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TI Designs: PMP9772

Low-Input Voltage High-Current Boost Converter With TPS61088

TI Designs

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Circuit Description

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.
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	All Design files
TPS61088	Product Folder
TLV61220	Product Folder

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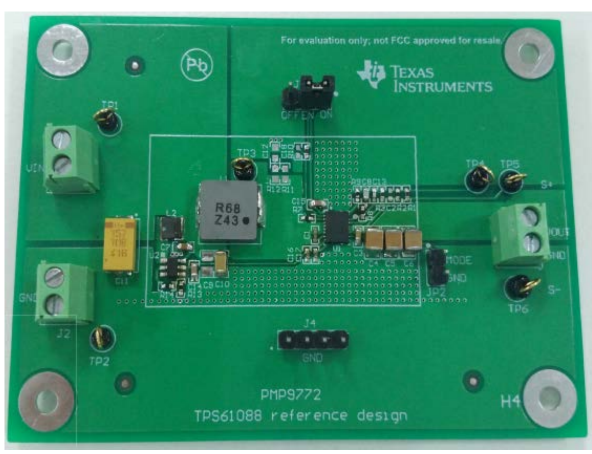

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1 Introduction

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 @ V_{in}=0.9V condition. This is the design target for this reference design.

Table 1. Input & Output Parameter

	Voltage	Maximum Current
Input	0.9-2.7V	--
Output	3.3V	2A

2.2 Reference Design Schematic

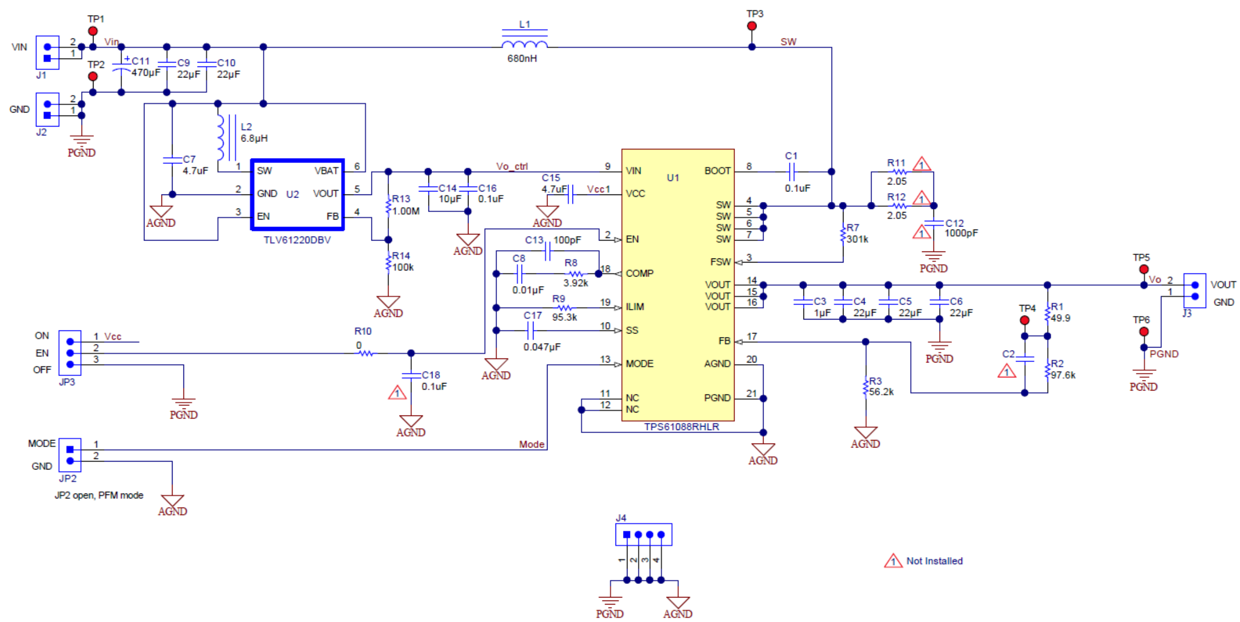

Figure 1. Schematic of the Reference Design

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 R14 of 100 kΩ is selected. The high side resistor R13 can be calculated by the following equation:

