Specialising Performance: Collaboration Gets it Right with Custom Power Magnetics

Holistic Design Approach Improves Efficiency, Reduces Risk and Costs

Off-the-shelf magnetic components are often a compromise solution for any application, both electrically and mechanically. To achieve ideal performance at minimum cost, custom inductors or transformers may be a better alternative, with greatest benefit realised when user and supplier work together closely. Headline specifications such as inductance, turn ratios and resistance are only part of the story; expertise helps identify other relevant parameters – critical to tooling options for the right fit components, from the outset of the design.

By Peter F Vaughan, Technical Director, TT Electronics

Prioritizing magnetics design

There's an argument that magnetic components should be considered first in any power electronics design. Often the largest components and the most difficult to terminate, these complex devices have the potential to set the overall mechanical arrangement of the product.

At the same time, it can be tempting to overlook the specification of magnetic components based on long-established technologies until later in the design process, instead exploring more enticing digital techniques and exotic wide band-gap semiconductors that promise near-zero losses, while device application notes often show magnetics as a deceptively simple and ideal components based on just an inductance value. With this thinking, all designers need to know is the current in the circuit – take a quick look in the catalogues to determine corresponding parts with inductance and current ratings to match. So, all set, right? Invariably the answer is no, as real magnetics have many secondary parameters that are often not specified for standard parts in catalogues and which affect circuit performance dramatically. This is especially true in designs looking to achieve highest efficiency in the smallest size and cost. In these scenarios, dropping in a standard part is not likely to drive optimum performance. Customised components are typically a better fit; however, designers must understand the complexities of magnetics including a range of parameters that impact performance, cost, and potential trade-offs required throughout the device's design.

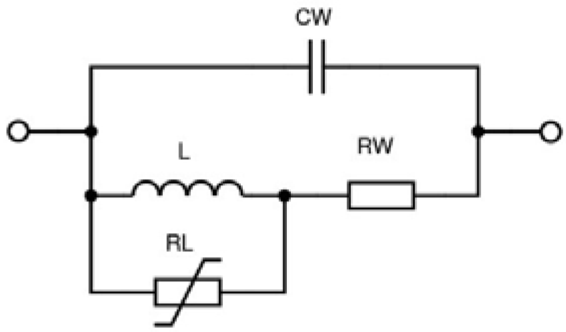

Figure 1: Simplistic inductor equivalent circuit

Magnetics have many parameters

It's feasible to have a store of resistors and capacitors – a broad slate of options from which engineers can choose to support their new designs, or perhaps even 'design around' without compromising overall product performance. Yet magnetic components are different (Figure 1). Depending on the application, factors such as inductance L, current rating, winding resistance RW, non-linear core losses RL, winding capacitance CW, leakage field, self-resonance, saturation characteristics and more might be crucial parameters. This would be for an inductor, but transformers require still more considerations including winding ratios, isolation/safety ratings, mutual inductance, inter-winding capacitance, and more. Many parameters vary with temperature and drive level and are in turn interdependent. All types have a wide range of possible mechanical formats. The permutations multiply dramatically – and while distributors of standard parts may stock popular variants, it is unlikely that any single option will fit all requirements exactly. Custom parts add value and should be considered.

Inductor specifications

For optimum design, details about current flows and available space are insufficient specifications to provide to a custom magnetics supplier. For example, the discussion should include a specification for inductance tolerance. Calculations will yield a required inductance; a wider acceptable range makes for easier manufacturing and lower cost, especially at high inductance values. The current waveform should also be specified; DC only produces ohmic losses, but any AC components generate core losses that are of strong frequency and level dependent. Core saturation must be avoided but is an instantaneous effect, so peak value of any AC current should also be specified. For example, it is quite common for converters using synchronous rectification to have a large proportion of AC current superimposed on DC in output filter inductors (Figure 2). For standard parts, maximum rated current is the DC value specified for an inductance drop of a certain percentage, which varies between manufacturers. A drop of 30% at rated current would not be uncommon, demonstrating the onset of saturation which might be disastrous in a practical circuit. Specifying a minimum inductance with a current waveform is advisable.

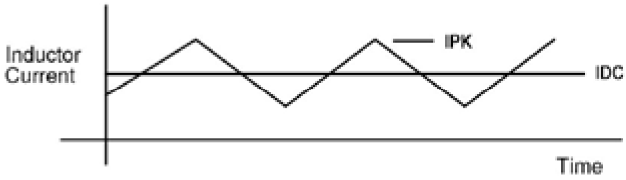

Figure 2: Typical buck converter inductor current with a high AC components

Even saturation has its characteristics. For instance, ferrite cores lose inductance suddenly at a threshold current but other types, such as iron powder, drop their value more gradually. If transient overloads are possible, this might be more desirable although powder has higher AC losses than ferrite, a situation in which a supplier can advise ideal trade-offs.

Operating temperature is a major consideration. For standard parts, maximum surface temperature rise is normally rated but the point of measurement varies. The limit can be reached for different reasons as well, either because of ohmic losses, core losses with AC bias, or a combination of both. Specifying the actual current waveform and a maximum ambient temperature allows the supplier's design team to select wire gauges and core materials. These can be selected to ensure acceptable surface temperature rise for the materials used in a given ambient.

