Application Note

Boost Behaviors During Shutdown (Disabled): Pass Through, Bypass or True Disconnection

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ABSTRACT

In conventional non-synchronous boost converters, the load is connected to the input voltage through the inductor and rectifier diode during shutdown. In some always-on systems in which the load needs to be powered by the input voltage when boost is disabled, some strategies like pass through and bypass are proposed to reduce voltage drop and power loss in the diode.

In some occasions, the load does not need to be powered by the boost converter and the system is sensitive to power loss during shutdown. True disconnection function is proposed to satisfy such a demand.

This application note introduces different control strategies and topologies to implement the features of pass through, bypass, and true load disconnection during shutdown.

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1 Overview

In conventional non-synchronous boost converters, the load (Vout) is connected to the input voltage through the rectifier diode when the device is shutdown (EN = low).

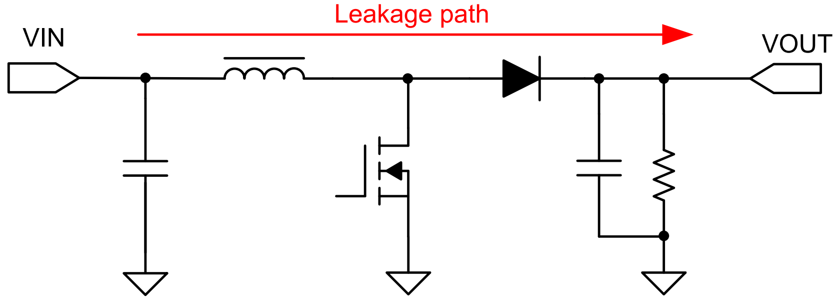

Figure 1-1. Conventional Non-synchronous Boost Converter

In some always-on systems, the output load must be connected to the input voltage when the boost converter is disabled. In Figure 1-1, the load is connected to the input voltage through the inductor and rectifier diode resulting in a large voltage drop and power loss. In synchronous boost converters, a HS-FET is used to replace the rectifier diode. To improve device performance, load connection strategies like pass-through and bypass are proposed for such demands.

When the load is not powered by the device during shutdown and the system is sensitive to shutdown power loss, the device needs to realize true shutdown. In this case, load disconnection function is important. The function also allows the output short protection and minimizes the inrush current at start-up.

This application note introduces typical boost behaviors of load connected or disconnected to the input voltage during shutdown.

2 Load Connected to Input Voltage

2.1 Body Diode Pass (TPS61288)

When high-side FET is an N-MOS, the MOSFET's body diode anode is connected to the inductor, as Figure 2-1 shows. When the device is shutdown, the input voltage connects the output load through the inductor and body diode, similar to non-synchronous boost during shutdown.

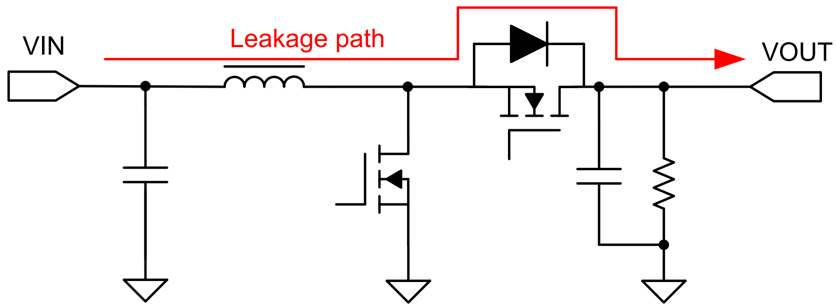

Figure 2-1. Body Diode Pass During Shutdown

The output voltage equals the input voltage minus the voltage drop across the DCR of the inductor and body diode forward conduction voltage. Output voltage follows input voltage.

$$V_{OUT} = V_{IN} - I_{OUT} \times DCR - V_D \quad (1)$$

In this situation, the output voltage is not zero even when boost is shutdown. Also, there is power loss and a voltage drop in the inductor and the body diode.

$$P_{loss} = I_{OUT}^2 \times DCR + I_{OUT} \times V_D \quad (2)$$

Meanwhile, the feedback resistor has leakage current since the output voltage is not zero which has an effect on the quiescent current. Take the TPS61288 as an example. Figure 2-2 shows the shutdown waveforms of TPS61288. The image shows that there is a distinct voltage drop between the output voltage and the input voltage. With a 50-Ω resistor load, there is still inductor current during shutdown.

