TI Designs: PMP9806

Accurate Output Current Limit Circuit Reference Design for TPS61088 Boost Converter

TEXAS INSTRUMENTS

Description

The PMP9806 reference design delivers an accurate output current-limit solution for the TPS61088 boost converter. This feature is made possible by utilizing an output current sense resistor and an operational amplifier for low cost applications. When the output current exceeds the current limit point, the output of the operational amplifier increases to a voltage higher than the TPS61088 1.204-V reference voltage, which causes the output voltage to drop. If the output current continues to increase, the output voltage decreases further in response. This configuration ensures that the maximum output power is always limited below a certain level.

Resources

PMP9806	Design Folder
TPS61088	Product Folder
TLV2314	Product Folder

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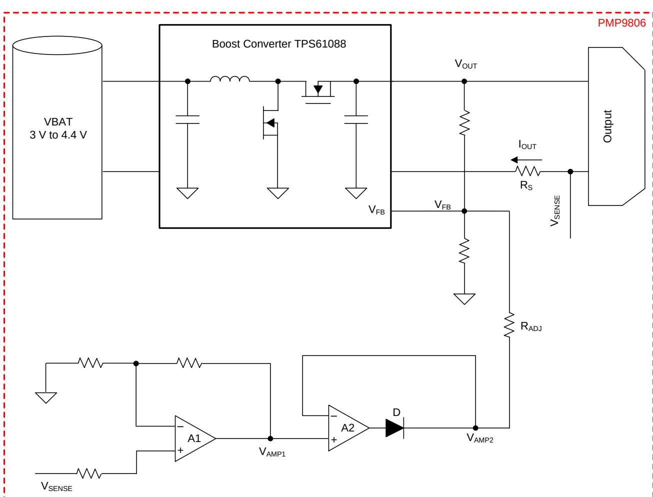
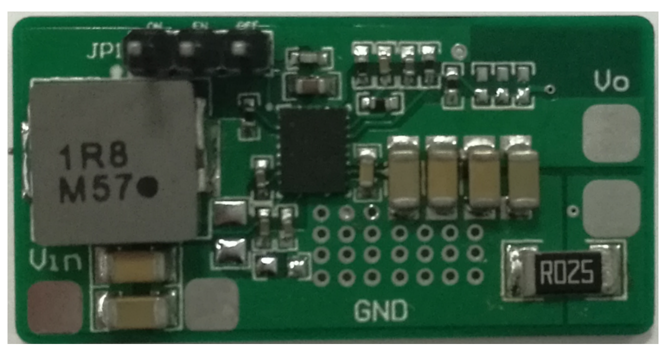
Features

- 2.7-V to 4.2-V Input Voltage Range
- 5-V/3-A, 9-V/2-A, and 12-V/1.5-A Output Capabilities
- Accurate Output Current Limit
- Limited Maximum Output Power
- Small Solution Size; Easy to Implement

Applications

- Power Banks
- Limited Maximum Output Power in Boost Converter Applications





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1 System Description

The latest generation power banks must utilize output power limit functions to avoid the overpower and overheating problems that occur during usage. Overheating is not allowable per Quick Charge 3.0 requirements.

The synchronous boost converter TPS61088 is widely used in quick charge power bank applications. This converter implements cycle-by-cycle current limit to protect the device from overload conditions during boost switching. This current limit function is realized by detecting the current flowing through the low-side MOSFET and has an approximate ±10% precision. The maximum output power varies significantly if designers utilize the current limit function of the TPS61088 itself. The part with a higher current limit threshold generates more heat in the overload conditions and some parts encounter overheating problems.

The PMP9806 reference design delivers an accurate output current-limit solution for the TPS61088 boost converter. This feature is made possible by utilizing an output current sense resistor and an operational amplifier for low cost applications. When the output current exceeds the current limit point, the output of the operational amplifier increases to a voltage higher than the TPS61088 1.204-V reference voltage and causes the output voltage to drop. If the output current continues to increase, the output voltage decreases further in response. This configuration ensures that the maximum output power is always limited below a certain level. The TLV2314 is a low-cost, small packaged operational amplifier. The PMP9806 reference design offers a cost effective and compact solution for power bank applications.

