Split-rail approaches extend boost-converter input-voltage ranges

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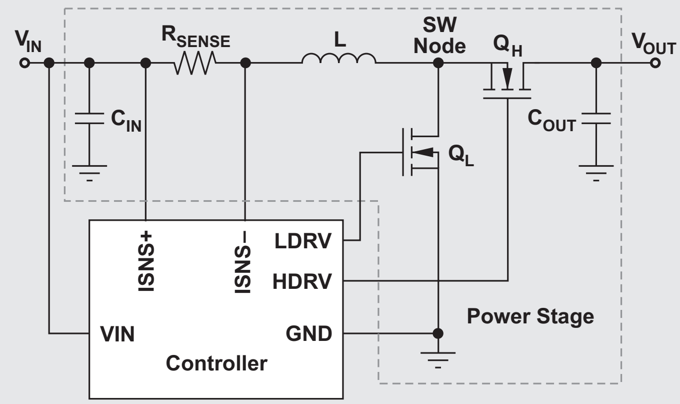
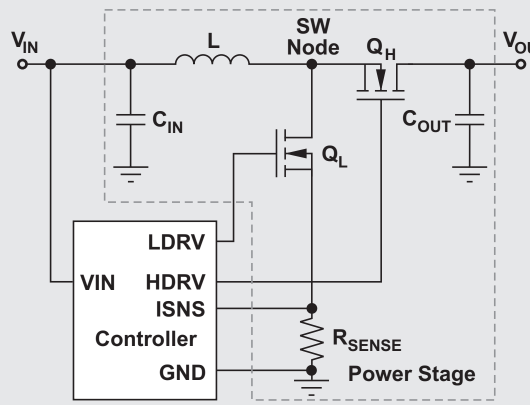
Introduction

Wide-input-range DC/DC controllers usually have built-in undervoltage lockout (UVLO) circuits to prevent the converters from misoperating when the input voltage is below the UVLO threshold. However, the UVLO circuit might also cause undesirable shutdown in the event of a load transient or a supercapacitor discharge in applications where input voltage is above the UVLO threshold at start-up but later may drop below this threshold. In addition, these controllers normally cannot be used in applications where the input voltage is always under the UVLO threshold. This article presents several split-rail approaches to extend boost-converter input-voltage ranges, enabling the use of these controllers with input voltage lower than their UVLO thresholds. Design examples along with test results are provided to validate these approaches.

Figure 1. Boost converters in single-rail configuration



(a) High-side current sensing



(b) Low-side current sensing

Minimum input voltage of a boost converter

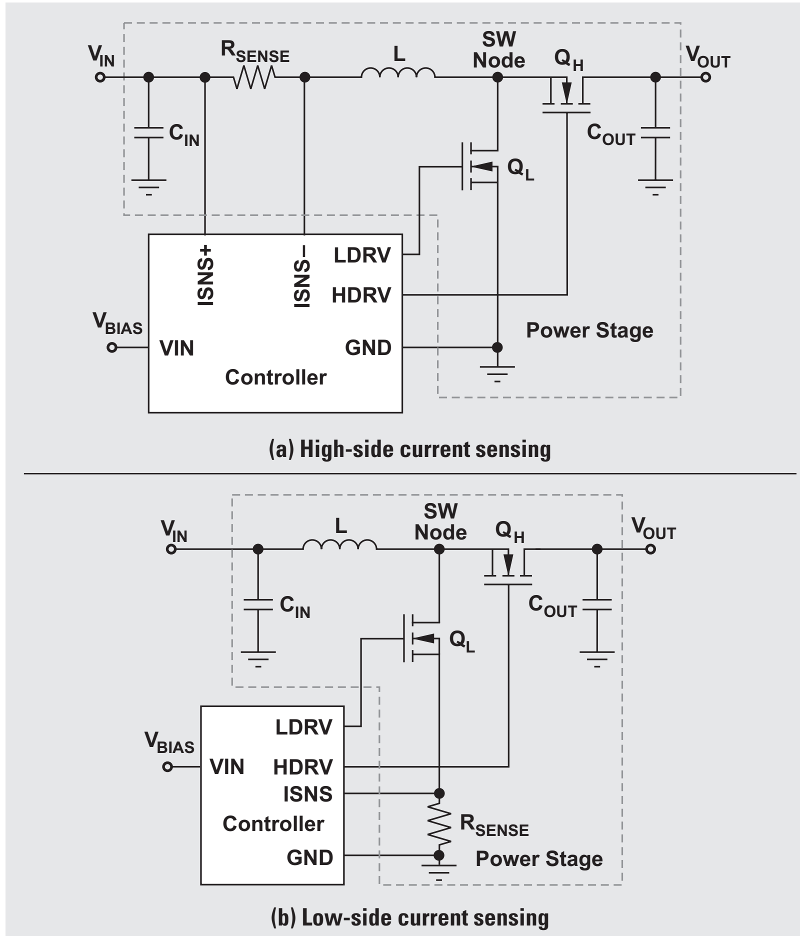
Figure 1 shows typical boost converters with a single input supply (V_{IN}) that provides the input voltage to the power stage and the bias voltage to the controller. The minimum bias voltage to the controller at the V_{IN} pin is set by the controller's input UVLO threshold. To guarantee functionality of boost converters with high-side current sensing (Figure 1a), the minimum input voltage to the power stage is defined by the minimum common-mode voltage of the current-sense comparator. This is because the input voltage is also connected with the non-inverting input of the current-sense comparator. The minimum common-mode voltage of the current-sense comparator often is less than the controller's input UVLO threshold. For the boost converter with low-side current sensing (Figure 1b), the input voltage to the power stage is not directly connected to the current-sense comparator. Therefore, it is not required to match the minimum common-mode voltage. Consequently, in the single-rail configuration where the input voltage to the power stage and the bias voltage to the controller are tied together, the controller's input UVLO threshold imposes a constraint on how low the input voltage to the boost power stage can go.

