Switching regulator inductor selection

Overview

In switching regulator applications the inductor is used as an energy storage device providing the ability for power and voltage conversion within a circuit. The basic converter topologies for switching regulator inductors are Buck (step-down), Boost (step-up), Buck-Boost (step-down/up) Cuk (step-up/down) and SEPIC (Step-down/up). This technical note looks at the basic operation of switching regulators and provides guidance on inductor selection for each of the converter topologies.

Basic Operation

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 calculated by the formula;

Energy = $1/2L \times I^2$ (Joules)

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 calculated by the formula;

$V1 = L \times di/dt$

V1 is the voltage across the inductor, di is the ripple current, and dt is the duration that the voltage is applied. This shows 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.

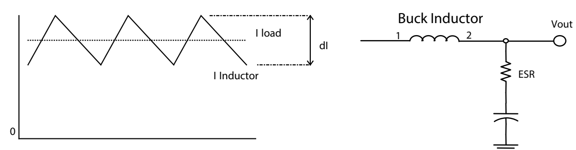

Figure 1. Simple switching regulator circuit operation

Figure 1 shows the inductor current is made up of AC and DC components. The AC component is high frequency and will flow through the output capacitor because it has a low HF impedance. A ripple voltage is produced by the capacitors 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 mVpk-pk - 500 mVpk-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. To achieve a good compromise between inductor and capacitor size a ripple current value of 10% - 30% of maximum inductor current should be chosen. The current in the inductor will be continuous for output currents greater that 5% - 15% of full load.

Inductor selection for Buck converters

The following criteria needs to be defined or calculated to be able to properly select a switching regulator inductor.

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

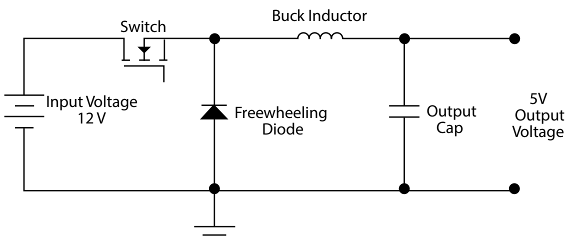

Figure 2. Buck inductor cricuit

Figure 2 is a typical Buck converter circuit. The defined application parameters for this example will be:

Switching frequency: 250 kHz

Input voltage range: 12 V ±10%

Maximum ripple current: 220 mA.

Output voltage: 5 V

Step 1. Calculate the duty cycle: D = Vo/Vi
D= duty cycle

Vo= output voltage

Vi= maximum input voltage

D= 5/13.2 = 0.379

Step 2. Calculate the voltage across the inductor

V1 = Vi – Vo (Switch on)

V1= 13.2 – 5 = 8.2 V

V1 = - Vo (Switch off)

V1= -5 V

Step 3. Calculate the required inductance
L = V1 (Switch on) x dt/di

L = (8.2 x 0.379/250 x 10^3)/0.22 = 56.5 µH

Inductor selection for Boost converters

The Boost converter uses the same procedure as the Buck converter with a modification of the formulas for duty cycle and inductor voltage change.

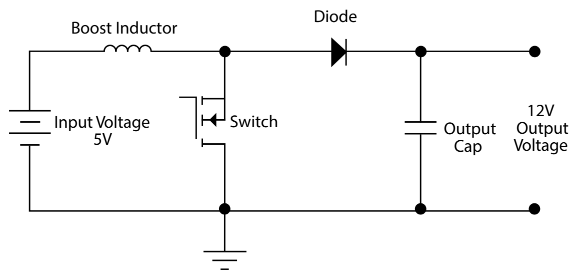

Figure 3. Boost inductor cricuit

Figure 3 is a typical Boost converter circuit. The defined application parameters for this example will be:

Switching frequency: 100 kHz

Maximum Input voltage: 5.5 V

Maximum ripple current: 100 mA.

Output voltage: 12 V

Step 1. Calculate the duty cycle: D = 1 – (Vi/Vo)

D= duty cycle

Vo= output voltage

Vi= maximum input voltage

D= 5.5/12 = 0.542

Step 2. Inductor voltage

V1 = Vi (Switch on)

V1= 5.5 V

V1 = Vo - Vi (Switch off)

V1= 6.5 V

Step 3. Calculate the required inductance
L = V1 (Switch on) x dt/di

L = (5.5 x 0.542/100 x 10^3)/0.1 = 298 µH

The Boost converter inductor current does not continuously flow to the load unlike that of the Buck converter. During the switch 'on' period the inductor current flows to ground and the load current is supplied from the output capacitor. The output capacitor therefore must have sufficient energy storage capability and ripple current rating in order to supply the load current during this period.

Inductor selection for Cuk converters (including Buck-Boost & SEPIC)

The procedure shown is for the Cuk converter but it applies equally well to the SEPIC and the single inductor Buck-Boost topologies. The example will be calculating for two separate inductors of equal value.

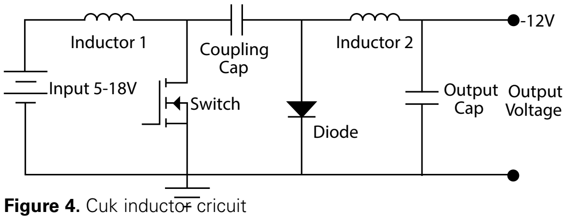

Figure 4. Cuk inductor cricuit

Figure 4 is a typical Cuk converter circuit.The defined application parameters for this example will be:

Switching frequency: 200 kHz

Maximum Input voltage: 18 V

Maximum ripple current: 200 mA.

Output voltage: -12 V

Step 1. Calculate the duty cycle: D = Vo/(Vo + Vi)

D= duty cycle

Vo= output voltage

Vi= maximum input voltage

D= 12/(12 + 18) = 0.4

Step 2. Inductor voltage

V1 = Vi (Switch on)

V1= 18 V

V1 = Vo (Switch off)

V1= 12 V

Step 3. Calculate the required inductance
L = V1 (Switch on) x dt/di

$L = (18 \times 0.4/200 \times 10^3)/0.2 = 180\ \mu H$

Both the SEPIC and Cuk topologies offer advantages over the single inductor Buck-Boost design. Input current is continuous resulting in lower peak values and drive circuit requirements are simple due to switch location. The use of a coupled inductor for the SEPIC and Cuk will also reduce the cost and board space penalties of the single inductor option and the inductor inductance needed will be half that of a single inductor design.

Eaton
1000 Eaton Boulevard
Cleveland, OH 44122
United States
www.eaton.com/electronics

Printed in USA
Publication No. 10637
December 2016

Powering Business Worldwide