

# Basic Calculation of a Boost Converter's Power Stage

Brigitte Hauke

Low Power DC/DC Application

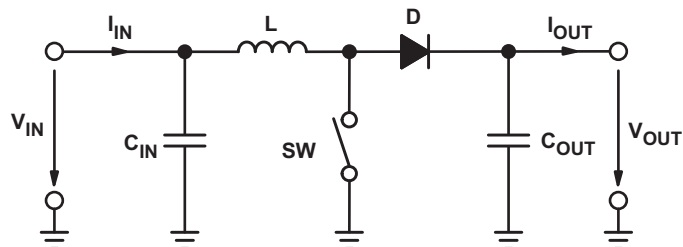
## ABSTRACT

This application note gives the equations to calculate the power stage of a boost converter built with an IC with integrated switch and operating in continuous conduction mode. It is not intended to give details on the functionality of a boost converter (see [Reference 1](#)) or how to compensate a converter. See the references at the end of this document if more detail is needed.

For the equations without description, See [section 8](#).

## 1 Basic Configuration of a Boost Converter

[Figure 1](#) shows the basic configuration of a boost converter where the switch is integrated in the used IC. Often lower power converters have the diode replaced by a second switch integrated into the converter. If this is the case, all equations in this document apply besides the power dissipation equation of the diode.



**Figure 1. Boost Converter Power Stage**

### 1.1 Necessary Parameters of the Power Stage

The following four parameters are needed to calculate the power stage:

1. Input Voltage Range:  $V_{IN(min)}$  and  $V_{IN(max)}$
2. Nominal Output Voltage:  $V_{OUT}$
3. Maximum Output Current:  $I_{OUT(max)}$
4. Integrated Circuit used to build the boost converter. This is necessary, because some parameters for the calculations have to be taken out of the data sheet.

If these parameters are known the calculation of the power stage can take place.

## 2 Calculate the Maximum Switch Current

The first step to calculate the switch current is to determine the duty cycle, D, for the minimum input voltage. The minimum input voltage is used because this leads to the maximum switch current.

$$D = 1 - \frac{V_{IN(min)} \times \eta}{V_{OUT}} \quad (1)$$

$V_{IN(min)}$  = minimum input voltage

$V_{OUT}$  = desired output voltage

$\eta$  = efficiency of the converter, e.g. estimated 80%

The efficiency is added to the duty cycle calculation, because the converter has to deliver also the energy dissipated. This calculation gives a more realistic duty cycle than just the equation without the efficiency factor.

Either an estimated factor, e.g. 80% (which is not unrealistic for a boost converter worst case efficiency), can be used or see the *Typical Characteristics* section of the selected converter's data sheet ([Reference 3 and 4](#)).

The next step to calculate the maximum switch current is to determine the inductor ripple current. In the converters data sheet normally a specific inductor or a range of inductors is named to use with the IC. So either use the recommended inductor value to calculate the ripple current, an inductor value in the middle of the recommended range or, if none is given in the data sheet, the one calculated in the [Inductor Selection](#) section of this application note.

$$\Delta I_L = \frac{V_{IN(min)} \times D}{f_s \times L} \quad (2)$$

$V_{IN(min)}$  = minimum input voltage

D = duty cycle calculated in [Equation 1](#)

$f_s$  = minimum switching frequency of the converter

L = selected inductor value

Now it has to be determined if the selected IC can deliver the maximum output current.

$$I_{MAXOUT} = \left( I_{LIM(min)} - \frac{\Delta I_L}{2} \right) \times (1-D) \quad (3)$$

$I_{LIM(min)}$  = minimum value of the current limit of the integrated switch (given in the data sheet)

$\Delta I_L$  = inductor ripple current calculated in [Equation 2](#)

D = duty cycle calculated in [Equation 1](#)

If the calculated value for the maximum output current of the selected IC,  $I_{MAXOUT}$ , is below the systems required maximum output current, another IC with a higher switch current limit has to be used.

Only if the calculate value for  $I_{MAXOUT}$  is just a little smaller than the needed one, it is possible to use the selected IC with an inductor with higher inductance if it is still in the recommended range. A higher inductance reduces the ripple current and therefore increases the maximum output current with the selected IC.

