TI Designs：TIDA-01423
3V 至 4.5V 输入电压、400mA、–12V 反向降压/升压参考设计

说明

TIDA-01423 TI 设计演示了反相降压-升压转换器（电压反相器），用于在 3V 至 4.5V 的输入电压下生成 –12V 的电压轨（电流为 400mA）。许多通信设备系统和工业设备（如测试和测量）需要此类负电压。使用 TPS62136 降压转换器可以实现非常简单的负电压反相器（反相降压/升压）设计，以便在 400mA 的电流下生成 12V 的负输出电压。

资源

TIDA-01423	设计文件夹
TPS62136	产品文件夹

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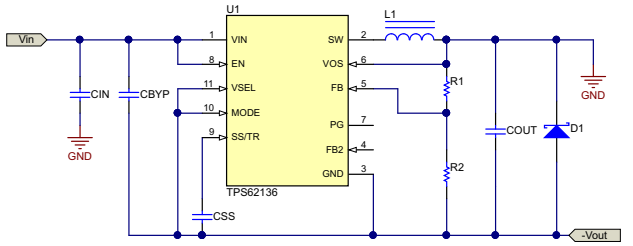
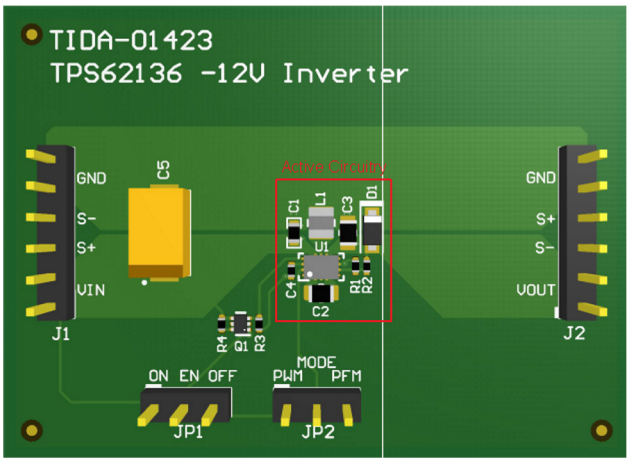
特性

- 高输出负电压，为 -12V
- 总体解决方案尺寸小于 65mm^2
- 高输出电流，为 400mA
- 低输出电压波纹 (<0.5%)
- 输入电压范围为 3V 至 4.5V

应用

- 电信基础设施
- 无线基础设施
- 光学模块
- 光纤网络：EPON
- 远程射频单元 (RRU)





该 TI 参考设计末尾的重要声明表述了授权使用、知识产权问题和其他重要的免责声明和信息。

1 System Description

A negative voltage in the range of -5 V to -12 V is frequently required in high-performance communications equipment systems, such as optical modules and remote radio units.

In an optical module, the negative voltage is required to supply modulators like the electroabsorption modulator (EAM) or Mach-Zehnder modulator (MZM). The high efficiency (low temperature rise) and small size is very important in such systems.

Such high negative voltages are also required for the new Gallium Nitride (GaN) technology (field-effect transistor (FET) and RF power amplifier) used in antenna systems and remote radio units.

The wide-output voltage range supports many of the different voltages required in such systems, which enables the same design to be reused for different systems that have different negative voltage rails.

1.1 Key System Specifications

表 **1. Key System Specifications**

PARAMETERS	SPECIFICATIONS	DETAILS
Input voltage range (V_{IN})	3 V to 4.5 V	—
Output voltage (V_{OUT})	–12 V	—
Output current	0.4 A	图 4

2 System Overview

2.1 Highlighted Products

2.1.1 TPS62136

The TPS62136 is a 4-A, step-down converter in a 2×3-mm QFN package based on a distributed control system (DCS). The device accepts up to a 17-V input voltage and supports up to 12 V on its output. This wide-input voltage range is ideally suited for an inverting converter, which, at a minimum, requires a voltage rating of the input voltage plus the output voltage.

2.2 Design Considerations

2.2.1 Inverting Buck-Boost Topology Concept

The inverting buck-boost topology is very similar to the buck topology. In the buck configuration that 图 1 shows: the positive connection (V_{OUT}) is connected to the inductor and the return connection is connected to the ground (GND) pin of the integrated circuit (IC). However, in the inverting buck-boost configuration that 图 2 shows, the IC ground is used as the negative output voltage pin (labeled as $-V_{OUT}$). The former positive output in the buck configuration is used as the ground. This inverting topology allows the output voltage to be inverted and always lower than the ground.

