# Low-Voltage, Reverse-Battery Protection Circuit Using the TPS61200 Boost Converter

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**ABSTRACT**

This application report describes how to implement a reverse-battery-protection feature using the TPS61200 boost converter in applications powered from a single alkaline, nickel-cadmium (NiCd), or nickel-metal hydride (NiMH) cell.

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## 1 Introduction

For many single-cell (such as alkaline, NiCd, or NiMH) applications, the battery voltage can drain as low as 0.8 to 0.9 V. Even under these conditions, at least 40% more power can be used from the battery cell, which is typically what end-product users try to do. This additional drain creates a low-voltage, 0.9-V start-up request for a power management IC.

A common requirement for most battery-powered applications is a reverse-battery-protection safeguard. This safeguard can be either mechanical or electronic, and there is often a special connector or symbol to highlight it in the application circuit. Electronic battery-reverse-voltage protection is preferred, however, because it provides a higher level of safety.

The challenge that we explore here is how to implement a low-cost and effective reverse-battery-protection circuit that works with a low-voltage (less than 0.9-V) start-up condition for a single-cell application.

## 2 Circuit Description and Basic Principles

### *2.1 Reverse-Protection Circuit*

Figure 1 and Figure 2 show simple reverse-battery-protection circuits using a single MOSFET. Figure 1 illustrates a low-side NMOS in the ground path, and Figure 2 shows a high-side PMOS in the power path. In each circuit, the MOSFET body diode is oriented in the direction of normal current flow. When the battery is installed incorrectly, the NMOS (or PMOS) gate voltage is low (or high), thus preventing the circuit from turning on.

When the battery is properly installed and the portable equipment powers up, the NMOS (or PMOS) FET gate voltage is taken high (or low), and its channel shorts out the diode.

Under a low-voltage start-up condition, however, there is a voltage drop of $R_{DS(ON)}$ x $I_{LOAD}$ across the MOSFET. In a worst-case scenario, the low input voltage of 0.8 V to 0.9 V in a single cell application is not sufficient to completely turn on the MOSFET. Therefore, the MOSFET will operate in its linear region. In the linear region, the $R_{DS(ON)}$ is much higher than in the saturation region, and causes significant voltage drop across the $R_{DS(ON)}$ of the MOSFET. Considering single-cell applications using the TPS61200, this voltage drop can be great enough that the actual input voltage of the TPS61200 falls below 0.5 V, preventing start-up of the converter.

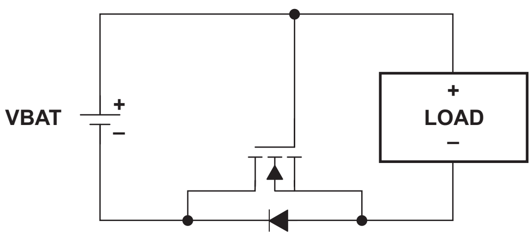


**Figure 1. NMOS in Ground-Return Path**

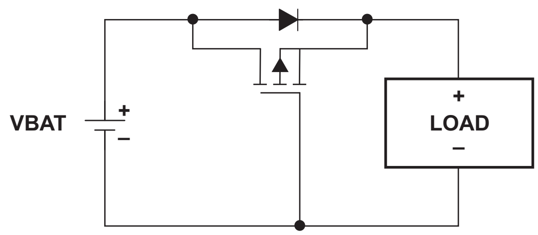


**Figure 2. PMOS in Ground-Return Path**

## 2.2 Basic MOSFET Transfer Characteristic Curves

For most low-voltage MOSFETs, the typical threshold voltage $V_{GS}$ is in the range of 1.6 V. As an example, consider the BSO064N03S 30-V, low-voltage MOSFET from Infineon Technologies.

Figure 3 shows the transfer characteristics of a typical MOSFET. The BSO064N03S product data sheet specifies a typical gate-source threshold voltage ($V_{GS}$) of 1.6 V, min. 1.2 V, max. 2.0 V. When $V_{GS}$ rises to 2.0 V, the MOSFET begins to operate in its region of saturation and the drain current ramps quickly. If $V_{GS}$ decreases, the MOSFET operates in its linear region and the drain-to-source resistance, $R_{DS}$, ramps up quickly. Figure 4 shows the typical MOSFET gate threshold graph.