As shown in Figure 2, the input supply to the boost converter can be split into two rails: the power-stage input rail (V_{IN}) and the controller's bias input rail (V_{BIAS}). In the split-rail configuration, although V_{BIAS} is still required to be above the controller's UVLO threshold to turn on the controller, V_{IN} can go below the UVLO threshold. Since V_{BIAS} needs to supply only a very small amount of power, it can be generated by a charge pump or even share another voltage rail already existing in the system. As a result, the voltage range of the power rail (V_{IN}) can be extended.

This article will discuss several approaches to implementing the split-rail configuration. The TPS43061 synchronous boost controller from Texas Instruments (TI) will be used to elaborate on the split-rail concept and to validate the presented approaches. This boost controller has a high-side current-sense comparator and an internal input UVLO circuit at the bias-supply input (V_{IN}) pin.

Figure 3 shows the turn-off waveforms of the boost converter in the single-rail configuration shown in Figure 1a. The converter stops switching once V_{IN} falls below 3.9 V, which is the controller's UVLO turn-off threshold. The boost converter can be turned on only when V_{IN} rises above the UVLO turn-on threshold of 4.1 V.

Figure 2. Boost converters in split-rail configuration



Extending input-voltage range after start-up

In some applications with only one input supply, the input-supply voltage is greater than the controller's UVLO turn-on threshold at start-up. However, it might fall below the input UVLO threshold afterwards, leading to undesired shutdown. For example, in power systems using a photovoltaic panel combined with a supercapacitor as an input supply, the input voltage may drop below the controller's UVLO turn-off threshold due to discharge. Another example is a power system powered by a USB power cable where the voltage drops significantly during a load transient, resulting in an unexpected system shutdown.