1.1 Key System Specifications

Table 1 provides the performance specification of this reference design. When the output current is higher than the setting point, the output voltage drops.

Table 1. Performance Specifications

INPUT VOLTAGE	OUTPUT VOLTAGE AND OUTPUT CURRENT	OUTPUT CURRENT LIMIT POINT
3 V to 4.2 V	9 V, 2 A	Io ≥ 2.1 A
	5 V, 3 A	Io ≥ 3.15 A
	12 V, 1.5 A	Io ≥ 1.575 A

2 System Overview

2.1 Block Diagram

Figure 1 shows the block diagram of the PMP9806 reference design. A shunt resistor, R_S, is placed in the output return and this resistor converts the output current to a voltage signal V_{SENSE}. The operational amplifier, A1, senses the voltage V_{SENSE} across the shunt resistor R_S and provides a magnified voltage, V_{AMP1}, to the amplifier A2.

When the output current is lower than the current limit point, V_{AMP1} is lower than the 1.204-V reference voltage of the TPS61088 device, the diode D cannot conduct, and resistor R_{ADJ} is floating. The boost converter functions per usual.

When the output current is higher than the current limit point, V_{AMP1} exceeds the 1.204-V reference votlage of the TPS61088 device and diode D conducts. Voltage V_{AMP2} is equal to the voltage V_{AMP1}; so, V_{FB} increases and the output voltage V_{OUT} drops. If the output current continues to increase, the output voltage decreases further. Thus the maximum output power always remains limited below a certain level.