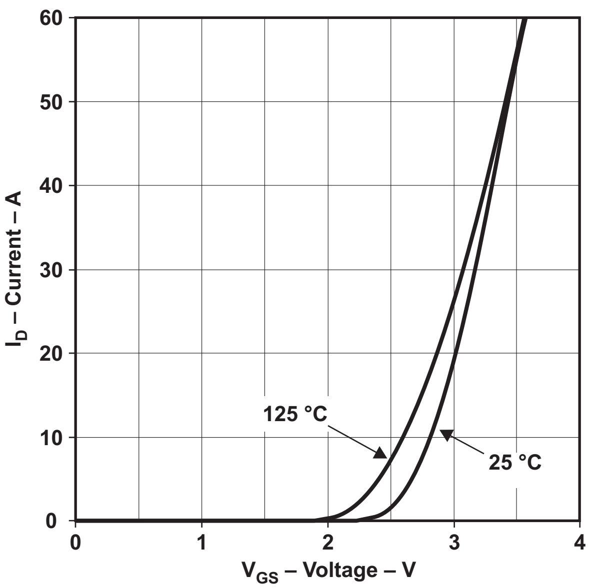


Figure 3. Typical MOSFET Transfer Characteristics

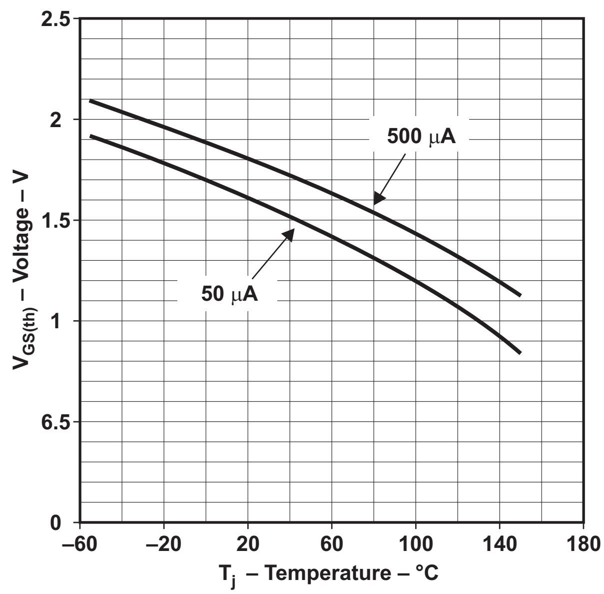


Figure 4. Typical MOSFET Gate-Threshold Voltage

## 2.3 Primary Issue for the Traditional Reverse-Protection Circuit

The TPS61200 is a low-input voltage, synchronous boost converter that can operate from input voltages down to 0.3 V. This device can start up into full load at a minimum input voltage of 0.5 V. However, at a low-input voltage condition of 0.9 V, a traditional reverse-battery-protection circuit that uses a single NMOS or PMOS FET has a problem, because the input voltage and gate-source voltage are not high enough to operate the MOSFET in its linear region. The MOSFET operates in its linear region with significantly higher $R_{DS}$. The drop in voltage across the $R_{DS}$ of the MOSFET increases and, therefore, the input voltage on the TPS61200 input decreases. In a worst-case situation, the input voltage may drop below 0.5 V, preventing start up of the converter.

## 2.4 Low-Voltage Start-Up Technology with TPS61200

The TPS61200 has a unique architecture (as Figure 5 shows) that enables the device to start up into a full load at input voltages down to 0.5 V. In addition to the main boost stage, the TPS61200 has a second boost converter, consisting of an integrated low-threshold switch and a diode to provide an auxiliary supply voltage (VAUX) for its internal supply. Once VIN ramps up to 0.5 V, the VAUX circuit begins to charge the VAUX capacitor until VAUX reaches 2.5 V. At that point, the converter switches to normal operation. As a result, the output capacitor is charged up while the load is connected and the output is supplied. To ramp up the output voltage in a controlled way, the converter starts to operate with an average current limit of 400 mA. The current limit increases proportionally as the output voltage increases.

