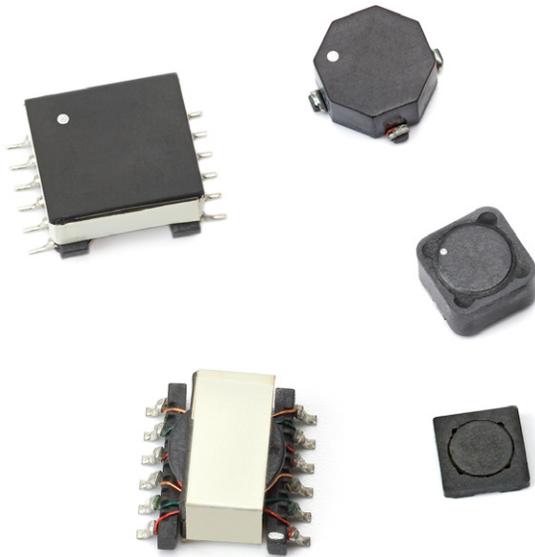


Inductor selection for SEPIC designs



Overview

The SEPIC (single-ended primary inductance converter) is 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 technical note 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 V_{in} . 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 C_p , neglecting ripple voltage, this voltage is constantly at the value of V_{in} . 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 V_{in} and the other at zero volts. When the switch is ON capacitor C_p is connected in parallel with L2, hence the voltage across L2 is the same as the capacitor voltage, $-V_{in}$. This in turn means that diode D1 is reverse bias and the load current is being supplied by capacitor C_{out} . During this period energy is being stored in L1 from the input and in L2 from C_p .

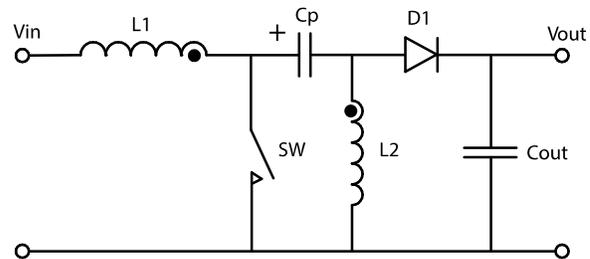


Figure 1. Simple SEPIC circuit

When the switch turns off the current in L1 continues to flow through C_p , D1 and into C_{out} and the load recharging C_p ready for the next cycle. The current in L2 also flows into C_{out} and the load, ensuring that C_{out} is recharged ready for the next cycle. During this period the voltage across both L1 and L2 is equal to V_{out} , once again this is fairly clear for L2 but no so for L1. However we already know that the voltage across C_p is equal to V_{in} and that the voltage on L2 is equal to V_{out} , in order for this to be true the voltage at the node of C_p and L1 must be $V_{in} + V_{out}$. This in turn means that the voltage across L1 is $(V_{in} + V_{out}) - V_{in} = V_{out}$.

Inductor Selection

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

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

Calculating the duty cycle (D);

$D = V_{out}/(V_{out} + V_{in})$
 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;

$V = L \times di/dt$
 Where V is the voltage applied to the inductor, L is the inductance, di is the inductor peak to peak ripple current and dt is the duration the voltage is applied for.
 $L = V \times dt/di$
 $dt = 1/F_s \times D$
 $dt = 1/(250 \times 10^3) \times 0.423 = 1.69 \mu s$
 $V = V_{in}$ during the switch ON time so;
 $L2 = 4.5 \times (1.69 \times 10^{-6}/0.4)$
 $L2 = 19 \mu H$
 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.

Input inductor L1;

$I_{rms} = (V_{out} \times I_{out}) / (V_{in} \text{ (min)} \times \text{efficiency})$
 $I_{rms} = (3.3 \times 1) / (2.8 \times 0.9) = 1.31 \text{ A}$
 $I_{peak} = I_{rms} + (0.5 \times \text{Ripple})$
 Although worst case ripple current is at maximum input voltage the peak current is normally highest at the minimum input voltage. Recalculate D and dt using minimum input voltage.
 $D = 3.3 / (3.3 + 2.8) = 0.540$
 $dt = 1 / (250 \times 10^3) \times 0.540 = 2.2 \mu s$
 $\text{Ripple} = (V \times dt) / L$
 $\text{Ripple} = (2.8 \times 2.2 \times 10^{-6}) / 22 \times 10^{-6} = 0.28 \text{ A}$
 $I_{peak} = 1.31 + (0.5 \times 0.28) = 1.45 \text{ A}$
 A 22 μH , 1.31 A rms and 1.45 A pk rated inductor is required. One such example would be the Eaton DR73-220-R inductor which is 7.5mm square and 3.5mm high with 1.62 A rms and 1.67 A pk current rating.

Output inductor L2

$I_{rms} = I_{out} = 1 \text{ A}$
 $\text{Ripple} = (4.5 \times 1.69 \times 10^{-6}) / 22 \times 10^{-6} = 0.346 \text{ A}$
 $I_{peak} = 1 + (0.5 \times 0.346) = 1.173 \text{ A}$
 A 22 μH , 1 A rms & 1.173 A pk rated inductor is required. For simplicity the Eaton DR73-220-R inductor could be selected for the L2 inductor also.

Coupled inductor selection

When calculating the value for a coupled inductor keep 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.

Calculating the inductance value:

$L = V \times dt/di$
 From our earlier example the output ripple current needs to be 0.4 A pk-pk, so now we calculate for 0.8 A pk-pk as the ripple current is split between the two windings.
 $L = 4.5 \times (1.69 \times 10^{-6}/0.8) = 9.5 \mu H$
 Using a coupled inductor allows the required inductance to be 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 10 μH ; calculate the worst case peak current requirement.
 Input inductor rms current = 1.31 A
 Output inductor rms current = 1 A
 $I_{peak} = I_{in} + I_{out} + (0.5 \times \text{Ripple})$
 $\text{Ripple} = (2.8 \times 2.2 \times 10^{-6}) / 10 \times 10^{-6} = 0.62 \text{ A}$
 $I_{peak} = 1.31 + 1 + (0.5 \times 0.62) = 2.62 \text{ A @ minimum input voltage}$
 A 10 μH coupled inductor with 2.31 A rms and 2.62 A pk current ratings is required, for example the Eaton DRQ74-100-R Inductor which is 7.5 mm square and 4.35 mm high.

Conclusion:

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.
 Eaton offers a number of coupled inductor options including the SDQ and DRQ family of shielded drum inductors, the Econo-Pac, Octa-Pac, and Octa-Pac plus range of toroid inductors and the Versa-Pac configurable inductor/transformer with inductance values from 0.30 μH to over 4.72 mH in a wide variety of sizes and current ranges.

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