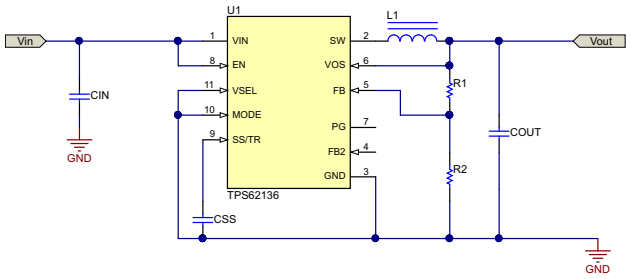


图 1. TPS62136 Buck Topology

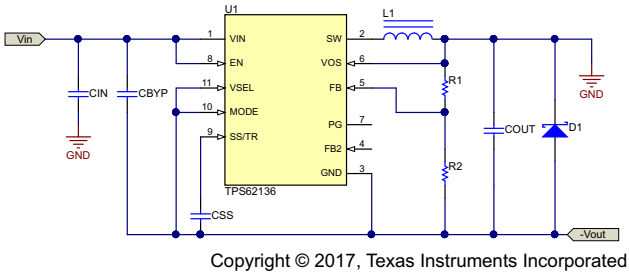


图 2. TPS62136 Inverting Buck-Boost Topology

The circuit operation is different in the inverting buck-boost topology than in the buck topology. 图 3 **(a)** shows that the output voltage terminals are reversed, though the components are wired the same as a buck converter. As 图 3 **(b)** shows, during the ON-time of the control MOSFET, the inductor is charged with current while the output capacitor supplies the load current. The inductor does not provide current to the load during this time. During the OFF-time of the control MOSFET and the ON-time of the synchronous MOSFET shown in 图 3 **(c)**, the inductor provides current to the load and the output capacitor. These changes affect many parameters, which the following subsections describe in further detail.

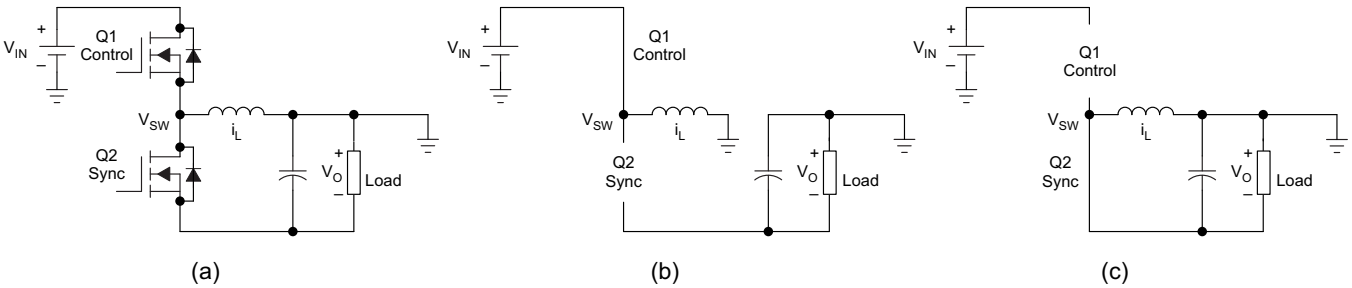


图 3. Inverting Buck-Boost Configuration

The average inductor current is affected in this topology. In the buck configuration, the average inductor current is equal to the average output current because the inductor always supplies current to the load during both the ON- and OFF-times of the control MOSFET. However, in the inverting buck-boost configuration, only the output capacitor supplies the load with current, while the load is completely disconnected from the inductor during the ON-time of the control MOSFET. During the OFF-time, the inductor connects to both the output capacitor and the load (see 图 3). Because the OFF-time is 1 – D of the switching period, the average inductor current in 公式 1 is calculated as:

$$I_{L(Avg)} = \left| \frac{I_{OUT}}{(1 - D)} \right| \quad (1)$$

The duty cycle for the typical buck converter is simply V_{OUT} / V_{IN}, but the calculation of the ideal duty cycle in 公式 2 for an inverting buck-boost converter becomes:

$$D = \frac{V_{OUT}}{(V_{OUT} - V_{IN})} \quad (2)$$

公式 3 provides the peak-to-peak inductor ripple current:

$$\Delta I_L = \frac{V_{IN} D}{f_S L} \quad (3)$$

where,

- ΔI_L (A): Peak-to-peak inductor ripple current
- D: Duty cycle
- f_S (MHz): Switching frequency
- L (µH): Inductor value
- V_{IN} (V): Input voltage with respect to ground, not with respect to the device ground or V_{OUT}.

公式 4 calculates the maximum inductor current:

$$I_L = I_{L(avg)} + \frac{\Delta I_L}{2} \quad (4)$$

2.2.2 V_{IN} and V_{OUT} Range

The input voltage that can be applied to an integrated circuit (IC) operating in the inverting buck-boost topology is less than the input voltage for the same IC operating in the buck topology. The reason for this difference is because the ground pin of the IC is connected to the (negative) output voltage. Therefore, the input voltage across the device is V_{IN} to V_{OUT}, not V_{IN} to ground. Thus, the input voltage range of the TPS62136 is 3 V to 17 V + V_{OUT}, where V_{OUT} is a negative value.

The output voltage range is the same as when configured as a buck converter, but negative. The output voltage for the inverting buck-boost topology must be set between –0.8 V and –12 V. The output voltage is set in the same way as the buck configuration, with two resistors connected to the FB pin. The TIDA-01423 design sets the output voltage at –12 V, which gives an input voltage range of 3 V to 5 V. However, TI does not recommend to use a 5-V input voltage because voltage tolerances on the input supply can violate the recommended operating range of TPS62136.

2.2.3 Capacitor Selection

An input capacitor, C_{IN}, is required to provide a low-impedance input voltage source to the inverter. A low equivalent series resistance (ESR) X5R or X7R ceramic capacitor is best for input voltage filtering and minimizing interference with other circuits. For most applications, a 10-µF ceramic capacitor is recommended from V_{IN} to ground (system ground, not $–V_{OUT}$). The C_{IN} capacitor value can be increased without any limit for better input voltage filtering.

On the output, the TIDA-01423 design uses a 22-µF output capacitor, which has an effective capacitance of about 10 µF at the –12-V output voltage. For maximum output current, a second output capacitor can help to increase the phase margin.