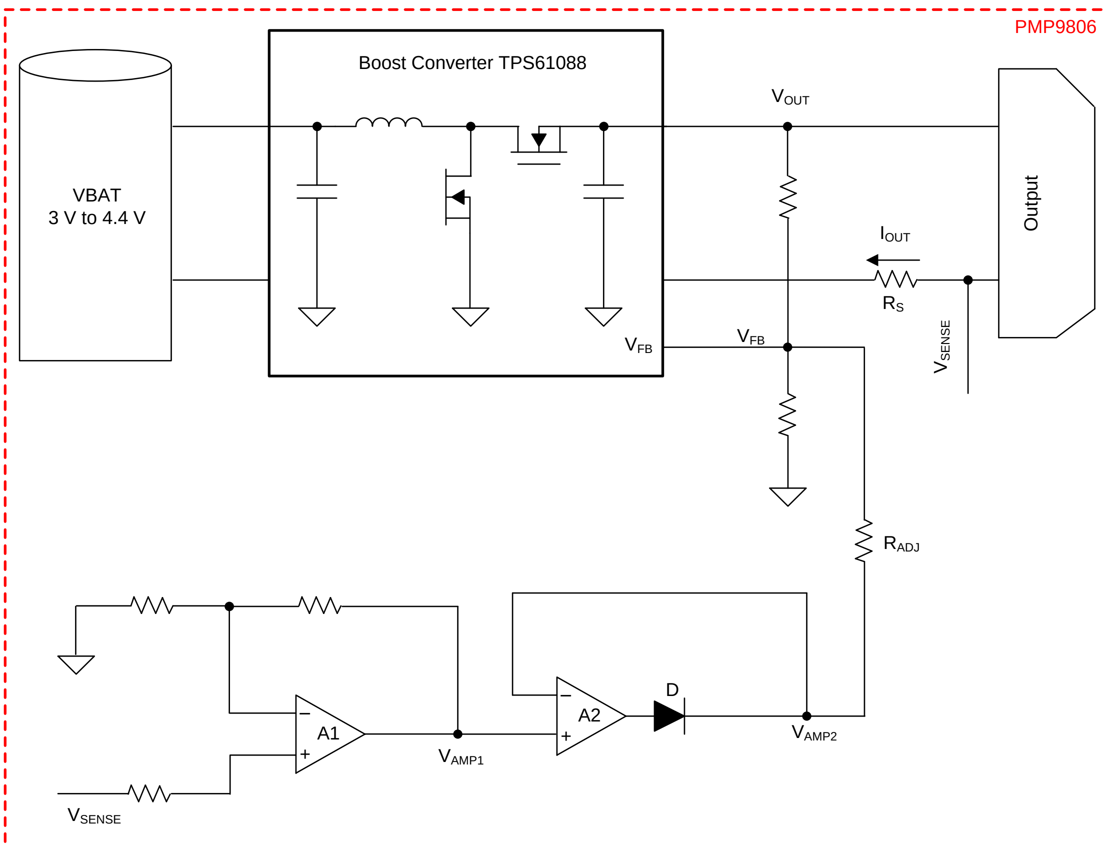

Figure 1. PMP9806 Block Diagram

2.2 System Design Theory

This section provides the PMP9806 output current limit circuit design. For the power components and compensation network calculation, see the *TPS61088 10-A Fully-Integrated Synchronous Boost Converter* datasheet[1].

2.2.1 Setting Current Limit Point

The output current limit point must be higher than the maximum output current. In this reference design, the maximum output current is 3 A when V_O = 5-V condition, 2 A when V_O = 9-V condition, and 1.5 A when V_O = 12-V condition. Set the output current limit point to 3.15 A, 2.1 A, and 1.575 A, respectively, to avoid the current limit circuit from false triggering during normal output current conditions.

2.2.2 Shunt Resistor Selection

The use of a shunt resistor is the most versatile and cost-effective means to measure the current. The voltage across this resistor must be kept to a low value to reduce the power loss. In this reference design, the shunt resistor value, R_S, has been selected as 25 mΩ. The maximum continuous current, I_{O_MAX}, which flows through the shunt resistor is 3.15 A when V_O = 5-V condition. So the maximum shunt voltage, V_{SENSE_MAX}, can be calculated using the following Equation 1:

$$V_{SENSE\_MAX} = R_S \times I_{O\_MAX} \tag{1}$$

The minimum power rating, P_{RATING}, of the shunt resistor can be calculated using the following Equation 2:

$$P_{RATING} = V_{SENSE\_MAX} \times I_{O\_MAX} \tag{2}$$

Using the previous equation, the minimum power rating of the shunt resistor is calculated as 0.248 W in this reference design. A general rule of thumb is to multiply this minimum power rating by 2. Therefore, TI recommends that the designer choose a ≥ 0.5-W resistor in this reference design to make it more robust in the overload or output short-circuit condition.

2.2.3 Output Current Limit Circuit Design

Figure 2 shows the output current limit circuit in this reference design. The current sense signal V_{SENSE} is connected to the non-inverting input of A1 through R15.

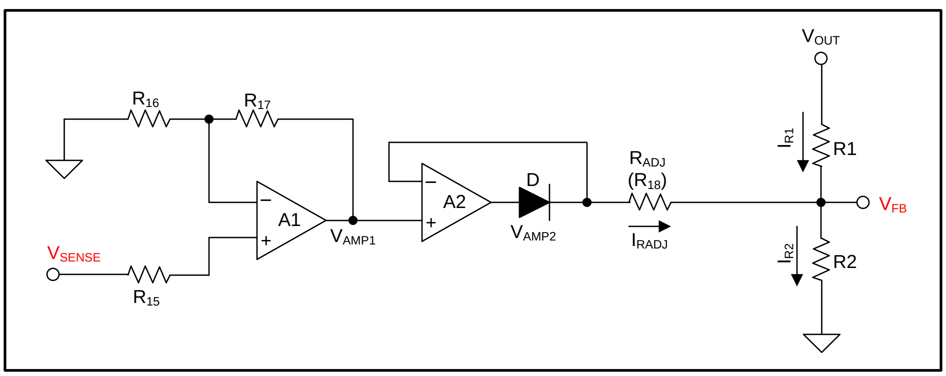

Figure 2. Output Current Limit Circuit

During the theoretical calculation (using the 9-V, 2-A output condition for example) of this reference design, the designer sets the operational amplifier A1 output voltage (V_{AMP1}) to 1.204 V when the output current is 2.1 A. This setting is 5% higher than the 2-A maximum normal output current.

