Select inductors for buck converters to get optimum efficiency and reliability

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There are numerous articles online about inductor selection for buck converters, but it all boils down to the operational basics of the buck converter, and how the inductor works hand in hand with the rest of the components to provide a reliable and trouble-free buck converter.

Key considerations in inductor selection include:

- Inductance—the rated value of the inductor and its impact on the ripple current in the buck converter.
- DC current rating—translated from the output current needs of the buck converter, the DC current rating is linked directly to the temperature rise of the inductor and its DC resistance (DCR).
- Saturation current rating—translated from the buck converter's output current, ripple current and protection features.
- Core loss—translated or linked to the switching frequency and materials used by the inductor manufacturer.
- Size—linked to the specific use case.

All of these considerations are directly related to inductor specifications. Some specifications affect the reliability of the inductor, whereas some affect the reliability of the buck converter.

For example, consider a buck converter that uses an inductor with a low DC/root-mean-square (RMS) current rating. The RMS current rating of the inductor is defined as the current at which the inductor temperature rises by 40°C. Depending on the actual location of the inductor on the board, it may be possible to tolerate a higher operating temperature, but in some cases the odds stack up and the inductor may be placed next to or above another hot component. In some situations, the inductor has even fallen off the printed circuit board, thus affecting the reliability of the buck converter.

Using an inductor with a low saturation rating means that the inductance value is very low at operating conditions of the buck converter and can cause failures. The saturation level is typically defined as the DC current level at which the device's inductance declines to 70% of its nominal inductance.

There are some parameters that affect the reliability of components around the inductor; one example is the ripple current (ΔI), expressed in Equation 1.

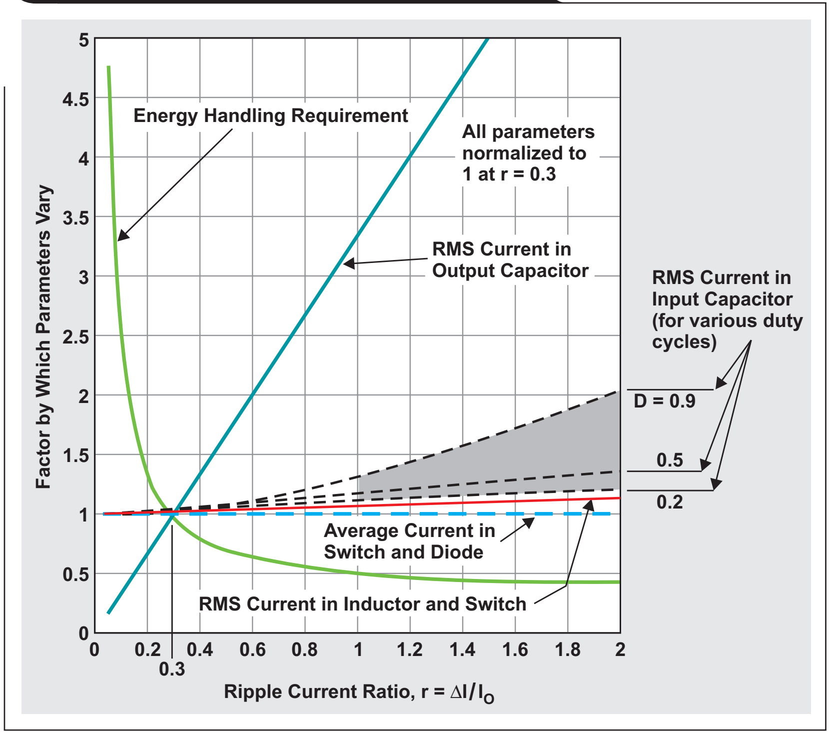
$$\Delta I = \frac{\left(V_{IN} - V_O\right) \times V_O}{L \times f_{SW} \times V_{IN}} \tag{1}$$

Ripple current is inversely proportional to the inductor value (L), switching frequency (f_{SW}) and input voltage (V_{IN}). High values of ripple current will increase the AC and core losses in the inductor and even affect the components around the inductor. For example, the ripple current directly affects the RMS current in the input and output capacitors. How is the ripple current defined as being too high? It is evaluated as a ratio to the output current, hence the term "ripple current ratio" (r). As shown in Equation 2, r is the ratio of the AC component of current to the DC component of current at maximum load conditions:

$$r = \frac{\Delta I}{I_O} \tag{2}$$

Figure 1 shows the key parameters affected by r. Note that the sweet spot for r is between 0.3 and 0.5. If r creeps to the high side, RMS current in the input and output capacitors and RMS current in the inductor will increase.

