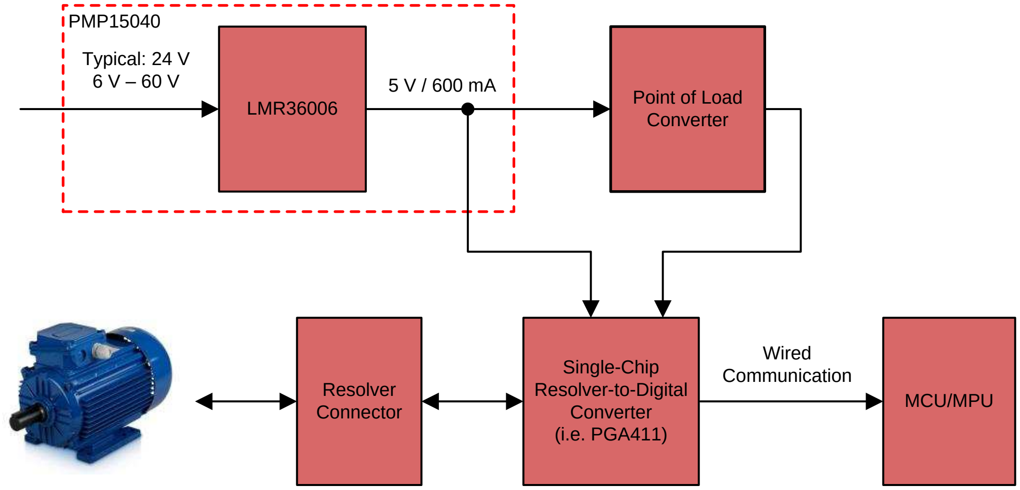


Figure 2. PMP15040 Rotary Encoder Block Diagram

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS
V_{IN} minimum	6-V
V_{IN} maximum	60-V
V_{IN} nominal	24-V
V_{OUT}	5-V
I_{OUT}	600-mA
F_{SW}	1-MHz
X - Dimension	8.3-mm
Y - Dimension	10-mm

2 System Overview

2.1 Block Diagrams

Figure 3 shows the PMP15040 block diagram.

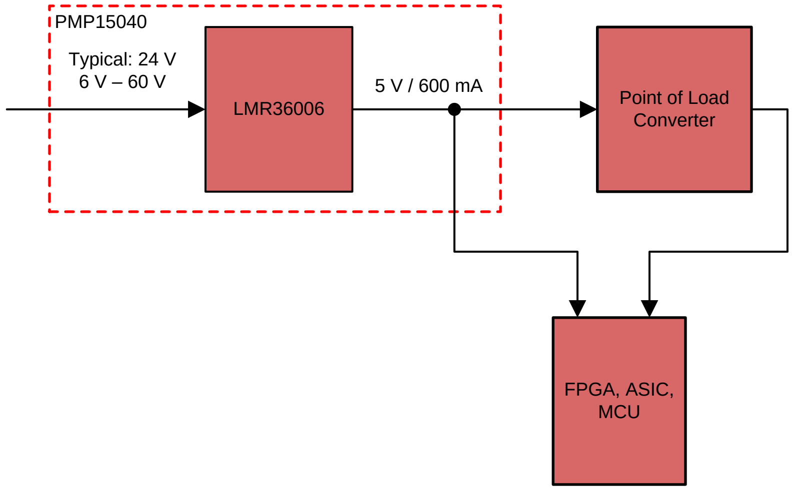


Figure 3. PMP15040 General Block Diagram

2.2 Highlighted Products

2.2.1 LMR36006

Features:

- Synchronous buck converter
- Wide operation input voltage: 4.2 V to 60 V (with transient protection up to 66 V)
- 1-MHz switching frequency
- Low quiescent current: 25 μA
- –40°C to +150°C junction temperature range
- Adjustable 1-V to 28-V output
- Maximum current load: 600 mA for LMR36006 and 1.5 A for LMR36015
- QFN package: 3 mm × 2 mm

2.3 System Design Theory

The PMP15040 highlights the 8.3 mm × 10 mm optimized solution size of the LMR36006. The synchronous buck converter, LMR36006, is a wide-input voltage range, low-quiescent current, high performance regulator with internal compensation. The LMR36006 is optimal for size-constraint applications because the LMR36006 has a 3-mm × 2-mm QFN package size, 1-MHz switching frequency, and a tight current limit. Figure 6 shows the schematic of the front-end DC/DC converter. Figure 4 and Figure 5 show the images of the front and back side of PMP15040 board.

