

Working with Boost Converters

Frank De Stasi

ABSTRACT

This brief note highlights some of the more common pitfalls when using boost regulators. These include maximum achievable output current and voltage, short circuit behavior and basic layout issues. It is assumed that the reader is familiar with the basic operation of a boost regulator.

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1 Introduction

The boost converter is used to "step-up" an input voltage to some higher level, required by a load. This unique capability is achieved by storing energy in an inductor and releasing it to the load at a higher voltage. This brief note highlights some of the more common pitfalls when using boost regulators. These include maximum achievable output current and voltage, short circuit behavior and basic layout issues. The references at the end of this document provide excellent overviews of the operation of a boost regulator; and should be consulted if the reader is not familiar with the basic operation of this type of converter.

2 Nomenclature

- V_{IN} = Input voltage to regulator
- V_{OUT} = Output voltage of regulator
- I_{IN} = Input current to regulator
- I_{OUT} = Output current of regulator
- R_1 = Resistance of MOSFET switch
- R_2 = Resistance of synchronous MOSFET (if applicable)
- R_L = Resistance of inductor
- V_D = Diode voltage drop (if applicable)
- η = Efficiency of regulator
- D = Duty cycle; ratio of MOSFET on-time to period
- D_{MAX} = Maximum duty cycle reached by regulator

3 Output Power Limitations

3.1 Maximum Output Current

[Figure 1](#) shows simplified versions of both the boost and buck converters. Only the power stage is shown; a complete regulator requires more circuitry to regulate the output. We will start by looking at the buck. Note that one side of the inductor is connected to the output node. Since no DC current can flow through the output capacitor, the entire load current flows through the inductor. The other side of the inductor is connected to the common node between the MOSFET and diode. [Figure 2](#) shows the inductor and MOSFET current in CCM. If we ignore the small triangular ripple, it is easy to see that the peak MOSFET current is nearly the same as the load current. This makes it easy for the regulator manufacturer to specify the maximum load current that the regulator can supply. Regardless of the input or output voltage, the MOSFET can be sized for the maximum load current. Also, the current limit can be set just above this maximum value. So, the maximum MOSFET current rating of a buck is the maximum load current rating. As an example the LM43603 is rated for 3A on the data sheet. This is the maximum load current for this device.

This is not the case for a boost converter. Note from [Figure 1](#) that the inductor is connected from the input supply to the common node between the MOSFET and diode. Therefore the peak MOSFET current is now nearly equal to the *input current*, not the load current. We will see shortly that the input current depends on the input and output voltages of the converter. The boost regulator is still rated based on the maximum MOSFET current but this does not represent the maximum load current, as with the buck.

