Application Note

Using External Bias to Broaden the Input Voltage Range of Boost Converters

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ABSTRACT

This application note introduces a method to broaden input voltage range of some boost converters. The input voltage range of these boost converters is normally limited by the VIN pin voltage rating, but not the voltage rating of the integrated power MOSFETs. This document analyzes the feasibility of the method and then provides a list of devices that support the method.

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1 Introduction

Many applications require a boost converter to obtain an output voltage higher than the input voltage. For boost converters, the VIN pin is connected to the power supply of the device, while the SW pin is connected to the drain of the internal low-side power MOSFET. Figure 1-1 shows the typical application of a boost converter. The power supply Vin of power stage is used as the source of the VIN pin so Vin should be compatible with the input voltage range of the device.

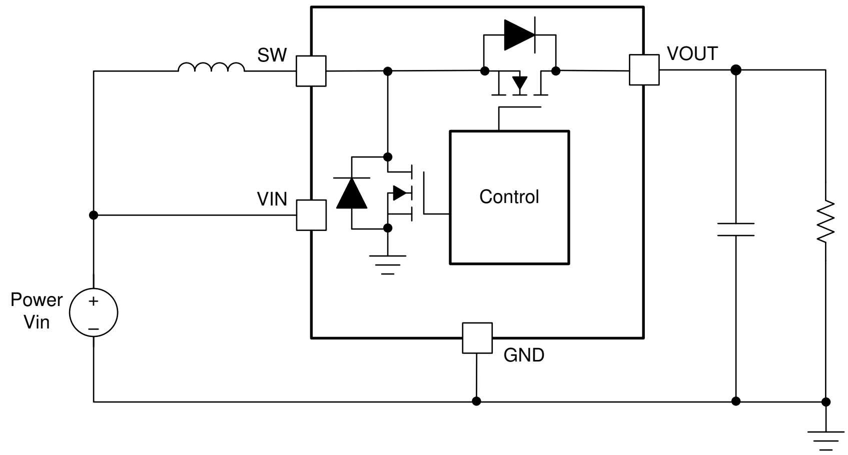

Figure 1-1. Typical Application of Synchronous Boost Converter

However, boost converters have strict restrictions on the input voltage range. It is not easy to choose an appropriate boost converter in some applications, especially when the power stage needs to work with very low input voltage. Figure 1-2 shows a simple solution using an external bias signal Vin for the VIN pin. The Vin signal should be compatible with the input voltage range but it is only for the IC itself, so the current consumption is only at the mA level. The actual power supply for boost power stage power Vin can be much wider than the input voltage range.

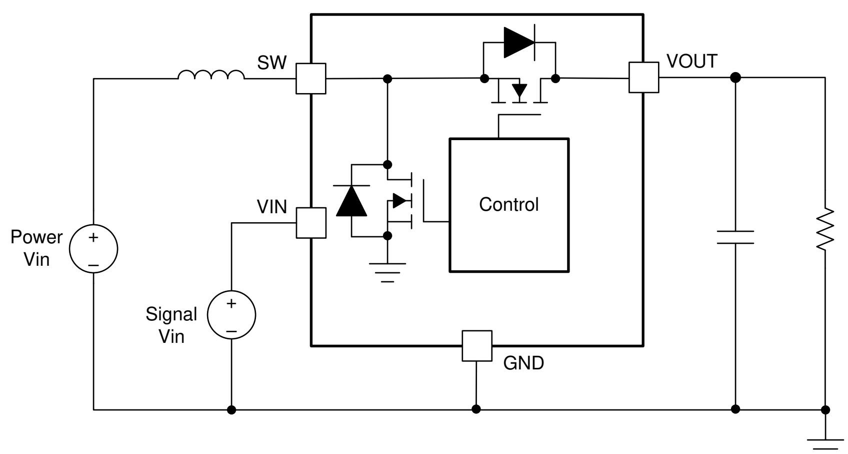

Figure 1-2. External Bias Application of Synchronous Boost Converter

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2 Requirements of External Bias for Boost Converters

To figure out the requirements of supporting external bias, it is necessary to analyze the control strategy of these boost converters. According to the different main control strategies, middle-voltage boost converters (output voltages above 7 V) can be divided into three control strategies.