$$R13 = R14 \cdot (\frac{V_{o\_ctrl}}{V_{FB1}} - 1) = 1M\Omega \quad (1)$$

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 R3 of 56.2 kΩ is selected. So the high side resistor R2 can be calculated as:

$$R2 = R3 \cdot (\frac{V_o}{V_{FB2}} - 1) \approx 97.6k\Omega \quad (2)$$

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 R7 which is connected between the FSW pin and SW pin. This resistor can be calculated by the following equation:

$$R7 = \frac{4 \cdot (\frac{1}{f_{sw}} - t_{DELAY} \cdot \frac{V_o}{V_{in}})}{C_{FREQ}} \approx 301k\Omega \quad (3)$$

Where

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

2.5 Inductor Selection

The inductor L1 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.

$$P_{o(\max)} = V_o \cdot I_{o(\max)} = 6.6W \quad (4)$$

Suppose the conversion efficiency ɧ=0.75 at the minimum input voltage condition, then the maximum input current is:

$$I_{in(\max)} = \frac{P_{o(\max)}}{V_{in(\min)} \cdot \eta} = 9.78A \quad (5)$$

As the maximum input current is very big, we set the inductor L1's ripple current to about 20% of the average inductor current (input current). Then the peak switching current is:

$$I_{sw(peak)} = I_{in(\max)} + I_{in(\max)} \cdot \frac{0.2}{2} = 10.98A \quad (6)$$

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:

$$L1 = \left(\frac{V_{in(\min)}}{V_o}\right)^2 \cdot \left(\frac{V_o - V_{in(\min)}}{I_{o(\max)} \cdot f_{sw}}\right) \cdot \left(\frac{\eta}{0.2}\right) \approx 0.68uH \quad (7)$$

Where

- $I_{o(max)}$ is the maximum output current ($I_{o(max)}$ = 2A).
- $V_{in(min)}$ is the minimum input voltage ($V_{in(min)}$ = 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:

$$\Delta I_{L1\_pp} = \frac{V_{in(\min)} \cdot (V_o - V_{in(\min)})}{L_1 \cdot f_{sw} \cdot V_o} = 1.925A \quad (8)$$

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:

$$L2 = \frac{V_{in(\min)} \cdot (V_{o\_ctrl} - V_{in(\min)})}{V_{o\_ctrl} \cdot f_{ctrl} \cdot 200mA} \approx 6.8uH \quad (9)$$

Where

- f_{ctrl} is the operation frequency of TLV61220 (choose f_{ctrl}=500KHz @ $V_{in(min)}$ = 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:

$$I_{LIM} = \frac{1190000}{R9} = 12.48A \quad (10)$$

Where

- R9 is the resistance connected between the I_{LIM} pin and ground (R9=95.3KΩ).
- I_{LIM} 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:

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

Where

- ΔV_o is the output voltage ripple.

Considering the capacitance derating under certain DC bias, three 22uF ceramic capacitors in parallel is fit for the ΔV_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).

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

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

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 Ω.
- 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 Ω).

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

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

$$C13 = \frac{R_{ESR} \cdot C_{out}}{R8} \quad (14)$$

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.

