

TI Designs: PMP15039

Two-Stage Power Supply Reference Design for Field Transmitters



Description

This dual output reference design provides an example of how to power FPGAs, ASICs, or MCUs 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 two-stage approach provides a 1.5% accurate 5-V rail and a 1.5-V point of load rail with 1% accuracy across the entire temperature range. The output voltages are adjustable and can be adapted to the specific needs of the user.

Resources

PMP15039	Design Folder
LMR36006	Product Folder
LMR36015	Product Folder
TPS62821	Product Folder



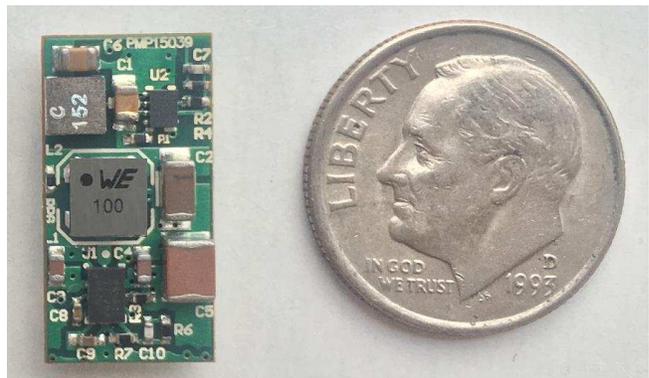
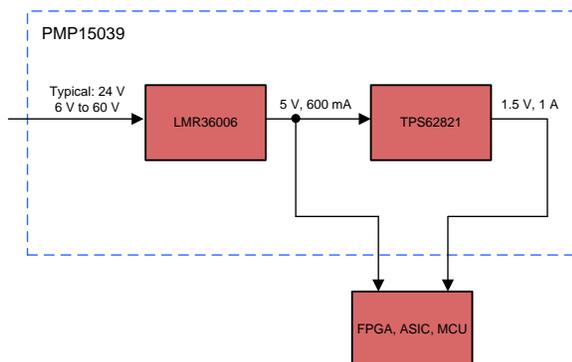
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Features

- Optimized Solution Size (9.25 mm × 18 mm)
 - Low Component Count
 - Single-Sided Populated Board
 - LMR36006 $F_{SW} = 1$ MHz
 - TPS62821 $F_{SW} = 2.2$ MHz
- Typical 24-V Input With Wide Input Voltage Range (6 V to 60 V)
- Dual Output Rails:
 - 5 V at 300 mA ($\pm 1.5\%$ Accuracy)
 - 1.5 V at 1 A (1% Accuracy)
 - Voltages Adjustable to Adapt to Specific User Requirements
- LMR36006/LMR36015 and TPS62821/TPS62822 Enable Scalable Power Solutions

Applications

- Factory Automation - Field Transmitter - Pressure Transmitter
- Factory Automation - Field Transmitter - Flow Transmitter
- Factory Automation - Field Transmitter - Displacement Transmitter
- Motor Drives - AC Drive - AC Drive Feedback

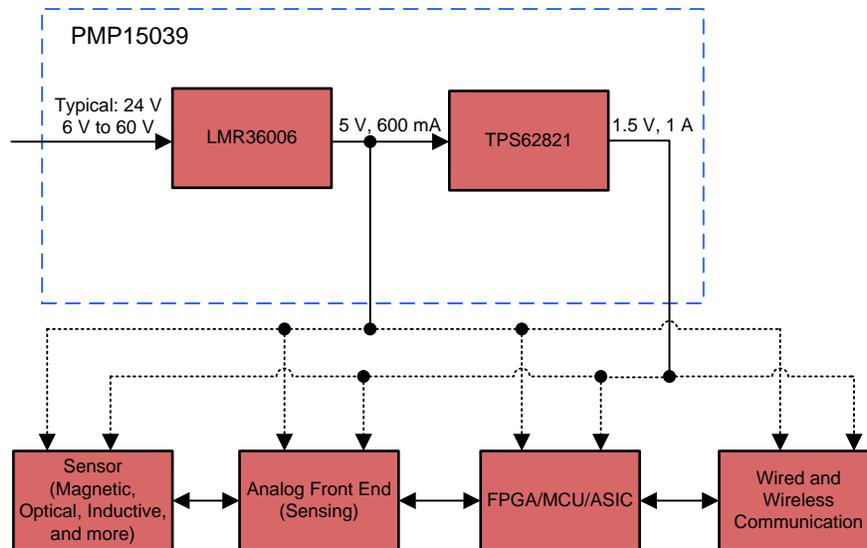


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1 System Description

The PMP15039 device is a two-stage power supply optimized for size-sensitive sensor applications, specifically field transmitters and AC drive feedback systems. The standard power stages use DC/DC converters, rather than LDOs, to enable peak efficiency above 90% as shown in [Figure 10](#).

A field transmitter uses an analog front-end to convert the signal of a sensor to an electrical representation and uses the digital processor to convert this signal to a digital representation. A standard field transmitter uses a nonisolated, wide V_{IN} 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 1](#) shows the PMP15039 standard placement within the field transmitter system.



*See [Section 2.3](#) for how to adapt output voltage to specific needs

Figure 1. PMP15039 for Field Transmitter Applications

An AC drive feedback system converts SIN/COS differential inputs from the resolver or encoder into digital outputs to enable accurate rotor position feedback of the AC drives. The AC drive position feedback uses a nonisolated, wide V_{IN} DC/DC converter as the primary power stage, paired with a point-of-load DC/DC converter. These two power rails are necessary for powering the digital processing component of the system. Figure 2 shows the PMP15039 standard placement within the AC drive position feedback system.