When the output current increases to the targeted transition point of 2.1 A, the voltage V_{SENSE} at the non-inverting positive input of A1 is calculated as the following Equation 3 shows:

$$V_{SENSE} = R_S \times I_{O\_MAX} = 52.5 \text{ mV} \tag{3}$$

To make V_{AMP1} equal to 1.204 V, the designer must rearrange the equation as follows in Equation 4:

$$V_{SENSE} \times \frac{R_{17} + R_{16}}{R_{16}} = V_{AMP1} \tag{4}$$

This rearrangement results in the following Equation 5:

$$\frac{R_{17}+R_{16}}{R_{16}}=\frac{V_{AMP1}}{V_{SENSE}}=\frac{1.204}{0.0525}=22.93 \quad (5)$$

So select R17 = 232 kΩ and R16 =10.5 kΩ in this reference design.

When the output current is higher than 2.1 A, V_{AMP1} exceeds the 1.204-V reference voltage of the TPS61088 device, the diode D conducts. This action causes V_{FB} to increase and the output voltage V_{OUT} to drop. The output voltage dropout is controlled by the resistor R_{ADJ}. The relationship between the output voltage V_{OUT} to the resistor R_{ADJ} can be deduced by the following Equation 6 through Equation 9:

$$I_{RADJ}+I_{R1}=I_{R2} \quad (6)$$

$$I_{RADJ}=\frac{(V_{AMP2}-V_{FB})}{R_{ADJ}} \quad (7)$$

$$I_{R1}=\frac{V_O-V_{FB}}{R1} \quad (8)$$

$$I_{R2}=\frac{V_{FB}}{R2} \quad (9)$$

Insert Equation 7, Equation 8, and Equation 9 into Equation 6 to obtain the following Equation 10:

$$V_O=V_{FB}+\left(\frac{V_{FB}}{R2}-\frac{(V_{AMP2}-V_{FB})}{R_{ADJ}}\right)\times R1 \quad (10)$$

Set the V_O to 6.5 V at a 3-A output current condition to limit the output power below a certain level, which results in the following Equation 11:

$$R_{ADJ}=\frac{(V_{AMP2}-V_{FB})}{\frac{V_{FB}}{R2}-\frac{(V_O-V_{FB})}{R1}}\approx 169\text{ k} \quad (11)$$

where,

- $V_{AMP2} = V_{AMP1} = V_{SENSE} \times (R_{17} + R_{16}) / R_{16}$ = 1.73 V when I_O = 3 A
- R1 = 768 k
- R2 = 120 k.

If set the V_O to 5.5 V when at a 3-A output current condition, R_{ADJ} = 121 k.

3 Test Results

3.1 Start-Up Waveforms

Figure 3 shows the start-up waveforms of the inductor current and the output voltage at V_{IN} = 3.3 V and Io = 2-A condition.