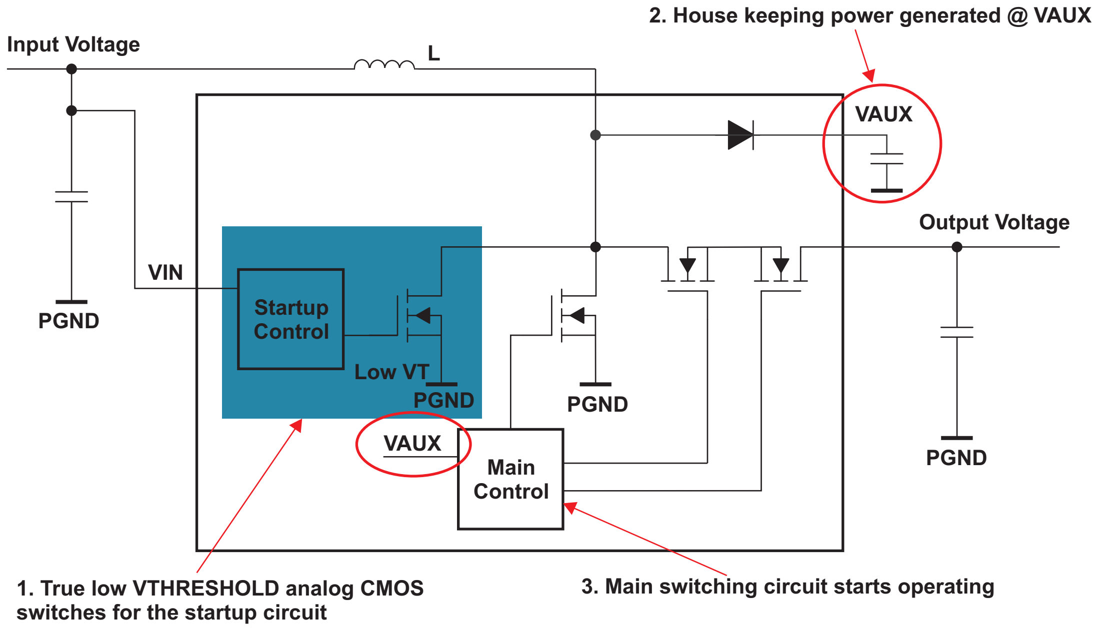


**Figure 5. Two-Step Boost Architecture for Low-Voltage Start-Up**

## 2.5 *Advanced Reverse Battery Protection Circuit with TPS61200*

Figure 6 illustrates an advanced reverse-battery protection circuit based on the TPS61200. A single N-Channel MOSFET in the ground path is used to disconnect the battery from the converter and, therefore, protect the converter from a negative input voltage. The gate of the N-Channel FET is connected to the VAUX pin of the TPS61200. When the input voltage reaches 0.5 V, the converter is enabled; the VAUX circuits start to operate and begin to charge up the VAUX capacitor and the gate of the MOSFET. VAUX and the $V_{GS}$ of the MOSFET ramp up to 2.5 V, turning on the MOSFET. The VAUX voltage is high enough to operate the MOSFET in its region of saturation, which overcomes the issue of a traditional reverse-battery protection as discussed earlier. Once the input voltage reaches 2.5 V, the converter also starts to ramp up the output voltage.