The first type is fixed frequency control (PWM), a relatively simple and commonly-used control strategy. The devices using this control strategy include the TPS61175, TPS61178, and so forth.

The second type is quasi-constant frequency control, or constant on or off time (COT) control. The constant off time control device will calculate an off time T_{off} based on the input voltage and output voltage to keep the frequency basically constant. The devices using this control strategy include the TPS61089, TPS61372, and so forth.

The third type is the pulse-frequency modulation control (PFM). There are fewer devices using PFM, including the TPS61096a and TPS61040.

For COT control, the device needs to sample input voltage to calculate T_{off} or T_{on}. There are also two methods to sample input voltage:

1. Directly sample the VIN pin voltage
2. Sample the average voltage of the SW pin, which is almost the same as Vin.

The derivation process is as follows:

The voltage waveforms of SW in CCM and DCM are shown in Figure 2-1.

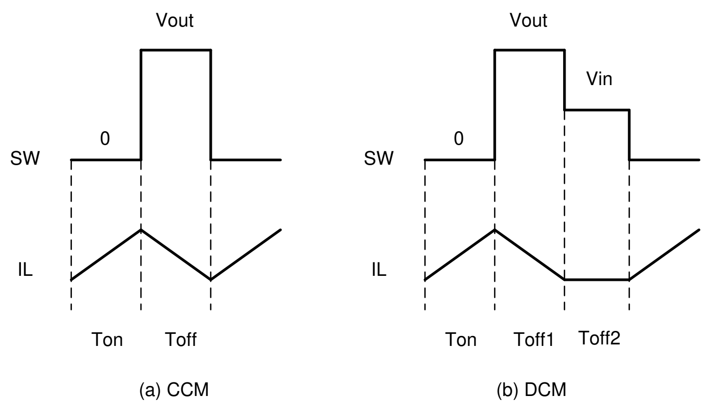

Figure 2-1. Waveforms of Boost SW Voltage in CCM and DCM

For CCM, the average voltage of the SW pin is calculated with Equation 1:

$$\bar{V_{SW}} = \frac{T_{on} \cdot 0 + T_{off} \cdot V_{out}}{T_S} = \frac{(1-D) \cdot T_S \cdot \frac{V_{in}}{(1-D)}}{T_S} = V_{in} \tag{1}$$

where

- D is the switching duty cycle
- T_S is the switching period

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For DCM, the T_{on} and T_{off1} are determined with Equation 2:

$$T_{on} = \frac{L \cdot I_{peak}}{V_{in}},\ T_{off1} = \frac{L \cdot I_{peak}}{V_{out} - V_{in}} \tag{2}$$

where

- L is the inductance of power inductor
- I_{peak} is the peak current of inductor

The average voltage of the SW pin is calculated with Equation 3:

$$\overline{V_{SW}} = \frac{T_{on} \cdot 0 + T_{off1} \cdot V_{out} + T_{off2} \cdot V_{in}}{T_{on} + T_{off1} + T_{off2}} = \frac{T_{off1} \cdot V_{out} + T_{off2} \cdot V_{in}}{T_{off1} \cdot \frac{V_{out}}{V_{in}} + T_{off2}} = V_{in} \tag{3}$$

Note that the device needs to sample the voltage of the SW pin to calculate a proper T_{off} and T_{on}. For external bias applications, the boost converter will not work as desired if the device samples the voltage of the VIN pin, signal Vin. For example, the working frequency of the TPS61087 will increase as the input voltage increases in CCM. This is because the T_{off} remains unchanged with external bias, while the required duty cycle reduces as the input voltage rises, so T_{on} decreases. Thus, the first and most important requirement of external bias is that the boost converter must sample power Vin for T_{off} and T_{on} calculation if the COT control strategy is used.