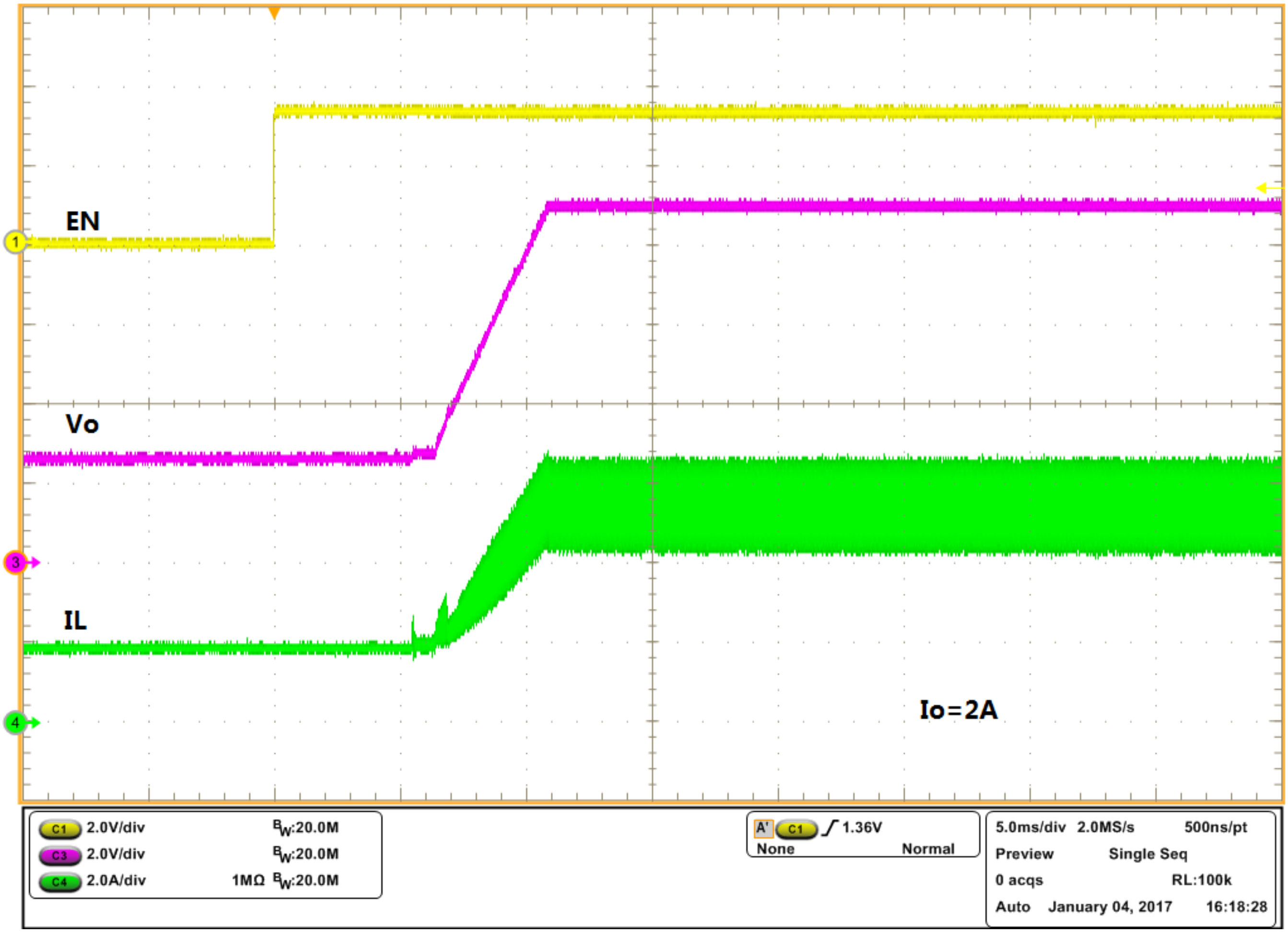

Figure 3. Start-up Waveforms at I_O = 2 A (V_O = 9 V)

Figure 4 shows the start-up waveforms of the inductor current and the output voltage at V_{IN} = 3.3 V and Io = 3-A condition. As the output current is higher than the current limit point, the boost converter enters into the current limit mode after start-up. The output voltage after start-up is 6.2 V.