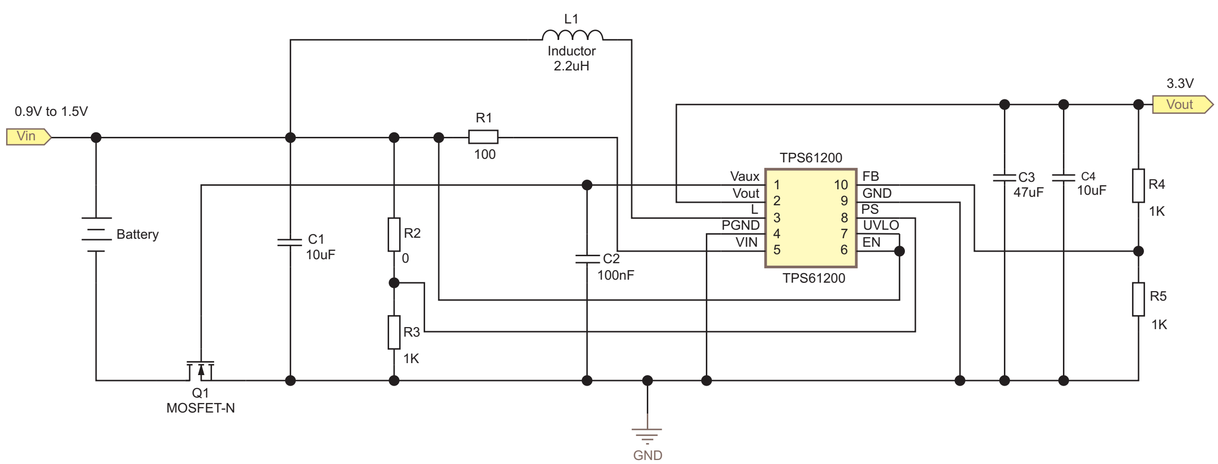


**Figure 6. Advanced Reverse-Battery Protection Circuit Based on TPS61200**

# 3 Test Waveform

## 3.1 Start-Up Waveform under Different Input and Load Conditions

Figure 7 to Figure 10 show the start-up waveforms under different input voltages and load conditions.

- CH1 (yellow) shows the input voltage.
- CH2 (blue) shows the output voltage.
- CH3 (magenta) shows voltage on the VAUX pin of the TPS61200

Figure 7 shows that when VIN reaches 0.5 V, the low-voltage boost circuit starts to operate, charging the VAUX capacitor up to 2.5 V. Then the NMOS FET is turned on completely and operates in its saturation region. Finally, the output voltage ramps up to its setpoint of 3.3 V. At this point, the entire start-up process completes successfully.

Figure 8 shows that under a 100-mA load with VIN also in the 0.9-V condition, the start-up process is similar to that the one that occurs under the 30-mA-load condition.

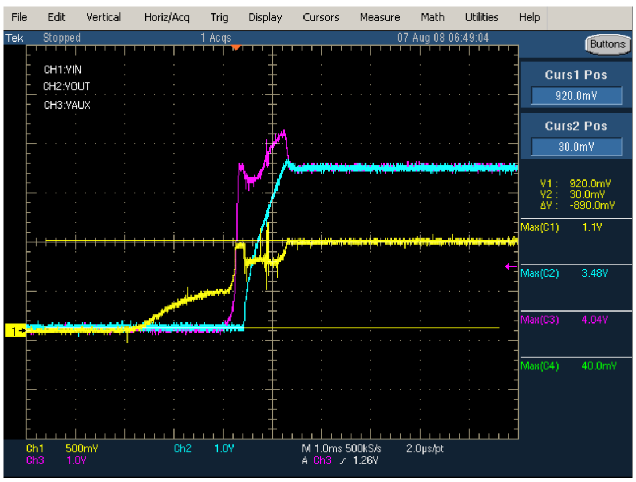


Figure 7. Input and Output Start-Up Voltage Waveform under 0.9-V, 30-mA Conditions

