Design Overview

This reference design delivers an output short-circuit protection solution for the TPS61088 boost converter. This feature is realized by an over current protection (OCP) circuit. When the output is shorted to ground or the load current is higher than a certain value, the OCP circuit will disconnect the TPS61088 from the load. This solution just requires an additional low-cost comparator, a sense resistor, and a small sized N-MOSFET. With this small amount of additional circuitry, the TPS61088 is protected from being damaged in the output short circuit and over load conditions.

Design Features

- 2.7V to 4.2V input voltage range
- 5V/3A, 9V/2A and 12V/1.5A output capability
- Output short circuit and over load protection
- True disconnection between input and output during shut down
- Ideal for power bank, blue-tooth speaker application, etc.

Design Resources

- PMP9779: Design folder
- TPS61088: Product Folder

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1 Introduction

The Synchronous boost converter TPS61088 is an easy to use step-up DC-DC converter which provides a high efficiency and small size solution in portable systems. It is widely used in quick charge power bank, blue-tooth speaker, and portable POS terminal application, etc. The TPS61088 implements cycle-by-cycle current limit to protect the device from overload conditions during boost switching. This current limit function is realized by detecting the current flowing through the low side MOSFET. So the current limit feature will lose function in the output short circuit condition or the over load condition when the output voltage drops below the input voltage.

Lithium ion or lithium polymer battery is one of the key components in some portable systems, especially like power banks. Although these types of batteries are commonly used, the safety of the battery related products are always the utmost concern. The lithium ion or the lithium polymer battery has the potential risks of “fires” and “explosions” in short circuit, over voltage, or high temperature conditions. An increasing number of such catastrophes have been reported in the past few years.

To safeguard the consumers against bodily harm and property damage, UL announced the first dedicated safety standard UL2056 for power bank industry at the end of last year. The test items include output power overload test. So a power bank with output short circuit protection can easily pass the UL’s over load test and it is safe for the end customers in the case of output short circuit during the usage.

This reference design delivers an output short-circuit protection solution for the boost converter TPS61088. This feature is realized by an over current protection (OCP) circuit. When the output is shorted to ground or the load current is higher than a certain value, the TPS61088 will be disconnected from the load. This solution just requires an additional low-cost comparator, a sense resistor, and a small sized N-MOSFET. With this small amount of additional circuitry, the TPS61088 is protected from being damaged in the output short circuit and over load conditions.
2 Specification

Table 1 gives out the performance specification of this reference design. When the output current is higher than 4.4 A, the TPS61088 will be disconnected from the load.

<table>
<thead>
<tr>
<th>Input Voltage</th>
<th>Output Voltage/Output Current</th>
<th>Over Current Protection Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>3V-4.2V</td>
<td>5V/3A, 9V/2A, 12V/1.5A</td>
<td>Io ≥ 4.4A</td>
</tr>
</tbody>
</table>

3 Design Process

This section provides the PMP9779 block diagram introduction and the over current protection circuit design. For the power components and compensation network calculation, please refer to the TPS61088 datasheet.

3.1 Block Diagram

Figure 1 shows the block diagram of this reference design. A shunt resistor Rs is placed in the output return. It converts the output current to a voltage signal VSENSE. In the overload or output short circuit condition, VSENSE is higher than the reference voltage VREF. The comparator TL331’s output signal VO_TL331 gets high, so Q2 turns on and Q1 turns off. Thus the boost converter TPS61088 is disconnected from the load. When the output overload or short circuit condition is removed, the circuits can recovery by toggling (disable then enable) the TPS61088’s EN pin.
3.2 Over Current Protection Circuit Design

3.2.1 Setting Over Current Protection Point

The over current protection point should be higher than the maximum output current. In this reference design, the maximum output current is 3 A (occurs at \( V_O = 5 \) V condition). We set the over current protection point at 4.4 A to avoid the protection circuit from false triggering at normal output current conditions.

3.2.2 Shunt Resistor Selection

Shunt resistor is the most versatile and cost effective means to measure the current. The voltage across it should be kept to a low value to reduce the power loss. In this reference design, the shunt resistor value \( R_S \) is chosen as 30 m\( \Omega \). The maximum continuous current \( I_{MEAN \_MAX} \) flowing through the shunt resistor before OCP is 4.4 A. So the maximum shunt voltage \( V_{SENSE \_MAX} \) can be calculated by the following equation:

\[
V_{SENSE \_MAX} = R_S \cdot I_{MEAN \_MAX}
\]  

(1)

The minimum power rating of the shunt resistor can be calculated by equation (2):

\[
P_{rating} = V_{SENSE \_MAX} \cdot I_{MEAN \_MAX}
\]

(2)

So the minimum power rating of the shunt resistor is calculated as 0.58W in this reference design. A general rule of thumb is multiplying this minimum power rating by 2. That is, we should choose a \( \geq 1 \) W resistor in this reference design to make it more robust in the overload or output short circuit condition.

