Application Report
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Low Dropout Operation in a Buck Converter

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ABSTRACT

Certain applications require the DC/DC to maintain output voltage regulation when the input voltage is only slightly higher than the target output voltage. They still require it to be regulated although the input voltage is lower than the target output voltage in some extreme cases. For a buck converter, these low dropout operation conditions require high duty cycle operation that may approach 100%. A similar description can be found like the following sentence in some buck converters datasheet: “To improve drop out, the device is designed to operate at 100% duty cycle as long as the BOOT-to-PH pin voltage is greater than 2.1 V (typical)". However, when operating near 100% duty cycle with light loads, the Bootstrap capacitor can be discharged below the BOOT UVLO threshold, causing high ripple voltage on the output side. This application report discusses the cause and various operating modes associated with the low dropout operation. The TPS54231 is an example to introduce this operation behavior and providing work-around to maintain the Bootstrap capacitor voltage.

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Trademarks

Eco-mode is a trademark of others.

1 Introduction

An N-channel MOSFET is widely used in a buck converter as the high-side (HS) switch. To drive this HS MOSFET properly, a bootstrap circuit is designed to generate a floating power supply between gate node and source node of the MOSFET and an external small ceramic capacitor between the BOOT and PH pins is required. This bootstrap capacitor is refreshed when the HS MOSFET is off and the catch diode or low-side (LS) MOSFET conducts. An undervoltage lock-out (UVLO) circuit is also required for the gate drive supply to keep the converter from attempting to switch when the gate drive may be too low.

Certain applications require the DC/DC to maintain output voltage regulation when the input voltage is only slightly higher than the target output voltage. They still require it to be regulated although the input voltage is lower than the target output voltage in some extreme cases. For a buck converter, these low dropout operation conditions require high duty cycle operation that may approach 100%. However, when operating near 100% duty cycle with light loads, the Bootstrap capacitor can be discharged below the BOOT UVLO threshold, causing high ripple voltage on the output side.

This application report discusses the cause and various operating modes associated with the low dropout operation. This report uses the TPS54231 as an example to introduce this operation behavior and providing work-around to maintain the Bootstrap capacitor voltage. The end of this report introduces some synchronous parts with the low dropout operation has been improved.

2 TPS54231 Low Dropout Operation

The input voltage range for the TPS54231 is 3.5 V to 28 V, and the rated output current is 2 A. The TPS54231 is non-synchronous and its low-side switching element is an external catch diode. The TPS54231 can operate in both continuous conduction mode (CCM) and discontinuous conduction mode (DCM) depending on the output current.

Figure 1 shows the TPS54231 circuit used for testing. Some modifications are needed to investigate low dropout.

1. Remove R1 and R2 to float EN pin. Internal input voltage UVLO is used to allow operation at low input voltages without the device shutting off.
2. Change R6 to 53.6 kΩ when testing the 5 V output.

Use the TPS54231EVM-372 for evaluation which is an official EVM board for the TPS54231 device with 3.3 V output. Similar modifications are needed if using the official EVM board.

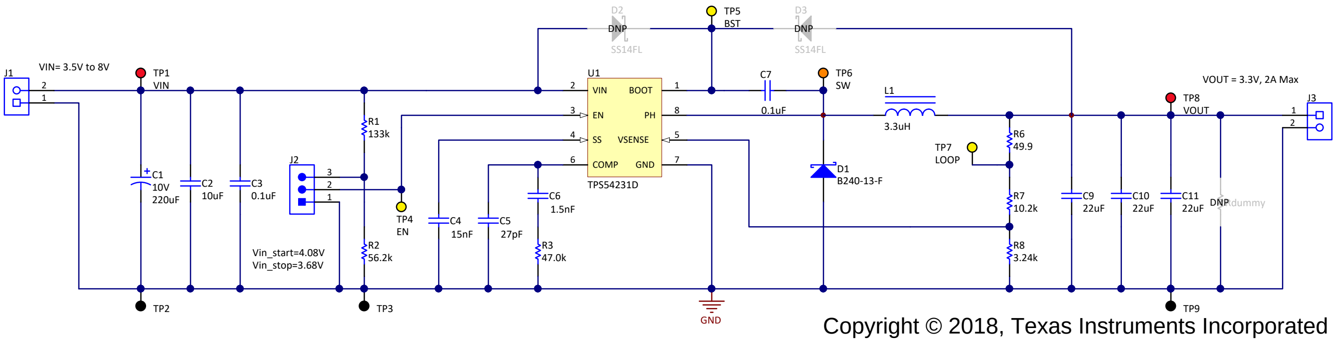

Figure 1. TPS54231 Test Circuit

2.1 Low Dropout Operation in CCM

In the CCM operation, when the HS MOSFET is turned off, the inductor current continues to flow in the catch diode, and the diode clamps the PH node voltage at one diode drop below ground. The BOOT to PH voltage is (V_{IN} + 0.7) V, allowing the Bootstrap capacitor to be fully charged. Therefore, low dropout operation can be obtained in CCM. Figure 2 illustrates the TPS54231 output waveforms at an input voltage of 4.25 V and an output current of 2 A. As the input voltage is 6 V, the Bootstrap capacitor voltage can remain higher than 2.1 V. The TPS54231 works in normal CCM with a nominal switching frequency of 580 kHz.