If the calculated value is above the maximum output current of the application, the maximum switch current in the system is calculated:

$$I_{SW(max)} = \frac{\Delta I_L}{2} + \frac{I_{OUT(max)}}{1-D} \quad (4)$$

$\Delta I_L$  = inductor ripple current calculated in [Equation 2](#)

$I_{OUT(max)}$  = maximum output current necessary in the application

D = duty cycle calculated in [Equation 1](#)

This is the peak current, the inductor, the integrated switch(es) and the external diode has to withstand.

### 3 Inductor Selection

Often data sheets give a range of recommended inductor values. If this is the case, it is recommended to choose an inductor from this range. The higher the inductor value, the higher is the maximum output current because of the reduced ripple current.

The lower the inductor value, the smaller is the solution size. Note that the inductor must always have a higher current rating than the maximum current given in [Equation 4](#) because the current increases with decreasing inductance.

For parts where no inductor range is given, the following equation is a good estimation for the right inductor:

$$L = \frac{V_{IN} \times (V_{OUT} - V_{IN})}{\Delta I_L \times f_S \times V_{OUT}} \quad (5)$$

$V_{IN}$  = typical input voltage

$V_{OUT}$  = desired output voltage

$f_S$  = minimum switching frequency of the converter

$\Delta I_L$  = estimated inductor ripple current, see below

The inductor ripple current cannot be calculated with [Equation 1](#) because the inductor is not known. A good estimation for the inductor ripple current is 20% to 40% of the output current.

$$\Delta I_L = (0.2 \text{ to } 0.4) \times I_{OUT(max)} \times \frac{V_{OUT}}{V_{IN}} \quad (6)$$

$\Delta I_L$  = estimated inductor ripple current

$I_{OUT(max)}$  = maximum output current necessary in the application

### 4 Rectifier Diode Selection

To reduce losses, Schottky diodes should be used. The forward current rating needed is equal to the maximum output current:

$$I_F = I_{OUT(max)} \quad (7)$$

$I_F$  = average forward current of the rectifier diode

$I_{OUT(max)}$  = maximum output current necessary in the application

Schottky diodes have a much higher peak current rating than average rating. Therefore the higher peak current in the system is not a problem.

The other parameter that has to be checked is the power dissipation of the diode. It has to handle:

$$P_D = I_F \times V_F \quad (8)$$

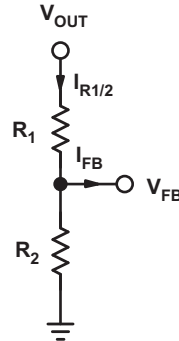
$I_F$  = average forward current of the rectifier diode

$V_F$  = forward voltage of the rectifier diode

## 5 Output Voltage Setting

Almost all converters set the output voltage with a resistive divider network (which is integrated if they are fixed output voltage converters).

With the given feedback voltage,  $V_{FB}$ , and feedback bias current,  $I_{FB}$ , the voltage divider can be calculated.



**Figure 2. Resistive Divider for Setting the Output Voltage**

The current through the resistive divider shall be at least 100 times as big as the feedback bias current:

$$I_{R1/2} \geq 100 \times I_{FB} \quad (9)$$

$I_{R1/2}$  = current through the resistive divider to GND

$I_{FB}$  = feedback bias current from data sheet

This adds less than 1% inaccuracy to the voltage measurement. The current can also be a lot higher. The only disadvantage of smaller resistor values is a higher power loss in the resistive divider, but the accuracy will be a little increased.

With the above assumption, the resistors are calculated as follows:

$$R_2 = \frac{V_{FB}}{I_{R1/2}} \quad (10)$$

$$R_1 = R_2 \times \left( \frac{V_{OUT}}{V_{FB}} - 1 \right) \quad (11)$$

$R_1, R_2$  = resistive divider, see [Figure 2](#).

$V_{FB}$  = feedback voltage from the data sheet

$I_{R1/2}$  = current through the resistive divider to GND, calculated in [Equation 9](#)

$V_{OUT}$  = desired output voltage

## 6 Input Capacitor Selection

The minimum value for the input capacitor is normally given in the data sheet. This minimum value is necessary to stabilize the input voltage due to the peak current requirement of a switching power supply. the best practice is to use low equivalent series resistance (ESR) ceramic capacitors. The dielectric material should be X5R or better. Otherwise, the capacitor can lose much of its capacitance due to DC bias or temperature (see [references 7 and 8](#)).

The value can be increased if the input voltage is noisy.