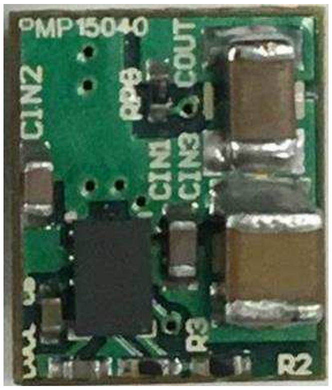


Figure 4. Front of the PMP15040 Board

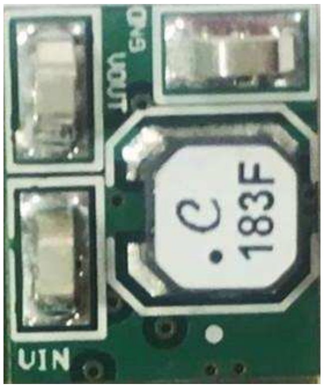


Figure 5. Back of the PMP15040 Board

The operating frequency for the LMR36006 regulator is 1 MHz, and the device implements a precise current limit. Consequently, the output filter size and component values are minimized. The LMR36006 offers three operating switching frequency variants: 400 kHz, 1 MHz, and 2.1 MHz. The 1-MHz switching frequency provides peak efficiency greater than 90% at 12 V_{IN}, and peak efficiency greater than 80% at 24 V_{IN}. When the user selects the 1-MHz variant, the inductance range can be decreased from 40 µH – 50 µH to 10 µH – 25 µH. When the user selects an inductor with an inductance of 18 µH, the inductor should be capable of handling a maximum current of 1.2 A. Ultimately, inductor manufacturers have a wide selection of 18-µH inductors in a 4-mm × 4-mm package size. The PMP15040 uses a 18-µH inductor with a C_{OUT} of 22 µF.

For the PMP15040, the LMR36006 output voltage is set to 5 V with a resistor divider from FB to V_{OUT}. The top feedback resistor (R_{FBT}) is set to 100 kΩ, and the bottom resistor (R_{FBB}) is calculated using Equation 1. V_{REF} is nominally 1 V.

$$R_{FBB} = \frac{R_{FBT}}{\left[\frac{V_{OUT}}{V_{REF}} - 1\right]} \tag{1}$$

For this 5-V example, values are R_{FBT} = 100 kΩ and R_{FBB} = 24.9 kΩ. Depending on the power requirement of the downstream digital component, the output voltage can be adjusted. For example, for a MCU which require a typical power rail of 3.3 V, the output voltage can be adjusted.

To scale the output voltage for specific system requirements, the output feedback resistors can be resized. For example, if a MCU requires a typical power rail of 3.3-V, the output voltage can be adapted by recalculating R_{FBB}. For this 3.3-V example values would be R_{FBT} = 100 kΩ and R_{FBB} = 43.5 kΩ. Furthermore, the PMP15040 output filter (L1 and C_{OUT}) will support the output voltage adjustment.

When scaling the output voltage from 5 V to 3.3 V, the corresponding output power capability of the LMR36006 will decrease from 3 W to 2 W. To increase the power capability of the PMP15040 to 7.5 W at 5 V_{OUT} and 5 W at 3.3 V_{OUT}, the pin-compatible LMR36015 offers a 1.5-A maximum output load current. To adapt the design to the LMR36015, the output filter (L1 and C_{OUT}) must be modified appropriately. TI recommends to modify the L1 to 4.7 µH and modify the C_{OUT} to 33 µF. Also, the saturation current of the inductor must support the increased current capability and peak current limit of 3 A. Powered iron cores exhibit a soft saturation current, allowing some relaxation in the current rating of the inductor.

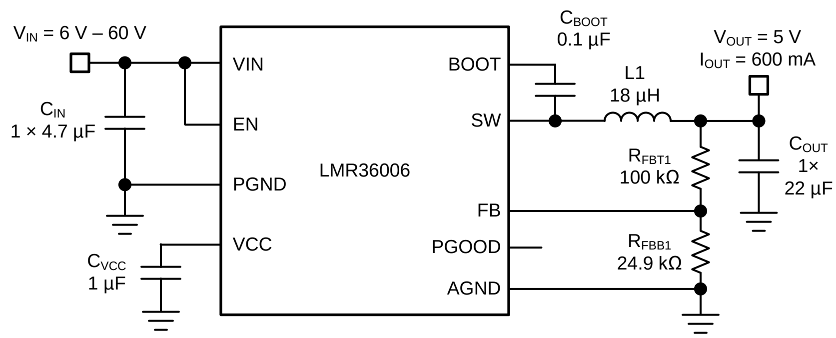


Figure 6. LMR36006 Schematic

The LMR36006 and LMR36015 devices are designed with a flip-chip or HotRod technology, which greatly reduces the parasitic inductance of the pins. Package lead inductance substantially increases the switch node ringing and the corresponding EMI performance. A wire-bond package, Figure 7, has significant lead inductance compared to a flipped-chip, on-lead (FCOL) package, Figure 8. HotRod technology eliminates wire bonds by attaching the silicon die directly the lead frame. Consequently HotRod technology lowers R_{DS_ON}, parasitic lead inductance, and dramatically reduces switch node ringing. The switch node waveforms of a wire bond package and a HotRod package can be seen in Figure 9 and Figure 10.