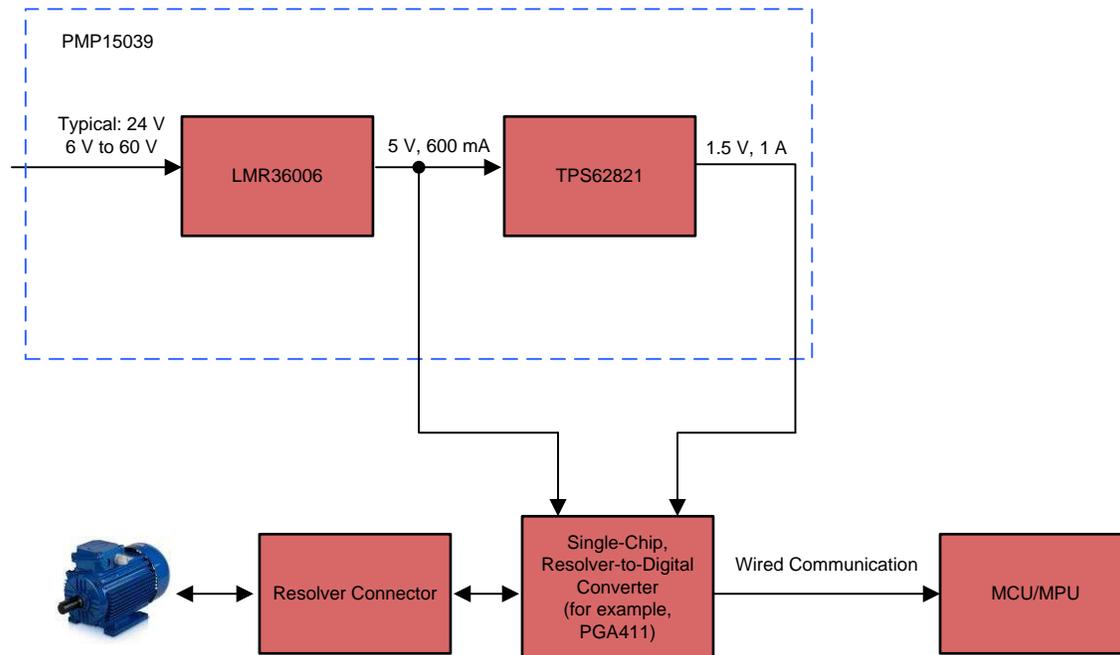


Figure 2. PMP15039 for AC Drive Position Feedback Applications

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATION
V_{IN} minimum	6 V
V_{IN} maximum	60 V
V_{IN} nominal	24 V
V_{OUT1}	5 V
I_{OUT1}	600 mA
V_{OUT2}	1.5 V
I_{OUT2}	1 A
U1 Feedback Voltage Accuracy	±1.5 %
U2 Feedback Voltage Accuracy	1 %
F_{SW_U1}	1 MHz
F_{SW_U2}	2.2 MHz
X - Dimension	9.25 mm
Y - Dimension	18 mm

2 System Overview

2.1 Block Diagram

Figure 3 shows the PMP15039 block diagram.

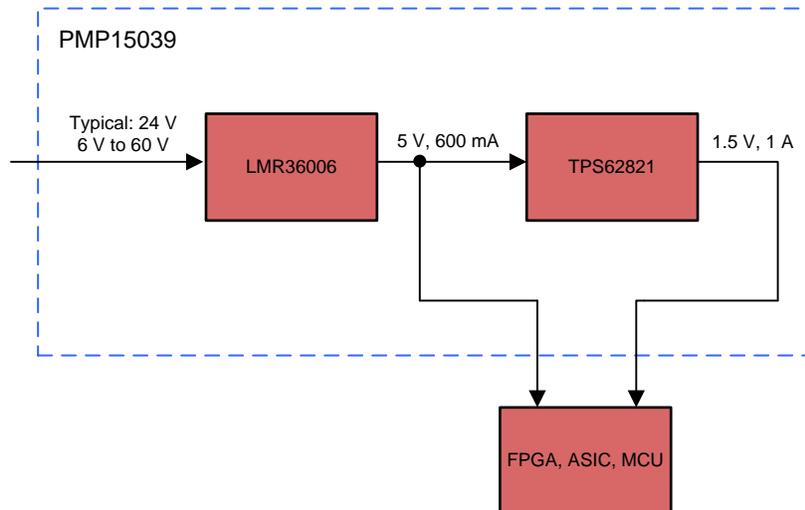


Figure 3. PMP15039 Block Diagram

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 μ A
- -40°C to $+150^{\circ}\text{C}$ 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 \times 2 mm

2.2.2 TPS62821

Features:

- Synchronous buck converter
- DCS-Control™ topology
- 2.2-MHz switching frequency
- Low quiescent current: 4 μ A
- -40°C to $+125^{\circ}\text{C}$ junction temperature range
- 1% Feedback Voltage Accuracy (Over Full Temperature Range)
- Adjustable 0.6-V to 4-V output
- Maximum current load: 1 A for TPS62821, 2 A for TPS62822, and 3 A for TPS62823
- QFN package: 1.5 mm \times 2 mm

2.3 System Design Theory

The PMP15039 reference design is the power management subsystem for industrial sensor applications that require dual outputs to power the digital processor. The reference design uses a wide V_{IN} converter (LMR36006) and a point-of-load converter (TPS62821) in a two-stage power supply with an optimized switching frequency, temperature range, and form factor. The PMP15039 was designed specifically for field transmitters and AC drive position feedback applications, but the LMR360xx and TPS282x families of devices offer the flexibility to use this size-optimized layout for the various power demands of additional industrial applications.

The LMR36006 synchronous buck converter is a wide input voltage, low quiescent current, high-performance regulator with internal compensation. The LMR36006 was chosen as the front-end, wide V_{IN} converter for the PMP15039 because of the small package size (3 mm × 2 mm), the switching frequency, the 600-mA current capability, and the input voltage range of the regulator. 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 device is designed with a flip-chip or HotRod technology, which greatly reduces the parasitic inductance of the pins. In addition, the layout of the device can help reduce the radiated noise generated by switching action through the partial cancellation of the current-generated magnetic field. Figure 4 shows the schematic of the front-end DC/DC converter.

For the PMP15039, 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 k Ω , and Equation 1 calculates the bottom resistor (R_{FBB}).

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

where

- V_{REF} is nominally 1 V. (1)

For this 5-V example, values are $R_{FBT} = 100$ k Ω and $R_{FBB} = 24.9$ k Ω . Depending on the power requirement of the downstream digital component, 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 $R_{FBT} = 100$ k Ω and $R_{FBB} = 43.5$ k Ω . Furthermore, the PMP15039 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 PMP15039 up to 7.5 W at 5 V_{OUT} and 5 W at 3.3 V_{OUT} , the pin-compatible LMR36015 offers a maximum output load current of 1.5 A. To adapt the design to the LMR36015, the output filter (L1 and C_{OUT}) must be modified appropriately. TI recommends that the user modify the L1 to 4.7 μ H and the C_{OUT} to 33 μ F. 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, which allows some relaxation in the current rating of the inductor.