The second requirement is that the boost converter has no load disconnection function or the function is not used in a practical application. Consider the TPS61372 as an example. It integrates a P-channel MOSFET connected in series with a high-side MOSFET. If the power Vin is high, the source voltage of the isolated PMOS on the output side is high. The device may not be able to generate a sufficiently high gate voltage and the PMOS will not shut down if the signal Vin is low. In addition, the signal Vin may be sampled to determine the driving signal of isolation MOSFET so it may bring abnormal behavior when output sides are shorted. Thus, those devices integrating isolation MOSFET are not recommended for external bias application.

The third requirement is power sequence. Power Vin should be provided before signal Vin to pre-charge the output capacitor. For some devices like the TPS61288 and TPS61089, the start-up will fail and the input sides will be shorted if the power Vin is provided later. This is because the device is already working before start-up and the error amplifier of the device will produce too large an EA output voltage due to 0-V power Vin. This brings almost infinite T_{on}. Figure 2-2 and Figure 2-3 show different start-up waveforms of the TLV61046a. In Figure 2-2, power Vin is provided first and then signal Vin is provided; while signal Vin is provided first and then power Vin is provided as shown in Figure 2-3. It is obvious that the inrush current of start-up is much larger and the soft-start feature is lost even if the power Vin can be provided later in an external bias application.

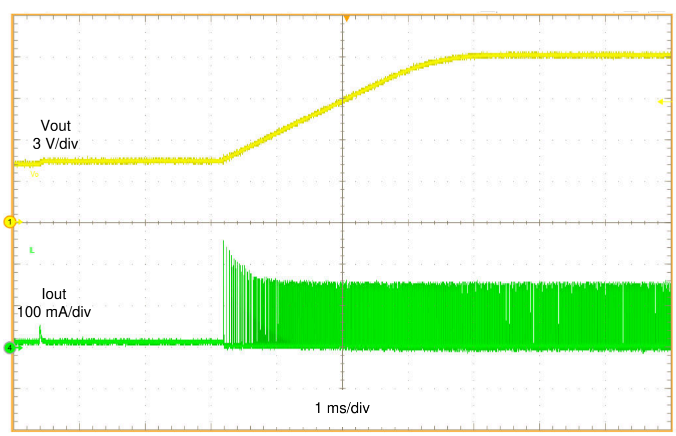

Figure 2-2. TLV61046a Power Vin = Signal Vin = 5 V, Vo = 12 V, Io = 10 mA, Power Vin Provided First

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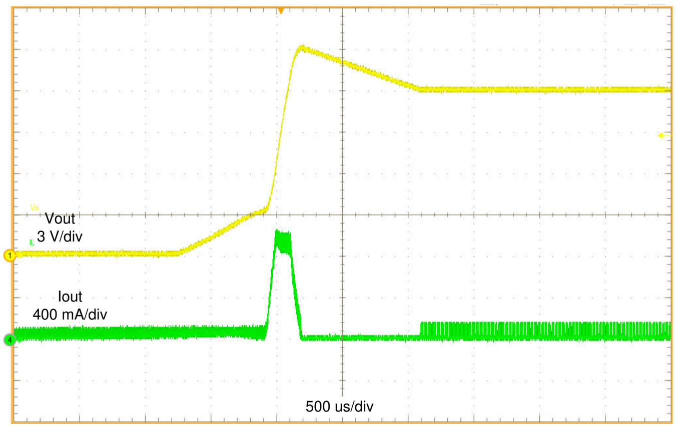


Figure 2-3. TLV61046a Power Vin = Signal Vin = 5 V, Vo = 12 V, Io = 10 mA, Signal Vin Provided First