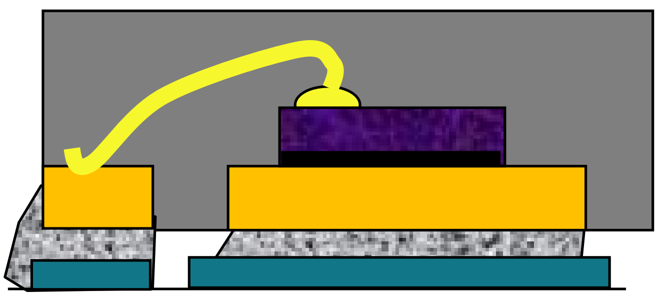


Figure 7. Standard QFN Package

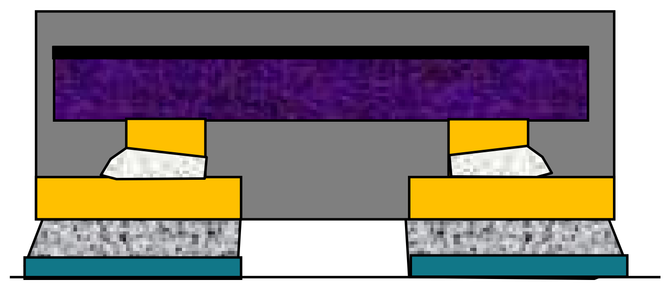


Figure 8. FCOL QFN Package

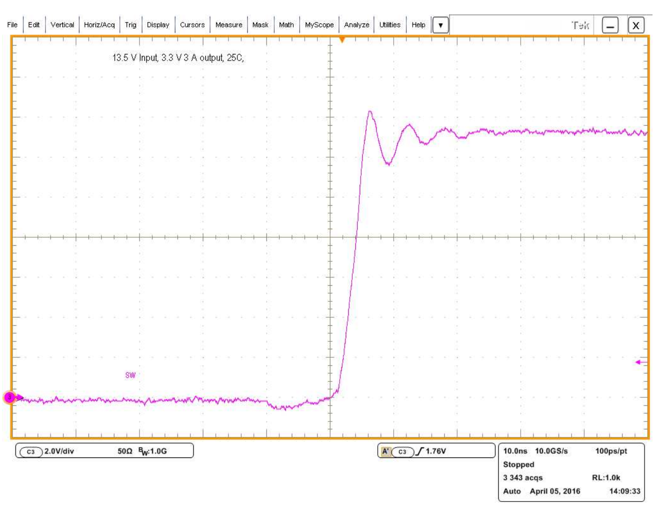


Figure 9. Wirebond Device Switch Node Signal

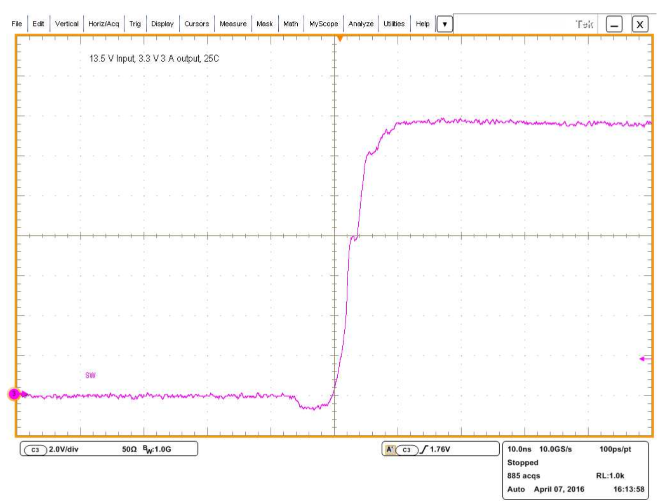


Figure 10. FCOL QFN Device Switch Node Signal

The LMR36006 HotRod package enables the smallest die to package ration and ultimately enables an optimized layout and total solution size of 8.3 mm × 10 mm shown in Figure 11. The optimized layout is highlighted in Figure 12 and Figure 13.