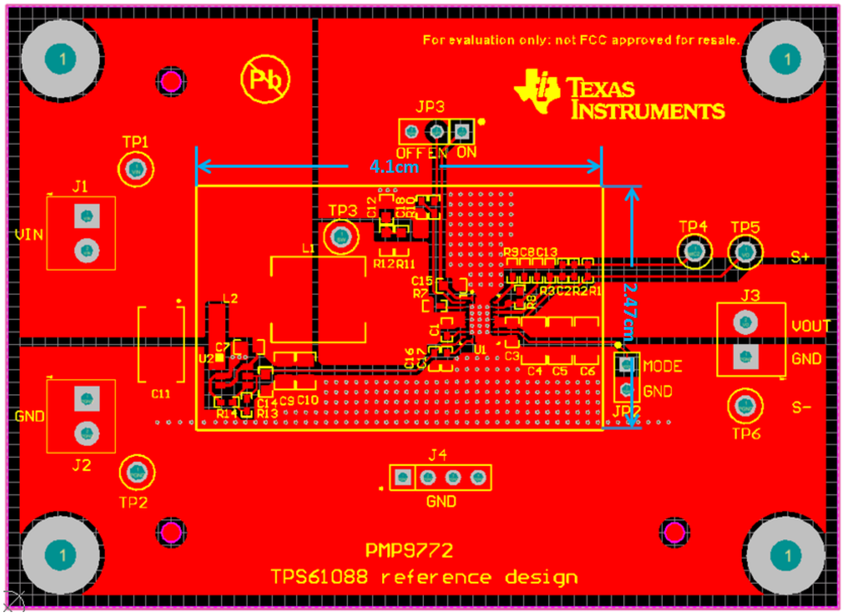

Figure 2 Top layer and Top Silkscreen

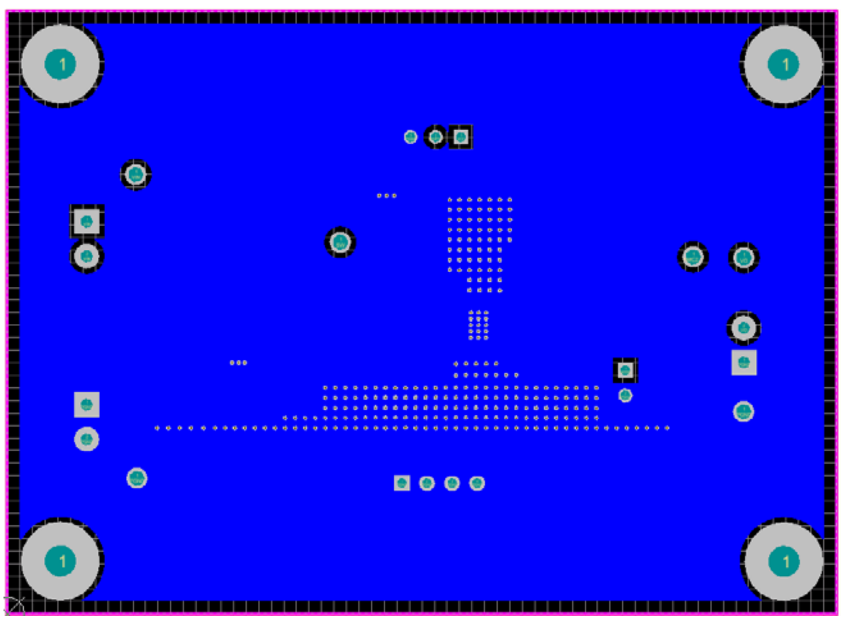

Figure 3 Bottom layer

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).

