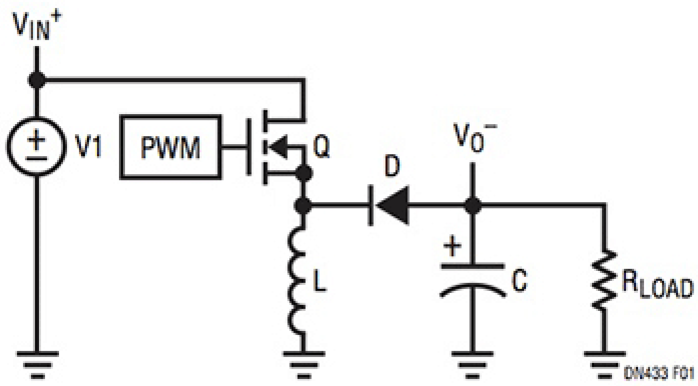
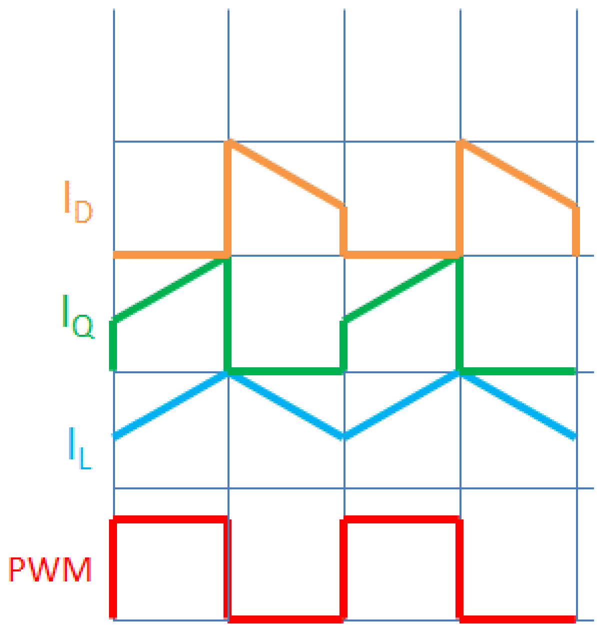
Inverting Buck-Boost Design

A buck-boost converter is a DCDC switching converter that combines the function of a buck and boost converter. Inverting buck-boost is a variant wherein the output is negative with respect to the ground.





1. Supply the Known Parameters

Start by defining the basics like input and output values. They must be given during the design stage.

Example:

Vin = 12V, Vout = -5V, Iout = 11A

Where;

- Vin – is the input voltage of the buck-boost converter
- Vout – is the output voltage
- Iout – is the load current

2. Compute the Ideal Duty Cycle

Buck-boost is a duty cycle-controlled DCDC converter. Once you are able to derive the duty cycle, you can compute the rest of the important parameters.

$$\boldsymbol{Duty} = \frac{\boldsymbol{-Vout}}{(\boldsymbol{Vin} - \boldsymbol{Vout})}$$

Using above given;

$$Duty = -\frac{Vout}{(Vin - Vout)} = -\frac{(-5V)}{[12V - (-5V)]} = \mathbf{29.412}\%$$

3. Define the Switching Frequency

You need to define what switching frequency level you will set for the converter. The defining factor in selecting the switching frequency is power density, controller capability, and EMI noise.

Example: $Fsw = \mathbf{250}\ \boldsymbol{kHz}$

4. Determine the Inductance Value

$$\boldsymbol{L1 = Ton \times \frac{Vin - VQ1}{\%di \times Iout}}$$

- $Ton = \frac{Duty}{Fsw} = \frac{0.29412}{250kHz} = \mathbf{1.18\,usec}$
-
- VQ1 – this is the voltage drop of the switch. Example: $VQ1 = \mathbf{0.2V}$
- %di –This is the set level of the inductor ripple current. This must be provided during the design stage. A good rule of thumb is 20%-40% of the load current. Example: $\%di = \mathbf{25\%}$
- Iout – this is the output current declared above

Thus;

$$L1 = Ton\,X\,\frac{(\,Vin - VQ1\,)}{(\,\%di\,X\,Iout\,)} = 1.18\,usec\,X\,\frac{(\,12V - 0.2V\,)}{(\,0.25\,X\,11A\,)} = \mathbf{5.06\,uH}$$

Consider a standard Inductor, say

$$L1\_selected = \mathbf{5uH}$$

5. Select the Inductor

Inductor Peak Current

$$Imax := -\frac{Iout - \frac{di\_actual \cdot (Duty - 1)}{2}}{Duty - 1}$$

$$\boxed{Imax = 16.972\,A}$$

Inductor DC Current

$$Idc_{L1} = Imax - di_{actual} + \frac{di_{actual}}{2} = 16.972A - 2.78A + \frac{2.78A}{2}$$
$$= \mathbf{15.582A}$$

Inductor RMS Current

$$Irms_{L1} = \left[\frac{di_{actual}}{\sqrt{3}}\right] + Imax - di_{actual} = \left[\frac{2.78A}{\sqrt{3}}\right] + 16.972A - 2.78A$$
$$= \mathbf{15.78A}$$

The selected inductor must have current rating that is higher to all the computed values above.

6. Select a MOSFET Switch

Peak Current

Imax = same inductor Imax above

DC Current

$$Idc\_Q1 := \frac{Duty \cdot di\_actual}{2} + Duty \cdot (Imax - di\_actual)$$

$$\boxed{Idc\_Q1 = 4.583\ A}$$

RMS Current

$$Irms\_Q1 := di\_actual \cdot \sqrt{\frac{Duty}{3}} + (Imax - di\_actual) \cdot \sqrt{Duty}$$

$$\boxed{Irms\_Q1 = 8.568\ A}$$

The selected switch must have a current rating higher than all the computed values above.