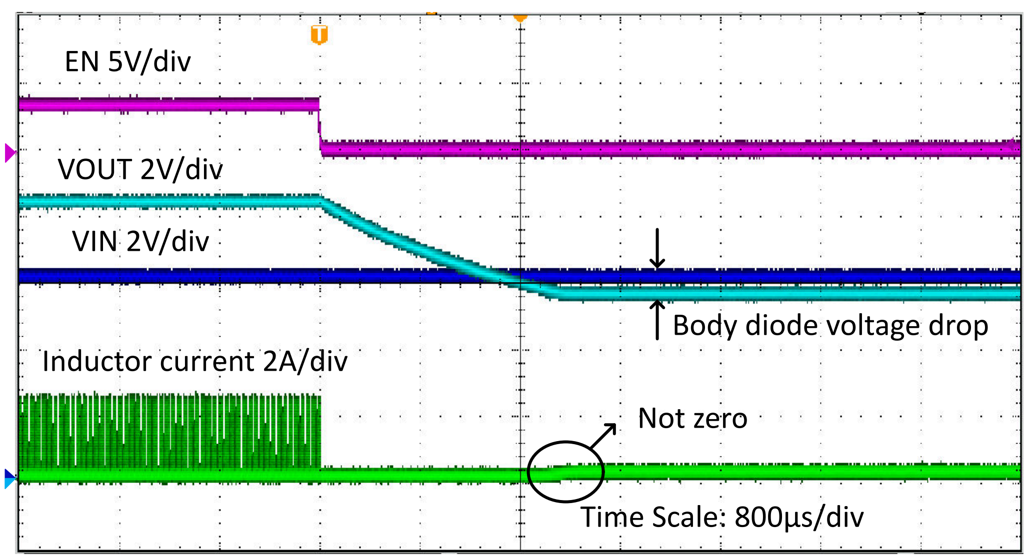

Figure 2-2. TPS61288 Shutdown Waveforms

2.2 Force Pass Through (TPS61253)

To reduce voltage drop and power loss in the diode, force pass through function (standby mode) is proposed. As Figure 2-3 shows, during shutdown, the high side P-MOS can still turn on by pulling the gate to ground.

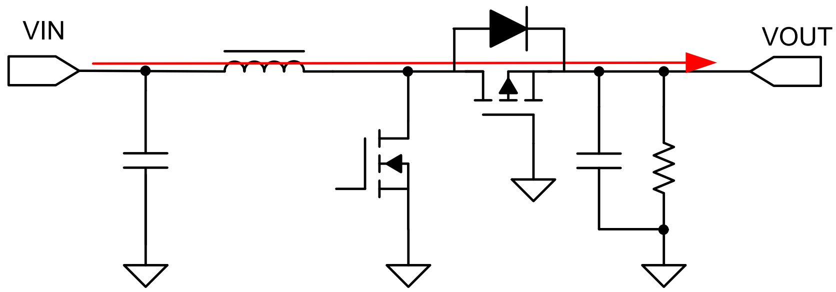

Figure 2-3. Force Pass Through During Shutdown

The output voltage equals the input voltage minus the voltage drop across the DCR of the inductor and the Rdson of the P-MOS. Output voltage follows input voltage.

$$V_{OUT} = V_{IN} - I_{OUT} \times \left(DCR + R_{ds(on)}\right) \tag{3}$$

$$P_{loss} = I_{OUT}^{2} \times \left(DCR + R_{ds(on)}\right) \tag{4}$$

The TPS61253 integrates force pass through mode. Figure 2-4 shows the shutdown waveforms of the TPS61253. Compared to body diode pass operation, there is less voltage drop and power loss in the P-MOS than the body diode. However, inductor power loss still exists because the inductor is in the connecting path. With a 50-Ω resistor load, there is inductor current during shutdown.