## 7 Output Capacitor Selection

Best practice is to use low ESR capacitors to minimize the ripple on the output voltage. Ceramic capacitors are a good choice if the dielectric material is X5R or better (see [reference 7 and 8](#)).

If the converter has external compensation, any capacitor value above the recommended minimum in the data sheet can be used, but the compensation has to be adjusted for the used output capacitance.

With internally compensated converters, the recommended inductor and capacitor values should be used or the recommendations in the data sheet for adjusting the output capacitors to the application should be followed for the ratio of  $L \times C$ .

With external compensation, the following equations can be used to adjust the output capacitor values for a desired output voltage ripple:

$$C_{\text{OUT}(\text{min})} = \frac{I_{\text{OUT}(\text{max})} \times D}{f_s \times \Delta V_{\text{OUT}}} \quad (12)$$

$C_{\text{OUT}(\text{min})}$  = minimum output capacitance

$I_{\text{OUT}(\text{max})}$  = maximum output current of the application

$D$  = duty cycle calculated with [Equation 1](#)

$f_s$  = minimum switching frequency of the converter

$\Delta V_{\text{OUT}}$  = desired output voltage ripple

The ESR of the output capacitor adds some more ripple, given with the equation:

$$\Delta V_{\text{OUT}(\text{ESR})} = \text{ESR} \times \left( \frac{I_{\text{OUT}(\text{max})}}{1-D} + \frac{\Delta I_L}{2} \right) \quad (13)$$

$\Delta V_{\text{OUT}(\text{ESR})}$  = additional output voltage ripple due to capacitors ESR

ESR = equivalent series resistance of the used output capacitor

$I_{\text{OUT}(\text{max})}$  = maximum output current of the application

$D$  = duty cycle calculated with [Equation 1](#)

$\Delta I_L$  = inductor ripple current from [Equation 2](#) or [Equation 6](#)

## 8 Equations to Calculate the Power Stage of a Boost Converter

$$\text{Maximum Duty Cycle: } D = 1 - \frac{V_{\text{IN}(\text{min})} \times \eta}{V_{\text{OUT}}} \quad (14)$$

$V_{\text{IN}(\text{min})}$  = minimum input voltage

$V_{\text{OUT}}$  = desired output voltage

$\eta$  = efficiency of the converter, e.g. estimated 85%

$$\text{Inductor Ripple Current: } \Delta I_L = \frac{V_{\text{IN}(\text{min})} \times D}{f_S \times L} \quad (15)$$

$V_{\text{IN}(\text{min})}$  = minimum input voltage

$D$  = duty cycle calculated in [Equation 14](#)

$f_S$  = minimum switching frequency of the converter

$L$  = selected inductor value

$$\text{Maximum output current of the selected IC: } I_{\text{MAXOUT}} = \left( I_{\text{LIM}(\text{min})} - \frac{\Delta I_L}{2} \right) \times (1-D) \quad (16)$$

$I_{\text{LIM}(\text{min})}$  = minimum value of the current limit of the integrated witch (given in the data sheet)

$\Delta I_L$  = inductor ripple current calculated in [Equation 15](#)

$D$  = duty cycle calculated in [Equation 14](#)

$$\text{Application specific maximum switch current: } I_{\text{SW}(\text{max})} = \frac{\Delta I_L}{2} + \frac{I_{\text{OUT}(\text{max})}}{1-D} \quad (17)$$

$\Delta I_L$  = inductor ripple current calculated in [Equation 15](#)

$I_{\text{OUT}(\text{max})}$  = maximum output current necessary in the application

$D$  = duty cycle calculated in [Equation 14](#)

$$\text{Inductor Calculation: } L = \frac{V_{\text{IN}} \times (V_{\text{OUT}} - V_{\text{IN}})}{\Delta I_L \times f_S \times V_{\text{OUT}}} \quad (18)$$

$V_{\text{IN}}$  = typical input voltage

$V_{\text{OUT}}$  = desired output voltage

$f_S$  = minimum switching frequency of the converter

$\Delta I_L$  = estimated inductor ripple current, see [Equation 19](#)

$$\text{Inductor Ripple Current Estimation: } \Delta I_L = (0.2 \text{ to } 0.4) \times I_{\text{OUT}(\text{max})} \times \frac{V_{\text{OUT}}}{V_{\text{IN}}} \quad (19)$$

$\Delta I_L$  = estimated inductor ripple current

$I_{\text{OUT}(\text{max})}$  = maximum output current necessary in the application

$$\text{Average Forward Current of Rectifier Diode: } I_F = I_{\text{OUT}(\text{max})} \quad (20)$$