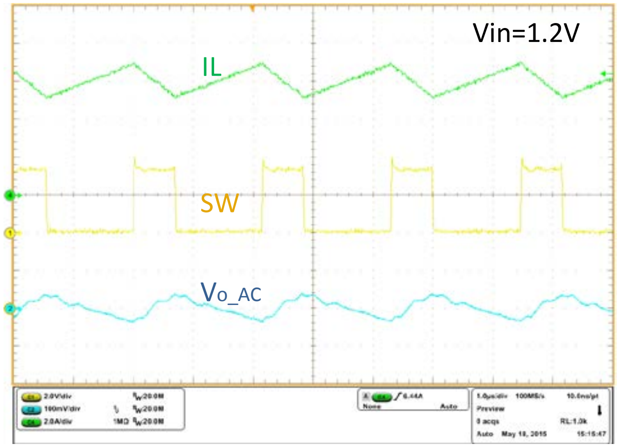

Figure 4.1 Switching Waveforms at heavy load

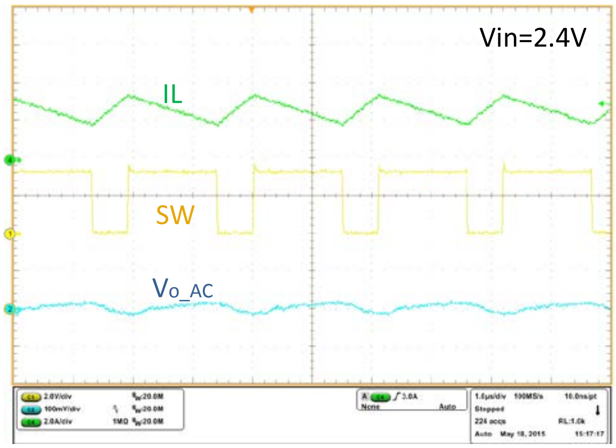

Figure 4.2 Switching Waveforms at heavy load

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.

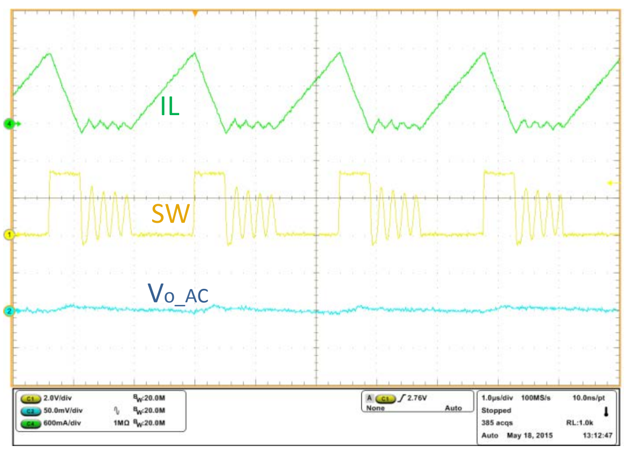

Figure 4.3 Switching Waveforms in DCM mode

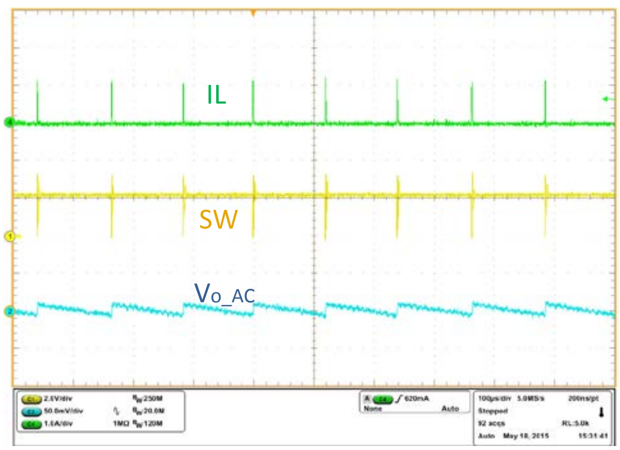

Figure 4.4 Switching Waveforms in PFM mode

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

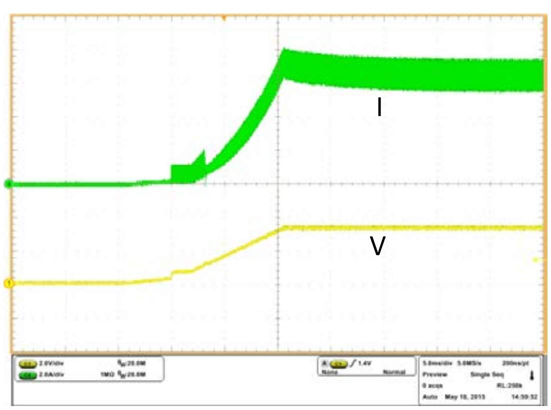

Figure 5 Startup Waveform

Figure 6.1 and Figure 6.2 show the load transient (0.5A to 1.5A) response of the output voltage.