3 Applicable Devices List and Test Results

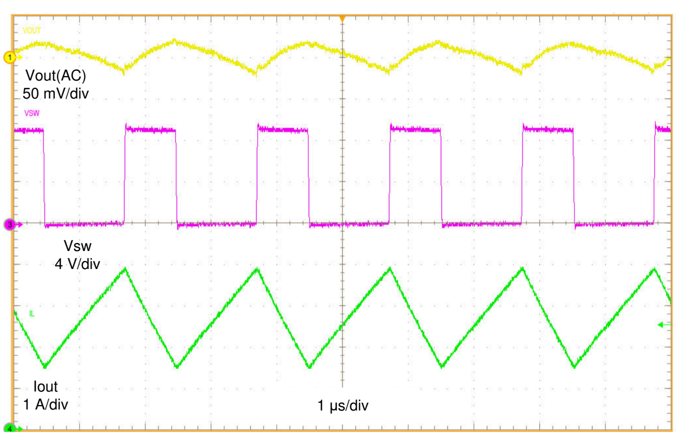
According to the previously-analyzed requirements, the middle-voltage boost converters that support external bias are listed and divided based on their control strategies in Table 3-1.

Table 3-1. MV Boost List for External Bias

Main Control Strategy	Control Strategy at Light Load	Devices Supporting External Bias
Fixed Frequency Modulation	Pulse Skipping Mode	TPS61175(1), TPS61170
	Pulse Frequency Modulation	TPS61178(2)
	Forced PWM Mode	TPS61175(1), TPS611781(2), TPS61080, TPS61081
Quasi-Constant Frequency Modulation	Pulse Skipping Mode	TPS61086, TPS61046, TLV61046a, TLV61048, TPS61085
	Pulse Frequency Modulation	TPS61288, TPS61088, TPS61089
	Forced PWM Mode	TPS610891
Pulse Frequency Modulation	Pulse Frequency Modulation	TPS61045, TPS61040, TPS61041, TPS61096a

(1) The TPS61175 works in forced PWM mode when the on time is longer than minimum (60 ns), and enters pulse skipping mode when on time is clamped to minimum.
(2) Do not use the isolation MOSFET of the TPS61178 and TPS611781.

Take the TPS61089 as an example. Figure 3-1, Figure 3-2, Figure 3-3, and Figure 3-4 show the main waveforms with external bias and without external bias in CCM and DCM, respectively. When power Vin equals to signal Vin, there is no difference for the device so the waveforms are the same. This assures that the TPS61089 can be used in external bias applications.



Power Vin = 3.6 V, Vo = 9 V, Io = 1 A

Figure 3-1. TPS61089 CCM Waveforms Without External Bias

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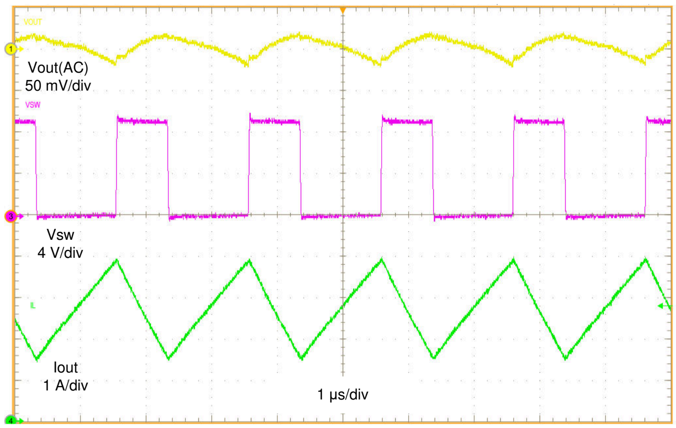
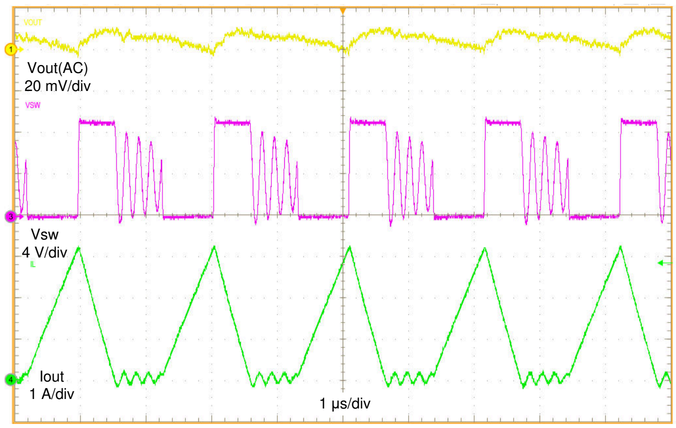