For the inverting buck-boost configuration of the TPS62136, installing a bypass capacitor, CBYP, to provide a low impedance source for the internal gate drivers is important. This capacitor is connected from V_{IN} to $–V_{OUT}$; therefore, it requires the highest voltage rating. For most applications, a 22-µF ceramic capacitor is recommended. The bypass capacitor provides an AC path from V_{IN} to $–V_{OUT}$. When V_{IN} is applied to the circuit, this dV/dt across a capacitor from V_{IN} to $–V_{OUT}$ creates a current that must return to ground (the return of the input supply) to complete its loop. This current may flow through the body diode of the internal low-side MOSFET and the inductor to return to ground. Flowing through the body diode pulls the VOUT pin below IC ground, which violates its absolute maximum rating. Such a condition may damage the TPS62136 device and is not recommended. For protective measure, a Schottky diode must be installed on the output, as the schematic in 图 2 shows.

To avoid excessive inrush current, a soft-start capacitor is installed on the SS/TR pin.

2.2.4 Maximum Output Current

In the inverting buck-boost topology, the maximum output current is reduced as compared to the buck topology. This reduction is a result of the peak inductor current being higher, as calculated in 公式 4.

For example, for an output voltage of –12 V, 1.5-µH inductor, and input voltage of 3.3 V, the following calculations produce the maximum allowable output current that can be ensured based on the TPS62136 minimum current limit value of 4.8 A. Due to increased duty cycles when operating at high load current, the duty cycle used for the following maximum output current calculation in 公式 5 must be increased by 5% for these conditions, which provides a more accurate maximum output current calculation.

$$D = \frac{V_{OUT}}{V_{OUT} - V_{IN}} \times 1.05 = \frac{-12}{-12 - 1.33} \times 1.05 = 0.82 \quad (5)$$

The switching frequency at maximum load is based on 图 9. Based on the inductor data sheet, the effective inductance value is approximately 1.1 µH at 3-A current (see 公式 6).

$$\Delta I_L = \frac{V_{IN} \times D}{f_S \times L} = \frac{3.3 \times 0.82}{0.55\,MHz \times 1.1\,\mu H} = 4.5\ A \quad (6)$$

Rearranging 公式 4 and setting $I_{L(max)}$ equal to the minimum value of I_{LIMF}, as specified in the data sheet, results in 公式 7:

$$I_{L(avg)} = I_{L(max)} - \frac{\Delta I_L}{2} = 4.8 - \frac{4.5}{2} = 2.5\ A \quad (7)$$

This result is then used in 公式 1 to calculate the maximum achievable output current in 公式 8:

$$I_{OUT} = I_{L(avg)} \times (1 - D) = 2.5\ A \times (1 - 0.82) = 450\ mA \quad (8)$$

图 4 shows the maximum output current for the TIDA-01423 design.

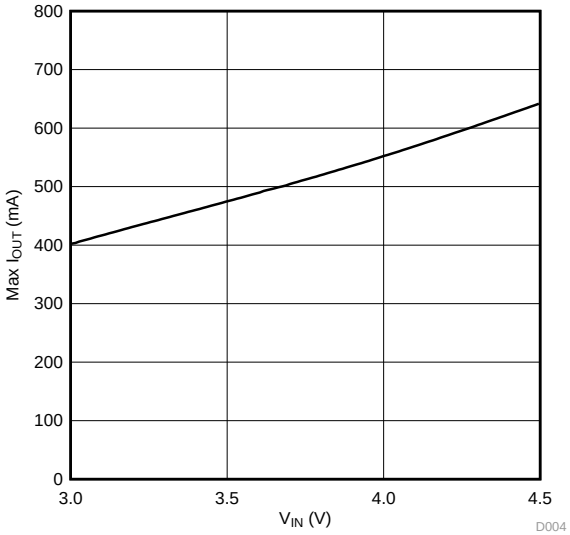


图 4. Maximum Output Current (V_{OUT} = –12 V)

2.2.5 Thermal Limits

With different conditions, thermal limits may become an issue as a result of the small size of the converter itself. As the output current increases, the absolute power loss (in mW) in the TPS62136 device also increases, which causes a higher temperature rise across the thermal impedance of the TPS62136 device.

The maximum allowed IC junction temperature is 125°C as stated in the TPS62136 data sheet. To calculate the IC temperature for different conditions, multiply the power loss of the TPS62136 device by the θ_{JA}, which is approximately 40°C/W for the TIDA-01423 printed-circuit board (PCB), and add this value to the ambient temperature.

To calculate the maximum output current at any ambient temperature, simply subtract the maximum ambient temperature from 125°C to obtain the allowable temperature rise. Divide the θ_{JA} of the PCB by this temperature rise to obtain the allowable IC power loss. Find this IC power loss for an input voltage of 3.3 V in 图 8 to determine the maximum output current under specific conditions. See 公式 9 for the calculation.