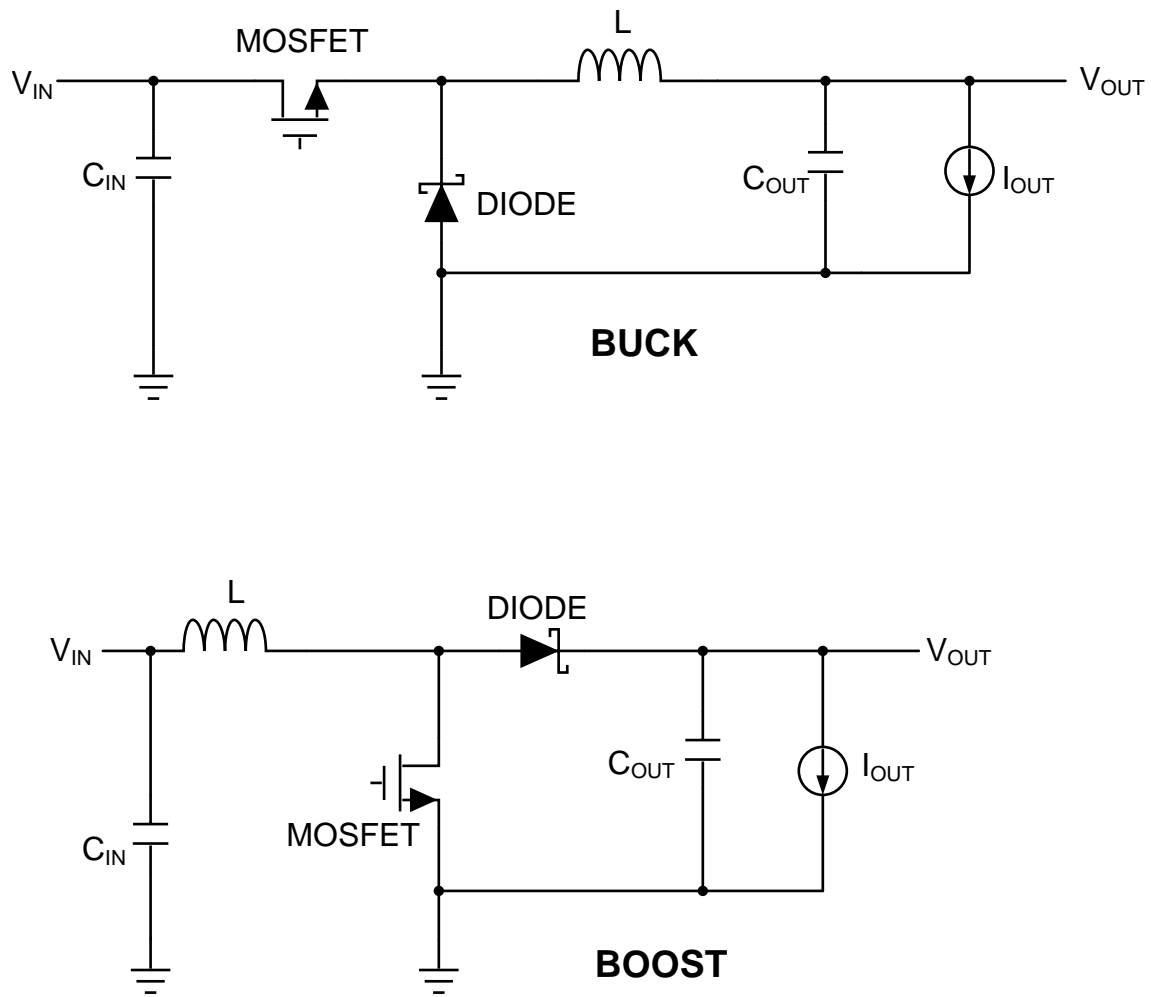
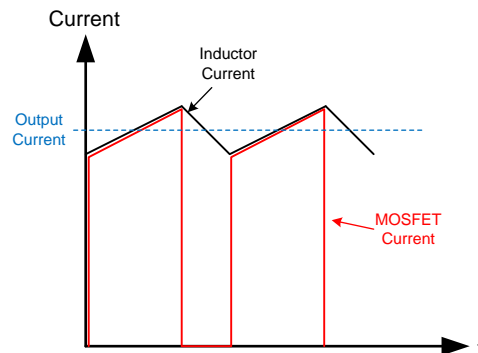


Figure 1. Buck and Boost Simplified Power Stage

Currents in Buck Regulator



Currents in Boost Regulator

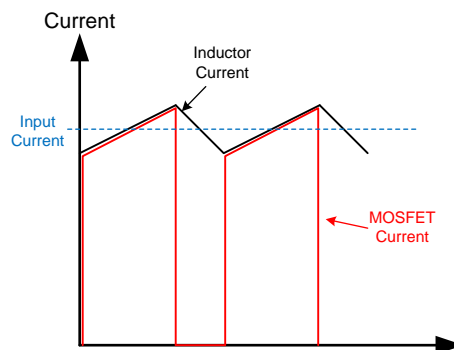


Figure 2. Inductor and MOSFET Current

The simplest way to calculate the input current of a boost regulator is to use the power balance equation, shown in [Equation 1](#). For a DC/DC converter, the input and output powers are just the product of their respective currents and voltages. Adding the triangular ripple current, we arrive at [Equation 2](#).