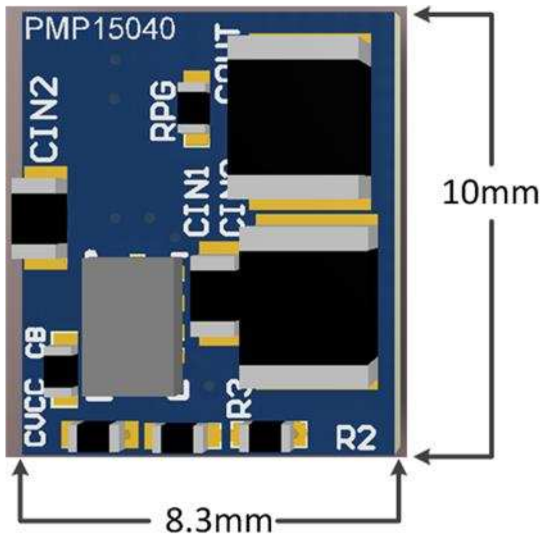


Figure 11. PMP15040 Board Dimensions

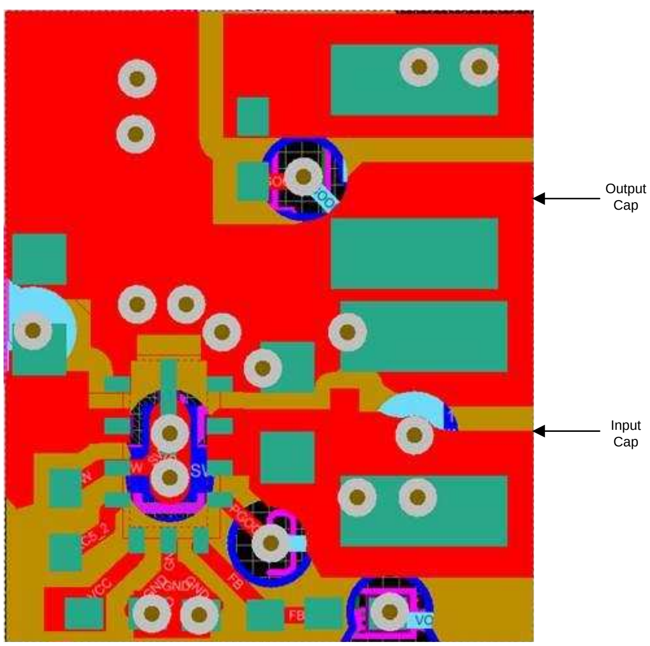


Figure 12. PMP15040 PCB Layout: Top Layer

Figure 13. PMP15040 PCB Layout: Bottom Layer

For design calculations and layout examples, see the relevant data sheet for the devices:

- *LMR36006 4.2-V to 60-V, 0.6-A Synchronous Step-Down Converter in HotRod™ Package* (SNVSB48)
- *LMR36015 4.2-V to 60-V, 1.5-A Synchronous Step-Down Converter in HotRod™ Package* (SNVSB49)

3 Hardware, Testing Requirements, and Test Results

3.1 Required Hardware

3.1.1 Hardware

These steps outline the hardware setup:

1. Connect a DC power supply to the board input as shown in Figure 14.
2. Connect an electronic or resistive load to the LMR36006 output (V_{OUT}), as shown in Figure 14, to imitate the typical load.