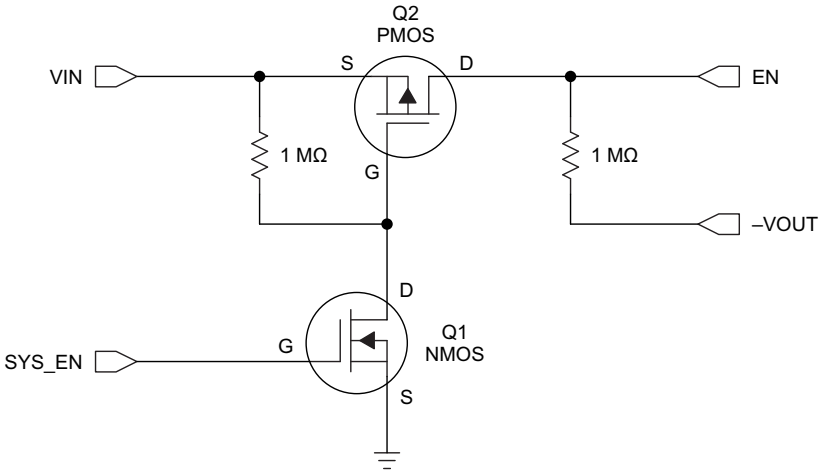
$$IC_{LOSS} \leq \frac{125 - T_{A\_MAX}}{\theta_{JA}} \quad (9)$$

2.2.6 Enable Pin Configuration

The device is enabled when the voltage at the EN pin trips its threshold and the input voltage is above the undervoltage lockout (UVLO) threshold. The TPS62136 device stops operation when the voltage on the EN pin falls below its threshold or the input voltage falls below the UVLO threshold.

Because V_{OUT} is the IC ground in this configuration, the EN pin must be referenced to V_{OUT} instead of ground. In the buck configuration, 0.83 V is considered as high and less than 0.67 V is considered as low. However, in the inverting buck-boost configuration, the V_{OUT} voltage is the reference; therefore, the high threshold is 0.83 V + V_{OUT} and the low threshold is 0.67 V + V_{OUT}. For example, if V_{OUT} = –12 V, then V_{EN} is considered at a high level for voltages above –11.17 V and a low level for voltages below –11.24 V.

This behavior can cause difficulties when enabling or disabling the part because, in some applications, the IC that provides the EN signal may not be able to produce negative voltages. The level-shifter circuit that 图 5 shows alleviates any difficulties associated with the offset EN threshold voltages by eliminating the requirement for negative EN signals. If disabling the TPS62136 is not desired, the EN pin may be directly connected to V_{IN} without this circuit.



NOTE: VOUT is the negative output voltage of the inverting buck-boost converter.

图 5. EN Pin Level Shifter

The positive signal that originally drives EN is instead tied to the gate of Q1 (SYS_EN). When Q1 is OFF (SYS_EN grounded), Q2 has 0 V across its V_{GS} and also remains OFF. In this state, the EN pin is at –12 V, which is below the low-level threshold, and disables the device.

When SYS_EN provides enough positive voltage to turn Q1 ON (V_{GS} threshold as specified in the MOSFET data sheet), the gate of Q2 is at ground potential through Q1. This action drives the V_{GS} of Q2 negative and turns Q2 ON. Then V_{IN} ties to EN through Q2 and the pin is above the high-level threshold, which turns the device ON. Be careful to ensure that the V_{GD} and V_{GS} of Q2 remain within the MOSFET ratings during both the enabled and disabled states. Failing to adhere to this constraint can result in damaged MOSFETs.

图 16 shows the enable sequence where the SYS_EN signal activates the enable circuit. This circuit has been tested with a 3.3-V SYS_EN signal and dual N/PFET Si1029X. The EN signal is the output of the circuit and goes from V_{IN} to V_{OUT} to properly enable and disable the device.

2.2.7 Mode Pin Configuration

The operation mode can be selected with the mode pin of the TPS62136. The device runs in automatic PFM or PWM mode when this pin is pulled low (IC ground which is –V_{OUT}), which results in a higher efficiency at a light load. When the pin is pulled high (V_{IN}), the device runs in forced PWM mode (for a constant frequency at a light load).

2.2.8 Power Good Pin Configuration

The TPS62136 has a built-in power good (PG) function to indicate whether the output voltage has reached its appropriate level or not. The PG pin is an open-drain output that requires a pullup resistor. Because V_{OUT} is the IC ground in this configuration, the PG pin is referenced to V_{OUT} instead of ground, which means that the TPS62136 device pulls PG to V_{OUT} when it is low.

This behavior can cause difficulties in reading the state of the PG pin because, in some applications, the IC that detects the voltage level of the PG pin may not be able to withstand negative voltages. The level-shifter circuit shown in 图 6 alleviates any difficulties associated with the offset PG pin voltages by eliminating the negative output signals of the PG pin. If the PG pin functionality is not required, it may be left floating or connected to V_{OUT} without this circuit.

