**TI Designs: PMP9772**

**Low-Input Voltage High-Current Boost Converter With TPS61088**

---

**TI Designs**

TI Designs are analog solutions created by TI’s analog experts. Reference designs offer the theory, component selection, and simulation of useful circuits. Circuit modifications that help to meet alternate design goals are also discussed.

---

**Circuit Description**

The TPS61088 is a high power density boost converter which can provide more than 10A peak switching current. This converter’s minimum input voltage of the VIN pin is 2.7V, which makes it unfit for the lower input voltage application. VIN pin is an independent IC power supply pin for the internal control circuit.

This reference design delivers a very low input voltage high current boost application with a combination of the TPS61088 and the TLV61220. The TLV61220 is a low-input voltage boost converter. Its minimum input voltage is 0.7V. Setting the TLV61220’s output voltage to 5.5V to supply the TPS61088’s VIN pin, can make the TPS61088 also fit for the low input voltage application.

---

**Design Resources**

- **Design Page**
- **TPS61088**
- **TLV61220**
- All Design files
- Product Folder
- Product Folder

---

An IMPORTANT NOTICE at the end of this TI reference design addresses authorized use, intellectual property matters and other important disclaimers and information.

TINA-TI is a trademark of Texas Instruments
WEBENCH is a registered trademark of Texas Instruments
1 Introduction

In some single-cell NiMH or alkaline battery powered systems and some single super-capacitor powered systems, the customers hope the equipment can keep the rated output power even the input voltage drops to a low value. For NiMH or alkaline battery powered systems, this value is around 1V; for super-capacitor powered system, this value can be down to 0.75V. So in these applications, the power stages have to handle big input current.

This reference design delivers a low input voltage high current boost application with a combination of the TPS61088 and the TLV61220. The TPS61088 is a high power density boost converter which can provides more than 10A peak switching current. This converter’s minimum input voltage of the VIN pin is 2.7V, which makes it unfit for the lower input voltage application. VIN pin is an independent IC power supply pin for the internal control circuit.

The TLV61220 is a low-input voltage boost converter. Its minimum input voltage is 0.7V. Setting the TLV61220’s output voltage to 5.5V to supply the TPS61088’s VIN pin, can make the TPS61088 also fit for the low input voltage application. The TLV61220 is a low cost and small package boost converter. So this reference design is a cost effective solution for the low input voltage and high input current boost application.
2 Design Process

2.1 Power Specification

The following table gives out the maximum output power capability @ Vin=0.9V condition. This is the design target for this reference design.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Maximum Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>0.9-2.7V</td>
</tr>
<tr>
<td>Output</td>
<td>3.3V</td>
</tr>
</tbody>
</table>

2.2 Reference Design Schematic

![Reference Design Schematic](image)

Figure 1. Schematic of the Reference Design

2.3 Output Voltage Setting

The TLV61220’s output is connected to the TPS61088’s VIN pin. This VIN pin is the IC power supply input for the internal control circuit. To ensure the TPS61088 work properly, the voltage added to the VIN pin should be higher than 5V. Here, we set the TLV61220’s output voltage \( V_{o,ctrl} \) to 5.5V. A standard low side resistor \( R_{14} \) of 100 k\( \Omega \) is selected. The high side resistor \( R_{13} \) can be calculated by the following equation:

\[
R_{13} = R_{14} \times \frac{V_{o,ctrl}}{V_{FB1}} \times 1M\Omega
\]

(1)

From the TPS61088’s datasheet, we know that the FB pin’s maximum leakage current is 100nA. So the current through the resistance divider should be higher than 20uA to ensure the output voltage precision and noise covering. A standard low side resistor \( R_{3} \) of 56.2 k\( \Omega \) is selected. So the high side resistor \( R_{2} \) can be calculated as:
\[ R_2 = R_3 \cdot \left( \frac{V_o}{V_{FB2}} - 1 \right) \approx 97.6k\Omega \]  \hspace{1cm} \text{(2)}

Where
- \( V_{FB1} \) is the TLV61220's feedback regulation voltage (500mV).
- \( V_{FB2} \) is the TPS61088's feedback regulation voltage (\( V_{FB2} = 1.212V \) under PFM mode).