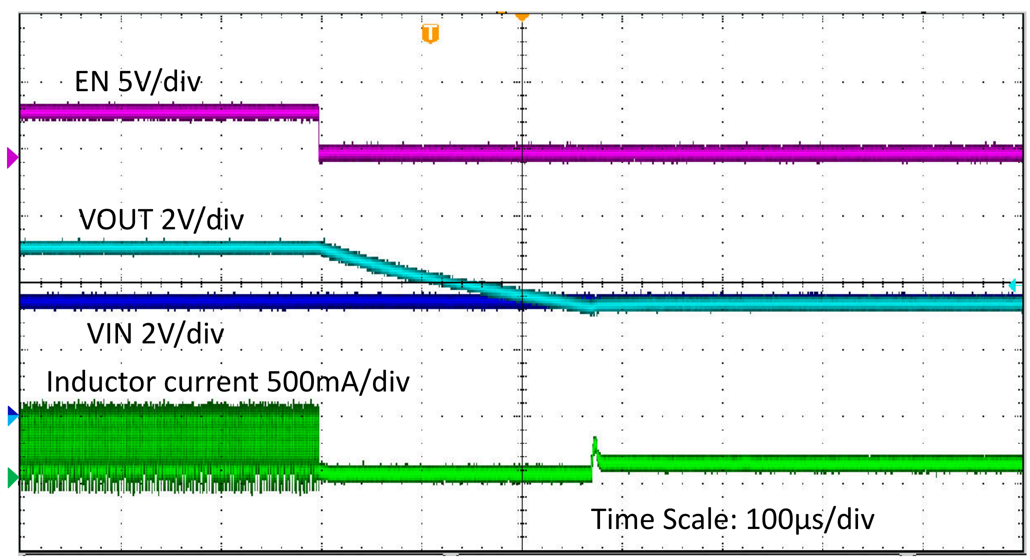

Figure 2-4. TPS61253 Shutdown Waveforms

2.3 Bypass (TPS61291)

In bypass mode, a separated P-MOS (bypass switch) between the Vin and Vout pins is integrated as Figure 2-5 shows. When the device is disabled (EN=LOW), bypass mode is activated to provide a direct, low impedance connection from the input voltage to output.

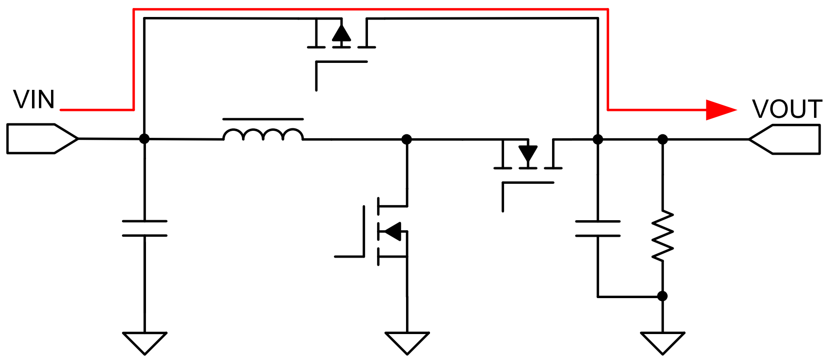

Figure 2-5. Bypass During Shutdown

Compared to body diode pass operation and force pass through operation, there is less voltage drop and power loss because the inductor is not in the connecting path. Higher efficiency is obtained when the device shuts down; therefore, the bypass mode is suitable for large current and power loss sensitive applications.

$$V_{OUT} = V_{IN} - I_{OUT} \times R_{ds(on)} \quad (5)$$

$$P_{loss} = I_{OUT}^2 \times R_{ds(on)} \quad (6)$$

The TPS61291 integrates bypass mode. Figure 2-6 is the shutdown waveform of TPS61291 (EN is low). The output voltage is discharged to Vin level and there is almost no voltage drop. During shutdown, there is no inductor current across the inductor and high side MOSFET.