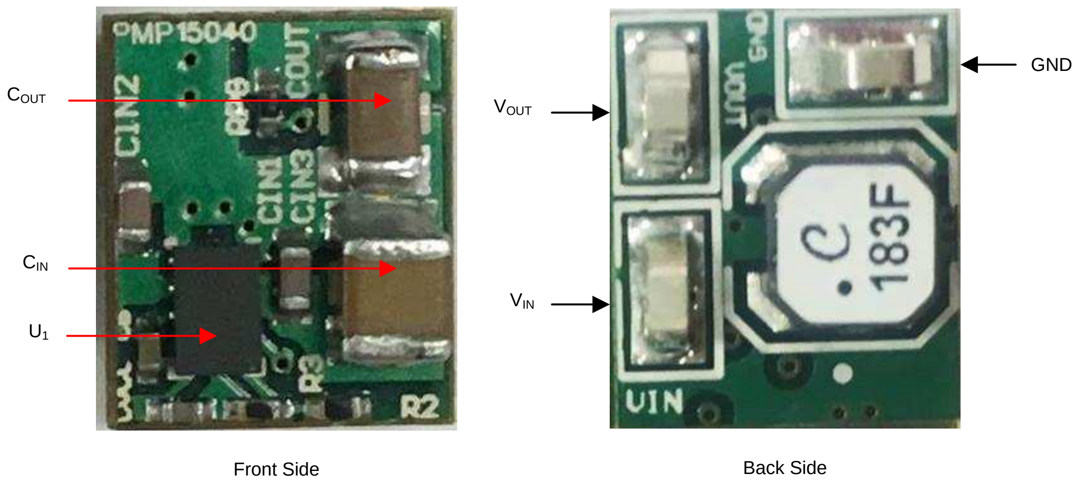


Figure 14. PMP15040 Board Setup

3.2 Testing and Results

The following diagrams show the design performance.

3.2.1 Thermal Data

The infrared (IR) thermal image in Figure 15 was taken at steady state with 24 V_{IN} and the LMR36006 output at a load of 10 mA (no airflow). The ambient temperature is approximately 22°C. The maximum IC temperature is 28.4°C.

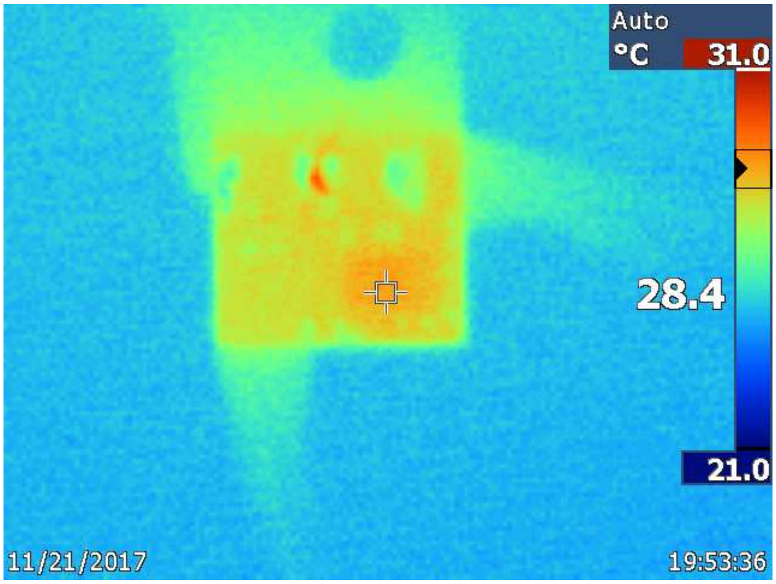


Figure 15. Thermal Image at 24 V_{IN}, 5 V_{OUT}, 10 mA I_{OUT}

The infrared (IR) thermal image in Figure 16 was taken at the steady state with 24 V_{IN} and the LMR36006 output at a load of 300 mA (no airflow). The ambient temperature is approximately 22°C. The maximum IC temperature is 68°C.

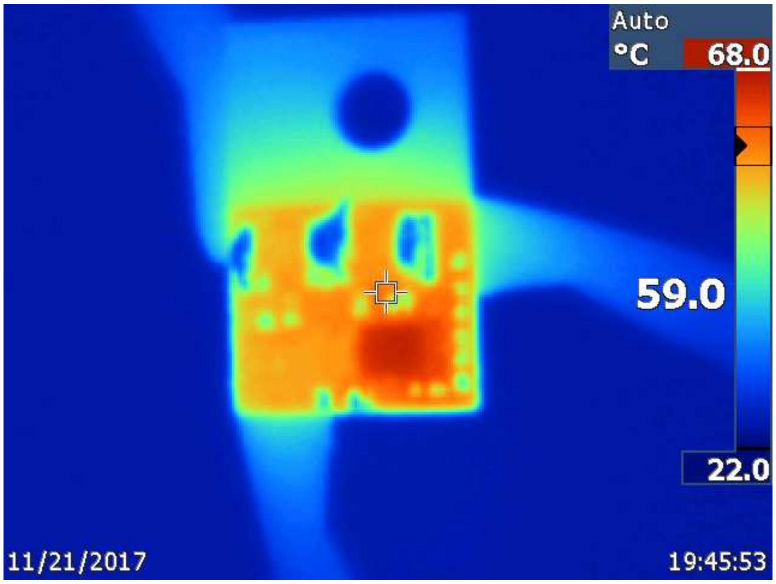


Figure 16. Thermal Image at 24 V_{IN}, 5 V_{OUT}, 300 mA I_{OUT}

The infrared (IR) thermal image in Figure 17 was taken at the steady state with 24 V_{IN} and the LMR36006 output at a load of 600 mA (no airflow). The ambient temperature is approximately 22°C. The maximum IC temperature is 85°C.