$$P_{IN} = \frac{P_{OUT}}{\eta} \quad (1)$$

$$I_{IN} = I_{OUT} \cdot \left(\frac{V_{OUT}}{V_{IN}} \right) \cdot \frac{1}{\eta} + \frac{\Delta I}{2} \quad (2)$$

This equation highlights the biggest stumbling block when working with boost converters: the input current will always be larger than the load current (I_{OUT}). Since the output voltage of a boost is always greater than the input voltage, the input current must be greater than the load current. This is a simple consequence of conservation of energy: the input power will be equal to the output power plus the losses. In this case the losses are taken care of by the efficiency factor, η . [Equation 2](#) also applies to a buck converter. And since the output voltage of a buck is less than the input voltage, the input current will be less than the load current, for any reasonable efficiency. As an example, suppose we wish to convert 6V to 12V at a load current of 2A. If the efficiency is 90%, and the peak-to-peak ripple current is 30% of the load, then [Equation 2](#) gives:

$$I_{IN} = 2A \cdot \frac{12V}{6V} \cdot \frac{1}{0.9} + \frac{2A \cdot 0.3}{2} = 4.74A \quad (3)$$

As mentioned above, the MOSFET in the regulator must be rated for this current and not the load current. It is easy to see that this current is much larger than the load. Devices such as the [LM2587](#) or [TPS55430](#) would be suitable for this application, based on a 90% efficiency. Note that both of these devices are specified as "5A" regulators; yet this rating is required to provide 2A of load current under these conditions.

All of the required information to use [Equation 2](#) is available to the designer except perhaps the efficiency. Unfortunately, it is difficult to predict the efficiency when designing a new application. As a first pass an efficiency of 100% ($\eta=1$) can be used. Then, when a candidate regulator is chosen, the efficiency curves in the data sheet can be used as a guide to refine the design. As always the WEBENCH® Design Tool can be used to generate a complete and optimized design for virtually any required regulator application.

3.2 Maximum Output Voltage

The most fundamental limitation on the maximum output voltage for the boost is the maximum rated voltage of the MOSFET and/or diode. This is specified in the data sheet and is one of the first steps in choosing a candidate converter for a given application. A more practical limitation arises from the maximum duty ratio at which the converter can operate. The duty ratio is defined as the on-time of the MOSFET divided by the total switching period. In all DC/DC converters the output voltage will be some function of this duty ratio. For the boost converter the approximate duty ratio (D) can be found with [Equation 4](#). Parasitic resistance in the inductor and MOSFET, and the diode voltage drop, will set an upper limit on the duty ratio and therefore the output voltage. As shown in [Figure 3](#), all practical boost regulators have a maximum duty cycle, beyond which the regulator will not boost. [Equation 5](#) can be used to find the approximate maximum duty ratio for a given load current, input voltage, and component resistance. This equation applies to both synchronous and non-synchronous converters. Also, the designer of the regulator may impose an upper limit to prevent control loop instabilities; this limit can usually be found in the data sheet. The smaller of this value and any maximum duty ratio given in the data sheet should be compared to that calculated in [Equation 4](#) to ensure that the candidate regulator will function correctly.

$$D = 1 - \frac{V_{IN} \cdot \eta}{V_{OUT}} \tag{4}$$

$$D_{MAX} \cong \frac{V_{IN} - I_{OUT} \cdot [R_1 + R_2 + 2 \cdot R_L]}{V_{IN} + I_{OUT} \cdot [R_1 - R_2]} \tag{5}$$

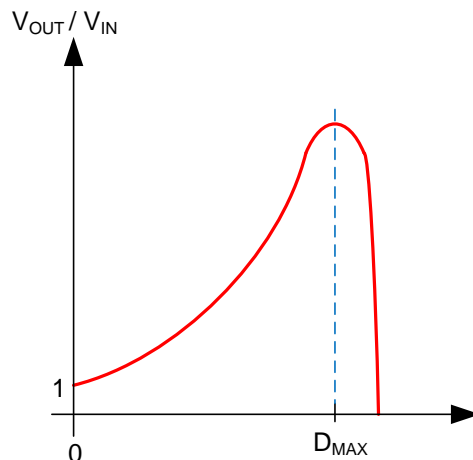


Figure 3. Boost Ratio vs. Duty Cycle

4 Example

The following example may help to illustrate some of the above considerations.