$I_{\text{OUT}(\text{max})}$  = maximum output current necessary in the application

$$\text{Power Dissipation in Rectifier Diode: } P_D = I_F \times V_F \quad (21)$$

$I_F$  = average forward current of the rectifier diode

$V_F$  = forward voltage of the rectifier diode

$$\text{Current Through Resistive Divider Network for Output Voltage Setting: } I_{\text{R}1/2} \geq 100 \times I_{\text{FB}} \quad (22)$$

$I_{\text{FB}}$  = feedback bias current from data sheet

$$\text{Value of Resistor Between FB Pin and GND: } R_2 = \frac{V_{\text{FB}}}{I_{\text{R}1/2}} \quad (23)$$

Value of Resistor Between FB Pin and  $V_{OUT}$ :  $R_1 = R_2 \times \left( \frac{V_{OUT}}{V_{FB}} - 1 \right)$  (24)

$V_{FB}$  = feedback voltage from the data sheet

$I_{R1/2}$  = current through the resistive divider to GND, calculated in [Equation 22](#)

$V_{OUT}$  = desired output voltage

Minimum Output Capacitance, if not given in the data sheet:  $C_{OUT(min)} = \frac{I_{OUT(max)} \times D}{f_s \times \Delta V_{OUT}}$  (25)

$I_{OUT(max)}$  = maximum output current of the application

$D$  = duty cycle calculated in [Equation 14](#)

$f_s$  = minimum switching frequency of the converter

$\Delta V_{OUT}$  = desired output voltage ripple

Additional Output Voltage Ripple due to ESR:  $\Delta V_{OUT(ESR)} = ESR \times \left( \frac{I_{OUT(max)}}{1-D} + \frac{\Delta I_L}{2} \right)$  (26)

ESR = equivalent series resistance of the used output capacitor

$I_{OUT(max)}$  = maximum output current of the application

$D$  = duty cycle calculated in [Equation 14](#)

$\Delta I_L$  = inductor ripple current from [Equation 15](#) or [Equation 19](#)

## 9 References

1. *Understanding Boost Power Stages in Switchmode Power Supplies* ([SLVA061](#))
2. *Voltage Mode Boost Converter Small Signal Control Loop Analysis Using the TPS61030* ([SLVA274](#))
3. Data sheet of *TPS65148* ([SLVS904](#))
4. Data sheet of *TPS65130* and *TPS65131* ([SLVS493](#))
5. Robert W. Erickson: *Fundamentals of Power Electronics*, Kluwer Academic Publishers, 1997
6. Mohan/Underland/Robbins: *Power Electronics*, John Wiley & Sons Inc., Second Edition, 1995
7. *Improve Your Designs with Large Capacitance Value Multi-Layer Ceramic Chip (MLCC) Capacitors* by George M. Harayda, Akira Omi, and Axel Yamamoto, Panasonic
8. *Comparison of Multilayer Ceramic and Tantalum Capacitors* by Jeffrey Cain, Ph.D., AVX Corporation

## Revision History

Changes from B Revision (July 2010) to C Revision	Page
• Changed $V_{IN}$ to $V_{OUT}$ in <a href="#">Figure 2</a> .....	4

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from A Revision (April 2010) to B Revision	Page
• Changed $I_{OUT(max)} \times (1-D)$ To: $I_{OUT(max)} \times D$ in <a href="#">Equation 12</a> .....	5
• Changed $I_{OUT(max)} \times (1-D)$ To: $I_{OUT(max)} \times D$ in <a href="#">Equation 25</a> .....	7

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (November 2009) to A Revision	Page
• Added $V_{OUT}/V_{IN}$ (Typical) to <a href="#">Equation 6</a> .....	3
• added $V_{OUT}/V_{IN}$ (Typical) to <a href="#">Equation 19</a> .....	6

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.



## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve 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 (also referred to herein as "components") 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 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.

TI does not warrant or represent that any license, either express or implied, is granted under 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.

Reproduction of significant portions of TI information in TI data books or data sheets 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.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

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 which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm 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 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 a special agreement specifically governing such use.

Only those TI components which 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 which have **not** been so designated is solely at the Buyer's risk, and that 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.

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Applications Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Automotive and Transportation	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

### TI E2E Community

[e2e.ti.com](http://e2e.ti.com)