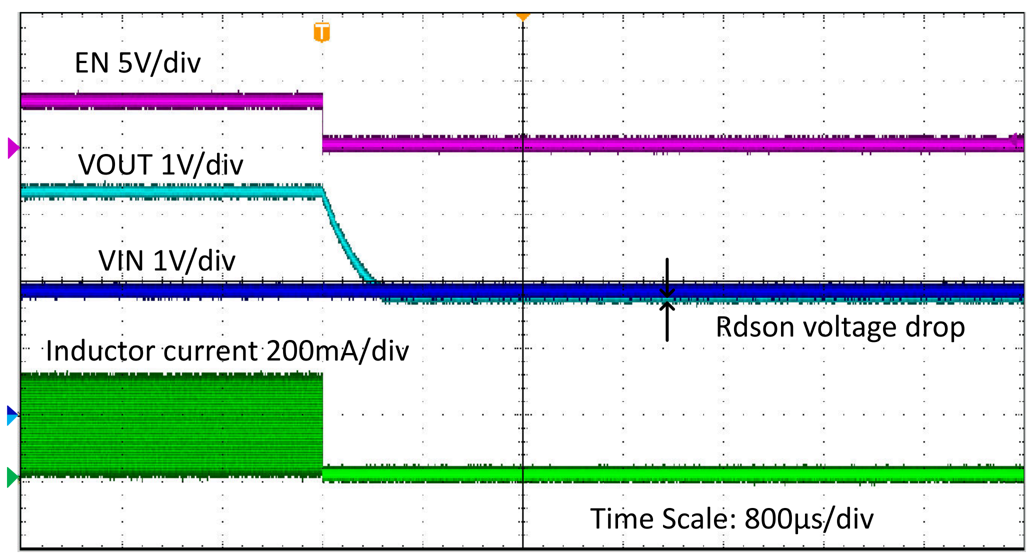

Figure 2-6. TPS61291 Shutdown Waveforms

2.4 Summary

Table 2-1 summarizes the main differences between three modes of output voltage behavior with the input when shutdown.

Table 2-1. Comparison Between Body Diode Pass, Force Pass Through, and Bypass

	Voltage Drop	Power Loss
Body diode pass	$I_{OUT} \times DCR + V_D$	$I_{OUT}^2 \times DCR + I_{OUT} \times V_D$
Force pass through	$I_{OUT} \times \left(DCR + R_{ds(on)}\right)$	$I_{OUT}^2 \times \left(DCR + R_{ds(on)}\right)$
Bypass	$I_{OUT} \times R_{ds(on)}$	$I_{OUT}^2 \times R_{ds(on)}$

Consider force pass through mode and bypass mode if the load device is powered by the boost input voltage when the boost converter is shutdown. Devices with force pass through mode realize the connection without integrating an extra MOSFET and have a lower cost than bypass mode in equivalent specifications. Bypass mode provides a higher-efficiency connection design and is the better choice in large load current cases.

3 Load Disconnected to Input Voltage

Load disconnection function is important when the load is not powered by the input voltage through the boost converter during shut down and the system is sensitive to shutdown power loss. The load disconnection function also allows for output short protection and minimizes the inrush current at start-up.

The device realizes true disconnection or true shutdown when a MOSFET in the path from the input to the load is fully turned off (including body diode).

3.1 Synchronous HSD FET With Switchable Body Diode (TPS61299)

When high-side FET is a P-MOS, the device stops switching and the high-side MOSFET is fully turned off by switching the body diode direction to realize true shutdown operation. As Figure 3-1 shows, the switchable body diode provides the completed disconnection between input and output.

