Inductor selection for SEPIC designs

A few simple calculations can remove the mystery of a coupled-inductor approach

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The single-ended primary inductance converter (SEPIC) is an increasingly popular topology, particularly in battery-powered applications, as the input voltage can be higher or lower than the output voltage. While this offers obvious design advantages, the circuit operation and component selection is a mystery for many engineers.

Even for those who understand the basics, the addition of a coupled inductor adds complexity. This article looks at the operation of the SEPIC and compares the design procedure for two single winding inductors with a coupled inductor approach.

Coupled inductors can simplify your SEPIC circuit design.

Basic operation
In a simple SEPIC circuit (see Fig. 1) during switch-on (SW-ON), the voltage across both inductors is equal to $V_{\text{in}}$. This is obvious for $L_1$, however it is not so clear for $L_2$. 
Fig. 1. In a simple SEPIC circuit, both inductors will always see the same applied voltage.

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 Vdc across \( L_1 \) or \( L_2 \), so one side of the capacitor is at \( V_{in} \) and the other at 0 V.

When the switch is on, capacitor \( C_p \) is connected in parallel with \( L_2 \), hence the voltage across \( L_2 \) is the same as the capacitor voltage \( V_{in} \). This, in turn, means that diode \( D_1 \) is reverse-bias and the load current is being supplied by capacitor \( C_{out} \). During this period energy is being stored in \( L_1 \) from the input and in \( L_2 \) from \( C_p \).

When the switch turns off, the current in \( L_1 \) continues to flow through \( C_p \), \( D_1 \), and into \( C_{out} \), and the load recharges \( C_p \) to prepare for the next cycle. The current in \( L_2 \) also flows into \( C_{out} \) and the load, ensuring that \( C_{out} \) is recharged and ready for the next cycle.

During this period, the voltage across both \( L_1 \) and \( L_2 \) is equal to \( V_{out} \) (this is fairly clear for \( L_2 \) but no so for \( L_1 \)). However, we already know that the voltage across \( C_p \) is equal to \( V_{in} \) and that the voltage on \( L_2 \) is equal to \( V_{out} \).

For this to be true, the voltage at the node of \( C_p \) and \( L_1 \) must be \( V_{in} + V_{out} \). This in turn means that the voltage across \( L_1 \) is \( (V_{in} + V_{out}) - V_{in} = V_{out} \). The output inductor value and ratings are calculated using the same basic equations.

**Inductor selection**

First let us look at the selection of two separate inductors for \( L_1 \) and \( L_2 \), where input voltage is 2.8 to 4.5 V, and output is 3.3 V at 1 A. Switching frequency is 250 kHz, and efficiency is 90%.

Calculating the duty cycle \( (D=V_{out}/(V_{out}+V_{in}) \) is the first step. The worst-case condition for inductor ripple current is at maximum input voltage, meaning \( D = 3.3/(3.3 + 4.5) = 0.423 \).

Normally, output inductors are sized to ensure that inductor current is continuous at minimum load and 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 \( L_2 \).

To calculate the value of \( L_2 \), we use \( V = L \, \text{di/dt} \), where \( V \) is the voltage applied to the inductor, \( L \) is the inductance, \( \text{di} \) is the inductor's peak-to-peak ripple current, and \( \text{dt} \) is the duration the voltage is applied. Hence, \( L = V \, \text{dt/di} \).

\[
dt = \frac{1}{F_s \times D}
\]

\[
dt = \frac{1}{(250 \times 10^3) \times 0.423} = 1.69 \, \mu s
\]

Since \( V = V_{\text{in}} \) during SW ON time, \( L_2 = 4.5 \times (1.69 \times 10^{-6}/0.4) = 19 \, \mu H \).

Typically, we can use the nearest preferred value, which would lead to the selection of a 22-\( \mu H \) 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 \( L_1 \), \( I_{\text{rms}} = \frac{(V_{\text{out}} \times I_{\text{out}})}{V_{\text{in}} \, \text{min}} \times \text{efficiency} \), so

\[
I_{\text{rms}} = (3.3 \times 1)/(2.8 \times 0.9) = 1.31 \, A
\]

\[
I_{\text{peak}} = I_{\text{rms}} + (0.5 \times I_{\text{ripple}})
\]

Although worst-case ripple current is at maximum input voltage, the peak current is normally highest at the minimum input voltage. So a 22-\( \mu H \) 1.31-Arms/1.45-Apk inductor is required.

**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. If the two windings are closely coupled, the ripple current will be split equally between them. So we use \( L = V \, \text{dt/di} \) to calculate the inductance value.

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

\[
L = 4.5 \times (1.69 \times 10^{-6}/0.8) = 9.5 \, \mu H
\]

From this equation, it is evident using a coupled inductor halves the required inductance. 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 \( C_p \) will act as a short circuit to the difference.

Continuing with the example using an inductance value of 10 \( \mu H \), we now need to calculate the worst-case peak-current requirement. We already know the input-inductor rms current is
1.31 A and the Output-inductor rms current is 1 A, meaning

\[ I_{\text{peak}} = I_{\text{in}} + I_{\text{out}} + (0.5 \times I_{\text{ripple}}) \]

\[ I_{\text{ripple}} = \frac{(V \cdot dt)}{L} \]

\[ I_{\text{ripple}} = \frac{(2.8 \times 2.2 \times 10^{-6})}{10 \times 10^{-6}} = 0.62 \text{ A} \]

\[ I_{\text{peak}} = 1.31 + 1 + 0.31 = 2.62 \text{ A at minimum input voltage} \]

Under these circumstances, a 10-µH coupled inductor with 2.31-Arms and 2.62-Apk current ratings is required.

Using a coupled inductor typically takes up less space on the pc board 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, which 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.