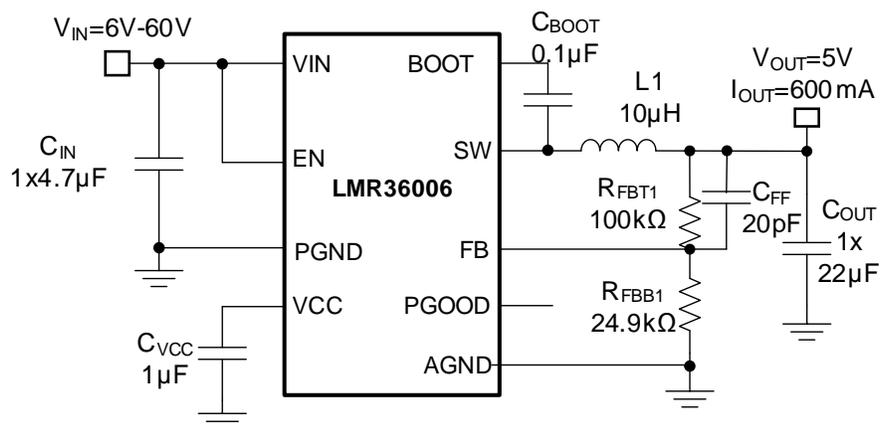


Figure 4. Front-End DC/DC Converter Schematic

The TPS62821 synchronous buck converter is a low quiescent current, high-performance point-of-load converter. The TPS62821 converter was chosen for the PMP15039 because of the small package size of the TPS62821 (2 mm × 1.5 mm), the 2.2-MHz switching frequency, the 1-A current capability, the high efficiency, and the feedback voltage accuracy of 1%. Both the LMR36006 and TPS62821 devices belong to a family of devices that offer various output power capabilities. With an operating frequency of 2.2 MHz, and a 2-mm × 1.5-mm QFN package, the TPS62821 device enables a small solution size. Based on the DCS-Control topology, PMP15039 provides a fast transient response. [Figure 5](#) shows the schematic of the point-of-load DC/DC converter.

For the PMP15039, the TPS62821 stage is set to 1.5 V with feedback resistors from FB to V_{OUT} . The top feedback resistor (R_{FBT}) is set to 100 k Ω , and [Equation 1](#) calculates the bottom resistor (R_{FBB}). V_{REF} is nominally 600 mV. For this 1.5-V example, values are $R_{FBT} = 100$ k Ω and $R_{FBB} = 66.5$ k Ω .

Depending on the power requirement of the downstream controller, the TPS62821 output voltage can be adjusted. For example, for controllers that require a typical power rail of 2.5-V, the output voltage can be adapted by recalculating R_{FBT} and R_{FBB} . For this 2.5-V example, the values would be $R_{FBT} = 475$ k Ω and $R_{FBB} = 150$ k Ω . See [Table 2](#) for the recommended feedback resistor values for typical output voltages.

Table 2. Feedback Resistor Values for Typical Output Voltages

VOUT (V)	RFB1 (k Ω)	RFB2 (k Ω)
1.5	100	100
1.8	100	100
2.5	475	150
3.3	732	162

Furthermore, in addition to the described changes for the front-end converter to modify the output power capability, the point-of-load converter may also need to support a higher load current. To adapt the TPS62821 to system-specific power requirements, the pin-compatible TPS62822 supplies a maximum load current of 2 A and TPS62823 supplies a maximum load current of 3 A. To modify the output filter accordingly, the saturation current of the inductor must support the increased current capability.

For further information on even smaller solution sizes and higher efficiencies for the TPS6282X, refer to the [TPS6282x 5.5-V, 1-, 2-, 3-A Step-Down Converter Family With 1% Accuracy](#) (SLVSDV6) data sheet and [TPS6282xEVM-005 Evaluation Module](#) (SLVUBA0) user guide.

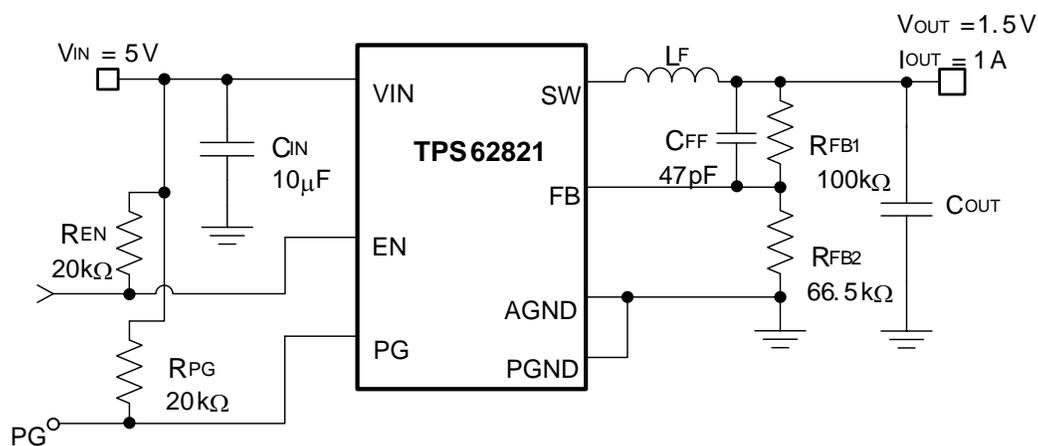


Figure 5. Point-of-Load DC/DC Converter Schematic

For design calculations and layout examples, see the relevant data sheet for these 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)
- [TPS6282x 2.4-V to 5.5-V, 1-, 2-, 3-A Step-Down Converter With 1% Accuracy](#) (SLVSDV6)

3 Hardware, Testing Requirements, and Test Results

3.1 Required Hardware

3.1.1 Hardware

The following steps outline the hardware setup.

1. Connect a DC power supply to the board input as shown in [Figure 6](#).
2. Connect an electronic or resistive load to the dual outputs (V_{OUT1} and V_{OUT2}) to imitate the typical load as shown in [Figure 6](#).

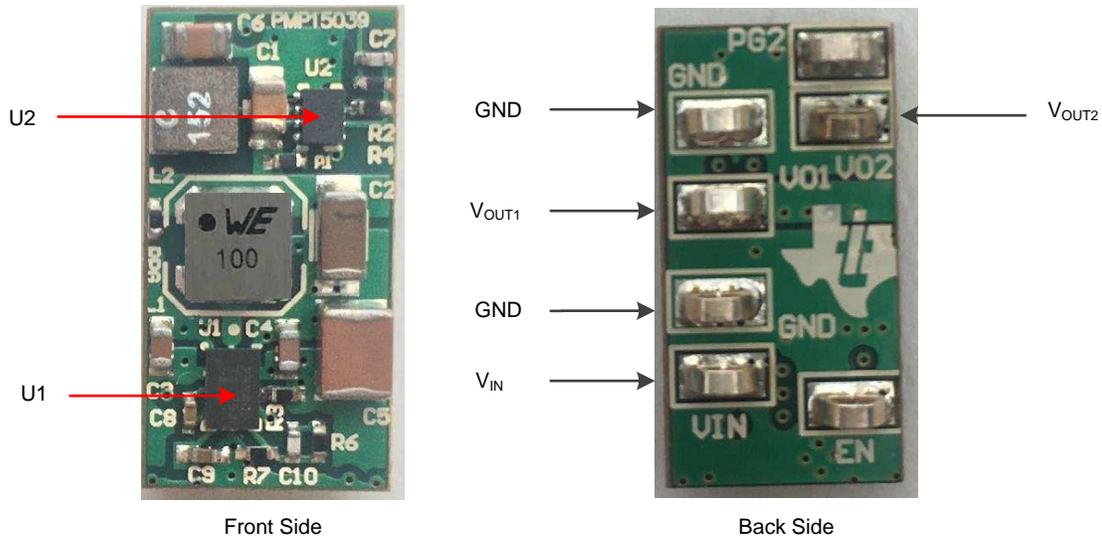


Figure 6. PMP15039 Board Setup

3.2 Testing and Results

The following diagrams show the design performance.