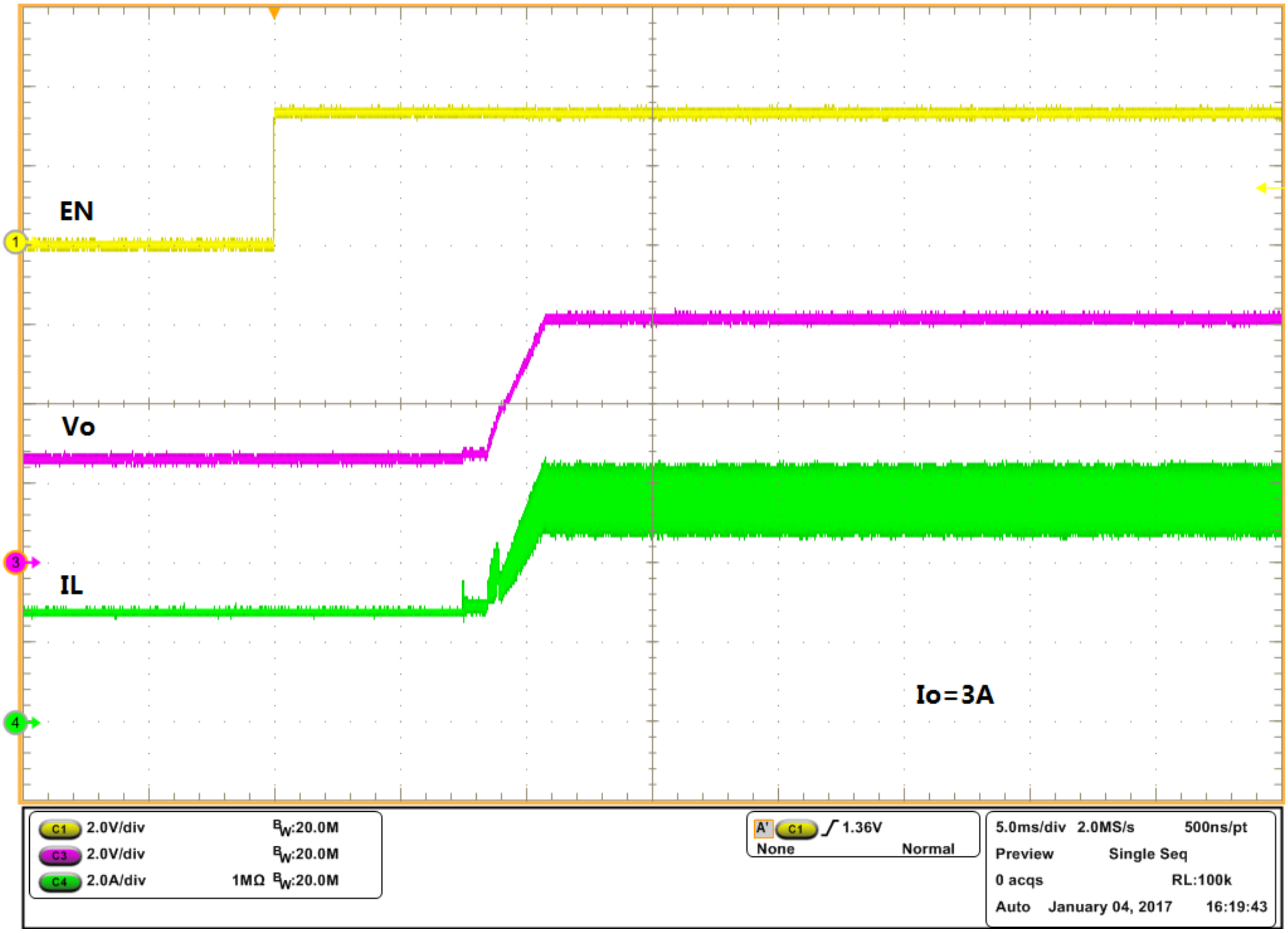

Figure 4. Start-up Waveforms at I_O = 3 A (V_O = 9 V)

3.2 Output Current Limit Waveforms

Figure 5 shows the output current limit waveforms at Vo = 9-V condition. From the waveforms of the output voltage, output current, and the inductor current, the designer can observe that the output voltage drops from 9 V to 6.2 V within 50 µs when the output current suddenly increases from 2 A to 3 A.