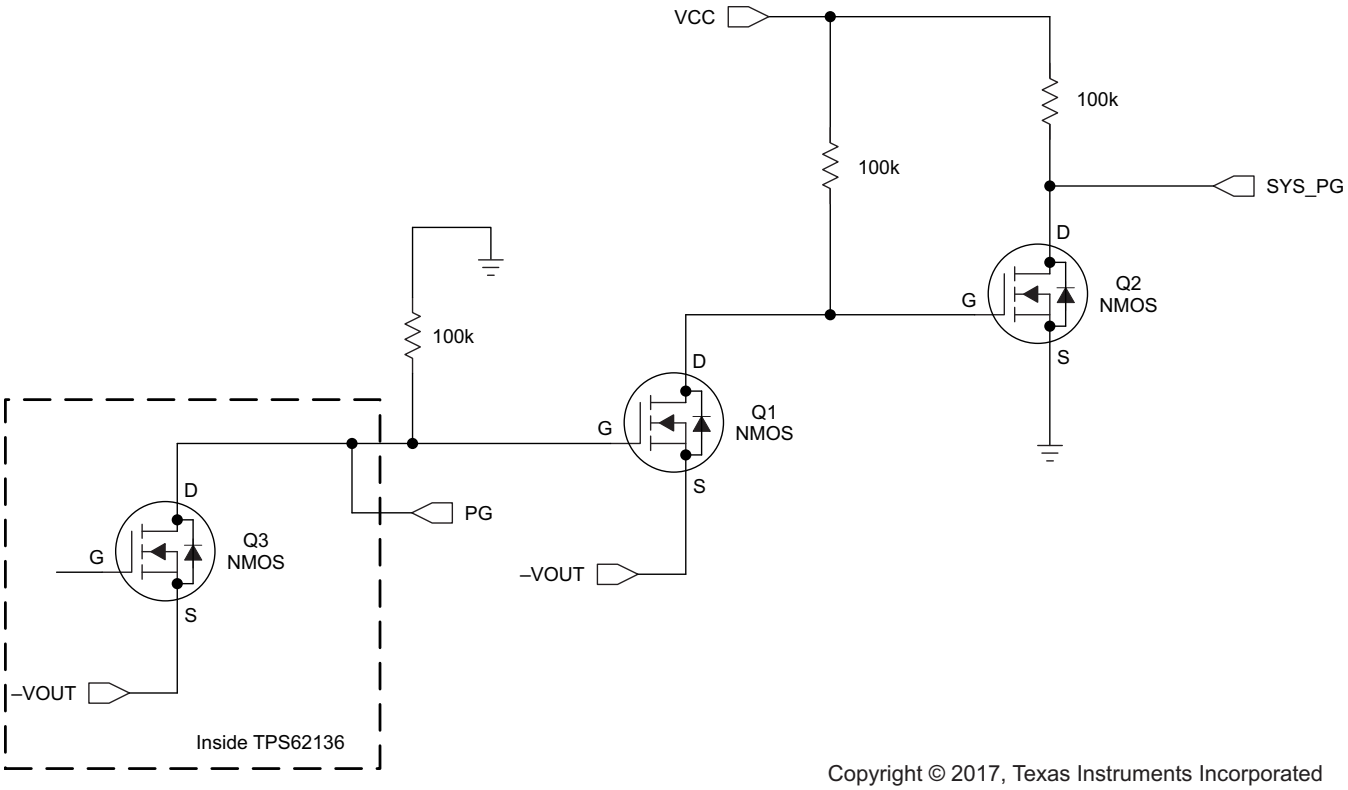


图 **6. PG Pin Level Shifter**

Inside the TPS62136, the PG pin is connected to an N-channel MOSFET (Q3). By tying the PG pin to the gate of Q1, when the PG pin is pulled low, Q1 is OFF and Q2 is ON because the V_{GS} of Q2 is at V_{CC}. SYS_PG is then pulled to ground.

When Q3 turns OFF, the gate of Q1 is pulled to ground potential, which turns Q1 ON. This sequence of events pulls the gate of Q2 below ground, which turns it OFF. SYS_PG is then pulled up to the V_{CC} voltage. Note that the V_{CC} voltage must be at an appropriate logic level for the circuitry connected to the SYS_PG net.

3 Getting Started Hardware

To test this TI Design, simply apply an input voltage on the J1 connector and the load to J2 connector. Then, connect a jumper between ON and EN on JP1. Set JP2 to the desired operating mode, PFM (for higher efficiency at light load) or PWM (for constant frequency at light load).

4 Testing and Results

All data in this section has been recorded using a 3.3-V V_{IN}, –12-V V_{OUT} unless otherwise noted.