3.2.1 Thermal Data

The infrared (IR) thermal image in [Figure 7](#) was taken at steady-state with $V_{IN} = 24\text{ V}$ and the TPS62821 output at a full load of 1 A (no airflow). The ambient temperature is approximately 22°C. The maximum IC temperature is 47°C.

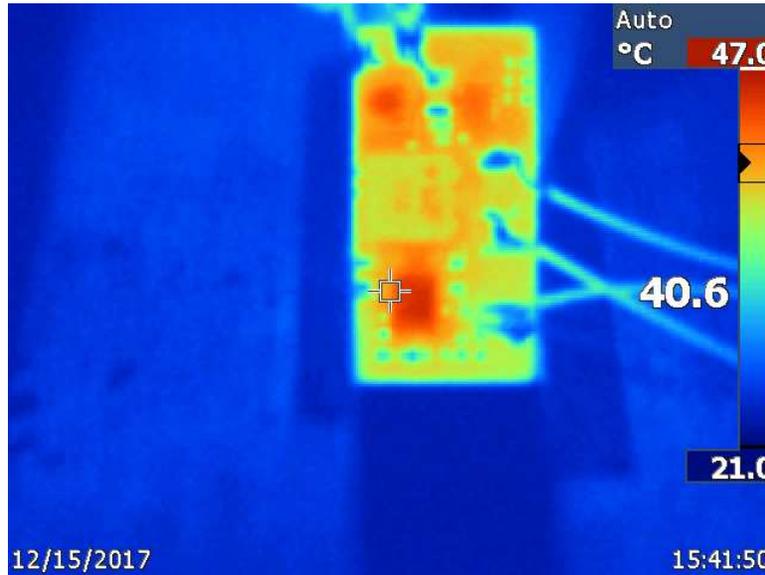


Figure 7. PMP15039 Thermal Image: $V_{IN} = 24\text{ V}$, $I_{OUT1} = 0\text{ A}$, $I_{OUT2} = 1\text{ A}$

[Figure 8](#) was taken at steady-state with $V_{IN} = 24\text{ V}$ and the LMR36006 output at a load of 300 mA (no airflow) and TPS62821 output at a load of 1 A (no airflow). The ambient temperature is approximately 22°C. The maximum IC temperature is 59°C.



Figure 8. PMP15039 Thermal Image: $V_{IN} = 24\text{ V}$, $I_{OUT1} = 300\text{ mA}$, $I_{OUT2} = 1\text{ A}$

3.2.2 Efficiency Data

Figure 9 and Figure 10 show the efficiency of the PMP15039 device versus a load current of U2, TPS62821.

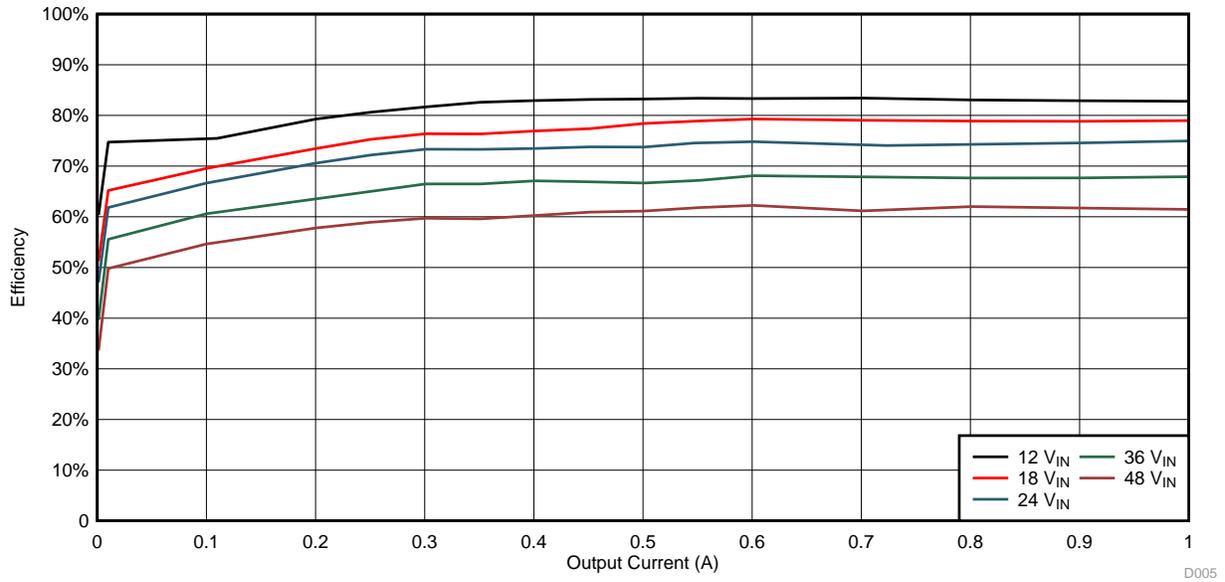


Figure 9. System Efficiency Versus Load Current: I_{OUT1} = 0 A, I_{OUT2} = 0 A to 1 A