Figure 3. Turn-off waveforms of boost converter in single-rail configuration

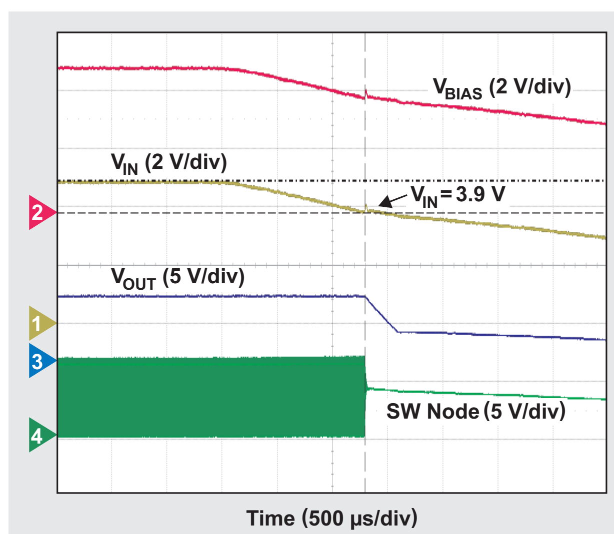
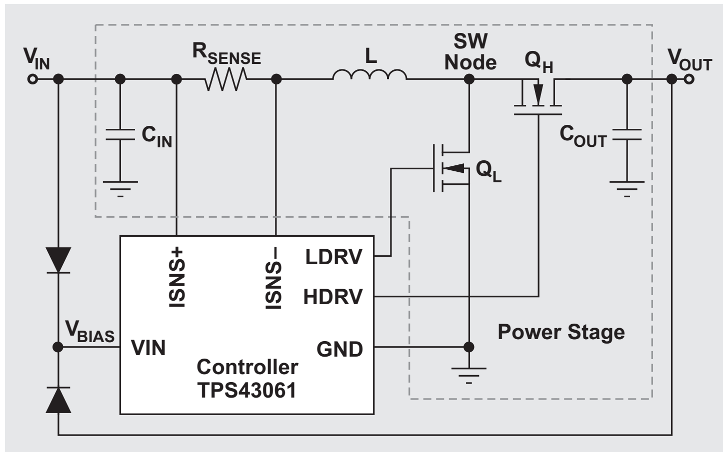


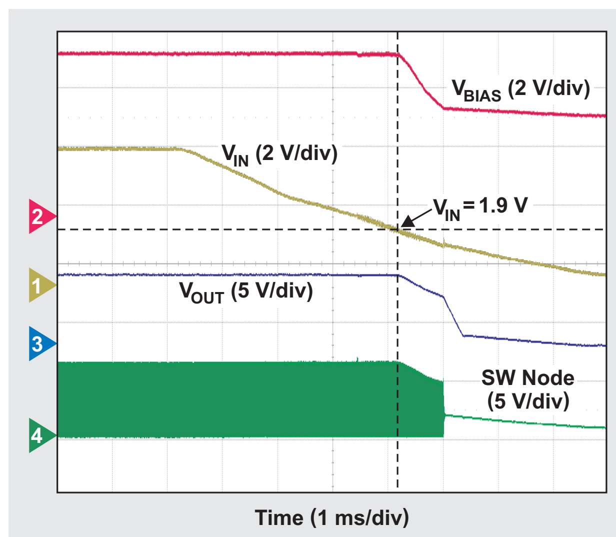
Figure 4. Split-rail approach feeding V_{OUT} back as bias supply



For these applications, if V_{OUT} is within the V_{BIAS} specification range, which is always higher than the UVLO turn-on threshold, V_{OUT} can be fed back as the bias supply (V_{BIAS}) via a diode (Figure 4). After start-up, V_{BIAS} is clamped to V_{OUT} rather than V_{IN} and stays above the UVLO threshold even if V_{IN} drops below this threshold. The boost converter can maintain normal operation as long as V_{IN} can meet the current-sense comparator's requirement for the minimum common-mode voltage.

Figure 5 shows the turn-off waveforms of the boost converter shown in Figure 4, where V_{OUT} is set as 6 V and fed back as the bias supply. With diode's forward voltage drop neglected, the bias-supply voltage (V_{BIAS}) is clamped to V_{OUT} rather than V_{IN} when V_{OUT} is higher than V_{IN} after start-up. Hence, V_{BIAS} stays above the 3.9-V UVLO turn-off threshold to avoid the undesired turn-off when V_{IN} falls below 3.9 V. V_{OUT} stays within regulation until V_{IN} falls below the minimum common-mode voltage of the current-sense comparator, in this example 1.9 V. This means that the minimum input voltage (V_{IN}) has been extended from 3.9 V to 1.9 V after start-up.