### 2.4 Switching Frequency Setting

The TPS61088's switching frequency is set by the resistor \( R_7 \) which is connected between the FSW pin and SW pin. This resistor can be calculated by the following equation:

\[
R_7 = \frac{4 \cdot \left( \frac{1}{f_{sw}} - t_{\text{DELAY}} \cdot \frac{V_o}{V_{\text{in}}} \right)}{C_{\text{FREQ}}} \approx 301k\Omega
\]  \hspace{1cm} \text{(3)}

Where
- \( f_{sw} \) is the desired switching frequency (\( f_{sw} = 500kHz \)).
- \( t_{\text{DELAY}} = 89 \) ns.
- \( C_{\text{FREQ}} = 23 \) pF.
- \( V_{\text{in}} \) is the input voltage.
- \( V_o \) is the output voltage (\( V_o = 3.3V \)).

### 2.5 Inductor Selection

The inductor \( L_1 \) is the most important component in the switching power supply design. Because it can affect the power supplier's steady state operation, transient behavior, loop stability, and the conversion efficiency.

One of the main parameter of the inductor is the saturation current. The saturation current of the selected inductor should be higher than the peak switching current at the maximum output power condition.

\[
P\_{o(\text{max})} = V_o \cdot I_{o(\text{max})} = 6.6W
\]  \hspace{1cm} \text{(4)}

Suppose the conversion efficiency \( \eta = 0.75 \) at the minimum input voltage condition, then the maximum input current is:

\[
I_{\text{in(max)}} = \frac{P\_{o(\text{max})}}{V_{\text{in(min)}} \cdot \eta} = 9.78A
\]  \hspace{1cm} \text{(5)}

As the maximum input current is very big, we set the inductor \( L_1 \)'s ripple current to about 20% of the average inductor current (input current). Then the peak switching current is:

\[
I_{sw(\text{peak})} = I_{\text{in(max)}} + I_{\text{in(max)}} \cdot \frac{0.2}{2} = 10.98A
\]  \hspace{1cm} \text{(6)}
So the inductor L1’s saturation current should be higher than 11A.

Another main parameter of the inductor is the inductor value. The inductor value can be calculated by the following equation:

\[
L_1 = \left( \frac{V_{\text{in(min)}}}{V_o} \right)^2 \cdot \left( \frac{V_o - V_{\text{in(min)}}}{I_{o(\text{max})} \cdot f_{\text{sw}}} \right) \cdot \left( \frac{\eta}{0.2} \right) \approx 0.68 \mu H
\]  

(7)

Where

- \( I_{o(\text{max})} \) is the maximum output current (\( I_{o(\text{max})} = 2A \)).
- \( V_{\text{in(min)}} \) is the minimum input voltage (\( V_{\text{in(min)}} = 0.9V \)).

Larger inductor value will results in smaller ripple current. In order to make the TPS61088 work properly, the inductor L1’s peak-to-peak ripple current should be higher than 1.3A. The ripple current can be calculated by the following equation:

\[
\Delta I_{L1_{\text{pp}}} = \frac{V_{\text{in(min)}} \cdot (V_o - V_{\text{in(min)}})}{L_1 \cdot f_{\text{sw}} \cdot V_o} = 1.925 A
\]  

(8)

The input current is about 10A. This is rather big comparing to the 6.6W maximum output power. So the inductor L1’s DCR is also a key factor during the inductor selection. DCR should be as low as possible to minimize the power loss.

Finally, make sure the selected inductor type is fit for the application. At switching frequencies of 500KHz, the inductor core loss, the proximity effect and the skin effect become very important. The inductor’s self-resonant frequency should be much higher than the operation frequency.

The inductor L2 is another important component in this reference design. In order to make the TLV61220 work properly, a suitable inductor must be selected. The inductor L2’s inductance can be calculated by the following equation:

\[
L_2 = \frac{V_{\text{in(min)}} \cdot (V_o \cdot f_{\text{ctrl}} - V_{\text{in(min)}})}{V_o \cdot f_{\text{ctrl}} \cdot 200mA} \approx 6.8 \mu H
\]  

(9)

Where

- \( f_{\text{ctrl}} \) is the operation frequency of TLV61220 (choose \( f_{\text{ctrl}}=500KHz \) @ \( V_{\text{in(min)}} = 0.9V \)).

### 2.6 Peak current limit Setting

The peak switch current limit is set by the external resistor R9 (Figure 1). We should make sure that the current limit point is higher than the required peak switch current at the lowest input voltage and highest output power condition. The current limit value under PFM mode can be calculated by the following equation:

\[
I_{L\text{IM}} = \frac{1190000}{R9} = 12.48 A
\]  

(10)

Where

- R9 is the resistance connected between the \( I_{L\text{IM}} \) pin and ground (R9=95.3KΩ).
- \( I_{L\text{IM}} \) is the peak switch current limit.
Considering the device variation and the tolerance over temperature, the minimum current limit at the worst case can be 1.3A lower than the value calculated by equation 10. The calculated value $I_{LIM}$ minus 1.3A should be higher than the peak switch current. So we choose $R9=95.3K$ and $I_{LIM}=12.48A$ to meet this design target.

