Application Note
Basic Calculation of a Boost Converter's Power Stage

TEXAS INSTRUMENTS

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.

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1 Basic Configuration of a Boost Converter

Figure 1-1 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.
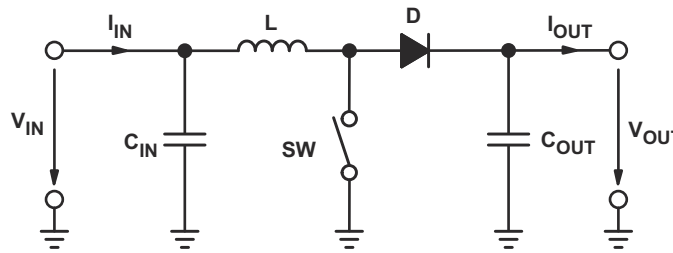

Figure 1-1. Boost Converter Power Stage

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.

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

(1)

$V_{IN(min)}$ = minimum input voltage
V_{OUT} = desired output voltage
η = 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.

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

(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.

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

(3)

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

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

(4)

ΔI_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:

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

(5)

V_{IN} = typical input voltage
V_{OUT} = desired output voltage
f_S = minimum switching frequency of the converter
ΔI_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.

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

(6)

ΔI_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:

$$I_F = I_{OUT(max)}$$

(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:

$$P_D = I_F \times V_F$$

(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.
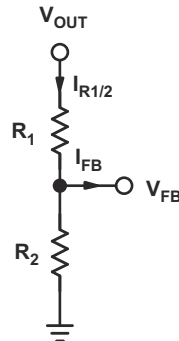
Figure 5-1. Resistive Divider for Setting the Output Voltage

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

$$I_{R1/2} \geq 100 \times I_{FB} \tag{9}$$

$I_{R1/2}$ = 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:

$$R_2 = \frac{V_{FB}}{I_{R1/2}} \tag{10}$$

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

R_1, R_2 = resistive divider, see Figure 5-1.
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 cane 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 × C.

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

$$C_{OUT(min)} = \frac{I_{OUT(max)} \times D}{f_S \times \Delta V_{OUT}}$$

(12)

$C_{OUT(min)}$ = minimum output capacitance
$I_{OUT(max)}$ = maximum output current of the application
D = duty cycle calculated with Equation 1
f_S = minimum switching frequency of the converter
ΔV_{OUT} = desired output voltage ripple

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

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

(13)

$\Delta V_{OUT(ESR)}$ = additional output voltage ripple due to capacitors ESR
ESR = equivalent series resistance of the used output capacitor
$I_{OUT(max)}$ = maximum output current of the application
D = duty cycle calculated with Equation 1
ΔI_L = inductor ripple current from Equation 2 or Equation 6

8 Equations to Calculate the Power Stage of a Boost Converter

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

(14)

$V_{IN(min)}$ = minimum input voltage
V_{OUT} = desired output voltage
η = efficiency of the converter, e.g. estimated 85%

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

(15)

$V_{IN(min)}$ = minimum input voltage
D = duty cycle calculated in Equation 14
f_S = minimum switching frequency of the converter
L = selected inductor value

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

(16)

$I_{LIM(min)}$ = minimum value of the current limit of the integrated witch (given in the data sheet)
ΔI_L = inductor ripple current calculated in Equation 15
D = duty cycle calculated in Equation 14

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

(17)

ΔI_L = inductor ripple current calculated in Equation 15
$I_{OUT(max)}$ = maximum output current necessary in the application
D = duty cycle calculated in Equation 14

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

(18)

V_{IN} = typical input voltage
V_{OUT} = desired output voltage
f_S = minimum switching frequency of the converter
ΔI_L = estimated inductor ripple current, see Equation 19

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

(19)

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

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

(20)

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

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

(21)

I_F = average forward current of the rectifier diode
V_F = forward voltage of the rectifier diode

Current Through Resistive Divider Newtwork for Output Voltage Setting: $I_{R1/2} \geq 100 \times I_{FB}$ (22)

I_{FB} = feedback bias current from data sheet

Value of Resistor Between FB Pin and GND: $R_2 = \dfrac{V_{FB}}{I_{R1/2}}$ (23)

Value of Resistor Between FB Pin and V_{OUT}: $R_1 = R_2 \times \left(\dfrac{V_{OUT}}{V_{FB}} - 1 \right)$ (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: $C_{OUT(min)} = \dfrac{I_{OUT(max)} \times D}{f_S \times \Delta V_{OUT}}$ (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
ΔV_{OUT} = desired output voltage ripple

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

10 Revision History

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