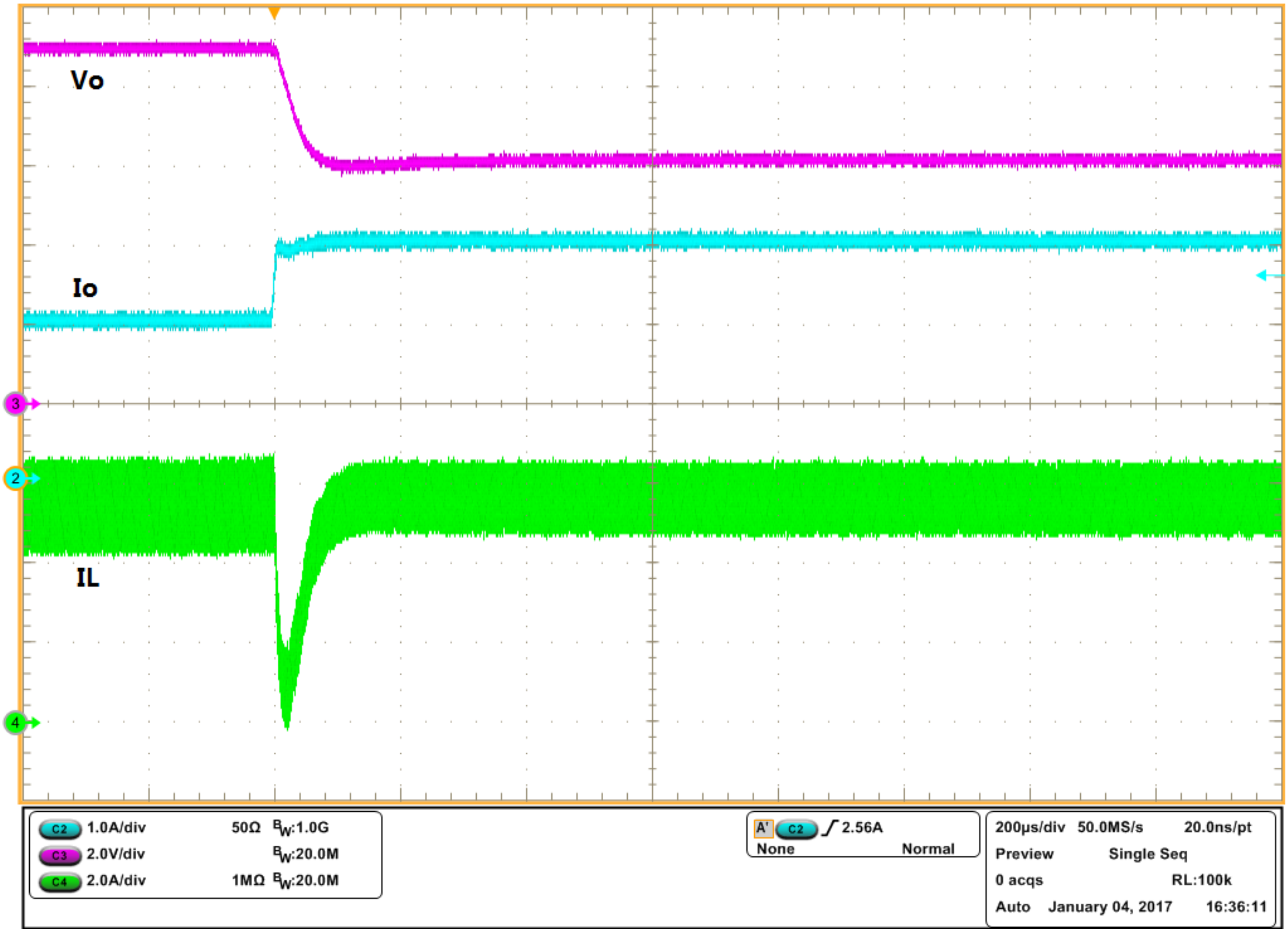

Figure 5. Output Current Limit Waveforms at V_O = 9 V (Io = 2 A to 3 A)

4 Design Files

4.1 Schematics

To download the schematics, see the design files at PMP9806.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at PMP9806.

4.3 Altium Project

To download the Altium project files, see the design files at PMP9806.

4.4 Gerber Files

To download the Gerber files, see the design files at PMP9806.

4.5 Assembly Drawings

To download the assembly drawings, see the design files at PMP9806.

5 Related Documentation

1. Texas Instruments, *TPS61088 10-A Fully-Integrated Synchronous Boost Converter*, TPS61088 Datasheet (SLVSCM8)

5.1 Trademarks

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6 About the Author

HELEN CHEN is an application engineer on the Texas Instruments BMC-BCS team. She brings more than 12 years of experience in power supply product design. Helen started her career as an AC-DC server power design engineer in Delta Power Electronics before joining TI in 2014. Helen specializes in various circuit topologies such as buck, boost, RCC, buck-boost, full-bridge, half-bridge, fly-back, CCM PFC, and DCMB PFC. She also has experience in the magnetic components design, PCB layout, and EMI solutions.

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