Figure 5. Turn-off waveforms of configuration shown in Figure 4

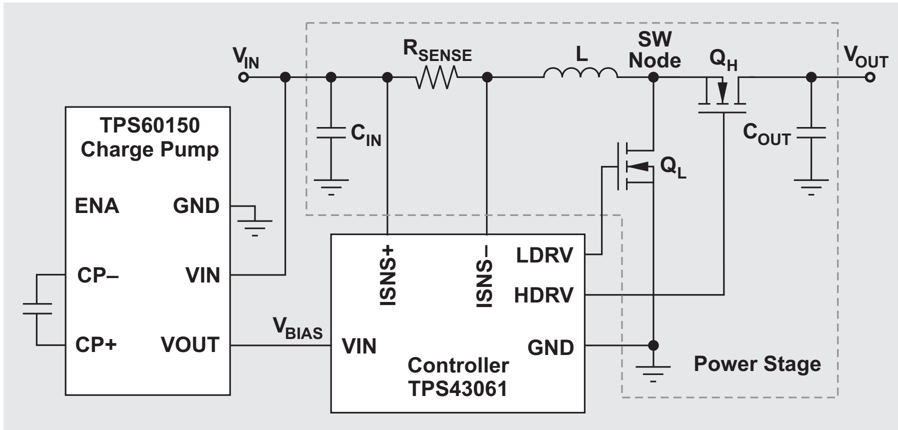


Extending the start-up input-voltage range

Lithium-Ion (Li-Ion) batteries are widely used in smartphones, tablet PCs, and other handheld devices. The voltage of a single-cell Li-Ion battery rated at 3.6 V usually ranges from 2.7 V to 4.2 V due to discharge and charge. This is lower than the UVLO threshold of some wide-input-range boost controllers, even before start-up. For these applications, neither a single-rail scheme nor a split-rail approach feeding V_{OUT} back as the bias supply works. A separate bias supply different from the battery input is needed.

Fortunately, a bias supply needs to supply only very low power. If there is another supply rail above the UVLO turn-on threshold already available in the system, it can be connected to V_{BIAS} while connecting the power rail (V_{IN})

Figure 6. Split-rail approach using charge pump to produce bias voltage

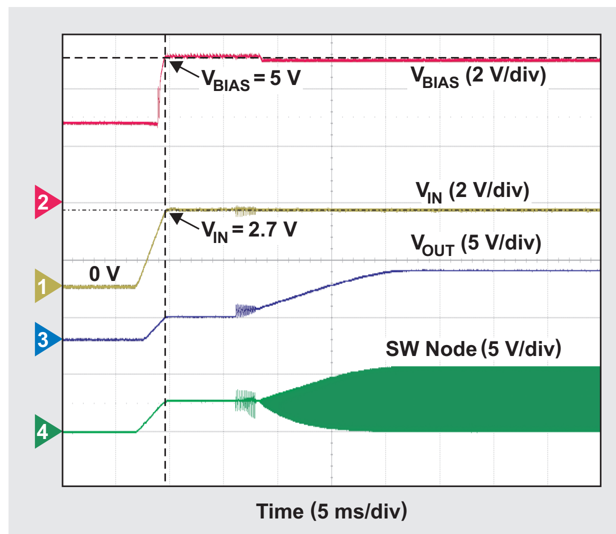


to the battery (Figure 2). If not, a charge pump can be added for a bias supply (Figure 6).

In this example, from the 2.7 V to 4.2 V of battery input, TI's TPS60150 charge pump produces a regulated 5-V supply, which is higher than the UVLO turn-on threshold of the TPS43061 controller, so it can be used as the bias supply. Using a charge pump with the split-rail approach, the boost converter can start up and operate with a single input supply that is lower than the boost controller's UVLO turn-on threshold .

Figure 7 shows the start-up waveforms of the boost converter shown in Figure 6. The converter can start up and operate with a single 2.7 V of supply since V_{BIAS} is regulated at 5 V, although V_{IN} is only 2.7 V. By using this split-rail approach, the boost converter's minimum operating input voltage is extended from 4.1 V to 2.7 V.

Figure 7. Start-up waveforms of configuration shown in Figure 6



Conclusion

Two inputs are usually required for a boost converter to operate: the input supply to the power stage and the bias supply to the controller. The controller's UVLO threshold sets the low limit of the bias supply. It also places a constraint on the input supply to the power stage, if these two rails are connected to share one input supply. Split-rail approaches separate the power rail from the bias supply rail to eliminate the constraint on the minimum operating voltage of the power rail. This extends the input-voltage range of boost converters.

References

1. "Low quiescent current synchronous boost DC-DC controller with wide V_{IN} range," TPS43060/61 Datasheet. Available: www.ti.com/slvsbp4-aaj
2. "TPS60150 5V/140mA charge pump device," TPS60150 Datasheet. Available: www.ti.com/slvs888-aaj

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