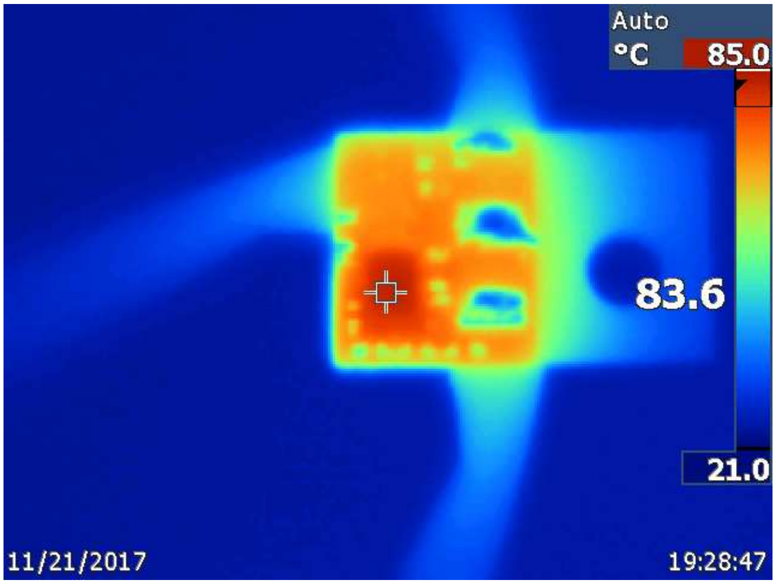


Figure 17. Thermal Image at 24 V_{IN}, $5V_{OUT}$, 600 mA I_{OUT}

3.2.2 Efficiency Data

Figure 18 shows the PMP15040 efficiency data versus a load current.

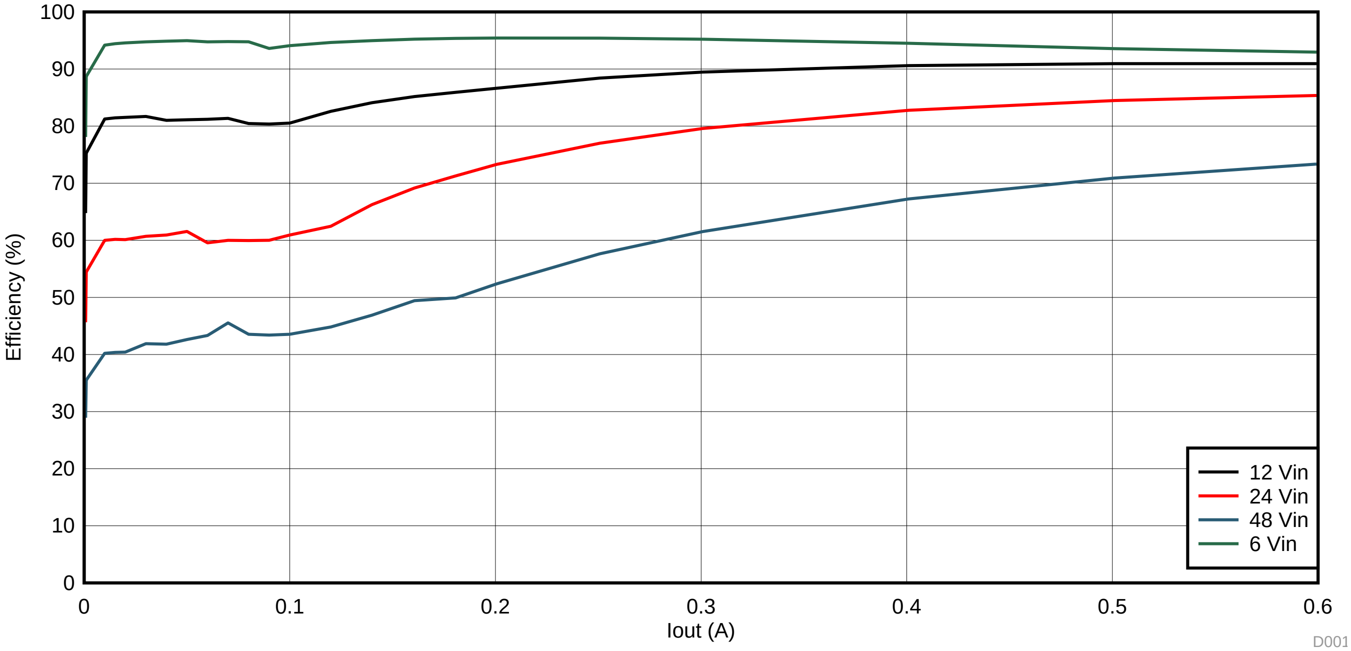


Figure 18. Efficiency vs. Output Current

3.2.3 Start-Up Waveforms

Figure 19 shows the start-up waveform at 24-V input and no load. Figure 20 shows the start-up waveform at 24-V input and 600-mA load.