Figure 1. Optimization chart for setting r



For example, the RMS current in the output capacitor doubles as r goes from 0.3 to 0.6. It's important to carefully consider the type and number of input and output capacitors in designs with high r.

To demonstrate how the theory translates into practice, Figure 2 shows the total losses in the inductor as the inductance value and r vary. The optimal ranges for r and losses are shown by the shaded box. The total loss in the inductor stays relatively flat for an r range from 0.6 (60%) to 0.2 (20%). The trade-off shown in Figure 2 is that an r that is too low (higher inductance values) translates to higher DCR losses, and an r that is too high (lower inductance values) translates to higher core plus AC losses.

The efficiency of a buck controller shown in Figure 3 was plotted from the information in Figures 1 and 2 assuming that V_{IN} = 9 V and V_{OUT} = 4 V at 500 kHz, with 0.56-µH and 1-µH inductors. The inductor is of the same form factor and from one series, so as expected, the DCR doubles for the 1 µH compared to the 0.56 µH. Looking at the curves in Figure 3, note that the converter is more efficient at light loads when it operates at a lower r. Figure 3 also confirms that the analysis in Figure 2 is applicable for different duty cycles.

A general guideline derived from Figure 3 is that an inductor value for an r of around 0.3 to 0.4 (30% to 40%) will yield the best efficiency across a wide range of output currents.

Conclusion

By paying attention to the various parameters of the inductor specification sheet and selecting the right value, a buck converter can operate at optimum efficiency and improve the overall reliability of a design.

Related Web sites

"AN-1197 Selecting Inductors for Buck Converters," TI application report (SNVA038b), April 2013.

Figure 2. The XAL7070 series inductor used in a buck converter operating at 500 kHz

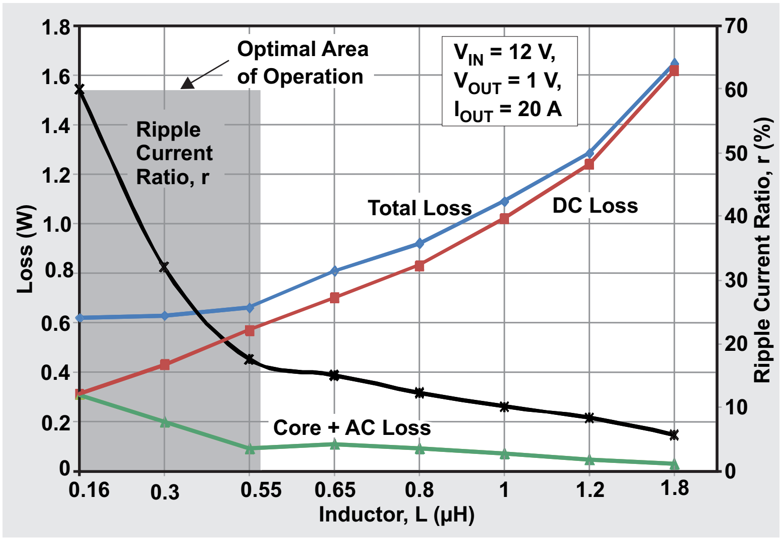
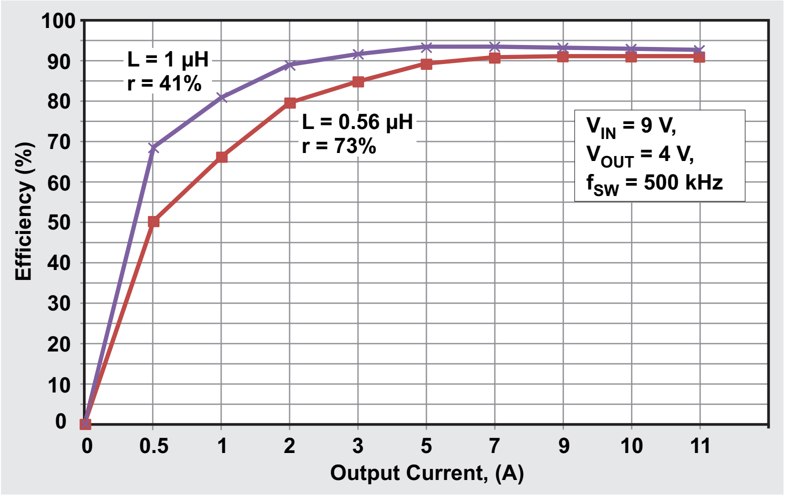


Figure 3. Efficiency for two inductor values



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