If the MODE pin is short to ground, the current limit value is 1.6A lower than that of floating the MODE pin. We need to change $R9$ to 82.5k to ensure the maximum output power ($V_o=3.3V$, $I_o=2A$) under $V_{in}=0.9V$ condition.

2.7 Output Capacitor Selection

The output capacitors $C4$, $C5$ and $C6$ can be calculated with the following equation:

$$C_{out} = \frac{V_o - V_{in(min)}}{V_o \cdot f_{sw}} \cdot \frac{I_{o(max)}}{\Delta V_o}$$  \hspace{1cm} (11)

Where

- $\Delta V_o$ is the output voltage ripple.

Considering the capacitance derating under certain DC bias, three 22uF ceramic capacitors in parallel is fit for the $\Delta V_o=66mV$ application.

2.8 Compensation Circuit

The COMP pin is the output of the internal trans-conductance error amplifier. The following equation can be used to calculate $R8$ (Rcomp) and $C8$ (Ccomp) (Figure 1).

$$R8 = \frac{2\pi \cdot V_o \cdot R_{sense} \cdot f_c \cdot C_{out}}{(1-D) \cdot V_{FB2} \cdot G_{EA}}$$  \hspace{1cm} (12)

$$C8 = \frac{R_o \cdot C_{out}}{2 \cdot R8}$$  \hspace{1cm} (13)

Where:

- $f_c$ is the crossover frequency (choose $f_c=8k$ under $V_{in}=2.4V$).
- $R_{sense}$ is the equivalent internal current sense resistor, which is 0.08 $\Omega$.
- $D$ is the switching duty cycle under $V_{in}=2.4$ V.
- $C_{out}$ is the output capacitance (effective $C_{out}=50$ uF).
- $G_{EA}$ is the error amplifier's trans-conductance ($G_{EA}=190$ uA/V).
- $R_o$ is the output load resistance ($R_o=1.65$ $\Omega$).

$R8=3.92k$ and $C8=10nF$ are used in this reference design.

The value of $C13$ can be calculated by the equation 14:

$$C13 = \frac{R_{ESR} \cdot C_{out}}{R8}$$  \hspace{1cm} (14)
As the ESR of the output ceramic capacitor is very small, so the value of C13 is very small. Here we let C13=100pF to filter the high frequency noise at the COMP pin.

3 PCB Layout

This reference design is implemented in a 4.1cm×2.47cm and 2-layers PCB. All the components are placed on the top layer. Figure 2 shows the top layer and top silk screen. Figure 3 shows the layout of the bottom layer.

Figure 2 Top layer and Top Silkscreen

Figure 3 Bottom layer
4  Test Result

Figure 4.1 and Figure 4.2 show the inductor L1’s current, TPS61088’s SW pin voltage and the output voltage ripple at heavy load (V_o=3.3V, I_o=2A).

![Figure 4.1 Switching Waveforms at heavy load](image1)

![Figure 4.2 Switching Waveforms at heavy load](image2)

Figure 4.3 shows the inductor L1’s current, TPS61088’s SW pin voltage and the output voltage ripple in DCM mode. Figure 4.4 shows the inductor L1’s current, TPS61088’s SW pin voltage and the output voltage ripple in the PFM mode when operating at the light load.

![Figure 4.3 Switching Waveforms in DCM mode](image3)

![Figure 4.4 Switching Waveforms in PFM mode](image4)

Figure 5 shows the startup waveform of the inductor current and the output voltage at heavy load (V_o=3.3V, I_o=2A).

![Figure 5 Startup Waveform](image5)
Figure 6.1 and Figure 6.2 show the load transient (0.5A to 1.5A) response of the output voltage.

Figure 6.1 Load Transient (Vin=1.2V)  
Figure 6.2 Load Transient (Vin=2.4V)

Figure 7 shows the efficiency versus load current.

Figure 7.1 Efficiency VS. Load Current (Vo=3.3V)  
Figure 7.2 Efficiency VS. Load Current (Vo=5V)
IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated (“TI”) reference designs are solely intended to assist designers (“Buyers”) who are developing systems that incorporate TI semiconductor products (also referred to herein as “components”). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer’s systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design. TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER’S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer’s safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have not been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2015, Texas Instruments Incorporated