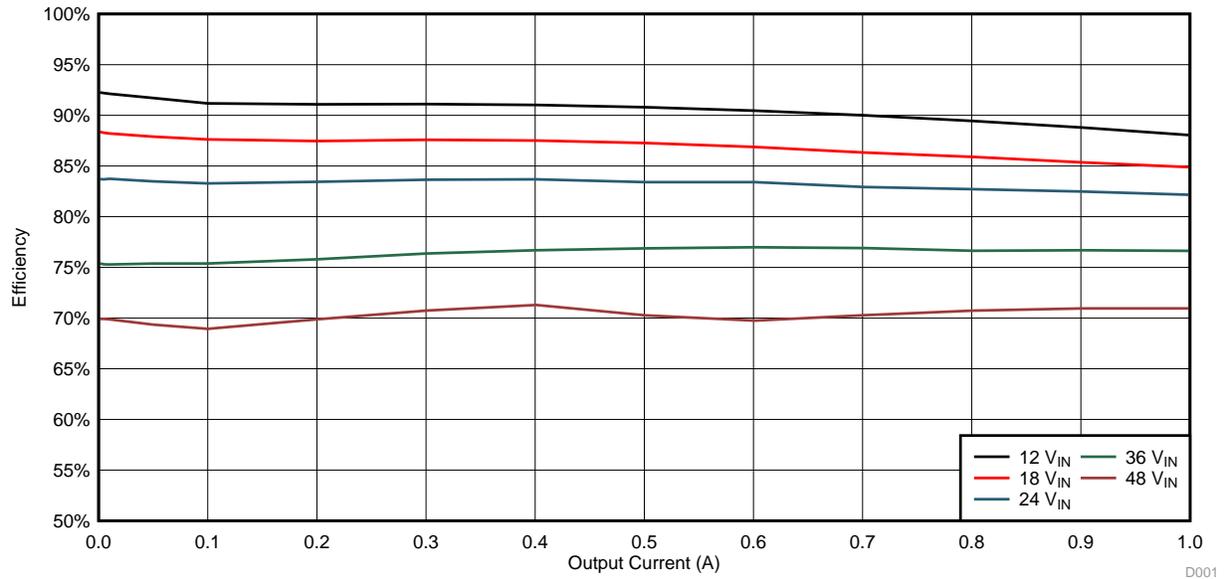


Figure 10. System Efficiency Versus Load Current: I_{OUT1} = 0.3 A, I_{OUT2} = 0 A to 1 A

3.2.3 Output Load Regulation

Figure 11 and Figure 12 show the output load regulation of the converter.

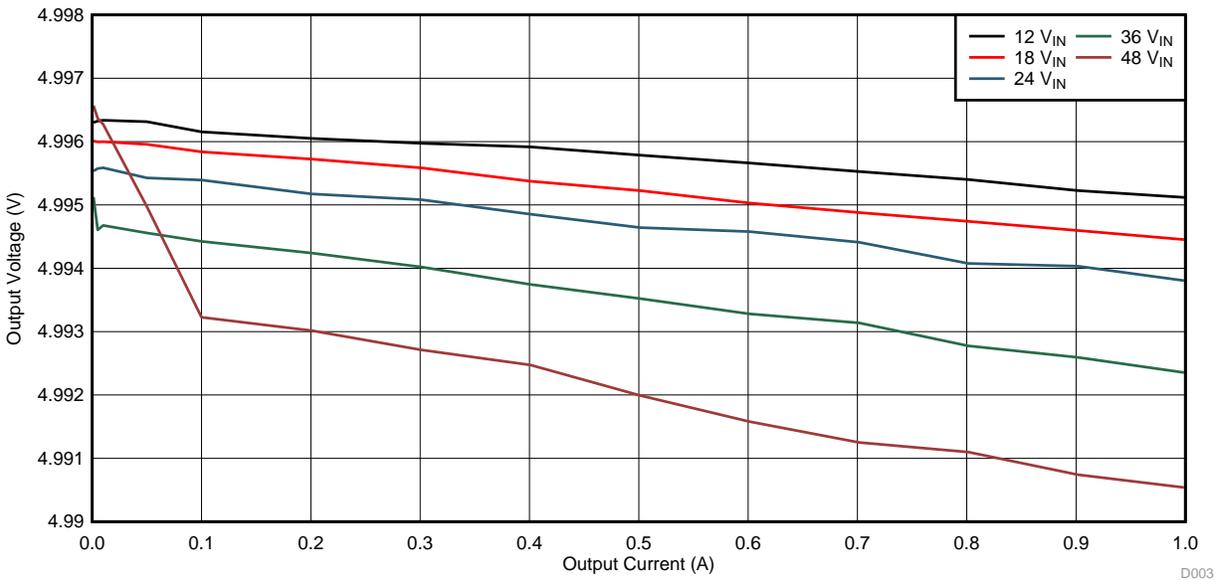


Figure 11. LMR36006 Load Regulation: V_{OUT1} vs I_{OUT2}

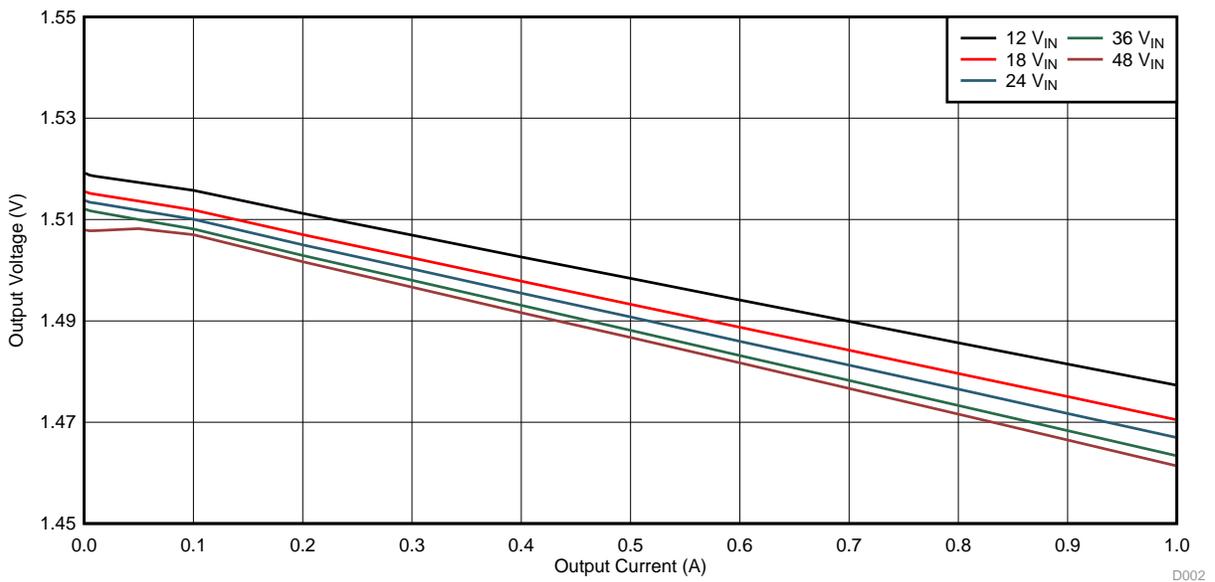


Figure 12. TPS62821 Load Regulation: V_{OUT2} vs I_{OUT2}

3.2.4 Start-Up Waveforms

Figure 13 shows the start-up waveform at a 24-V input and no load. Figure 14 shows the start-up waveform at the 24-V input and 1-A load at V_{OUT2} .