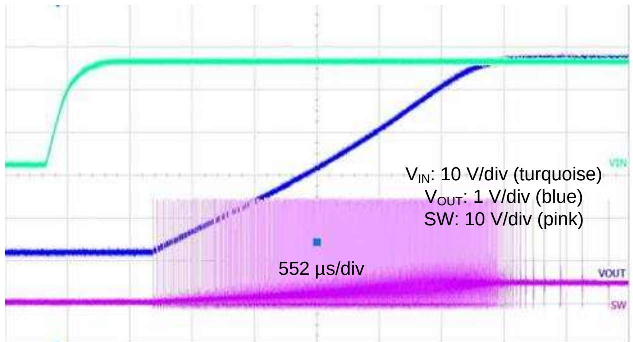


Figure 19. Start-Up Waveform: V_{IN} = 24 V, I_{OUT} = 0 A

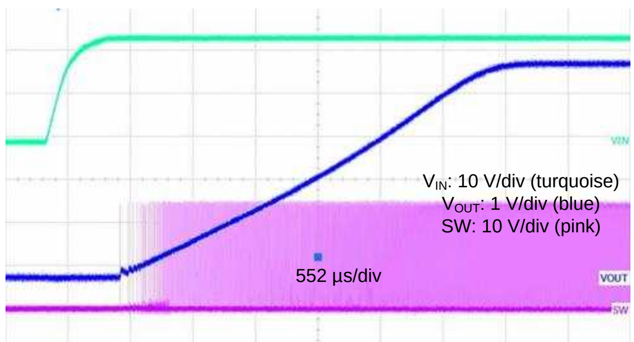


Figure 20. Start-Up Waveform: V_{IN} = 24 V, I_{OUT} = 600 mA

3.2.4 Switch Node and Output Voltage Ripple

Figure 21 shows the steady-state switch-node voltage and output voltage ripple at 24 V_{IN} and 0-A load. Figure 22 shows the steady-state, switch-node voltage and output voltage ripple at 24 V_{IN} and 600-mA load. Figure 23 shows the steady-state switch-node voltage and output voltage ripple at 60 V_{IN} and 0-A load. Figure 24 shows the steady-state, switch-node voltage and output voltage ripple at 60 V_{IN} and 600-mA load.

