Inductor Selection for SEPIC Designs

The SEPIC (single-ended primary inductance converter) in an increasingly popular topology, particularly in battery powered applications, as the input voltage can be higher or lower than the output voltage. This presents obvious design advantages but for many engineers the circuit operation and component selection is a mystery, for those that understand the basics the addition of a coupled inductor is an added complication. This article looks at the operation of the SEPIC and compares the design procedure for two single winding inductors with a coupled inductor approach.

Basic Operation

Figure 1 shows the simple circuit diagram for a SEPIC, during the switch (SW) ON time the voltage across both inductors is equal to Vin. This is obvious for L1, however it is not so clear for L2. In order to understand this we first need to look at the voltage across Cp, neglecting ripple voltage, this voltage is constantly at the value of Vin. The simplest way to see this is when the circuit is at equilibrium, under these conditions there is no DC voltage across L1 or L2, so one side of the capacitor is at Vin and the other at zero volts.

When the switch is ON capacitor Cp is connected in parallel with L2, hence the voltage across L2 is the same as the capacitor voltage, -Vin. This in turn means that diode D1 is reverse bias and the load current is being supplied by capacitor Cout. During this period energy is being stored in L1 from the input and in L2 from Cp.

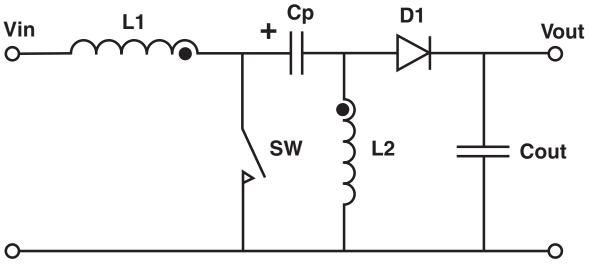

Figure 1 - Simple SEPIC Circuit

When the switch turns off the current in L1 continues to flow through Cp, D1 and into Cout and the load recharging Cp ready for the next cycle. The current in L2 also flows into Cout and the load, ensuring that Cout is recharged ready for the next cycle.

During this period the voltage across both L1 and L2 is equal to Vout, once again this is fairly clear for L2 but no so for L1. However we already know that the voltage across Cp is equal to Vin and that the voltage on L2 is equal to Vout, in order for this to be true the voltage at the node of Cp and L1 must be Vin + Vout. This in turn means that the voltage across L1 is (Vin+Vout) – Vin = Vout.

Inductor Selection

First, let us look at the selection of two separate inductors for L1 and L2 in the following example:

Input voltage (Vin) – 2.8V – 4.5V
Output (Vout & Iout) – 3.3V, 1A
Switching Frequency (Fs) – 250kHz
Efficiency - 90%

First we need to calculate the duty cycle;

D = Vout/(Vout + Vin)

The worst case condition for inductor ripple current is at maximum input voltage so;

D = 3.3/(3.3 + 4.5) = 0.423

Normally, the output inductor is sized to ensure that the inductor current is continuous at minimum load and that the output voltage ripple does not affect the circuit that the converter is powering. In this case we will assume a 20% minimum load thus allowing a 40% peak to peak ripple current in the output inductor L2.

Calculating the value of L2;

V = L di/dt

Where V is the voltage applied to the inductor, L in the inductance, di is the inductor peak to peak ripple current and dt is the duration the voltage is applied for. Hence;

L = V.dt/di

dt = 1/Fs x D
dt = 1/(250 x 10^3) x 0.423 = 1.69 μs

V = Vin during the switch ON time so;

L2 = 4.5 x (1.69 x 10^{-6}/0.4)
L2 = 19 μH

Using the nearest preferred value would lead to the selection of a 22 μH inductor. It is common practice to select the same value for both input and output inductors in SEPIC designs although when two separate parts are being used it is not essential.

Having selected the inductance value we now need to calculate the required RMS and peak current ratings for both inductors.

For input inductor L1;

Irms = (Vout x Iout)/(Vin (min) * efficiency)
Irms = (3.3 x 1)/(2.8 x 0.9) = 1.31A

Ipeak = Irms + (0.5 x Iripple)

Although worst case ripple current is at maximum input voltage the peak current is normally highest at the minimum input voltage.

Iripple = (V.dt)/L
Iripple = (2.8 x 2.2 x 10^{-6})/22 x 10 -6 = 0.28A

Ipeak = 1.31 + 0.14 =1.45A

So a 22µH, 1.31Arms & 1.45Apk rated inductor is required. For example the DR73-220 from Cooper Bussmann's Coiltronics® range, this part is 7.5mm square and 3.5mm high with 1.62Arms and 1.67Apk current ratings.

For the output inductor L2

Irms = Iout = 1A

Iripple = (4.5 x 1.69 x 10^{-6})/22 x 10^{-6} = 0.346A

Ipeak = 1 + 0.173 = 1.173A

So a 22µH, 1Arms & 1.173Apk rated inductor is required, which for simplicity could be the same DR73-220 inductor used for L1.

Coupled Inductor Selection

When calculating the value for a coupled inductor you need to bear in mind that all the current is effectively flowing in one inductor and that if the two windings are closely coupled the ripple current will be split equally between them. So calculating the inductance value;

L = V.dt/di

From our earlier example the output ripple current needs to be 0.4Apk-pk, so now we calculate for 0.8A as the ripple current is split between the two windings

L = 4.5 x (1.69 x 10^{-6}/0.8) = 9.5µH

From this it can be seen that by using a coupled inductor the required inductance is halved. It is also important to note that because the two winding are on the same core they must be the same value. If they are not the voltage across each winding will not be equal and Cp will act as a short circuit to the difference.

Continuing with the example using an inductance value of 10µH we now need to calculate the worst case peak current requirement. We already know the RMS current in each winding,

Input inductor RMS current = 1.31A
Output inductor RMS current = 1A

Ipeak = Iin + Iout + (0.5 x Iripple)

Iripple = (2.8 x 2.2 x 10^{-6})/10 x 10^{-6} = 0.62A

Ipeak = 1.31 + 1 + 0.31 = 2.62A @ minimum input voltage

So a 10µH coupled inductor with 2.31Arms and 2.62Apk current ratings is required, for example the Coiltronics® DRQ74-100. This part has the same 7.5mm square footprint as the DR73-220 that was selected in the example using separate inductors but is 4.35mm high.

Using a coupled inductor takes up less space on the PCB and tends to be lower cost than two separate inductors. It also offers the option to have most of the inductor ripple current flow in either the input or the output. This is achieved by using a winding construction that positions most of the leakage inductance in one winding, this will cause most of the ripple current to appear in the opposite winding. By doing this the need for input filtering can be minimized or the output ripple voltage can be reduced to very low levels when supplying sensitive circuits.

Cooper Bussmann offer a number of coupled inductor options from the Coiltronics® range, including the SDQ and DRQ series of shielded drum inductors and the Econo-Pac and Octa-Pac range of toroid inductors. With inductance values from 0.33µH to 1mH and sizes from 5.2mm 2 x 1.2mm high up to 12.5mm 2 x 8mm high Coiltronics® offer one of the broadest ranges of coupled inductor solutions.

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