To improve dropout, the TPS54231 device is designed to operate at 100% duty cycle as long as the BOOT-to-PH pin voltage is greater than 2.1 V. For a buck converter, the duty cycle D = V_{OUT} / V_{IN}. Note that the effective duty cycle during dropout of the regulator is mainly influenced by the voltage drops across the power MOSFET, inductor resistance, catch diode, and printed circuit board resistance. With the decreasing of VIN, the duty cycle is increased to maintain the output voltage. When the duty cycle approaches 100%, the on-time of the HS MOSFET can be extended with the effective switching frequency decreased. Figure 3 illustrates the TPS54231 output waveforms at an input voltage of 3.87 V and an output current of 2 A. The switching frequency has been reduced to approximately 34 kHz from the nominal of 580 kHz.

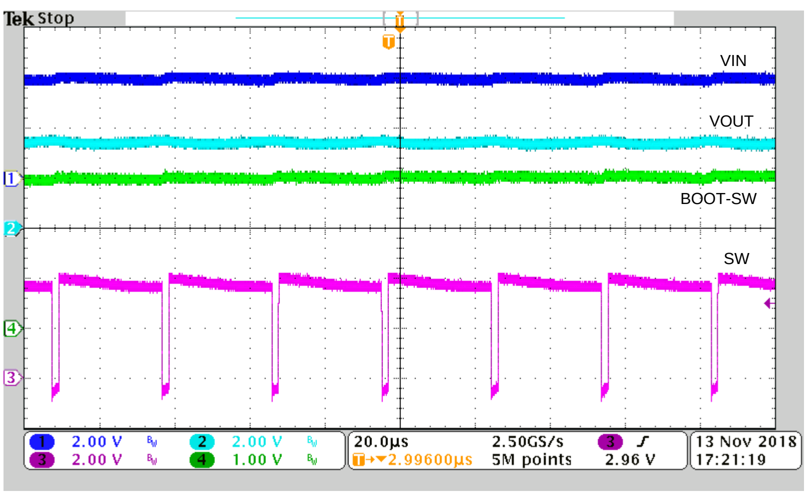

Figure 2. TPS54231 Waveforms at V_{IN} = 4.25 V, I_{OUT} = 2 A

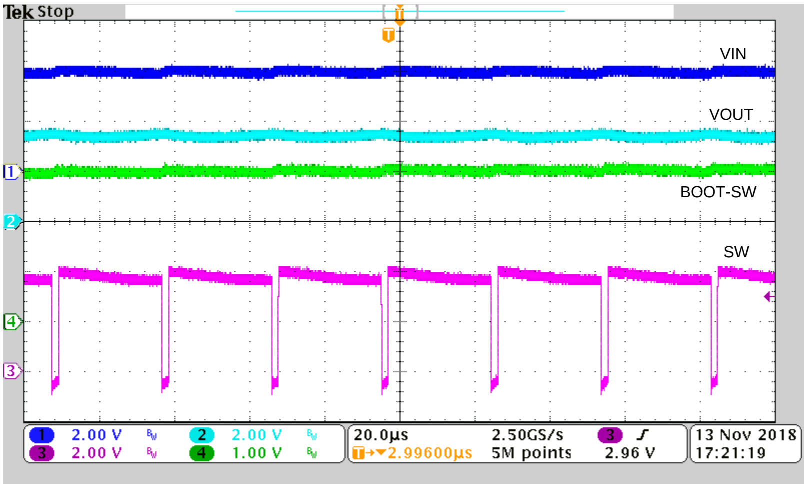

Figure 3. TPS54231 Waveforms at V_{IN} = 3.87 V, I_{OUT} = 2 A

2.2 Low Dropout Operation in DCM

Decreasing the output current makes the device work in DCM. Figure 4 and Figure 5 show the waveforms of the PH node with a different output current. There are three states during each duty cycle. During ON state, HS MOSFET is on, the catch diode D1 is off, and the PH node voltage equals to VIN. During the OFF state, HS MOSFET is off, D1 is on, and the PH node voltage is clamped one diode drop below ground. During IDLE state, both HS MOSFET and D1 is off, the PH voltage waveform oscillates because the output inductor, the junction capacitance of the catch diode and HS MOSFET constitute a resonant LC network. The Bootstrap capacitor can be charged during OFF state and IDLE state. Thus, low dropout operation can be obtained in DCM.