- $V_{IN} = 5V$ (min.)
- $V_{OUT} = 15V$
- $I_{OUT} = 1.2A$ (max.)
- $\eta = 0.8$
- $V_D = 0.4V$
- $R_L = 0.05\Omega$
- TPS55340: $R_1 = 0.11\Omega$, $D_{MAX} = 0.89$ From Data sheet
- D from [Equation 4](#) = **0.73**
- $D_{MAX} = \mathbf{0.93}$

Since 0.73 is less than 0.93 and 0.89, this design seems safe. However, [Equation 2](#) must also be checked. Substituting the example values we arrive at a peak current of about 4.7A. This is just within the minimum current limits of both the [LM2587](#) and [TPS55430](#). This example clearly shows the importance of checking both the maximum inductor current and maximum duty cycle when choosing a boost regulator. In this case for an input voltage of 5V and an output voltage of 15V, the maximum load current is about 1.2A when using a 5A boost regulator. ([Equation 6](#))

$$I_{IN} = 1.2A \cdot \frac{15V}{5V} \cdot \frac{1}{0.8} + \frac{1.2A \cdot 0.3}{2} = 4.7A \quad (6)$$

5 Short Circuits and Transients

5.1 Output Short Circuit

From [Figure 1](#) we see that there is a direct path between the input supply and the load for an ordinary non-synchronous boost converter. This has several implications. First, if the output is shorted, a potentially large current will flow from the input supply to the output short. Without going into the detailed circuit analysis, if the output of a boost regulator is pulled down to the input voltage or below, the inductor current will try to increase without limit. The regulator cannot prevent this, since at most it can only turn on the MOSFET. This will divert the current from the output, but will still cause large currents to flow from the input to ground. If the application requires that the converter survive a hard short on the output, then either some form of disconnect switch must be used or a more advanced boost architecture is required. For overloads that pull the output voltage out of regulation, while still above the input voltage, the current limit of the converter will protect the input supply and the power stage components.

5.2 Inrush Current

The other concern is the initial inrush current required to charge the output capacitor to the level of the input voltage. When the input supply is initially connected (such as "hot plugging" a battery to the system) the output capacitor will resonantly charge through the inductor and diode, even if the regulator is disabled. Once the output reaches the input voltage, the diode blocks and stops the current. The approximate waveforms are shown in [Figure 4](#). If we ignore the damping effects of the inductor resistance and load, we can approximate the charging time and peak current with [Equation 7](#).

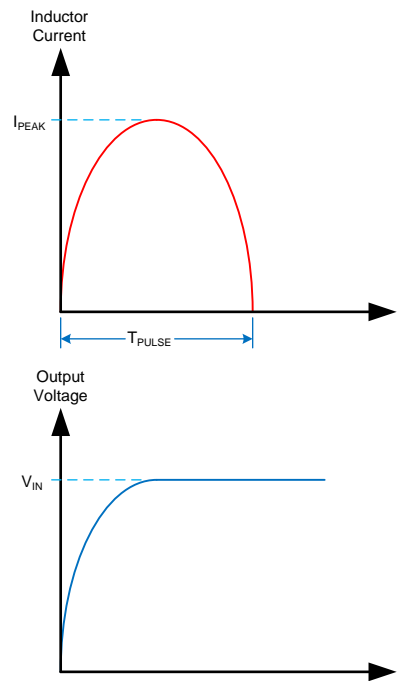


Figure 4. Boost Inrush Current

$$I_{PEAK} \cong V_{IN} \cdot \sqrt{\frac{C_{OUT}}{L}}$$

$$T_{PULSE} \cong \pi \cdot \sqrt{L \cdot C_{OUT}} \tag{7}$$

In many cases this current and/or the charging time will not be a major concern. However, it is good to check this detail.