4.1 Test Results

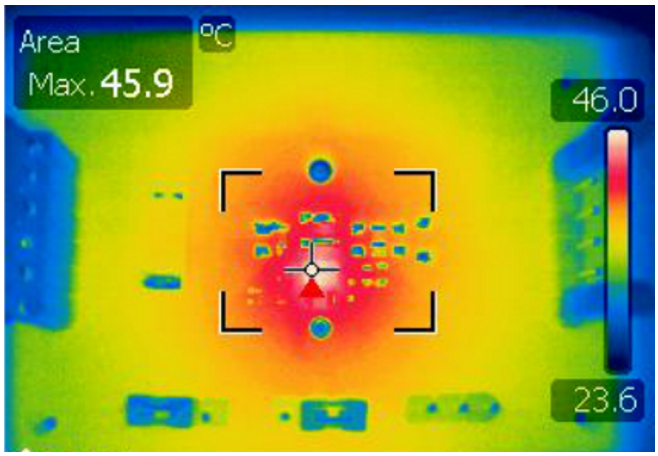


图 **7. Thermal Performance (250-mA Load)**

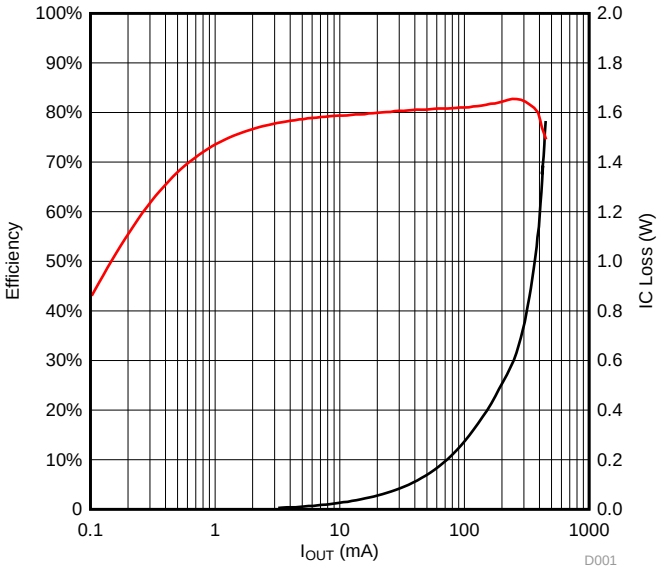


图 **8. Efficiency Over Load (Mode = PFM)**

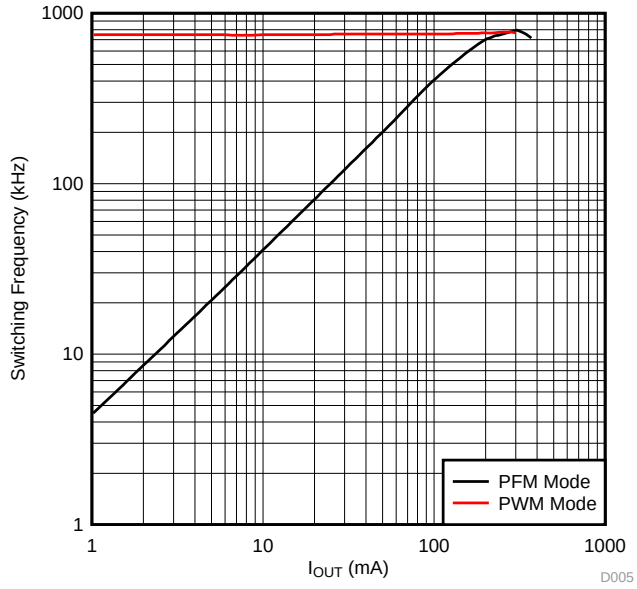


图 **9. Switching Frequency Over Load**

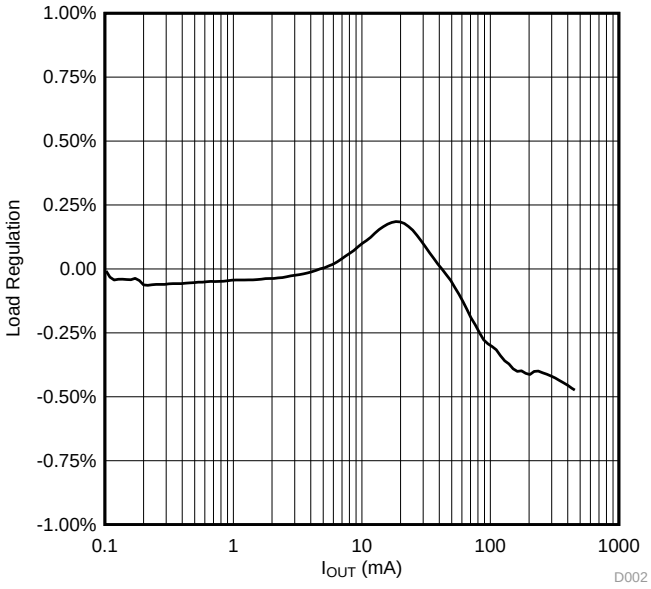


图 **10. Load Regulation (Mode = PFM)**

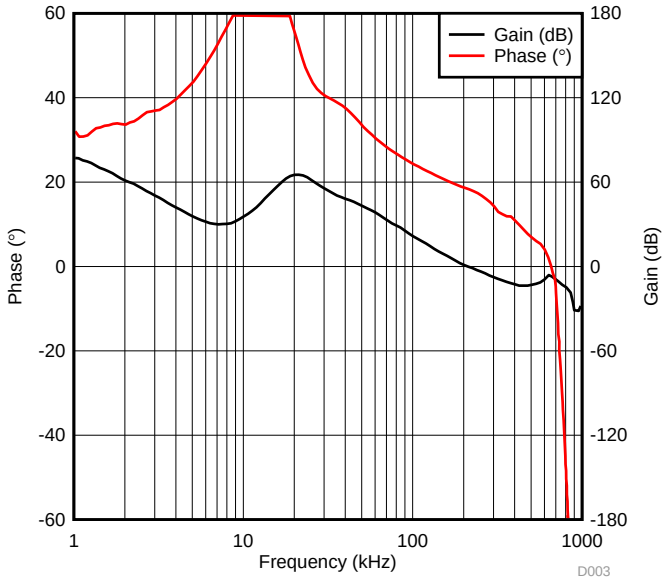


图 11. Loop Gain (300 mA)