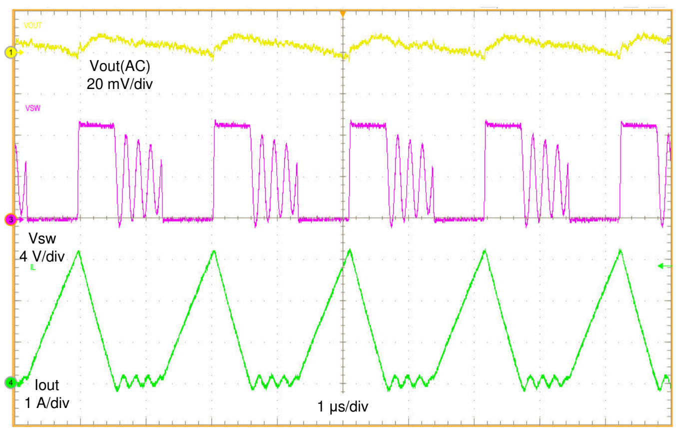
Power Vin = Signal Vin = 3.6 V, Vo = 9 V, Io = 1 A

Figure 3-2. TPS61089 CCM Waveforms With External Bias



Power Vin = 3.6 V, Vo = 9 V, Io = 0.2 A

Figure 3-3. TPS61089 DCM Waveforms Without External Bias



Power Vin = Signal Vin = 3.6 V, Vo = 9 V, Io = 0.2 A

Figure 3-4. TPS61089 DCM Waveforms With External Bias

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With external bias, the input voltage range of the TPS61089 can be extended as previously analyzed. Figure 3-5 shows the waveforms of the TPS61089 when the signal Vin is 3.6 V while the power Vin is only 1.5 V. Compared with the 2.7-V minimum input voltage for a typical application, the device can work with much lower input voltage as long as the current limit is not reached.

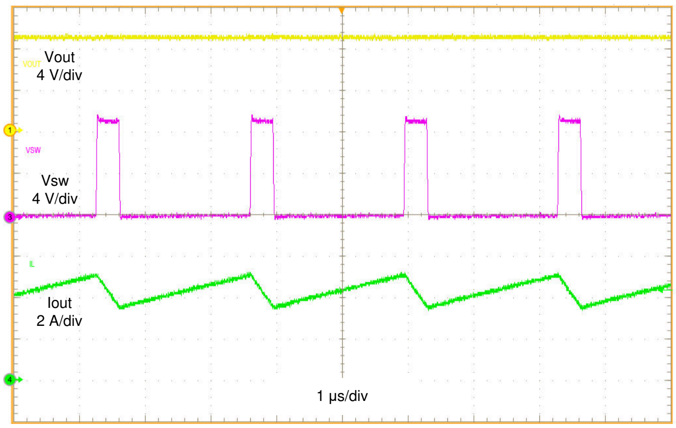

Figure 3-5. TPS61089 Power Vin = 1.5 V, Signal Vin = 3.6 V, Vo = 9 V, Io = 1 A

4 Application Cases

A super capacitor is usually used as the energy storage cell in backup power supply systems. The super capacitor is charged when the bus voltage VBUS exists and discharged when the bus voltage falls to hold the VBUS. The lower the boost converter minimum operating voltage, the deeper the super capacitor can be discharged, the longer the backup time. To meet the backup time requirement, the minimum operating voltage is set lower than 2 V but there is no extreme low-voltage boost converter with enough load capability. To optimize the application, the TLV61048 can be used when the VIN pin is supplied by external bias from a buck converter. The details are found in the *Smart Meter PLC Module Backup Power Supply Reference Design*. Figure 4-1 shows the simplified block diagram of the power structure.