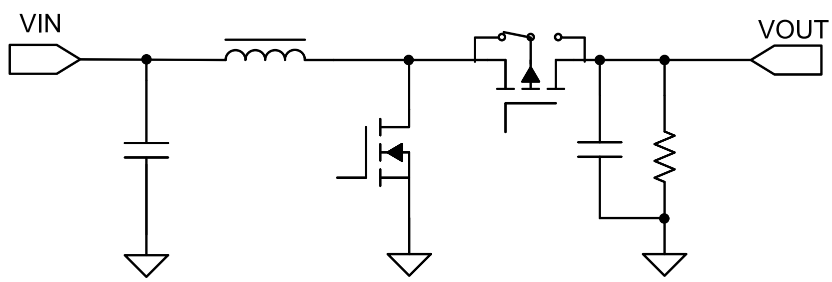

Figure 3-1. Ture disconnection During Shutdown

Meanwhile, the device monitors on the VMAX (the higher voltage between input voltage and output voltage). When output voltage exceeds input voltage, the body diode direction is switched to prevent the output from feeding back into the input voltage. The TPS61299 integrates ture disconnection function. Figure 3-2 shows the shutdown waveforms of the TPS61299.

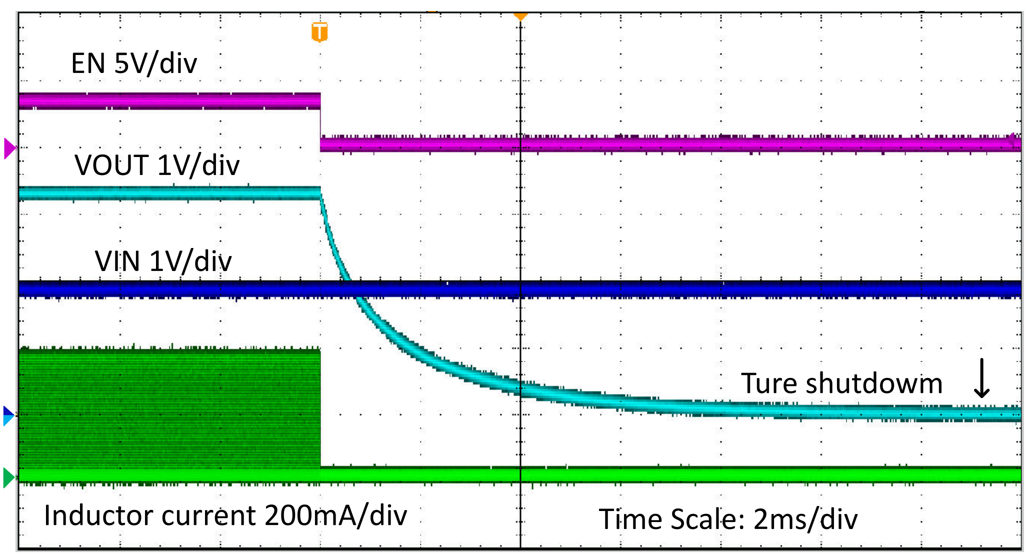

Figure 3-2. TPS61299 Shutdown Waveforms

3.2 Extra ISO FET to Cut-Off Leakage Path

A separated isolation MOSFET is needed in cases when the high side MOSFET cannot switch its body diode direction. The body diode cathode of the ISO-FET is connected to the input side. ISO FET is turned off when EN is low, completely cutting off the path between the input side and output side during shutdown and realizing true disconnection.

ISO FET can be placed both on output or input path. The TPS61378-Q1 is integrated with a separated N-MOS isolation FET on the output path as shown inFigure 3-3. The TPS61376 moves the separated N-MOS isolation FET to the input path as shown in Figure 3-4. In this case, the ISO FET can be reused as an inductor current sense FET. Therefore, the TPS61376 can program the input average current limit threshold. The shutdown waveforms of the TPS61378 and the TPS61376 is similar to Figure 3-2.