5.3 Solutions

As mentioned above, the only way to avoid these issues is to either provide an input disconnect switch in the system or use a more sophisticated boost regulator. Boost converters such as the [LM3017](#) or [TPS61230](#) provide full isolation between input and output, including true shutdown and inrush current limiting. In the case of the TPS61230 this is accomplished by replacing the diode with a second MOSFET (synchronous MOSFET) and controlling both the gate and body voltages to completely open the path between input and output. The LM3017 is designed to control an external MOSFET in series with the inductor to provide true isolation.

6 PCB Layout

The PCB layout of any DC-DC converter is critical to the optimal performance of the design, and the boost converter is no exception. Bad PCB layout can disrupt the operation of an otherwise good schematic design. Even if the converter regulates correctly, bad PCB layout can mean the difference between a robust design and one that cannot be mass produced. Furthermore, the EMI performance of the regulator is dependent on the PCB layout, to a great extent. In a boost converter, the most critical PCB feature is the loop formed by the output capacitor, diode and the regulator ground, as shown in Figure 5.

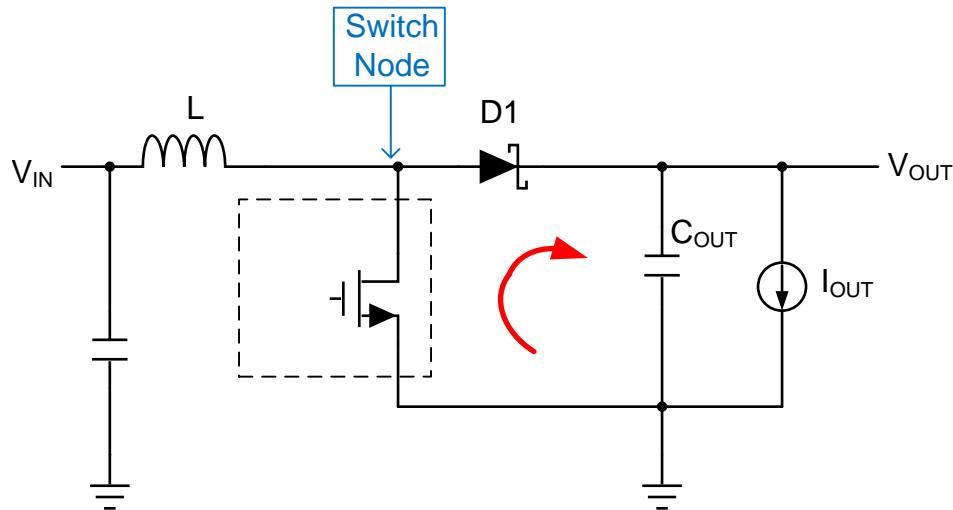
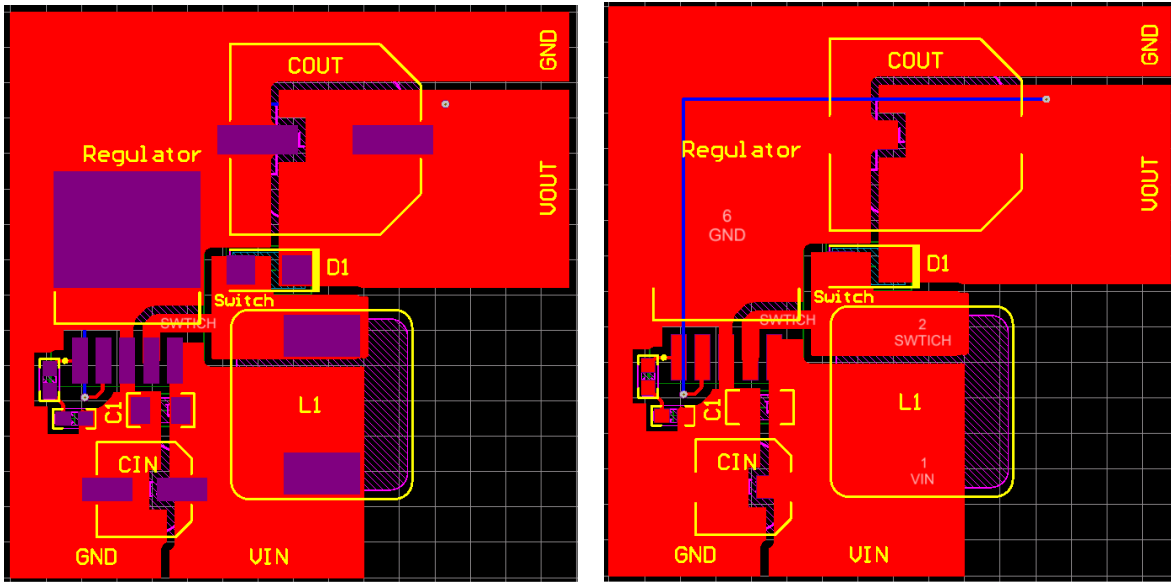