3.2.3 Comparator Circuit Design

Figure 2 illustrates the hysteresis comparator circuit in this reference design. The reference voltage \( V_{REF} \) is put at the TL331’s inverting input, \( V_{REF} = 110 \) mV. The current sense signal \( V_{SENSE} \) is connected to the TL331’s non-inverting input through \( R_{12} \).

During the normal operation, the output current is lower than the over current protection point, the comparator’s output is at logic low (0 V). So the voltage \( V_{NON \_INVERTING} \) at the TL331’s non-inverting positive input is:

\[
V_{NON \_INVERTING} = V_{SENSE} \cdot \frac{R_{15}}{R_{15} + R_{12}}
\]

(3)

When the output current increases to the targeted transition point, we have:
Insert (4) and (5) into equation (3), we can get:

\[ R_{15} = 5 \cdot R_{12} \]  \hspace{1cm} (6)

So select \( R_{12} = 100 \, \text{k}\Omega \), \( R_{15} = 499 \, \text{k}\Omega \) in this reference design.

After the over current protection, the comparator’s output is at logic high. Q1 turns off. The TPS61088 disconnects with the load. In order to avoid the Q1 being turned on and off frequently before fault clearing, the voltage \( V_{\text{NON-INVERTING}} \) at the TL331’s positive input should always higher than the reference voltage \( V_{\text{REF}} \) after OCP happens. We can realize this by choosing an appropriate resistance \( R_{16} \) under the minimum input voltage condition:

\[ V_{\text{IN_MIN}} \left( \frac{R_{12}}{R_{12} + R_{15} + R_{16}} \right) \geq V_{\text{REF}} \]  \hspace{1cm} (7)

\[ R_{16} \leq \frac{V_{\text{IN_MIN}} - R_{12} - R_{15}}{V_{\text{REF}}} \]  \hspace{1cm} (8)

Where

- \( V_{\text{IN_MIN}} = 3V \)

We choose \( R_{16} = R_{12} = 100 \, \text{k}\Omega \) in this reference design.
4 Test Result

4.1 Startup Waveforms

Figure 3 shows the startup waveforms of the Q1’s gate drive signal, inductor current and the output voltage at $V_{\text{IN}} = 3.6\, \text{V}$ condition.

![Figure 3. Startup Waveforms at $V_{\text{IN}}$=3.6V ($V_{\text{O}}$ = 9V, $I_{\text{O}}$ = 2A)](image)

4.2 Short Circuit Protection Waveforms

Figure 4 shows the output short circuit protection performance at $V_{\text{O}}$=5 V condition. From the waveforms of the Q1’s gate drive signal $V_{\text{GS\_Q1}}$ and the output current $I_{\text{O}}$, we can see that the TPS61088 can be disconnected from the load within 5 us in the output short circuit condition.

![Figure 4. Output Short Circuit Performance at $V_{\text{O}}$=5V ($V_{\text{IN}}$ = 3.6V)](image)

Figure 5 shows the output short circuit protection performance at $V_{\text{O}}$=9 V condition. From the waveforms of the Q1’s gate drive signal $V_{\text{GS\_Q1}}$ and the output current $I_{\text{O}}$, we can see that the TPS61088 can be disconnected from the load within 5 us in the output short circuit condition.
Figure 6 shows the output short circuit protection performance at $V_O=12$ V condition. From the waveforms of the Q1’s gate drive signal $V_{gs,Q1}$ and the output current $I_O$, we can see that the TPS61088 can be disconnected from the load within 5 us in the output short circuit condition.

![Figure 6. Output Short Circuit Performance at $V_O=12$ V ($V_{IN}=3.6$ V)](image-url)
5 Schematic, Bill of Materials and PCB Layout

This section provides the PMP9779 schematic, bill of materials (BOM) and board layout.

5.1 Schematic

Figure 7 illustrates the schematic of this reference design.

Figure 7. PMP9779 Schematic
## 5.2 Bill of Materials

Table 2 displays the PMP9779 bill of materials.

### Table 2. PMP9779 Bill of Materials

<table>
<thead>
<tr>
<th>Designator</th>
<th>QTY</th>
<th>Value</th>
<th>Description</th>
<th>Package</th>
<th>Part Number</th>
<th>MFG</th>
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<td>22uF</td>
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<td>MuRata</td>
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<td>SON 3.3x3.3mm</td>
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5.3  **PCB Layout**

Figure 8 through Figure 13 show the PMP9779 PCB layout.

**Figure 8.** PMP9779 Top Layer and Top Silkscreen

**Figure 9.** PMP9779 Bottom Layer and Bottom Silkscreen

**Figure 10.** PMP9779 Internal Layer 1
Figure 11. PMP9779 Internal Layer 2

Figure 12. PMP9779 Top-side Assembly Drawing

Figure 13. PMP9779 Bottom-side Assembly Drawing
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