Selecting a Power Inductor for your SMPS Design

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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 Vout even if Vin 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 (dl/dt) is determined by the inductance and the voltage dropped across the inductor, given by the expression: V = L*dl/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 dl/dt, its value is selected to achieve desired limits to the ripple current (Ir), 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 (Isat) is greater than the application’s peak inductor current, (Ip = Iout + Ir/2).

Non-Isolated Switching Regulators

According to the position of the switch and the rectifier, different types of voltage converters can be made:

- Step down “Buck” regulator
- Step up “Boost” regulator
- Step up / Step down “Buck - Boost” regulator

There are many catalog choices for the inductor used in buck, boost, and buck-boost circuits, and where there is a special need, custom inductors are available as well.
A Buck converter is one of the most common topologies. It is used in SMPS circuits where the DC output voltage (load) needs to be lower than the DC input voltage (supply). The DC input can be derived from rectified AC or from any DC supply. The buck converter consists of a diode, a switch (typically a MOSFET) and a single inductor for single-phase applications. To reduce voltage ripple, filters made of capacitors are normally added to such a converter’s output (load-side filter).

**Buck Converter**

Unlike the buck topology, the boost steps up voltage (while stepping down current) from its input to its output. The boost converter is a high efficiency step-up DC/DC switching converter. One of the most common applications is driving the motors used in electric vehicles. A single battery is not sufficient to drive a voltage in the region of 500V. Even if banks of batteries are used, the space and weight will be an obstacle. Hence, the boost converter answers the problem by using fewer batteries and boosting the available DC voltage to the required level.

**Boost Converter**

A Buck-Boost converter is a type of SMPS that combines the principles of the Buck and Boost converters in a single circuit. The buck-boost topology is sometimes called a step-up/down power stage -as it has an output voltage magnitude that is either greater than or less than the input voltage magnitude. The output voltage is of the opposite polarity to the input. One possible drawback of this converter which complicates the driving circuitry, is that the switch does not have a terminal at the ground.

**Buck-Boost Converter**
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 (Irms) flowing through the resistance (Rdc) of the conductor winding, simply expressed as: \( P_{cu} = R_{dc} \times I_{rms}^2 \). Inductor datasheets typically specify a given temperature rise current—for example, the equivalent 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 data-sheet 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 technologies can be briefly outlined and compared and contrasted as in the following sections.

Drum Cores

Wire wound on a ferrite dumbbell shaped core inductor, a drum core can be either magnetically shielded or unshielded. The unshielded version 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.

Pulse has released a family of six new, ultra-low profile, SMT shielded inductors for compact point of load and mobile devices. With mounted height profiles of 1.0mm to 3.2mm, they’re a valuable addition to our existing lineup of power inductors and are ideal for today’s mobile computing, home automation, portable POS, and other small handheld devices.

Toroid

Using a mature winding technology, the toroid inductor is relatively bulky and 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.

Our shielded toroidal inductors are available in surface mount (SMT) construction types complete with a toroidal ferrite core. Our toroids serve as versatile multi-use platforms for single and dual winding applications and help minimize leakage flux in order to protect nearby components from excessive electromagnetic interference (EMI).
Flat Coils

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.

Round Wire Coils

RWC inductors are commonly designed into applications which do not require the very low profile offered by the flat coil inductor at a price premium. These inductors are used as energy storage devices and filters in point-of-load (POL) regulators and as DC/DC converter output inductors for applications such as Telecom, Datacom, Server, and Industrial control.

The RWC inductors use a ferrite core material which yields a 90% core loss reduction and 30% increase in maximum operating temperature when compared to standard iron powder material used in flat-coil inductors. Because ferrite material is immune to thermal aging, these inductors are more reliable and better performing at higher temperatures and frequencies than non-ferrite core inductors. Using round wire instead of a flat coil results in a 25% cost reduction.

Molded Powder

The Molded powder inductors feature an iron powder core material that directly mold to the copper wire. This provides an optimal solution for designs that require high frequencies and high current with low DC resistance.

These inductors have high EMI performance. And the reason for that, is the copper turns that are completely surrounded by magnetic material. This controls the flux in the package, eliminating the noise, and keeping the magnetic flux from straying outside the inductor.

The molded inductor series is ideal for high current, non-isolated DC/DC converters and voltage regulators. The addition of the AEC-Q200 qualification now allows these parts to be used in automotive applications such as radios, USB chargers, navigation systems and backup cameras. They can also be used for LED brake lights, LED daytime running lights, and EV charging applications, all of which are outside the passenger compartment. Pulse offers these inductors with extended operating temperature (-55 to +155°C) for Automotive Oil Pump and Engine Cooling System.
Power Beads

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.

Pulse offers a shielded SMT bead inductors that come in coupled and integrated construction types and are ideal for multiple applications, including VRD, VRM, Graphic Card and PoL.

The coupled power beads combine two (or more) inductors into one single package with magnetic coupling between them, reducing the overall footprint and enabling lower phase ripple current resulting in higher system efficiency. While the integrated power bead inductors also combine two inductors into one single package but do not allow magnetic coupling between them, offering the same circuit performance as two separate inductors while still reducing the overall footprint.

Planars

In Planar technology, a low number of turns implemented using stamped copper plates or a helical coil winding enables low inductance with a very high current carrying capability. The ultra-low DCR of this product makes it the most efficient solution available on the market today.

Pulse has released a new shielded ferrite core flat coil family, designed for high current and low voltage power supplies. The new series is with a third mounting pad for greater stability on PCB. The flat wire in addition to the ferrite core offer an extremely low DC resistance.

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.
Pulse Electronics Power BU offers a complete line of power magnetics for voltage conversion applications in a broad range of packaging options from through hole to surface mount. This includes power inductors and transformers used in AC/DC power supplies and DC/DC converters, power inductors, high-frequency power transformers, gate drive transformers, current sense magnetics, and CM chokes.

To obtain a quotation, a technical application assistance, or to place an order, contact a Pulse representative in your area.

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