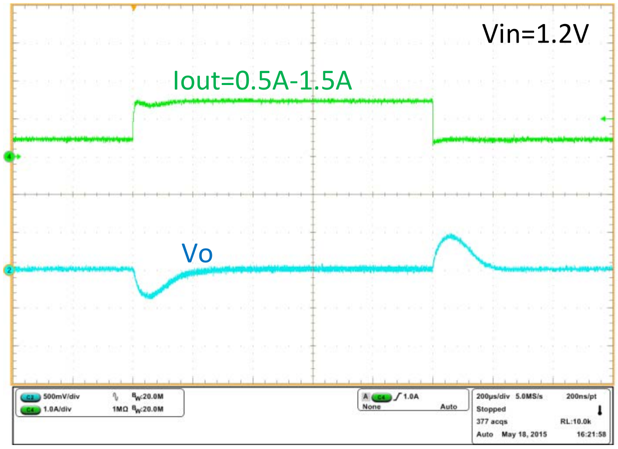

Figure 6.1 Load Transient (V_{in}=1.2V)

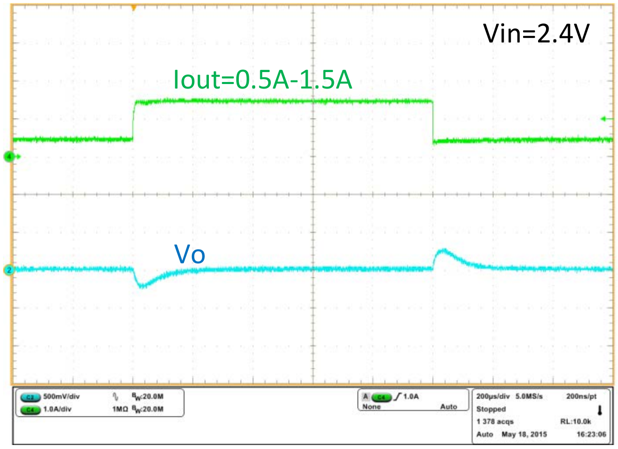

Figure 6.2 Load Transient (V_{in}=2.4V)

Figure 7 shows the efficiency versus load current.

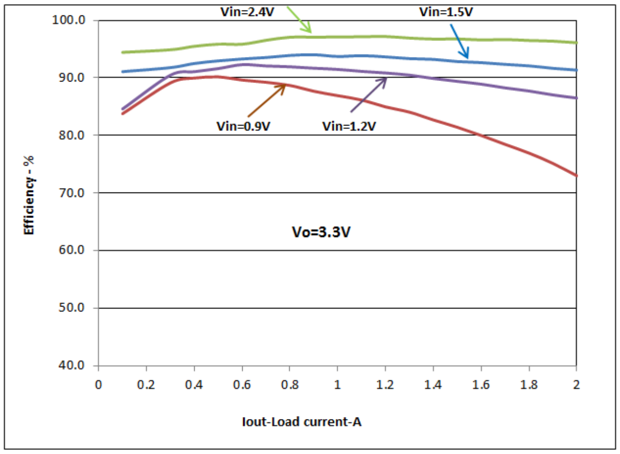

Figure 7.1 Efficiency VS. Load Current (V_o=3.3V)

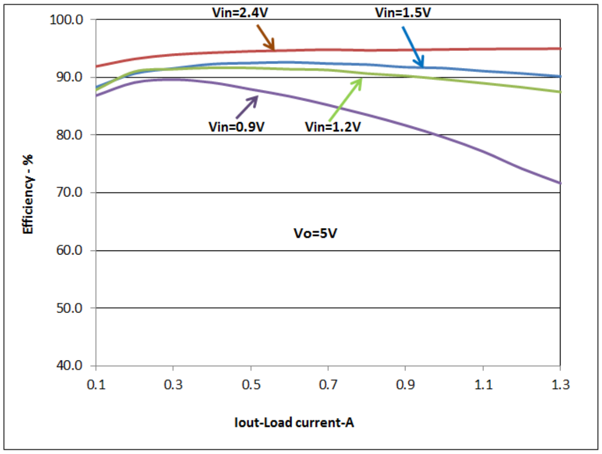

Figure 7.2 Efficiency VS. Load Current (V_o=5V)

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