Figure 5. Fast Current Loops in Boost Regulator

This loop carries fast transient currents that can cause large transient voltages when reacting with the trace inductance. These unwanted transient voltages will disrupt the proper operation of the converter. Because of this, the traces in this loop should be wide and short, and the loop area as small as possible to reduce the parasitic inductance. Figure 6 shows a recommended layout for the critical components of a generic boost converter. The top-side metal is shown in red; the bottom in blue. The following important guidelines should be followed:

1. Keep the ground loop between the output capacitor, C_{OUT} , and the regulator (MOSFET) ground as small as possible.
2. Place the output capacitor, diode and inductor as close together as possible. This will keep the loop area small.
3. Note that the feedback is taken from near the output capacitor. In the example the trace is on the bottom and routed away from the noisy switch node. Avoid connecting the feedback between the output capacitor and diode.
4. Some devices require external compensation components; such as R_C and C_C . The ground of these components should be close to the ground of the regulator.
5. If the regulator requires a feedback divider, it should be placed physically close to the regulator. This divider should be grounded close to the regulator ground.



Top (red) and Solder Mask

Top (red) and Bottom (blue)

Figure 6. Example PCB Layout for the LM2587

7 Other Considerations

There are several other aspects of the complete design that need consideration. These include small signal stability, transient performance, power dissipation, and EMI. The best resource to address these issues is the data sheet for the candidate regulator. Of course, every design should be tested on the bench before committing to production. One of the best ways to begin a new design is with the WEBENCH® Design Tool. The resources found in [Table 1](#) should also prove helpful. Finally, some of our more popular boost regulators, and controllers, can be found in [Table 2](#).

Table 1. Boost Regulator Design Resources

TITLE	LINK
SLVA372 <i>Basic Calculation of a Boost Converter's Power Stage</i>	SLVA372
SNVA021 <i>Layout Guidelines for Switching Power Supplies</i>	SNVA021
SNVA408 <i>Modeling and Design of Current Mode Control Boost Converters</i>	SNVA408
SLVA633 <i>Practical Feedback Loop Analysis for a Voltage Mode Boost converter</i>	SLVA633
SLVA636 <i>Practical Feedback Loop Analysis for a Current Mode Boost converter</i>	SLVA636
SNVA067 <i>Compensation for the LM3478 Boost Controller</i>	SNVA067
SNVA255 <i>LM2735 Boost and SEPIC DC-DC Regulator</i>	SNVA255

Table 2. A Sample of Boost Regulators and Controllers

Device Name	Link
LMR62014	LMR62014
LMR61428	LMR61428
LMR62421	LMR62421
LM2735	LM2735
LM3478	LM3478
LM3488	LM3488
LM3017	LM3017
TPS61230	TPS61230
LM2587	LM2587
TPS55430	TPS55430

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