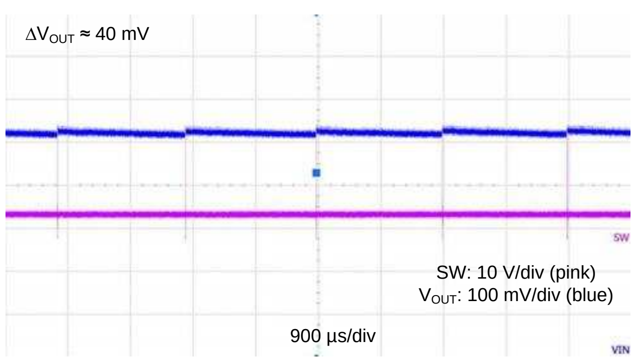


Figure 21. Steady-State Waveform: V_{IN} = 24 V, I_{OUT} = 0 A

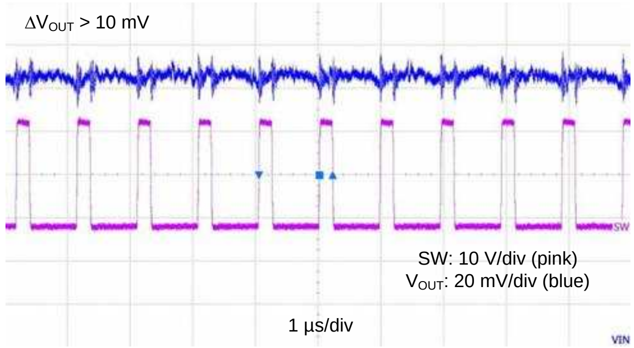


Figure 22. Steady-State Waveform: V_{IN} = 24 V, I_{OUT} = 600 mA

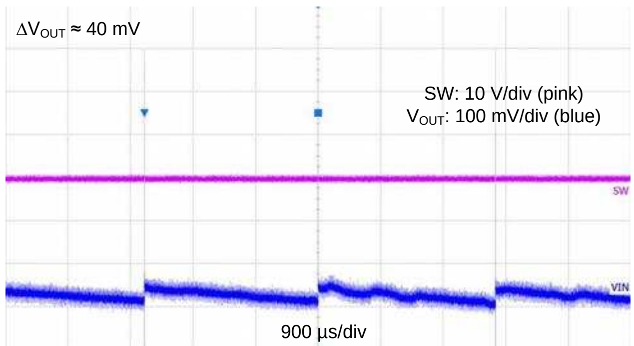


Figure 23. V_{IN} = 60 V, I_{OUT} = 0 A

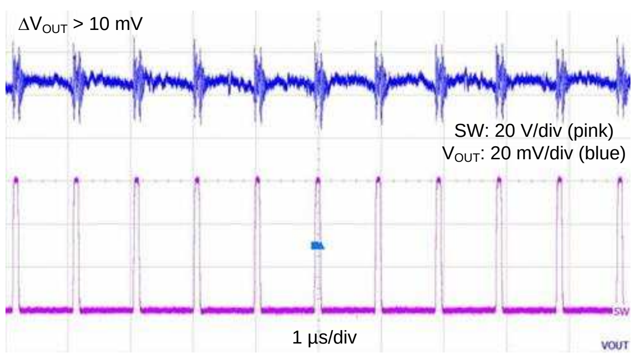


Figure 24. V_{IN} = 60 V, I_{OUT} = 600 mA

3.2.5 Load Transient

The load transient waveforms monitor the output voltage and the load current. Channel 1 (blue) shows the output current of the LMR36006 (I_{OUT}). Channel 2 (purple) shows the output voltage of the LMR36006 (V_{OUT}). Figure 25 and Figure 26 show the load transient results.

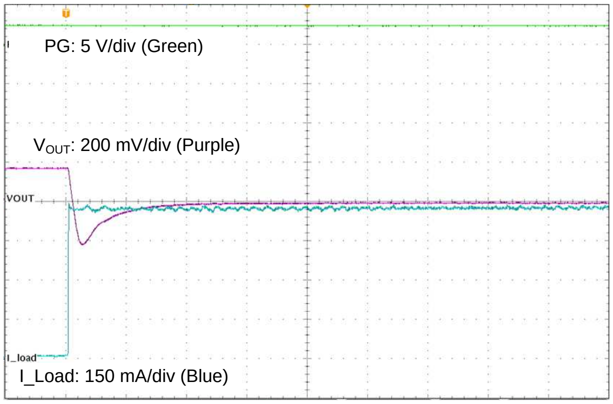


Figure 25. Load Transient: I_{OUT} = 0 A to 600 mA, V_{IN} = 24 V, t_R=1 A/µs

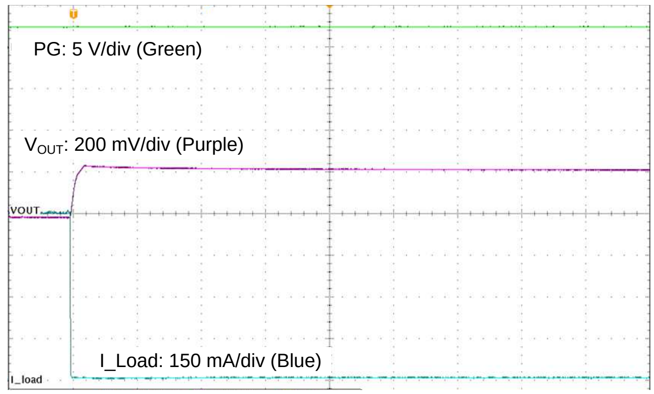


Figure 26. Load Transient: I_{OUT} = 600 mA to 0 A , V_{IN} = 24 V, t_F=1 A/µs

4 Design Files

4.1 Schematics

To download the schematics, see the design files at PMP15040.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at PMP15040.

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at PMP15040.

4.4 Altium Project

To download the Altium project files, see the design files at PMP15040.

4.5 Gerber Files

To download the Gerber files, see the design files at PMP15040.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at PMP15040.

5 Related Documentation

1. *LMR36006 4.2-V to 60-V, 0.6-A Synchronous Step-Down Converter in HotRod™ Package* (SNVSB48)
2. *LMR36015 4.2-V to 60-V, 1.5-A Synchronous Step-Down Converter in HotRod™ Package* (SNVSB49)
3. *Powering up the Performance of Sensitive Test and Measurement Systems*, blog

5.1 Trademarks

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Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (June 2018) to A Revision	Page
• Changed *Efficiency vs. Output Current* graph	10