Switching Regulator Inductor Design

In switching regulator applications the inductor is used as an energy storage device, when the semiconductor switch is on the current in the inductor ramps up and energy is stored. When the switch turns off this energy is released into the load, the amount of energy stored is given by;

$$\text{Energy} = 1/2L.I^2 \qquad \text{(Joules)} \qquad (1)$$

Where L is the inductance in Henrys and I is the peak value of inductor current.

The amount by which the current changes during a switching cycle is known as the ripple current and is defined by the equation;

$$V_1 = L.di/dt \qquad (2)$$

Where V_1 is the voltage across the inductor, di is the ripple current and dt is the duration for which the voltage is applied. From this we can see that the value of ripple current is dependent upon the value of inductance.

Choosing the correct value of inductance is important in order to obtain acceptable inductor and output capacitor sizes and sufficiently low output voltage ripple.

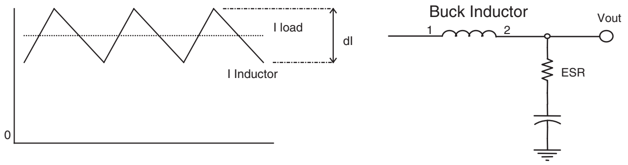

Figure 1

As can be seen from figure 1 inductor current is made up of AC and DC components, because the AC component is high frequency it will flow through the output capacitor as it has a low HF impedance. This will produce a ripple voltage due to the capacitor 'equivalent series resistance' (ESR) that will appear at the output of the switching regulator. This ripple voltage needs to be sufficiently low as not to effect the operation of the circuit the regulator is supplying, normally in the order of 10-500mVpk-pk.

Selecting the correct ripple current also impacts on the size of inductor and output capacitor, the capacitor will need to have a sufficiently high ripple current rating or it will overheat and dry out. In order to get a good compromise between inductor and capacitor size a ripple current value of 10-30% of maximum inductor current should be chosen. This also means that the current in the inductor will be continuous for output currents greater that 5-15% of full load.

Inductor Selection for Buck Converters

When selecting an inductor for a Buck converter, as with all switching regulators, you will need to define or calculate the following parameters:

- Maximum input voltage
- Output voltage
- Switching frequency
- Maximum ripple current
- Duty cycle

For the example shown in figure 2 lets assume a switching frequency of 250kHz, input voltage range of 12V±10% and a max ripple current of 220mA.

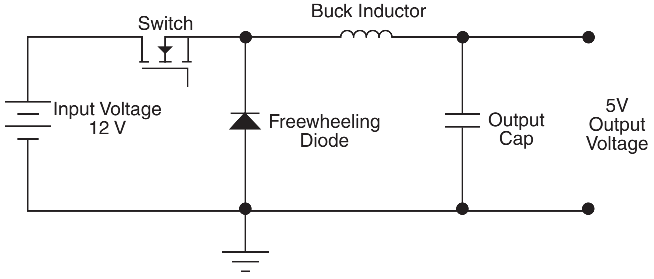

Figure 2

For an input voltage of 13.2V the duty cycle will be:

$$D = V_o/V_i = 5/13.2 = 0.379 \qquad (3)$$

Where V_o is the output voltage and V_i is the input voltage.

Voltage across the inductance:

$$V_1 = V_i - V_o = 8.2V \qquad \text{when the switch is on} \qquad (4)$$
$$V_1 = - V_o = -5V \qquad \text{when the switch is off} \qquad (5)$$

Require inductance:

$$L = V_1.dt/di = (8.2 \times 0.379/250 \times 10^3)/0.22 \qquad (6)$$
$$L = 56.5\mu H$$

Inductor Selection for Boost Converters

In order to calculate the require value of inductance for a Boost converter we follow the same procedure as described for the Buck converter, the difference being that the equations for duty cycle and inductor voltage change.

Taking maximum input voltage as 5.5V, switching frequency as 100kHz and maximum ripple current as 0.1A.

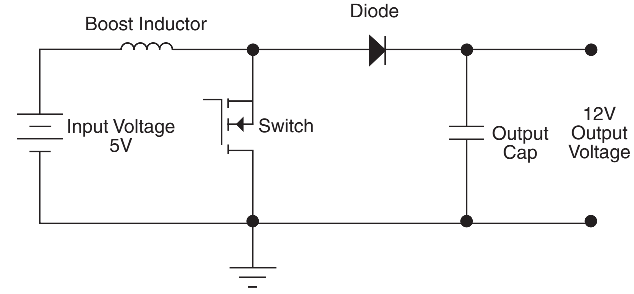

Figure 3

Duty cycle:

$$D = 1 - (V_i/V_o) = 1 - (5.5/12) = 0.542 \qquad (7)$$

Inductor Voltage:

$$V_1 = V_i = 5.5V \qquad \text{when the switch is on} \qquad (8)$$

$$V_1 = V_o - V_i = 6.5V \qquad \text{when the switch is off} \qquad (9)$$

Using equation 6, inductance:

$$L = (5.5 \times 0.542/100 \times 10^3)/0.1$$

$$L = 298\mu H$$

One thing to note about the Boost converter topology is that, unlike the Buck converter, inductor current does not continuously flow to the load. During the switch 'on' period the inductor current flows to ground and the load current is supplied from the output capacitor. This means that the output capacitor must have sufficient energy storage capability and ripple current rating in order to supply the load current during this period.

Inductor Selection for Buck-Boost Converters (including Cuk & SEPIC)

The procedure shown here is for the Cuk converter but it applies equally well to the SEPIC and the single inductor Buck-Boost topologies. Initially we will consider the circuit utilizing two separate inductors of equal value and then look at some of the advantages of using coupled inductors.

For this example we shall use a switching frequency of 200kHz and a maximum ripple current of 200mA.

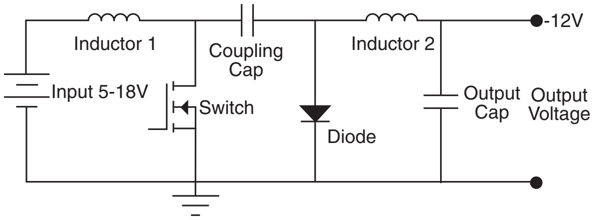

Figure 4

Duty cycle:

$$D = V_o/(V_o + V_i) = 12/(12+18) = 0.4 \qquad (10)$$

Inductor voltages:

$$V_1 = V_i = 18V \qquad \text{when the switch is on} \qquad (11)$$

$$V_1 = V_o = 12V \qquad \text{when the switch is off} \qquad (12)$$

Using equation 6, inductance:

$$L = (18 \times 0.4/200 \times 10^3)/0.2$$

$$L = 180\mu H$$

Both the SEPIC and Cuk topologies offer advantages over the single inductor Buck-Boost design. Input current is continuous resulting in lower peak values, drive circuit requirements are simple due to switch location and the use of a coupled inductor reduces the cost and PCB space penalties of these topologies.

One thing to note when using coupled inductors, for the total ripple current and total inductive energy stored to remain the same the inductance of each winding should be halved (for our example Lcouple = 90μH).

Visit us on the Web at www.cooperbussmann.com
1225 Broken Sound Pkwy. Suite F Boca Raton, FL 33487
Tel: +1-561-998-4100 Toll Free: +1-888-414-2645 Fax: +1-561-241-6640