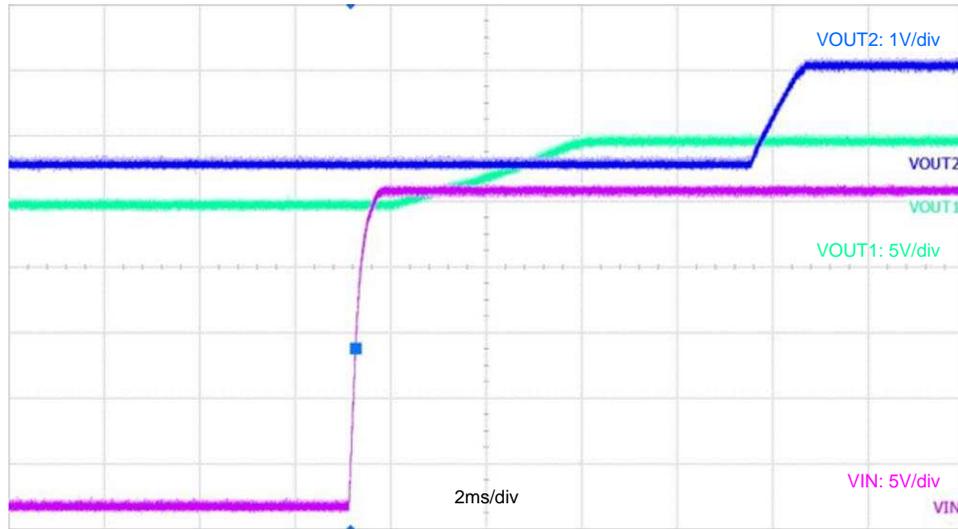


Figure 13. Start-Up Waveform: $V_{IN} = 24\text{ V}$, $I_{OUT2} = 0\text{ A}$

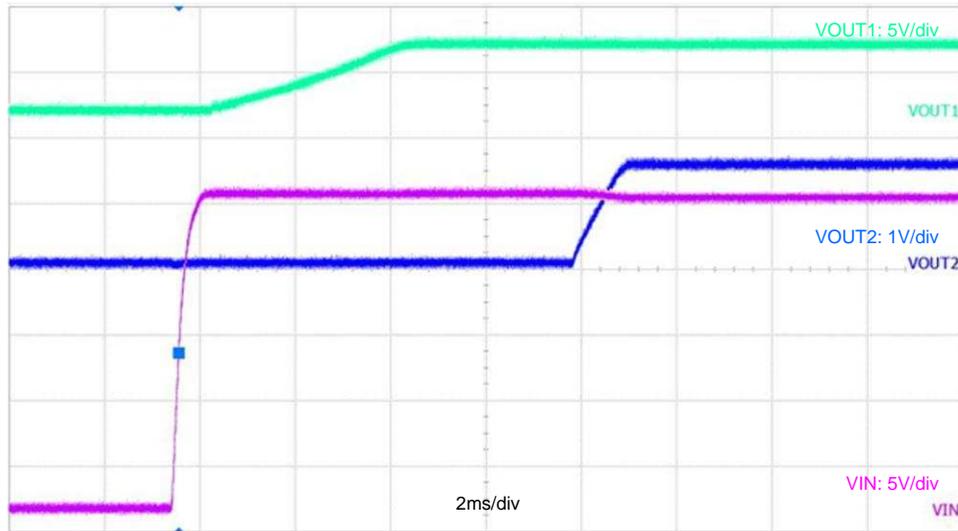


Figure 14. Start-Up Waveform: $V_{IN} = 24\text{ V}$, $I_{OUT2} = 1\text{ A}$

3.2.5 Switch Node Voltage and Output Voltage Ripple

Figure 15 shows the steady-state, switch-node voltage and output voltage ripple at 24-V_{IN} and 10-mA load. Figure 16 shows the steady-state, switch-node voltage and output voltage ripple at 24-V and 1-A load.

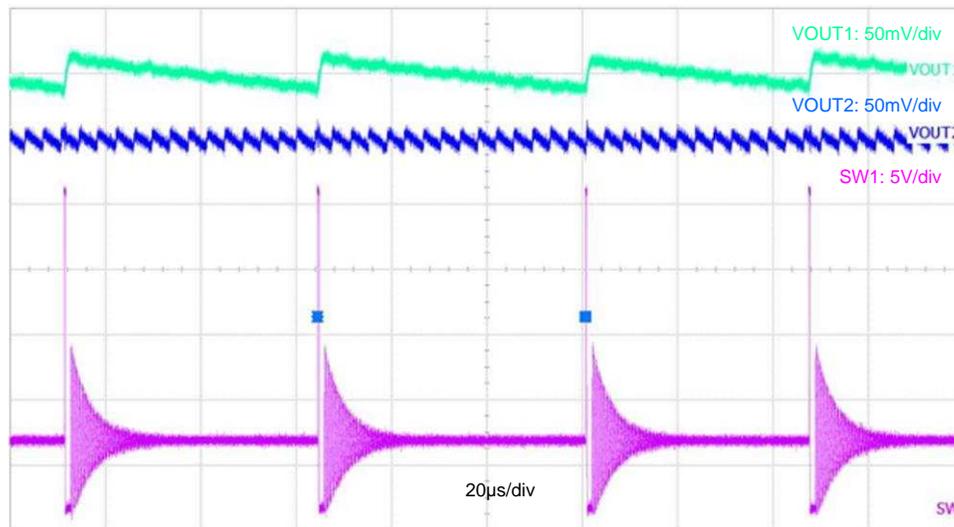


Figure 15. Steady-State Waveform: V_{IN} = 24 V, I_{OUT2} = 10 mA

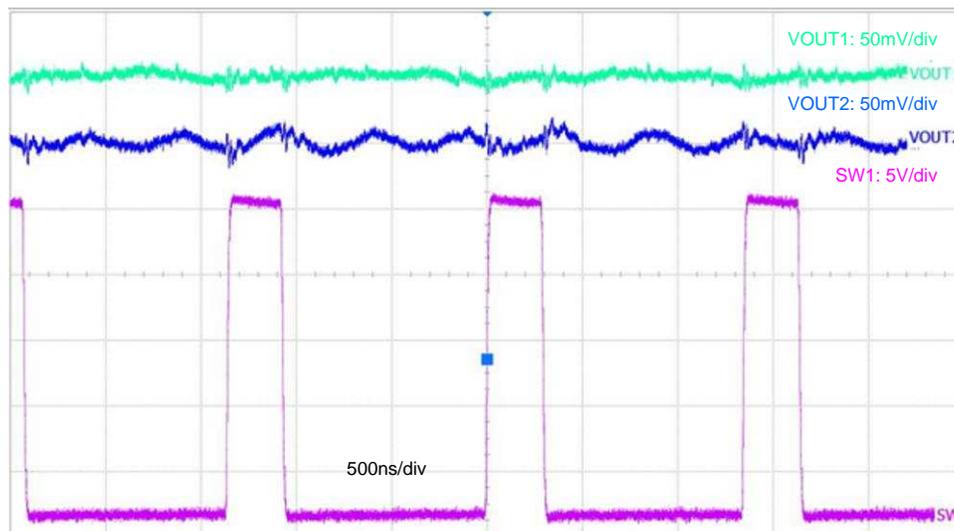


Figure 16. Steady-State Waveform: V_{IN} = 24 V, I_{OUT2} = 1 A

3.2.6 Load Transient

The load transient waveforms monitor the output voltage and the load current. Channel 1 (blue) represents the output current of the TPS62821 (I_{OUT2}). Channel 2 (purple) represents the output voltage of the TPS62821 (V_{OUT2}). Channel 3 (green) represents the output voltage of the LMR36006 (V_{OUT1}). Figure 17 to Figure 19 show the load transient results.