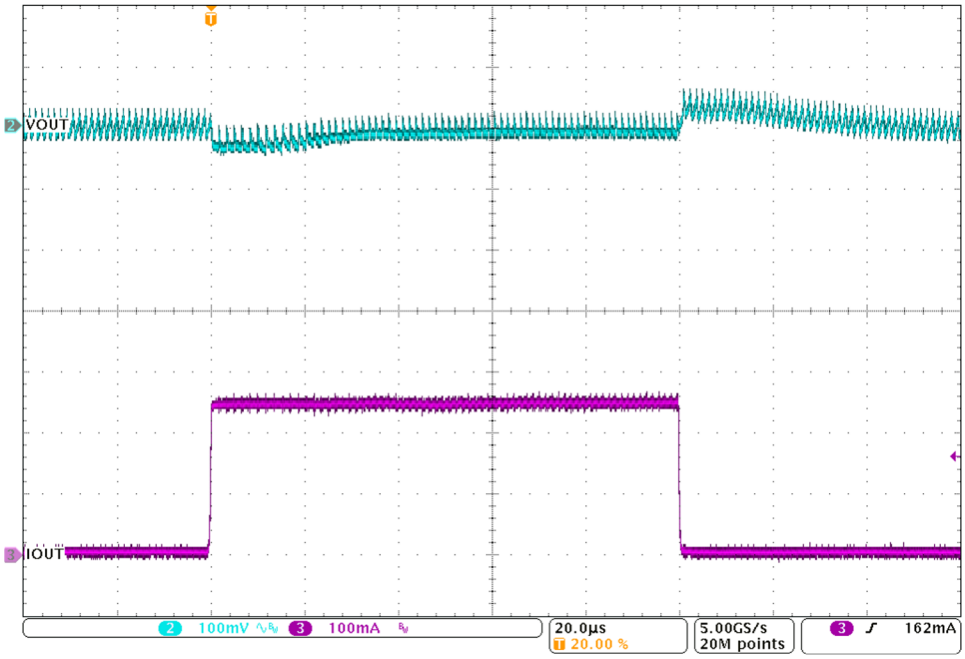


图 12. Transient Response (0-A to 250-mA Load Step, Mode = PWM)

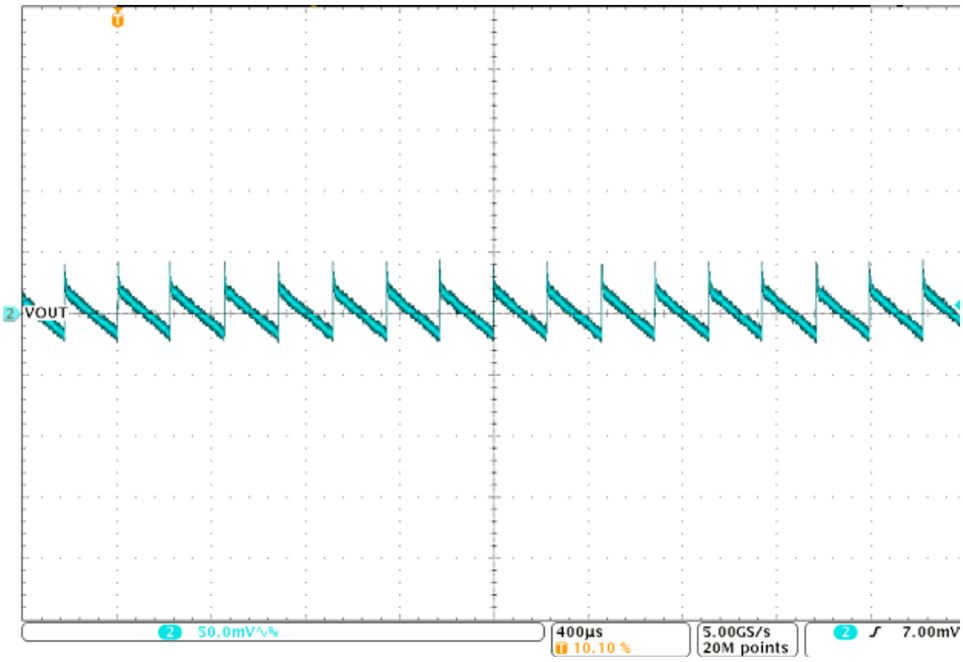


图 13. Output Voltage Ripple (1-mA Load, Mode = PFM)

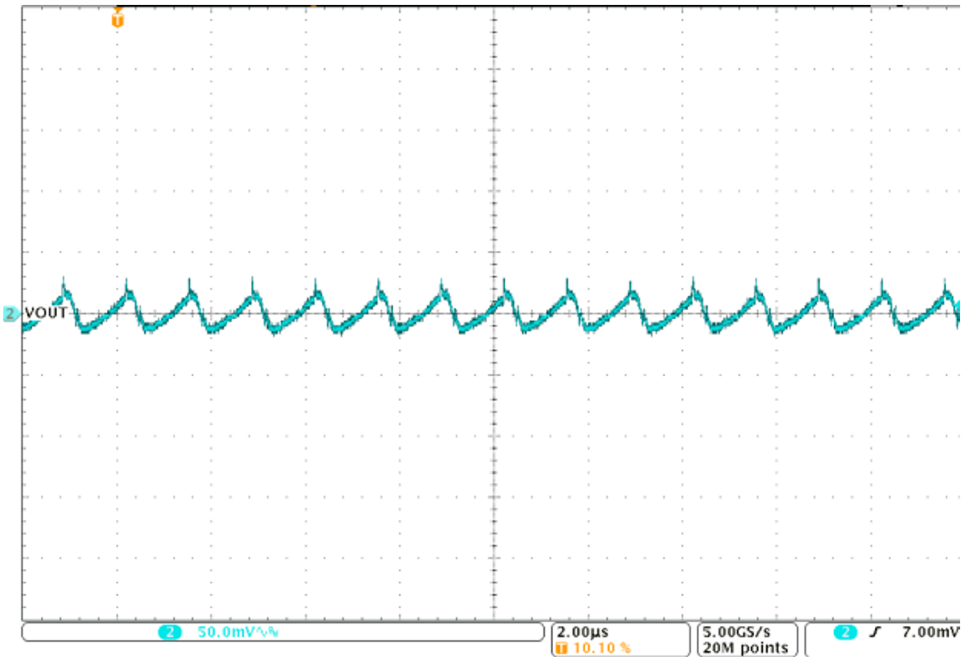


图 14. Output Voltage Ripple (1-mA Load, Mode = PWM)

