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Article

Magnetics Update – Taking Care of Noise in Power Designs

Right-First-Time Design with RoHS-Compliant Inductors

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Magnetic component technology cannot advance in line with Moore's Law, but designers are under pressure to meet tough targets for miniaturisation, time to market and cost. A wide choice of inductors, as well as concise component selection guidance, are both necessary to deliver advanced products on time and on budget. Another factor to consider is the impact of lead-free legislation on the construction and materials of magnetic components to withstand higher reflow temperatures.

Introduction: Inductors and Power Supply Filtering

The inductor plays a critical role in a wide variety of power-related applications, including filtering and smoothing of input and output power lines when used in conjunction with one or more capacitors. For example, when selecting a storage inductor for use at the output of a switching regulator, the device should be chosen to minimise losses and avoid core saturation, which can occur if the device is under-specified, reducing inductance and thereby impairing filter performance.

In practice, the designer must achieve an optimal balance of component parameters. For example, selecting a lower inductor value results in a lower DC resistance (R_{DC}) leading to reduced losses in the inductor windings. With fewer turns, the lower-value inductor also has a higher DC saturation current and can therefore satisfy higher load conditions with a smaller component. Lower inductor values also display faster transient response and require fewer capacitors for good load transient recovery.

On the other hand, choosing a larger inductance value results in a lower output ripple current, lower inductor losses in the core and windings, along with reduced conduction losses in the switching MOSFETs. In addition, current flow in the inductor is continuous over a wider range of load current values.

The optimum value for the inductor is also related to the switching frequency of the converter. Whatever the inductance value, the R_{DC} should be as low as possible to reduce losses and minimise any self-heating effects of the inductor.

An accepted rule of thumb is to size the inductor for a ripple current (I_{RIP}) between 10% and 30% of the full-load DC (I_L) current. The saturation current should be several times greater than the maximum full-load DC to prevent saturation, which otherwise will result in a sharp fall in inductance. Other factors the designer should bear in mind include the applied voltage to the inductor, the maximum physical size of the component, and the operating temperature range.

Calculation and Inductor Selection for Filtering

An understanding of how to identify a suitable inductor for filtering applications can be seen by considering the design of an output filter for a DC/DC converter module (figure 1). In this example the parameters in the table below are known:

C	R_C	R_L	f
4.7µF	0.23Ω	1.0Ω*	200kHz

*estimated

where C is the capacitor value, R_C is the ESR (equivalent series resistance) of the capacitor, R_L is the R_{DC} of the inductor, and f is the operating frequency.

To attenuate noise by a factor of 100 (i.e. from 0.5V to 5mV), the impedance of the inductor (Z_L) must be 100 times that of the capacitor (Z_C) at the given frequency:

i.e.

$$Z_L = 100 Z_C$$

now,

$$Z_C = \frac{1}{2 \pi f C} + R_C$$

$$= 0.4\Omega$$

therefore,

$$Z_L = 40\Omega$$

now,

$$Z_L = 2 \pi f L + R_L$$

therefore,

$$L = \frac{Z_L - R_L}{2 \pi f}$$

$$= 31\mu H$$

So in this situation, a 33µH inductor with a sufficient DC rating would be deemed suitable. In practice, designers should take these guidelines into account to gain an approximate solution, and then identify the optimum inductor after evaluating several closely related components. The inductor must also interoperate optimally with the chosen capacitor values.

Rapid Inductor Selection by Look-Up

An easier and faster way to ensure optimum DC/DC converter performance is for the regulator vendor to evaluate a number of inductors and recommend the best device to perform according to a given set of parameters. Examples include the C&D Technologies NME, NMH and NMJ series of DC/DC converters, which have been pre-evaluated to determine an optimal combination of output inductor and capacitors to deliver high all-round performance in relation to efficiency, noise, current-handling and cost. The recommended inductor type and capacitor values are published in the applicable supporting datasheet for fast and easy reference. This represents a similar approach to that of the IC chipset; presenting designers with a turnkey, compatibility-guaranteed solution saving numerous stages of trial and error.