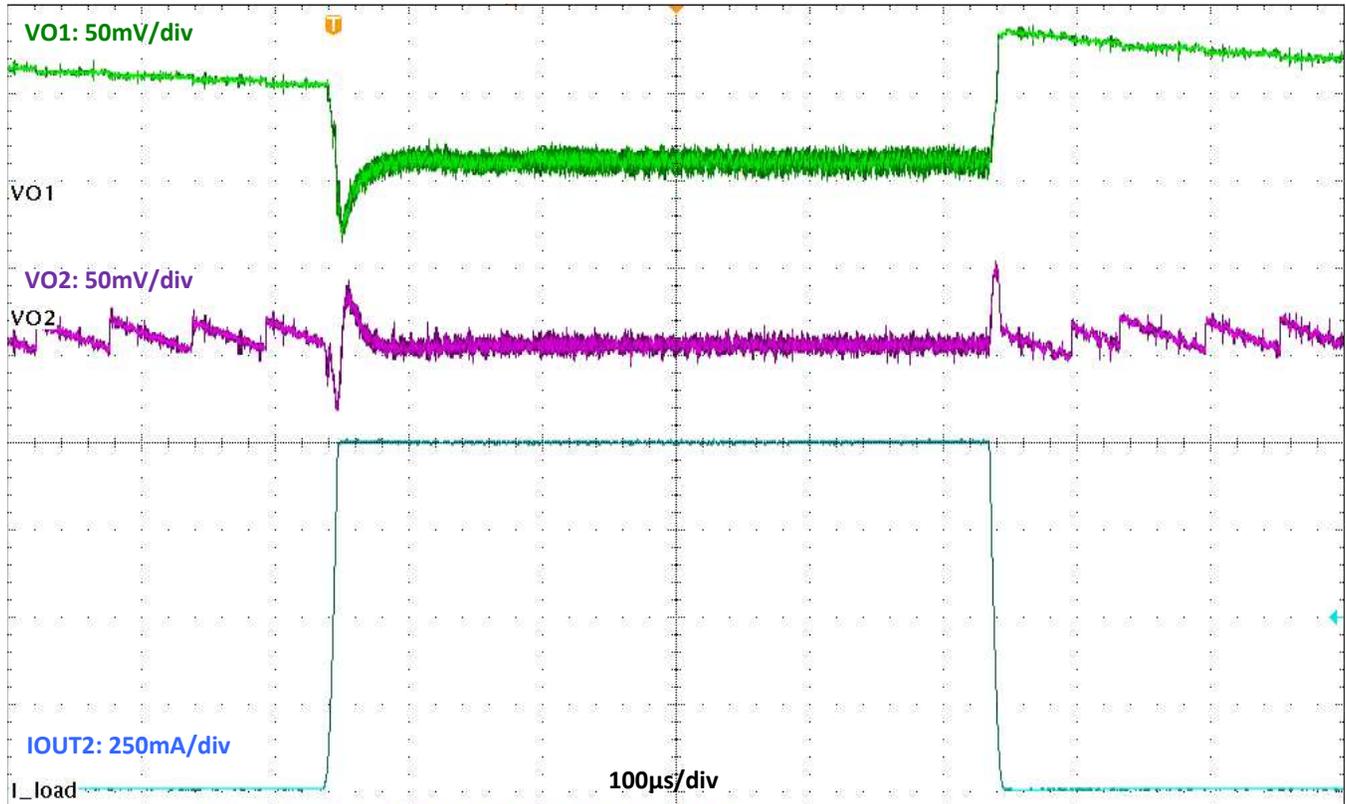


Figure 17. Load Transient: $V_{IN} = 24\text{ V}$, $I_{OUT1} = 0\text{ A}$, $I_{OUT2} = 0\text{ A to } 1\text{ A to } 0\text{ A}$, $t_R = t_F = 10\text{ }\mu\text{s}$