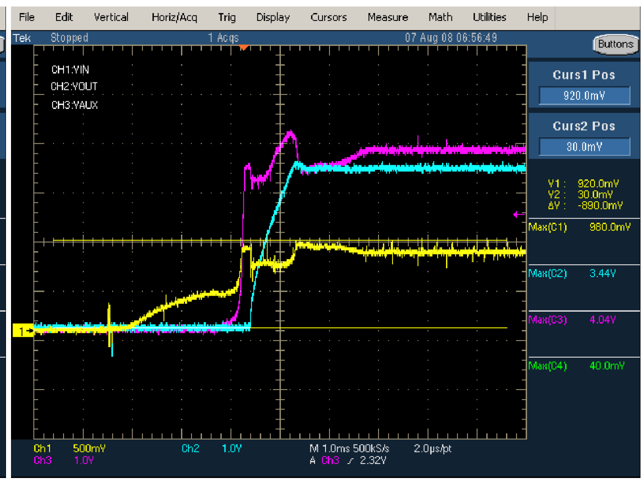


Figure 8. Input and Output Start-Up Voltage Waveform under 0.9-V, 100-mA Conditions

Figure 9 and Figure 10 show that under the 1.5-V input and 30-mA/100mA condition when VIN rises above 0.55 V, the first boost begins to charge the VAUX capacitor until it goes above 2.5 V. NMOS is turned on, and the output voltage ramps up to 3.3 V.

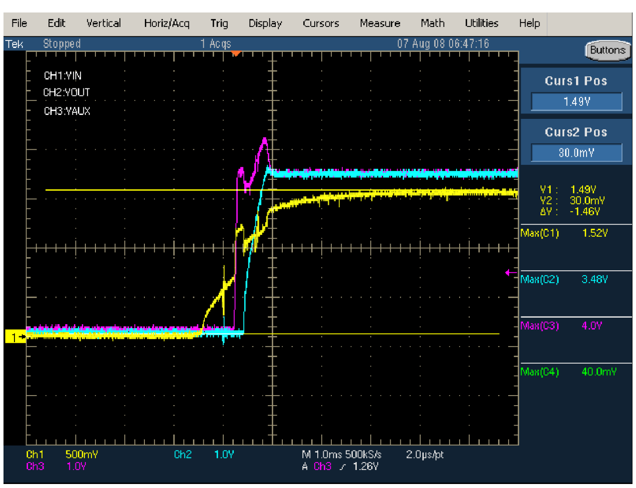


Figure 9. Input and Output Start-Up Voltage Waveform under 1.5-V, 30-mA Conditions

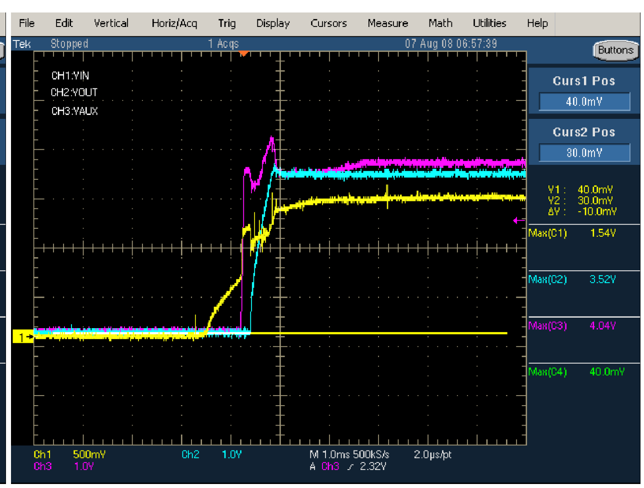


Figure 10. Input and Output Start-Up Voltage Waveform under 1.5-V, 100-mA Conditions

All of these examples show that this circuit can operate successfully under a full single-cell battery input voltage from 0.9 V to 1.5 V, and that the load can go up to 100 mA. Further tests are needed to determine if it can support a higher load.

## 4 Summary

Low-voltage and reverse-battery protection are common requirements for many single-cell consumer applications. This principle and the test verified that this reverse-protection circuit based on the TPS61200 is suitable for this application.

## 5 References

Unless otherwise noted, all documents are available through the Texas Instruments web site at www.ti.com.


1. Falin, J. *Reverse Current/Battery Protection Circuits*. Application report (SLVA139).
2. TPS61200 product data sheet (SLVS577B).
3. TPS6120XEVM-179 evaluation module user guide (SLVU207).
4. Loo, S.K. and K. Keller.*Single-cell Battery Discharge Characteristics Using the TPS61070 Boost Converter*. Application report (SLVA194).

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