As an example, the C&D Technologies NMJ1205SC 1W, dual output ±5V DC/DC converter module supplies up to 100mA per output and operates at 70kHz switching frequency. An output inductor of 22µH is required to reduce the output ripple voltage to 5mV peak-to-peak at full load current (figure 2). The datasheet recommends the 82223C inductor, which fulfills all of the requirements on the output inductor without involving the designer in lengthy trial and error to identify the optimal component.

The 82223C is an I-core surface mount device with a low profile to serve applications including ExpressCard™ technology and handheld devices. Characteristics include very low

R_{DC} of 0.92Ω, high saturation current of 320mA relative to the converter output current, and a self resonant frequency (SRF) of 25MHz. At the rated current, the inductor R_{DC} is low enough to ensure that the voltage drop across the inductor is less than 2% of the rated voltage of the DC/DC converter. This is a useful guideline to guard against self-heating of the inductor, leading to loss of inductance.

The datasheet also recommends low ESR ceramic capacitors to complete the output filter design, also shown in figure 2. These are placed between the output ground and the positive and negative rails. Requirements include a voltage rating of at least twice the output voltage of the converter. The recommended capacitors are 10V, 4.7µF, 1206-format surface-mount devices. Similar selection guidelines for input filter design are also available for designers using the NDY-series and NDH-series converters.

In other instances the behaviour of the inductor is critical to operation of the DC/DC converter, for example in converters that employ synchronisation techniques to eliminate dead-time insertion circuitry. These are so sensitive to inductor selection that a recommended, matched inductor must be used to ensure correct operation of the power supply.

Lead-free Device Design

In addition to ensuring optimal electrical operation, designers must increasingly factor in the need to comply with the growing worldwide adoption of legislation on hazardous substances in electronic components. Since the EU RoHS legislation came into force in July 2006, for example, China has also now introduced its own RoHS legislation, making this an even more important consideration for new power supply designs.

While most attention during the transition to lead-free assembly has focused on materials compatibility and optimisation of new reflow profiles, many assemblers are seeing increased instances of thermal damage to components on the board. The peak temperature necessary to solder successfully with lead-free alloys, at around 245°C is very close to the maximum case temperature of 260°C for semiconductor devices, as recommended by the IPC. Results may include cosmetic damage such as scorching of the PCB substrate, or induced functional failures for example by stress-cracking of semiconductor die. These experiences show that source temperatures of soldering equipment should be chosen very carefully, but also highlight a requirement for components to be more robust against exposure to higher lead-free soldering temperatures.

As an example, inductor manufacturers such as C&D Technologies have developed new materials to ensure close matching between the coefficient of thermal expansion (CTE) of the constituent parts of shielded surface mount inductors, throughout the wider lead-free soldering temperature range, to maximise the structural integrity of the device during reflow. A number of leading inductor manufacturers have identified new materials and construction techniques as being critical to completing development of a production-ready RoHS-compliant product range.

Conclusion

Successful product engineering is predicated on achieving right-first-time solutions, quickly, all the way from design to production. Selection of magnetic components can be a skilled discipline requiring specialist knowledge, and increasingly requires manufacturer support to ensure the optimum result and eliminate time-consuming evaluation of multiple candidate components. At the same time engineers need to be sure of high product quality, to maintain consistent production yield and optimal reliability in the field in order to safeguard profitability at a competitive price. Post-RoHS, this also requires component manufacturers to ensure that all devices are able to withstand higher reflow temperatures for lead-free assemblies.

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Figure 1: Output filter design for single-output DC/DC converter module.

Figure 2: Output filter design for dual-output NMJ-series DC/DC converter.

Andrea Polti photo caption: “Any compromise when sourcing filtering components can have a significant effect on the reliability of your overall design, which is vastly disproportionate to any cost saving which might be made.”