Leakage field around an inductor may also represent a system issue, producing EMI and coupling to other components. While it would be difficult to specify an acceptable level, it is useful to tell a supplier that it might pose a problem. This would steer the design towards a solution that offers an element of self-shielding. Drum cores are especially bad for external field but are very low cost while enclosed structures, such as pot-cores or some E-cores, are much better yet more expensive. The required inductance will affect the decision – if it is high, drum cores with their inherent large gap would require many turns of thin wire with high consequent resistance and losses. An ungapped E-core, for example, would need fewer turns, allowing thicker wire and a reduction in losses. Suppliers can assist by marking the 'start' pin of a wire-wound inductor, which is an inner winding layer. This pin can then be the noisier connection, often a switching node, so that the outer or quieter layers of the winding act to some extent as an electrostatic shield (Figure 3).

While a circuit design may indicate a certain inductance value, it is worth considering whether the natural variation of the manufactured part can be used to advantage. For example, DC chokes with iron powder cores have inductances that strongly vary with current. Some types might double their nominal inductance at light load. In this scenario, buck converters with diode rectifiers would enter discontinuous mode at lower load currents, benefitting designs by supporting stability and improving secondary output cross-regulation. Collaboration with suppliers will increase insight on these effects and advocate choosing cores that may provide this advantage.

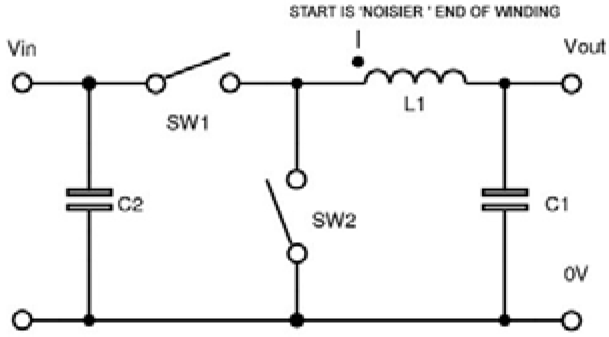

Figure 3: Noisy end of an inductor as innermost layer for shielding effect

Self-resonance is also an important consideration, as self-capacitance of windings can resonate with winding inductance at relatively low frequencies and may affect circuit stability. Winding methods can be employed, however, to keep the resonant frequency high. For example, toroids with single layer windings provide favourable results.

Resonance may provoke high voltages across inductors, but wire insulation is usually sufficient. There are instances however, when an inductor does need a high voltage rating. For example, non-isolated buck converters dropping rectified mains to low voltage DC are common. In this case, their inductors experience up to ~370V switched at high frequency across their terminals. Wire and termination insulation must be appropriate and even the core may be a source of breakdown due to different materials having varying resistivity. Again, an experienced supplier can guide an ideal approach.

Transformer specifications

Power transformers are even less standard and have more parameters to consider (Figure 4).

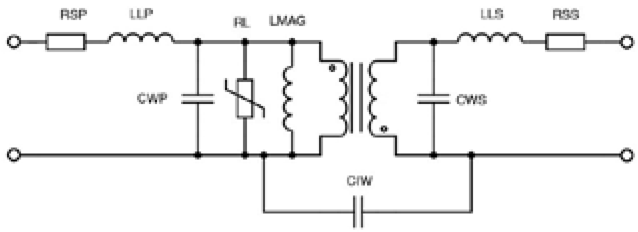

Figure 4: Transformer equivalent circuit

Parasitic transformer characteristics, such as leakage inductance LLP and LLS, can affect circuit performance dramatically, sometimes for the better. Some resonant converter topologies require a minimum value and a simplistic design would integrate this as a separate, discrete component. It could be built-in to the transformer; however, this requires judicious placement of windings and core gaps. Expertise is critical here, ensuring design viability while maintaining other specifications and isolation ratings that save the cost and space of discrete external components.

Designing for an exact isolation rating is a skill that a custom magnetic suppler will often possess, with knowledge of the creepage and clearance requirements for various safety standards. Materials used should be in an approved insulation system[1] which makes agency acceptance much easier. Designers can save significant resources by tapping into a supplier-recommended combination of wire, tape, plastics, varnish, etc., that are proven to be compatible.

Custom magnetics suppliers will sometimes support power converter reference designs – an excellent way to achieve the promised performance from a specific PWM IC, for example, with low-cost electromagnetics.

Taking advantage of existing tooling and buying power

Specialist magnetics manufacturers often rely on unique tooling for high performance bobbins and cores. Further, these bobbin and core shapes may be more affordable if the supplier is already purchasing in volume for multiple clients.

It's also likely that these engineering teams have already addressed the same issues you're facing in your application. Their specific skills have been honed, such as ultra-fine wire-winding and edge-winding or forming helical coils from flat copper stock.

Eliminate risk with specialised design skills and experience

Given these complexities, the perfect power magnetics components for your robust or critical application are unlikely to be found in a catalogue listing. Collaboration is ideal in developing an optimum solution. Where it may appear that designs can choose between E-cores, toroids, drum cores and more with through-hole and surface-mounts, a specialist supplier's design team can advise when there are electrical trade-offs between each of these choices. Considering the overall system helps determine the best fit magnetics components, yielding system-wide savings by improving efficiency, assembly time, reliability, functionality, and, of course, unit cost.

References

[1] UL 1446, Standard for Systems of Insulating materials https://standardscatalog.ul.com/standards/en/standard_1446_7

[2] www.ttelectronics.com

About the Author

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Peter has been developing switch-mode power supplies and magnetics components since 1983. He has held the role of Chief Designer for the TT Electronics Barnstaple facility since 1991, and is responsible for custom design of transformers and inductors from 4kW 50Hz, 3-phase 400Hz, filter and smoothing inductors for 20kHz comms-on-power diplexers, and RF inductors to 2MHz.

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