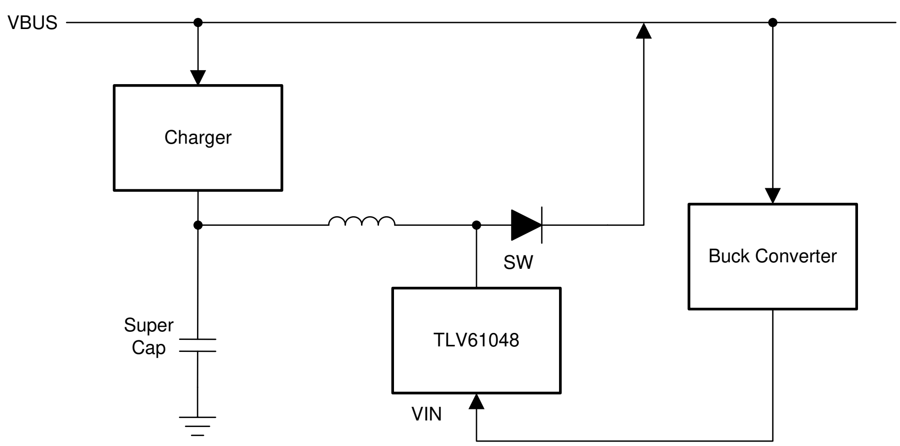

Figure 4-1. Simplified Block Diagram of Backup Power Supply

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Another case of external bias is for solar panel with only a 0.4V to 0.55V input voltage range. As shown in Figure 4-2, a discrete charge pump circuit outputting 2 × Vout voltage is used to supply the VIN pin after start-up in the *Energy Harvesting From Single Cell Solar Panel for Li-Ion Battery Reference Design*. The battery voltage is also under the minimum output voltage of the TPS61089 but the system operates well with higher efficiency.

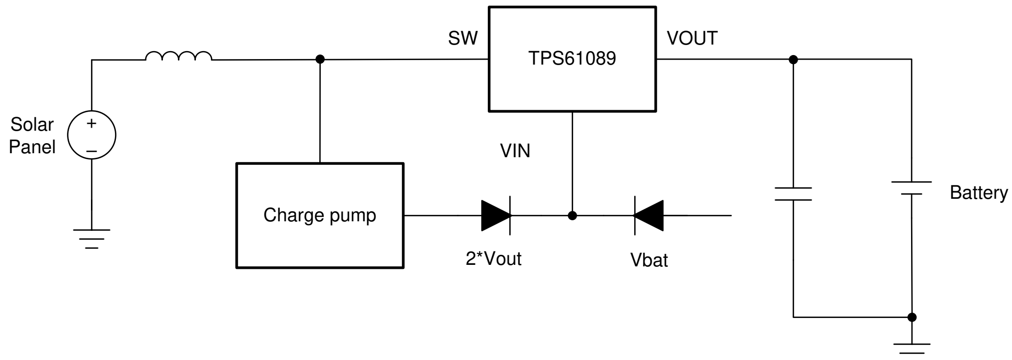

Figure 4-2. Simplified Block Diagram of Energy Harvest System

5 Summary

External bias is an effective and easy solution for boost converters to expand the input voltage range in a backup power system. Only partial boost converters support the external bias application and the requirements are analyzed in detail. The applicable MV boost devices are summarized and listed in this application note.

6 References

- Texas Instruments, *Smart Meter PLC Module Backup Power Supply Reference Design*
- Texas Instruments, *Energy Harvesting From Single Cell Solar Panel for Li-Ion Battery Reference Design*

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