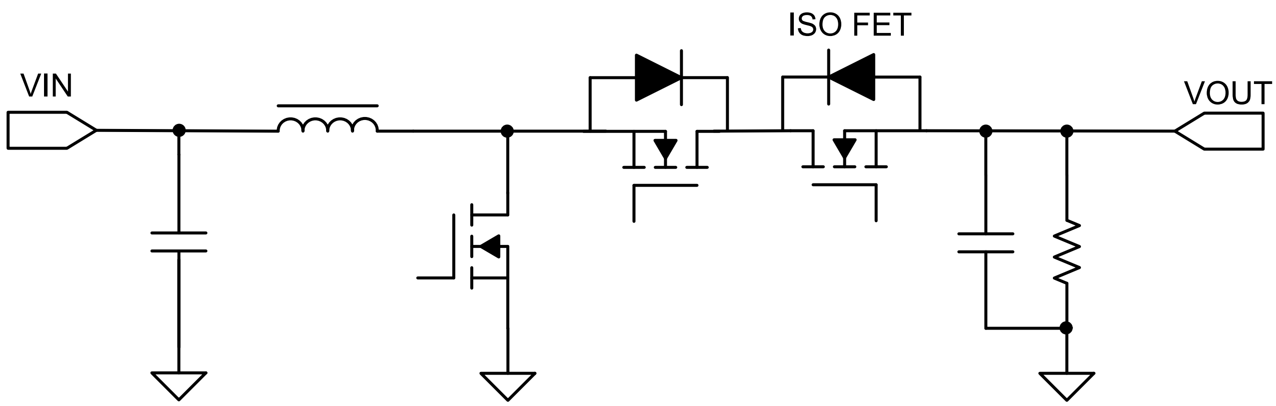

Figure 3-3. TPS61378-Q1: ISO-FET on the output path

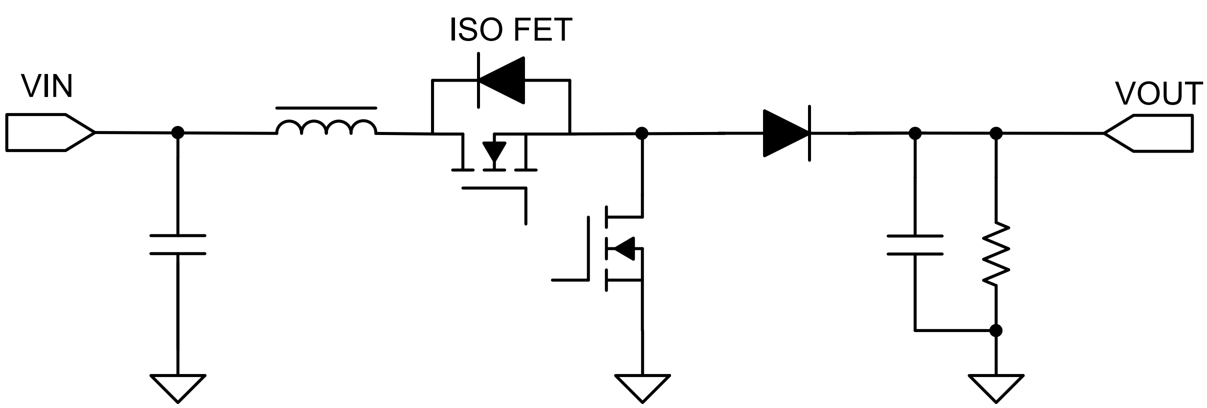

Figure 3-4. TPS61376: ISO-FET on the input path

4 Summary

This application note discussed different behaviors of boost converters during shutdown. In always-on systems, devices with force pass through and bypass functions should be considered to maintain high efficiency. Consider devices with a load disconnection function when the load is not powered by the device and the system is sensitive to power loss during shutdown. If short protection function is needed, use devices with true disconnection function.

5 References

1. Texas Instruments, TPS61288 18-V, 15-A, Fully Integrated Synchronous Boost Converter data sheet.
2. Texas Instruments, TPS6125x 3.5-MHz High Efficiency Step-Up Converter In Chip Scale Packaging data sheet.
3. Texas Instruments, TPS61291 Low Iq Boost Converter with Bypass Operation data sheet.
4. Texas Instruments, TPS61299 95-nA Quiescent Current, 5.5-V Boost Converter with Input Current Limit and Fast Transient Performance data sheet.
5. Texas Instruments, TPS61378-Q1 25-μA Quiescent Current Synchronous Boost Converter with Load Disconnect data sheet.
6. Texas Instruments, TPS61376 23-VIN, 25-VOUT, 4.5-A, Boost Converter with up to ±2.5% accuracy Input Average Current Limit and True Load Disconnection data sheet.

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