SELECTING A POWER INDUCTOR FOR YOUR SMPS DESIGN

Introduction

Choosing the right part shouldn't require knowledge of the Black Arts

The demand for higher power efficiencies and the proliferation of distributed power architecture has forced many design engineers — some of whom are more comfortable working in the digital domain — to turn their attention to system power requirements. Since these power considerations are no longer the preserve of the hardware design engineer, this article gives a step-by-step explanation of the fundamental requirements of power inductors in switch-mode power supplies (SMPS).

The Inductor in the SMPS

The SMPS can keep a constant V_{out} even if V_{in} varies (that is, a regulated output) by varying the duty cycle. One characteristic of an inductor is that the current flowing through it cannot change instantaneously, giving the SMPS a steady output current. Without the inductor, the current would drop to zero when the switch is open.

The Power Inductor

The practical power inductor consists of a wound conductor coil on a ferromagnetic material. This combination yields an inductance (L) that offers a reluctance to a change in current, and therefore the current through an inductor cannot change instantaneously.

The rate of change of current through an inductor (dI/dT) is determined by the inductance and the voltage dropped across the inductor, given by the expression: V = L*dI/dT.

Furthermore, the use of ferromagnetic material as the inductor core allows energy to be stored in the inductor. When a positive voltage is dropped across the inductor, the current increases and energy is added to the inductor.

It is these fundamental characteristics that make the inductor useful in the dc/dc converter, since it acts as both a current ripple filter and an energy-storage element. When the switch is closed, current flowing to the load increases and energy is also stored in the inductor.

When the switch is opened and the output is disconnected from the input, stable output current is maintained by drawing energy from the inductor. Since inductance determines the dI/dT, its value is selected to achieve desired limits to the ripple current (I_{ripple}), providing a steady output current.

The inductor can only hold a finite amount of energy before the ferromagnetic material will saturate, the inductance decreases, and ripple current increases. When making an inductor selection, it is important to check that the current at which the core saturates (I_{sat}) is greater than the application's peak inductor current, ($I_{pk} = I_{out} + I_{ripple}/2$).

Dissipated Losses

Another important consideration is that the temperature of the inductor will rise due to dissipated losses. The designer needs to consider copper loss and core loss.

Copper loss is due to the effective current (I_{rms}) flowing through the resistance (R_{dc}) of the conductor winding, simply expressed as: $P_{cu} = R_{dc} * I_{rms2}$. Inductor datasheets typically specify a given temperature rise current — for example, the equiva-lent dc current yielding a 40°C temperature rise. The lower value of the temperature rise and saturation current is termed the rated current of the inductor.

The mechanism of core loss is more complex. To begin, we need to recall that current flowing through an inductor winding induces a magnetic flux in the ferromagnetic material, or the core. So the changing current in our power inductor generates a changing flux density (Bac) and the reluctance of the core material tends to oppose this Bac.

As current flowing through the conductor results in copper losses due to the conductor's resistance to the flow of current, the core's reluctance to a changing flux generates a core loss. The core loss is determined by the type of core material, the amount of material, the Bac, and the frequency of change, that is, the switching frequency (F). A good power inductor datasheet will simplify this equation based on a calculated Bac for the operating condition of the inductor and the core material and size.

While the datasheet may specify a temperature rise current, it is important to note that where the core losses are significant, the inductor will reach the specified temperature rise at lower rms current due to the additional temperature rise impact of the core loss.

Inductor Selection

As there are a diverse range of power-converter requirements—supplying a wide range of power levels at a multiplicity of voltages and currents— there is a wide range of inductance/ current requirements. Consequently, a number of inductor winding technologies exist to provide the optimum inductive solution for different requirements (see Fig. 1).

There are also some cost and performance considerations, so the different winding technol-ogies can be briefly outlined and compared and contrasted as in the following sections.

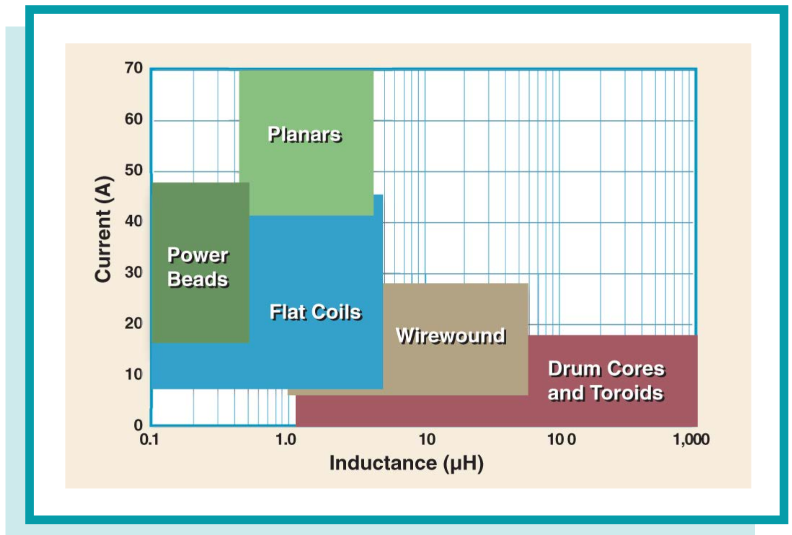

Fig. 1 Current and inductance characteristics of the various types of power inductors.

Drum Core

Wire wound on a ferrite dumbbellshaped core inductor, a drum core can be either magnetically shielded or unshielded. The unshielded ver-sion can support relatively high peak currents before saturation.

Due to its open flux path, the drum core is limited by the operating frequency and EMI performance. If suitable for the application, this is the best technology choice because it is the least-expensive inductor.

The shielded version is a little more expensive and suitable for higher-frequency and noise-sensitive applications. It has a very wide inductance range and is limited by current-carrying capability. Ferrite is a good low-core material across the frequency range.

Toroid

Using a mature winding technology, the toroid inductor is relatively bulky and the typical core material used, iron powder, while offering soft saturation and low noise characteristics, has relatively high core losses at higher frequencies.

A toroid's main limitation is size and performance. Where available, the equivalent drum core solution is normally more cost effective. A toroid can still be a good solution where the current requirements exceed the limits of drum core technology.

Wirewound

In wirewound technology, a wound coil is mounted in a shaped-core ferrite material. Larger than the shielded drum core, it has a higher current carrying capability without the frequency limitation of the toroid. The wirewound is a good medium-inductance medium-current inductor solution at a medium price.

As there are a diverse range of power-converter requirements — supplying a wide range of power levels at a multiplicity of voltages and currents — there is a wide range of inductance/current requirements.

Flat Coil

Rectangular cross-section wire wound into a helical coil gives flat coil technology high current capacity in a low profile. The core material is typically powdered iron with the associated soft-saturation and low-noise benefits.

However, since voltage drops are typically low, the core losses are not excessive even at high frequencies. The flat coil inductor has a relatively low number of turns so the technology is limited by low inductance and increased cost.

Bead

The bead inductor is a single-turn part with very low inductance for high currents. Bead inductors are suitable for converters designed for low-voltage high-current outputs operating at high switching frequencies, such as a motherboard power supply units.

Planar

In planar technology, a low number of turns implemented using stamped copper plates enables low inductance with a very high current-carrying capability. However, this technology is limited by cost.

After the application requirements have identified the optimum power inductor winding technology, the final step is to select the size that can provide the correct characteristics while also being geometrically suitable for the application.

Written By: Gerard Healy