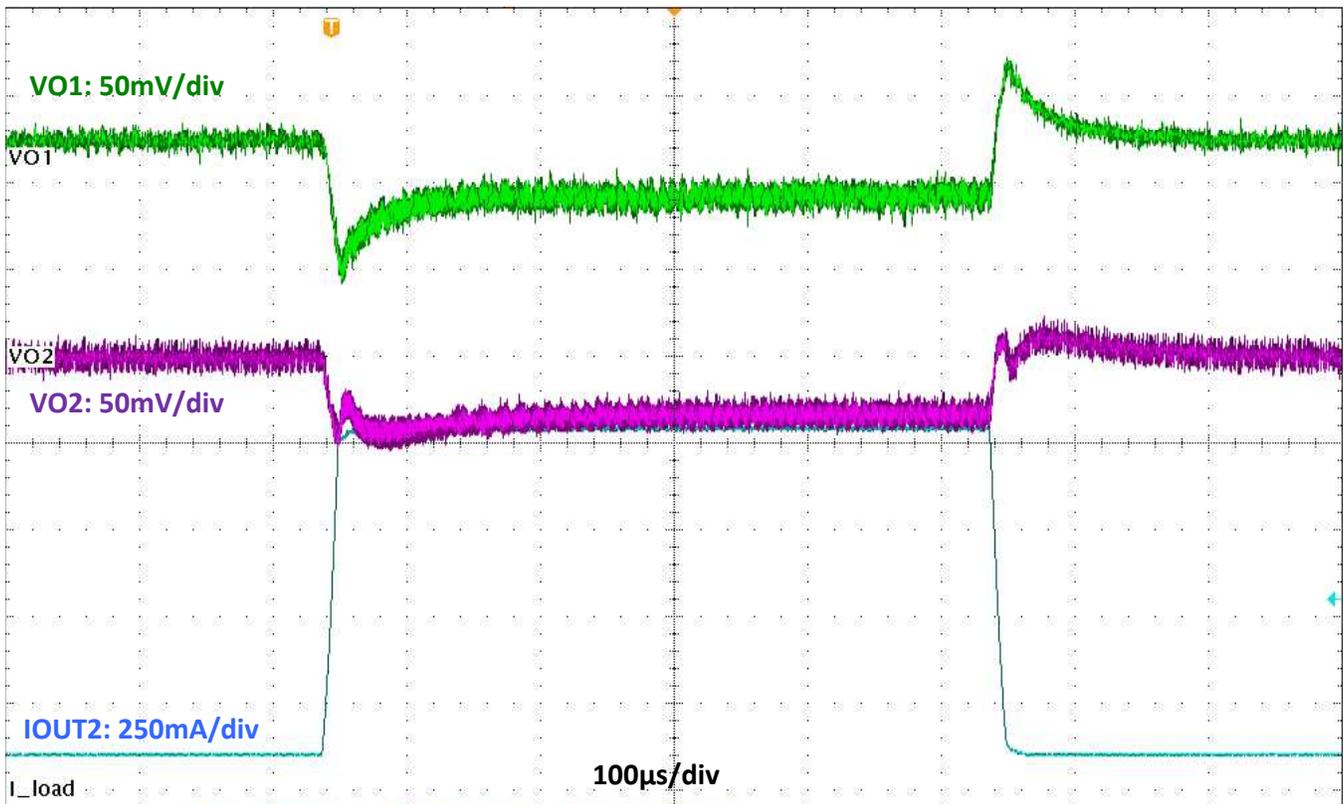


Figure 18. Load Transient: $V_{IN} = 24\text{ V}$, $I_{OUT1} = 300\text{ mA}$, $I_{OUT2} = 0.1\text{ A to } 1\text{ A to } 0.1\text{ A}$, $t_R = t_F = 10\text{ }\mu\text{s}$

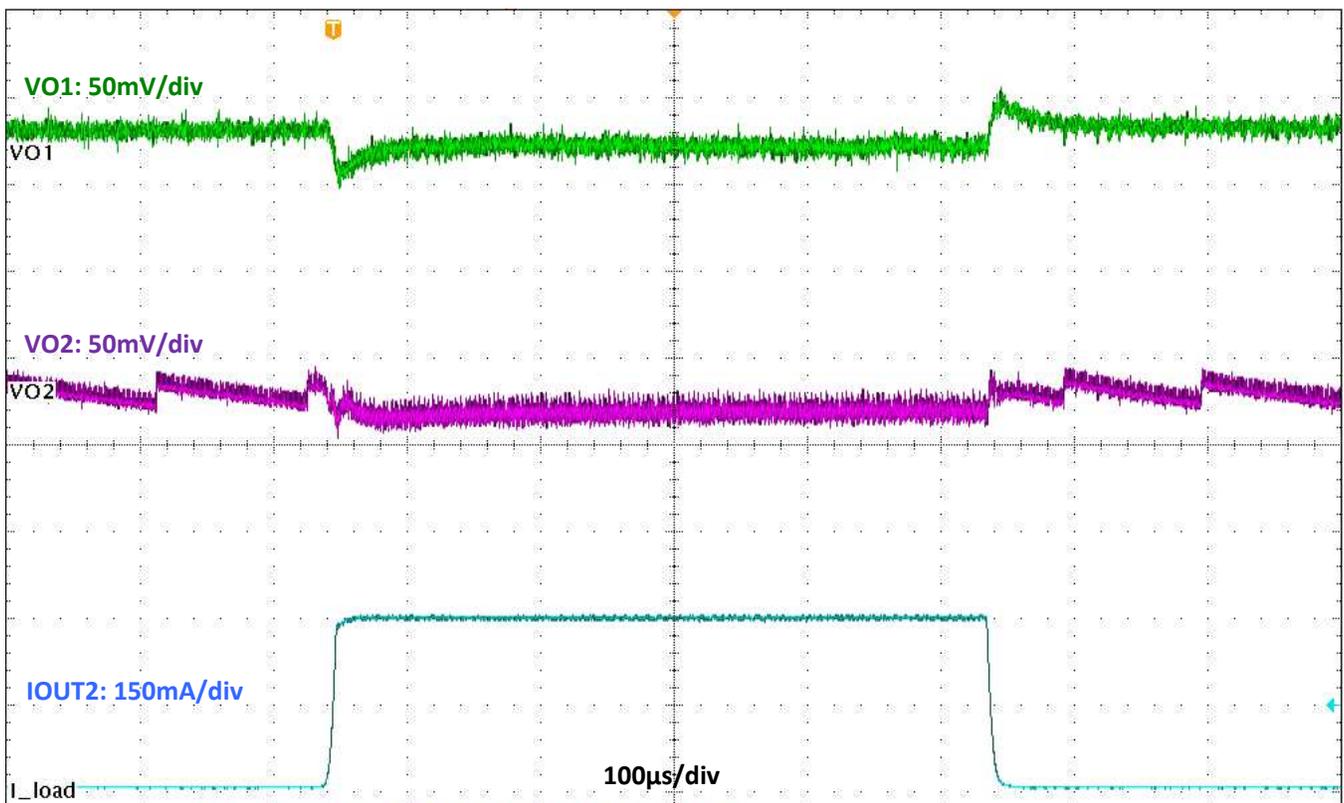


Figure 19. Load Transient: $V_{IN} = 24\text{ V}$, $I_{OUT1} = 300\text{ mA}$, $I_{OUT2} = 0\text{ A to } 300\text{ mA to } 0\text{ A}$, $t_R = t_F = 10\text{ }\mu\text{s}$

4 Design Files

4.1 Schematics

To download the schematics, see the design files at [PMP15039](#).

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at [PMP15039](#).

4.3 PCB Layout Recommendations

4.3.1 Layout Prints

To download the layer plots, see the design files at [PMP15039](#).

4.4 Altium Project

To download the Altium project files, see the design files at [PMP15039](#).

4.5 Gerber Files

To download the Gerber files, see the design files at [PMP15039](#).

4.6 Assembly Drawings

To download the assembly drawings, see the design files at [PMP15039](#).

5 Software Files

To download the software files, see the design files at [PMP15039](#).

6 Related Documentation

1. [LMR36006 4.2-V to 60-V, 0.6-A Synchronous Step-Down Converter in HotRod™ Package](#), data sheet
2. [LMR36015 4.2-V to 60-V, 1.5-A Synchronous Step-Down Converter in HotRod™ Package](#), data sheet
3. [TPS6282x 5.5-V, 1-, 2-, 3-A Step-Down Converter Family With 1% Accuracy](#), data sheet
4. [TPS6282xEVM-005 Evaluation Module](#), user guide

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