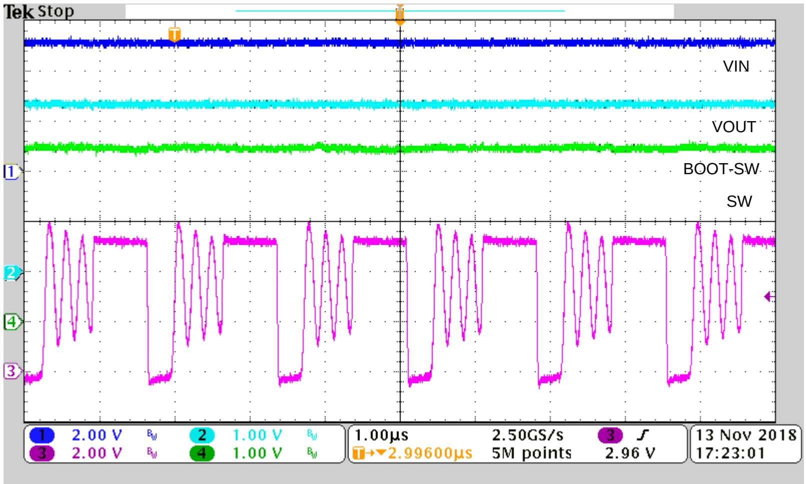

Figure 4. TPS54231 Waveforms at V_{IN} = 5 V, I_{OUT} = 0.1 A

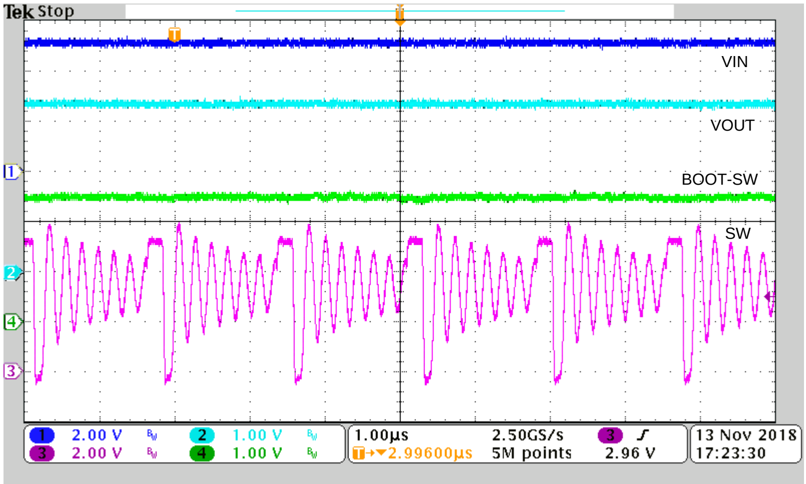

Figure 5. TPS54231 Waveforms at V_{IN} = 5 V, I_{OUT}= 10 mA

2.3 Low Dropout Operation in No-Load

In the no-load condition, there is no current flowing in the output inductor, so the OFF state is gone. The PH node voltage is very close to VOUT, and the BOOT to PH voltage is (VIN-VOUT). When running in low dropout operation, the (VIN-VOUT) can be significantly less than the BOOT UVLO voltage. If the (VIN-VOUT) is less than 2.1 V (the BOOT UVLO threshold), the device stops switching and the output voltage decays. As the output voltage decaying, the Bootstrap capacitor is charged until the output voltage decays to (VIN-2.1) and the HS MOSFET turns on again. Figure 6 shows a high ripple voltage was presented on the output.

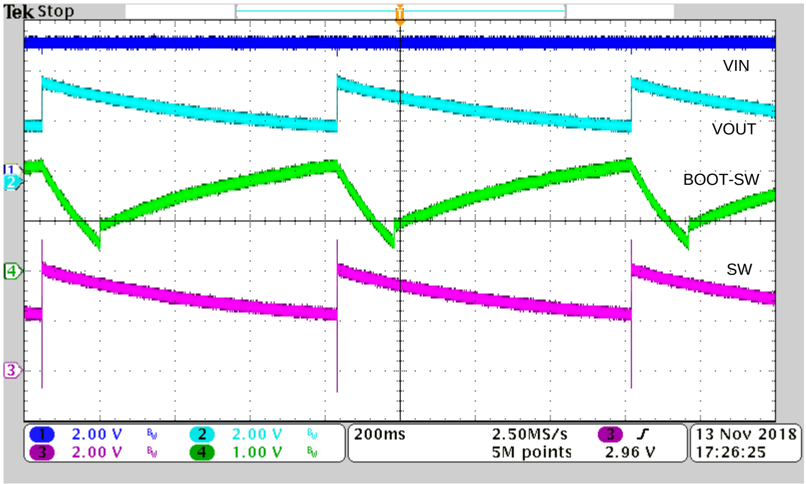

Figure 6. TPS54231 Waveforms at V_{IN}=5 V, I_{OUT}=0 A

When decreasing the input voltage from nominal 8 V with no load, the output begins to exhibit this ripple at a certain input voltage. This voltage is defined as the entry voltage. If the input voltage is increased again, the converter returns back to expected operation. This voltage level is defined as the recovery voltage. There is hysteresis between the entry and recovery voltages.

3 Solutions for Non-synchronous Part

Based on the above description, two basic methods can be used to improve the low dropout operation. Solution (A) is adding a dummy load at the output to keep the OFF state and extend the duration time. Solution (B) is adding an external voltage at BOOT pin to raise the BOOT to PH voltage directly.

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