Voltage Stress

$$\boldsymbol{VQ1\_max = Vin + VD1 - Vout}$$

VD1 – this is the voltage drop of the diode. Example: VD1 = **0.7V**

Thus,

$$VQ1\_max = 12V + 0.7V - (-5V) = \mathbf{17.7V}$$

The selected MOSFET must have a voltage rating higher than this value with ample of margin.

Power Dissipation

Pdiss_Q1 = Ploss_conduction + Ploss_switching

$$\boldsymbol{Ploss_{conduction} = Irms_{Q1} \times Irms_{Q1} \times RDSon_{Q1}}$$

RDSon_Q1 = on state resistance, Example: RDSon_Q1 = **0.01 ohm**

Thus,

$$\begin{aligned} Ploss\_conduction &= Irms\_Q1\ X\ Irms\_Q1\ X\ RDSon\_Q1 \\ &= 8.568A\ X\ 8.568A\ X\ 0.01ohm = \mathbf{0.734W} \end{aligned}$$

Ploss_switching = Ploss_gatecharge + Ploss_COSS + Ploss_risefall

- Plos_gatecharge = ½ X Qgtotal X Vdrive X Fsw
- Qgtotal – this is the total gate charge indicated in the MOSFET datasheet. Example: Qgtotal = **1nC**
- Vdrive – this is the voltage applied to the gate to source of the MOSFET. Example: Vdrive = **12V**
- **Thus,**
- Ploss_gatecharge = ½ X Qgtotal X Vdrive X Fsw = 0.5 X 1nC X 12V X 250kHz = **0.0015W**
- Ploss_COSS = ½ X COSS X (Vdrain_max)^2 X Fsw
- COSS – this is the output capacitance of the MOSFET. Example: COSS = **1nF**
- Vdrain_max – this is the peak drain voltage. This is equal to the VQ1_max above.
- **Thus,**
- Ploss_COSS = ½ X COSS X (Vdrain_max)^2 X Fsw = 0.5 X 1nF X (17.7V)^2 X 250kHz = **0.039W**
- Ploss_risefall = 0.5 X (trise + tfall) X Irms_Q1 X Vdrive X Fsw
- trise – this is the rise time of the MOSFET. See datasheet. Example: trise = **1nsec**
- tfall – this is the fall time of the MOSFET. See datasheet. Example: tfall = **1nsec**
- **Thus,**
- Ploss_risefall = 0.5 X (trise + tfall) X Irms_Q1 X Vdrive X Fsw = 0.5 X (1nsec + 1nsec) X 8.568A X 12V X 250kHz = **0.025W**

Finally,

$$\begin{aligned} Pdiss\_Q1 &= Ploss\_conduction + Ploss\_switching \\ &= 0.734W + 0.0015W + 0.039W + 0.025W = \mathbf{0.8W} \end{aligned}$$

The selected MOSFET must have a power dissipation rating higher than this value with ample of margin.

7. Select the Diode

Peak Current

The diode peak current is the same to the peak inductor and MOSFET current.

$$Imax = same\ inductor\ Imax\ above$$

DC Current

The DC current of the diode is just equal to the output current

$$Idc\_diode = Iout$$

RMS Current

$$Irms\_diode := \sqrt{1 - Duty} \cdot \left[Imax - di\_actual \cdot \left(1 - \frac{\sqrt{3}}{3} \right) \right]$$

$$\boxed{Irms\_diode = 13.273\ A}$$

The selected diode must able to handle all the computed currents above with ample of margin.

Peak Reverse Voltage

$$\boldsymbol{PRV\_D1 = Vin - VQ1 - Vout}$$

Using all the values declared above,

$$PRV\_D1 = Vin - VQ1 - Vout = 12V - 0.2V - (-5V) = \mathbf{16.8V}$$

The selected diode voltage must be higher than this with more margin.

Power Dissipation

$$\boldsymbol{Ploss\_diode = VF\_diode \times Irms\_diode}$$

VF_diode – this is the forward voltage of the diode. See the datasheet.
Example: $VF\_diode = \mathbf{0.7V}$

Thus,

$$Ploss\_diode = VF\_diode \times Irms\_diode = 0.7V\ X\ 13.273A = \mathbf{9.29W}$$

The selected diode must have a power rating higher than this with a good margin.

8. Select the Output Capacitor

Ripple Current

$$Cout\_ripplecurrent := \sqrt{Irms\_diode^2 - Idc\_diode^2}$$

$$\boxed{Cout\_ripplecurrent = 7.428\ A}$$

The selected capacitor must have a ripple current higher than this with ample of margin.

Voltage

The selected output capacitor must have a voltage rating higher than the output voltage by a enough margin.

Minimum Capacitance

$$Cout\_min := \frac{irip\_Cout}{Fsw \cdot |Vout\_ripple|}$$

$$\boxed{Cout\_min = 2.971 \times 10^{-4}\,F}$$

Where;

$irip\_Cout := Cout\_ripplecurrent$

$\%ripple := 2\%$

This is percentage ripple of the output voltage. You need to set this.

$Vout\_ripple := \%ripple \cdot Vout$

Capacitor Equivalent series resistance (ESR)

$$ESR := \frac{|Vout\_ripple|}{Cout\_ripplecurrent}$$

$ESR = 0.013\,\Omega$