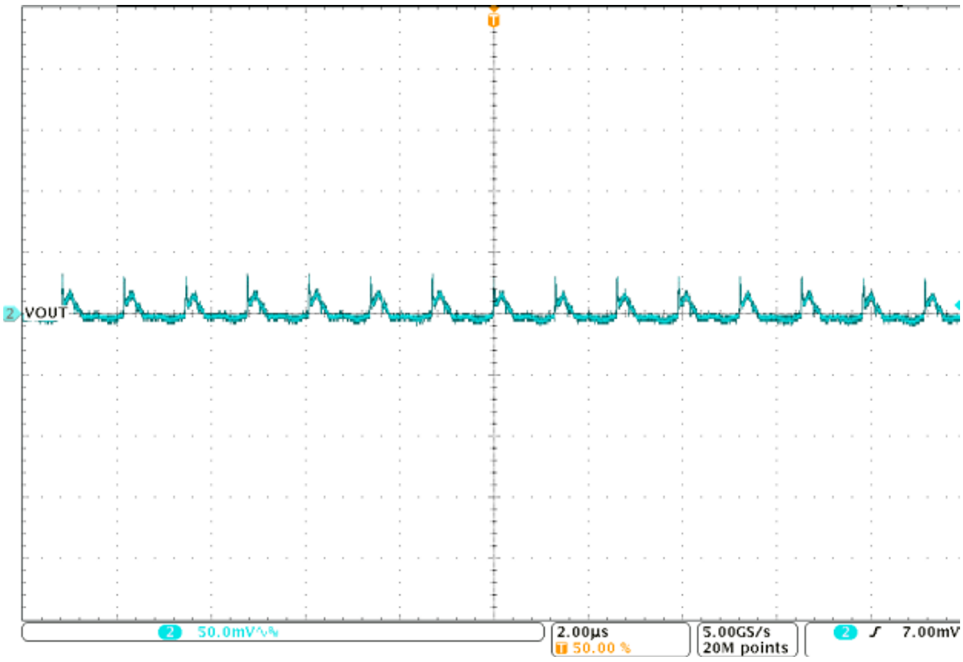


图 **15. Output Voltage Ripple (250-mA Load)**

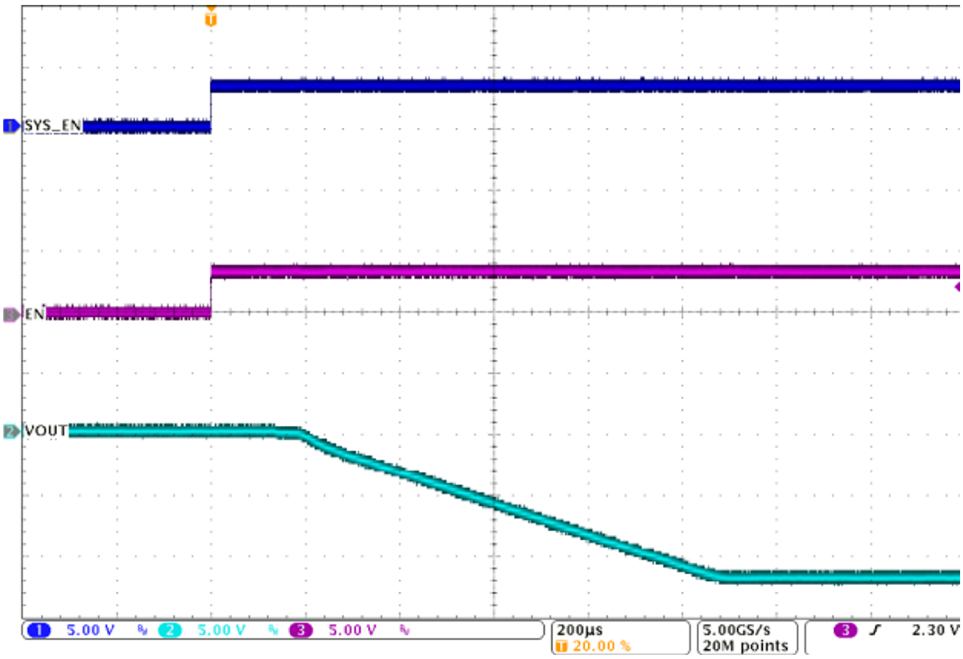


图 **16. Start-Up on EN (No Load)**

5 Design Files

5.1 Schematics

To download the schematics, see the design files at TIDA-01423.

5.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01423.

5.3 PCB Layout Recommendations

5.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01423.

5.4 Gerber Files

To download the Gerber files, see the design files at TIDA-01423.

5.5 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01423.

6 Related Documentation

1. Texas Instruments, *Simplifying Stability Checks*, Application Report (SLVA381)
2. Texas Instruments, *Using the TPS62125 in an Inverting Buck-Boost Topology*, TPS62125 Application Report (SLVA514)
3. Texas Instruments, *TPS62136 1-MHz High Accuracy 3-V to 17-V 4-A Step-Down Converter*, TPS62136 Data Sheet (SLVSDV2)

6.1 商标

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